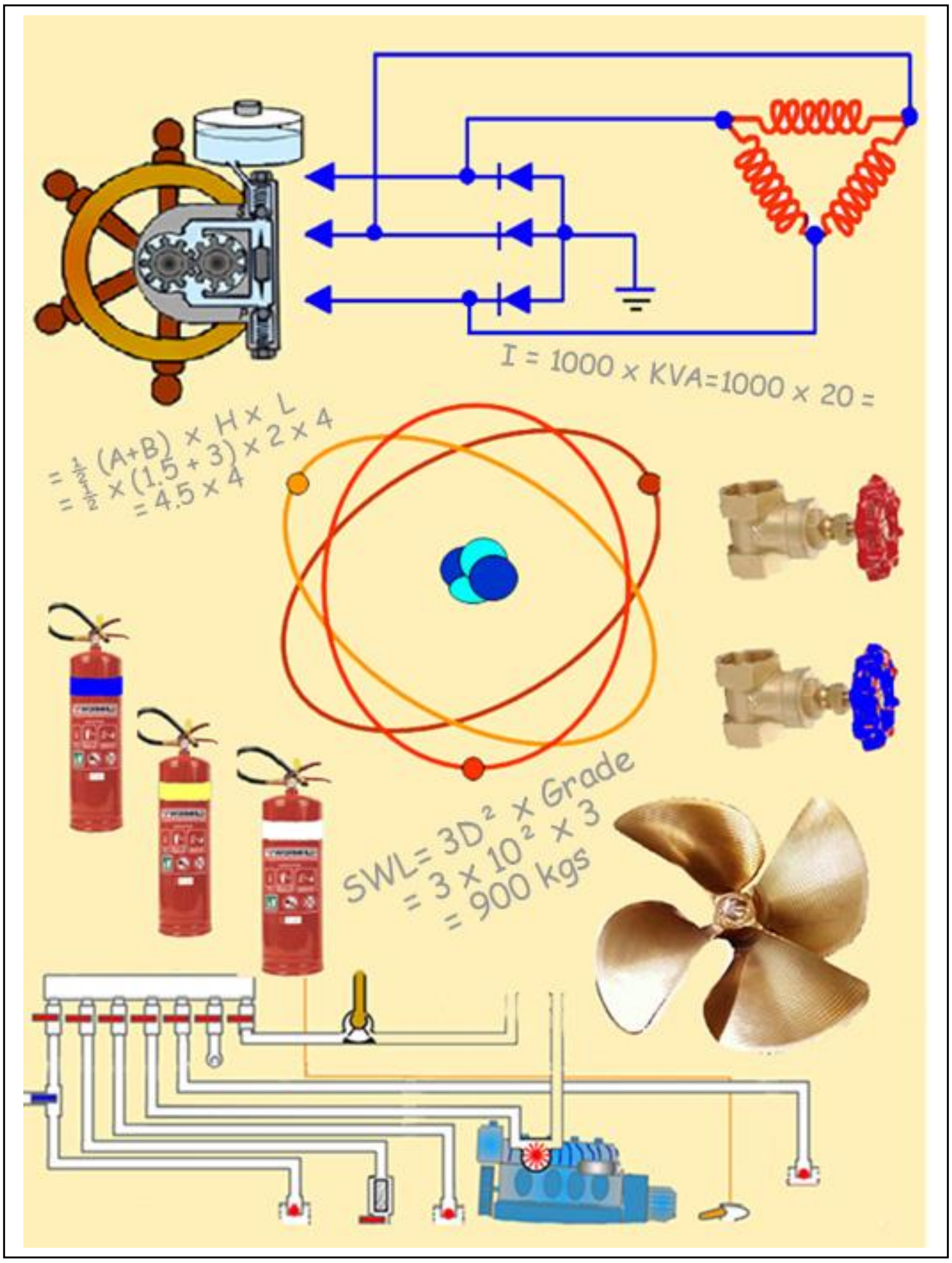
AUXILIARY EQUIPMENT & SYSTEMS FOR MARINE ENGINE DRIVERS

Ranger Hope © 2008

View as Html file



AUXILIARY EQUIPMENT & SYSTEMS FOR MARINE ENGINE DRIVERS

Introduction

A well found vessel has equipment sufficient for the trade and seas that she embarks upon. Modern engineering is very reliable, often incorporating fail safe mechanisms and sophisticated non serviceable components. Expert service engineers can be required to meet a manufacturer's warrantee. Licensed installers (LPG, electrical, and refrigeration systems) may be required by National regulations. However, the Marine Engineer remains on the spot, responsible to ensure that the vessel is ready, and if systems fail, to repair them sufficient to reach a safe haven.

A basic understanding of maths and science, including calculation, how heat and pressure change material, how forces stress materials and how momentum and gravity affect motion will assist the reader. Engineers use these principles to understand why machinery works and to interpret the signs and symptoms of malfunction.

The equipment and systems described may not be exactly match that fitted on your vessel. Your manufacturer's operating manuals must be consulted in practical tasks.

Ensuring a safe work practice and applying WH&S is paramount. This includes using the correct tool for the job, use of personnel protective equipment, (loose clothing can become entangled in moving parts) and maintaining a tidy workplace.

Contents

Chapter 1: Safe practice

1.1 The standards

An historical perspective

To ensure safe vessels that would enjoy low insurance rates and higher resale value seafaring nations in the past developed *Classification Societies* to keep *registers* (lists of approved safe vessels). Those remaining today still determine *rules* (specifications) for construction, equipment and maintenance for each vessel class (the trade and sea area of operations).

American Bureau of Shipping AB
Lloyds Register of Shipping LR
Bureau Veritas
Det Norske Veritas NV
Germanischer Lloyd GL
Nippon Kaiji Kyoka
China Classification Society

For a new vessel, a classification society such as those above will approve the design plans and check the quality of materials and workmanship of all stages of the construction process at what is called the *Initial Survey*. Seafarers are additionally protected by their assignment of the vessel's load line to show minimum freeboard (preventing overloading) appropriate to the intended sea area and by mandatory minimum safety equipment. To ensure maintenance to the survey standards, regular ongoing thorough examinations are scheduled, called *Periodic Surveys.*

Subsequently, concern from nations that unregistered and unsafe foreign ships could sink in their home waters, blocking their ports and polluting their seas resulted in forming the *International Maritime Organisation* as a forum to promote sea safety. The IMO now encourages conformity in their Conventions that include:

Safety of life at sea conference (SOLAS)
Loadlines conference (LOADLINES)
Marine pollution conference (MARPOL)
Standards of training and certification of watchkeepers (STCW)
International Safety Management Code (ISM)

These conventions, the *World's best practice*, are supported in domestic legislation in the jurisdictions of the Commonwealth of Australia and its States and Territories.

Marine Orders and Australian Maritime Regulations

The Commonwealth of Australia's jurisdiction operates to 200 nm offshore, the States' to within 3nm offshore, but extensions may cover zones of particular State interest. Where State and Commonwealth Laws are incompatible, the latter can override. Like *Class Societies*, the *Australian Maritime Safety Authority* (AMSA) registers large vessels to Australian standards, and the *State Authorities* manage small vessels to their regulations.

Marine Orders are body of delegated legislation from the Commonwealth *Navigation Act 1912* and *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* that update *rules* for commercial vessel construction, operation and manning. They incorporate reference to *Australian Standards* (AS) for materials and components.

COLOURS OF UTILITIES USED IN - AUSTRALIAN STANDARDS 2000			
Water -	Emerald Green	Fire lines -	Signal Red
Steam -	Silver Grey	Air -	Arctic Blue
Oil -	Golden Brown	Gas -	Light Beige
Hazardous - (Services).	Golden Yellow	Acids /Alkalis-	Violet
Electricity -	Light Orange	Communications -	White
Other fluids, including drainage pipes, bilge lines -			Black

The examples below show some of the *Marine Orders* of particulars relevance to Marine Engineers for commercial vessel construction and operations. The full list of *Marine Orders* currently in force can be accessed at the *AMSA website*.

Marine Order 11 *Substandard ships*
Marine Order 12 *Construction-Subdivision & stability, machinery and electrical installations*
Marine Order 14 *Accommodation*
Marine Order 15 *Construction-fire protection, fire detection and fire extinction*
Marine Order 16 *Load Lines*
Marine Order 17 *Liquefied gas carriers and chemical tankers*
Marine Order 23 *Equipment-Miscellaneous and Safety Measurements,*
Marine Order 25 *Equipment - Life-saving*
Marine Order 31 *Ship surveys and certification*
Marine Order 32 *Cargo Handling Equipment*
Marine Order 34 *Solid bulk cargoes*
Marine Order 41 *Carriage of dangerous goods*
Marine Order 42 *Cargo stowage and securing*
Marine Order 43 *Cargo & Cargo Handling-Livestock*
Marine Order 49 *High Speed Craft*
Marine Order 58 *International Safety Management Code*
Marine Order 91 *Marine Pollution Prevention – Oil*

Smaller vessel registration and survey is devolved to the State Authorities, including:

New South Wales NA *Queensland QA*
Tasmania TA *Victoria VA*
South Australia SA *Western Australia WA*
Northern Territory NT

Australian Standards and the USL/NSCV are increasing maritime uniformity nationwide and negotiations are ongoing to form a Single National Jurisdiction for conformity in maritime standards and law enforcement.

The Uniform Shipping Laws Code (USL)

The geographic zones under the authority of Australian States range from the balmy Tropics to the wind swept Southern Ocean. Not surprisingly, locally focused State determined standards were different, creating barriers for vessels trading inter-state.

The voluntary Uniform Shipping Laws Code (USL) was devised to promote uniformity in commercial vessel manning and construction regulations for small vessels (< 35 metres). Five of the Codes' eighteen Sections, directly affected the day-to-day operations of Marine Engineers, specifically:

Section 1 - Definitions and General requirements
Section 10 - Life Saving Appliances
Section 11 - Fire Appliances
Section 13 - Miscellaneous Equipment
Section 15 - Emergency Procedures

The Code lists the classes of vessels and prescribed standards that *shall* be met.

Class 1 – Passenger vessels (i.e. carrying more than 12 passengers).
Class 2 – Non-passenger vessels (workboats of 12 or less passengers).
Class 3 – Registered commercial fishing vessels (passengers not allowed).
Class 4 – Hire & drive vessels

Each class of vessel includes an operational area as follows:

A – Unlimited seagoing
B – Offshore to 200 nautical miles
C – Offshore to 30 nautical miles
D – Sheltered smooth and partially smooth waters (wave height <1.5 metres)
E – Sheltered smooth waters only (wave height <0.5 metres)

From the 1990's the USL Code was incorporated into States' regulations while accommodating existing arrangements of vessels operating to earlier standards. Being voluntary it was implemented more completely in some States than others. It continues to have a profound influence on small vessel regulations and safety nationwide.

The USL code lists prescribed standards. For every vessel class there is a tabulated specification that *"shall be met".* In some operations (novel and fast craft), industry found it stifled the use of equivalent or better modern technological innovations.

National Standards for Commercial Vessels (NSCV)

A newer *National Standards for Commercial Vessels* has been drafted. While drawing from the USL code, the NSCV updates and provides the flexibility required by marine developers and operators. It retains a prescriptive approach to compliance in its "*deemed to satisfy"* standards (standards that *shall* be met) but also provides a flexibility with performance based *"equivalent solutions"* (that can be proven to be as effective as those deemed to satisfy). The Standards, accessed at the *AMSA* website are:

Part A: Safety Obligations
Part B: General Requirements
Part C: Design & Construction
Section 1: Arrangement, Accommodation and Personal Safety
Section 2: Watertight and Weathertight Integrity
2a-Load Line Vessels
2b-Non Load Line Vessels
Section 3: Construction
3a-General
3b-Design Loadings
3c-Aluminium Construction
3d-FRP Construction
3e-Steel Construction
3f-Timber Construction
Section 4: Fire Safety
Section 5: Engineering
5a-Machinery
5b-Electrical
5c-LPG for Appliances
5d-LPG for Engines
Section 6: Stability
6a-General Requirements
6b-Intact Stability
6c-Buoyancy and Stability after Damage
Section 7: Equipment
7a-Safety Equipment
7b-Communication Equipment
7c-Navigation Equipment
7d-Anchoring and Mooring Equipment
Part D: Crew Competencies
Part E: Operational Practices
Part F: Special Vessels
Section 1: Fast Craft
1a-General Requirements
1b-Category F1 Fast Craft
1c-Category F2 Fast Craft
Section 2: Hire and Drive
Section 3: Novel Vessels
Section 4: Special Purpose Vessels

Another difference from the USL code is that the principles of risk management outlined in the International Safety Management Code (ISM) are adopted by the NSCV (particularly in *Section 4, Fire Safety)* where a risk factor based on vessels class and operations determines survey requirements.

National Standards for the Administration of Marine Safety (***NSAMS)***
These newest Standards are intended to be applied through a single national jurisdiction reform under Commonwealth legislation. It envisages a single national Authority with multiple survey organisations that may be operated by private industry or by State or Territory Government agencies. There are three possible models specified in the Regulatory Impact Statement for *National Approach to Maritime Safety Reform (NAMSR).* No decision had been taken about the service delivery model at the time of publication of this standard.

1.2 Survey

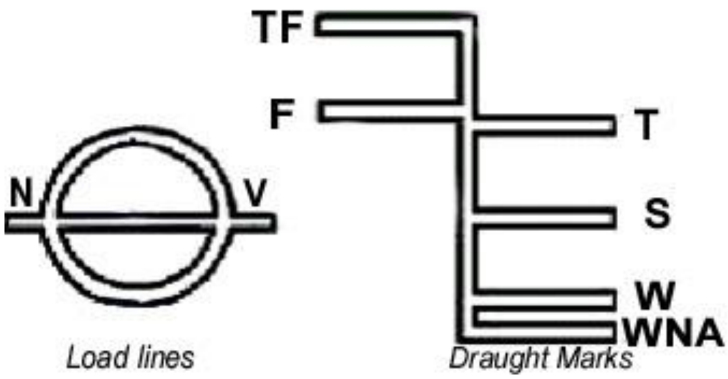
This text primarily refers to the standards of NSCV. Your commercial vessel may be in Class, AMSA or State survey and you must consult their standards and rules to ensure survey compliance. However, some general principles apply.

To approve a vessel authorities and/or classification societies *survey* their vessels (a thorough examination by a surveyor or approved person). Some items may be just require *inspection* (be visually checked by an approved person) or some may require a *test* (be subject to meeting a performance criteria).

Initial survey and load lines
A vessel brought into survey for the first time is required to undergo an *initial survey* to approve the plans and check that the quality of materials/workmanship meets the safety parameters appropriate to the trade and sea state (vessel class) likely to be encountered. Most vessels require a Load Line Certificate, other than small vessels less than 24 metres or those operating solely on sheltered waters with passenger restrictions or fishing vessels (that would not be able to read their marks at sea).

At the construction stage, hydrostatic particulars are worked out by the naval architect and are verified in an *inclining experiment* (the vessel is heeled by weights to proof test its ability to safely return to the upright). The vessel is then subjected to the Load Line regulations. *Freeboards* (height from waterline to deck) are computed on the basis of the *Conditions of Assignments* (usage instructions). A five year valid Load Line Certificate is then issued subject to annual checks.

The initials of the survey authority are marked on the load line (as shown in the *Det Norske Veritas* registered vessel below) and a Certificate of Survey is issued.



Periodic survey and survey schedule
A vessel’s structure, machinery and fittings are surveyed at specified intervals called the *periodic survey* (usually annually). However, a surveyor may board a vessel at a reasonable time to make an inspection. The owner of the vessel is required to inform the authority of changes which may alter the vessel or survey requirements such as change of trade, alteration to structure or machinery, collision, fire or grounding. An alteration may initiate further inspection. A current Certificate of Survey must always be prominently displayed on board.

In the periodic survey the surveyor checks the position of the load line marks, that the hull retains its water tight integrity and remains sound, the condition of the fittings/appliances for the protection of openings, guard rails, freeing ports and means of access to crew's quarters. The hull and superstructure will be inspected for any alterations and that the vessel has the Stability Information Booklet and the Conditions of Assignment on board. The surveyor uses a Survey Schedule (a list of items to be inspected and/or surveyed) to enable owners to slip and prepare their vessels for the checks.

USL SURVEY SCHEDULE *vessels < 35 metres in length (Sect. 14 of the USL Code) is listed below:*
Annual Surveys
Equipment.
Running trial of each main engine and associated gearbox.
Operational test of bilge pumps, bilge alarms and bilge valves
Operation test of all valves in the fire main system.
Operational test of all sea injection and overboard discharge valves and cocks.
Operational test of main and emergency means of steering.
Running trial of all machinery essential to the safe operation of the vessel.
Inspection of all pipe arrangements.
General examination of machinery installation and electrical installation.
All safety and relief valves associated with the safe ops of vessel set at required working pressure.
Pressure vessels & mountings for generation of steam under pressure or heating of water to >99º C
Inspection of the liquefied petroleum gas installation.
Inspection of escapes from engine room and accommodation spaces
Inspection of personnel protection arrangements in machinery spaces.
Inspection of cargo handling, fishing and trawling gear.
Inspection of casings, superstructures, skylights, hatchways, companionways, bulwarks and guard rails, ventilators and air pipes, together with closing devices.
Inspections of ground tackle (anchors and chains).
Two Yearly Surveys
Hull externally and internally except in way of tanks forming part of the structure.
Sea injection and overboard discharge valves and cocks.
Inspection of propellers, rudders and under water fittings.
Pressure vessel & associate mountings of air pressure/salt water sys - working pressure > 275 kPa.
Four Yearly Surveys
Each screw and tube shaft.
Anchors and cables to range.
Chain locker internally.
Tanks forming part of the hull, other than oil tanks, internally.
Void spaces internally.
Compressed air pressure vessels having a working pressure of more than 275 kPa and mountings.
Pressure vessel and associated mountings of an air pressure/fresh water system having a working pressure of more than 275 kPa.
Cargo handling, Fishing and trawling gear.
Insulation test of all electrical installations above 32V A.C. or D.C.
All safety and relief valves associated with safe ops of vessel set at the required working pressure.
Eight Yearly Surveys
Each rudder stock and rudder stock bearing
Each rudder stock and rudder stock bearing
Steering gear.
Hull in way of removable ballast.
Selected sections of internal structure in way of refrigerated space.
Twelve Yearly Surveys
Fuel oil tanks internally

During the course of a survey or inspection, the surveyor may require the opening up for examination of any other part or parts of the vessel including removal of linings and ballast. After a survey a list of repairs/ deficiencies is handed to the Master. The survey is not complete until all repairs and/or deficiencies have been made good. After a subsequent survey the registering authority issues a new certificate.

Under exceptional circumstances a Certificate of Survey extension may be granted if the authority is satisfied that the immediate survey of the vessel is impracticable (three months extensions may be granted but an interim inspection may be required). An authority may suspend a Certificate of Survey if the requirements are not being met. The owner will be advised and must not operate the vessel without the approval of the authority. An owner is also required to advise the authority of its sale or withdrawal from commercial operations.

National Standards for the Administration of Marine Safety and Survey

The NSAMS envisages that a single national authority will oversee surveys with a frequency determined by risk level. Risk factors include age, attributes, operational area and nature, incident history of vessel class and performance of the operator. Greater risk category vessels include:

Class 1A, 2A, and 3A vessels;
Class 1 > 35m in measured length;
Class 1B/1C that berth one or more pax or berth >12 persons or carry more >36 pax;
Class 1D/1E that berth one or more pax or berth >12 persons or carry >75 pax;
Class 2B vessels > 35m in measured length;
Class 2 tankers, dangerous goods or tug boats.

NSAMS SURVEY REGIME	**Survey Regime for Commercial Vessels** *(Table F.1)* **Vessel Class**				
	Class 1 (pass. vessels)	**Class 2 (trading vessels)**	**Class 3 (fishing vessels)**	**Class 4 (hire and drive)**	**Other**
Survey Level 1 Vessels Full Initial & Periodic surveys	Class 1 – all operational areas	Non-propelled barges of high risk	3A		Ferries in chains
		2A	3B		
		2B and 2C > 7.5mt	3C > 7.5mt		
		2D, 2E and 2C < 7.5mt of high risk			
Survey Level 2 Vessels Full Initial & Partial Periodic Survey		2C < 7.5mt with pax		4C (both o/night & not o/night)	
		2D with pax		4D o/night	
		2E with pax		4E o/night	
Survey Level 3 Vessels Initial Survey Only		2C < 7.5mt with no pax	3C < 7.5mt		
		2D < 7.5mt with no pax	3D > 7.5mt	4D > 7.5mt (not o/night)	
		2E < 7.5mt with no pax	3E > 7.5mt	4E > 7.5mt (not o/night)	
Compliance to NSCV required (no pre-determined survey)		Non-propelled barges (sheltered, < 24mt)** (excl. spudded)			
Other Compliance with level floatation standards, rec. boat equipment standard or ABP and/or NSCV Part E		2D < 7.5mt no pax*	3D < 7.5mt*	4D < 7.5mt (not o/night)	Sailing school - AYF
		2E < 7.5mt no pax*	3E < 7.5mt*	4E < 7.5mt (not o/night)	

The extract above specifies various survey level categories of vessels based on the risk factors.

Survey cycles -The periodic survey inspections of a vessel shall be arranged in survey cycles of 5 years as shown in the extract below from Table E1 (for vessels determined as level one). Table *E.2* refers to level two vessels and *E.3* refers to vessels with steam machinery. An intermediate survey having both in-water and out of water components is carried out during the third year of the survey cycle however, the interval between two consecutive out of water surveys is not to exceed 36 months. The last survey in a cycle shall be in the nature of a renewal survey that verifies the safety systems on the vessel essential for ensuring continuity in meeting the applicable safety standards required by legislation. For small vessels that is planned to refer to the NSCV specifications.

Scope and depth of survey - *NSAMS Tables E.1, E.2 and E.3 specify the* scope and depth of periodic survey of a vessel. These periodic surveys are not intended to confirm the vessel's compliance with every requirement but to identify and verify the continued existence and functionality of components, equipment and safety systems.

Ten yearly surveys -In addition to the items specified in *Tables E.1, E.2 and E.3*, the following inspections shall be carried out every tenth year:

Ultrasonic thickness for vessels having metallic hull;
Withdrawal of sample fastening for vessels having wooden hull;
Hull in way of removable ballast;
Internal foam buoyancy if not inspected in fifth year because of inaccessibility;
Internal hull inspection if not inspected in fifth year because of inaccessibility;
Pressure test all sea water pipes;
Non-destructive testing of shaft/rudder stock especially keyway, taper and threads;

The NSAMS term to *examine* means a process that commences with a visual inspection that identifies the evidence of damage, deterioration and/or modification (may require dismantling if deficiencies are found).

The NSAMS term to *test* means the physical gauging of properties with the objective of ascertaining continued readiness to function, condition or conformance with standards. E.g. hammer tests, ultrasonic thickness measurements, oil analysis, starting of machinery, turning of handles

The NSAMS term to *trial* means a specific type of rest of a system or component to ascertain functional performance and/or compliance with applicable standards. E.g. machinery trials, emergency generator trials, steering trials, fire hydrant appliance trials, anchoring trials, evacuation trials.

The NSAMS term to *verify* means to ensure that an item exists and is as per the plan, meets an applicable standard or has been declared as meeting an applicable standard by a recognised organisation or an Authority.

Survey Schedule Level 1 vessels	Extract from *Table E.1* - General Survey Year of 5-Year survey cycle				
	Year 1	Year 2	Year 3	Year 4	Year 5
Equipment	Annual in-water survey	Annual in-water survey	In and out of the water survey	Annual in-water survey	Renewal in/out of water
General Items					
Hull markings & signage	Verify	Verify	Verify	Verify	Verify
Equipment marked	Examine	Examine	Examine	Examine	Examine
LPG sys alarms/sensors	Examine + Verify + Test	Examine + Verify + Test	Examine + Verify + Test	Examine + Verify + Test	Examine + Verify + Test
Toilets	Verify	Verify	Verify	Verify	Verify
Sewage sys/holding tanks (external)	Verify	Verify	Examine	Verify	Examine
Modifications/additions	Examine	Examine	Examine + Verify	Examine	Examine + Verify
Lightship verification (draft or weight check, re-incline or roll period test as appropriate)					Trial
Operational management					
Safety management plan	Verify	Verify	Verify	Verify	Verify
Logbooks	Verify	Verify	Verify	Verify	Verify
Maintenance records	Verify	Examine + Verify + Test	Verify	Verify	Verify
Training/drills record	Verify	Verify	Verify	Examine + Verify + Test	Verify
Manifests	Verify	Verify	Verify	Verify	Verify
Documentation					
Class certification	Verify	Verify	Verify	Verify	Verify
Stability documents	Verify	Verify	Verify	Verify	Verify
Vessel survey record book	Verify	Verify	Verify	Verify	Verify
Compass deviation card	Verify	Verify	Verify	Verify	Verify
IOPP certificate	Verify	Verify	Verify	Verify	Verify
Electrical installation test results including insulation test	Verify	Verify	Verify	Verify	Verify
Fire detection & smothering system test certificates	Verify	Verify	Verify	Verify	Verify
Radio survey certificate	Verify	Verify	Verify	Verify	Verify
Load line certificate (where issued)	Verify	Verify	Verify	Verify	Verify
Safety Equipment					
Lifejackets, stowage & signage	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify
Lifejacket lights	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify
Lifebuoys	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify
Lifebuoy self igniting lights	Examine + Verify + Test	Examine + Verify + Test	Examine + Verify + Test	Examine + Verify + Test	Examine + Verify + Test
Lifebuoy buoyant line	Examine	Examine	Examine	Examine	Examine
Buoyant appliance(s)	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify
Internal buoyancy (where accessible)	Examine	Examine	Examine	Verify	
Life raft	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify
Rescue boat & launching arrangements	Examine + Verify	Examine + Verify + Trial	Examine + Verify + Trial	Examine + Verify + Trial	Examine + Verify + Trial
Dinghy (if counted for lifesaving purposes)	Examine + Verify	Examine + Verify + Trial	Examine + Verify + Trial	Examine + Verify + Trial	Examine + Verify + Trial
Hydro release	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify	Examine + Verify
List of further items continues:					

1.3 Safety Management

The process of documented management plans for standing orders, bridge, engine room, restricted visibility has long been implemented by sound Masters. The IMO International Regulations for Preventing Collision at Sea in Rule 2 stipulate that the safety of the vessel is the responsibility of the *owner, master or crew* to ensure *all precautions which may be required by the ordinary practice of seamen, or by the special circumstances of the case.*

The hell of the "Piper Alpha" Oil North Sea oil rig fire and the equally devastating "Marchioness" (a ferry mown down in London's Thames River whose passengers were washed into the rescuing crafts' propellers), were wake up calls that preventable accidents waiting to happen keep happening. An overall management plan therefore includes all parties (with the statutory authority) and needs a pro-active approach where the responsibility for coordination is allocated. In 2002 the IMO published the International Safety Management Code (ISM) to address this problem.

The *designated person* or persons is tasked to maintain, document and report, the *Safety Management System* using a *SMS Manual* format (see the accompanying text *SMS manual for a small vessel*). It should be available at work stations, remain current and be audited systematically for effectiveness. A SMS manual includes:

Company information including job descriptions and responsibilities
Information necessary for a safe workplace
Risk analyzed plans for operations and contingency plans for emergencies
Information necessary to ensure effective maintenance, documentation & review

Staff training, inclusion in safety planning and the valuing of safe attitudes are encouraged in order to develop safe procedures. In this context, examining "*case studies"* (such as the Piper Alpha and Marchioness) and relating them to your own operations are a key concept from ISM 2002.

The risk analysis process

The process of ensuring that hazards are identified, recorded, investigated, analyzed, corrected (eliminated or controlled) and that this process is verified can be summarised by the four steps:

1. Identification of all potential hazards.	*What could happen?*
2. Assessment of the risk of each hazard.	*How likely is it to happen?*
3. Elimination or a control plan.	*How to stop it happening.*
4. Monitor & re-evaluation.	*To improve/update the plan.*

1. Hazard Identification:

Hazards to persons are associated with:

Gravitational	*Striking*
Electrical	*Chemical*
Work environment	*Manual handling*

Hazards to persons may include:

Falls	Electricity	Heat and Cold
Noise	Atmosphere	Falls from heights and falling objects
Fire/Explosion	Confined Spaces	Manual Handling
Pressure vessels	Cranes and hoists	Hazardous materials

Hazards to vessels are Navigational, Structural or Environmental, and may include:

General Hazard	Description	Incident / Accidental Event
Impacts and collision	Being on a collision course, or breaching the separation distance between vessels, or approaching a stationary object with speed, etc.	Vessel on collision course
		Approaching berth with speed
		Strikings while at berth
Ship related	Hazards related to ship specific operations and/or equipment	Flooding
		Loading/overloading
		Mooring failure
		Anchoring failure
Navigation	Potential for a deviation of the ship from its intended route or designated channel	Navigation Error
		Pilotage error
Manoeuvring	Failure to keep the vessel on the right track, or to position the vessel as intended	Loss of steering
		Propulsion failure
		Blackout
		Fine manoeuvring error
		Berthing/unberthing error
Fire/explosion	Fire or explosion on vessel or in the cargo bay	Cargo tank fire/explosion
		Fire in accommodation
		Fire in engine room
		Other fires
Environmental	Weather exceeds vessel design criteria, or harbour operations criteria	Extreme weather
		Wind exceeds criteria
		Strong currents

The identification of hazards can carried out by the designated person in a number of ways including:

Systematic walk around inspection. (of the vessel)

Task analysis

Consultation and interview of the workforce /customers and staff meetings.

The compilation and review of safety information including, Material safety data sheets, AMSA Marine Notices , OH&S advisories and OH&S safety alerts and the study of other ships incidents & accidents (case study).

Audit by an independent expert.

If hazards are recognized, then their *risk* (significance) must be determined. This is to ensure that corrective measures are targeted and timely. For these determinations the risk assessment process is used.

2. *Risk assessment*

Risk assessment may be informal (intuitively reached) or formal (by audit) and needs to consider the following factors:

Risk Level = Consequence x Exposure x Probability
(outcome severity) (frequency/duration) (likelihood)

The level of risk from a hazard will determine the scale and priorities of control measures required. Low risk activities may be addressed over a period of time, whereas high risk activities will require ceasing operations until the deficiency is rectified. If a *formal* assessment is appropriate, the matrix shown below with supportive documentation should be researched by the designated person.

View a printable copy of this simple risk assessment template

	Fatal Catastrophe	Critical	Major	Minor	Negligible
Very Likely	1	1	2	3	4
Likely	1	2	3	4	5
Unlikely	2	3	4	5	6
Very Unlikely	3	4	5	6	7

3. The Control plan

Solutions to minimise or eliminate the risk may include:

Engineering controls-
Get the design right in the first place or redesign
Removal at source
Substitution

Administrative controls-
Checklists
Entry permits
Segregation / Isolation
Signage
Record keeping

Work practice controls-
Safe work practices
Passenger and crew briefing
Personal protective equipment and rescue equipment
Drill and musters
Training and staff development

4. Monitoring and re-evaluation:
This is coordinated by the designated person whose audits will include:

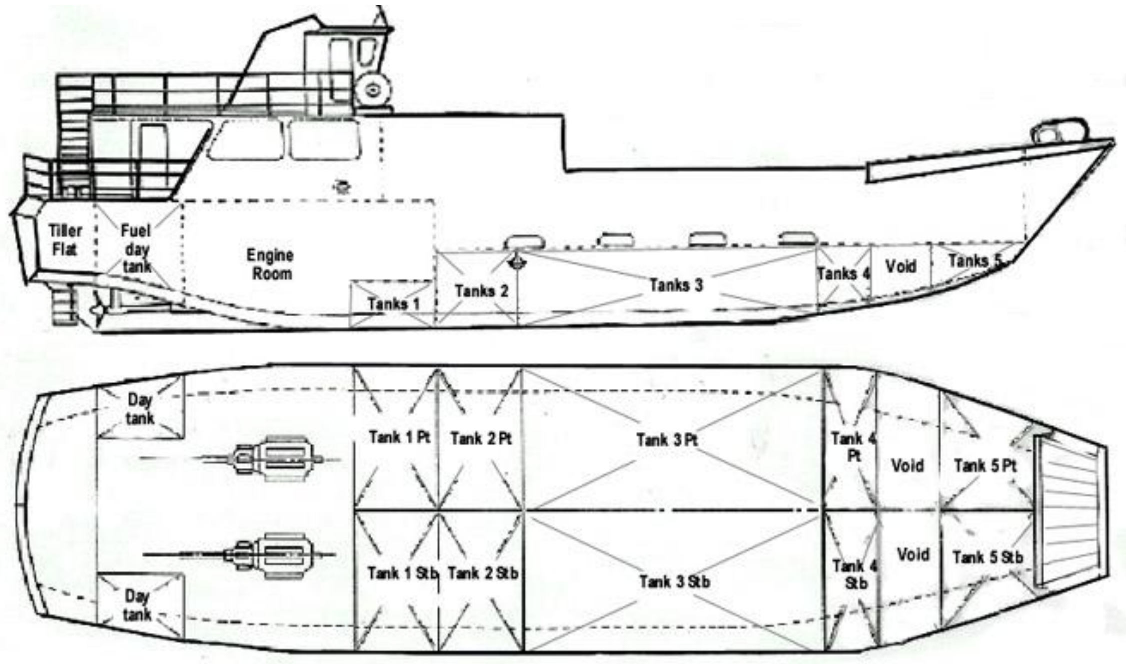
Vessel's record books, incident/accident books and record of drills and musters
The currency of staff qualifications and in-service training
The appropriateness of the vessel's operational & emergency plans to current operations and equipment
Update of the SMS to meet changed circumstances and regulation

Training & staff development:
The cooperation of the staff is essential in implementing an effective control plan. While the necessity to monitor and document places an immediate burden on staff, their engagement in the safety plan will encourage safe attitudes and develop workable safe practices. In the long term this foundation will repay the efforts many fold.

Tanks, Valves, Pumps and Bilge Systems

2.1 Tank arrangements

A vessel's tanks, in addition to storing fuel and fresh water, can provide a second skin that increases the watertight spaces (limiting in-flooding) and increases stability (by loading cargo or ballast water low in the vessel).The tank arrangement below shows day tanks from which fuel is gravity fed to the motors. Port and starboard tanks 1 are dedicated to the fuel oil needs the vessel's passage, and are regularly pumped to press up (fill) the day tanks. Tanks 2-3 can be used for ballast or fresh water cargo, and tanks 4 & 5 are suitable for oil cargo. The latter tanks are separated by a void that can be filled with water to limit the spread of fire (a coffer dam).



Tank Components

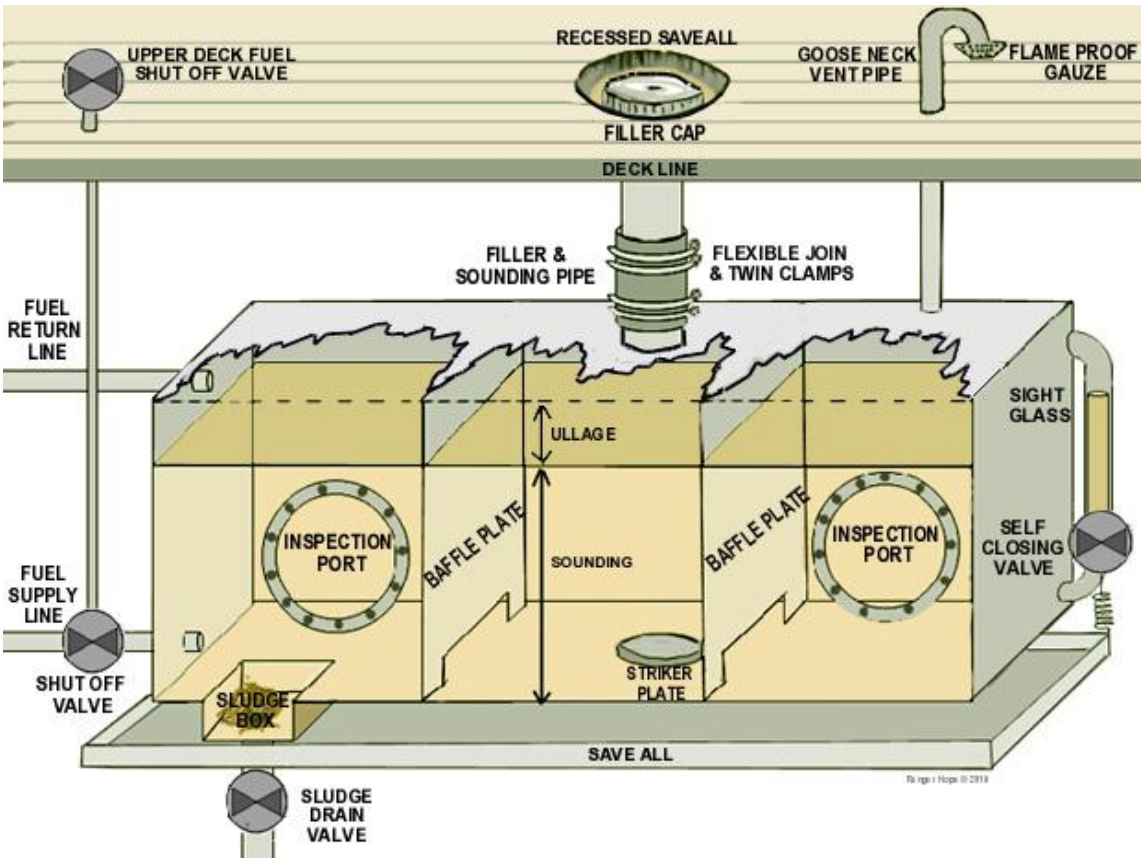
The following comments refer specifically to fuel tanks, but the same components are often incorporated in other tank systems.

Breathers- Fuel tanks, containing flammable liquids, are required to be vented to atmosphere (not into the vessel). This breather pipe will terminate in a gooseneck or swan neck (a cranked pipe), which limits rain and spray from entering. If the vent pipe is greater than 18 mm in diameter, the outlet is fitted with a wire gauze for a *flame trap*.

Filler pipes- Filler pipes are arranged so spillage will not enter the vessel. The inlet or delivery end of the pipe is located outside the vessel and will have a valve and fuel tight cap. The pipe between the deck and the top of the tank may be flexible, but must be reinforced and secured with twin corrosion resistant clips.

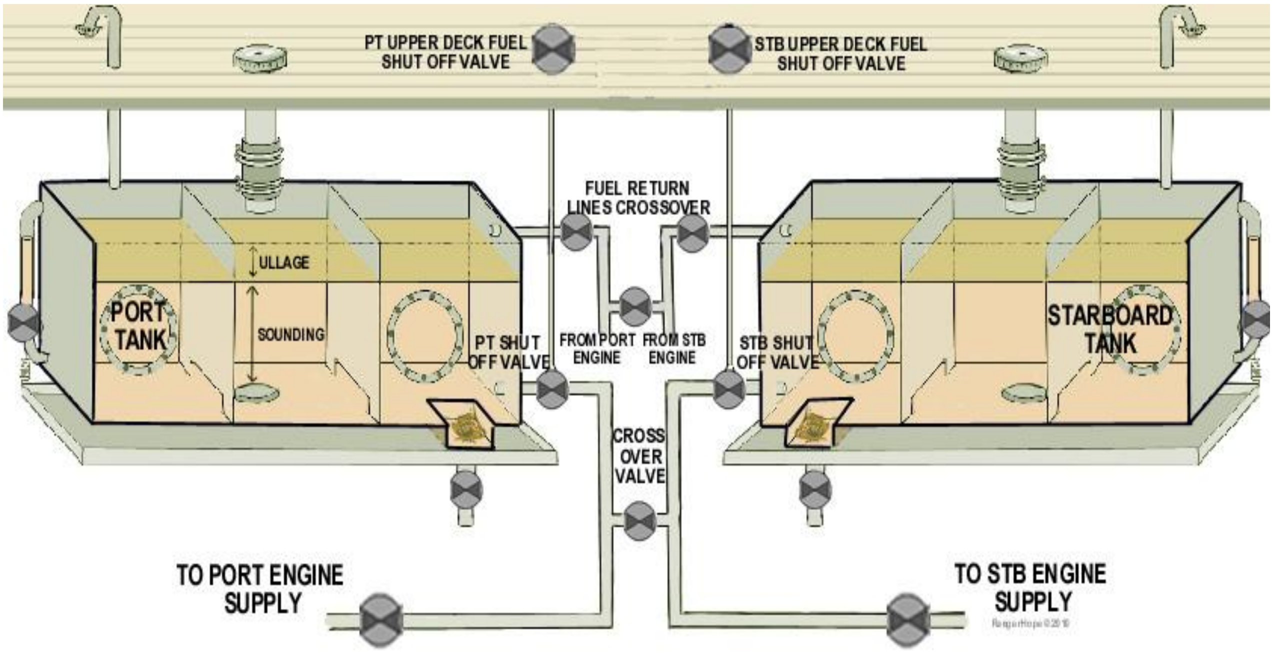
Sounding and sight gauges - Float fuel gauges are unreliable due to a vessel's changing trim, so checking the contents of the tank can utilise poking a calibrated stick (sounding rod) down the filler pipe until it hits the bottom of the tank and reading off the height of fuel that coats the retrieved rod (sounding the tank). An alternative is to read the dry end of the retrieved rod showing the airspace above the fuel (*an ullage*). If the tank's pressed up capacity is known then its remaining fuel can be calculated. Whether a filler pipe or a dedicated sounding pipe is fitted, at the tank bottom a reinforcing striker plate is welded to prevent a hole being eventually battered into the tank bottom.

An alternative measuring technique is a transparent sight glass spanning top to bottom whose fuel level reflects that of the main tank. This clear plastic/glass tube is more vulnerable to fire and impact than the main steel tank, so survey regulations specify that a self closing valve be fitted in case of rupture. Under no circumstances must these valves be left open. A recent variation is a non ferrous sight gauge containing a steel float whose height (and tank volume) can be determined by magnetic sensors. Tanks may be fitted with an overflow pipe which leads to an overflow tank or relief double bottom fuel tank. These overflows can be fitted with a sight glass and audible alarm. When re-fuelling, a safety managed procedure that utilises pollution and spill control devices must be operated to prevent spillage or fire. The only way to prevent accident is to ensure that personnel are trained and competent in the refuelling operation.



Shut off valves - All fuel supply lines have shut off valves fitted as close as possible to each tank (preferably on the tank). In case of fire these can be closed from outside the engine room on the upper deck (remotely) by a non-flammable linkage of steel wire or rod.

Multiple tanks can have a cross over valve fitted to either the fuel supply or return lines enabling the engines to be run from either tank or in the event of contamination, to isolate an offending tank. Care must be taken if redirecting a fuel return line to one tank only as this effective fuel transfer can be rapid and may affect the vessels stability or even overflow the tank. Some vessels may have two day tanks, thus the fuel return from the engines injectors should be changed over when the delivery is changed. Similarly, it is wise to close cross over fuel supply lines when refuelling from a high pressure fuel pump. The thrust of fuel entering the port tank filler pipe may depress the fuel in the tank and even force fuel up to overflow the starboard tank. The reverse will occur when the filling stops as fuel from the starboard tank can surge back to spill out from the port filler pipe.



Baffles – Perforated baffles (or not continuous baffles) are fitted inside the tank to allow limited liquid movement but minimise free surface area effects of liquids sloshing around as the vessel moves. Normally spaced not more than 1 m apart, those fitted longitudinally will reduce free surface caused by the vessel rolling and transverse baffles will reduce that caused by the vessel pitching.

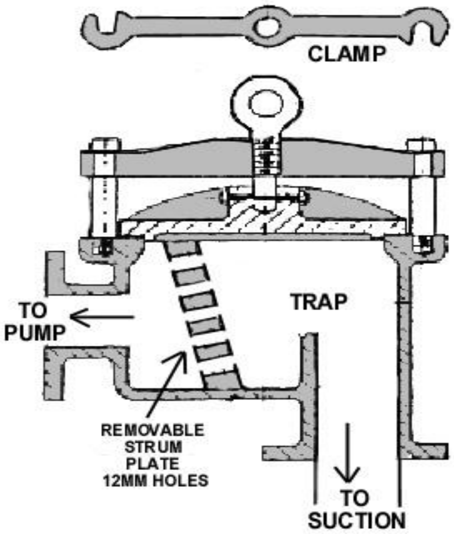
Sludge box & drain - Sediment contaminants of water, algae and debris will gather at the tank bottom where they must be periodically removed through a self closing sludge valve. In the event of the tank rupture or for periodic inspections, all fuel tanks which are not double bottoms must be fitted with a method of draining them into another storage tank (not the bilge).

Save all – Tanks that are fitted above machinery must have drip trays (savealls) fitted to prevent leaks onto moving parts. Fillers, engines and gearboxes are similarly fitted to stop oil reaching the bilge. Save alls also need drainage arrangements.

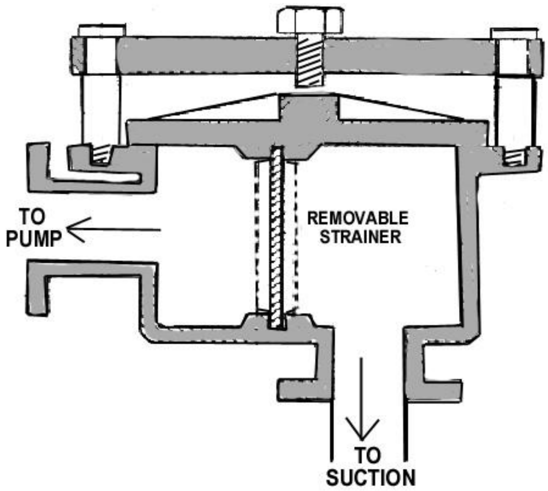
Inspection port- The top or bottom of tanks, where water and condensation accumulate, are prone to corrosion and need regular inspection. The bottom of the sounding pipe can corrode or even jam the sounding device. Consequently fuel tanks of more than 800 litres capacity require opening up and inspecting at periods of not more than 12 years through a manhole or inspection port. A larger tank may also have modified vent pipes or fitted purging (by inert gas) pipes to ensure tanks are evacuated of flammable gasses before opening up. The precautions of entering a confined space must be applied.

Double bottom and void tank tops are equally prone to corrosion but must be more regularly inspected. A weep of water entering a double bottom tank through damage to the outer hull will suddenly become a flood if the tank's resisting internal air pressure fails due to the tank top watertight seal corroding away.

Strums, Strainers, and Mud Boxes - Strums are boxes of perforated metal plate are mounted at the suction end of pipes from bilges and tanks to prevent larger objects entering and damaging the pumps while not entirely clogging the piping. They can be constructed with brass bolts or tongues and split brass pins so they can be periodically dismantled for cleaning.



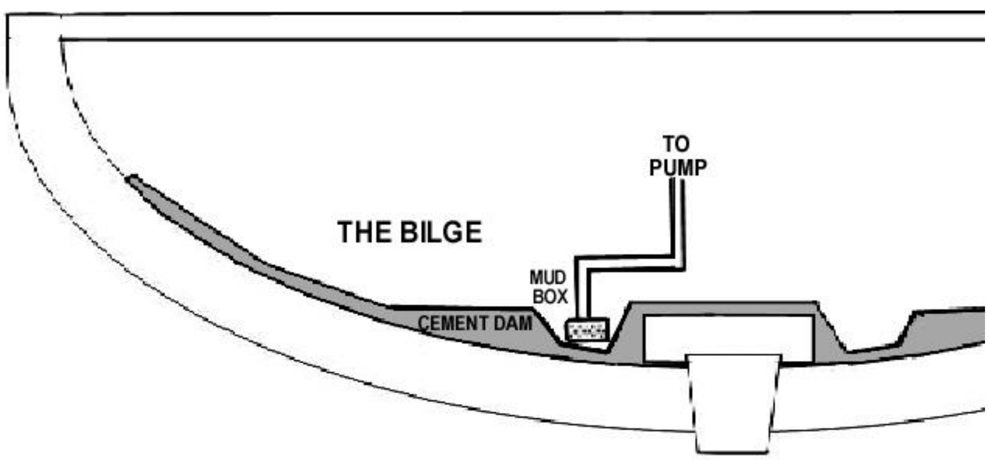
Strum box



Strainer

Strainers are used where frequent or constant cleaning is required and so must be mounted for easier access. The body and lid are usually of cast iron to provide an air-tight suction seal. Other parts are mild steel. The strainer plate is removable for cleaning.

A mud box is created by a (cement) dam around the base of the strainer plates. Solids that drop off the strainer plates are retained in the dam and prevented from flowing further back into the lower bilges. The mud box needs to be cleaned out periodically.



For NSCV specifications for piping see Section 1.5, *bilge piping.*

Fuel tank arrangements

Fuel systems are more fully described in the accompanying text *"Marine engine and propulsion systems for Marine Engine Drivers"*. Fuel arrangements must take into account its highly flammable nature, particularly in the critical operations of loading, unloading and refuelling. Safety considerations for refuelling should include but not be limited to the following:

Training all personnel to understand the systems and operate the safety procedures.
Understand and comply with all port regulations and ensure incoming fuel is clean.

Moor the vessel securely, secure fuel lines and pad where there are sharp edges.
Pipe bends should be smooth, not leak and if necessary be earthed.

Isolate naked flames or smoking and have fire-fighting appliances in readiness.
Plug scuppers on deck, ensure tank vents are clear and have clean up gear ready.

Maintain a constant watch to monitor flow and prevent spills, close filler caps after fuelling and clean any spills on deck.

Refuelling is more fully described in the accompanying text *"Refuelling and transfer operations".*

Fresh Water Systems

Fresh water must be stored in a designated tank as it can take on an unpleasant taste or worse still become polluted and a risk to health. It should not be possible to pump fuel or ballast into fresh water tanks or vice versa. Those other tanks should be separated by a cofferdam so that if there is a leak it does not contaminate the fresh water. Fresh water tanks were traditionally coated internally with a cement wash in order to limit corrosion and maintain the water quality. More effective modern coatings are now available but tanks should still be inspected at regular intervals and renewed as required.

Water stored in a cooler area is preferred but as water quality will deteriorate over time it is common practice to flush periodically and filter drinking water. It can be additionally treated with chlorine or by UV sterilisation to kill bacteria.

Water usage demand will be created as soon as a tap is turned on. In any arrangement other than a gravity feed a pump is required. To prevent the fresh water pump from starting and stopping constantly, a pressure tank system is usually incorporated. It uses a buffer tank of compressed air that allows water to be continuously supplied under pressure, with the pump operating only intermittently to top up the pressure in the tank.

The most common cause of poor drinking water quality is from loading contaminated water from the wharf. It is wise to examine a test sample of water closely before any loading takes place.

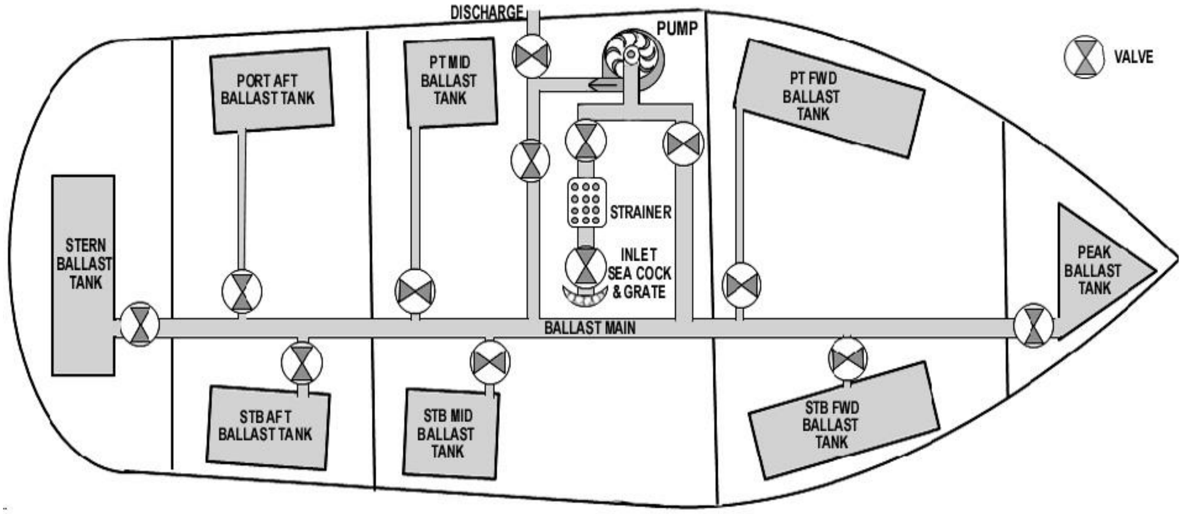
Ballast Water Systems

Ballast, or heavy weight such as rock or gravel, can be loaded into a vessel to improve her stability by adjusting her trim or lowering/raising her centre of gravity. Water ballasting allows a larger vessel to more conveniently achieve the same ends by pumping sea water in or out of dedicated ballast tanks. These are typically the double bottom tanks low down in the hull. Smaller vessels may use water ballasting to improve their operations, such as tugs loading ballast to immerse their large propellers to gain greater thrust or landing craft to pin the bow on the beach after landing.

Ballast arrangements

Each ballast tank is provided with means of filling, venting, sounding and emptying. Tanks can be filled by transfer pumps or gravity by opening the tank inlet valves directly to the sea. Filling or emptying by gravity saves the fuel that would normally be used to drive the pump. When gravity is used for filling there is no danger of over-pressurising the tank. The sea connections or sea cocks with their grates prevent debris from entering the system. On the inboard side of the seacock a strainer filters out the finer solids to protect the system from blockage or damage. An isolating valve enables the inboard strainer to be opened up for the regular cleaning needed without flooding the vessel. Care is required when servicing to ensure that the filter screen is clean and undamaged, that the seals are in good condition and that any sacrificial anodes are inspected and replaced as required. All need to be inspected and repaired whenever the vessel is on the slip.

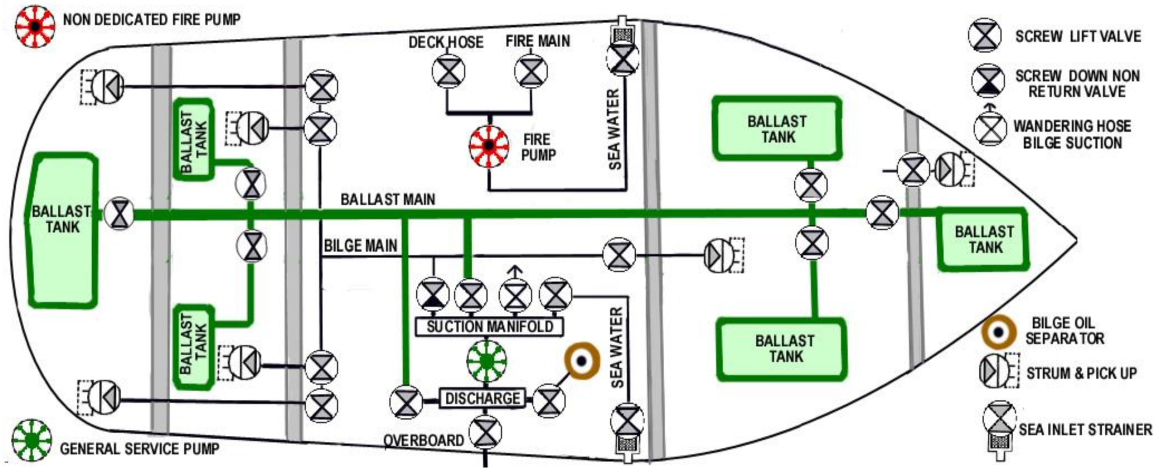
The transfer pump, typically an electrically driven centrifugal type, can direct sea water to each of the ballast tanks. (Impeller general service pumps may be used on small vessel). In the schematic drawing below, by the opening the relevant valves, water is pumped to the port and starboard aft ballast tanks through the common ballast main pipe. Similarly, by opening and closing the relevant valves, if flow can be reversed to empty from the ballast main to the overboard discharge.



The simple ballast arrangement shown may alternatively use a general service pump with a common manifold for bilge pumping operations (shown below)

As centrifugal pumps are not self priming it is not advised to run a pump dry. With centrifugal pumps, common practice at the latter stages of pumping is to have the sea water inlet slightly open to act as a pump lubricant and coolant, and to maintain priming.

Ballasting operations
Before operations physically check that all valves on the suction and discharge manifolds of the fire and bilge and general service pump are shut.



Note: Schematic drawing only. NSCV Part C Section 4 Fire Safety allows some vessels non-dedicated main fire pumps (doubling with deck hose or ballast) provided they are not used as bilge pumps.

Ballasting a tank by gravity
Open the sea inlet valves at the vessel’s side. At the suction manifold of the general service pump, open the sea suction and ballast suction valves. Open the valve to the tank to be filled. Sea water will then flow by gravity from the sea inlet along the manifold through the ballast suction into the ballast main, and to the tank to be filled.

Using gravity, the tank fills only to the draft the vessel is floating at. If the top of the tank being filled is higher than the current draft of the vessel, it will be necessary to complete filling by pumping.

Ballasting a tank by pumping
Open the sea inlet valves. Open the sea suction valve at the suction manifold and close the ballast suction valve. Open the ballast line on the discharge side of the general service pump. Open the valve for the tank to be filled. Start the pump. Ballast water will now pump from the sea inlet to the selected ballast tank.

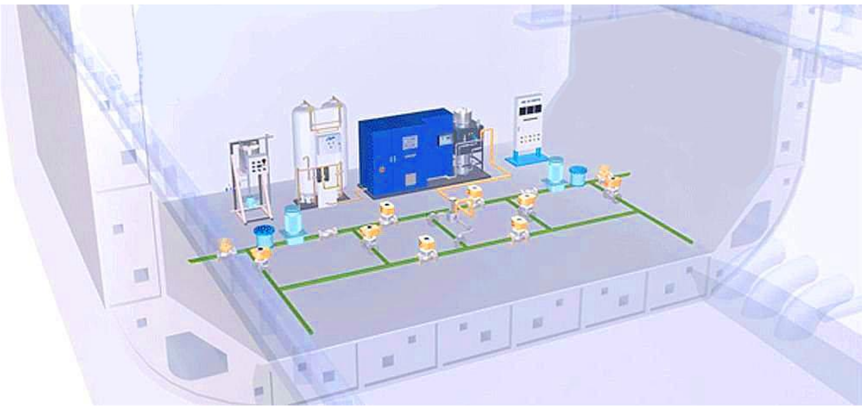
Note: With impeller positive displacement pumps, all valves should be open before starting the pump.

When filling, soundings of the tank should be taken at intervals. The pump should be shut down and all valves closed when the tank is full. In some vessels it remains standard practice to allow the tank to fill until water overflows from the tank air vents that are a minimum of 1.25 times the area of the filler line. This practice should be treated with caution particularly with older vessels.

De-ballasting by pumping out (emptying a ballast tank)
Check that all valves on the suction and discharge manifolds of the fire and bilge fire and bilge and general service pump are shut. Open the valve on the tank to be emptied. Check

that the shipside overboard discharge valve for the general service pump is open. On the general service pump, open the ballast suction valve.
Start general service pump and open the overboard discharge. The tank will start to empty. Take soundings at regular intervals. When the tank is empty close all valves.

The transfer of ballast from sea and river water and discharging on the other side of the world has led to the unintended importation of pests and exotic species. There are now tight laws worldwide regulating discharge of ballast and larger ships may incorporate sophisticated water ballast handling systems to limit pollution like that shown below.



Ballast management system drawing Courtesy of Wikipedia

Sullage

Whether a gravity feed of pressurised system is used, any holding tank will have to be heavily reinforced to withstand at least the pressure of a shore pump out (a requirement within territorial waters) if not the vacuum from toilet to tank. The small bore vacuum piping common in vessels lends itself to blockage so arrangements are made for internal access for cleaning. Gloves and hygiene precautions must be operated while maintaining sullage systems to avoid illness by contact with faeces including that due to the bacteria e coli and the virus hepatitis.

Most vacuum systems incorporate a one way valve to evacuate air from the tank (to de pressurise). If a tank is allowed to overfill, solid debris will be sucked into the valve preventing its seal fully closing - symptoms will include poor flushing, continuous pump operation and cold or frozen valve housing. Additionally the breathers that carry away the flammable methane and other smelly gases may invade the vessel.

Confined spaces

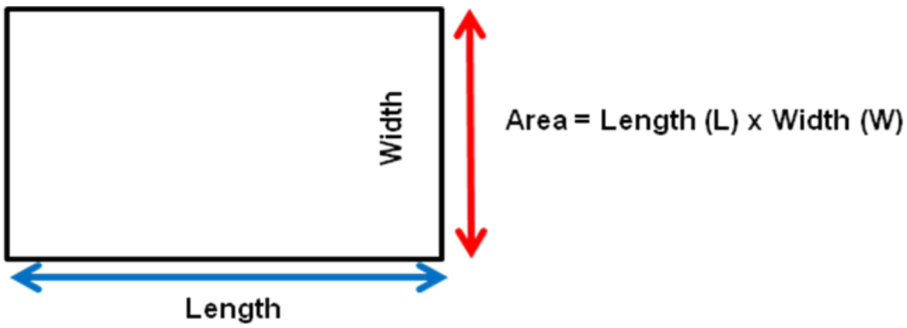
Tanks are typical confined spaces defined as fully or partially enclosed areas which aren't designed to be normal places of work, and where entry and exit are restricted. Tanks are likely to have depleted or contaminated atmospheres. Before any internal maintenance OH&S legislation requires confined space (tank) venting/purging to remove contaminants, a gas free test certificate confirming the atmosphere is safe to enter, certificates to enter/ work and an entry management plan that includes a watch sentry, rescue equipment and strategies. More about confined spaces is included in Chapter 10 and the associated *texts "Working in confined spaces"* and "*Pollution & prevention"*

2.2 Calculating tank capacity

In determining the vessel's fuel, water or loading conditions, gauges are inaccurate due to the rolling and pitching at sea. Using standard mathematical formulas calculations can be made from each tank's dimensions. These formulas include:

Areas of Common Shapes:
Area is the measurement of the footprint for a two dimensional object.

Rectangles - The area of a rectangle is measured by multiplying the Length by the Width.



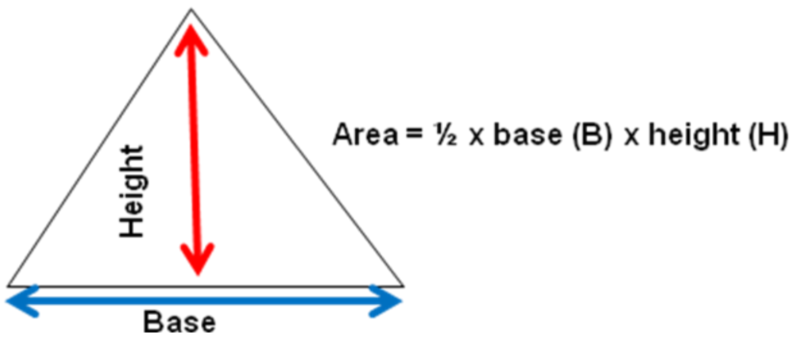
Example: Find the area of a rectangle measuring 10.2 metres long and 6 metres wide.

AREA = L **x** W

= 10.2 **x** 6

= 61.2 $mtrs^2$ (square metres)

Triangles -The area of a triangle is calculated by multiplying half of the base of the triangle by the height of the triangle. Or equivalently, the base can be multiplied by the height and the result then divided by two.



Example: What is the area of a triangle with a base of 3.8m and 1.1m high?

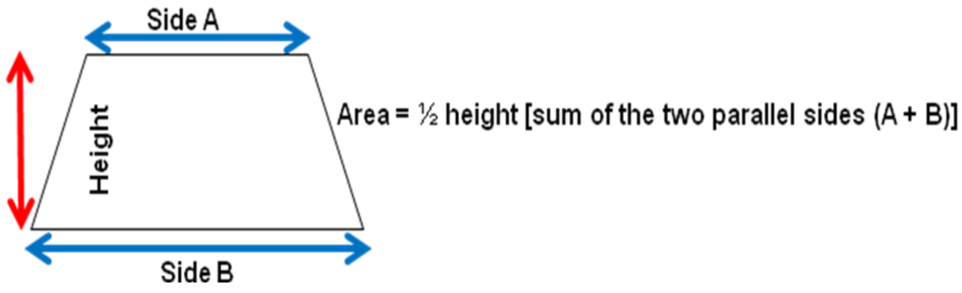
Area (A) = ½ x B x H

A = ½ x 3.8 x 1.1

= 2.09 $mtrs^2$ (square metres).

Trapeziums - A trapezium is a four sided figure that has only two parallel sides.

Its area is calculated by multiplying half its height by the sum of the two parallel sides.



Where ***A*** & ***B*** are the parallel sides and ***H*** is the perpendicular (shortest) distance between them, the height. Note: Do not measure up one of the sides.

Example: What is the area of a trapezium having parallel sides of 2.12m and 3.1m which are 1.2m apart.

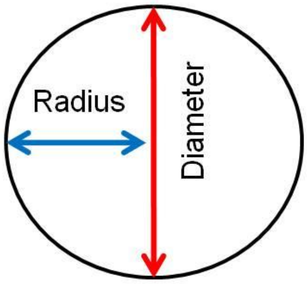
Area (A) = ½ x *(A + B)* x *H*

A = ½ x (2.12 + 3.1) x 1.2

A = ½ x (5.22) x 1.2

= 3.132 $mtrs^2$

Circles - The area of a circle is given by using the formula:



Area = π x r²

Where: π = pi = approximately 3.14, or as given by your calculator.

r = radius = half of the diameter of a circle.

Example:

Find the area of a circle with a diameter of 2.6cm. Give your answer to 2 decimal places.

$$\begin{aligned} \text{Area} &= \pi \times (\tfrac{1}{2} \times 2.6)^2 \\ &= \pi \times 1.3^2 \\ &= 5.309291585 \\ &= 5.31 \text{ cms}^2 \end{aligned}$$

Some prefer to use the alternative formula

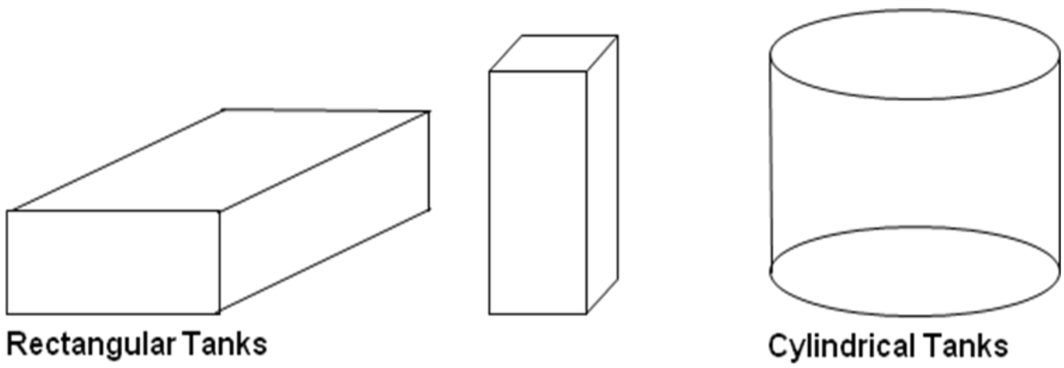
$$\textbf{Area} = \frac{\pi}{4} \times \textbf{diameter}^2$$

Volumes of common tank shapes

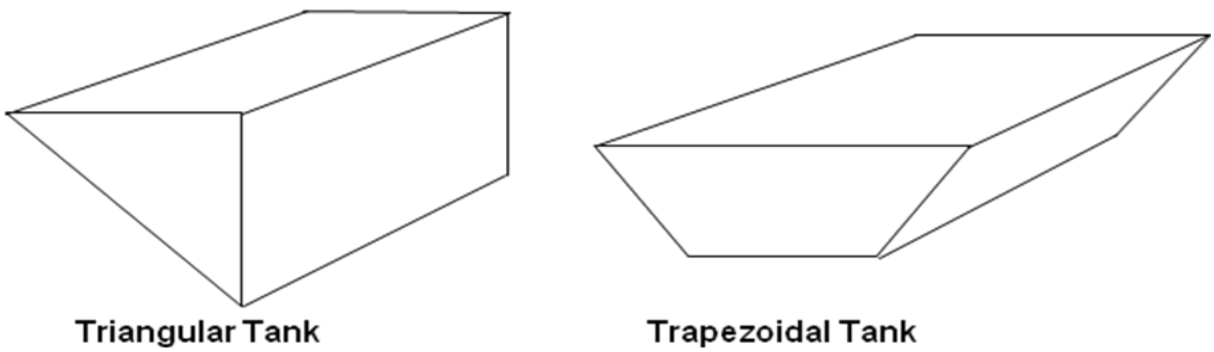
Volume is the capacity measurement for three dimensional objects.

Tanks can be considered to be “regular” or “irregular” in shape:

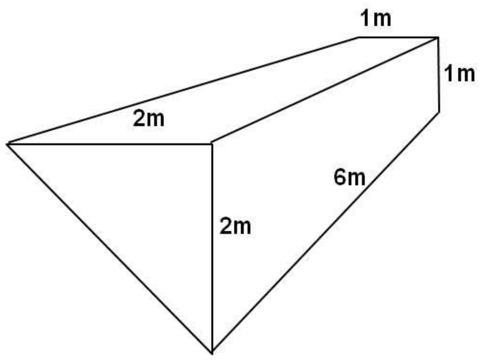
Regular shaped tanks:



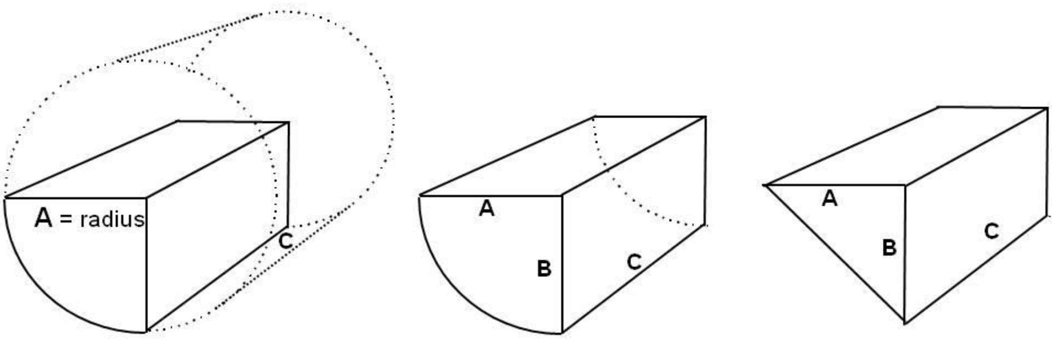
Irregular shaped tanks:



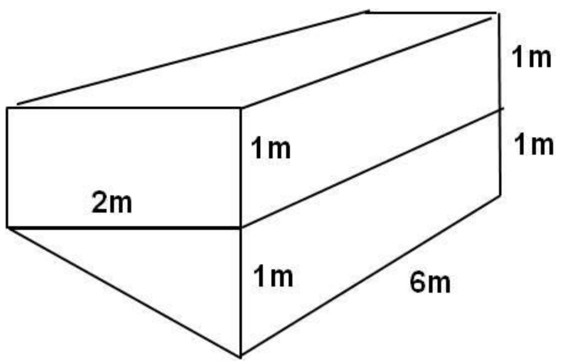
Tanks that taper also fit into this category.



In practical situations you may need to make calculations based on an approximate shape. For example, this curved tank can be approximated as a triangular tank or a quarter of a cylinder depending on the lengths of **A** and **B** and the curvature.

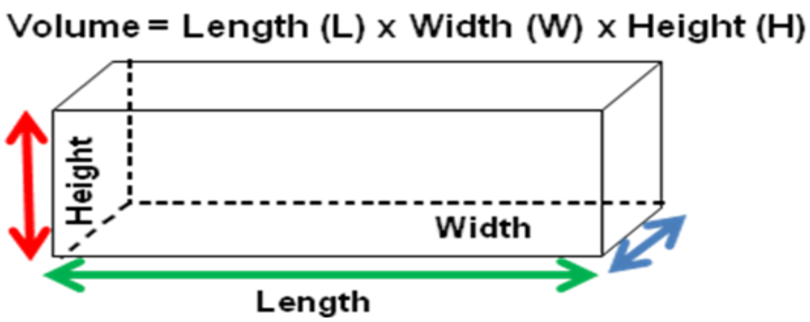


Alternatively, tanks may be considered as composite shapes and the capacity of section each calculated separately. For instance, the tank below is calculated as the composite of a rectangular top section added to the triangular bottom section to give the overall tank volume.



Rectangular Tanks:

To calculate the volume (and capacity) of rectangular tanks the formula is Length multiplied by the Width multiplied by the Height of the tank.



Example: If a tank is 3.1m long and 2.24m wide, what would be its volume if the depth of the tank is 1.1m.

Volume (V) = L x W x H

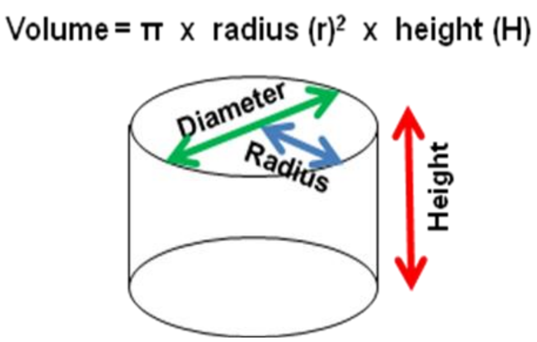
= 3.1 x 2.24 x 1.1

= 7.6384 mtr^3

= 7.64 mtr^3 (in cubic metres to 2 decimal places)

Cylindrical Tanks:

The volume of a cylindrical tank is measured by multiplying the area of the circle by the height or length of the tank.



Example: A cylinder has a circular base of 1.8m in diameter and stands 2.2m high. What is the capacity of the cylinder?

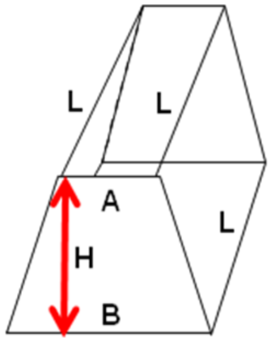
Volume = $\pi r^2 \times h$

V = $\pi \times 0.9^2 \times 2.2$

= 5.595 mtr^3

Trapezoidal tanks:

Given the shape of some vessels and the limited space available below decks, it is often necessary to make fuel tanks in an irregular shape.



The area of a trapezium is calculated by multiplying half its height **H** by the sum of the two parallel sides **A** and **B**.

Area = ½(A+B) x H x L

Once you have calculated the area of the side ends, you can calculate the volume of the tank by multiplying it by the length **L**.

Example: Referring to the above shape, calculate the volume if the dimensions of the tank are:

A = 1.5 B = 3 H = 2 L = 4

Area = ½ (A+B) x H x L

= ½ x (1.5 + 3) x 2 x 4

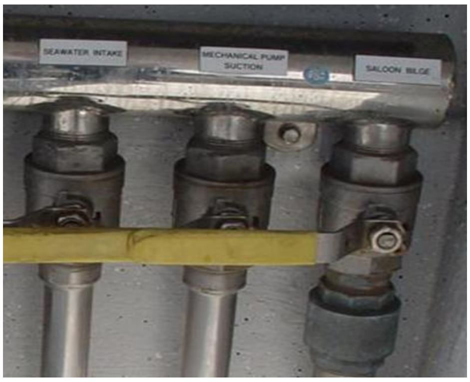
= 4.5 x 4

=18 mtr^3 or the tank has a volume of 18 cubic metres

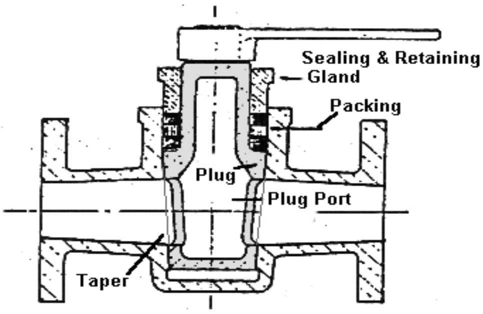
For more exercises see the associated text *"Fuel Usage".*

2.3 Valves

Ball valves
These increasing utilised valves rely on accurate machining in manufacture. They use a ball with a matching nylon seat. Older versions may use a cone shape. With the cock turned on, a hole through the centre of the cone/ball lines up with the pipe and opens a full flow. When not line the pipe is blocked. One advantage is that (if properly fitted) the handle will point in the direction of the pipe when open, allowing a visual check of the status of the valve. A disadvantage is that repair can require specialist tools and spares, so the smaller sizes can be regarded as disposable.

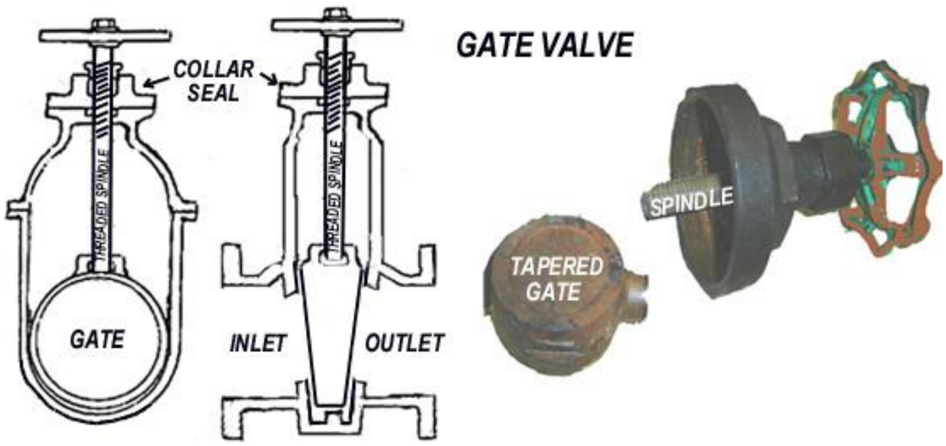


Ball valves



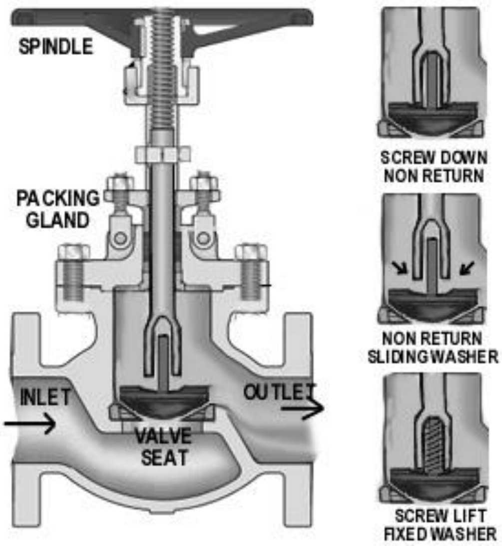
Plug Cock

Gate valve
This traditional full flow shut off valve uses a tapered 'gate' which wound down onto a seat in the off position. It can suffer from debris and scale build up if not used regularly that can jam the gate from fully closing, but is easy to service. The spindle gland can be adjusted with a gland nut, to reduce weeping.



Other screw-down valves
The screw-down valve will give full bore flow and is easily maintained. In the non-return version the valve washer assembly and the spindle are loosely connected. A back-flow into the open valve will force the valve washer down against the seat, closing it. In low pressure applications, there may be insufficient 'head' at the inlet to lift a valve which may stick to the seat. The screw-lift version can be used in these applications, as the valve is fixed to the spindle and forcibly lifted from the seat. There will be no non-return function

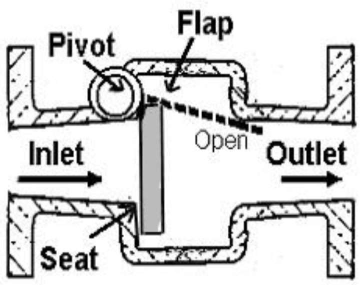
with this variation on the standard valve. (This non return problem can be overcome by placing a non-return check valve in the line before the screw lift valve.)



A screw down non return valve

Other non return valves

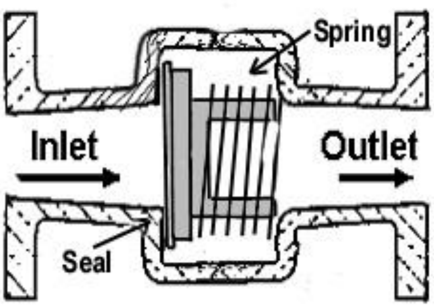
Some *non-return valves* use pivoting flaps and some spring loaded plungers to allow one way flow. They are used to limit back flow. The flap type is mounted so that gravity closes the flap when flow stops. Back pressure then holds them closed.



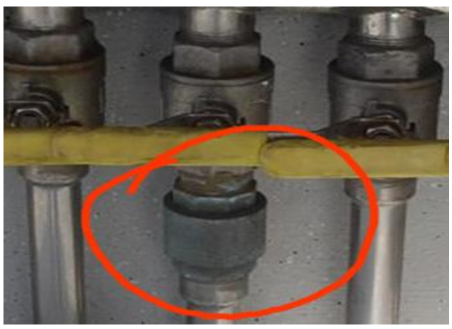
Non-return flap valve

Use as exhaust cover

The check or plunger type is spring activated and will open only when under pressure from the inlet side. If debris collects around the seal then it will not fully close. This can happen if vacuum storage tanks (sullage) are allowed to overfill and back flow.

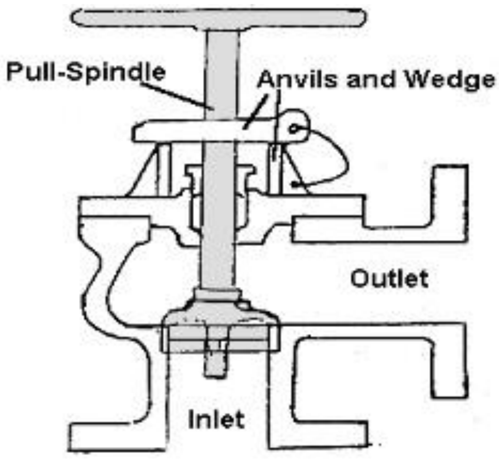


Non-return check valve



Use to limit bilge water back flow

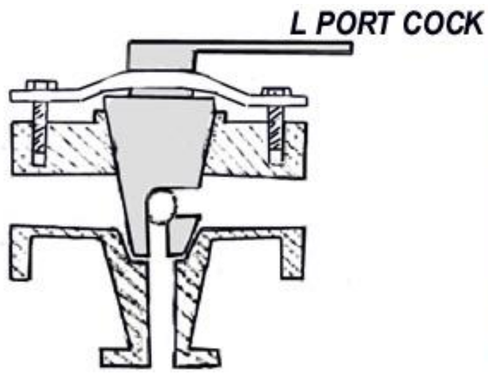
The pull lift globe valve for overboard discharges, is opened by a straight pull-lift. The wedge inserted through a slot in the shaft will hold the spindle in the raised position. The valve will move freely while water is discharged, but when the water stops flowing, sea pressure will close the non-return valve.

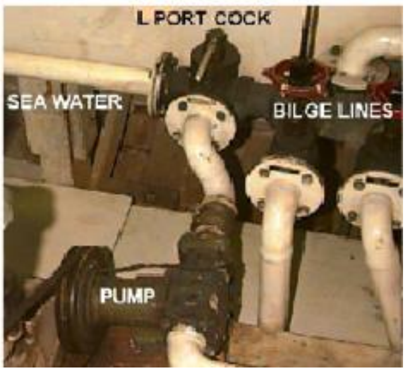


The pull lift globe valve

L port cock

The L port cock is a modification of a plug valve machined with a *Morse* taper fit into the valve housing. It allows two different flow pathways. The typical application is for bilge systems where the pump can be directed to the empty the bilge lines or supply the deck hose (from the sea water inlet). The safety feature of the L port cock is that connecting the seawater to the bilge cannot occur. Morse taper valves will stick if left for long periods (usually in the bilge to pump mode). It is advisable to turn the cock on a scheduled basis to avoid this problem occurring when you really need that sea water hose for fighting a fire.





Butterfly valve

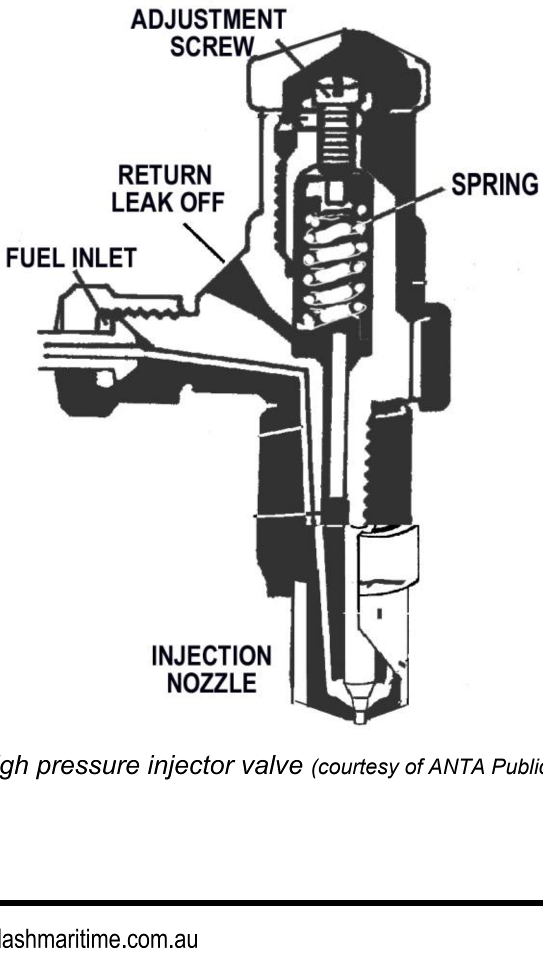
This simple valve is constructed from a flat metal disc attached to a shaft that can be rotated on its central axis to restrict the flow within a circular pipe or housing.

It is often found in low pressure air control systems such as engine room air vents. A more sophisticated version is used in demand air supply systems such as petrol engine carburettors.

Butterfly valve (courtesy of sureflowequipment.com)

High pressure valves

Diesel fuel injector valves are typical examples of where the resistance of a strong (adjustable) spring can be set to open a valve at a precise pressure rating. These valves require very clean fuel in order to operate without blockage by dirt, debris or other contaminants of the fine passageways.



High pressure injector valve (courtesy of ANTA Publications)

2.4 Pumps

Pumps can be hand (manual) or power driven from the vessel's main engines, an auxiliary motor, by a hydraulic system or by electrical motors. The pumps on a vessel are known as devices to move water but they also move gasses, other liquids and slurries. Modern vessels use pumps to take the hard work out of many onboard services including fuel, lubrication, steering, machinery, ballasting, plumbing, ventilation and cargo handling.

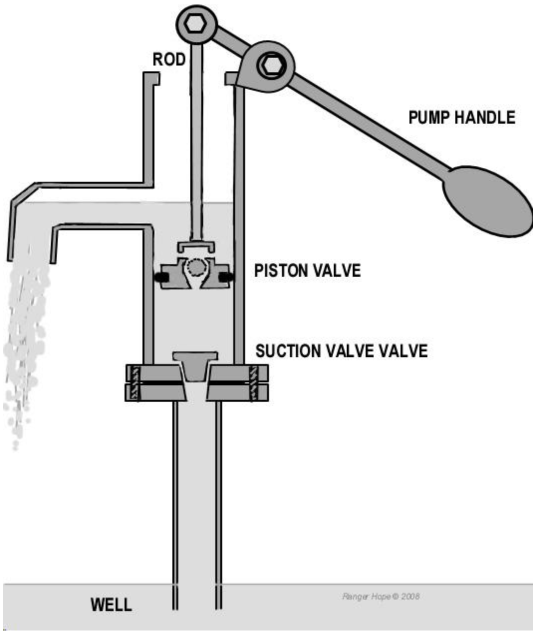
On the ship "Zulu" shown above, a reciprocating steam piston turns a rotary paddle wheel

Pumps work in a reciprocating (back and forth) or a rotary action. The first lends itself to pulsing flow and the later to a continuous flow. Common pumps types can use the principles of positive displacement, dynamic (or kinetic) or gravity for their operation.

Positive displacement pumps

These pumps use the principle of expanding and reducing volumes creating pressure difference between sealed chambers (commonly called suction). They are typically self-priming, but air leaks in the suction side will reduce or stop the flow. The suction side seal must be carefully maintained.

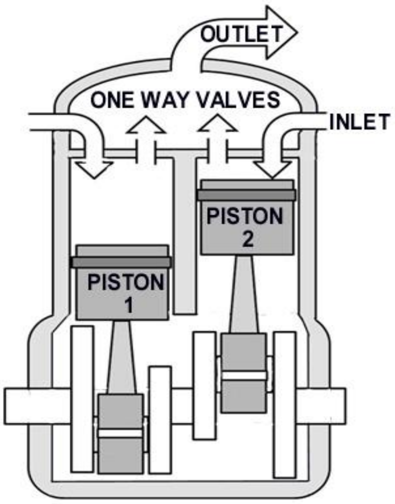
Piston pump - A rod raises the piston valve to expand the middle chamber's volume.



A stand pipe is a traditional reciprocating piston pump, used here to pump water from a well

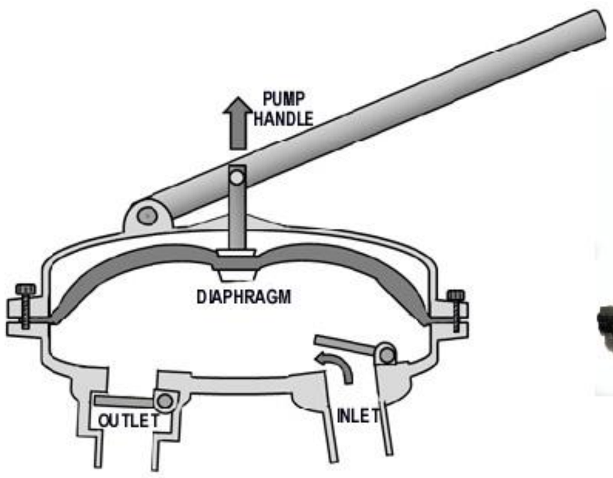
The reduced pressure forces water up through the suction valve. On the rod's down stroke, the raised water is squeezed up through the piston valve and on the next up stroke is further lifted to overflow through the spout. Just as these *stand pipes* were universally used to access communal village wells a century ago, similar leather valved hollow trunk version served as a bilge to deck pump on old sailing ships.

Twin piston compressor - The modern compressor uses one way metal flap valves to hold pressure in a tank above the twin cylinders. The inlet metal flap valve opens on each piston's down stroke so gas enters the cylinder. As the piston rises the inlet valve is forced shut and the compression tank valve above opens. Compressed gas is forced up. A shut off or bypass arrangement is needed to avoid over pressurisation of the holding tank and subsequent internal damage. The bottom of the pistons can be splash lubricated from crankshaft action in an oil sump below. As liquids are non compressible, measures need to be taken to avoid water or oil of lubrication entering the cylinders. Typical applications for this type of pump are air compressors and refrigeration pumps.



A compressor pump

Diaphragm pump - Another positive displacement pump is the diaphragm hand pump, often used as an emergency bilge pump. The flexible rubber diaphragm is squeezed up and down to create suction controlled by the twin valves.

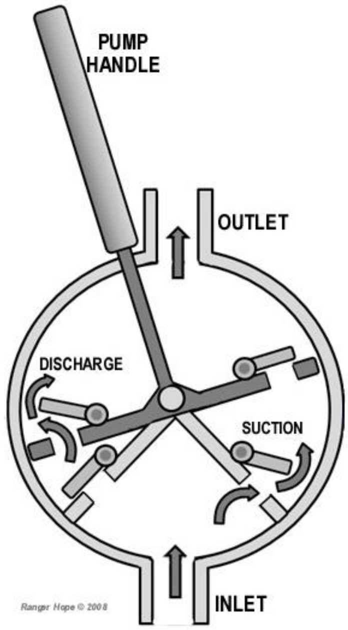


A diaphragm hand pump operated by the reciprocating action of the removable handle

Despite their great advantages of simplicity, low cost, self priming and good flow rate these pumps are reliant on the perishable diaphragm. A spare diaphragm should always be carried. The most common models have plastic housings so are not fire resistant.
The diaphragm principle is also used for small electrical compressors.

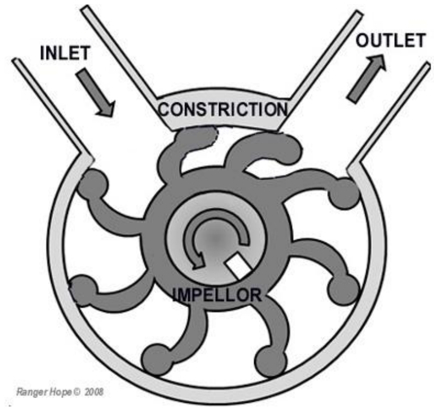
Semi-rotary pump - This marine hand pump is made from a housing of cast iron with bronze moving parts. As the handle is moved, the volume of left middle chamber is squeezed as the volume of right middle chamber is expanded. The one-way valves allow liquid in the squeezed chamber to flow up to discharge, while on the other side liquid is sucked into the expanding chamber to await the next stroke's lift to discharge.

Its self priming capabilities are inferior to the previously described pumps but it is fire resistant and rugged. Consequently it is the commonly approved manual bilge, fire and deck hose pump. Forcing its handle hard over against the stops in an effort to get it pumping can damage internal components. Pouring water down the outlet will be necessary to prime the pump. Unless regularly operated (as required for emergency musters and drills) it can drain dry and debris with rust will seize it. A splash of olive oil poured down the outlet will reduce corrosion and when next used for deck wash will stain them less than the alternative of mineral oil or heavy grease.

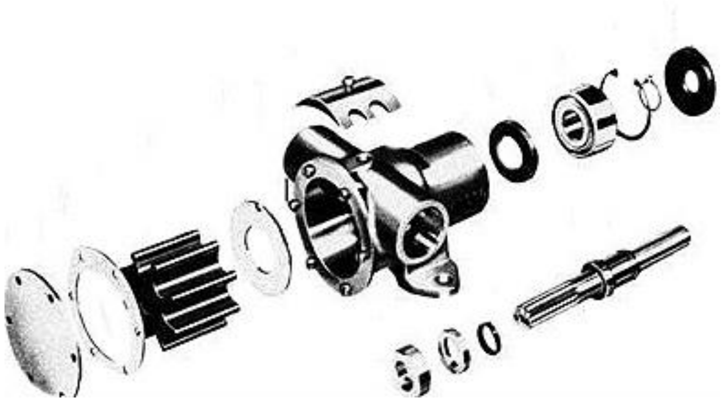


A semi-rotary hand fire and bilge pump

Flexible impeller rotary pump - This rotary positive displacement pump is so widely found in marine engine's salt water cooling and bilge systems that it is often called by its trade name, *"a Jabsco pump".* The casing in which the impeller revolves is not uniformly circular, having a constriction (or cam) over a third of its diameter between the inlet and outlet. As water is carried around the casing the space between the impeller blades expands around the inlet (drawing water in) and contracts around the outlet (pushing water out). Water pumps use rubber or neoprene while oil or fuel pumps use alternative chemical resistant materials for impellers.



A rotary impeller positive displacement pump and housing



Flexible impeller pump construction (Courtesy of ANTA publications)

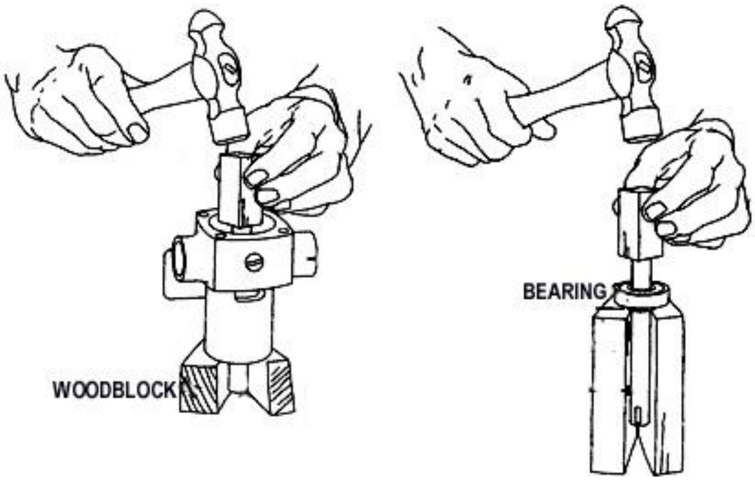
The engine driven shaft is sealed by packing or a mechanical seal. All suction side connections must also be air-tight as leaks will stop or slow flow through the pump.
A cover plate over a gasket gives easy access to the casing and impeller. The impeller is a drive fit onto a splined shaft or one with a keyway. Although it is a self-priming pump the flexible impellor relies on the pumped fluid for lubrication so it will be damaged if the pump runs dry. Unless an automatic cut-off is fitted this type of bilge pump must therefore be constantly monitored while operated.

Stripped blades of flexible impellers damaged by debris drawn into the pump

Other failures of flexible impellers result from chemical attack (from polluted bilge water), water flow cavitations (from narrow piping or over speed pumps) or more traumatically solid materials that evade the inlet gratings and screens and are drawn into the pump. A sudden increase in wet exhaust engine noise is a sign that salt water cooling has dramatically failed, and the impeller is a prime suspect. Pumps that are not used for extended periods can develop misshapen and brittle impellers that need to be replaced and can adhere to the pump cover.

With a clean bilge and effective strainers a bilge pumping impeller pump will give years of service, but in a commercial vessel the raw water *Jabsco* works continuously and will require regular servicing. Spare impellers sets should always be onboard so timely replacement can be carried out by:

Removing pump cover and gasket beneath and sliding the impellor off the splined drive shaft to inspect for damage. They can be reluctant to let go and may have to be carefully prised off with levers. Check for broken blades, impeller end clearance, worn casing wear plate and leaking seals. The end plate and impeller must be a good fit to pump and self prime. Old end plates may have become grooved so will have to be honed flat again. Repairs may include attention to the gasket or replacing a worn bearing. To separate the bearings from the shaft use a wood block to support the unit while tapping out the shaft.

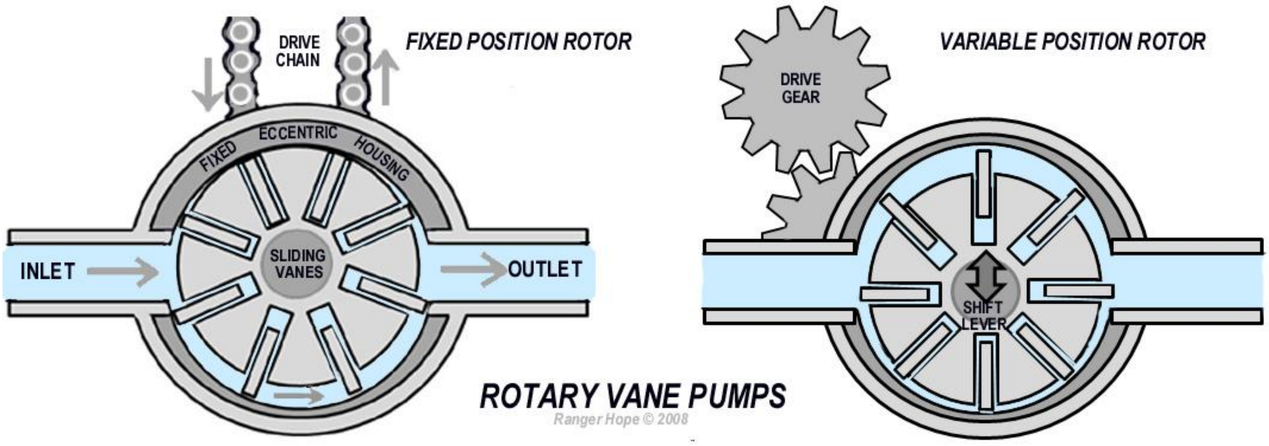


Drawing courtesy of ANTA Publications

A new impeller can be just as reluctant to squeeze back onto the shaft and into the casing. A smear of soap and the assistance of a rubber mallet may be required.

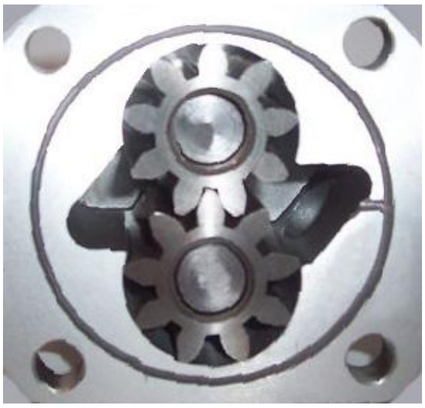
Before starting the pump ensure that drive belts (if fitted) do not slip. It may be necessary to initially prime the system especially if the pump is fitted high in the vessel. Smaller portable electric pumps are unlikely to pump up to more than one to two metres so outlets may have to be initially positioned by trial and error.

Rotary vane pump - This simple fixed rotor pump below operates by the solid vanes housed in a slotted rotor being flung by centrifugal force into the eccentric (nylon) housing on rotation. The drive direction (by belt, chain, air or hydraulic) determines the flow direction. Modified versions are often used as hydraulic pumps for steering and winches, though the type has limited pressurisation capabilities. It is best suited for clean fluids only.



The variable rotor pump operates similarly, but the rotor's position in the housing can be shifted by a control lever so altering flow speed and direction. With constant anticlockwise drive the variable position rotor pump shown above will create full flow from right to left when positioned at the bottom of the housing, decreasing to no flow in the centre and then increasing to full flow from left to right at the top of the housing.

Gear pumps -These use intermeshed cogs, screw threads or helical gears and are used as lubricating oil pumps. They withstand heat and will pump relatively viscous liquids at medium to high pressure.



An intermeshed cog gear pump

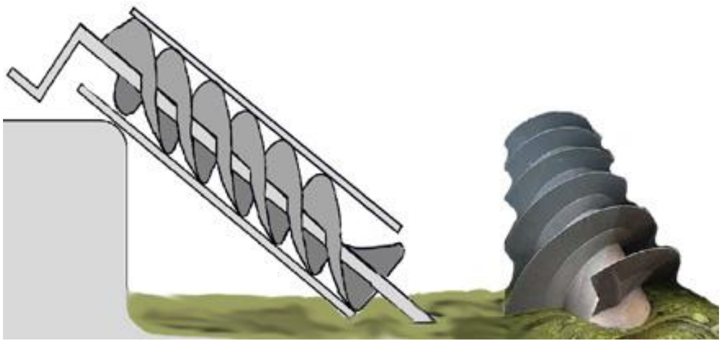
The roots air blower is a variation of this principle using intermeshed elongated fan blades. A typical application is the supercharger blowers on Detroit engines.

All positive displacement pumps are best operating with an open outlet and the more powerful can sustain internal damage if piping or valves are shut off while the pressure of pumping is allowed to continue building. High pressure pumps are fitted with over pressure relief or bypass valves.

Dynamic or Kinetic pumps

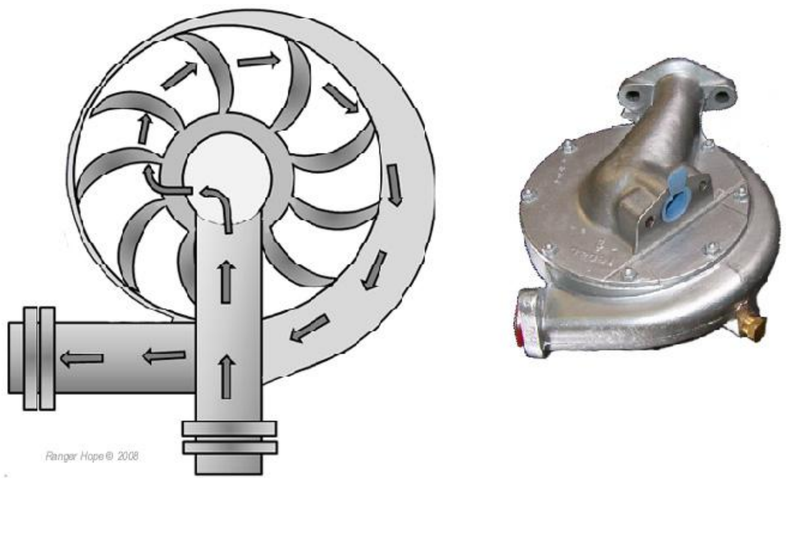
Dynamic pumps use the principle of picking up the gas, liquid or slurry and moving it as in a conveyor belt. Unlike the positive displacement pumps they are not as easily damaged by working against a closed valve, so do not have to be closely monitored to shut down as soon as they suck the tank dry.

Archimedes screw – This ancient water pump is turned within a barrel or trough. It is ideal for slurries and is found adapted for farm machinery and for bulk cargo handling conveyor systems. It is the forerunner of the modern propeller.



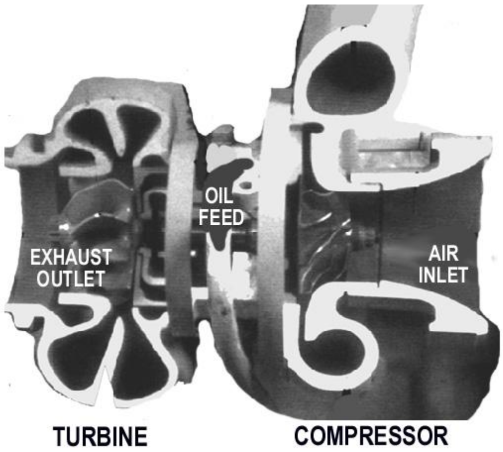
Archimedes screw lifting slurry

Centrifugal pump – This pump type is also resistant to damage by a closed outlet as it will cease to draw in further material. However cavitations and erosion will cause longer term damage. It uses a rotor (solid or flexible impeller) with swept back blades to push material down onto the central rotor, spin it around the “volute” shaped casing and throw it to the outlet. They are suitable for moving less viscous liquids, air and (with sufficiently robust rotor blades) will suck up and spit out solids such as sawdust and shavings.



A centrifugal pump

Centrifugal pumps are not self-priming so air locks must not be introduced when laying out and installing piping. A short distance between inlet and rotor is critical. Typical applications of this pump include fresh water engine cooling pumps, ballast transfer pumps, blower fans and domestic vacuum cleaners.

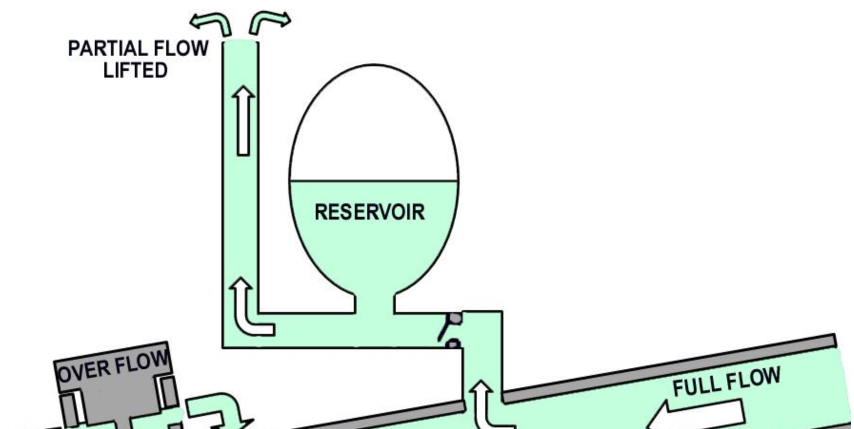


Cutaway of a turbocharger courtesy of ANTA Publications

The specialised turbocharger uses the kinetic energy (energy of movement) of the exhaust gasses to spin a turbine to push more air into engine. It spins very fast and gets hot. Its bearings can be cooled by the engines oil pump, so if the engine is shut down suddenly the turbo continues spinning and will suffer damage. This is typically at the rotor blade bases where the solid hub and thin blades cool at different rates.

Gravity pumps

Gravity pumps or hydraulic rams work by using a large liquid flow rate (high pressure) to lift a smaller quantity of the whole at a lower flow rate (lower pressure). This is achieved by using the “water hammer” effect to sustain a pressure head in a vacuum reservoir. A limited flow can continuously be drawn off and up. Not commonly found on small vessels these pumps are restricted to mining and scientific applications.

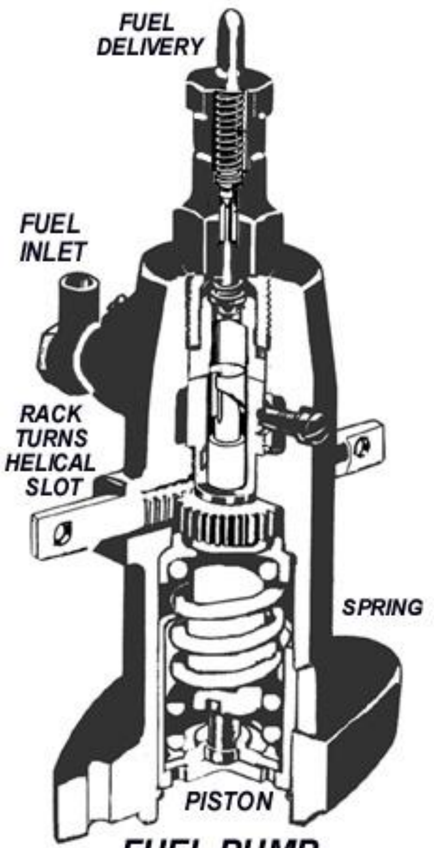


A hydraulic ram

A variety of the type is the mineral extraction water cannons of New Zealand. Piping was laid from a high dam to a nozzle way below. In subsequent use as a *water cannon,* the pressure from the dam's head of water supplied a jet of water sufficient to break up the clay and gravels of the mountain sides to allow panning for the gold content in the slurry created.

High pressure and metering pumps

In the jerk fuel pump shown below, an engine driven cam pushes the plunger against a sturdy spring to deliver pressurised fuel injection. As the plunger forces the fuel up it is squeezed through a helical grove. This is rotated in the housing by a rack and pinion gear to meter the amount of fuel and provide throttle control.



FUEL PUMP

Fuel pumps are more fully described in the accompanying text *"Marine engine and propulsion systems for Marine Engine Drivers".*

For NSCV specifications for piping see Section 1.5, *bilge piping.*

2.5 Bilge systems

It is said that "a desperate man with a bucket is most motivated to fight a fire or save his sinking ship". The critical need to maintain floatation and control fire is recognised in Class Rules, the NSCV and USL codes. These rules specify that an effective method must be provided. In small vessels fire buckets with lanyards (to reach the water) and more effective manual and/or mechanical pumps are specified.

A bilge system removes unwanted water and liquids from within the vessel in order to maintain its reserve buoyancy and stability. It is cost effective to share pipes and pumps. Water being pumped in to fight fire will eventually need to be pumped out before it sinks the ship. Consequently shared bilge/fire systems are common in small vessels. Reliable equipment and alarms are vital, particularly in the engine room where water ingress may stop the motors, power supply and the pumps themselves. The new NSCV Part C Section 4 Fire Safety however does not allow fire pumps to be used as bilge pumps, so fire systems are dealt separately in the next chapter.

Survey Requirements

Class Rules, the *NSCV* and *USL* codes determine requirements for construction and operation by vessel trade, size and plying zone. For brevity, where requirements are stated, this text refers to the *NSCV Part C Section 5 "Machinery".* If your vessel is larger or not surveyed to these standards, the relevant Class rules or your State's survey regulations must be sought.

The *NSCV* provides two methods for builders and owners to gain survey compliance. "*Deemed to comply*" solutions are prescribed in the rules and prefaced by the word "*shall*"- they are not negotiable. "*Equivalent*" solutions may be approved by a survey authority if they can be shown to effectively meet the intentions of the rules.

NSCV Part C Section 5 Chapter 5 specifies requirements for seawater and bilge systems of vessels less than 35 m in measured length. Vessels "*shall*" be fitted with a pumping system capable of draining any bilge or watertight compartment. Open vessels less than 5 metres with access for bailing may be provided with a bucket.

Pumps

Class 1B vessels of 15 metres and over *shall* permit pumping and draining from every space in the vessel while any one watertight compartment is flooded.

NSCV	Manual pumps		Powered pumps	
Vessel Measured length	Qty	Pump capacity in kLitres/hour	Qty	Pump capacity in kLitres/hour
<5 undecked	Bailing bucket & ready access to bilge			
<7.5	1	4.0	N/A	N/A
> 7.5 and < 10	2	4.0	N/A	N/A
>10 and <12.5	1	5.5	1	5.5
>12.5 and <17.5	1	5.5	1	11.0
>17.5 and <20	1	8.0	1	11.0
>20 and <25	N/A	N/A	2	11.0
>25 and <35	N/A	N/A	2	15.0

Note; Pumps should be self priming or have a suitable priming device.

Where two pumps are required, each power pump *shall* not be dependent on the same source of power. The pumps and piping systems shall be arranged to enable simultaneous pumping of each machinery space bilge by both pumps on all vessels of 20 metres and more in length. For vessels other than Class A, one of the two pumps may be a portable pump provided it can be operated at full capacity within 5 minutes of flooding becoming known.

The pump is the heart of the system, dependent on the piping and the valves described in earlier sections being in good order and in the correct position for the intended operation. These also are specified in the *NSCV.*

Bilge piping (and seawater)

All piping that may come into contact seawater *shall* be corrosion-resistant. Metal pipes shall be copper, stainless steel, suitable grade of aluminium alloy or carbon steel which is protected against corrosion (galvanised). The thickness of piping shall be sufficient to withstand the likely maximum pressure allowing for corrosion and erosion. Piping *shall* be protected from mechanical damage arising from the cargo stowage or from other causes. Pipe fittings *shall* not be made of malleable iron.

Flexible piping for vibration damping or to accommodate machinery movement *shall* be in short lengths of less than 760 mm and be readily visible and located so as to prevent mechanical damage or contact with hot surfaces. At least two corrosion-resistant clips *shall* be fitted to secure flexible piping of 25 mm internal diameter and above. Flexible piping may be used in vessels less than 12.5 metres in length, provided that its join to a fitting *shall* be appropriate for the nature of fluid carried and the risks of fluid leakage.

Rigid plastic bilge piping may only be used in vessels less than 12.5 metres in measured length except in locations of high fire risk.

The minimum diameter of bilge piping in vessels less than 10 metres in length *shall* not be less than 25 mm, in vessels of 10 metres and over in length shall be determined by formulas from the NSCV, which shall in no case be less than 32 mm,

Suction lines

Bilge suctions *shall* be located to facilitate the drainage of water from within each compartment over a range of list not less than +5°. Limber holes *shall* be provided to allow water to drain to the bilge suctions.

A watertight compartment less than 7% of the total under deck volume may be drained into an adjacent compartment by means of a self-closing valve. The adjacent compartment *shall* itself be served by the bilge system.
Where a pipe pierces a collision bulkhead, it *shall* be fitted with a suitable valve at the bulkhead that clearly indicates whether the valve is open or closed. Where the valve is fitted on the after side of the bulkhead and is readily accessible at all times, it need not be controllable from the bulkhead deck.

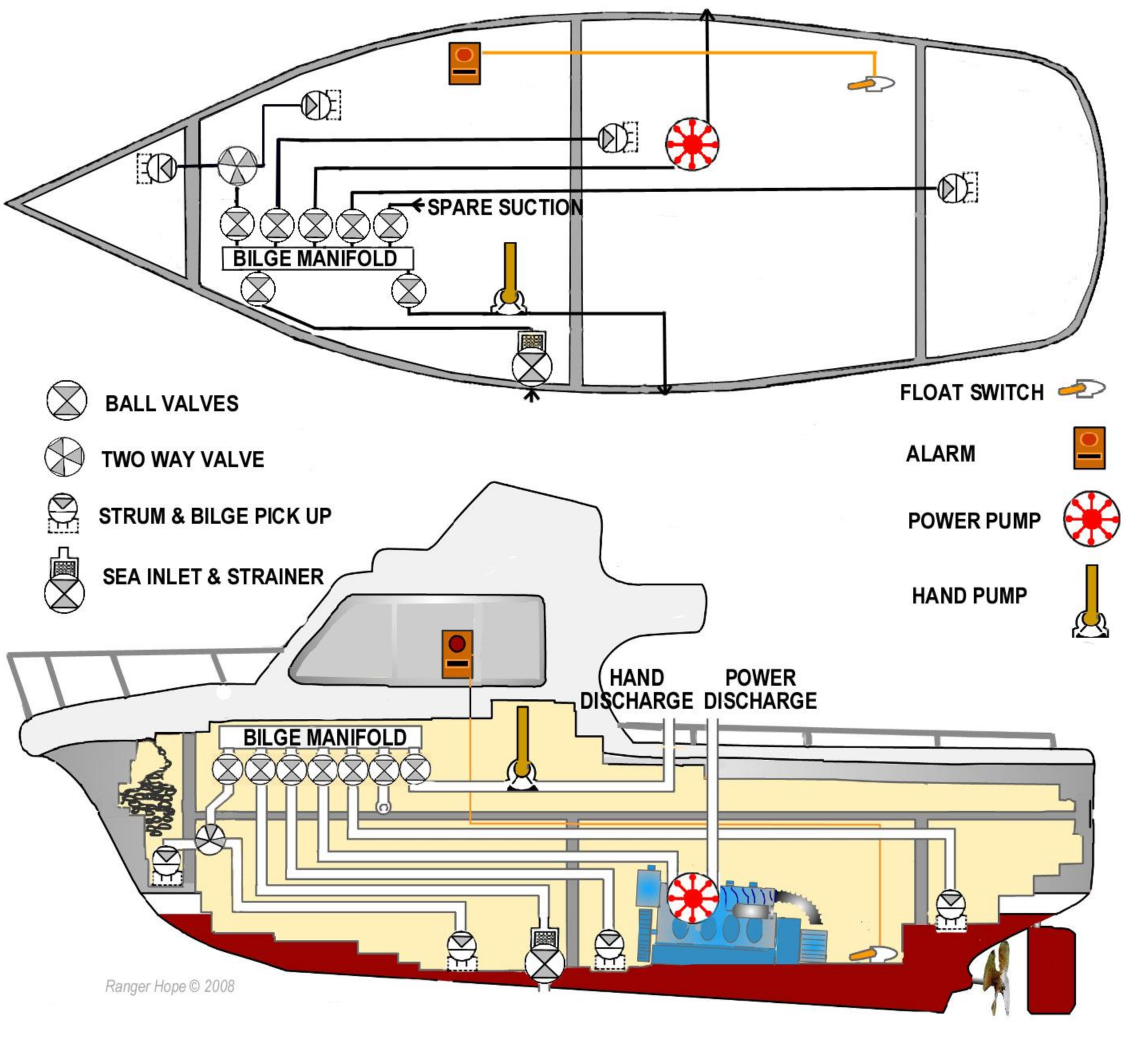
Strainers

Grids or gratings are fixed to the exterior of the vessel’s hull over sea inlets as initial coarse strainers to prevent large pieces of foreign matter being drawn into the pipes.

Each of the *bilge suctions* in a machinery space *shall* be fitted with a mudbox and metallic tail pipe. All bilge suctions in vessels of 20 metres *and over* are required to be fitted with strum, strainer or mud boxes to prevent solids from entering and either blocking or damaging the system. Strainer holes *shall* not be greater than 10 mm in diameter, and the total area of the holes shall not be less than twice the suction pipe area.

Isolating and non return valves

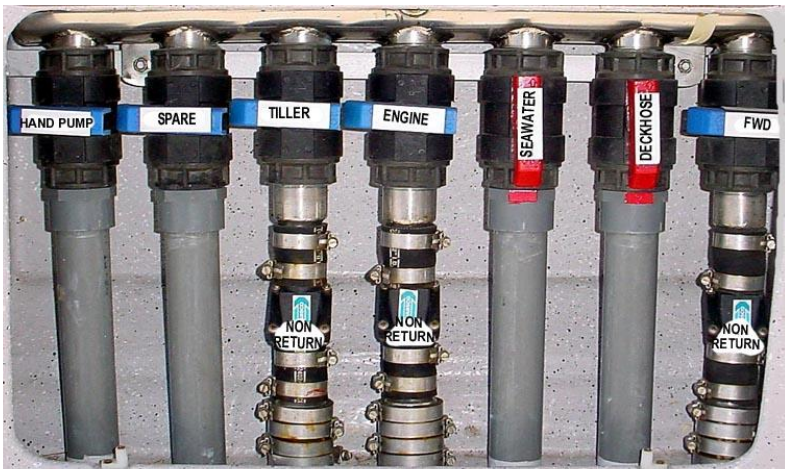
All sea inlet and overboard discharge pipes (including sanitary discharges) *shall* be fitted with valves or cocks. Isolating valves are screw down valves used to isolate a section of piping. Non-return valves prevent liquid flowing back in the opposite direction. They can be uncontrolled (they do not have a positive means of closing) or controlled (they have a spindle and hand wheel to positively close the valve).
In the latter case they are called screw down non-return valves.



The >10 metre and <12.5 metre vessel shown relies on manifold height, non return lines and good practice to avoid backfooding from sea to bilge.

Bilge manifold

Vessels of 25 metres and over *shall* be provided with an accessible bilge distribution manifold with non-return valves. This is dedicated main pipe with a line of valve connections that are selected to direct the required suction to the chosen pump.



Non return valves are incorporates in the >10 metre and <12.5 metre vessel manifold shown.

Backflooding and downflooding

The bilge system *shall* be arranged to prevent water back-flooding from the sea into watertight compartments or machinery. The bilge connection to any pump that also draws from the sea *shall* be either a screw down non-return valve, or a cock that cannot be opened at the same time to the bilge and to the sea.

Backflooding- Bilge pumps are often used for other duties such as ballast, fire and wash deck which draw from the sea. If sea water can flood back, or one bilge space can flood into another this undesirable situation may lead to the vessel sinking. Non return valves are fitted to prevent water entering the bilge line and L-port cocks are used that prevent bilge and sea water lines being simultaneously selected. Yet sometimes a malfunction such as a jammed valve or dirty valve seat could admit water into the bilge line. To reduce the possibility of such occurrences a regular maintenance program should be followed, including:

Avoid trailing deck hoses that may siphon sea water back to the manifold.
Clean all bilge wells, mud boxes and strainers.
Put some water in each bilge well and pump out each in turn to confirm operation.
Open up and service bilge suction non-return valves in scheduled maintenance.

Larger vessels use L port cocks and screw down non return valves to prevent backfooding from sea to bilge.

Down-flooding- If a vessel heels over sufficiently for the deck edge to be immersed the sea can spills over into the spaces below decks, or *down-flood.* This will result in loss of buoyancy and a reduction in the righting moment (the ability of a vessel to return to the upright position from a heeled position) and can result in the loss of the vessel due to progressive flooding and capsize.

Entry points for down-flooding are door openings, hatch coamings, ventilators and vent pipes. All hatches should be closed and secure prior to leaving port, vents must have means for closing and doors should be kept closed in heavy weather.

Note: The International Load Line Regulations specify minimum requirements for strength, height and method of closure of doors, hatches, ventilators and air pipes. The Regulations require higher standards for vessels under 100 metres.

A flexible suction hose bilge pumping system may be fitted to service compartments in Class C, D or E vessels of measured length less than 12.5 metres. Where there is a risk of down flooding if hatches or other weathertight or watertight covers leading to a void compartment are opened, void compartments should also be provided with a deck-mounted cam lock fitting connected to a suction pipe permanently mounted within the compartment.

Alarms

On decked vessels, a bilge level alarm *shall* be fitted in the propulsion machinery space and all other compartments that contain seawater pumping systems. The alarm *shall* be clearly audible at a continuously manned control position with the machinery operating under full power conditions and the power supply for the alarm shall be available at all times there is a person on board.

Bilges in engine rooms and compartments must be ventilated by fans and open vents. These will remove any build-up of vapours and gases. The fans must be stopped and vents closed if a fire occurs.

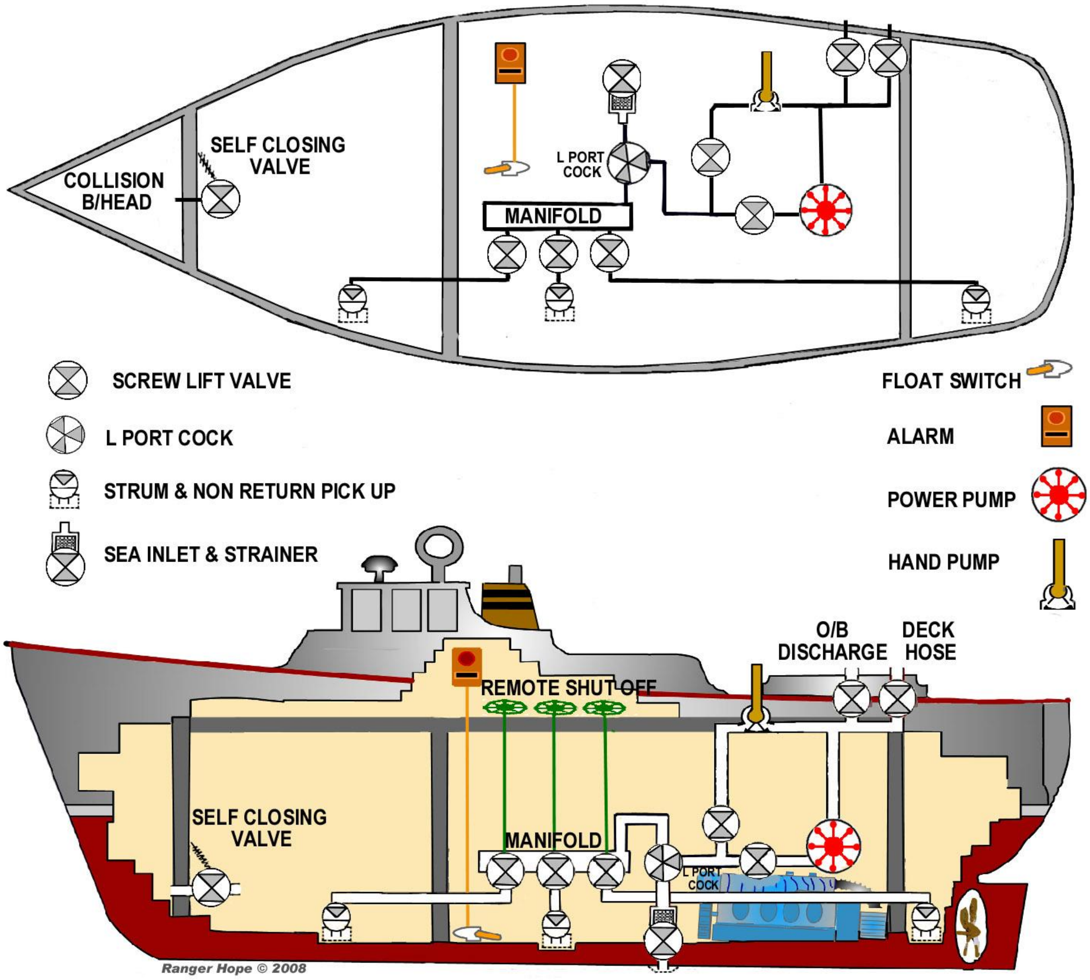
Typical Arrangement

The drawing below shows a bilge system fitted on a vessel of between 17.5 metres and 20 metres in length.

The sea water connection acts as a primer for the flexible impeller pump and is used to flush the system after pumping bilges. The forward bilge suction is into the chain locker beyond the collision bulkhead. Consequently it has a self closing valve in case water can enter the main compartments of the vessel after a collision. Each *bilge suction* line is fitted with a strum box and a non return valve. If the vessel is not fitted with a separate oily waste tank, the oily bilges should be pumped into a large drum or container on deck for disposal ashore at a later stage.

A key safety feature of this system that prevents back-flooding is the L port cock. It cannot be turned to direct from the sea water inlet towards the bilge, yet allows the same power pump to be used for bilges, deck hose and fire hose.

Because the bilge manifold is in the engine room, remote handles are provided above the deck for access in an emergency.



The >17.5 metre and <20 metre vessel shown uses an L port to avoid backfooding from sea to bilge.

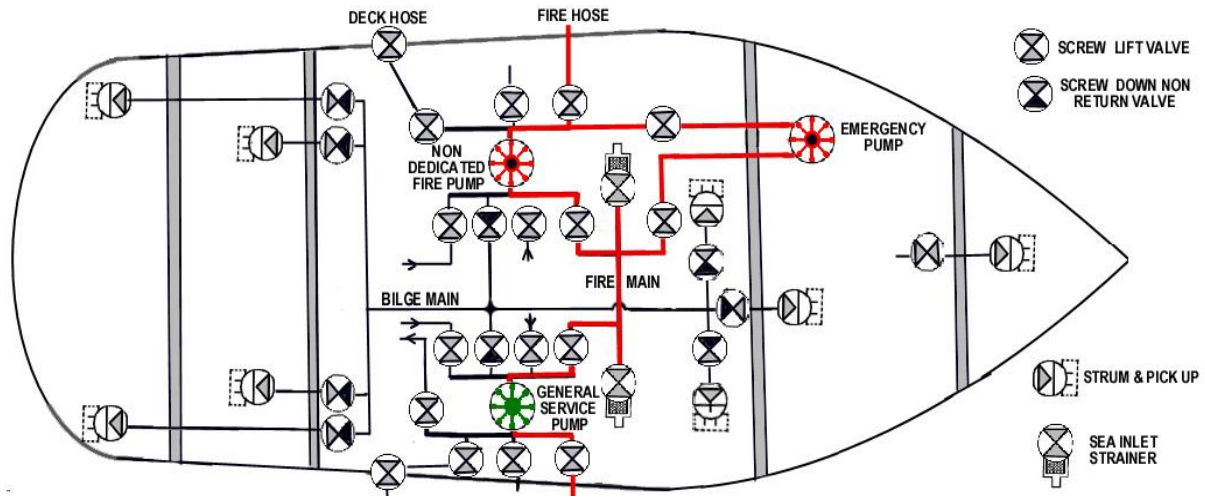
To operate

On the bilge pump check that the sea suction valve and discharge to deck hose valve are shut and the suction valve to the bilge manifold open. If oily water separation is fitted, also shut the oily bilge suction valve discharge and oily water separator valve.

Check that the ship side overboard discharge valve for the fire and bilge pump is open. If the bilge pump is a positive displacement pump, open the overboard discharge. If a centrifugal pump, the valve should be closed.
Start pump (in the case of a centrifugal pump, open up the overboard discharge). Each bilge can now be pumped out. A rattling noise in the bilge valve is an indication that the well is empty. The pump can then be stopped. If vacuum gauges are fitted on the suction side of the pump, a zero reading on the gauge is an indication that the well is empty. To confirm the well is empty it should be sounded. When the well is confirmed as empty, close all valves that are open.

Combined bilge pump & fire main systems

As it is cost effective to share pipes and pumps shared bilge/fire pump systems are common in older non NSCV compliant vessels as described below.



It includes:

Manifolds on both the suction and discharge side of the pump. *(See Section 1.1 Ballast operations Schematic drawing only).*

A screw down non-return valve connecting the suction manifold to the bilge prevents water from flowing back from pump to bilge.

A screw lift valve connecting the suction manifold to the sea suction piping allowing the pump to direct sea water into the fire pumping system.

A screw lift valve connecting the discharge manifold to the overboard discharge. (The valve is opened when the bilge system is being used) and a screw lift valve connecting the discharge manifold to the fire main. (The valve directs water to the fire main).

The USL code specifies emergency fire and/or portable pumps (hand or power dependent on vessel size). The specifications of a portable emergency fire pump include compatibility for use as a bilge pump. Operated as a fire pump, its flexible suction hose is lowered into the sea while a fire hose is connected to the pump's discharge. Alternatively, for bilge duty, the flexible hose is lowered into the flooded space and the fire hose directed overboard. Hand operated bilge pumps can be adapted for emergency use on small craft.

The new NSCV Part C Section 4 Fire Safety however does not allow fire pumps to be used as bilge pumps, so fire systems are dealt separately in the next chapter.

Common faults

Mechanical Failure of Pump

Pump not turning - check power source switch is on and cable etc in good repair.

If the pump is driven from an engine it is possible that the clutch is slipping or not engaging properly. Flexible impeller pumps shed their vanes either through old age or having been run dry. If this is the case then the impeller will need to be replaced according to manufacturer's instructions (see the previous section on pumps).

Air Leaks

Air sucked into the bilge system reduces the efficiency of the pump and the amount of water which it can be discharge. Excess air in the system may damage the pump itself. This common suction side problem may be caused by:

Leaking glands on pump drive shafts, valves or cocks;
Holes in the pipe work caused by mechanical damage or corrosion;
Empty compartment valves being opened or leaking to drawing air into the system.

Blocked Bilges

Strum boxes and strainers are provided to prevent debris such as rags and other waste from entering the system. They are prime areas for a blockage can be difficult to get at to clear, hence keep the bilges clean at all times. High level bilges can lead to dangerous situations including:

Poor stability due to effect on trim, heel and draft and free surface effects;
Oil and water splashing on machinery and dangerous slippery work environment;
Fire hazard due to oil or explosive gases in the bilges
Corrosion, lack of cleanliness and unpleasant odours
Impaired visibility the vessels structure covered by bilges

Periodic Survey Requirements

As per the NSCV/USL Code, for vessel less than 35 metres in length, pumping systems are to be surveyed as follows:

Annual Survey: Operational test of bilge pumps, bilge alarms and bilge valves. General examination of machinery installation. Inspection of all pipe arrangements.

2 Yearly Survey: Sea injection and overboard discharge valves and cocks.

4 Yearly Survey: Tanks forming part of the hull except fuel tanks, internally.

12 Yearly Survey: Fuel tank internally.

Pollution Prevention

Oily bilges must only be discharged into a proper mobile or shore based facility. It is an offence under State and Commonwealth law to pump oil into the water.

Vessels over 400 Gross Tonnage are allowed to discharge oily bilges into the sea if certain strict conditions are met. To comply with these conditions, vessels must be fitted with oily water discharge monitoring equipment, oily water separators and sludge holding tanks. Penalties for breach of pollution regulations are very high.

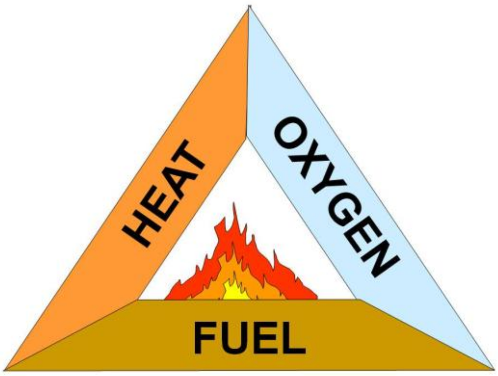
Fire Control Systems

3.1 Principles of fire control

Flash point
In order to *catch on fire*, a material must be heated sufficiently to cause it to partially vaporize. The temperature that a material releases flammable vapor is called its flash point. Technically petrol and diesel are cocktails of hydrocarbons of different flash points. Commonly from - 40°C to 0°C for petrol and 60°C for diesel is the temperature that they will burn if heat is applied. (Diesel's higher flash point means it is safer to use than petrol). If a fire is cooled below its flash point then the flame will not be sustained.

The fire triangle
The three elements necessary for a fire to start to burn and continue to burn are:

Oxygen + Heat + Fuel = The chain reaction that is fire



The heat of the fire vaporizes the fuel and maintains the chemical chain reaction. Remove at least one of the elements to break the chain reaction and so control the fire.

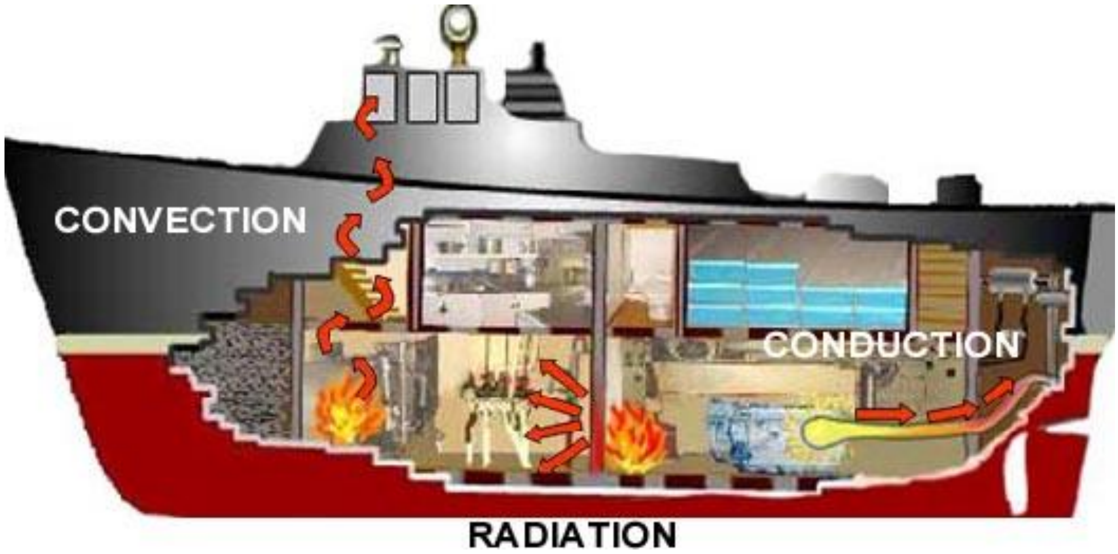
Heat transfer, the spread of fires
Heat moves (*transfers*) in three ways:

Convection *Heat moving in a liquid or gas.*
Conduction *Heat traveling through a solid.*
Radiation *Heat energy traveling out as heat rays (direct heat).*

Hot air and flame that experience convection move upwards, overcoming escapees that cannot climb quicker than the fire, or become trapped above it.

Conducted heat may transfer through steel bulkheads or pipes from welding or flame into another compartment remote from the fire itself.

Radiated heat may char material that is close enough or even set it alight. Cooling the exterior of compartments that are on fire (boundary cooling) and removing surrounding flammable materials (boundary clearance) are essential to limit fire spread by radiation.



Classes of fire
The six classes of fire are defined the type of material burning.

Class	Fuel	Examples
Class A	*Solids containing carbon*	*Wood, paper, cloth, plastic*
Class B	*Combustible liquids*	*Petrol, oil, tar, paint.*
Class C	*Combustible gases*	*LPG (liquid petroleum gas).*
Class D	*Combustible metals*	*Aluminium, sodium, potassium.*
Class 'E'	*Live electrical equipment*	*Switchboards, generators.*
Class F	*Cooking oils and fats*	*Sunflower oil, olive oil.*

An electrical fire highlights risk of electrocution by use of water based extinguishers when the current is on. Switch it off and the fire reverts to another classification.

Causes of fire
Situations that result in increased fire hazard include fuel and explosive gas transfers (LPG being heavier than air collects in the bilge), engine friction, battery sparking, use of flammable cleaning fluids, accumulation of oily rags, poor and careless housekeeping.

Bad maintenance - Loose tools, untidy work habits, build up of litter, improper disposal of oils, dirty bilges, lack of engine servicing and make shift repairs can all cause fires.

Matches and cigarettes - Limit and sign the areas where persons can and cannot smoke.

Oily rags - The cloth can be oxidised by the oil to generate heat, just like a garden compost heap. If the heat cannot escape then the cloth may burst into flame in *spontaneous combustion*. It is important to dispose safely of oily rags and other fire hazards, including swarf and dross waste produced in cutting and machining metals.

Fats and oils - In rough weather, cooking fats and oils may slop out of the pan into the stove to ignite. Accumulated grease in overhead fume extractors build up and may catch on fire. Such areas should be checked and kept clean. Spirit stoves in smaller boats are a similar risk.

Overloaded power points and circuits - Tightly coiled or partially broken/kinked electrical cable can have increased resistance that may cause local heating leading to fire. Incorrect installation and electrical protection devices (fuses and circuit breakers) are major causes of fire on vessels. All equipment should be installed by a licensed electrician.

Cleaners and solvents - Labelling warns of most cleaner, paint and solvent hazards and their safe use is further described in the manufacturers *Hazardous Material Data Safety Sheets*. Paint lockers can contain a cocktail of serious fire hazards. Incorrectly stowing non compatible chemicals together can lead to fire. The classification of materials and advice for separation can be found in the *IMDG code*

International Maritime Dangerous Goods Code Labeling

3.2 Fire Safety and Survey (NSCV Part C Section 4)

The NSCV (*Fire Safety)* prescribes a *defence-in-depth* strategy based on a series of measures applicable to different states of a fire as it progresses from ignition to fully developed state. These are illustrated in *Table 1 of Section 4* that lists:

Ignition & incipient fire	featuring	*Control of heat sources, fuels, interactions*
First item development	featuring	*Material properties, Fire detection*
Spread to secondary items	featuring	*Fire detection, Fire suppression*
Full space Involvement	featuring	*Fire suppression, Ventilation control*
Spread to other spaces	featuring	*Fire resistance, Manual suppression*
Spread to essential systems	featuring	*Fire resistance, Manual suppression, Redundancy*

The functional requirements for fire control therefore require passive and active fire protection measures by the avoidance of all fire hazards, the restricted use of combustible materials and the minimisation of ignition potential from flammables liquids. Early detection, containment and extinction in the space of origin is the next line of defence. Separation of spaces by thermal and structural boundaries (to limit spread by smoke & fire) with access protection for escape and fire-fighting are required in addition to the ready availability of fire appliances.

The NSCV also assigns risk categories in *Table 2* (not SOLAS vessels) based on class, operations and carriage of day or overnight passengers to determine survey stringency.

Fire Risk Category I (lowest risk)

Fire Risk Category II (moderate risk)

Fire Risk Category III (high risk)

Fire Risk Category IV (highest risk)

Extracts of Table 2 – Fire Risk Category	**A** Unlimited domestic operations	**B** Offshore operations	**C** Restricted offshore operations	**D** Partially smooth waters	**E** Smooth waters
Class 1- Length of vessel	**< 35 m (1)**	**<35 m (1)**	**All lengths**	**All lengths**	**All lengths**
Class 1: 13 to 36 day pax	III	II	II	I	I
Class 1: 37 to 200 day pax	IV	III	II	II	II
Class 1: 201 to 450 day pax	IV	IV	III	II	II
Class 1: 451 or more day pax	NA (2)	NA (2)	IV	IV	III
Class 1: 13 to 36 berthed pax	IV	III	II	II	II
Class 1: 37 or more berthed pax	NA (2)	NA (2)	IV	IV	IV
Class 2- Length of vessel	**< 35 m (1)**	**All lengths**	**All lengths**	**All lengths**	**All lengths**
Class 2 Fire Risk Category	II	II	I	I	I
Class 3- Length of vessel	**All lengths**	**All lengths**	**All lengths**	**All lengths**	**All lengths**
Class 3 Fire risk category	II	II	I	I	I

(1) No Fire Risk Category is specified for Class 1A, 2A and 1B vessels 35 m and more in measured length since these vessels are required to comply with the requirements specified in Marine Orders 15 for SOLAS ships, refer to Clause 2.9.
(2) No Fire Risk Category is specified for Class 1A and 1B vessels carrying more than 450 day passengers or more than 36 berthed passengers since these vessels are required to comply with the requirements specified in Marine Orders 15 for SOLAS ships, refer to Clause 2.9.

NOTE: Excludes *tankers* and special vessels including fast craft and novel vessels, see Clauses 1.2 & 2.9.

In *Table 3* The NSCV also assigns risk to spaces within a vessel that shall be provided with *active* and *passive fire protection measures* that satisfy the specified requirements.

Extract of Table 3 - Categories of spaces		
Space	**Description**	**Examples**
High Fire Risk Spaces	Spaces where, without appropriate controls, the likelihood and consequence of fire are high. Within such spaces, there is: potential for the spillage or escape of potentially dangerous quantities of *flammable liquid* or explosive vapour, and the presence of one or more sources of heat or other sources of ignition.	a) Enclosed machinery spaces containing— internal combustion machinery for main propulsion where the aggregate power output of internal combustion machinery for all purposes within the space is 120 kW or more; internal combustion machinery for purposes other than propulsion where the aggregate total power output of the machinery within the space is: 375 kW or more; or 120 kW or more where the machinery is not intended only for emergency or very occasional use2; any oil-fired boiler; or any oil fuel unit. b) Ro-Ro spaces. c) Store spaces containing flammable liquids, including paint lockers. d) Spaces containing dangerous goods. e) Sales shops of deck area 50 m2 or more containing packaged flammable liquids for sale and where no dedicated store is provided separately. f) Trunks in direct communication with the above spaces.
Moderate Fire Risk Spaces	Spaces that: contain potentially dangerous quantities of *flammable liquids* but where the sources of ignition have relatively low frequency; or contain heat sources or other sources of ignition but where the quantity or nature of material within the space to fuel a fire is such that the risk is significantly reduced.	a) Enclosed machinery spaces containing: Internal combustion machinery where the aggregate power output of internal combustion machinery for all purposes within the space is less than 120 kW; Internal combustion machinery for purposes other than propulsion where the aggregate total power output of the machinery within the space is less than: 375 kW where the machinery is intended only for emergency or very occasional use2; or 120 kW otherwise. switchboards, electrically powered main propulsion or auxiliary motors or transformers when such equipment within the space has a total aggregate power of 30 kVA or more. an oil fuel pump, oil fuel filter or oil fuel separator, not being an oil fuel unit. any solid fuel fired boiler. b) Galleys. c) Sales shops of deck area less than 50 m2 containing packaged flammable liquids for sale and where no dedicated store is provided separately.
Accommodation Space	Spaces that are likely to contain persons who: are unfamiliar with the vessel, may be asleep or disoriented at the time of an emergency, or may inadvertently or deliberately initiate a fire.	a) Sleeping rooms. b) Mess rooms. c) Pantries. d) Public spaces. e) Toilets and washrooms. f) Sales shops not containing flammable liquids for sale. g) Storerooms of floor area less than 4 m2 incorporated within or adjacent to other types of Accommodation Spaces and which are not used for the storage of combustible or flammable liquids or dangerous goods.
Minor Fire Risk Spaces	Spaces where the likelihood and/or consequence of fire is low.	a) Spaces used for the carriage of cargo that is not dangerous goods. b) Closed vehicle spaces. c) Void spaces. d) Fuel tanks and spaces containing fuel tanks for fuel of flashpoint above 60ºC. e) Storerooms including baggage or mail rooms not used for the storage of combustible or flammable liquids or dangerous goods.
Control Stations	Spaces containing systems essential to the safety of persons, which, if destroyed or rendered unusable by fire, would substantially increase the risks to those on board.	a) Operating compartment. b) Radio room. c) Central fire Control Station. d) Damage Control Station. e) The emergency source of electrical power or the emergency switchboard. f) Fixed fire extinguishing Control Station, agent storage or machinery room.
Escape or Evacuation Routes	Spaces essential for escape from spaces on board the vessel and for evacuation from the vessel, which if destroyed or rendered unusable by fire, would substantially increase the risks to those on board.	a) Corridors of length 14 m and over in Accommodation Spaces and corridors for escape and evacuation elsewhere. b) Enclosed stairways and stairway towers. c) Assembly stations. d) Survival craft stowage locations. e) Ship's side in way of survival craft stowage or embarkation point.

Passive and active methods of fire control

A holistic *defence-in-depth* strategy approach to fire control will consider prevention as well as cure. Passive measures are structural solutions to limit fire outbreak/spread, and to ensure escape routes for personnel such as access to high risk spaces (twin hatches for engine rooms), emergency lighting, exit and safe muster plan signage.

At the Initial Survey of a vessel its fire risk category will be determined. Certain compartments will require greater fire protection (see Table 3- engine room spaces and fuel stowage areas):

A class divisions- are fire resistant divisions made of steel or equivalent material, suitably stiffened and capable of preventing the passage of smoke and flame up to the end of the first 1 hour of the standard fire test. For timber vessels the type may include flame resist surface coated steel sheathing enclosing a protective blanket of rock wool (fibreglass insulation). Any bulkhead opening will need to be airtight and may include an intumescing sealing strip (expands on heat to seal gaps) and a control station indication device to warn if doors are open or closed.

Typically, flammable liquid cargo tanks are separated by a coffer dam containing water (or can be filled with water). Vents with flame traps and electrical earthing against sparks are also provided. See *Chapter 2.1 Tanks* for more information.

Certain areas will require less fire protection (such as accommodation areas):

B class divisions- are fire resistant divisions made of incombustible material and capable of preventing the passage of smoke and flame up to the end of the first ½ hour of the standard fire test.

This prepared approach also requires an emergency plan and sign placed where it will be best seen by all on board. The plan must be practiced regularly to ensure that in the *active* use of the fire fighting equipment it is ready and that the theoretical plan will actually work.

The Emergency Fire Signal is a continuous ringing of a bell. **(example only)**	
In the event of an emergency go immediately to your muster station with your lifejacket for instructions from the crew. Your muster station is at **Liferaft Starboard No.2**	
Crew Duty List – engine room fire **(example only)**	
Master or Engineer on the instructions of the master	Crew
	Report fire
Inspect fire	Maintain communications
Isolate fire, shut fans, vents & engine	Get passengers into life jackets
Shut off fuel	Muster passengers and report head count
Evacuate engine room	Take grab bag and to muster point
Activate smothering system	Prepare life raft
Monitor bulkheads, boundary clear & cool	Assist with fire fight
Distress & abandon ship if necessary	Launch life raft

3.3 Fire detectors and alarms

The commonly available detectors are:

Ionisation Smoke Detector-They react to the visible and invisible products of combustion and are common in accommodation areas.

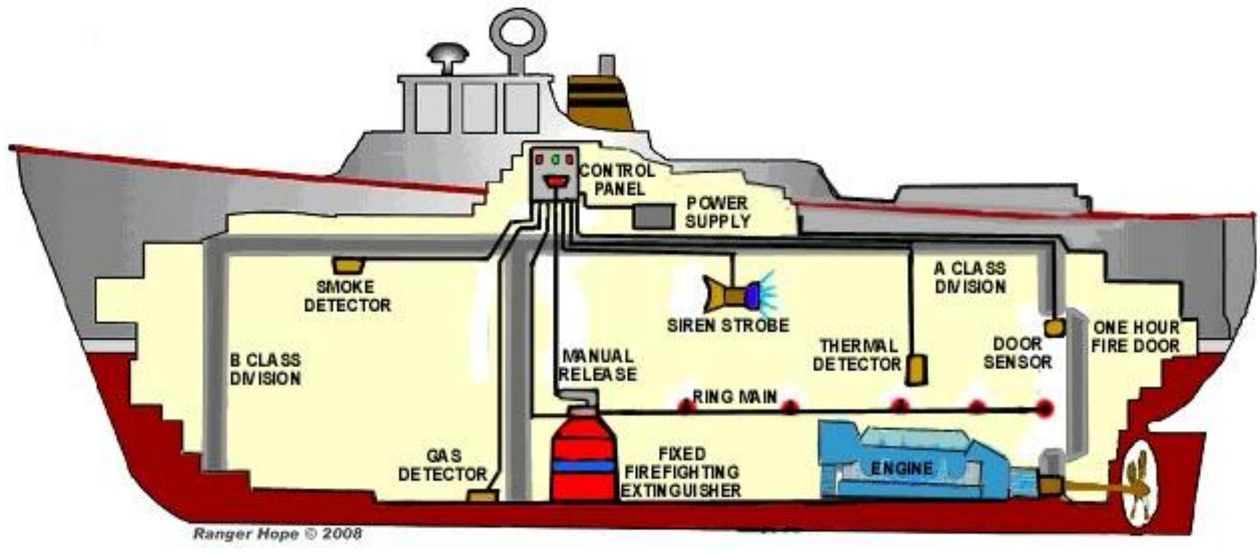
Photoelectric Smoke Detector-They are triggered by smoke obscuring their photoelectric beam. They will also alarm with fumes and dusts, so are not practical for most engine room spaces and small galley areas.

Fixed Temperature Thermal Detector-The atmosphere reaching a pre-set temperature activates the alarm so they are commonly used in the vessels galley (commonly 80º Celsius). In an engine room the ambient temperature may already be quite high.

Variable Thermal Detectors-Both the atmosphere reaching a pre-set temperature and too rapid a rise in temperature activates this alarm. They are ideal for engine room spaces.

Ultra-Violet Flame Detector-These detect the ultra-violet radiation emitted from flames and warn at the earliest moment, but only if they can “see” the spark or fire. They are only suitable for uncluttered spaces with no blind spots such as across a bulk cargo surface.

Operation of fire detector systems- The thermal detector is normally positioned on the ceiling of the machinery room in the direct line of hot air rising from the machinery below. For a specific purpose, the thermal detector may also be located high on a side wall of the machinery room.



All components of the fixed fire fighting system are directly connected to a control panel and audio visual display located at the helm station. It has a dedicated power source. The control panel also monitors the system integrity and will show a light if a fault occurs. A test function (button) is also provided. The system manufacturer will detail the maintenance program to be followed and this will generally include weekly and monthly tests. The system should also be fully inspected annually by the manufacturer or its agent.

If the detectors are activated, the control panel will sound an alarm and light up. If the extinguishing agent has been released, the cylinder will need to be replaced by the manufacturer. The system can only be reset from the control panel and you may require the assistance of the system's manufacturer or its agent.

Part	Function
Fire control panel	*Monitors system & indicates faults*
Thermal Fire Detector	*Detects heat and sends signal to fire alarm panel*
Smoke Detector	*Detects products of combustion in accommodation areas*
Gas Detector	*Sniffs LPG and isolates gas supply to LPG lines*
Siren and Strobe	*Audio & visual indicators of fire*
Release Cable	*Automatic or Manual if automatic systems fail*
Extinguisher Cylinder	*With spaced nozzles on a ring main for even spray in space*

3.4 Fire Fighting Equipment

With all types of fire equipment, it is imperative that the units are in the correct position, free from obstruction and in ready to use condition. Typical equipment for controlling or extinguishing fire in small vessels include:

Fire bucket and fire blankets
Portable extinguishers
Isolation and control equipment
Fire pumps
Fixed firefighting equipment

Portable Fire Extinguishers

Various types of portable extinguishers available, colour coded for their suitability for particular classes of fire.

Water Extinguishers (Red) - are operated by expelling water under stored pressure or CO2 pressure charge. They are operated by pulling the safety pin or ring, squeezing the handle and aiming at the seat of the paper or wood fire (carbonaceous). They may be used as a cooling mist spray by holding your thumb against the nozzle. A standard 9 litre bottle will last for about one minute - that is thirty seconds to approach a fire in attack, and thirty seconds to withdraw under a cooling curtain.

Foam Extinguishers (Red with Blue band) - are designed to extinguish fire by excluding the oxygen with a blanket of foam. Aqueous film forming foam (AFFF) has the added advantage of partially cooling the surface of an oil fire with its water film. They are aimed at the walls or roof around a fire to roll out a layer rather than directly onto the flaming liquid to minimize spread by splashing. The foam creating air intake on the nozzle must not be blocked for efficient operation. Foam is ideal for oil fires.

Dry Powder Extinguisher (Red with White band) - a variety of chemicals are used in dry powder extinguishers including sodium bicarbonate, ammonium sulphate and ammonium phosphate. The most suitable of this multipurpose extinguisher for vessels is those for Class A, B, and (E) fires. They fight fire by chemical reaction and smothering. They are safe to use on electrics but are prone to powder settling in the cylinder and clogging the nozzle. They are messy to clean up after use. The fine powder may affect sufferers with asthma***.*** Avoid intermittent bursts that may block the nozzle with dry powder. Extinguishers differ, so manufacturer's instructions must be checked for operation method.

Carbon Dioxide Extinguishers (Red with Black Band) - is stored under pressure (in liquid form). When the trigger is squeezed, the liquid vaporises, and the resulting gas is ejected through a horn to smother the fire. They are most effective in an enclosed space. To operate - pull pin, depress handle and test operation by:

Approach as close as possible to the fire
Direct horn at base of fire
Depress trigger fully
Direct the gas over the fire area in a sweeping motion.

Users should be aware that carbon dioxide extinguishers are noisy and create a freezing ice film on the horn rim. By replacing oxygen (to smother the fire) they can also suffocate unwary occupants when used in an enclosed space.

Wet Chemical Powder Extinguishers (Red with Beige/Oatmeal Band) - are special purpose extinguishers designed for cooking oil fires. They extinguish fire by turning the burning liquid into a soapy solution which will not sustain combustion.

Vaporizing Liquid Extinguishers (Red with Yellow Band) - contain a blend of hydro chlorofluorocarbons called NAF P-111. They replace halon extinguishers that have been removed from service.

Class D extinguishers- specific materials are used for differing metals in these specialised extinguishers.

Care of Extinguishers - Portable fire extinguishers are required to be serviced at 6 monthly intervals (date noted on tag). The charge should be replaced at 5 yearly intervals for all extinguishers (CO_2 extinguishers 10 yearly intervals per USL Code).
All fire extinguishers, other than the carbon dioxide gas type, have a gauge showing the pressure charge in the tank. (If not in the green section, they must be laid on their side to indicate unserviceability and be recharged without delay).
During inspection, all dry chemical extinguishers need to be shaken to loosen the powder inside.
The carbon dioxide gas extinguisher needs to be weighed to determine whether it requires recharging. If there has been a drop from the original weight (marked on the body of the extinguisher) of 10% or more, then the extinguisher needs to be recharged.
In addition fire extinguishers also have a security seal on the trigger. If this seal is broken, then the extinguisher should be recharged.

EXTINGUISHER	COLOUR		Class A	Class B	Class C	Class E	Class F
			Wood paper	Flammable liquids	Flammable Gases *	Live electrical equipment	Cooking oils and fats
WATER		All Red		✗	✗	✗	✗
FOAM (AFFF)		Red & Blue Band	✓	Not on alcohol fires- use alcohol resistant 	✗	✗	✗
DRY CHEMICAL (ABE)		Red & White Band	✓	✓	✓	✓	✓
CARBON DIOXIDE		Red & Black Band	✓	✓	✗		✓
WET CHEMICAL		Red & Beige Band	✓	✗	✓	✗	
VAPORISING LIQUID		Red & Yellow Band	✓	✓	✓	✗	✗

Fixed Fire Extinguishing Installation

Most commercial vessel machinery spaces (12.5 metres and over in length) are fitted with total flooding fixed fire-extinguishing systems to comply with the requirements of Section 11 of the USL Code. For newer built vessels, the NSCV Part C Section 4 continues the requirement for high fire risk areas (>120 kW machinery spaces) but also allows for ro-ro, cargo and other spaces containing flammable liquid/dangerous goods, lockers, galleys and accommodation spaces to be similarly protected.

The systems commonly in use include:

CO_2 **-** an asphyxiating gas that requires storage of the CO_2 bottles in well-ventilated cabinets (above deck). Effective sealing of the machinery space is required and personnel must evacuate the space before deployment. Operating instructions must be displayed and a detection system and pre-release alarm be installed.

NAF S-111 – is a blend of liquid hydro-chlorofluorocarbons that on release instantaneously vaporise to flood the engine room. It leaves no residue, is colourless and non-corrosive. The cylinders may be installed inside or outside the. Operating instructions must be displayed and a detection system and pre-release alarm be installed.

Fm 200 - is a trade name for an HFC which disturbs the chain reaction. Operating instructions must be displayed and a detection system and pre-release alarm be installed.

Hi-Fog- propels a mist of water droplets with high momentum. It cools the fire and displaces oxygen. The cylinders must only be located outside the machinery space and operated manually. Operating instructions must be displayed and a detection system be installed.

Inergen- is a mix of Nitrogen, Argon and CO_2 that depletes oxygen levels to below that required for combustion. CO_2 is incorporated to increase breathing rate to enhance individual's survivability if they are temporarily exposed.

Halogen- is a superseded extinguishing agent that, due to its detrimental effect on the environment, is no longer legal to install.

To operate a fixed fire fighting system in a machinery space, the following basic procedure applies:

*Account for **all** personnel before operating the system.*

Open up the door to the system enclosure, which should be separate from the machinery space. This should sound the alarm in the space.

Stop all machinery space ventilation fans, machine driven forced and induced draught fans, fuel and lubricating oil, hydraulic oil pumps and oil separators.

Close all skylights, doors leading to space, ventilator duct closing flaps, annular spaces around funnels and other openings to the machinery space.

Read the system's instruction plate and follow the instructions exactly to discharge extinguishing media into the engine space.

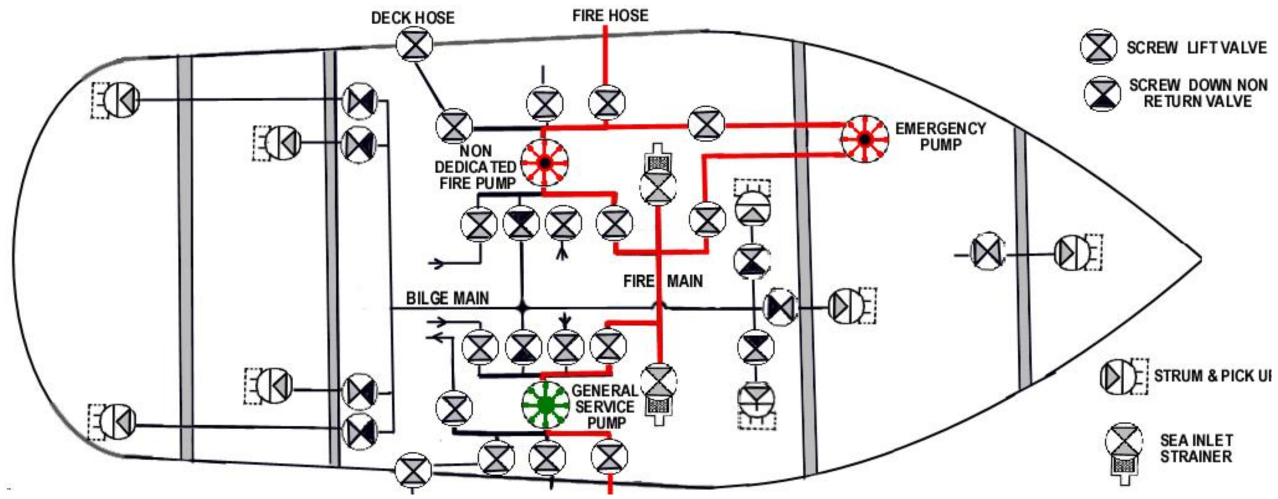
Start emergency fire pump for possible use in cooling bulkheads or decks.

All fixed fire-extinguishing systems installations are serviced annually by an approved agent and a service certificate issued stating that they meet the relevant requirements.

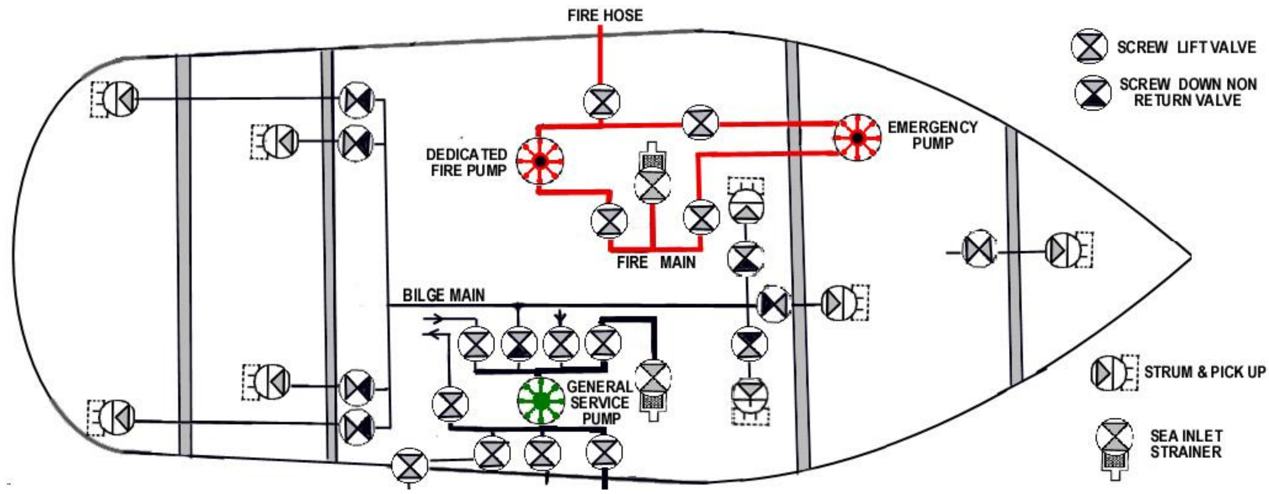
Fire control panels

Fire main systems

As it is cost effective to share pipes and pumps shared bilge/fire pump systems are common in older vessels, as drawn below.



The new NSCV Part C Section 4 Fire Safety however does not allow fire pumps to be used as bilge pumps so newer systems must conform to the principles of those described below. A hand operated pump may be included in the fire main subject to vessel size.



Emergency fire and/or portable pumps (hand or power dependent on vessel size) are required to be sited outside of the engine room space. Operated as a fire pump, its flexible suction hose is lowered into the sea while a fire hose is connected to the pump's discharge.

3.5 Testing fire fighting equipment

Testing fire hoses and hydrants

Fire hoses, hydrants and their valves and nozzles should be checked regularly to ensure that they remain in good working condition and remain always operational. The method of checking fire hoses and hydrants is by practical test:

Start a fire pump and open the valve to the fire main.

Collect all hoses, fit a nozzle on each, and connect them to a hydrant.

Open each hydrant in turn and discharge water through each hose.

Check each hose and nozzle and hydrant connections for leakage.

Repair or replace hoses with major leaks and renew joints of leaking connections.

Drain, dry & re-coil hoses.

Testing emergency shut downs and closures

It is important to regularly test emergency shut downs and closures to ensure that these will operate effectively in an emergency. The procedures for testing emergency shut downs and closures are as follows:

Ensure the appropriate personnel are advised that testing is taking place.

Go to each station where shut downs and closures are located.

For shut downs, press the stop button.

For closures, close the valve by means of the extended spindle or operate the trip wire.

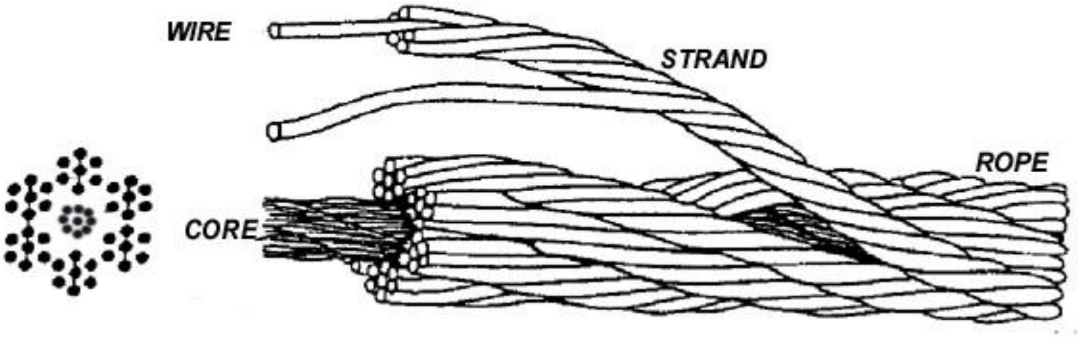
Note: If machinery on the vessel is operating, ensure that the engines are not starved of fuel by ensuring the supply fuel tank remains open. It can be tested later at changeover.

Chapter 4: Deck Gear and Hydraulic Systems

4.1 Steel wire rope, chain and breaking strain.

Steel wire rope (SWR)

The chief component parts of a stranded wire rope are shown below.

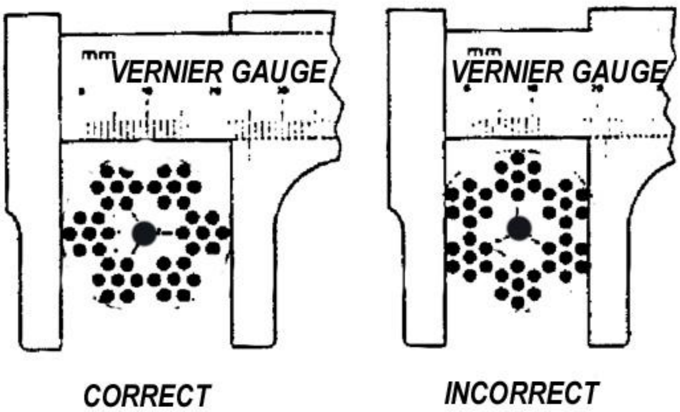


Flexibility is introduced into a wire rope, either by building the strands around a fibre heart and the wire in each round a fibre core, or by building the strands around a fibre heart and increasing the number of wires in each strand while reducing their individual thickness.

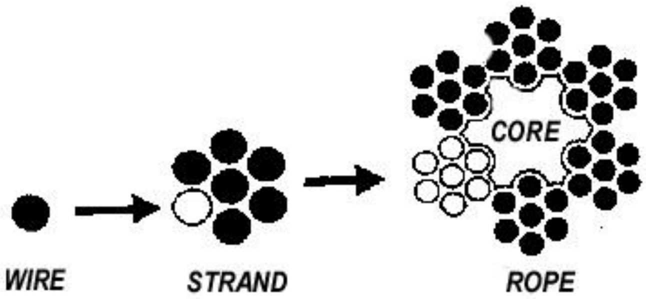
The properties of SWR include:

Construction
Size
Type of Core
Lay
Flexibility

The *size* of ropes refers to its diameter, correctly measured as shown below.



The *construction* of a steel wire rope is described by the number of strands in the wire, then the number of wires in the strand.

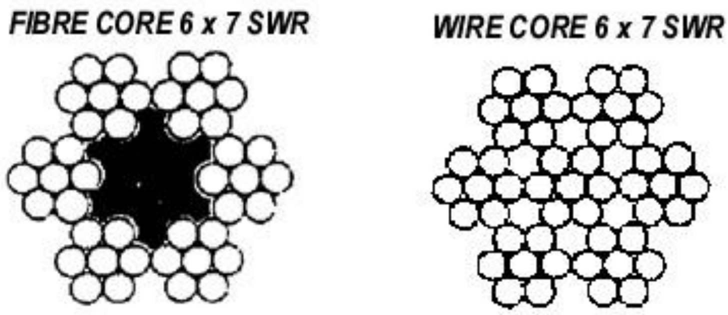


A 6/7 Steel Wire Rope (6 strands of 7 wires each).

The centre of the rope is named the heart or core. Its function is to act as a lubrication sponge and provide support enabling the rope to keep its shape. Hearts can be of fibre (natural or synthetic) or wire strand.

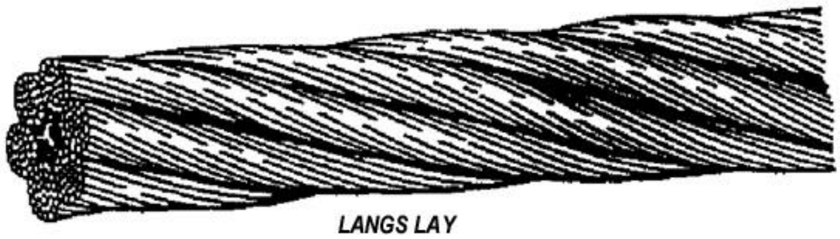
Fibre Cores - Generally made from hemp, jute or polypropylene. They provide a resilient foundation for the strands and are used for ropes not subject to heavy loading. Used where flexibility in handling is required. They are inadequate where wire rope is subjected to heavy loading, prolonged outdoor exposure, and crushing on small drums and sheaves. Natural fibre acts as a good sponge, but if re-lubrication is not adequate, rot and rust may form. Synthetic are rot proof, chemically resistant and more flexible than wire cores.

Wire Strand Cores - Used chiefly for standing ropes (Guys or Rigging). They offer high tensile strength, and have a greater resistance to corrosion failure due to larger wires in the core.



The lay refers to the way the wires in the strands, and the strands in the rope are formed into the completed rope. Steel wire ropes are ordinarily produced with Right Hand lay unless special circumstances require Left Handed. In Right Hand Ordinary Lay (R.H.O.L.) wires are laid left handed and strands laid right handed.

Langs Lay - The strands are laid up in the same direction as that in which their constituent wires are twisted, ie., both wires and strands Right Handed or both Left Handed.



LANGS LAY

Langs lay makes for a more flexible rope and wears well when used for hoisting, due to wear being spread over a larger area of wire. It can only be used when both ends are anchored and prevented from rotating, (e.g. crane topping lifts), because it is liable to unlay when under stress if one end is free to rotate. Not as easy to handle as ordinary lay.

Non Rotating Wire Rope - The outer strands may look like a LANGS LAY formation, but all the wires and strands are very much smaller in size. The inner strands are arranged so that any tendency for the rope to rotate under load is reduced to a minimum. It is very flexible and well suited to crane whips (runners).

Pre-Formed - During the manufacture of pre-formed wire rope, the wires and strands are given the exact spiral form they take up in the finished rope. They lie naturally in position, free form internal stress, and will not spring out of place like ordinary rope, where the wires are held forcibly in position.

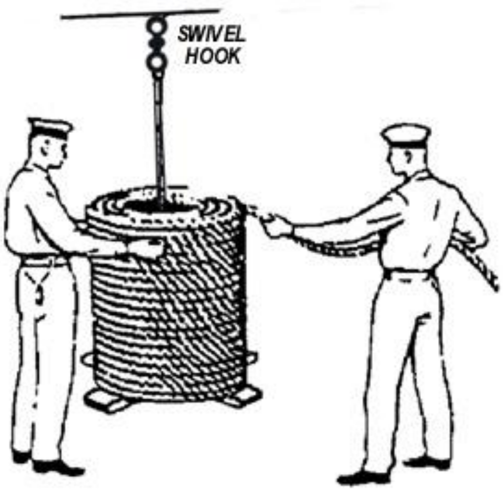
Describing Steel Wire Rope - A full description includes the following details.

Rope diameter (mm)
Number of strands & number of wires per strand
Direction of lay - R.H. or L.H.
Type of lay - O.L / L.L / N.R
Pre-formed or non pre-formed
Type of core
Mild steel, galvanised or stainless

Example:				
Diameter	Construction	Strand	Direction & lay	Qualities
20 mm	6 x 24 SWR	(15/9/F)	R.H.O.L	Pre-formed, Galvanised F.S.W.R with Fibre core

Care and Maintenance - Wear eye protection when using or inspecting wire rope. Incorrect handling of rope from reels and coils can result in *springing* of wires and strands and *kinking* of the rope. The above damage can seldom be entirely rectified and can greatly reduce the effective life of the rope.

Uncoiling - With easy to handle coils it can be rolled like a hoop. If the coil is too large to be handled manually, it should be mounted on a swivel. When coiling R.H. lay ropes down by hand, coil down clockwise and secure by lashing to prevent the coils working open.



Storage - Ropes should be stored on reels where possible and be kept on gratings to prevent corrosion (turn from time to time to prevent lubrication drainage). Removed ropes waiting further use should be thoroughly cleaned, inspected, lubricated and stored under the same conditions as new ropes. The basic factors affecting rope life include:

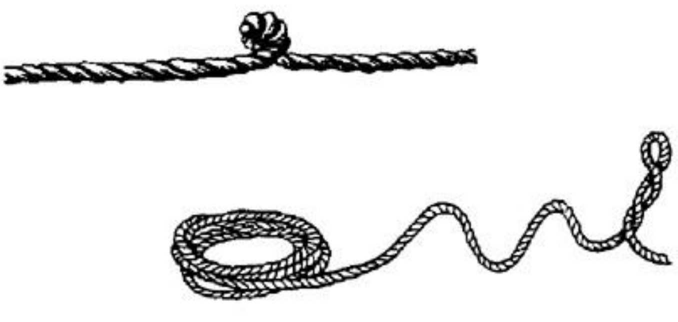
Basic equipment design and installation (i.e. sheave size and drums)

Operating environment - Corrosion - Internal and External

Wear caused by drum, sheaves & obstructions, drum creep, acceleration and breaking

Fatigue - broken wires should be bent back and broken off, not snipped.

Kinking, crushing or spiralling (due to being wound on a drum of too small a diameter)



Strand Distortion - Strand distortion is generally a result of damage caused by kinking, crushing, bad nips or other violent treatment. Commonly found in berthing hawsers, and ropes which have to be worked in adverse conditions.

Abrasion - Occurs both internally and externally and is caused by friction over sheaves, leads, sharp or rough objects and grit lodging within strand wires. It is often indicated by deposits of fine brown powder between strands and flattening of internal surfaces of individual wire.

Corrosion – is generally caused by lack of lubrication. When wire rope is under tension, the fibre heart and cores are also compressed, releasing oil to overcome friction. The normal methods of protecting SWR against corrosion are galvanising and regular lubrication. During manufacture the rope is impregnated with oil but is generally insufficient to last the rope's life. Additional lubrication should be carried out during service with a light bodied penetrating lubricant.

End for Ending and Cropping - will both increase rope life due to the wear points being re-located. If additional rope can be accommodated on the drum, then this will allow for cropping, bringing 'new' rope into the system, and will re-locate wear points.

Inspection of Wire - NSCV compliant wire ropes are certified to AS 3569 or AMSA recognised ship classification society standards. A visual and physical examination should take place at regular intervals. Under normal usage, wire rope can be inspected every 3 months. If a broken wire is discovered, then it should be inspected more often. A thorough external inspection should include any:

Termination of rope at the drum and other points
Broken wires, corrosion, deformation, surface wear, defective coiling
Deterioration due to snatch loading
Lengths that run through blocks, particularly around sheaves under load

A thorough internal inspection should include opening the lay and:

Check internal lubrication
Degree of corrosion
Indentation caused by pressure of wear
Presence of broken wires

An accurate log should be kept of inspection dates, rope condition, end for ending and replacement. Discard the rope if *the total number of broken wires visible in a length of S.W.R. equal to 10 times its diameter should not exceed 5% of the total number of wires constituting the rope (Marine Order part 32*). Broken wires are usually the result of fatigue and wear.

Chain

Chain is well suited for use as slings, lashings, preventers as it withstands corrosion and abrasion better than steel wire ropes.

Properties of Chain- Chains are made of mild or special steel, and are of short link, long link and stud link type. Those used for *chain blocks* are calibrated (i.e. the link sides are made parallel). Chain identification depends on material composition. Welded chains, if tested and marked in compliance with I.S.O. are graded 3 upwards to 9 (higher the number, better the grade).The grade numbers are usually stamped on the chain approximately. Some manufacturers may use letters.

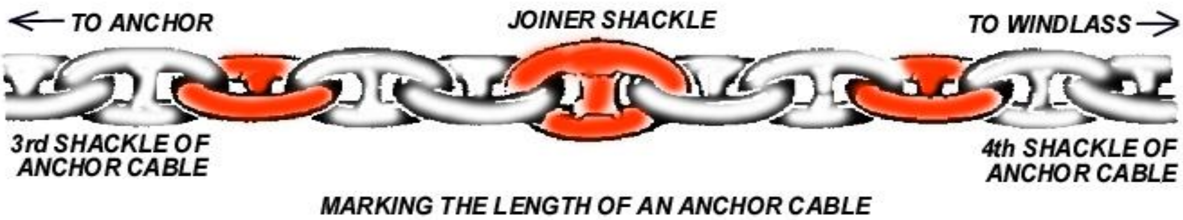
Unmarked chains should be treated as grade 3 (mild steel).

ISO Chain markings (Grade 3 or L)

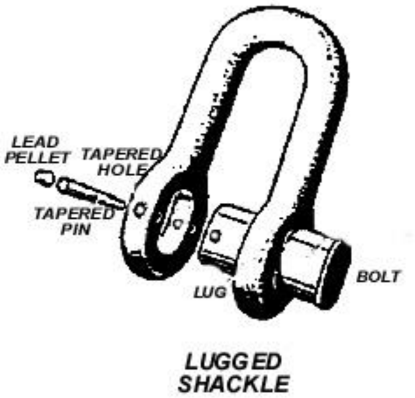
NSCV compliant chain is certified to ISO 1704, AS 2321 or AMSA recognised Ship Classification Society standards

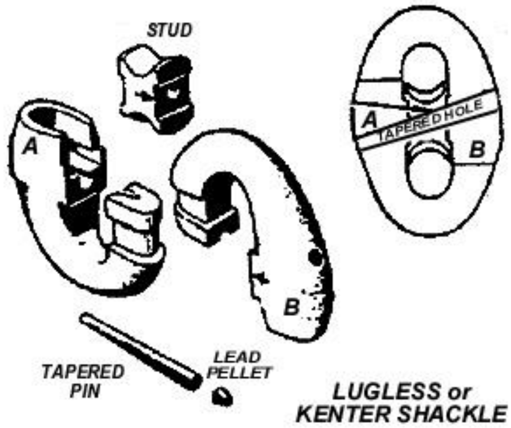
Anchor cables - Stud link chain has the greater strength and the studs help to prevent distortion, forming of kinks, and knots thus making it easier to handle. Short or close link chain is used in small vessels in preference to rope. Stud link chain is used by larger vessels such as tugs and landing barges.

A length of cable is known as a *shackle* or *shot*, the standard length being 15 fathoms, (90 feet or 30 metres). The cable is marked from either side of each joining shackle.



The shackles are joined together using a special joining shackles a shown below. The lugless or kenter shackle has the advantage that it sits in the gypsy (cable holder) of the windlass just like any intermediate link of the chain. The tapered pin is rammed home and then capped in place with the malleable lead pellet.





Care And Maintenance - Faults in chain are not easily seen and should be examined frequently for wastage due to rust, missing studs or distorted links. The following lists bad practice in usage of chain.

Cross, twist, knot or kink a chain
Drag from under a load or use around sharp corners, without protective padding
Use bolts or bull-dogs clips (compression) for joining or shortening
Use if over 10% wear or if any elongation in links
Use any chain for slinging unless it has the approved SWL tags

Wrought iron chain needs annealing because it is subject to surface becoming brittle, which deepens with time. If not annealed regularly (heated & allowed to cool slowly) it becomes dangerous.

Inspection of Chain – Schedules are every 6 months for less than 12 mm diameter and every 12 months for over 12 mm. Chains of mild steel should be checked for the flexing or bending of links. Damage to links where a chain has been used around sharp edges, causing cuts or nicks, is a good reason for condemning. High tensile and alloy chain have great ability to stretch under shock loads and revert to normal size. If elongation is apparent while not under load, it has been seriously overloaded and should be discarded.

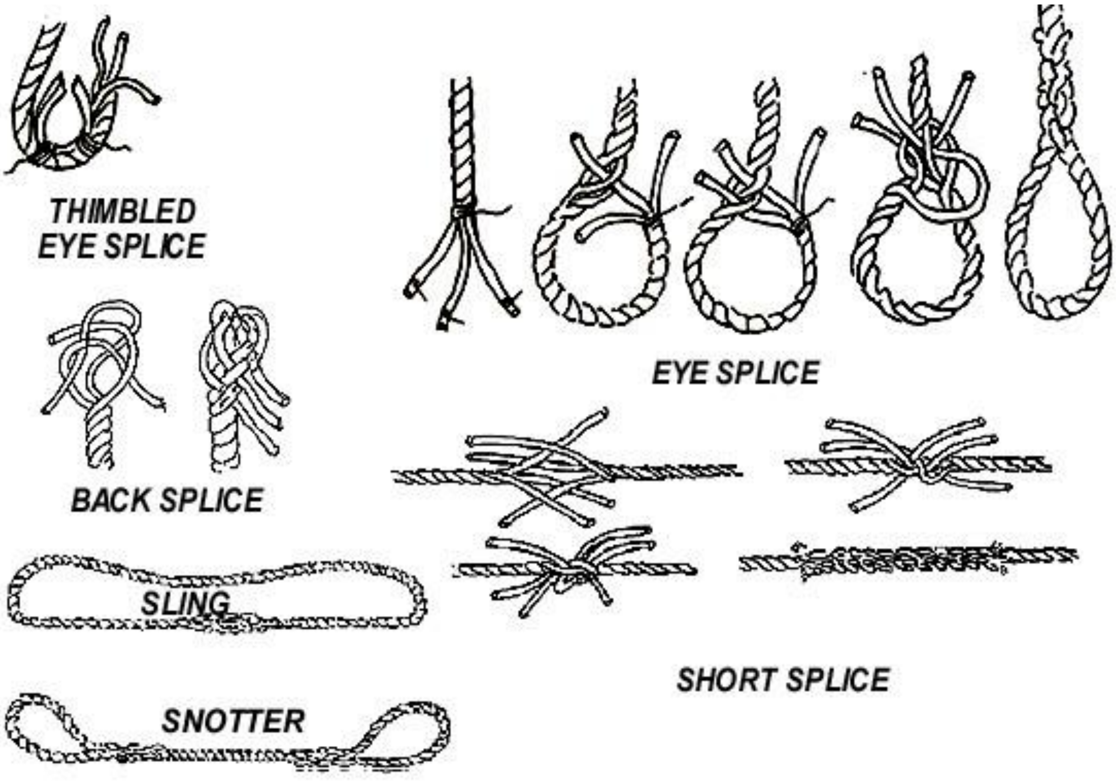
Splicing

Splicing can only be learned through practice. To begin, seize the ends of unlaid strands, and seize the rope at the point to which you plan to unlay it.

Eye Splice - An eye splice is formed by unlaying the end of a rope, then turning the end back to from an eye, and tucking the separated strands into the standing part. Natural fibre uses three full tucks and synthetic fibre, a minimum of four full tucks. If splicing round a thimble, tie the rope securely to the thimble with light twine, then splice

Short Splice -This is used to join two ropes when not required to pass through a block. Unlay the two ropes and clutch them together, so that the strands of one rope go alternately between the strands of the other. Tuck each strand over one strand and under the next, take two or more tucks with each strand, then turn the line and do the same with the other rope. Pull each strand up taught. A minimum of three full tucks for each rope.

Back Splice - Back splice is used in the means of finishing off the end of a fibre rope to prevent fraying. It is commenced with a *crown knot*, then the strands tucked as in the short splice.

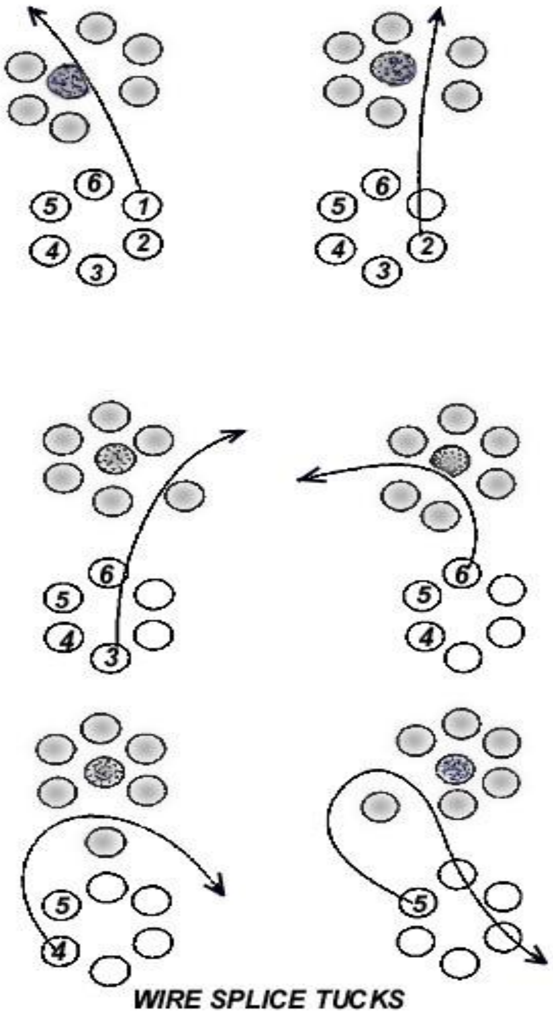


Wire Rope Splicing - There are many types of wire splicing. The other commonest splice used at sea is the eye splice, and though most wire is received on board ready spliced these days, there may be the occasion when a seaman is called upon to do some splicing.

A bench vice is required to hold the wire firmly, a fid to separate the strands, a set of heavy duty pliers and a good deal of muscle. The splicing tail should be about 40 diameters of the wire. Whip the wire at this point, and form the eye and seize to the main part. Unlay strands of each tail down to the seizing and whip each strand with twine, then cut away the heart.

The diagrams give the sequence for the first tuck of an eye splice in common 6 strand rope. After completion of the first tuck, continue tucking each strand over one and under two, against the lay, until 3 full tucks and 2 reduced tucks (with each strand halved) have been completed.

Once the splice has been completed it would traditionally be protected by worming, parcelling and serving. Worming is the process of embedding greased hemp around the gaps between the strands to give the wire a flat surface. Parcelling is bandaging around the wire to trap the greased lubricating hemp, and serving is to overlay the whole with a tight seizing of marlin twine or wire. This would then be painted over with pitch.



Strength of Rope and Chain

NSCV compliant fibre ropes are manufactured as per AS 4142.2 and tested as per AS 4143.1 or to AMSA recognised ship classification society standards.

Stress denotes the load put on material, and strain is the molecular disturbance made evident by a change of shape or a fracture of the material due to the stress which has been applied. The term breaking or ultimate strength is the load or weight applied to material when testing to destruction. Every item used in rigging has a B.S. (Breaking Strength), from which a S.W.L. (Safe Working Load) may be found by dividing the B.S. by a factor of safety for the function of the gear.

Rope (Fibre) - Their relative order of strength is Coir (never to be trusted), Sisal, Manila, Hemp, Polythene, Polypropylene, Terylene and Nylon.

Splicing a rope reduces its strength by at least 10%. Knots reduce a rope's strength by at least 50%. The ultimate strength of fibre ropes depends much upon the quality of fibre and the process of manufacture.

The diameter of fibre and steel wire rope is in mm. A safety factor of fibre and steel wire rope of 1/6 is used in the marine industry. Thus S.W.L. can be taken to be 1/6 of the breaking strength for fibre and wire rope.

An approximate S.W.L. of a Rope = D^2 x F kgs.

D is diameter of rope in mm and F is a factor of safety. The S.W.L. is taken to be (1/6 of the breaking strain of the rope)

Material	Factor	Approximate S.W.L.
Natural Fibre	1	D^2
Polyamide (nylon) < 50 mm	3	$3D^2$
Polyamide (nylon) > 50 mm	2.5	$2.5D^2$
Polyester (Terylene)	2.5	$2.5D^2$
Polypropylene	1.8	$1.8D^2$
Polyethylene (Mono)	1.8	$1.8D^2$
Polyethylene (Staple)	1.2	$1.2D^2$
Wire	8.0	$8D^2$

Example 1 - find SWL of 30 mm Nylon

SWL (kgs) $= 3D^2$
$= 3 \times 30^2$
$= 2700$ kgs

Example 2 - find SWL of 12 mm Wire Rope (6 x 24)

SWL (kgs) $= 8D^2$
$= 8 \times 12^2$
$= 1152$ kgs

It is common practice to allow a 'Factor of Safety' of 6 in general marine work for both fibre and wire rope. Wire slings can have a 'Safety Factor' of 5 in some cases.

Chain - It is common practice to allow a 'Factor of Safety' of 5 for chain. The S.W.L. = B.S. x 1/5 tonnes.

Grade 1 - Mild Steel
Grade 2 - Special Quality Steel
Grade 3 - Extra Special Quality Steel

Stud Link	Size	B.S. (Breaking Strength)
Grade 1	12.5 mm to 120 mm	($20D^2$) over 600
Grade 2	12.5 mm to 120 mm	($30D^2$) over 600
Grade 3	12.5 mm to 120 mm	($43D^2$) over 600

With the I.S.O. standards - Grade 3 is mild steel - Grade 4-9 is tensile steel.

Example - in this case the S.W.L. = $3D^2$ x Grade (kgs)

10 mm Grade 3 chain
SWL (kgs) = $3D^2$ x Grade
= $3 \times 10^2 \times 3$
= 900 kgs

When calculating SWL of chain, beware of two different identification systems. If in doubt, assume the chain is the lowest grade, (i.e. mild steel).

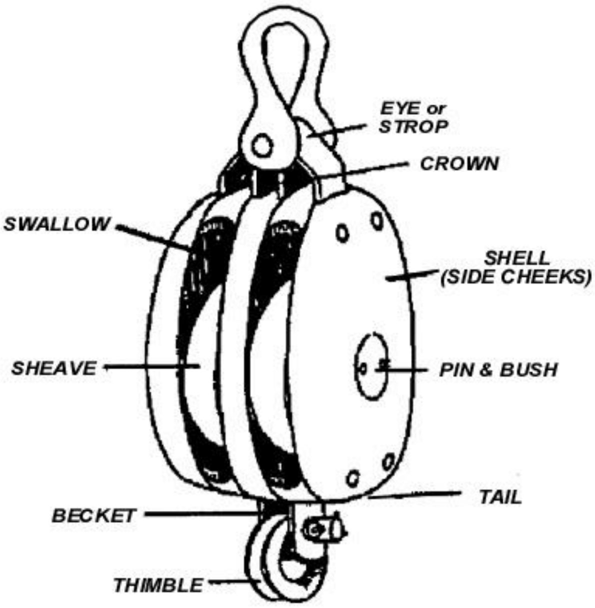
4.2 Blocks, purchases and tackles

A purchase is any mechanical device which can increase output power. A tackle is a simple device comprised of rope and blocks.

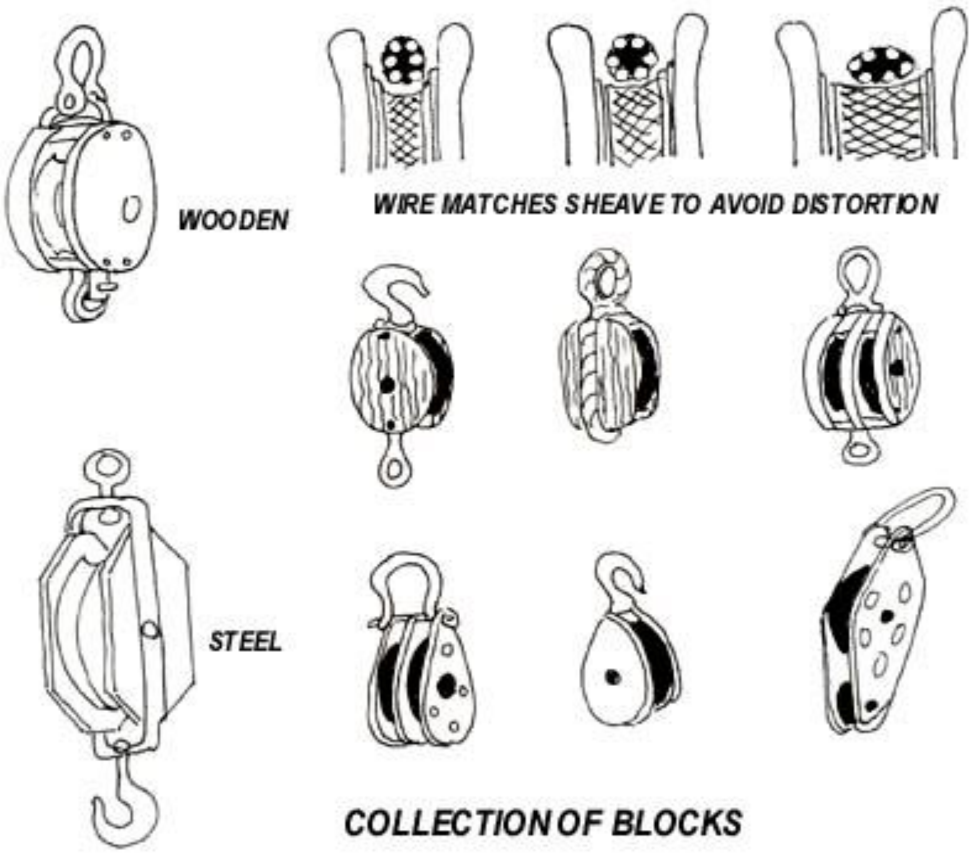
Blocks

These are frames of wood or steel fitted with one or more sheaves. They are designated as single, double or treble depending on the number of sheaves, or from some special shape or construction (snatch blocks).

Fibre Rope Blocks - The older wooden blocks had steel sheaves and plain bearing axles. The later type have a steel strap or band running outside the shell, with the sheave pin going through both strap and shell. The modern type tends to be all metal. If no S.W.L. is marked on them, then it is equivalent to that of the largest diameter rope that can be reeved through comfortably. The diameter of sheaves used for fibre rope should be at least six times the diameter of the rope used when hand operated. When power operated the sheaves should be 12 times the rope diameter (diameter in mm).



The drawings show parts of a wooden block above and a collection of blocks below. The rope must match the size of the sheave to avoid crushing, kinking and deformation. The diameter of a sheave is measured to the bottom of the groove. For wire ropes the sheave diameter should be 20 times the rope diameter for power operated blocks and it can be 10 times on non power operated blocks.

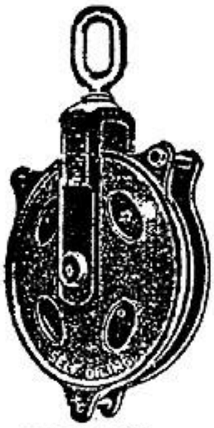


COLLECTION OF BLOCKS

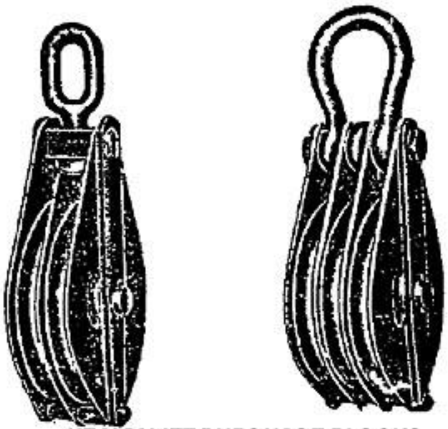
Wire Rope Blocks - Generally referred to as steel blocks and more often used for heavier applications on board a vessel. There should be a small plate affixed to the cheek of the block showing:

Serial Number
Safe Working Load
Last Test Date

Some typical wire rope blocks are shown below.



CARGO GIN



HEAVY LIFT PURCHASE BLOCKS

One special type of block that the mariner will come in contact with on occasions is the Snatch Block. This is a small strong steel block with hinged side. This permits the fall to be put over the sheave through an opening in the side, without reeving the end through. They are very handy as lead blocks when moving cargo, or gear around the decks.

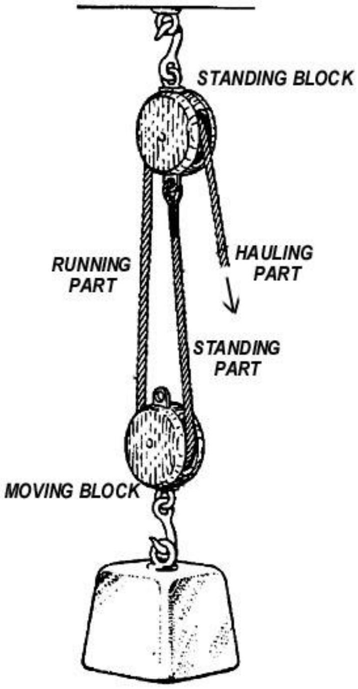
Care And Inspection Of Blocks - Check the swivel eyes and sheaves for free movement Grease swivel, shank and bearings regularly.

Examine side plates for distortion.
Check axle pins cannot work loose.
Oil all surfaces rather than paint. (Paint clogs oil holes and hides defects).
Check wooden blocks for splitting.
Never drop a block on the deck.

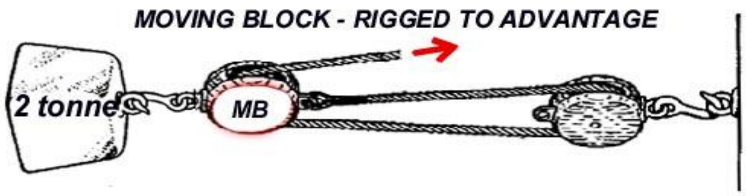
Purchases and tackles

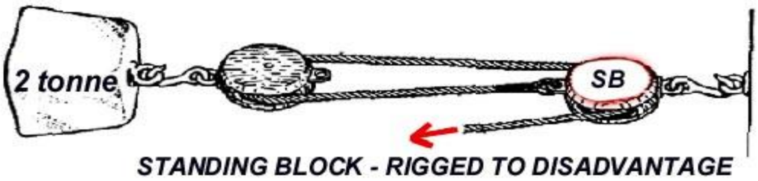
The lifting power of a purchase or tackle is referred to as the *Mechanical Advantage* ratio (MA). MA depends on the number of sheaves in the block and how much rope is moved by rigging it to advantage or to disadvantage.

To find the MA of any purchase, count the number of parts of rope at the moving block. (This assumes no friction in the sheaves and no benefit of counterbalancing the hauling persons own body weight). In the *Gun tackle* below the ratio is 2:1.



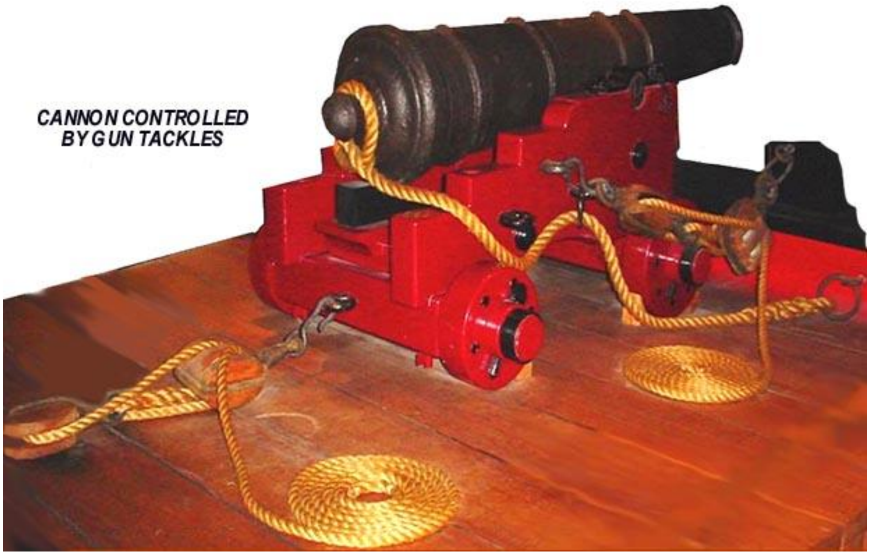
When hauling from the moving block, the tackle is rove to advantage. In comparison, rove to disadvantage is when hauling, from the standing block. A *Gun tackle* is shown below rigged to advantage and disadvantage.



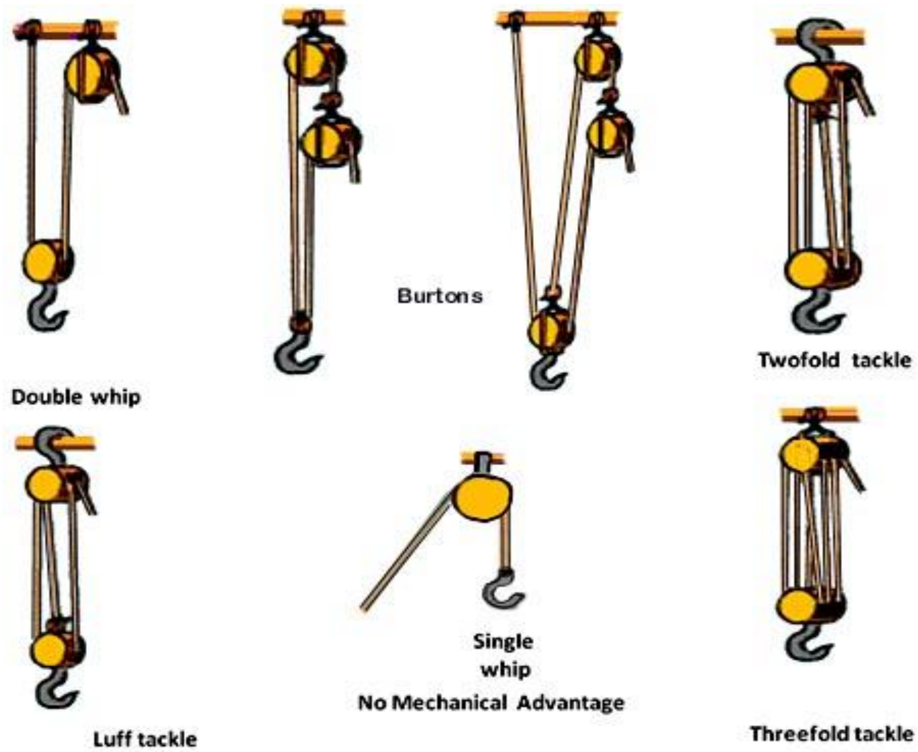


Where the tackle is rigged to disadvantage the mechanical advantage is the same as the number of sheaves in the tackle (MA 2:1- stress to lift 2 ÷ 2 = 1 tonnes) and when rigged to advantage it becomes the number of sheaves plus one (MA 3:1- stress to lift 2 ÷ 3 = 0.66 tonnes). This is because the gear like action of the greater length of rope needed to haul through the tackle in *advantage* to move the weight the same distance.

The tackle above is called a gun tackle. Ingenious use was made of the twin ratios in the operation of historic warships cannons' to quickly run the guns out for firing and enable greater friction to control the recoil after firing.



Types of Tackle - Special names are given to the various types of tackle used at sea, many of which owe their origin to their former use in the sailing ships of the last century.



Chain Hoists (Chain Blocks) - Chain blocks are used for lifting machinery found in the engine room. Due to the slow movement of the load, it can be placed with precision. They should be constructed with the lower hook as the weakest part, so it will start to spread before the hoist is overloaded. Evidence of spreading or wear is cause for replacement. Any distortion of the chain links means it has been overloaded and is unsafe to use.

4.3 Access- stages, bosun's chair and rope ladders.

Rigging a Stage

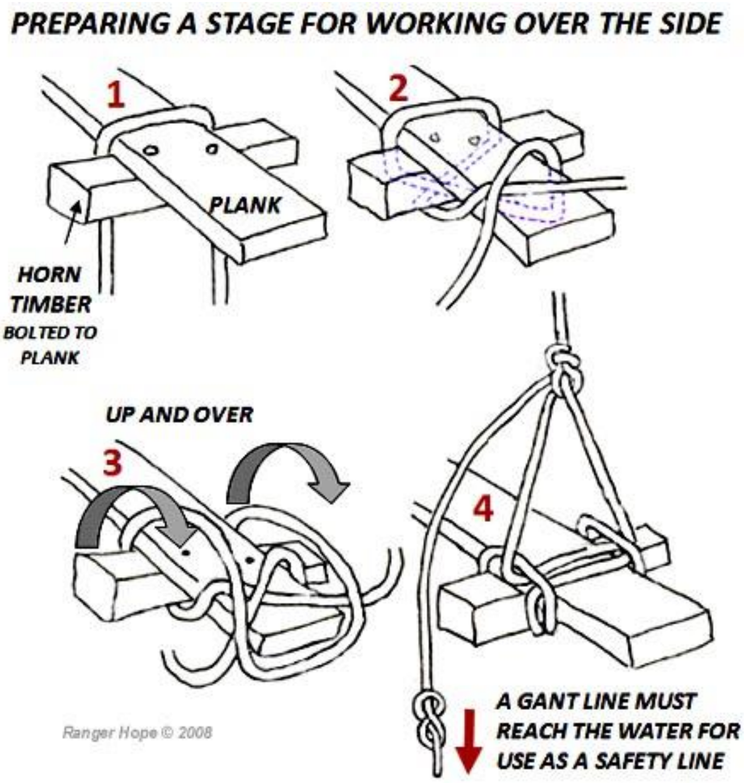
A practical size line for a stage rope is 20 mm. Lay a scaffold plank suitable to take the weight to walk on over a square horn timber and bolt them together. Lash together as shown below by taking turns of the hauling part around the end of the stage and the horn as a means of lowering. The rope tail is made fast to the standing part after the hitch is completed, using a bowline. The standing part should be reeved through a lizard, shackle or best of all a block to enable it to be lowered and adjusted by those working from the stage. The fall beyond the bowline must be long enough to reach the waterline (a *gant line*) for working over the ship's side.

If the stage is extra long, it is advisable to rig a centre line to prevent sagging in the middle.

Precautions - Inspect stage, lines and fittings for correct rig and free of defects.

Load test the stage to 4 times the intended load.
Always set down before raising and lowering.
Gantlines must trail in the water to be used as lifelines.

Stages should only be rigged over water, not used whilst underway and be positively attended with a life buoy ready and available to deploy. Rig a rope ladder for access.



Rigging a Bosun's Chair

A bosun's chair and gantline is used in work done aloft. The traditional rope bosun’s chair has been superseded by modern propriety safety harnesses. Not only are web harnesses much more comfortable than rope, but they are accurately rated for the loads of personnel and tools that will be carried aloft.

Additionally modern climbing accessories and fittings such as ascenders, descenders, carabineers with stretchable ropes provide far greater levels of protection than the traditional rope supported chair (stretch factored climbing ropes reduce the snatch force experienced as a rope takes up the weight of a person’s fall). The rope chair is therefore described here for historical interest only.

In the traditional chair the gantline is attached by means of a double sheet bend and end seized to the standing part. The gantline should be reeved through a tail block or lizard for ease of hauling and lowering oneself.

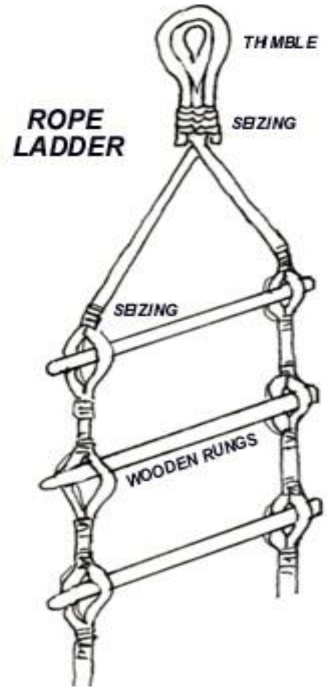
Precautions - Correctly rig the gantline and inspect all lines, fittings and chair for defects.

Load test 4-5 times the intended load.
When hauling aloft in a bosun’s chair it should be done by hand.
Ensure that no tools can be dropped (use lanyards) for the safety of personnel below.
If riding a stay ensure the bow of the shackle rides the stay and mouse the shackle pin.
Wear a safety harness if more than 2 metres aloft.

The practice of holding on with one hand and making the lowering hitch with the other hand is dangerous. Without weight on the chair, seize the fall and gantline together above the thimble eye of the support ropes (or use a propriety *abseiling descender*) before making the lowering hitch. A long bight of the hauling part is pulled through the strop of the chair, passed over the head and allowed to drop behind to the feet. It is then passed under the feet and brought to the front. The slack on the hauling part is pulled tight forming the hitch. When ready to lower, feed slack on the hauling part through the hitch or abseiling *descender* as utilised.

Portable Ladders

Rope ladders are light and suitable for low height only. The top of the ladder can be left with the rope ends whipped or a thimble can be used.

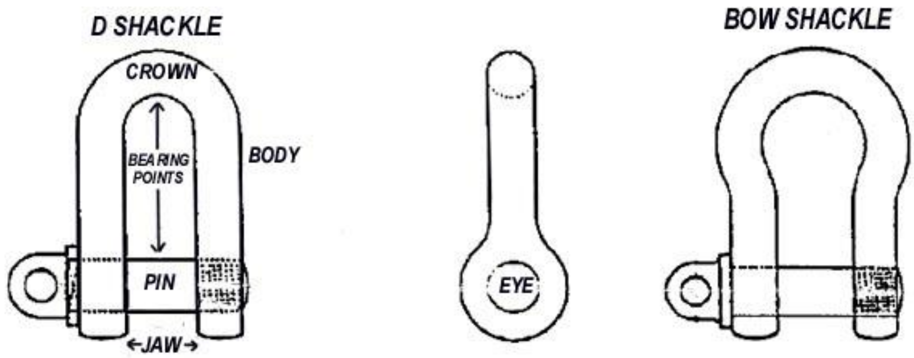


4.4 Lifting gear

Shackles, hooks and strops.

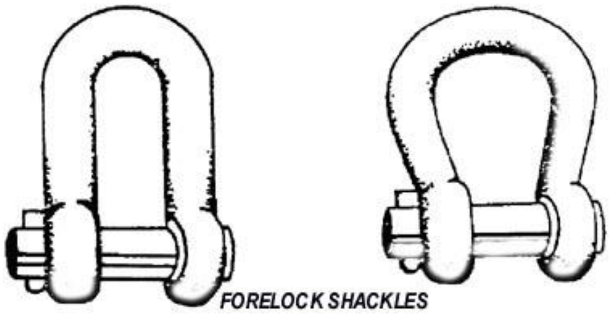
Specification for lifting gear is found in *Marine Orders 32 Cargo Gear*.

Shackles are used as connectors of one wire to another, a sling to a load, a hook to a block or a hook to a wire rope eye. Their nominal size is given by the diameter of the shackle body.



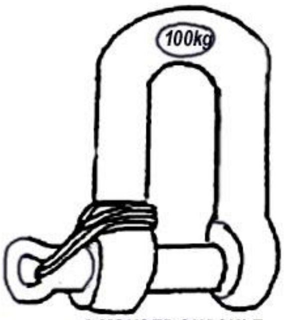
The two principal designs are *D* and *Bow* shackles, shown with screw pins above. Bow shackles are used when more than one attachment is to be made to the body.

Other types of shackles are usually named in relation to the pin type, including the *forelock shackle* that is used for standing rigging, or where vibration is present. The pin is unthreaded, but it has a flat split pin as a keeper.


FORELOCK SHACKLES

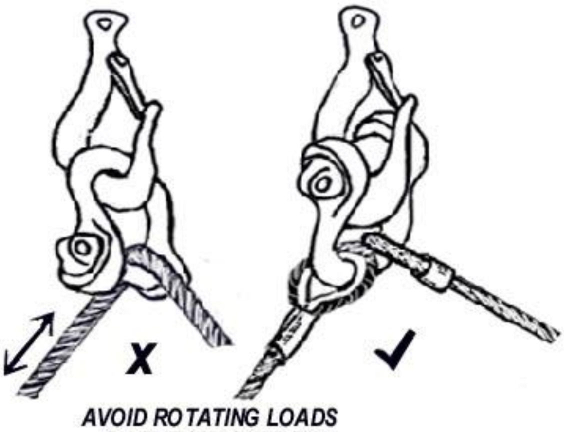
Safety checks with shackles - Any shackles used in lifting purchases must be tested and have the SWL marked on the body. Never use a pin that is bent, strained or damaged in any way. It is poor practice to replace a shackle pin with a nut and bolt that may bend under load. If the crown or pin is worn to more than 10% of its original diameter it must be discarded.

All permanently attached shackles should be the locking type or should be *moused* (secured against accidental opening by wire seizing).

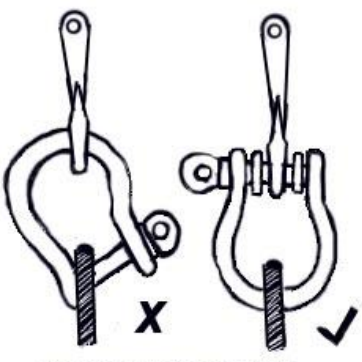


A MOUSED SHACKLE

Avoid using a common shackle where the pin can roll and unscrew under load (i.e. as a slide along a wire stay or with strops).



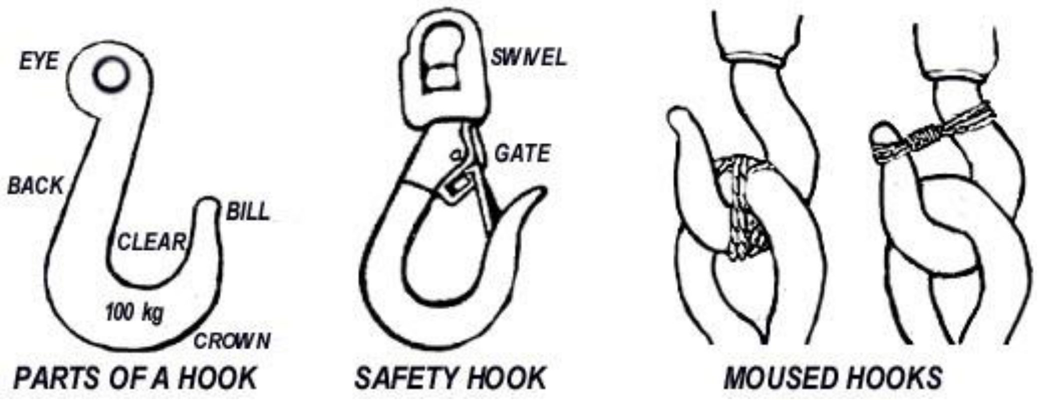
AVOID ROTATING LOADS ON THE SHACKLE PIN



PULL CENTRALLY FROM THE SHACKLE CROWN

Do not allow shackles to be pulled at an angle. Pack the pin to hold it square on the hook.

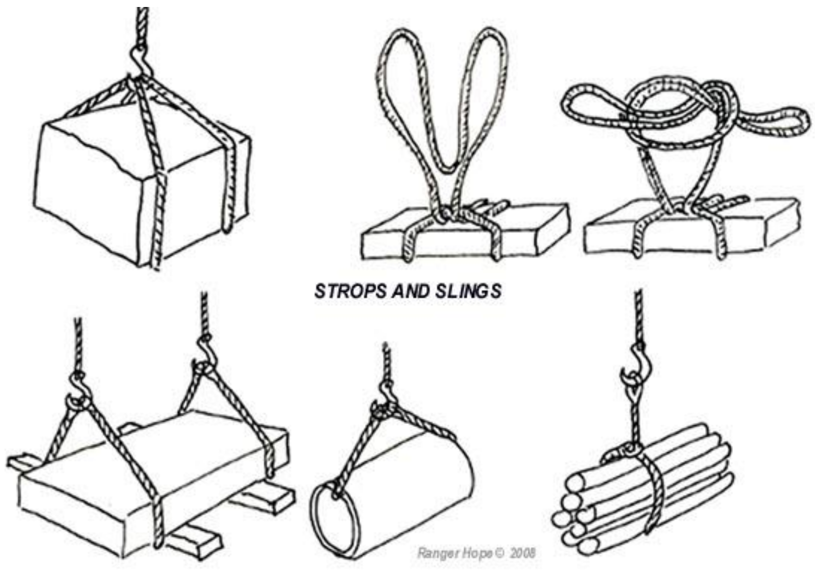
Hooks - Hooks are used to attach the load. Because of its open construction, the hook is usually the weakest part of the lifting rig. New hooks are stamped with their S.W.L.



Safety checks with hooks - When used for raising or lowering cargo they should have a device to stop the slings jumping off. Hooks should be free to rotate under all conditions of loading. Swivels should be inserted wherever a twist is possible. If the hook throat opening has stretched more than 5% it must not be used. Damaged, distorted or bent hooks must not be used. The throat opening must be large enough to fit the largest rope, ring or shackle to go on it. Do not overcrowd the hook. Use a bow shackle or ring.

Slings and Strops - are made from fibre rope, wire rope or chain.

Fibre Rope lifts without scratching, protect load surfaces and are flexible.



Steel wire rope slings are more suitable for lifting machinery or material that will cut easily into fibre ropes. Size for size they are much stronger than fibre rope slings but are more expensive. New slings will have their Working Load Limit stamped on them.

Chain Slings are stronger than both wire and fibre rope and are often used in combination with them, especially the two, three and four legged variety, when lifting bulky loads and machinery. The *collar sling* can have different sized end links so that one may be rove through the other to act as a *choke hitch*. New chains will have their Working Load Limit stamped on them.

To shorten a chain sling if no clutches available, pull slack of chain through the large ring to form a bight. Pass one hand through the bight, catch hold of standing part, let everything else drop and place standing part over the cargo hook ready for heaving.

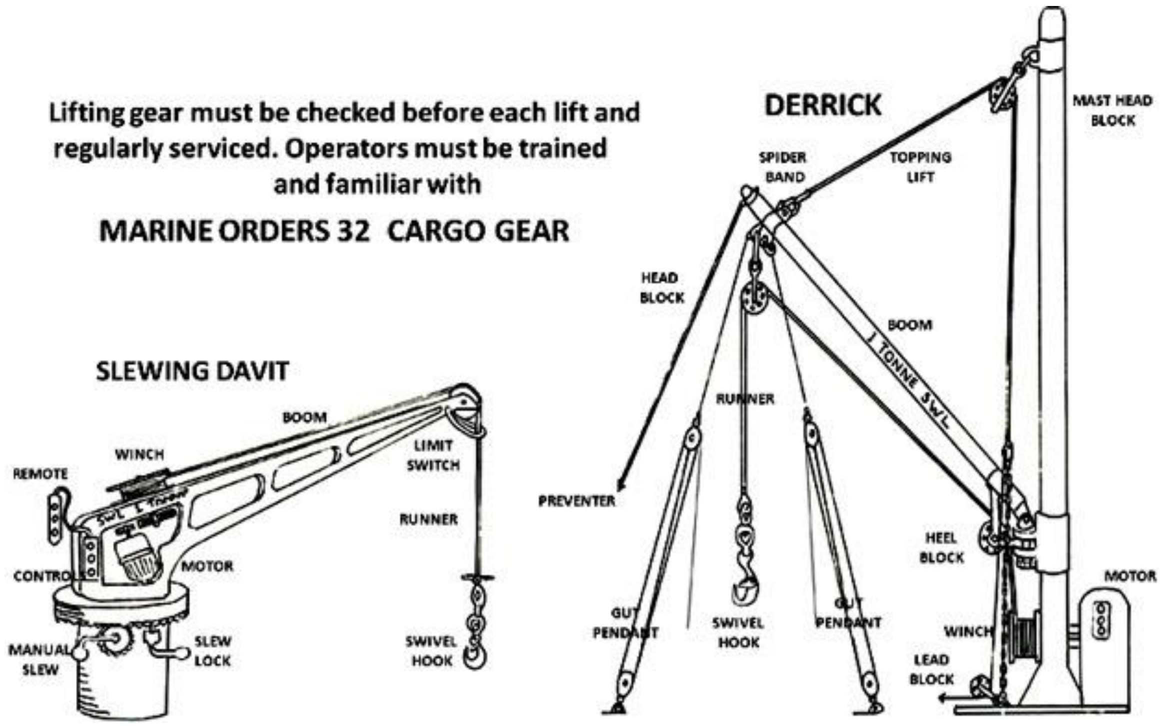
Working Load Limits - New chains will have their stamped on them.

It must be appreciated that the stress on the spread arms of a sling will increase with the angle that they make at the swivel hook. Therefore the shorter the strop (from load to hook) the less load can be safely lifted to remain within the Working Load Limits.

Derricks

Even though the traditional derrick is now seldom seen handling cargo on smaller trading vessels, the principles of its use apply to fishing and sail equipment. A *boom* or *jib* is attached to the *mast* at a *gooseneck* (hinged fitting). The jib can be raised or lowered by use of a *topping lift* cable, in order to position the cargo *swivel hook* vertically over the cargo hatch or over the shore side wharf for unloading. Both union purchase rig and a mast with single boom used as a derrick to unload a cargo are shown below. Safety cargo netting is omitted for clarity.

The boom is held steady (*stayed*) by *guy tackles* and their *pendants are* made fast. A winch (capstan) can then control the *cargo runner* with its attached swivel hook and load. The disadvantage of this system is that repeatedly swinging the boom from over hatch to over the shore requires temporarily securing a preventer line and re-adjusting the guys for each lift and lowering - a time consuming task. This problem is resolved by the *union purchase rig* that uses twin booms, one stayed above the hatch and the other above the wharf. The cargo runner from each boom is attached to a single swivel hook so the load can be swung from one boom over to the other. Care must be taken not to pull up the load so high that the two cargo runners are pulling against each other, with the consequence of severe overload (the angle between the load and the two cargo runners must not be greater than 120º).



The safe working load is painted on the derrick boom or jib

The union purchase rig is replaced in modern cargo vessels by tandem or dedicated cranes for heavier lifts. For smaller lifts, retractable jib hydraulic cranes of the slewing davit type, (HIAB or Palfinger) are now widely used as general purpose cranes to address the disadvantage of derrick system's slewing (swinging) limitations

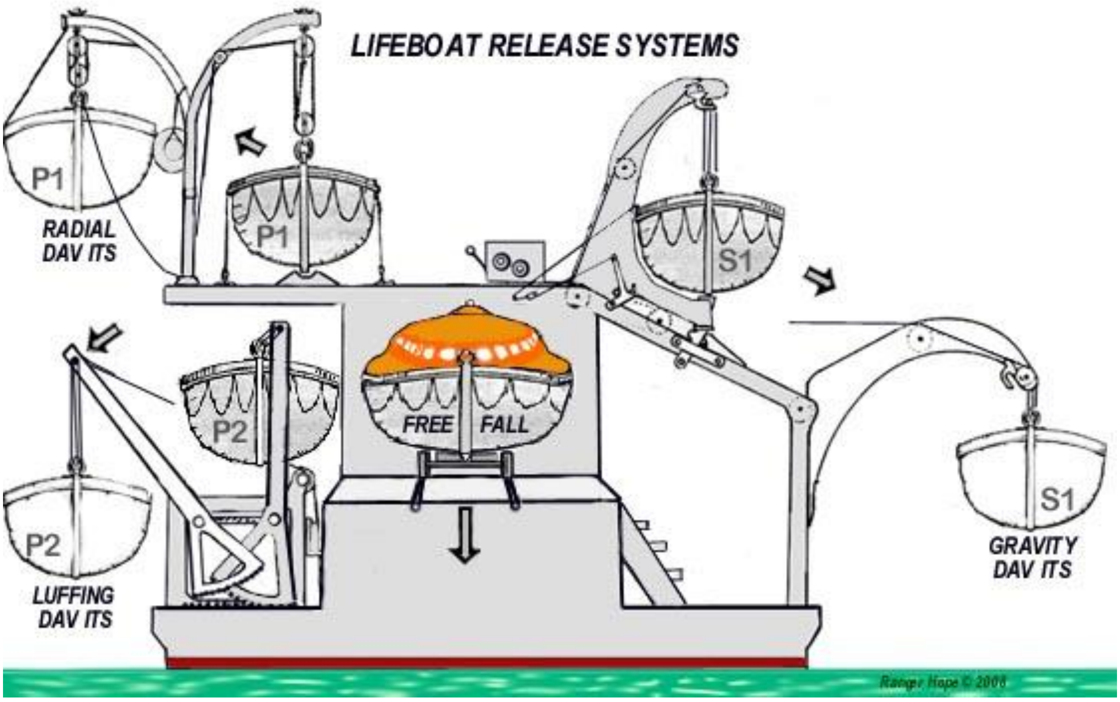
The slewing davit above may be slewed in either direction through 360^{o}, often by means of a manually driven gearbox. To prevent movement when not in use it is fitted with a locking device. Hoisting is achieved by operation of an electric/hydraulic motor mounted on the davit. Raising and lowering is affected by a remote control with separate buttons for *up, down* and *emergency stop*. The winch is equipped with a centrifugal brake, and a *limit switch* cuts the motor if the swivel hook is drawn too close to the jib head.

Lifeboat davits

The considerable amount of running rigging (rope or wire) and exposed position of traditional davit lifeboat launching systems make them prone to jamming due to deterioration or corrosion. They must be regularly maintained and operationally tested for the trying conditions that will prevail when needed for use in earnest.

An emergency signal will call crew to their lifeboat muster station, named by the letter P or S (port or starboard) and boat number (numbered from bow to stern). On instruction of the leading hand life jackets are donned, the lifeboat (with equipment and supplies) is readied and secured with temporary *bowsing lines*.

Radial davits - are normally operated with rope tackles or manual winches. After the abandon ship signal, if all is clear below, the securing *gripes* are let go and the lifeboat hoisted on both *radial davits* to clear the chocks. A *guy or bowsing line* from the after davit is hauled taught, pulling the lifeboat backwards sufficient that the forward davit can be rotated outboard and the bow of the lifeboat swung out. Next the *guy or bowsing line* from the forward davit is hauled tight pulling the lifeboat forwards sufficient that the aft davit can be rotated outboard and the stern of the lifeboat swung out ready to lower. If safer to do so, passengers may be boarded at that stage and controlled lowering can commence.



Luffing davits - are wound out (manually or more commonly with electrically driven screw). To enable sufficient outboard clearance for the lifeboat on its descent they require a greater height of davit to meet Class rules requiring life boats to be successfully lowered from the high side with angles of heel up to 15º. Consequently they are more often sited at the extreme ends of a vessel.

Gravity davits - enable larger outboard clearance for the lifeboat with compact stowage. A release is initiated by freeing the brake. The weight of the vessel is used to slide the lifeboat down the skids. From this position continued release will allow it to be deployed.

A safe boarding station is provided on the deck below the skids. This system is suitable for larger capacity lifeboats but being more complex than those before it requires a fastidious attention to maintenance and greasing to ensure free running.

The problems of deterioration or corrosion inherent in davit launching systems are being avoided in non passenger vessels by the use of free fall lifeboats. As with canister liferafts the release mechanism and the skids need comparatively minimal attention, however the importance of personnel restraints functionality and structural/watertight integrity of the lifeboat (that may free fall may metres) cannot be overstated.

Safe use and maintenance of lifting gear.

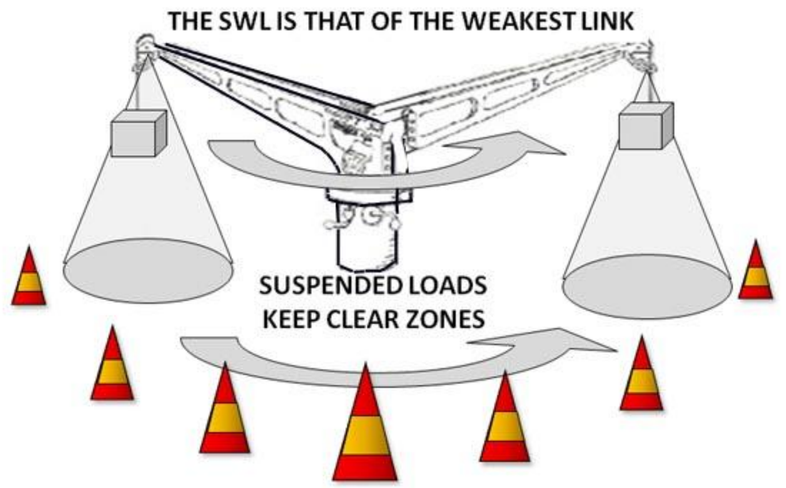
There is always a danger whenever weights are to be lifted or moved by means of cranes, booms, tackles, topping lifts or other appliances due to the unevenness of the working platform and changes in dynamic loadings on the gear. Therefore the correct and safe use of the gear, machinery and associated hardware is of vital importance, as is its care and maintenance.

Preparations for moving lifts - Inspect all equipment for defects. Determine weight of load and position of the centre of gravity in relation to the lifting points. The safe working load of the equipment must never be exceeded. A lifting appliance is only as safe as its weakest part. Decide upon the method of slinging and lifting the load. Take into account whether the lift requires tag lines (to steady the load from swinging wildly or position it in tight spots) and packing or chafing pieces.

Ensure the load is free to be lifted (not still bolted down or lashed) and any loose parts secured or removed.

Make sure there is a clear method of communication between the operator and the signal man and that the plan is understood by all. Be aware of the code of hand and whistle signals if operating with a crane or derrick. Some commonly used hand signals are shown below. Only one person should signal a driver at a time; however the driver should obey anyone who gives the *stop signal* to indicate an emergency. High visibility gloves or armbands may be worn by the signaller to show his/her authority and to make the signals clear.

The operator must not pass a loaded boom over personnel, so stay out from under or between loads and any solid obstruction against which you could be crushed. Never keep a load in the air any longer than necessary. Heavy weights should never be allowed to drop no matter what the distance.



The lift - The greatest force must be applied at the time of starting a load, in order to overcome inertia. Apply the load gradually to avoid exceeding the SWL. Check the load's balance and general security. If this is satisfactory speed may be increased once the load is moving dependant on safety and smoothness of operation. All motion with heavy weights should be slow to avoid creating momentum.

Avoid swinging the load. If you're lifting something off a wharf, drag it until the load is directly under the head of the crane or boom. Remember those tag lines to steady to heavy unwieldy loads. When lowering, stop a short distance above the landing site to allow steadying, to check position for landing, dunnage, and to make sure the slings will not be caught under the load.

Avoid sudden shocks or strains and side pulls as this puts great stress on lifting gear. Listen for changes of sound in a wire, rope or block. Wire or cordage normally hums under strain. If it starts to squeak or squeal, watch out. A faulty block may give warning by squeaking or groaning. Never use running gear as a handhold.

Check lifting equipment before returning to stowage.

4.5 Deck machinery

Warping, capstan, winch and windlass

Warping winches/windlasses and capstan winches/windlasses differ in that the drum of the warping winch is horizontal the capstan is vertical. Warping winches tend to be favoured for use on merchant vessels whereas the capstan is more common on naval vessels. The requirements for safe operation of both types are similar. *(Warping* is the act of hauling or moving a vessel fore or aft usually along a wharf, or when adjusting mooring wires/ropes.) In merchant vessels, a warping drum is usually included as an extension at one or both ends of a windlass or winch, so that that the motor can be utilised for more than one function.

A line may be *surged* out (let go without restraint), *veered* out (let go under control of a brake) or *walked* out (by mechanical rotation under power). Never surge a synthetic line on a rotating drum. Surging causes friction, heat is generated and synthetic fibres may melt onto the drum and part.

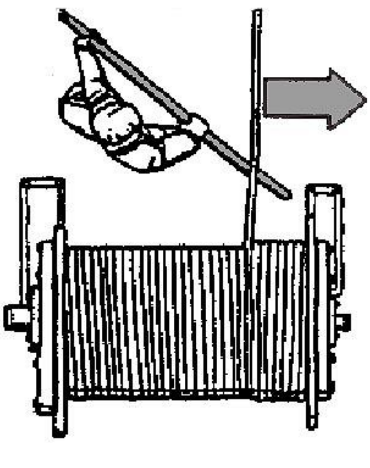
Survey requirements for deck machinery - Windlass/capstans, winches and other machinery must be operated in accordance with Safety Management operational procedures that address *Marine Orders 32 Cargo Gear* and the *NSCV Part C Section 7 Subsection 7D-Anchoring and Mooring Equipment*. Older vessels may comply with *USL Code Section 9 Engineering.* These regulations require a windlass to be:

Provided with cable stoppers (or devils claws) between the windlass and the hawse pipe
Designed for immediate dropping of the anchor
Provided with an efficient brake

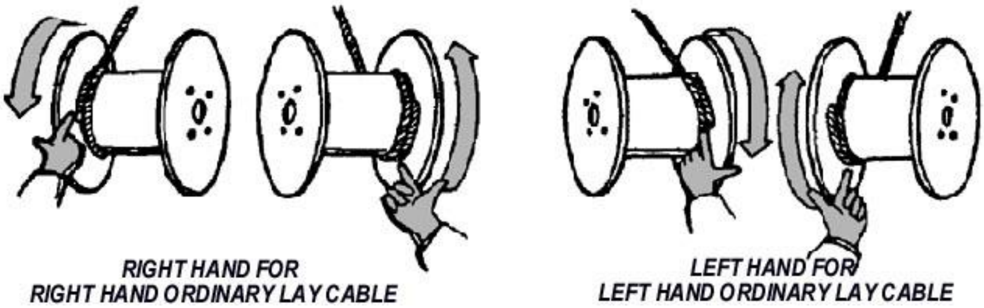
For an anchor of less than 50 kg, a windlass may be hand operated. This is provided that the applied effort shall not exceed 155 Newtons when lifting the anchor and the weight of the entire length of the anchor cable. For an anchor of 50 kg and above, a power operated windlass shall be provided, and be capable of lifting one anchor and 35 metres of its cable plus a 20% overload at a speed of not less than 7.5 metres per minute. The NSCV *Part C Section 7 Subsection 7D*.3 also provides formula for calculating compliant weight/number of anchors for vessels over 24 metres and tables for vessels of 24 metres and under.

It should be noted that lifeboat davits and other mechanical launching arrangements are also deck machinery. The requirements can be found in *NSCV Part C Subsection 7A-Safety Equipment.* Older vessels may comply with *USL Code Section 10 Lifesaving Appliances.*

Wear good safety footwear wear, gloves, clothing that is not loose and avoid standing in the direct line of the hauling part or in the bight of lines. Keep the area clear of passengers and unnecessary crew and take extra precaution in wet weather. You should never manually guide the wire rope onto an operating winch drum (*barring over*). This is a very dangerous practice.



The *thumb rule* as drawn below is used to determine how to start winding the wire or rope onto a winch drum. With the pad of the index finger touching the over wound or under wound wire, the thumb will point to the correct side of the drum.



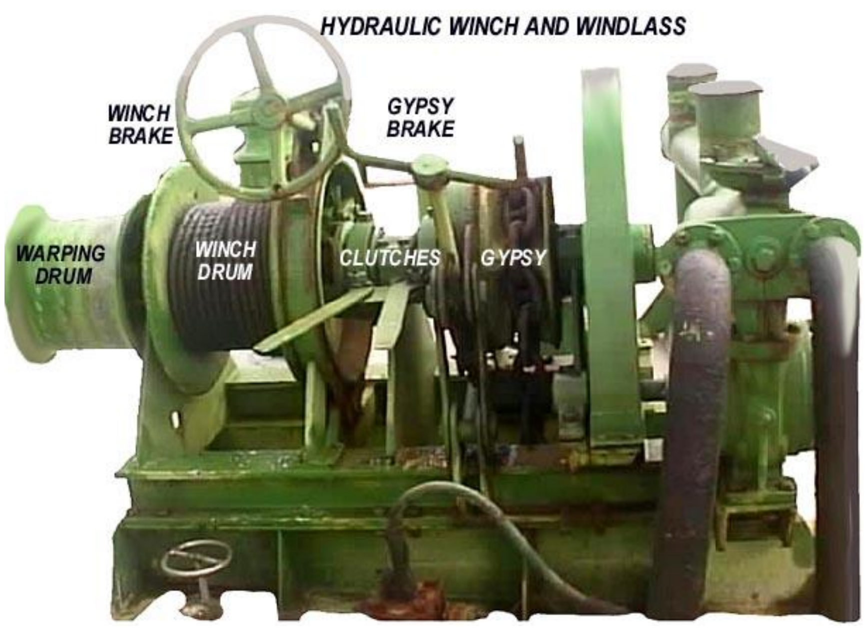
If you need to assist wire rope onto a drum (when loading a new rope) always use a guide tool, never use your hands.

Winch Operations

Prior to operation always inspect that the winch is clear (not fouled), the wire rope is roved correctly, all fittings are serviceable and the controls are unobstructed. Inform crew and keep personnel clear before test operating the winch to check that the:

Controls and interlocks are operating correctly
Brake and pawl functions are working
Wire rope is correctly spooling onto the drum

Never use the winch end terminal as a stop. Leave at least 2 turns on the drum when fully unwound. Continually check the system whilst operating.
Where the winches run on electrically-operated hydraulic pumps, they can be run out under power. This gives the operator much greater control and eliminates the ever-present risk of brake failure which can result in lost or damaged gear.



In most cases careful manipulation of the hydraulic control allows them to be slowed right down to a bare *crawl* and, in the neutral position, acts as a brake when the hydraulic motor is running. All such winches have a manual brake as standard.

Safety - The operator is directly responsible for the safety of gear handling operations. If there is any doubt about safety, stop the machinery immediately and rectify the problem or isolate the system. The operator must know the SWL of the equipment and operate within the designed limits of the winch.

Operators should never leave machinery unattended with gear running, or with a load suspended. Avoid overwinds of cable. Always be sure everyone is clear of the danger zone before applying a load, and never pass a suspended load over another crewman. Machinery should be provided with a means to prevent over-hoisting and to prevent the accidental release of a load if the power supply fails. Check you know where the Emergency Stop button is for all machinery.

Machinery guards should always be in place, except when carrying out repairs. Never work on running equipment, it must be stopped and rendered incapable of accidental restarting. Be sure the area around the controls is unimpeded, and that your view is as unobstructed as possible. Make sure that all lighting is in working order and that guards protect the globes.

Warping Drum Operation - Always test a winch prior to use for warping. *(Warping* is to haul a vessel along a wharf when adjusting lines.) Normally pass 2 - 3 turns around the drum and *tail* the line (keep strain on the rope as it passes over the warping drum) keeping about a metre away from the drum surface. If it slips on the drum add more turns.

In merchant vessels, a warping drum is usually included as an extension at one or both ends of a windlass or winch, so that that the motor can be utilised for more than one function. In such cases it is necessary for both the main winch drum and the warping drum to be capable of being clutched or de-clutched from the mainshaft. This is so that both can operate independently. If this is not the case, when using the warping drum, any wire coiled on the winch drum (*runner*) must be removed before using the winch for warping.
In the case of windlasses being operated for the purpose of warping, the cable lifter (*gypsy*) should be disconnected (*de-clutched*) from the mainshaft.

Warping a vessel is a skilled operation and requires one end of a wire or hawser being fastened on a bollard on the wharf. The wire then goes through a fairlead or guide on the vessel to the warping drum on the winch.
The wire is loosely wrapped around the drum and the remaining loose end coiled nearby. The winch is set in motion, but as the wire is loosely wrapped it slips and does not move with the rotation of the drum. On the signal to haul the operator pulls on the loose end of the wire, this tightens the wire on the drum. Due to the friction between the wire and drum, the wire is hauled in around the drum and at the operator’s end is pulled off the drum and the vessel slowly moves.

The skill in warping comes from the operator’s ability to adjust the pull on the wire so that the hauling is smooth. He can adjust the speed of hauling, up or down, by increasing or reducing the pull or allowing the wire to slip at a controlled rate on the drum. The balance between hauling and slipping is critical and it may be necessary to quickly wrap extra turns around the drum or reduce the number of turns without getting entangled in the wire.

Passing a Stopper - If a *riding turn* develops (where the line overruns itself leading to jamming), stop and remove with caution (riding turns usually develop because of incorrect lead or tailing). If there is strain on the line then use a *stopper* to temporarily take the strain.

A stopper is used to transfer the weight on a line from one fitting to another, such as a warping drum to a bollard.

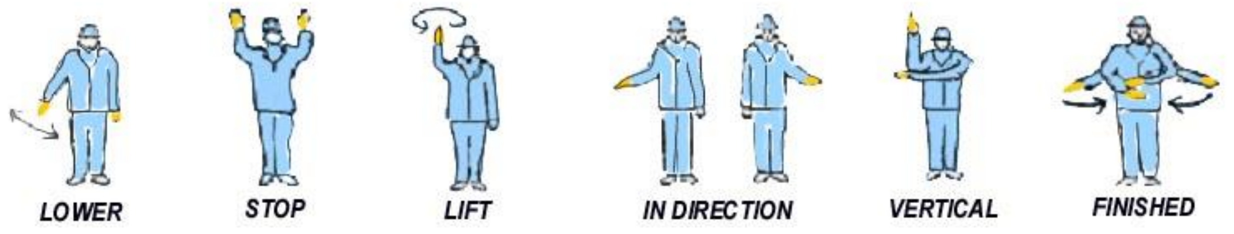
It is secured to a strong point and led along the tight line towards the strain. The tail is half hitched around the line against the lay and passed around with the lay. The end can be held or whipped. When attached, the tight line can be eased off the warping drum allowing the load to be transferred onto the stopper. Use a natural fibre stopper on a natural fibre line and synthetic for synthetic line - do not use a nylon cord for stoppers.

Anchor windlass operations

A windlass consists of a chain gipsy (or gipsies if more than one anchor is involved) and may have one or two warping drums at either end. To enable these components to be operated separately, dog clutches and brake bands are fitted.

Before starting the motor- check that the area is clear of ropes/wires and other gear. It may be necessary to start the motor to take the load off to remove stoppers, claws or lashings, a process called *clearing away.* While clearing away ensure all clutches and brakes are in the appropriate position to avoid an unintended let go of the anchor.

At all times, stand aft of windlass and ensure you are not in line with the run of the cable. Keep clear of warping drums (if they cannot be de-clutched).

The steps to lowering the anchor with a windlass – letting go the anchor	
	
Step 1: Brief the crew	
a.	Clear communication between the Master/supervising officer and the crew are required in anchoring procedures. While the use of hand held radio is used in vessels so equipped, non verbal hand signals for commands and acknowledgements must be agreed for alternative use/backup. Hand signals are not effective if eye contact between parties is not maintained.
Step 2: Clear away	
a.	Check the windlass pump's hydraulic oil level in the supply tank, start the pump, check for leaks.
b.	Engage the dog clutch for the chain gipsy (may require the dog clutch lever to be rocked between raise and lower positions to engage/disengage).
c.	Slowly release the gypsy's brake and wind in the chain cable to take the weight off the devil's claw or stopper.
d.	Re-apply the brake and ensure it is holding. Clear away (remove) the devil's claw or stoppers.
Step 3: Let go	
a.	Ensure there is nothing in the way of the anchor being dropped, the vessel is stopped or moving astern, and all personnel are clear of the cable or bights in any attached buoyed lines.
b.	Dependant on the water depth and /or urgency, the master will determine if the anchor is to be: i. walked out (let go under power) ii. veered out (let go under partial braking the gypsy) iii. surged out (let go freewheeling the gypsy) Eye protection must be worn as metal scale & rust from the chain will be shed as it passes through the gipsy.
i.	Walking out. Ensure the dog clutch is engaged, release the gypsy brake, and operate the windlass pump control to let out the cable.
ii.	Veering out. Ensure the dog clutch is disengaged; release the brake slowly allowing the anchor cable gipsy to partially freewheel under control of the brake.
ii.	Surging out. Ensure the dog clutch is disengaged; release the brake allowing the anchor cable gipsy to freewheel. Stand clear. This method is not advised in deep water.
Step 4: Make fast	
a.	When the Master considers sufficient chain has been let out, put the brake on tight, ensure the dog clutch is engaged.
b.	Check that the vessel is not dragging its anchor, (by monitoring its relative position with transits). Display anchor day shapes or lights
c.	If anchoring for an extended period, re-apply the devils claw or stoppers and switch off the oil supply pump. Maintain an anchor watch.

When lowering cable check that dog clutch is clear of cable lifter. Release brake sufficient to control the run out speed of the cable. If lowered too quickly it may whip and jump on and off the cable lifter.

The steps to retrieving an anchor – to weigh anchor	
The Master will have to steam the vessel towards the anchor cable, taking the weight off it to facilitate retrieval. From his/her position, the cable cannot be seen. The direction and the elevation of the cable must be communicated continuously by the foredeck crew to the master.	
Step 1: Brief the crew	
a.	As the cable is leading seaward, the direction and elevation hand signals given by crew persons are easily masked (from the master's viewpoint) behind their bodies. In any event they are not effective if the crew does not maintain eye contact with the supervising officer.
Step 2: Clear away	
a.	Check the windlass pump's hydraulic oil level in the supply tank, start the pump, check for leaks.
b.	Engage the dog clutch for the chain gipsy (may require the dog clutch lever to be rocked between raise and lower positions to engage/disengage).
c.	Release the gypsy's brake and wind in the cable to take the weight off the devil's claw or stopper as may have been fitted.
Step 3: Weigh anchor	
a.	Continue winding in the cable, as the crew signal the direction and elevation of the cable to the supervising officer.
b.	The crew should additionally signal when the cable is standing vertically. The crew should additionally signal if the vessel runs over the cable. The crew should additionally signal when the anchor breaks water, the windlass should then be slowed.
Step 4: Clew up	
a.	Before the anchor is fully drawn up into the hawse pipe it may be convenient to hose off the attached mud while it is still over the side.
b.	In pulling tight into the hawse, the windlass should be slowed right down to ensure the flukes are positioned correctly.
c.	Once the anchor is housed, put the brake on, attach the devil's claw or stopper, disengage the dog clutch and turn off the pump.

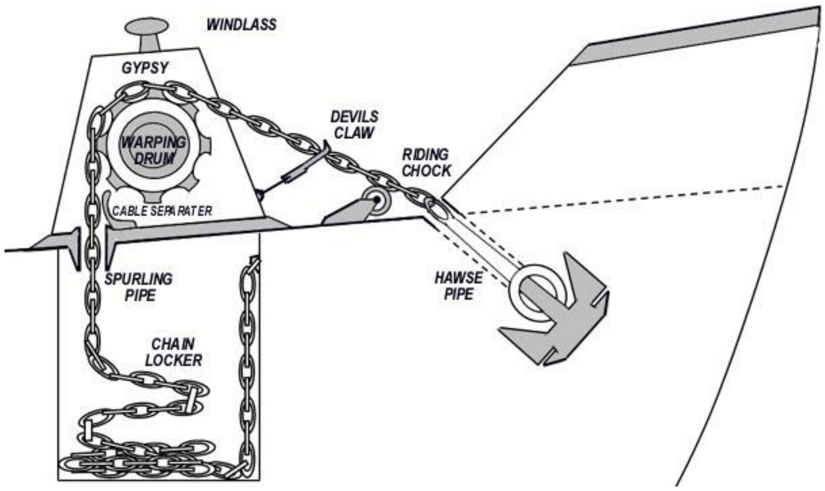
Caution - The windlass is in an exposed position on the foredeck or forecastle. The deck area is often wet and could be slippery. Wires, ropes and cable and fittings are hard to handle. Non-slip footwear and heavy duty gloves should be worn.

When riding at anchor - fit the chain stopper, claws or lashings to secure the cable. Release the clutch so that the anchor and cable weight is carried on its stopper and the windlass is isolated from load and shocks.

When the anchor is fouled - If the anchor does not break ground while being hauled vertically, then it may be fouled. Engage the brake on the winch and slowly drive the vessel forward to see if this clears the anchor. If this doesn't work, try making the anchor chain fast with cable stoppers and the run the vessel slowly in wide circles on a taut line.

It is essential to secure the chain by the cable stoppers to avoid strain on the windlass.

When it is impossible to break free, the vessel should be run up as close as possible, a float marker that will be visible at high tide attached to the chain on the anchor, and the



chain broken at the nearest shackle. The scope of the marker must be of sufficient length to reach the bottom at high tide. This will enable retrieving the anchor later. *Sudden jerks or extreme tension can bend the shaft on which the gipsy is fitted.*

Mechanical faults in deck machinery

Deck machinery is built to basic robust designs that have withstood the test of time, but it is exposed to weather, can be mishandled, overloaded or suffer from poor maintenance.

Windlass- common problems for include bent shafts due to overloading arising from allowing the load to be carried by the windlass when the anchor is fouled in the ground, instead of breaking it clear by putting the load on the chain stopper and pulling the anchor hard home such that the windlass is overloaded.

Lack of maintenance resulting in wear in bearings and shaft in way of bearings, worn linkages causing slackness (thus making operation of the gear difficult), lack of brake maintenance (resulting in reduction in braking effect or break failure).

Winches - Bent shafts due to overloading arising from exceeding the safe working load, allowing the cargo hook to jam in the derrick head or lack of maintenance

4.6 Hydraulic power units used in winch application

The main components required to drive a hydraulic powered winch are a:

Hydraulic pump to convert energy from a motor into hydraulic energy
Hydraulic motor to provide the hydraulic power at/to the winch
Discharge and return piping between pump and motor
Directional control valve for winch motor control and operation
Over pressure controls at strategic points in the system
Filter (usually in the hydraulic oil return line)
Oil tank (sufficient capacity for return oil to settle and cool, before re-cycling)
Heat exchanger (if necessary) to cool the hydraulic oil

Where other deck equipment (windlass, cranes, capstans etc) is hydraulically operated, the discharge and return piping can be laid out as a ring main with tappings to each hydraulic motor. Then only one hydraulic pump is required to serve all the equipment. It is common to locate the pump in the main machinery space. In some vessels, other locations may be considered more suitable. The size of a pump is determined by the anticipated peak load, based on the cycle of operation of the equipment.

Hydraulic pumps- are described in Chapter 2.4, but can include the following range:

Simple external or internal gear pumps
Screw, vane and cam pumps
Axial piston operated by swashplate or tilting head in line piston and radial piston pumps

The former are fixed displacement pumps and the latter variable displacement pumps. Internal relief systems from discharge to suction are provided to prevent over pressure.

For deck machinery hydraulic pumps must have pressure relief protection on the discharge side which shall operate in a closed circuit. Materials of hydraulic pumps, motors and accessories must be compatible with the working fluid. Hydraulic fluid must be non-flammable or shall have a flashpoint of 157^0C or over. Hydraulic hose must comply with AS. B-226. Installation and fittings must in be accordance with the manufacturer's requirements.

Hydraulic motors - Most designs of pumps are capable of operation as motors. If this is the case, oil under pressure from the pump is admitted via the directional control valve to the forward or reverse port of the motor. This will turn and rotate the output shaft in the desired direction.
The load requirements for a winch are a high starting torque, which are not provided in some of the designs mentioned. This has led to the development of slow speed, high torque motors of the radial piston type which are suited to cargo winch operation.

Hydraulic motors are protected against overload by relief valves. On loss of hydraulic power (usually failure of electrical power source) a brake is spring loaded to the stop position. It is moved to operating position by a hydraulic cylinder whenever the control lever starts the motor. If there is a failure of hydraulic pressure or electric motor, the brake returns to the on position and stops the winch.

Survey requirements for hydraulic equipment

Initial Survey - At the initial survey during construction, survey of all hydraulic equipment is required. As the equipment is new, this would normally be confined to operational tests to ensure the equipment performs satisfactorily.

Annual survey - An inspection of all pipe arrangements. In this case, if the hydraulic power source is located in the machinery space, and the motor for equipment such as winches is on deck, the piping between pump and motor is to be inspected.
General inspection of machinery installation (this will include hydraulic pumps) and electrical installation.

Hydraulic winch and windlass maintenance - Routine maintenance is required to ensure better and more efficient operation of that machinery.

Inject grease into all grease points including the main bearings.
Oil all linkages. Use penetrating oil if needed
Oil or grease the threads on spindles of brake operating gear.
Check motors in accordance with the manufacturers instructions.

Ramps

There are many and varied types of ramps. When in use, if the hydraulic system fails, the ramp should remain in place. Where ramps are held in position by hydraulic rams, check all valves in the supply line. This will prevent the ramp falling under its own weight. As an added precaution, fit mechanical locking devices.

Chapter 5 Steering Gear

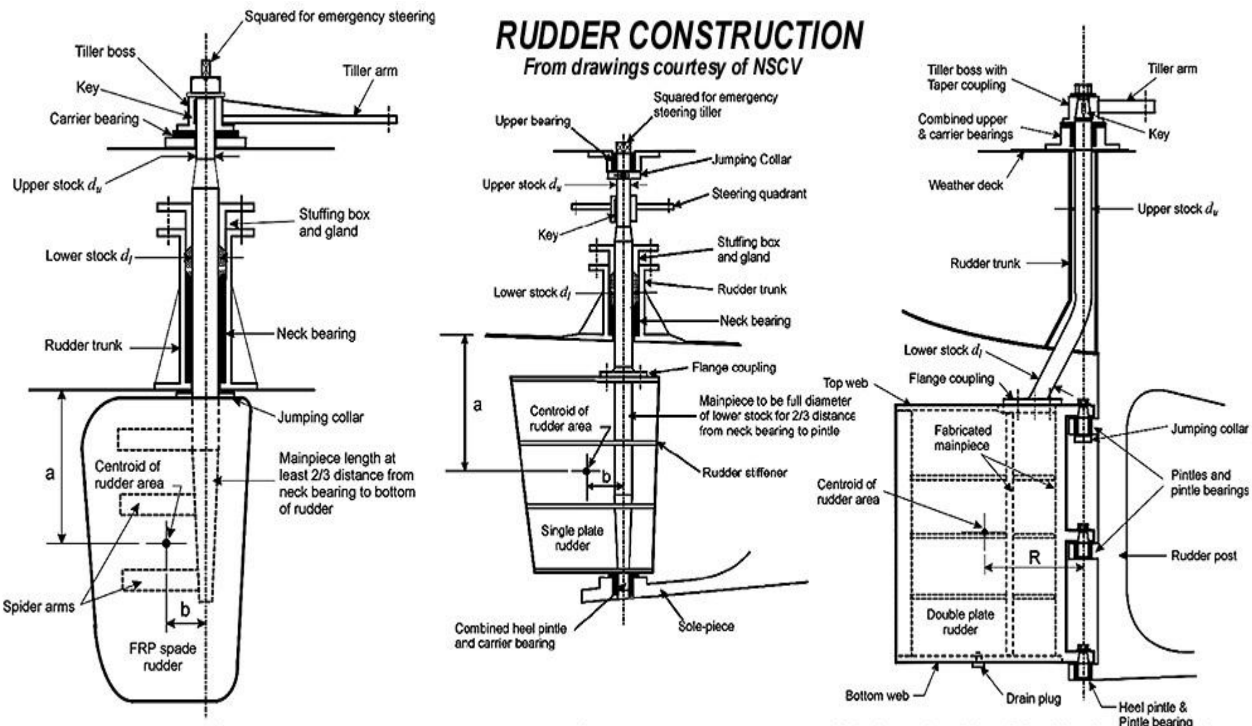
5.1 Survey requirements for steering systems

Performance
The NSCV Part C, Section 5, Subsection 5A.6 - Machinery (USL Section 9) specifies requirements for steering systems for vessels of less than 35 m in measured length. The steering gear must be designed to withstand maximum helm at maximum ahead and astern speed. The steering arrangement must be such that the person at the helm has a clear view ahead while at the normal steering position.

Rudder movement must be no less than 35° to port to 35° to starboard. In vessels of 12.5 metres the steering gear must be capable of putting the rudder over from 35° on one side to 30° on the other in 30 seconds when the vessel is at maximum ahead service speed with the rudder totally submerged. It must not allow prevent violent recoil at the wheel.

All vessels, except twin screw vessels, must be fitted with two independent means of steering unless steering is normally achieved via a hand tiller. The secondary or emergency means of steering shall be capable of being brought speedily into action.
A rudder position indicator in full view of the person at the helm must be fitted on all vessels of 15 metres and over (not applicable at the emergency steering position).

Construction specifications are detailed in the drawings below courtesy of NSCV Part C, Section 5, and Subsection 5A.6.



Balanced spade rudder of FRP construction *Balanced rudder of single plate construction* *Unbalanced rudder of double plate construction*

5.2 Rudders

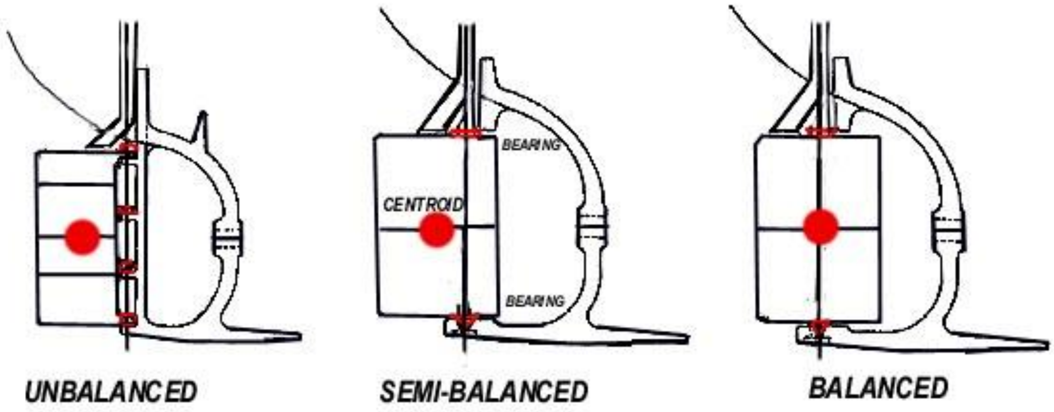
Conventional (passive) rudders

Passive rudders use a streamlined hydrofoil blade that can be turned around a vertical axis and (depending on the relative position of the blade's *centroid*) are defined as:

Unbalanced rudder - where all the rudder area is aft of the turning axis

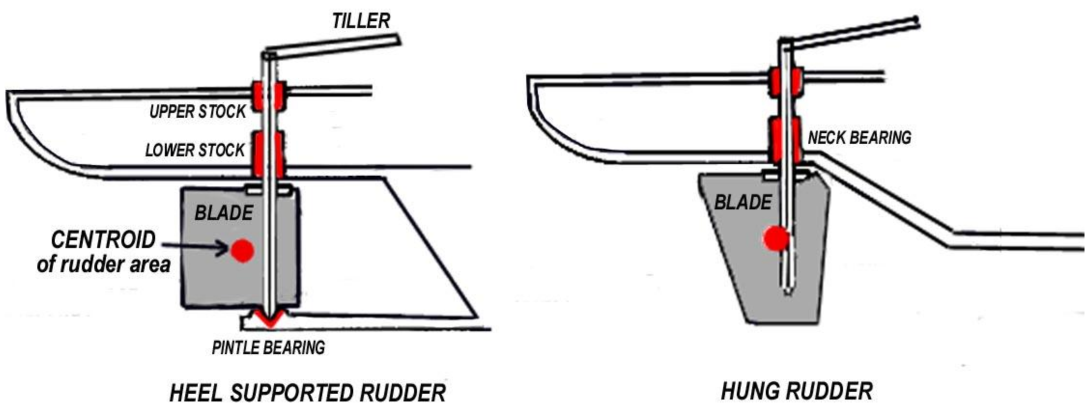
Semi-balanced rudder - where some of the rudder area is forward of the turning axis

Balanced rudder - where more than 25% of the rudder area is forward of the rudder axis



The *centroid* of the rudder blade area is the position of the centre of effort acting upon the blade when turned against the water flow. The turning effort (needed to move the helm) required for semi-balanced and balanced rudders is less than that for unbalanced rudders. The part of the rudder forward of the turning axis provides a turning moment assisting rudder movement once the rudder is moved either side of amidships. Because of the reduced turning moment (torque) a reduction in rudder stock diameter is permissible.

Two common types of rudder are shown below. The *heel supported* or *pintle type* arrangement is very securely mounted by bearings at the deck, under the hull and under the rudder at the *heel* or *sole* (an extension to the keel).



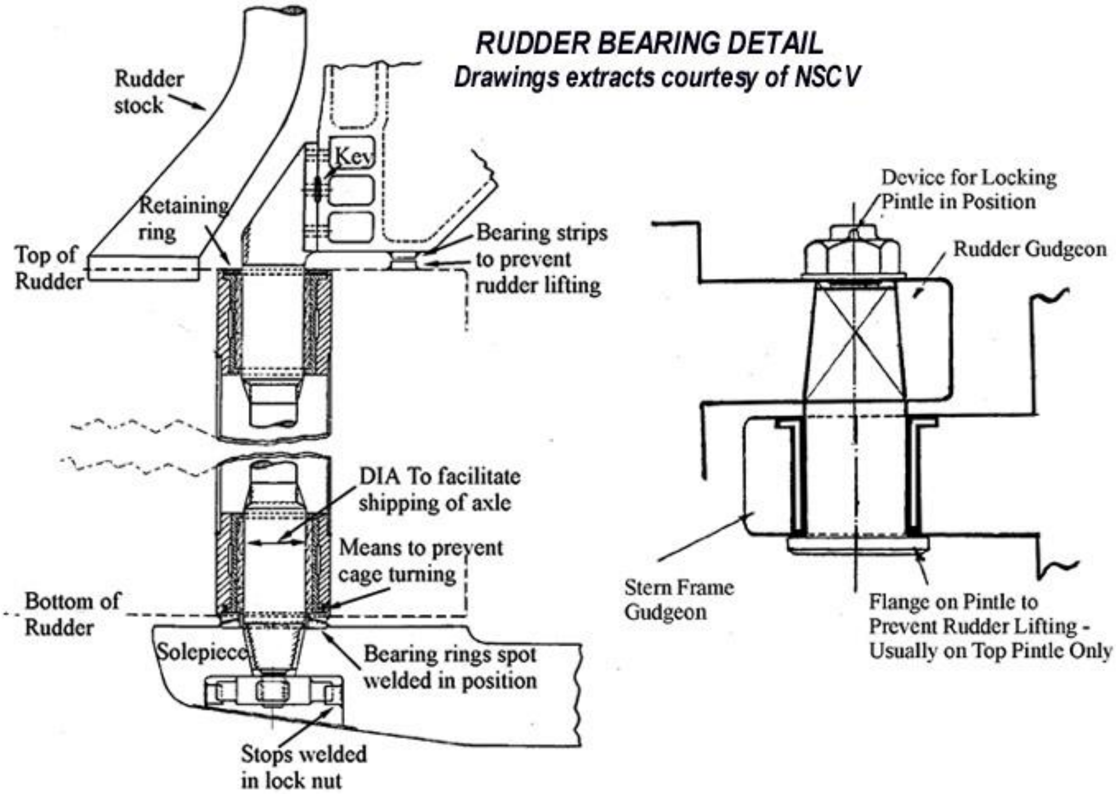
The rudders are secured to the stock by flanged couplings. These also need to be carefully checked whenever the vessel is out of the water.

The hung rudder shows a mounting arrangement where the forces on, and the weight of the rudder are carried by the rudder stock. This means that the stock and bearings need to be of greater size and strength to withstand stresses concentrated around the neck bearing form forces acting upon the centroid. Visual inspection of the rudder stock under these bearings is very limited without withdrawal and dismantling.

Rudder attachment

The attachment and support of rudders depends on rudder type of and the design of the stern area. Larger vessels will usually be constructed with supported rudders, while yachts and small commercial vessels may have hung or *spade* rudders.

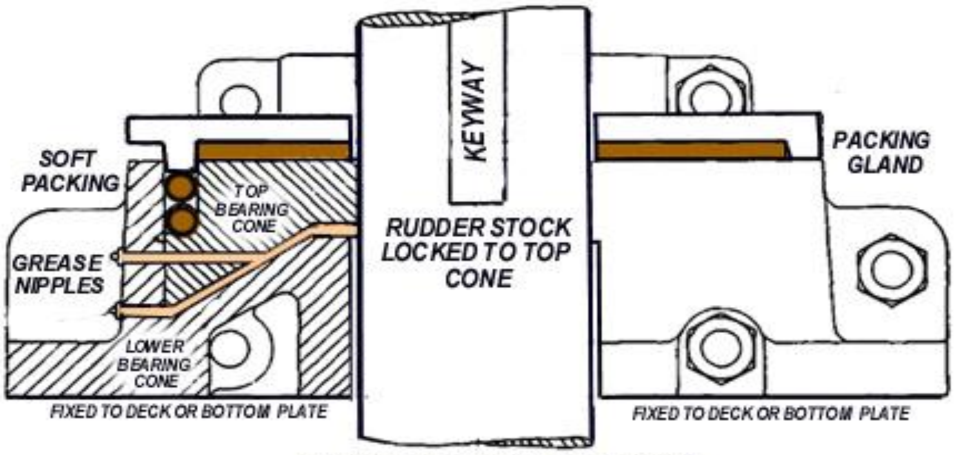
Vessels with a *sternpost* require an unbalanced rudder. Therefore the connection of the rudder to the frame is by gudgeons (eyelets) on the forward end of the rudder, and matching gudgeons on the aft end of the sternpost. Pintles (pins) are fitted through rudder and post gudgeons and form the axis around which the rudder turns.



The stern framing of semi-balanced or balanced rudders has no sternpost. The rudder is connected to the sternframe at the top and at the bottom by means of an axle passing through the rudder itself.

The axle is flanged at the top and bolted to the sternframe. It is tapered at the bottom to fit a matching hole in the bottom (solepiece) of the sternframe. Upper and lower bearings are fitted in the rudder. Part of the weight may be carried by thrust faces on the bottom of the rudder and top of the solepiece.

The weight of some balanced or semi-balanced rudders is carried totally or in part by the stock and a rudder carrier (also known as a *Pallister Bearing*). This comprises a base frame with thrust face fixed in the steering space. Keyed and fixed on the rudder stock is a collar which is the upper thrust face. It transfers the rudder weight to the thrust face of the base frame. The upper and lower thrust faces are either flat or conical and are grease lubricated.



RUDDER STOCK BEARING

Note: A gland or seal is fitted where the stock enters the hull to prevent water entering. This gland may be combined with the rudder carrier.

Except for some smaller vessels the rudder stock is always separate from the rudder. This is to facilitate removal of the rudder without disturbing the tiller and steering gear. The rudder and stock are joined by means of flanges on the bottom of the stock and top of the rudder secured by bolts. Usually the joining flanges are horizontal but vertical faced flanges are occasionally used.

Checking rudder stock and pintle bearing wear

The rudder is used to guide the vessel’s direction. This is particularly important if the vessel has only one engine and the balancing of power from a second engine cannot be used to assist steering. It is important to include the rudder system in routine maintenance to ensure it remains in satisfactory working condition. In most cases, if a rudder fails it will occur under load at the most difficult time. This may disable the vessel’s steering and result in a loss of control.

If the rudder has been poorly constructed or allowed to deteriorate, the rudder stock could break loose within the rudder itself. This will result in the rudder stock effectively rotating inside the rudder while the rudder remains still. If there is any sign of separate movement between the rudder stock and the rudder, the rudder should be replaced.

The wear of pintles or bearings can be checked by feeler gauges. Clearance must be taken fore, aft, port and starboard as the pintles and stock are vertical and may not be lying central in the bearings. Jacking the rudder hard one way (as for shafts) is an alternative, but care must be taken to ensure that it is jacked squarely and the rudder is not canted.

If there is more than slight movement, the bearing should be replaced. If the bearing fails the rudder will be free to move violently under force from water action.

Active Rudders

Unlike Mr *Hamilton's* water jet propulsion invention, his early fixed outboards with steerable rudders were superseded by the now ubiquitous directional thrust steerable outboards. In active rudders that principle of propellers capable of providing a thrust at various angles is utilised.

HAMILTON STEERABLE OUTBOARD

Steerable Thrusters - (other names azimuth thrusters, Z pellers, duck pellers, variable angle kort nozzles) are a propeller driven by a vertical shaft through bevel gears in a housing. The housing and propeller rotate as one. This is so that propeller thrust can be directed either side of the longitudinal centre line of the vessel. In tugs and some special purpose ships this can be rotated through 360^0 to provide exceptional manoeuvring ability. Other advantages are found in limited transverse thrust and greater protection from ropes/debris fouling the propeller.

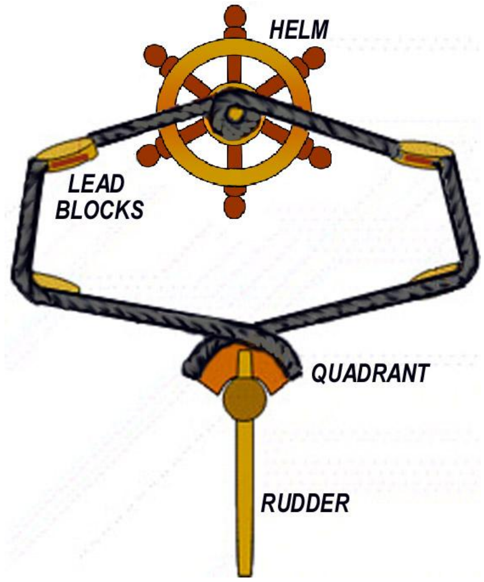
Voith Schneider Propeller - is a vertically rotating device. It has vertical blades of aerofoil section located around a disc. The blades can be rotated by cams and the angle of the blades determines the magnitude and line of thrust. The thrust can be in any direction.

Pleuger Active Rudder - comprises an electric motor driving a small propeller in a streamlined housing built into a normal type rudder. The steering gear turns the rudder. The thrust of the small propeller in line with the rudder blade applies a turning moment to the ship. This is independent of the ship's movement or the action of the main propeller. The motor operates *wet* in that it is water filled and the windings are suitable for continuous immersion. All bearings are water lubricated.

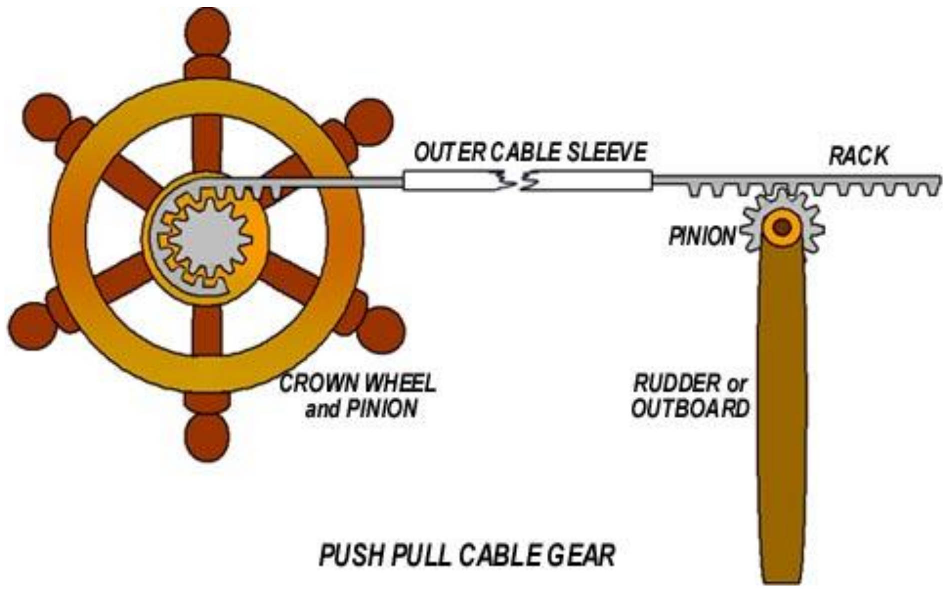
5.3 Steering systems

Direct drive systems

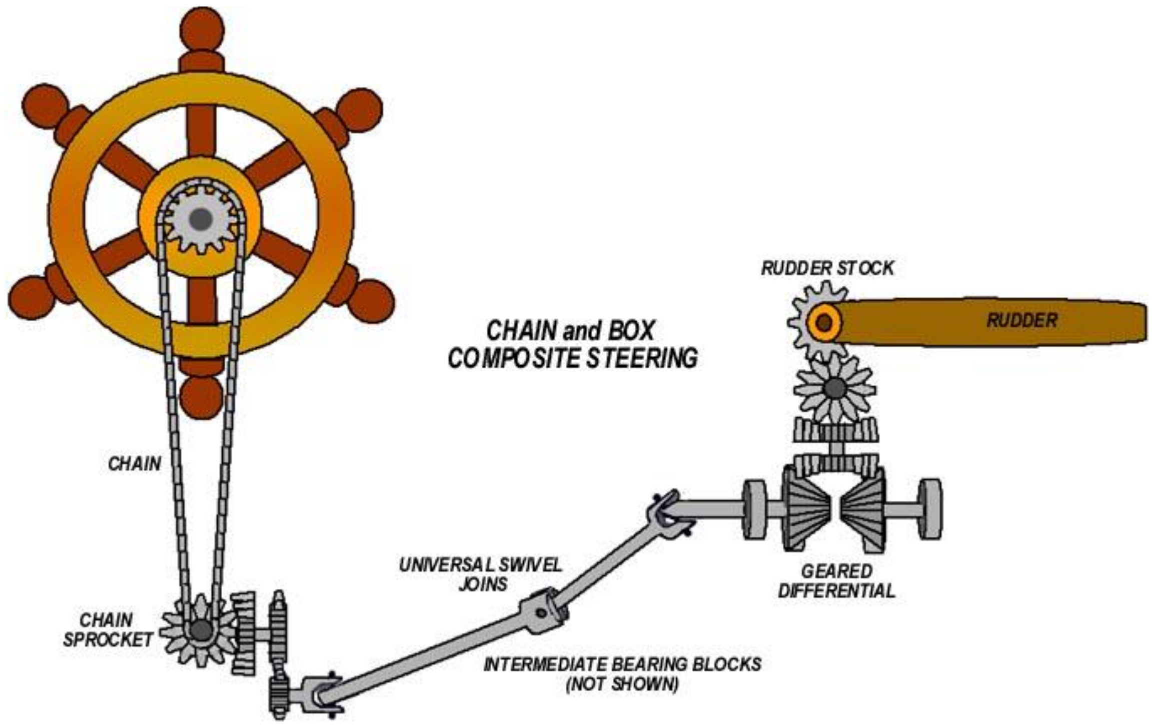
Wire & pulley, Chain & drum - a wire, cable or rope is wound around a steering drum at the wheel then passed through a series of pulleys on each side of the vessel to drive the tiller or *quadrant* of the rudder mechanism. The quadrant spreads the load at the cables attachment point with the rudder stock. To avoid excessive strain and bending of the wire the pulley blocks should be as large as practical, positioned to avoid excessive angle and kept tight. Buffer springs are provided on both port and starboard to prevent violent recoil of the steering wheel. All components should be regularly inspected and greased or oiled.



Push-Pull Cable - This arrangement is commonly adapted for outboard motors. The cable should not be too long or too short as this can affect the tiller response. In case of cable or rod seizing, it must be possible to release the push-pull rod (rack) from the tiller to operate the emergency steering.



Chain and box – These composite installations that are common in older small fishing vessels make use of automotive parts such as shafts, universal joins and truck steering boxes (differentials) and are consequently highly individual and often over engineered for their re-birthed use. There are many intermediate bearings and alignment can be problematic. They require periodic inspection, lubrication and adjustment, particularly the chain which is liable to stretch and is often adjustable.



Hydraulic steering systems

Hydraulic systems become common in vessels over 12 metres in length. They range from simple manual types in smaller vessels to very complex electro-hydraulic ones. The principle however remains the same, that a flow of pressurised hydraulic fluid (oil) is directed through a ram to control the movement and position of the rudder.

They have a reservoir to hold a reserve of oil to feed the hydraulic pump. It may also cool and settle the fluid. Stainless or synthetic gauze mesh filters remove larger contaminants and a filter condition indicator may be provided to give an indication of its state.

A two way hydraulic pump, (internal gear pump or vane pump) is linked to the helm. Piping leads fluid from the pump to the hydraulic cylinder and ram, this in turn is connected to the tiller. The rotation of the wheel forces oil from the pump to one side of the ram thus rotating the rudder. Direction, check and one way valves control the fluid path. Relief valves (regulators) reduce the pump pressure to a safe level and a bypass circuit is included to enable change over to emergency steering. Force, leverage, and movement can be altered by changing the sizes of rams, gears, ratios, and linkages. The major problem associated with any hydraulic system is air (a compressible gas) entering the system so most systems are built to be self purging of air.

Survey requirements - Steering systems must comply with the following requirements:

Have a quick change over from the primary to the secondary steering.

Have a relief valve in systems with a power pump to prevent damage to the steering gear.
Hydraulic pumps shall have pressure relief protection on the discharge side. Such pressure relief protection shall operate in a closed circuit.

Hose and piping must be installed to minimise mechanical, fire or other damage.
Mechanical damage includes chafing, crushing and holing.The materials of hydraulic pumps, motors and accessories shall be compatible with the hydraulic fluid. Hydraulic fluid shall be non-flammable or shall have a flashpoint of 157ºC or over.

Nylon tubing may be used in hand hydraulic applications on vessels provided it meets the requirements of AS 3791 or an equivalent national or international standard and;

Is stabilised against degradation due to exposure to ultra-violet light;

Is only used where suitable for the application;

Has a pressure cycling resistance equivalent to that required for hoses to AS 3791

Does not pass through a space designated as a high risk or machinery space or is adequately shielded from fire within such a space (see Part C Section 4: Fire Safety NSCV).

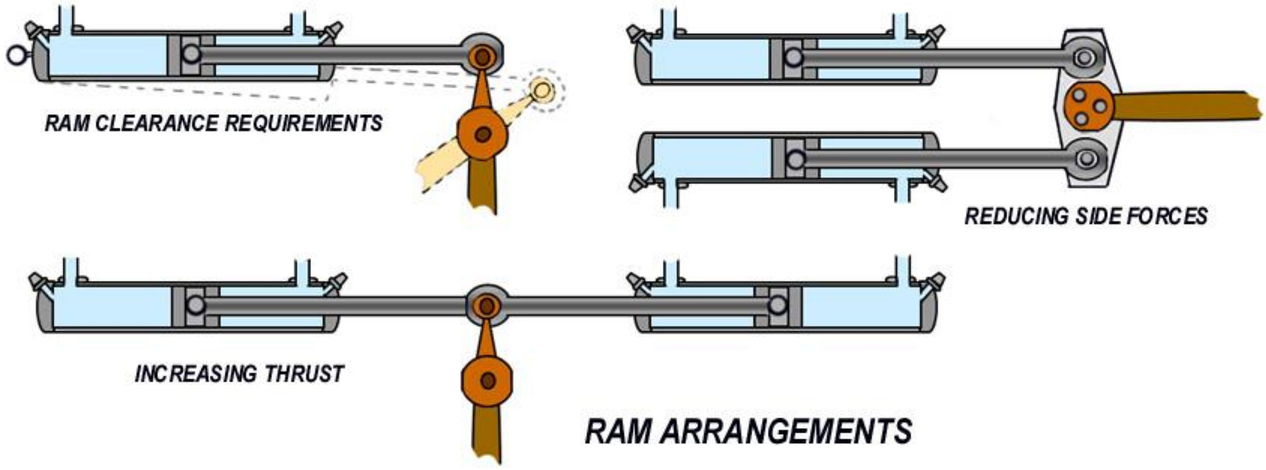
While the National Standards for the Administration of Marine Safety specifies survey schedules (see Chapter 1.2), some authorities have incorporated NSCV into USL. Section 14 of the USL Code specifies the survey items required for currency of a Certificate of Survey over a vessel’s life. For steering systems including emergency steering these are:

All vessels - At the initial survey during construction the survey of the steering gear and emergency steering gear is required. As such equipment is new this survey would normally be confined to operational tests to ensure the gear performs satisfactorily.

At each annual survey - An operational test of the main and emergency means of steering.

Eight yearly survey - Test of electrically or hydraulically operated steering gear.

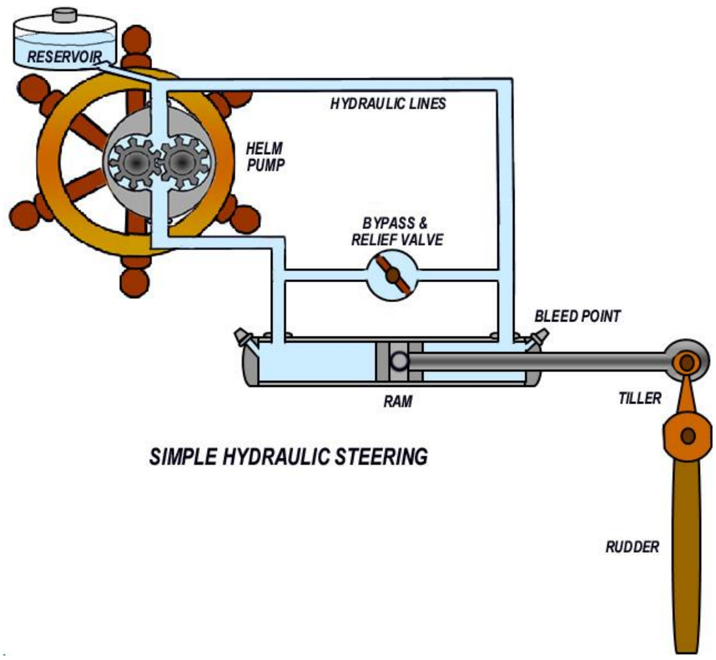
Ram Arrangements - As the ram extends or retracts it moves the tiller in an arc requiring the ram to pivot at its fixed end. Clearance is needed for the sweep of the tiller and ram and linkages must provide sufficient flexibility for this movement.



RAM ARRANGEMENTS

Dual cylinder installations can increase the steering torque on the rudder, however large hydraulic side-force can be exerted on the rudder-post, especially at the extremes of the rudder stroke, with single rams or double rams fitted in opposition. Arrangements to cancel side forces will utilise two double-acting rams, one pushing, the other pulling, both from the same side from a fixed rudder stock head plate.

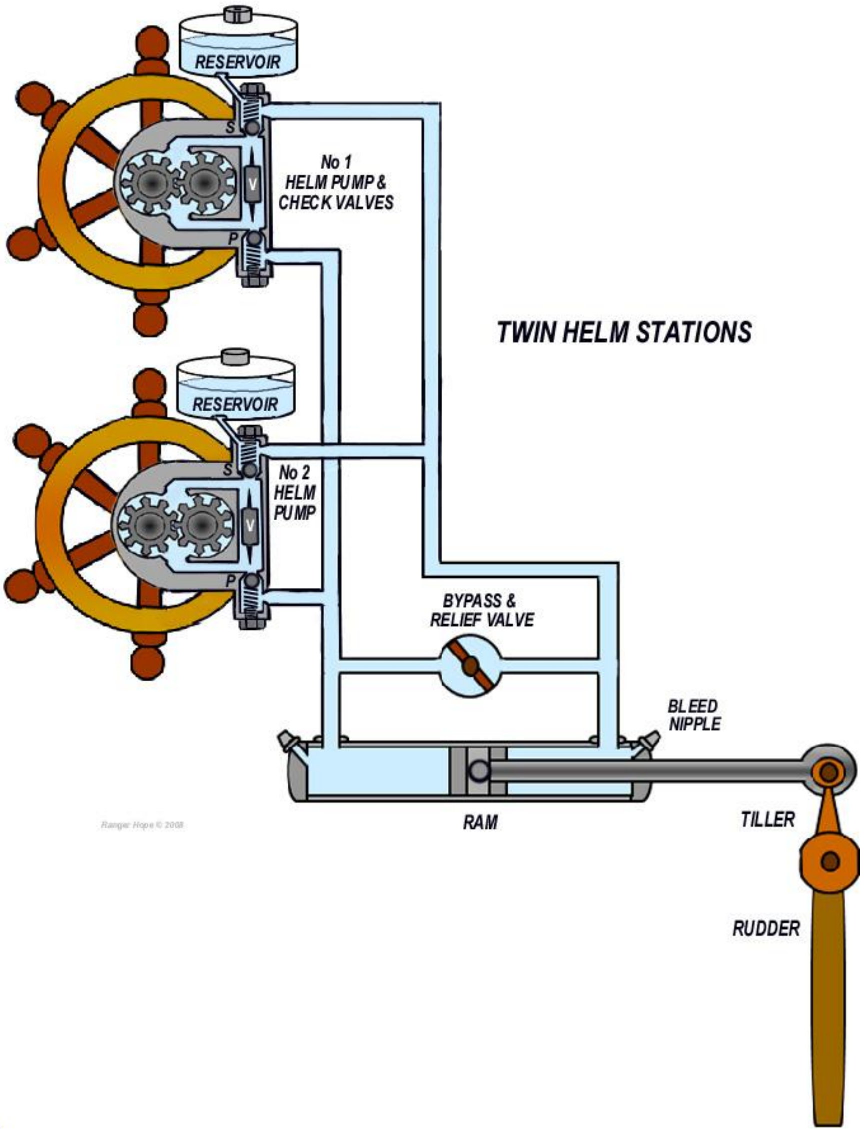
Direct hydraulic steering (hand-operated)



SIMPLE HYDRAULIC STEERING

The emergency steering will require the fluid to be by-passed and a valve is placed between the two sides of the system for this purpose (bypass valve). To prevent hydraulic locking, this valve will need to be opened when the emergency system is to be operational. In addition, there should be a relief valve (bypass & relief shown as one above for simplicity) which spills the oil from one side to the other in the event of shock loading to the system from a rogue wave. Specific maintenance requirement for this system is to ensure that the oil level is adequate and that there are no leaks.

Twin helm station hydraulic steering (hand-operated)

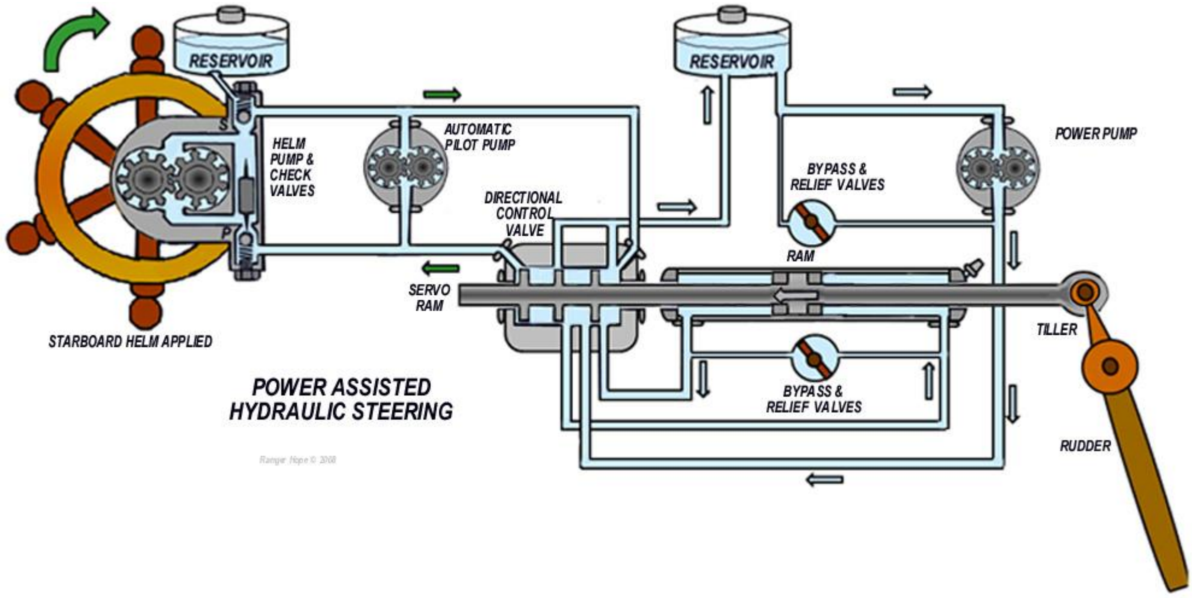


Check valves direct control to the helm station being operated. As the upper wheel is turned clockwise (to starboard), helm pump No1 pushes oil up into the top oil passage and forces the ball valve (S) to lift up from the seating against its spring. Thus oil flows outwards towards the steering ram. Simultaneously spool valve (V) is forced downward and its stylus pokes the lower ball valve (P) away from its seating, so allowing return oil to enter the pump.

The pressure of oil flowing out from helm pump No1 also acts against the back of the ball valve in helm pump No 2 and hence keeps it closed tight against its seating.

Power assisted hydraulic systems

In the example shown below a manual helm pump operates a servo ram to initiate a power assisted starboard turn (flow from the power pump through a directional valve). Thus hydraulic pressure from the power pump (electrically driven or by the vessels motor) assists the operator to activate the tiller and rudder. If the power assist pump fails, manual steering remains, but extra effort is needed. If the automatic pilot pump (electrically driven) is operated, the back pressure toward the manual helm pump bypasses the manual section of the hydraulic circuit.



Typical power assisted hydraulic steering components from a variety of systems include:

Oil reservoir- *The helm pump and header tank are often combined to form the one unit.*

Helm pump - *A reversible pump driven by the steering wheel attached directly or by chain. If drive shafting protrude from the pump, oil seals are fitted.*

Dual helm pumps- *Check valves (lockout) located in the helm pump bypass the second helm when not required. If not fitted, operating one pump would cause the other to move.*

Rudder indicator- *Situated by the steering wheel to indicate the position of the rudder.*

Oil lines- *Typically of copper and fitted between pump and flexible hoses at the rams. Positioned for security against to mechanical impacts, no or only a few joins in visible/accessible positions are a permitted.*

Servo ram- *So called to distinguish from the power ram. Oil lines connect to both ends of the ram. Bleed valves are fitted to facilitate removal off air trapped in the system. Through the ram with sealing rings passes a piston rod that activates a directional control valve.*

Directional control valve- *It is activated by the manual pump to direct the flow of oil from the power pump to either side of the power ram dependant on the direction steered. It consists of a number of ports and a spool running through the centre of it.*

Hydraulic power pump reservoir- *It fills the power system with hydraulic oil and tops up the system if there are leaks. It provides expansion room for oil due to temperature change.*

Hydraulic oil pump- *It is driven by the main or an auxiliary engine and is a gear or vane type pump (positive displacement type pump) and is fitted with a relief valve.*

Pump relief valve- *Normally in the closed position, it protects the positive displacement pump in case of system blockage/overload. (A bypass may be fitted for manual operation with emergency steering)*

Non-return valve - *(Not shown in the drawings for simplicity). May be fitted between the power reservoir and pump to allow oil to flow to the suction side of the hydraulic oil pump but not allow the oil returning from the power ram to directly enter the reservoir*

Flow control valve - *(Not shown in the drawings for simplicity). Fitted between the hydraulic oil pump and the directional control valve to maintain regulated oil flow.*

Power ram - *One end is swivel mounted. The piston rod is driven by the servo ram and drives the tiller arm through a clevis and detachable pin (for release to engage emergency steering). Oil lines from the directional valve are connected to each end of the ram. A bleed valve is fitted to each end of the ram to remove any trapped air.*

Flexible hoses - *Flexible hoses are fitted between the oil lines and hydraulic and servo rams to allow for their swivel movement.*

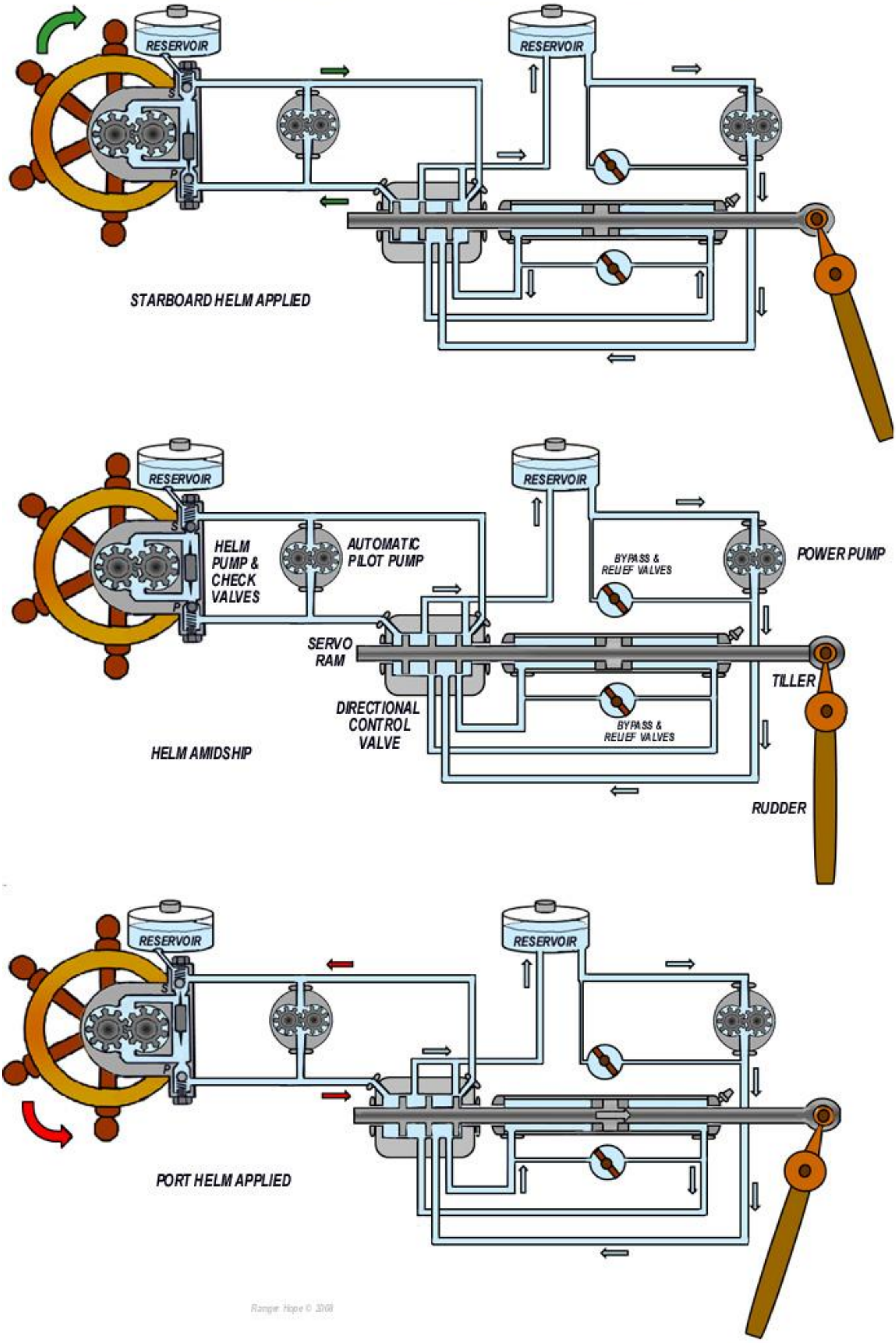
Power ram by-pass valve - *Normally closed, it is situated between the two oil lines by the power ram. It is opened when the emergency steering is used to allow oil to by-pass the helm pump making it easier to operate. A relief valve will also be fitted to protect the oil lines from bursting if overloaded from rogue wave action on the rudder.*

Tiller arm and stops- *May be attached to the rudder stock by a key and clamping arrangement enabling mechanical advantage by lever action. They are fitted to stop the rudder from moving more than 35º from the centre line as steering becomes less effective over this deflection and hydraulic system could become overloaded. They also prevent the rudder from fouling the propeller when the vessel goes into astern propulsion.*

Auto pilot- *Solenoid (electro-magnetically operated) valves operated by the auto pilot may be attached to the directional valve. If the vessel deviates from course, the gyro/electro compass of the auto-pilot operates a solenoid valve to allow hydraulic oil to pump to one side of the power ram, turning the vessel back to the selected course.*

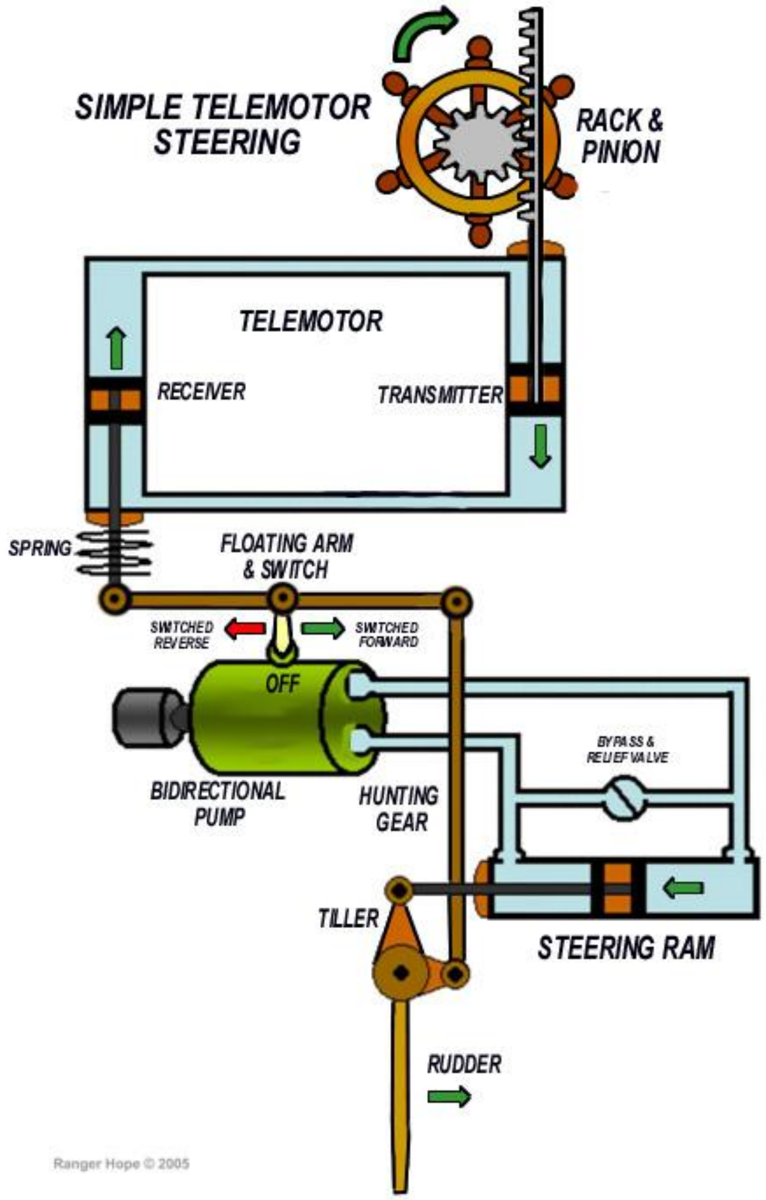
Operation of a power assisted steering system - Start up the engine (main or auxiliary) which drives the hydraulic oil pump. When the steering wheel is turned, the piston and piston rod in the receiver will move a corresponding amount. The piston rod forces the directional control valve to move and line up the ports in the direction for the oil to be pumped from the hydraulic oil pump to the relevant side of the power ram. The oil on the other side of the piston in the power ram will return via the directional control valve to the suction side of the hydraulic oil pump. When the piston moves, the piston rod pushes or pulls the tiller arm. The tiller arm being attached to the rudder stock causes the rudder to move.

POWER ASSISTED HYDRAULIC STEERING HELM ACTION



Simple Telemotor - In many larger systems the signal from the steering wheel is transmitted to the steering gear by means of a *telemotor* (a remote activating transmitter and receiver). This not only ensures that the steering system is isolated to the steering flat, but that the steering system can be used even if the wheel and connections are damaged or become inoperative.

The telemotor shown below consists of a transmitter in the wheelhouse and a receiver in the steering flat. The movement of the wheel activates a hydraulic piston in the transmitter. The fluid displaced by this piston is used to displace a similar piston in the receiver. This activates the switch of a bi-directional electric pump that in turn operates a power hydraulic pump and its steering ram, tiller and rudder. The receiver is usually spring loaded so that the steering wheel will easily return to the amidships position. A floating lever and hunting gear provides a feedback loop to switch off the bi-directional pump when the degree of helm applied matches the deflection of the tiller.



In the drawing shown above, when the helm is turned to starboard the telemotor (upper hydraulic circuit) transmitter piston is wound downward causing the receiver piston to be forced upwards pulling with it the floating lever. The upward movement of left hand end of the floating lever operates the pump switch attached at its central pivot point. In this case the switch turns the bi-directional pump into forward (clockwise) motion and oil is pumped into the top of the lower hydraulic circuit. The lower steering ram piston forces the tiller to move to the left and results in starboard helm at the rudder. The hunting gear attached to the rudder head provides feedback to the floating arm. It moves upward as the rudder steers to starboard and balances the movement of the floating arm to return the switch to the off position, thus maintaining the degree of starboard helm determined by the steering wheel.

Split telemotor steering systems - Split systems for telemotor operation are essentially duplicated systems. These feature double transmitters operated by a single steering wheel that operate receivers in the steering gear flat via two sets of connecting pipes, the path of each pipe set being widely separated. These systems are particularly common on naval vessels so that the possibility of steering failure due to piping damage is reduced. Charging and purging for these systems is similar to that for single systems described below, but each system is done by turn.

Charging a telemotor system - Ensure the lines are clear by blowing them through with compressed air and clean them with a liquid compatible with the charging fluid. The steering wheel should be amidships and receiver disconnected from the steering gear.

A small tank and charging pump is usually located in the steering gear space. Fill the wheelhouse reservoir/pump tank with oil. Ensure all the valves including bypass valve at the transmitter are open. This is to ensure that there is a complete circuit from the charging pump through one side of the receiver ram, one line to the transmitter back through the other line to the receiver and return to the charging tank. Commence pumping. It may be necessary to close the reservoir/pump valve in the wheelhouse to prevent the tank overflowing.

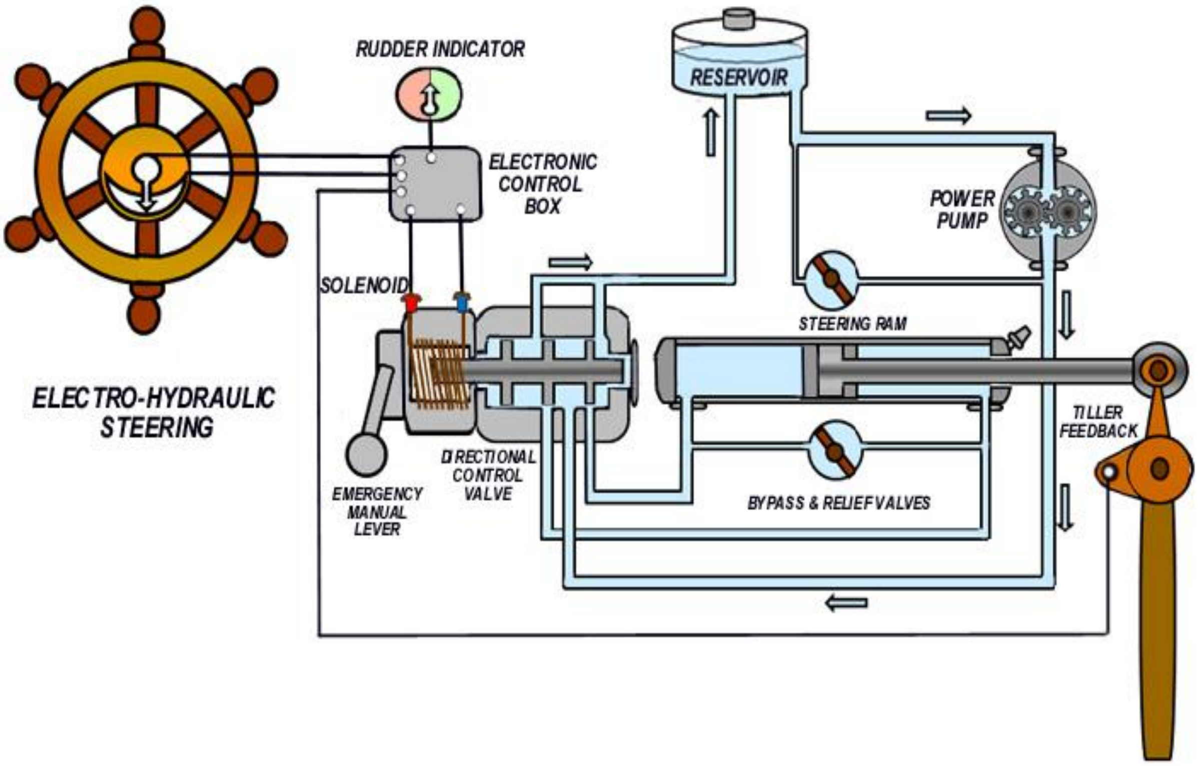
When oil starts to return to the charging pump tank, vent the system via valves (air cocks or plugs) on transmitter and receiver. They should be opened in turn to release any air then closed. When a solid discharge (spurt) occurs at the return pipe to the charging pump tank that coincides with the stroke of the pump shut the charging valves.

Return all valves in system to the working position. The steering wheel should be turned both ways a number of times and vent valves opened on receiver and transmitter until all air is eliminated from the system.

Electro-Hydraulic -The electro-hydraulic system, shown below, has the advantage that the signal from the wheelhouse to steering flat is electrical. The system also uses a uni-directional pump which is less complex and cheaper than a bi-directional. This pump supplies oil at a constant rate to a directional control valve in the steering flat.

The valve has three positions that control oil supply to either side of the double acting ram. When in the neutral position, oil is locked in the ram, thus maintaining the given rudder angle, whilst the pump flow is circulated back to the tank. The valve is operated by solenoids controlled from the wheelhouse via the control box.

As in the previous system there is a by-pass and a relief valve fitted between the left and right sides of the ram. Emergency steering can be carried out by operating the emergency steering lever located in the steering flat.



Auto pilot components and feedback mechanisms - An automatic pilot (*auto pilot*) is often incorporated in the steering console. It has a tiller position sensing unit in the steering flat to take the signal sent from the console and provide feedback to the auto pilot. The manufacturer's instructions should be followed as units vary widely, but systems are generally arranged so that when the vessel is on course, the rudder is amidships. When the compass signals an error to the auto pilot (resulting from a drift off course), it applies a sufficient amount of rudder to compensate and to bring the vessel back on course. The feedback loop from the rudder to the auto pilot uses the hunting system principle described earlier in the telemotor section.

Emergency steering

The USL Code and NSCV require all except twin screw vessels to be fitted with two effective independent means of steering, the second intended for emergency use. NB: Twin screw vessels do not require an emergency steering arrangement as the vessel can be steered by altering the revolutions of each engine.

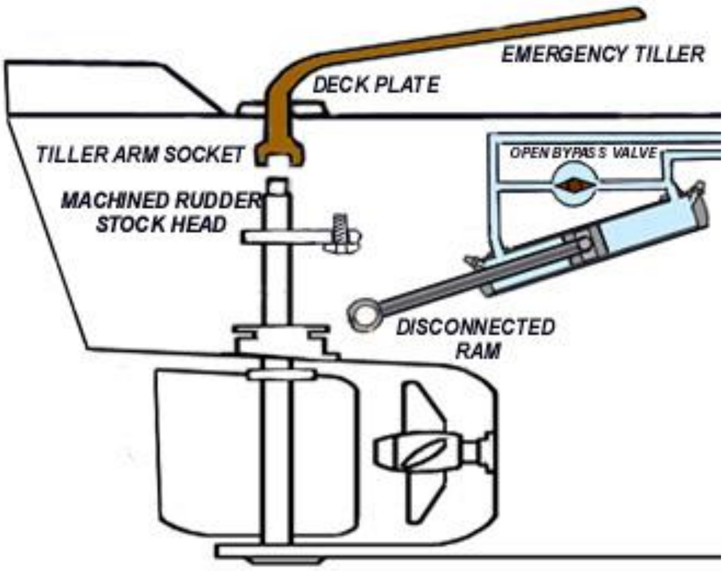
The performance requirements for emergency steering gear are that it shall be capable of being brought speedily in to action and include communication system as required. In small vessels the operation by an emergency power source is unlikely. Common methods of providing emergency steering include:

Manual over-ride - Normally, there is only one hydraulic oil pump. Should this pump or the power source driving this pump fail, the receiver operated by the steering wheel can take over through the directional control valve. Should the failure be in the helm pump or servo ram, the manual override can be set on the directional control valve, to allow assisted steering of the vessel.

Where power steering is operated using a hydraulic ram -on power failure the power system can be isolated and with the ram's equalising valve open.

Where an emergency hand operated pump is fitted but normally remains isolated from the rams - the pump is temporarily linked into the hydraulic circuit and the ram operated by the hand pump. Oil to rams is controlled by directional valves.

Emergency Tiller Arm - Should a failure occur in either the power ram or the oil lines and flexible lines attached to it, the emergency tiller arm can be used. With the by-pass valve open and or the ram disconnected, the vessel can be steered via the emergency tiller arm.



The rudder stock is extended beyond the normal tiller attachment point and is machined square on the top. An emergency tiller arm goes through a plugged hole in the deck and fits over the square. It may be located in the steering flat dependent on the available room. When not in use a watertight cover is secured over the hole. To provide additional mechanical advantage this system can be combined with a rope block and tackle system as discussed below.

Rope Block Steering - Direct tiller control can be gained by using twin rope blocks and tackles that are shackled to the tiller head and hauled from points made fast on either side of the vessel. Steering is effected by tightening one block and tackle while loosening the other (to pull the tiller one way and slacken off in the other). The ram by-pass valve must be open.

Use of drogues - In the worst of scenarios of the rudder being completely jammed or lost altogether, then twin warps and drogues with tripping lines could be streamed behind the vessel to enable a directional steering pull to the side under strain. In any but the smallest vessel the forces will be very large and hard to manually handle. An alternative may be to stream a single drogue and warp that can be hauled from one side of the vessels stern to the other with the assistance of blocks and tackles.

In all the systems listed above, due to the limitation of power, the vessel will probably not steer well at full speed except on a direct heading (with rudder amidships and minimal torque). When the vessel is turning, the torque on the rudder increases with its angle from amidships. If the torque is greater than the manual effort that can be applied, the ship must be slowed down to a speed at which the rudder can be controlled.

5.4 Troubleshooting

Pre-departure checks

Sudden loss of steering in close quarters to other vessels or in heavy weather could be disastrous. The need for a consistent maintenance program to avoid such a situation is self evident as summarised in the NSCV and the USL Code.

If the vessel is fitted with an automatic pilot the manual steering shall be tested after prolonged use and before entering areas where navigation requires special caution. Before departure the vessel's steering systems shall be checked and tested including the full and accurate movement of the rudder, visual inspection of all parts and linkages, the operation of the means of communication between the wheelhouse and steering gear compartment. Simple operating instructions and a block diagram should be permanently displayed in the wheelhouse and steering gear compartment. Emergency steering drills shall take place at least once every three months. Details of all tests, checks and emergency steering drills shall be recorded in the log book or the vessel record book.

At the helm - Rudder movement must be no less than 35° to port to 35° to starboard. With all steering systems the steering wheel should be capable of a turn hard over to port (35º) and then hard over to starboard (30º) within thirty seconds to meet NSCV requirements (NSCV vessels over 15 metres). The movement should be smooth and unimpeded and be monitored by a correctly reading helm indicating gauge.
With sprockets and chain steering check the attachment linkages and the chain tension - lubricate as required. Communication equipment (radio) should be ready in case the emergency steering needs to be deployed from the tiller flat (*stern steering compartment).*

With hydraulic steering look out for spongy feel to the steering that may indicate air in the system. Check for oil leaks where the two oil lines connect to the helm pump and the oil seal on the at the pump shaft. You may have to top up the helm pump oil reservoir, so follow the manufactures instructions and use the recommended type of hydraulic oil.

In the steering compartment - Check the flexible hoses are not perished, cracked or leaking, especially at their connections. Check the hoses are not too short (as they may pull out of their connections) on a turn or too long (as they may kink or foul). The hoses should be protected from chaffing and all connections should be free of corrosion. Check the hydraulic oil pump if power assisted steering is fitted.

Then start up the hydraulic oil pump and have the crew turn the wheel to watch the movement of the hoses, receiver, ram and tiller arm. Watch out for oil leaks at the connections of the flexible hoses, the seal on the servo and power ram, the servo and power ram bleed valves , the connections and seals of the directional control valve and the connection and seal of the hydraulic oil pump and at the relief and by-pass valves. There should be no bulges in any of the flexible hoses. Check that the manual override on the directional control valve is operating. All locking arrangements must be in place and tight.

Check for excessive wear (movement) in the clevis pin or hole in the tiller arm. Excessive wear (otherwise hidden) may be detected when the direction of the steering wheel is reversed, as in the hole in the tiller arm is hidden by the arms of the clevis. The wear can be detected when the steering wheel is reversed as the piston rod will move immediately while the tiller arm will remain stationary until the excess wear is taken up. Check that the tiller arm stops are effective, that the tiller arm is securely attached to the rudder stock and there is no sign of wear.

Check that the rudder stock gland shows no sign of excessive leakage (a small drip is acceptable to lubricate the gland packing). On some vessels the rudder stock gland may be above the water line and the packing in the gland tends to be ignored and in time becomes ineffective. When the vessel’s stern drops, water will pass the gland packing and enter the vessel.

Ensure that ropes, fishing nets, drums, and any other equipment are stowed so they cannot foul the operation of the steering gear system.

Confirm that the emergency tiller arm is on board, readily available and that the communication equipment should be ready in case the emergency steering needs to be deployed.

Common faults of steering systems

Steering systems are reliable and faults generally arise from lack of regular inspection or, poor maintenance.

Common mechanical steering faults

Corrosion of parts in steering compartment - Steering gear in smaller vessels are located in enclosed spaces where the atmosphere is damp and humid and may lack adequate ventilation. Condensation or water in the compartment will cause corrosion that can cause parts to seize up over time and the effects may even be noticeable between daily checks.

Wear and linkages coming loose - Being located over the propeller and rudder, steering components are subject to shock and vibration. This can result in nuts becoming loose, fractures in welds and excessive wear. Chain steering needs to be tightened regularly.

Common hydraulic steering faults

The following steps should be followed to prevent and correct steering gear faults- Oil should be maintained to the correct level in the header tank using the correct grade oil recommended by the manufacturer. The oil must be free from impurities or seals and piston rings can be damaged allowing leaks to develop. The oil must also be free from moisture otherwise corrosion may occur internally. Any leak should be attended to immediately.

The relief valve setting must only be altered to the manufacturer's installation instructions. Grease all linkages where required and clamp oil piping to prevent vibration.

Air in the steering gear system - Hydraulic oil is not compressible so the movement of the steering wheel will result in an immediate movement of the rudder. Air can be compressed so if trapped in a hydraulic system will not transfer immediate movement of linkages. The presence of air in a steering gear system results in a spongy or jerky operation. This can be felt at the steering wheel or seen at the piston rod and tiller arm.

Excessive air enters the system when it is initially filled and can also enter the system where the oil can leak out, such as seals on the helm pump and servo ram, flexible hose connections, oil line connections to the helm pump, or at the bleed, relief and by-pass valves.

Removing Air from the Steering Gear System - Operation of the system by turning the steering wheel slowly will cause the air to make its way to the end of the line in the direction that the oil is being displaced.

As the oil reaches the helm pump, the air will separate from the oil and go into the air space above the oil in the header tank. At the other end of the oil lines, the bleed valve on one end of the servo ram will have to be opened while the oil is being delivered until bubble free oil is released. Should the steering wheel be placed hard over before bubble free oil is released, the bleed valve will have to be closed while the steering wheel is returned to the amidships position. The procedure would be repeated until bubble free oil is released.

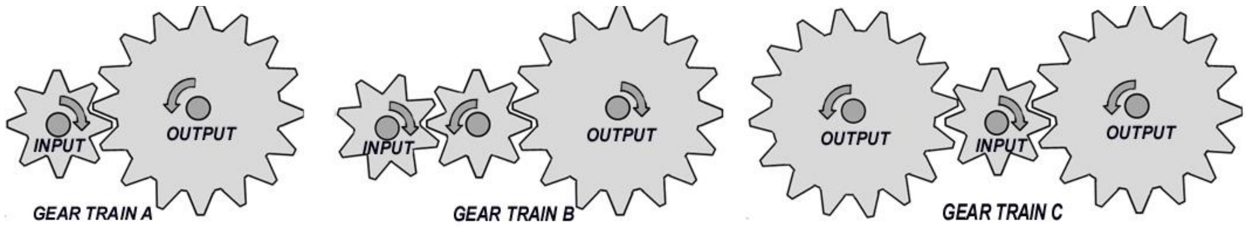
If the air enters the hydraulic oil pump/power ram lines, oil can be bled by starting the pump and operating the manual override. Oil will flow to one side of the power ram and through a bleed valve until bubble free oil is released. Repeat the procedure for the lines on the other side of the power ram.

In twin helm station setups the lower helm station is usually bled before the upper helm station.

Chapter 6: Gears, Shafts and Propellers

6.1 Gears and clutch mechanisms

Gearing is used in *drive trains* (sets of intermeshed gear wheels) to alter direction, position or speed/mechanical advantage of propulsion and auxiliary equipment such as winches, pumps and steering. The gear and shaft driven directly by the motor can be called the input and the final gear and shaft it drives can be called the output. Drive train A shown below illustrates reduction and reversal of the output, drive train B illustrates reduction only with further displacement (to the right) of the output, drive train C illustrates reduction and splitting into two outputs.



Principles of marine gear boxes
The efficient crankshaft speed of a small high speed motor is greater than the efficient speed of a propeller that revolves in relatively dense salt water. The solution to this is to use of a drive train with an input shaft and drive gear wheel enmeshed with a set of follower gear wheels connected to an output shaft (a gear box). The output shaft follower (to the propeller) has more gear teeth than the input shaft driver (from the crankshaft), and therefore it rotates more slowly. The number of teeth in each gear wheel has a direct relationship to not only the speed of the follower but also the transfer of torque. The reduction ratios shown in the drawings above are calculated by the:

$$\frac{\textit{number of gear teeth (cogs) in the large wheel}}{\textit{number of gear teeth in the small wheel}} = \frac{16}{8} = \textit{2 or a Reduction Ratio of 2:1}$$

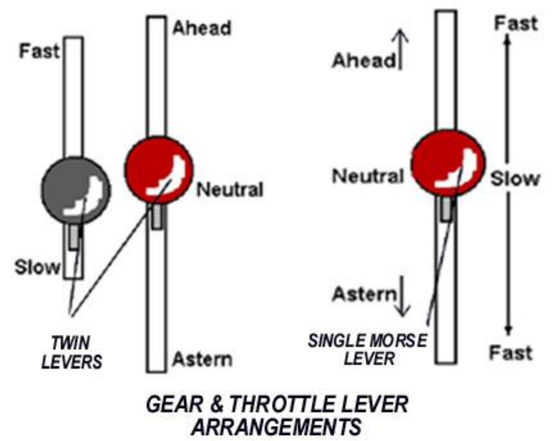
Therefore if the engine speed is 1000 rpm and the propeller speed is 500 rpm then:

$$\frac{\textit{rpm of the engine}}{\textit{the rpm of the propeller}} = \frac{1000}{500} = \textit{2 or a Reduction Ratio of 2:1}$$

While the speed has been halved, the mechanical advantage has been doubled (not allowing for efficiency losses due to friction and heat). Marine gear boxes are designed to reduce the speed of the propeller shaft but some applications require a greater speed from the output shaft. This is simply achieved by using a smaller follower to give higher output speed with less mechanical advantage. It must also be noted that by adding a following gear wheel it will turn in the opposite direction to its driving wheel (in reverse).

Gear selection and engagement

Gear box arrangements to select reverse gear include mechanically (using a gear lever directly or through a cable or linkage), electro-mechanically (using electrical solenoids which change the gears directly or hydraulically through clutches) or by hydraulic operation alone. The gearbox control and engine throttle (speed) may use separate levers for thrust and speed, or be combined in a single control lever as drawn below.



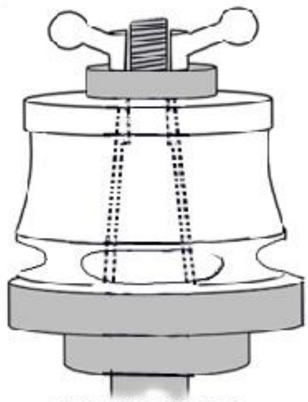
Marine transmission systems are heavy and generate considerable momentum so changing gear is smoothed by clutches. To avoid clashing of gears and overload on clutches the sequence of changing requires a delay for the propeller and shaft to slow down. Modern systems operate sequentially, or have override safety systems, however good practice remains to follow the manufacturer's instructions always.

Clutches

In most operations it is convenient to be able to positively engage and disengage an input shaft from an output shaft. The mechanism that smooths this operation is called a clutch.

Dog clutch - The simplest arrangement as found on windlasses and winches is the *dog clutch*. Shown below, a collar is splined to the driving motors shaft that can be pushed by the clutch lever to engage hard against a lug in the winch drum's side. This arrangement only allows engagement when winch and motor are stopped or both moving slowly at the same speed (a neat trick if at all possible for the arrangement shown below).

Cone clutch - The cone clutch does allow for engagement while the motor is running and is suitable for slow running operations such as capstans, windlasses and winches.

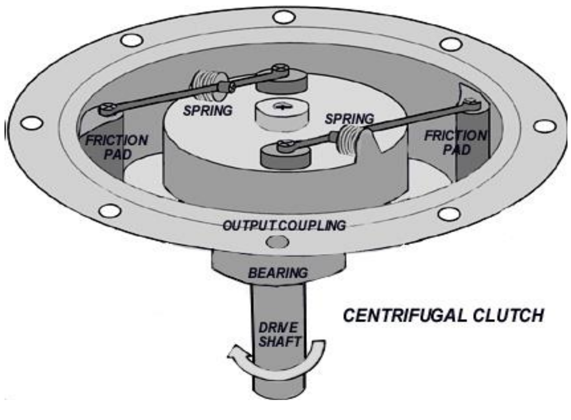


CONE CLUTCH OF A CAPSTAN WINCH

The warping drum (rope carrier) or gypsy (chain carrier) is machined with a *tapered* central hole. The drum is fitted over a matching tapered axle and can revolve smoothly when in the disengaged mode. The tapered axle can also be turned by a directly fitted motor. When the drum is tightened down onto the axle it grips (engages) and will turn with the motor driven axle. The system can snatch as it engages and although usually of heavy duty build, as with all friction type clutches there will always be momentary slip before engagement resulting in heat and wear.

More sophisticated systems are held in engagement with a heavy coil spring that can be manually compressed to disengage the drum from the axle. For a better grip the driving axle may be machined to mate inside a wide tapered drum and the mating cone's surface be coated with a friction lining material.

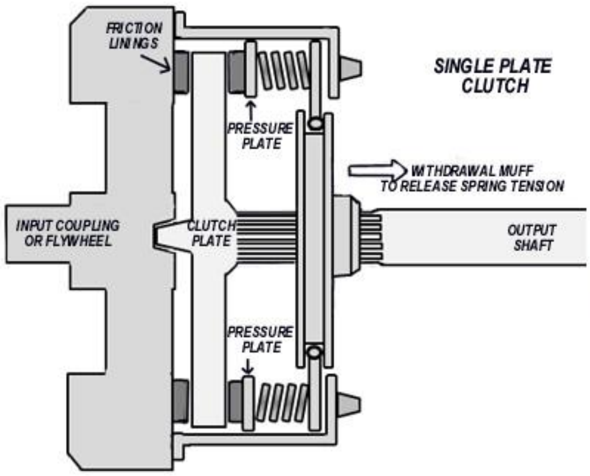
Centrifugal clutch - A driving shaft and output coupling drum can revolve independently at their common bearing. The driving shaft has hinged weighted friction pads that at rest are restrained clear of the drum's surface by springs. When the driving shaft is revolved the friction pads are thrown outwards by centrifugal force sufficient to overcome the springs and bind onto the drums surface (engaging the coupling). Light duty pumps and power tools often use a centrifugal clutch for its light weight and economy.

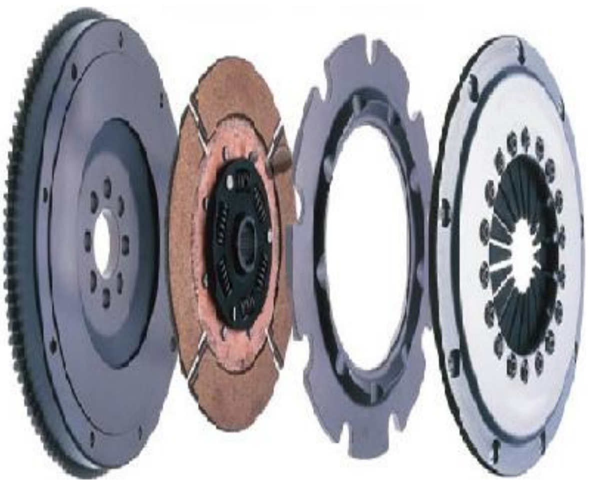


CENTRIFUGAL CLUTCH

Double de-clutching - Before the modern *synchromesh gearbox* the earliest motor cars used a *crash gearbox*. To change gear, a lever is first applied to rip the currently engaged gearwheel away from the output gear train and into *neutral* (disengaging the engine from the road wheels). While temporarily in *neutral* the accelerator is revved to boost the engine speed to match the speed of the lower gear wheel (determined by the road wheel speed). This is called *double de-clutching.* When the driver judges that the speeds are matched the gear lever is applied to enmesh the lower gear by crashing it into the engine gear wheel, with hopefully not too much crunching of the gear teeth.

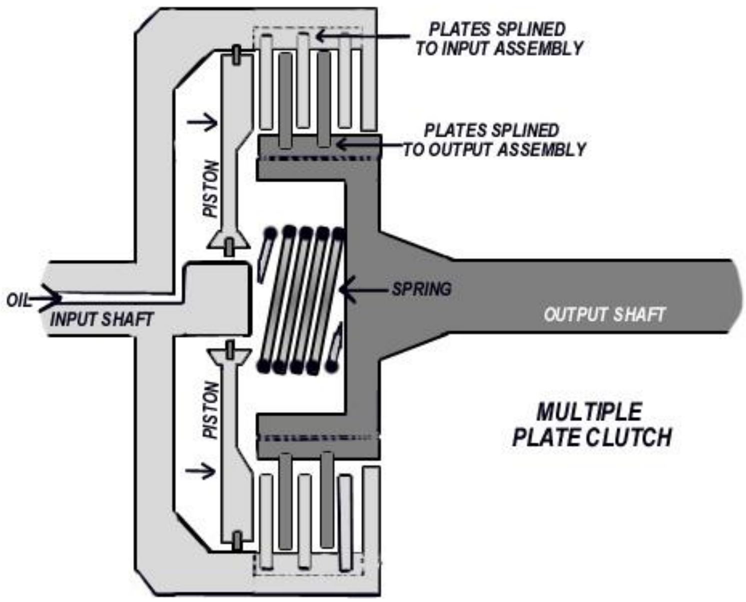
Single plate clutch - a clutch plate disc is held firmly squeezed by heavy duty springs between friction pads on the flywheel and on the pressure plate disc.





A sliding muff coupling can be withdrawn using a lever mechanism to release the spring tension and enable disengagement. Not shown in the drawing for simplicity are the photos of the flexible links between the clutch plate and the output shaft that allow for shock loads and natural oscillation in engine output.

Multiple plate clutch - The single plate clutch mechanism operates externally of the gear box and is typical for auto applications. For weight and space saving, marine applications usually have clutches that operate within the gear box. The large single clutch plate is replaced by several smaller ones enabling equivalent surface area contact in a more compact unit.



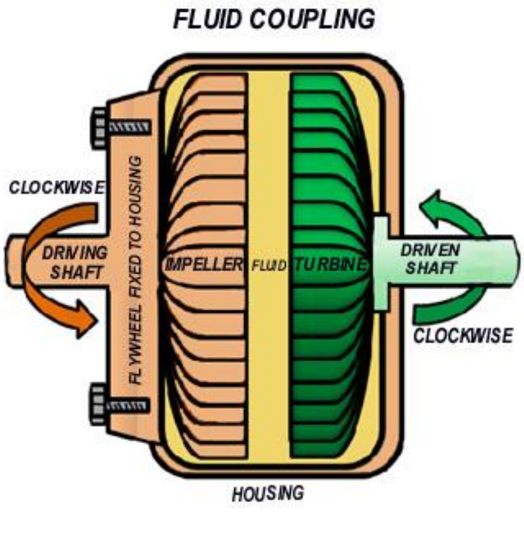
Hydraulic oil is pumped in through the input shaft which forces the internal piston disc to overcome the hold off resistance of the return spring and move towards the output assembly. This in turn squeezes together the plates that are alternately splined (embedded) inside the rim of the input shaft assembly and on the outer rim of the output shaft assembly. Adjusting the hydraulic pressure enables accommodation for heavy loading operations as may be required for low gear or reverse gear.

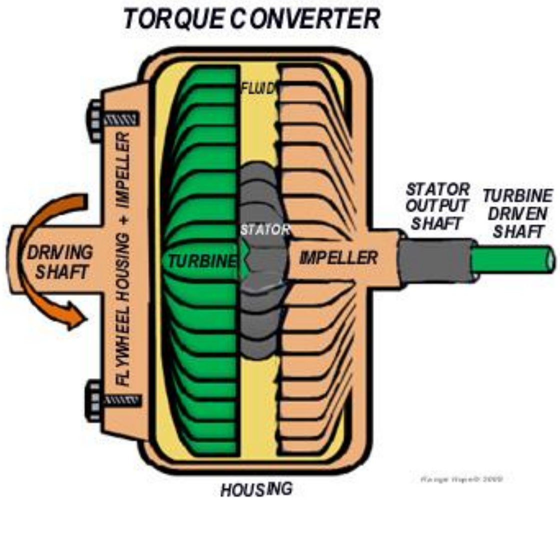
Clutch slip - Clutch slip describes when there is incomplete engagement between the driving and driven side of the clutch. The power developed by the engine is therefore not fully transmitted to the propeller. Wear of friction plates or linings is unavoidable due to momentary slippage when clutch is being engaged. Each engagement results in a slight loss of the friction material. In the course of time, this accumulated wear allows slippage. With regular maintenance, adjustments can be made to the clutch to reduce this problem but eventually wear will be such that the friction material will need to be replaced.

Fluid (hydraulic) coupling – while a hydraulic linkage may be the activating mechanism to enable positive engagement in the previous clutch types, the fluid coupling transfers thrust by smooth fluid action. Consider a household electric fan pointed towards another. The second fan will slowly rotate in the breeze. This induced motion in the driven turbine (second fan) enables a cushioned engagement/disengagement between a driving motor shaft and a driven shaft albeit with some slip (poor thrust transfer) at low speed.

A fluid coupling transmits rotation from one shaft to another by accelerating hydraulic fluid inside its housing containing closely fitted rotors; the input driving shaft pump (impeller) and the output driven shaft turbine (runner). The flywheel, impeller and housing *(shell)* are fixed and the cavity filled with hydraulic fluid. The impeller spins the fluid from the centre where the velocity is low, to the periphery where the velocity becomes high. A net force of multiplied torque on the turbine causes it to rotate with the direction of the impeller.

Fluid couplings have a stall speed where the impeller is turning but not fast enough to coax the turbine into rotation (i.e. when the car driver stopped at traffic lights selects the gear while his brakes are still on). In this condition for excessive periods or if the runner becomes jammed, the engine's power could transfer its energy as overheated fluid, possibly leading to damage. A fluid coupling only achieves about 94% transmission efficiency due to fluid friction and turbulence.





Torque converter - Unlike the two rotor fluid coupling, the torque converter has at least three rotors- the impeller (motor driven), the turbine, (load driving) and positioned between them the stator (that modifies oil flow returning from the turbine to the impeller).

The fluid flow returning from a *fluid coupling's* turbine can oppose the direction of impeller rotation during slip, causing lost efficiency. The torque converter uses its stator to redirect the returning fluid to assist the rotation of the impeller so improving efficiency and output torque. Though simple stators can be fixed often they are mounted on a one way clutch allowing forward motion only. Since the returning fluid is initially travelling in a direction opposite to impeller rotation, the stator will likewise attempt to counter-rotate as it forces the fluid to change direction, an effect prevented by the one-way stator clutch. The typical torque converter in automatic transmissions has three stages of operation:

Stall- the motor turns the impeller but the turbine cannot rotate. (When the car driver stopped at traffic lights selects the gear while the brakes are still on).

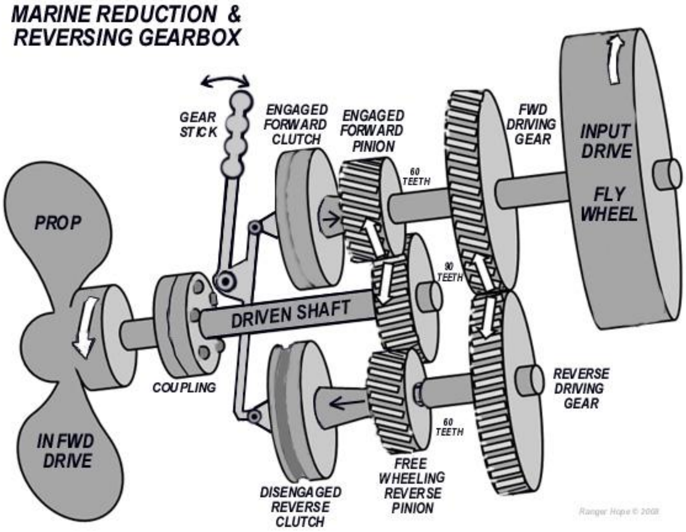
Acceleration-the motor accelerates with the impeller spinning at a greater rate than the turbine.

Coupling-The turbine has reached approximately 90% of the speed of the impeller. Torque multiplication has ceased and the torque converter is behaving like a fluid coupling.

Lock-up clutches such as the Voith TurboSyn coupling overcome the problem of slip and improve fuel efficiency by coating the periphery of a multi-section impeller with friction plates. Centrifugal force throws the impeller onto the turbine at higher revolutions, creating a positive clutch lock at speed.

6.2 Reverse and reduction gear boxes

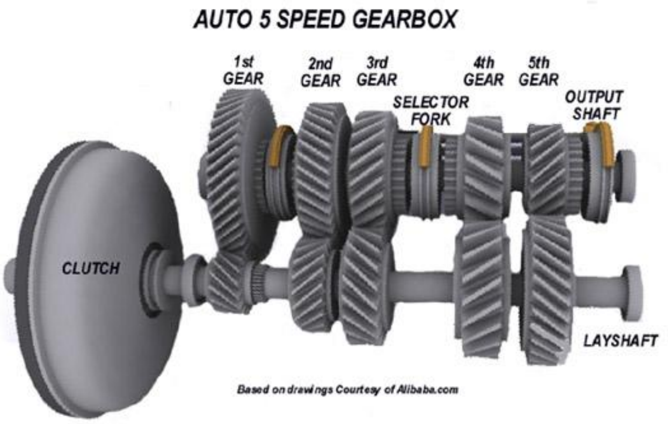
The gear system below has an input shaft and forward shaft (often combined), a reverse shaft and an output shaft turning within an oil bath called the *sump (not shown)*. The forward and reversing shafts have *pinions* (driving gear wheels) engaged by clutches. When disengaged as below the reverse pinion gear wheel rotates freely on its shaft.

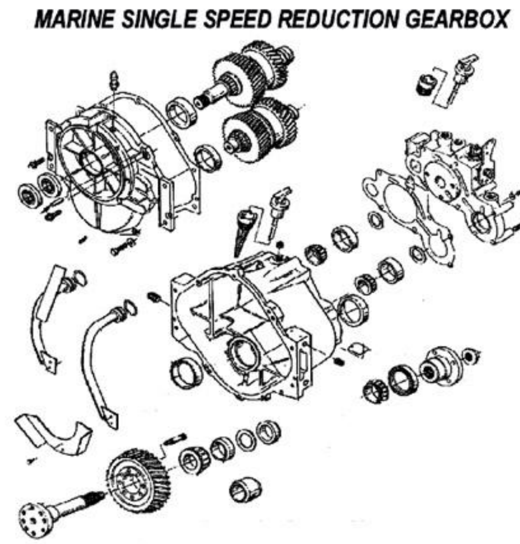


Ahead mode operation - The forward clutch pushes the forward pinion to engage on the forward/input shaft. The forward pinion then drives the driven shaft as shown above. The reverse clutch is not active so the reverse pinion rotates freely on the reverse shaft.

Astern mode operation - The reverse clutch pushes the reverse pinion to engage on the reverse shaft. The reverse pinion then drives the driven shaft as shown above. The forward clutch is not active and the forward pinion rotates freely on the forward/input shaft.

An input shaft driven oil pump provides oil flow for lubrication and operation of the clutches. Oil pressure is regulated by a pressure relief valve before distribution to the gears, bearings, clutch and control via passages in the gearbox. A control box is mounted on the top of the gearbox and connected by linkage (electronic, hydraulic, pneumatic) to the throttle and forward/reverse control at the wheelhouse and gearbox (for manual emergency operation). An oil cooler and oil filters may be mounted on the gearbox.



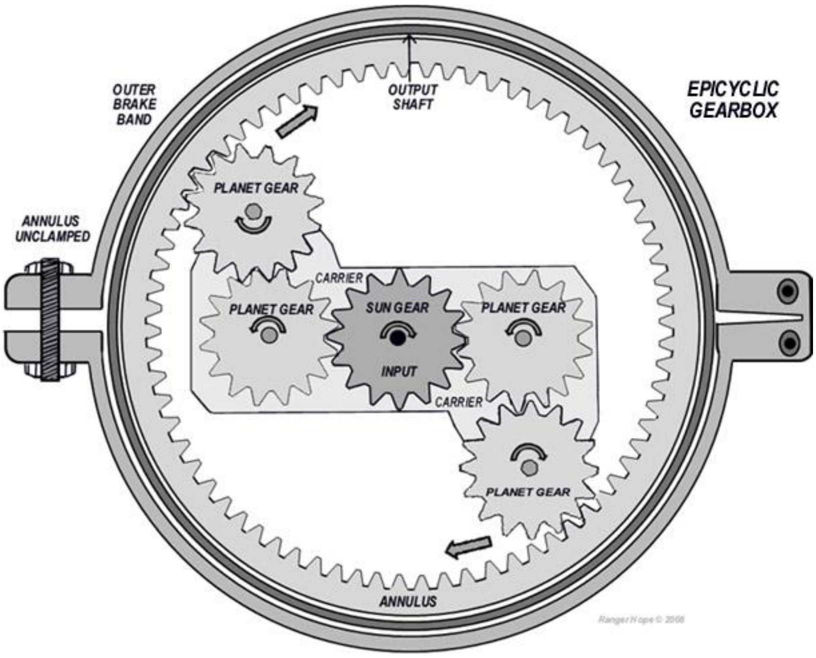


Epicyclic or planetary gearing

Epicyclic or *planetary* gearing systems provide the advantages weigh saving, balance and compactness for a gear box suitable for marine applications. Variations of three basic geared components of a *sun gear*, *planet gear* and *annulus* are utilized.

One or more outer gears *(planet gears)* revolve about a central gear wheel *(sun gear)*. In more complex systems groups of planet gears can be mounted on a movable arm (*carrier*) which as a body can rotate around the sun gear. An outer ring (annulus) with inward-facing teeth mesh with the planet gear. In operation one of the three components (*star, planet or annulus*) is held stationary, another is used as a power *input* and the last component is used as the *output*. The ratio of input to output is dependent upon the number of teeth in each gear, and upon which component is held stationary.

In the reversing gearbox shown below the output shaft can revolve in ahead mode (anticlockwise) with the annulus free to rotate within the shaft. If however the annulus is locked on the output shaft by the outer tightening collar (brake band) the annulus and shaft are rotated in reverse (clockwise) by the planet gears.



Epicyclic gear arrangements can be simple or compound. Compound arrangements enable large reduction ratios, weight saving and flexibility. They may be *meshed-planet* (at least two or more planets in mesh within each planet train), *stepped-planet* (a shaft connects two planets within each planet train), or *multi-stage* structures (two or more planet sets).

Main thrust bearing

The main thrust bearing is located on the output shaft near the aft end of the gearbox. Its function is to carry the reaction to the thrust of the propeller and transmit it through the gearbox casing/frame to the framework of the vessel. This ensures the gears and engine are not affected and remain in the correct longitudinal alignment.

Gear box maintenance

Assuming that normal maintenance has been carried out on the gearbox, for daily pre-departure checks it should be sufficient to:

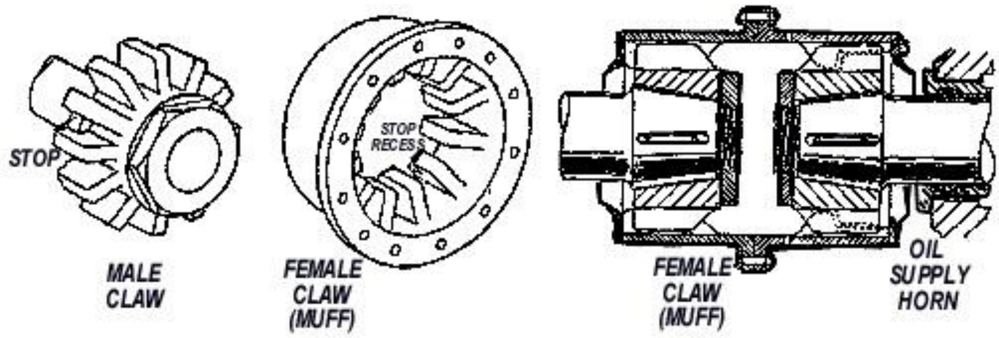
Check the oil level in the gearbox sump.
Run the engine with the gearbox in neutral position and check for leaks.
Operate the gearbox in the head and astern mode to ensure satisfactory operation after ensuring that the lines holding the vessel are secure during testing.

Gearboxes are fairly reliable. Faults tend to be due to lack of normal maintenance such as:
Adjustment of clutches and operating mechanism
Maintenance of filters
Cleaning of oil coolers

6.3 Couplings and intermediate shaft

Muff Coupling

A muff coupling is a sleeve joining two in-line shafts. Unlike flange type couplings which butt solidly together, the muff coupling allows for a gap between the joining shafts so that expansion of one shaft (due to heating) can be accommodated. It is therefore used where one of the shafts must expand longitudinally due to heating (such as steam turbine shafts). The coupling shown below is heated and shrunk on. To remove, oil is pumped under pressure into grooves assisting release of one half of the coupling.

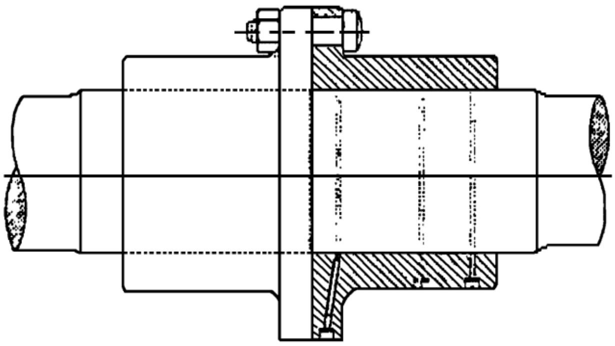


Muff Coupling

Alternative arrangements include keyed half couplings that are a press fit on shafts or half couplings that are forged integral (are part of) with the shaft

Flange Coupling

A flange is fitted to the end of a shaft and bolted to a similar flange on the end of the adjoining shaft. The flange may be an integral part of the shaft or separate from it. If separate it has to be keyed and secured to the shaft. The mating flanges are butted and bolted together using fitted bolts with accurate alignment to avoid wear on the bolts.



Flange coupling

Faulty couplings are rare, the problem usually being misalignment or loose bolts, the later often created by excessive vibration from misalignment. Care should be taken in alignment adjusted on the slipway with older wooden boats as the hull may alter shape when fully supported when back in the water.

Flexible couplings

Some flange type couplings (known as flexible couplings) have bolts that are secured in one half of the coupling and loose in the other. The loose half bolt has a rubber or synthetic sleeve which allows for flexibility in alignment. This type of coupling is often used as a less than ideal last resort where satisfactory alignment has not been successfully achieved in a marine shafting.

Checking intermediate shaft alignment

Misalignment will cause noise and vibration. Gearbox and shaft bearings can overheat and collapse more quickly. The flange couplings of the intermediate shaft of a vessel in service can be checked for parallel, concentricity and alignment using:
Dial indicators and/or

Feeler gauges and straight edges.

Utilising a dial indicator -

1. Inspect the intermediate shaft. If supported on two bearings go to step 2. If supported on a single bearing it is necessary to provide a temporary support to ensure the shaft does not tip. This could be a vee block set up to ensure the shaft maintains the same alignment.

2. Remove the coupling bolts at either end. If muff couplings are fitted, dismantle them and slide the muff/s away from the shaft ends.

3. Using an indicator gauge, clamp the gauge on the engine/gearbox side half coupling. Set the pointer on the top of the intermediate shaft coupling flange and record the reading on the indicator dial. Rotate the engine gearbox shaft and take readings of the dial at 90, 180 and 270 degrees. For perfect alignment, the indicator reading should remain the same at all angles. The procedure for a muff coupling is similar except that the indicator gauge is clamped on the shaft and the pointer set on the intermediate shaft.

4. As a double check transfer the dial indicator to the intermediate shaft. Set the pointer on the engine gearbox shaft and repeat the action in Step 3. The readings should be the same as before.

Using feeler gauges and straight edge -

1. Inspect the shaft. If supported on two bearings go to step 2. If supported on a single bearing, provide a temporary support to ensure the shaft does not cant or tip. (This could be a vee block carefully set up to ensure the shaft maintains the same alignment.)

2. Remove the coupling bolts at either end. If muff couplings are fitted, dismantle them and slide the muff/s away from the shaft ends.

3. Lay the straight edge across the outer diameters of the half couplings at 0, 90,180 and 270 degrees. Any mis-alignment will show as a gap between straight edge and one half coupling. This gap can be measured by feeler gauge.

4. Again as a double check, rotate one of the shafts 90 degrees and repeat step 3. Allowable mis-alignment will depend on the diameter of the shaft. The vessels operating manual or other documents will often provide the information.

Setting up for propeller shaft alignment

The shaft coupling must accurately line up with the gearbox coupling. The engine & gearbox unit position can be adjusted by loosening its mounting bolts and adding or removing *shims* (metal spacers) to lift/lower the gearbox & coupling for correct tilt & elevation (alignment).

If the shaft is drawn (removed) while the vessel is on the slipway, alignment can be positively adjusted by stringing a taut piano wire through the dead centre outer bearing, the inner bearing and carried on to the gearbox flange. If the wire does not meet the dead centre of the gearbox flange then either the engine & gearbox unit must be adjusted with shims, or the outer bearing bracket moved (the latter being more problematic.)

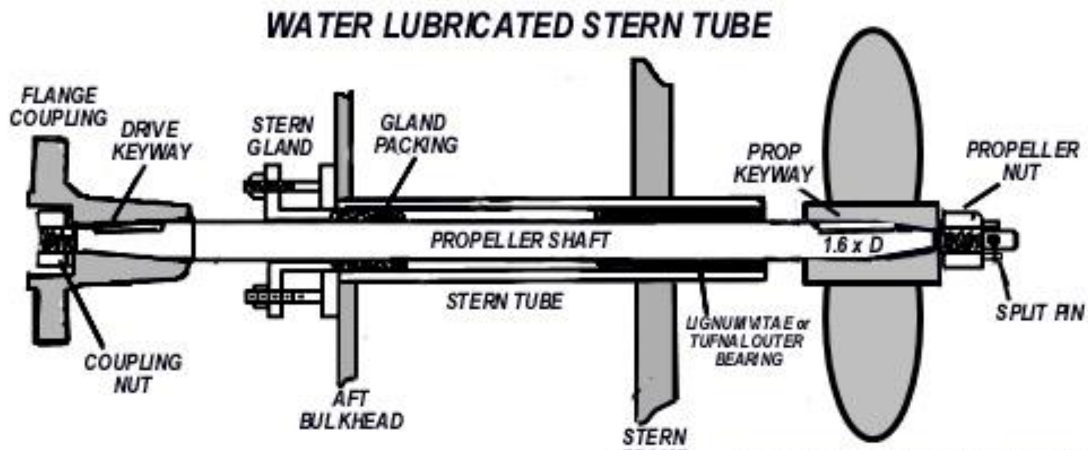
6.4 Stern tubes and shafts

Stern Tubes

The stern tube contains the propeller shaft, and shaft bearings and seals. The stern tube may be water lubricated, or oil-filled.

Water lubricated - The water lubricated stern tubes (as below) allows the stern tube to fill with sea water, and the shaft runs in water lubricated bushes. Some systems can also use pumped engine cooling (*raw*) water from the *jabsco* supply to inject water around the stern gland housing. A gland sealed by compressible rings of rope like *gland packing* material the *inboard* end stops too much sea-water leaking into the vessel, but some dripping is acceptable as this helps to lubricate the gland.

Some systems provide a grease nipple on the inner stuffing box. Though the grease will initially stop leaking it should be used with discretion as grit and sand can create a paste that actually wears the shaft and ultimately increases leaking. The gland can be periodically checked and tightened slightly to reduce dripping if necessary. Feel the bearing after tightening for excessive heat due to friction, and loosen if required.



Based on drawing courtesy of ANTA Publications

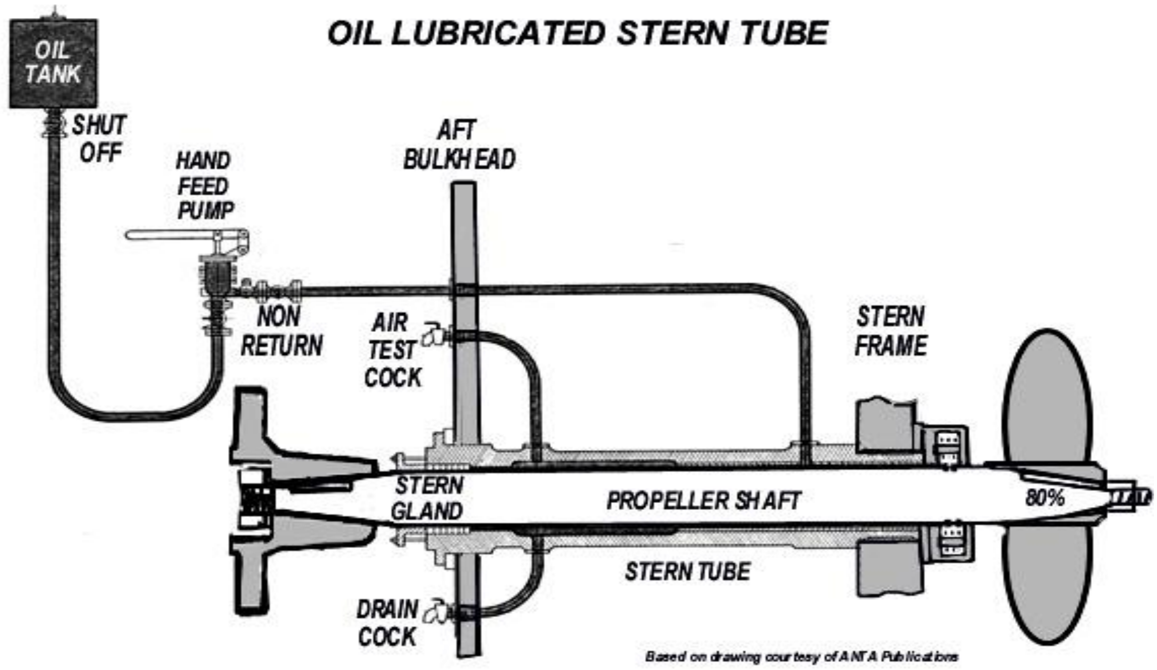
The stern gland can be re-packed as the *gland packing* material wears away. Dig out the old *gland packing* carefully to avoid scoring the bearing. New *gland packing* coils must be cut to the correct length from the continuous lengths supplied by your marine dealer.

Consult your manufacturer's instructions for the correct size (usually at least three coils of gland packing sized appropriately to the shaft diameter). When cutting the coils make a diagonal cut (scarf) to increase the overlap at the ends. A minimal wipe of grease on the shaft may be acceptable to ease fitting, but don't overdo it. Tighten the gland and monitor for heat and dripping for a few days until it settles in. Re-adjust as required.

The propeller fits tightly onto a tapered shaft and is positioned with a keyway. This keyway needs to support the propeller over 1.6 x diameter of its hub length along the shaft (i.e. a shaft diameter *50 mm x 1.6 = 80 mm* keyway).

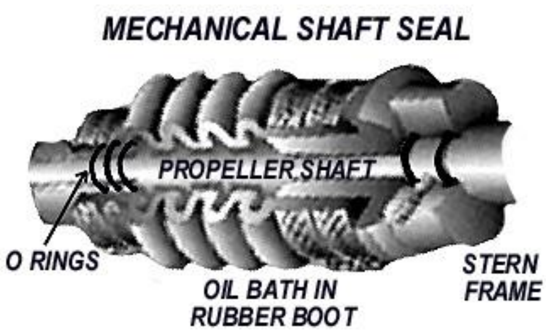
Routine management - Check the stern gland for leakage. Though it is common practice to allow a slight leakage from the gland to keep it cool, many modern stern gland packings (due to their low coefficient of friction) will operate satisfactorily without leakage. Listen to the noise generated by the rotation of the propeller. Increase in noise generally means wear in the after stern tube bearing.

Oil-filled stern tubes - give better lubrication and reduce corrosion. Sea-water is kept out of the stern tube by a complex outboard seal with springs and *o rings* that retains the oil bath. An inboard mechanical or standard packing gland seals oil inside the stern tube to lubricate the white metal bearings. The stern tube oil header tank should be regularly checked and topped up. A pump to circulate the oil around the system may be provided and valves for venting and draining are also provided.



Routine management - Check header tank to ensure there is no loss of oil. Check oil for water dilution. Most oils are designed to emulsify if water enters the stern tube. If the forward gland is the packing type there should be no leakage. Adjust to stop leakage if necessary. Mechanical seals at the forward end are usually trouble free but should be regularly checked. A save all should be provided to catch any oil leakage thus preventing it from entering the bilges.

Mechanical shaft seals or PPS –The shaft is contained in an oil bath within a rubber boot and sealed with *o rings* running in grooves. These are often called drip-less shaft seals with the obvious advantage of maintaining a dry bilge. They are very common in smaller craft with small diameter shafts.



Outboard engines have a sealed, oil filled *foot* containing gearbox, bearings, shafts and seals. The oil level in the foot should be regularly checked and periodically changed as shown in the engine maintenance schedule. The differences between oil lubricated and water lubricated stern tubes include:

Water lubricated stern tubes -	
Advantages	**Disadvantages**
A tried and tested sturdy system. Simple to repair wearing parts or replace, but usually requires dry dock for repair. No complex mechanical seals.	High wear rates at the aft bearing and shaft liner or shaft as it carries the weight of the propeller. Carbon steel shafts have to be protected from corrosion by a sleeve or liner. On smaller ships the shaft is often made from corrosion resistant steel or monel and a liner is not required.

Oil lubricated stern tubes -	
Advantages	**Disadvantages**
The shaft runs in oil. Friction is reduced and more power is available at the propeller due to white metal bearings. Less wear and longer life from reduced friction. For carbon steel shafts, liners are not required for protection of the shaft from corrosion as the shaft is not exposed to sea water.	Initial cost is greater as additional piping. An oil header tank is required. After end of the stern tube requires a mechanical seal which, to ensure reliability, is of a fairly complex design. The forward end can be fitted with either a mechanical seal or conventional packing gland.

Measuring stern tube bearing and tail shaft wear

Two bearings usually support the propeller shaft (*tailshaft* or *shaft)*. One is located at the forward end where the shaft penetrates the aft engine room bulkhead and the other is at the after end of the stern tube. The forward bearing is not accessible unless the shaft is removed. As it only carries part of the weight of the shaft, wear is not usually a concern. The aft bearing has to take part weight of the shaft and the whole weight of the propeller so considerable wear takes place in this bearing. W*eardown* is a measure of the *sag* (deflection) of the shaft due to bearing and shaft wear.

Shafts should be withdrawn for inspection every 4 years. Increased vibration at the vessel's stern with persistent stern gland leaks (despite adjustments) are symptoms of excessive weardown. If exceeded, the consequences include fracture of the shaft with propeller loss. *Weardown* allowance is determined by the manufacturer, but rules of thumb range from 3% of diameter as due for replacement to 6% being condemned (3% of a 50mm diameter shaft is 1.5mm permissible movement within the bearing).

Water lubricated tailshaft wear - The aft bearing is accessible via the small gap between the aft end of the stern tube and the front end of the propeller boss. If a rope guard is fitted over this gap, it must be removed. The shaft rests on the bottom half of the bearing. The gap between shaft and stern tube bearing can be measured by using long feeler gauges inserted at the top of the shaft. Many bearings have longitudinal grooves to allow water to circulate. Ensure measurement is taken at the bearing surface not the groove. If the gap above is too small to allow access of the feeler gauges another method of measuring the weardown is to clamp a dial indicator gauge to the hull with the pointer resting on the top of the shaft between the stern tube and propeller. Note the dial reading, then jack up the prop until resistance to jacking increases. Note the new reading. The difference is the weardown (the sum of the wear in the bearing and shaft wear).

Oil lubricated tailshafts wear - These shafts can have a mechanical seals at each end. The standard method of checking wear is by depth gauge. A collared plug in the gland housing or the stern tube just forward of the gland is removed. The depth from the face of the plug boss to the top of the shaft is measured. This should be compared to the original measurement when the shaft was installed. The difference is the weardown.

6.5 Propellers

Propeller theory

Pitch (geometric pitch) The action of a propeller is similar to a carpenter's auger rotating to drill a hole through a piece of timber. The drill digs a hole equal to the angle of the shavings clearance spiral (the *pitch*) of the auger with each complete rotation. Unlike the auger, a propeller is not a continuous spiral but sections from it (blades) are placed around a central hub. As it rotates in a fluid medium the hole the propeller digs in the fluid (the actual advance of the propeller) is less than the geometric pitch. The difference is termed the slip.

Pitch angle Ø is the pitch divided by the circumference of the prop at a given diameter.

ie. Tan Ø = pitch/π x diameter of the propeller.

Diameter Means the maximum diameter. With an even number of blades, it is the distance from the tip of one blade to the centre of the blade. Directly opposite for odd numbers, it is twice the distance from the centre of the propeller to the tip of any blade.

Cavitation The results from pressure variations on the back (forward face) of a blade forming vapour filled cavities (bubbles). This leads to a loss of thrust/torque and increase in revolutions until the bubbles collapse. The collapsing bubbles produces intense local pressure on the blade that results in erosion and surface pitting.

Excitation Where the natural frequency of the propeller blades is the same as frequencies derived from other sources. Examples include:
the variation in torque of the engine
pressure variation as a blade passes the stern
the flow of the water into the propeller
the natural hull frequency

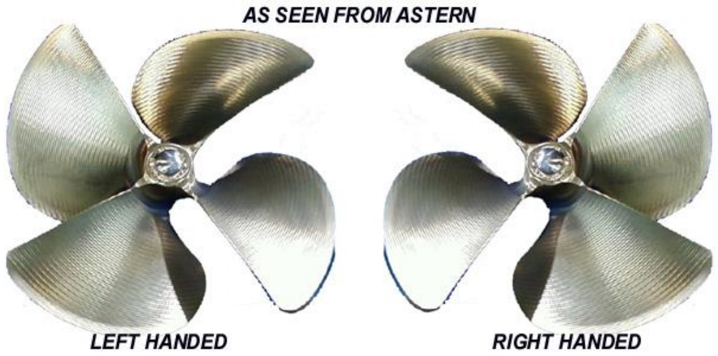
The synchronised result can produce resonance in the blades and unacceptable vibration of the propeller or shaft. Sometimes the blades generate disturbing noises called a *singing* propeller.

Propeller calculations

Description - Viewed from the stern of a vessel the shaft may be configured to turn in clockwise direction (*right handed*) or in an anticlockwise direction (*left handed*). Due to the differential water density and aeration experienced by a propeller's uppermost submerged blades and the lower submerged blades, a right handed prop will create a *paddle wheel effect*. This pushes the vessels head to port when ahead propulsion is first engaged and pushes the vessels stern to port when astern propulsion is first engaged. The inertia of a vessel accelerating from a stall (being stopped in the water) accentuates this effect.

With twin propped vessels the starboard prop is usually configured to be right handed and the port prop to be left handed. Some props may be set up as twins on the same shaft, counter rotating to negate this *paddle wheel* or *transverse thrust effect*. The prop may have two, three or multiple blades. Consequently a propeller it is described by its number of blades, the direction it turns, its diameter and its pitch.

A four bladed, right handed, 75 cm diameter x 150 cm pitch propeller.



Gear and propeller ratio –The gearbox reduces the drive speed from the engine to the shaft and propeller to reduce the likelihood of excitation and slip. For an engine that turns at 2400 rpm with a propeller designed to turn at 800 rpm, the following can be found:

$$\textit{Gearbox ratio} = \frac{\textit{Engine speed}}{\textit{Propeller speed}} = \frac{2400}{800} = \textit{3:1 Ratio}$$

This relationship is also described by the formulae:

$$\textit{Gearbox ratio} = \frac{\textit{Engine speed}}{\textit{Propeller speed}} = \frac{\textit{Engine ratio}}{\textit{Propeller ratio}}$$ or

$$\textit{Engine speed} = \frac{\textit{Propeller speed} \times \textit{Engine ratio}}{\textit{Propeller ratio}}$$ or

$$\textit{Propeller speed} = \frac{\textit{Engine speed} \times \textit{Propeller ratio}}{\textit{Engine ratio}}$$

Using a *75 cm diameter x 150 cm pitch propeller* at theoretic speed (discounting slip) for every revolution it could move the boat 1.5 mtrs forward through the water. The vessel's speed would be:

Propeller pitch x revolutions per minute = distance travelled per minute or

$$\textit{Theoretical speed} \text{ in knots} = \frac{\textit{Propeller pitch x propeller revolutions x 60 minutes}}{\textit{1852 mtrs per nautical mile}}$$

$$\textit{Theoretical speed} \text{ in knots} = \frac{1.5 \times 800 \text{ rpm} \times 60}{1852} = 38.87 \text{ nautical miles/hour}$$

With a *50 cm diameter x 75 cm pitch propeller* the theoretical speed for every revolution could move the boat 0.75 mtrs forward. Assuming 350 rpm prop speed:

$$\textit{Theoretical speed} \text{ in knots} = \frac{0.75 \times 350 \text{ rpm} \times 60}{1852} = 8.5 \text{ nautical miles/hour}$$

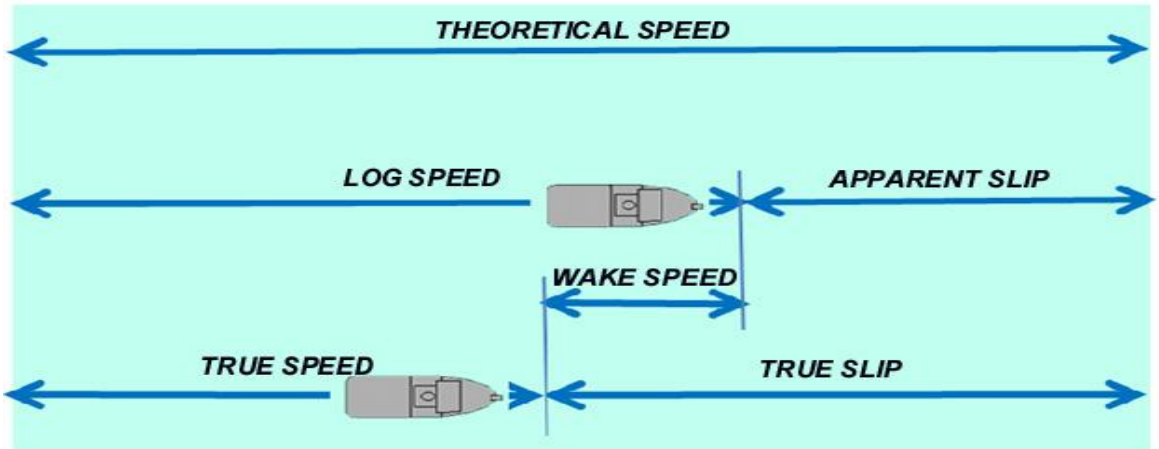
The process of the vessel through the water (*the apparent speed*) is often measured by a *log* (an impeller device recording water flow past the hull). The log suffers inaccuracies due to calibration error, water flow anomalies and the envelope of water that is dragged along with the vessel's hull (the wake). The log will read higher or lower than the *theoretical speed*. The difference between these two distances is called the *apparent slip*. For example our 8.5 knots theoretical speed read 7.7 miles on the log

Theoretical speed - Apparent speed (Log speed) = Loss/gain in speed (apparent slip)

8.5 - 7.7 = 0.8 knots *Positive apparent slip*

(Where log speed is less than theoretical speed it is called *positive apparent slip*.)

The *True speed* of the vessel between two points can be found from traditional position fixing or electronically by GPS or radar. The difference between the *True speed* and the *Theoretical speed* is the *True Slip*. The relationship of the terms is shown below:



Fixed pitch propellers

The propellers may have two, three or multiple blades of varying sizes and pitch. The aim of the ship designer is to match the engine, gearbox, shaft and propeller to enable the most efficient propulsion system for the intended trade and sea area.

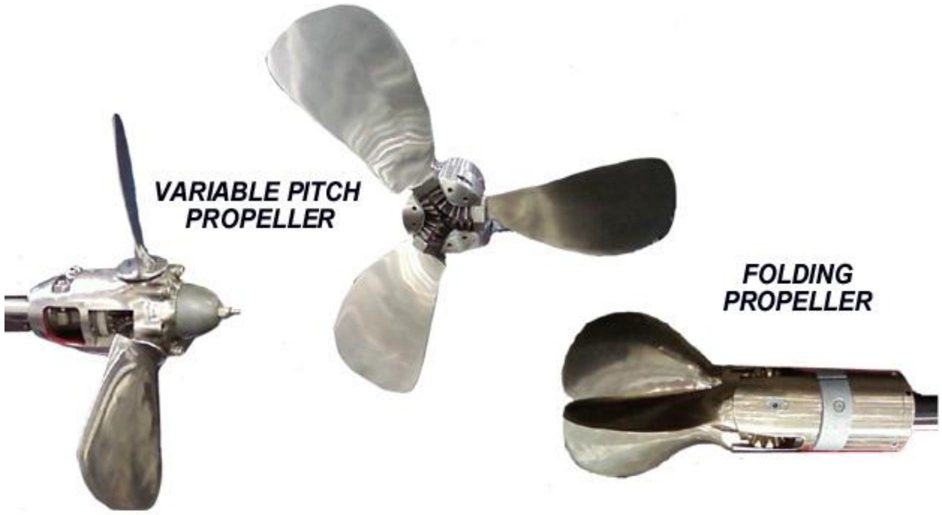
All displacement vessels will have a predetermined maximum speed at the point when the movement the hull through the water creates a displacement wave matching the vessel's underwater length. To go faster the vessel would have to climb over its own displacement wave requiring expediential and inefficient use of power. These vessels usually have shafting parallel or nearly parallel to their water line, allowing horizontal thrust from the propeller.

Planing vessels have sufficient power with flat bottoms that climb over and escape their wave of displacement to skim over the water surface. But the shaft often has to dip steeply down to reach the water, and the consequent clearance between outer bearing and the hull bottom restricts the size of propeller that can be fitted. The thrust from extreme variations of this set up can have a significant vertical (downward) component.

The selection of propellers is complex and can be aided by software calculators. General principles are that slip is reduced by a coarser pitch. High revving props and ones required for high torque operations such as towing will usually have a coarser pitch.

Controllable pitch propellers

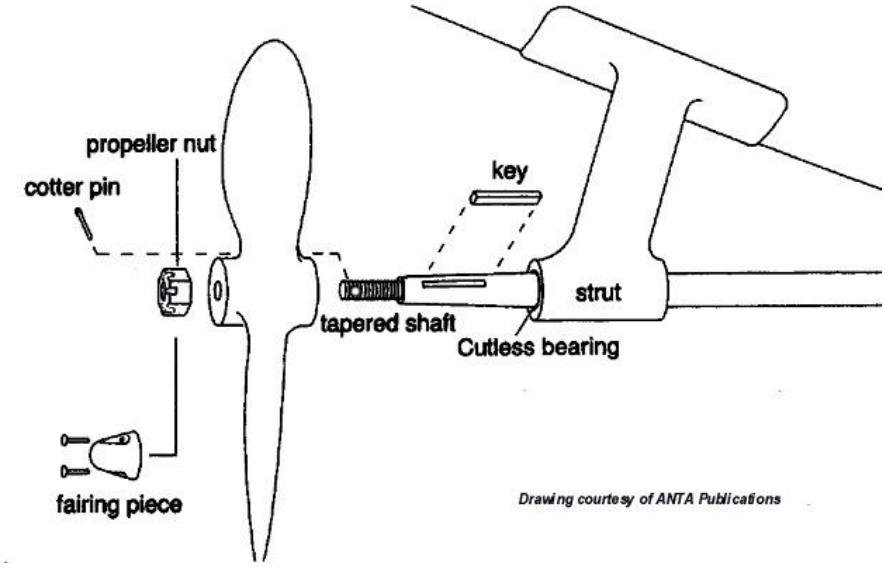
Controllable pitch propellers have blades that rotate on their axis around the hub. This provides a method of adjusting the pitch of the blades from the normal full ahead position to zero pitch then to full astern. With these props the transverse thrust is always in the same direction, as the shaft always turns in the same direction independent of ahead of astern propulsion. Controllable pitch propellers including folding props also allow refining the pitch for versatility in multitasking operations such as towing, trawling, sailing or making good speed back home with the catch.



There are many types of adjusting mechanisms. Some rely on oil pressure provided by an oil distribution/control box mounted around a section of the after most intermediate shaft, or on the end of the aft end of the reduction gear. Oil pressure is generated by a shaft or electric motor driven pump. A control mechanism is mounted on the distribution box. A piston rod passing down the centre of the shaft actuates a servo motor in the propeller hub which, by means of sliders/cranks, turns the blades.

Fitting and removing propellers

Fitting a Propeller - A machined taper of usually 1 in 12 on the propeller end of the shaft and a matching taper in the bore of the propeller positively position the propeller on the shaft. A keyway over a distance of 80% and key is provided in the shaft with a matching keyway in the propeller. The small end of the shaft is extended and threaded to take a nut. The propeller is hardened up on the shaft taper by tightening the nut. A locking device is fitted to prevent the nut from slackening that can be a *Setscrew* or *Allen screw* that penetrates both the nut and the propeller boss. Often a castellated nut and split pin or cotter pin is used.



Removing a Propeller - Think safety, as propellers can be very heavy and may have sharp edges. Always beware that as the propeller becomes free, it can quickly slide along the shaft. You should take precautions to ensure that the moving propeller does not fall off the shaft causing personal injury or damage.

To remove a large propeller first fit lifting arrangements to support the prop.

To remove a small propeller remove rope guard and fairing piece from propeller nut, then remove locking device and nut. The prop may be stuck fast on the shaft. That means that when it does come off it may do so suddenly, so refit the propeller nut and tighten for a loose fit sufficient to stop the prop jumping off the shaft when it finally becomes free.

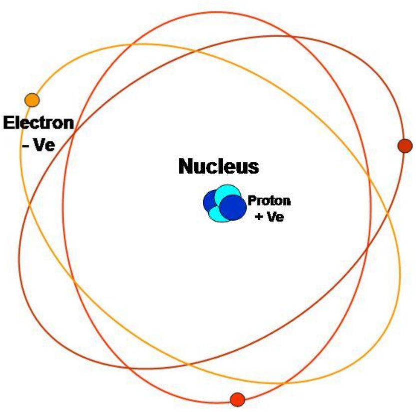
Fit the drawing gear (two or more long studs that screw into threaded holes) in the back of the propeller boss and a *strongback*. Place the strongback over the studs so that it bears on the end of the shaft and run nuts down on studs. Tighten the nuts to increase load on studs. At some point, the load will hopefully overcome the friction between propeller and shaft taper and the propeller will dislodge. If the propeller is holding, a sharp hit with a large hammer on the strongback will often produce results. In extreme cases heat may have to be applied to break the seal of corrosion.

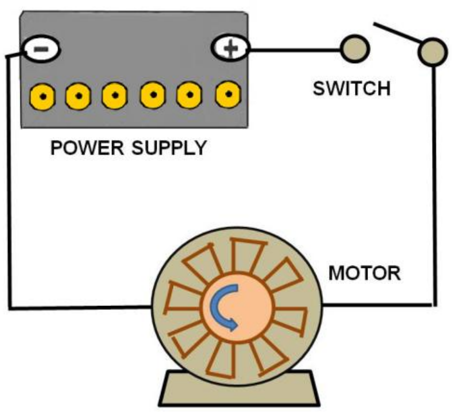
Chapter 7: Marine DC electrical systems

7.1 Basic principles, units and simple circuits

Installation and repair of electrical systems requires trained and licensed electrical tradespersons. Even though systems may incorporate warning and disabling safety devices, it is vital that any circuitry is isolated (turned off at source) before opening up for inspection. This section limits itself to basic principles sufficient that a Marine Engineer can recognise unsafe systems and call in a licensed expert if needed. Misuse can kill.

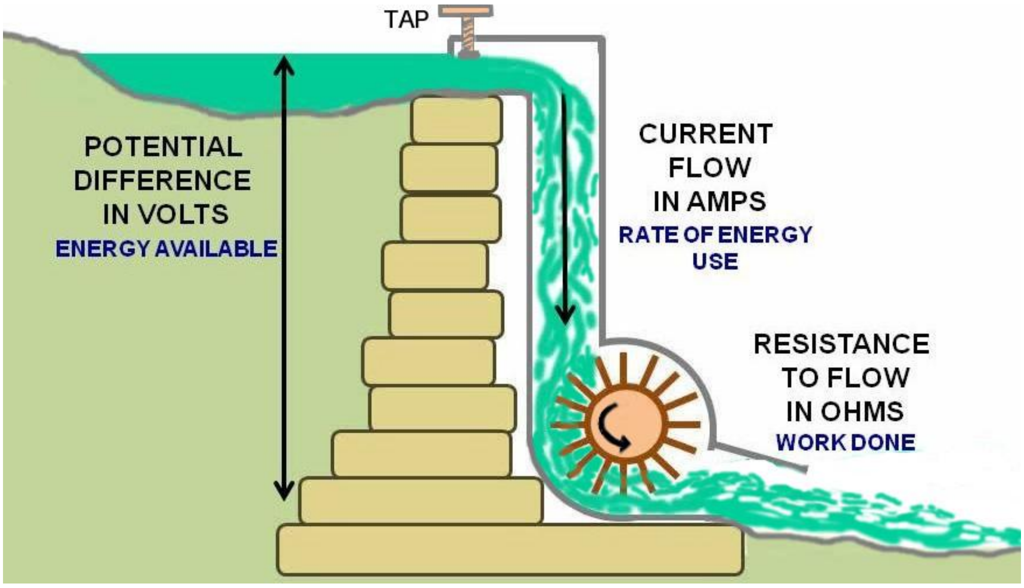
Four fundamental forces hold our universe together - *Gravity, Electromagnetism, the Strong Nuclear Force and the Weak Nuclear Force*. The building block of the universe's matter, the *atom*, has a central *nucleus* composed of particles including *protons and neutrons* (positive and neutrally charged) and an outer boundary of trapped orbiting *electrons* (negatively charged particles). A comparison can be made to planets orbiting a sun, but it is not *gravity* (the glue of solar systems) that stabilises the atom, but the *strong nuclear force* locally bonding the *nucleus's* particles and *electromagnetic* attraction of negatively charged *electrons* to positively charged *protons*. If friction, as in the collisions of ice and water within storm clouds, causes sufficient imbalance of forces to ionise the air (strip billions of electrons from their stable orbits) an energy differential can develop between the clouds tops and bottoms. In the inevitable lightning blast electrons escape in an electric charge seeking a path of lowest resistance to earth to re-bond and stabilise.



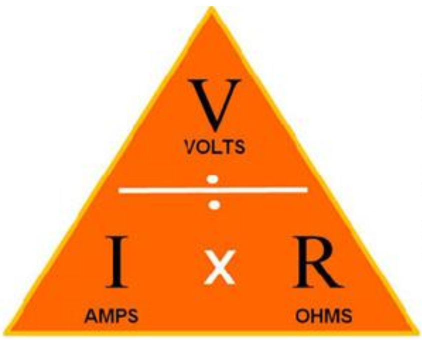


Alternatively, that charge can be harnessed within an electrical circuit. The electricity that we use to power our industry and homes uses a flow of electrons through a material described as a *conductor*. Metals and liquids (including human's tissue) are good conductors, but plastic, rubber and ceramics are so resistant to electrical flow that we call them *insulators*. Consequently, we use metals such as copper for electrical cables and plastics or ceramics to sheath them from each other or from dissipating back to earth. The simple electrical *circuit* shown above can direct current from a battery (power supply) along a conductor (the cable), through a switch and drive the electrical motor. This is an *open circuit* (the switch is off) so the motor will not work until the switch is turned on (*closed circuit*).

We cannot see the electricity, but with appropriate electrical gauges we can measure a *potential difference* across the battery (in units called *volts*), a *current* along the cable (in *amperes*) and *resistance* to turn the motor (in *ohms*). This relationship of these units can be compared with the drawing below. The top dam contains a pressure head of water (like voltage). If the tap is turned on the water flows down the pipe (like current through a conductor) and spins a water wheel below. In overcoming the water wheel's reluctance to rotate work is done and resistance is created in the water circuit.

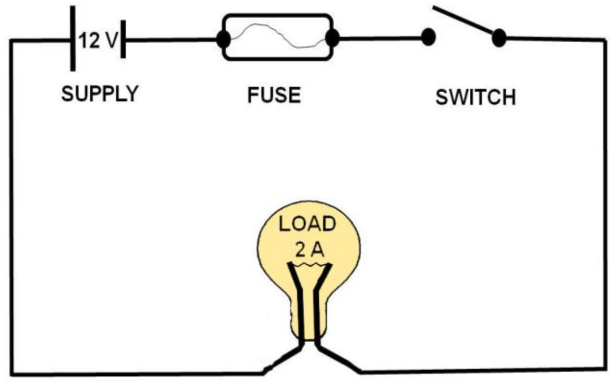


The relationship of electrical pressure, current flow and resistance (called *Ohms Law)*, is shown in the triangle and its formulas below. If we know two of the units of measure we can calculate the other and so monitor the performance of our system (its electrical *rating*).



Volts (V) = A x Ω
Amps (A) = V ÷ Ω
Ohms (Ω) = V ÷ A

Simple circuits
In the next circuit there is a battery with a potential of 12 volts and a load (light globe) that when switched on will demand 2 amps to burn brightly. Conductors resist the flow of electric current (not super conductors) and convert a portion of the electrical energy into heat. That work done will create a resistance to flow that we can calculate using *Ohms Law - The ratio of the potential difference (volts) between the ends of a conductor and the current flowing through the conductor is constant.* This ratio is called the resistance of the conductor and is expressed in the circuit and formula below:



Volts	**÷**	**Amps**	**=**	**Resistance**
12 V	**÷**	**2 A**		**6 Ω**
Volts	**x**	**Amps**	**=**	**Power**
12	**x**	**2 A**	**=**	**24 Watts**

Commonly the power consumption of a load is described by the unit called *watts*, where:

Watts = Volts x Amps

In the circuit above it can be calculated that the globe rating required is 24 watts.

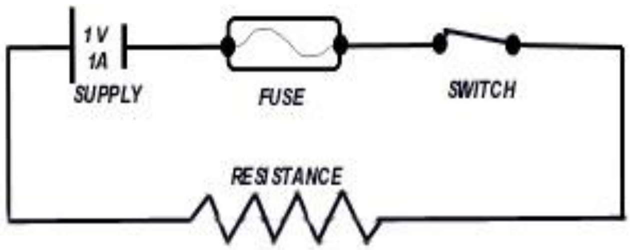
24 Watts = 12 V x 2 A

Watts (W) or Joules (P) are defined as units for the amount of work done in one second with a potential difference of one volt and a constant current of one ampere.

$$P = V \times A \qquad P = A^2 \times \Omega \qquad P = V^2 / \Omega$$

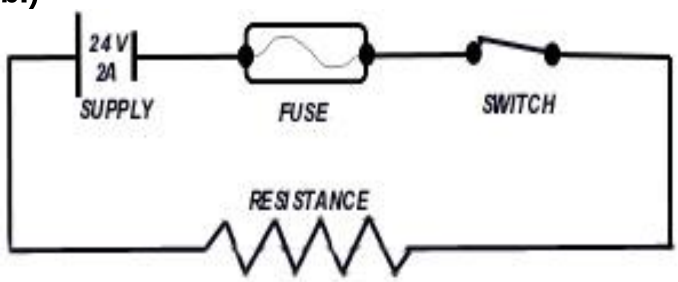
In the following diagrams:

a.)



$$R = \frac{V}{A} = \frac{1}{1} = 1\ \Omega \qquad P = V \times A = 1 \times 1 = 1 \text{ Watt}$$

b.)

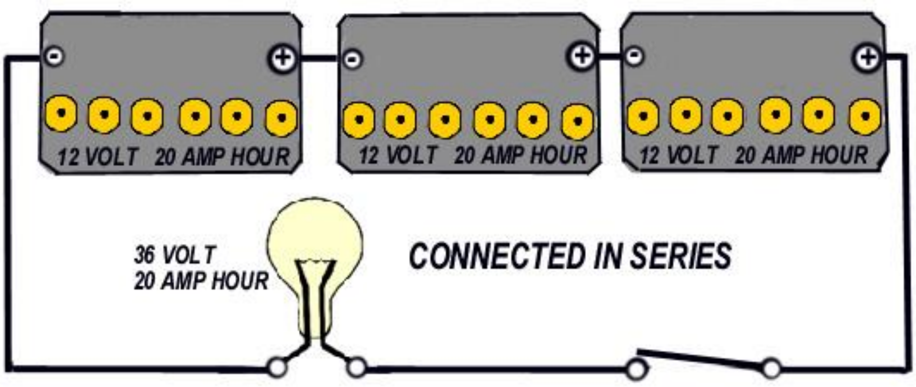


$$R = \frac{V}{I} = \frac{24}{2} = 12\ \Omega \qquad P = V \times A = 24 \times 2 = 48 \text{ Watts}$$

The circuit above includes a basic safety feature called a fuse. If the circuit is *overloaded* then the thin sacrificial wire of the fuse will glow red hot, melt and break before serious damage can occur to the circuit's cabling. This could happen if a *short circuit* occurred (where the cable's insulation is damaged and current bypasses the globe, typically by tracking through the metal of the vessel's hull or other exposed conductor). Clearly, keeping the insulation of our cables in tip top condition is a high priority for electrical safety. Don't drag power cords over sharp surfaces, coil too tightly or expose to deterioration by the heat, weather or chemicals.

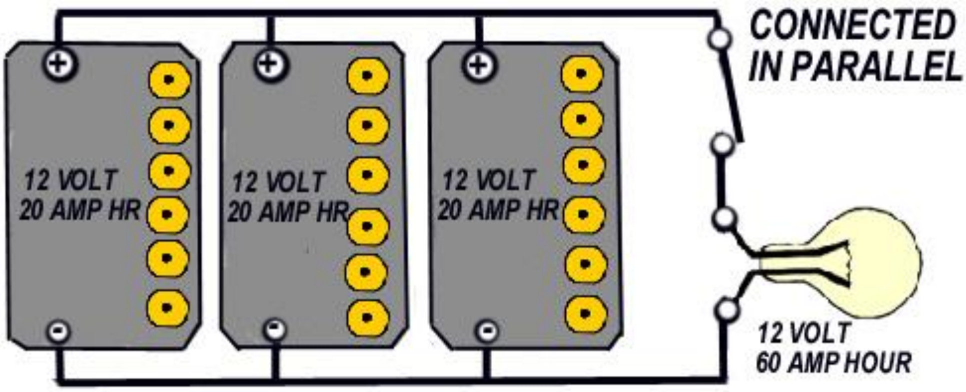
Series and parallel circuits
Series and parallel connections are made when a large storage capacity is needed but a single battery would be too heavy or cumbersome to handle.

Series Circuits- If two or more batteries are connected in line with each other, they are said to be connected in series. The total voltage would be the sum of the individual batteries added together. While the output voltage increases, the total amp-hour capacity of the three batteries together remains the same as the amp-hour rating of one. In the case below the circuit provides 36 volts at 20 amps for an hour.



Similarly other components such as resistors (electrical devices that create resistance) connected in series would have their total resistance increased.

Parallel Circuits - If two or more batteries have all their positive poles linked and all their negative poles linked they are said to be connected in parallel. The total voltage would as one of the batteries. While the output voltage remains the same, the total amp-hour capacity of the three linked batteries increases. In the case below the circuit provides 12 volts at 60 amps for an hour.



The total power available would be:

Volts x **Amps = 12 x 60 = 3600 watts**.

The resistance of the circuit would be equal to the sum of the resistance of each path. From the example above, the Ohms Law formula can be converted to:

$$R = \frac{12V}{20A + 20A + 20A} = \frac{12V}{60A} = 0.2\ \Omega$$

In the case of three batteries in parallel, they still have the same voltage, but there is an increase in the capacity. This means the linked batteries could be used for three times longer when charged but the battery with the highest terminal voltage will regulate the charger. This means the battery with the lower terminal voltage may never reach a fully charged condition.

7.2 The battery

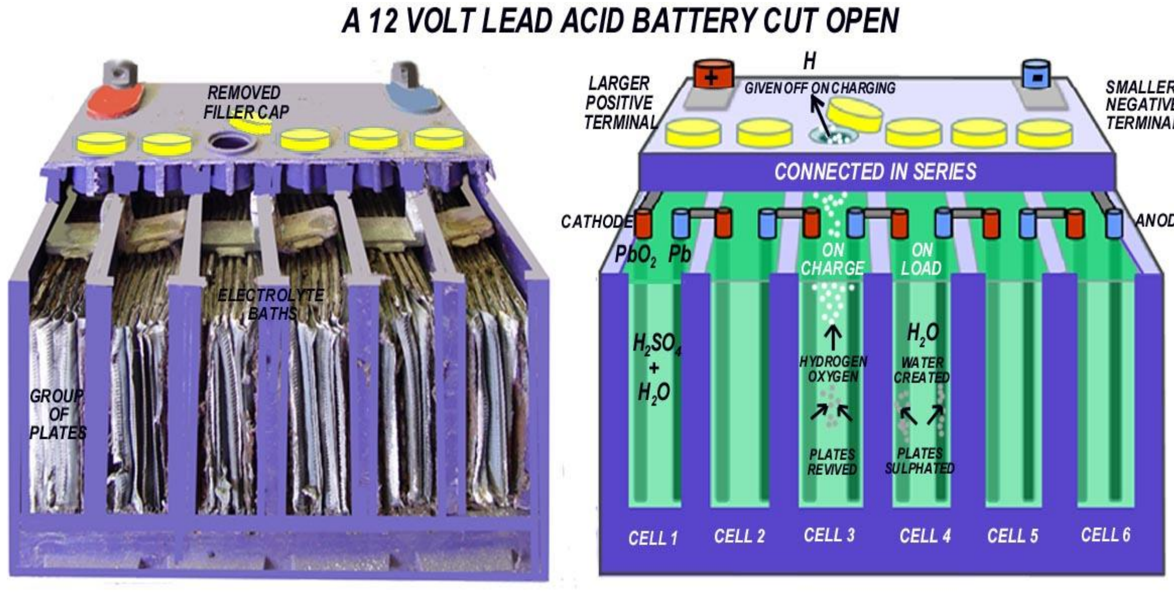
Common marine rechargeable batteries
A battery is a storage device for electrochemical energy that easily enables conversion into electrical energy and vice versa. If two *electrodes* (pieces of dissimilar metals) are immersed in a *cell* (a bath) of *electrolyte* (a reactive acid or alkali) a voltage will be produced across the electrodes. While many materials will produce a limited charge the two most common types of battery, described by their electrode metal and electrolyte, are the *lead acid battery* and the *alkaline battery*. In a *lead acid battery* (dilute sulphuric acid and lead), each cell produces approximately 2.1 volts. A nicad *alkaline battery* (potassium hydroxide and nickel/cadmium) produces 1.22 volts in each of its cells. For usefully higher voltages these batteries need groups of cells to be connected in series. Great care must be taken not to cross contaminate acidic and alkaline materials in order to maintain their fortitude and to avoid explosive reaction.

Lead acid batteries
The components of a lead acid battery cell are:.

Positive plate cathode of lead dioxide (PbO_2)
Negative plate anode of lead (Pb)
Dilute sulphuric acid electrolyte ($H_2SO_4 + H_2O$).

While undergoing a discharge cycle (battery on load) lead sulphate is deposited on both plates and water is formed due to chemical reaction. The water dilutes the electrolyte, lowering its specific gravity from approximately 1.26 to 1.15.
When charging, the lead sulphate is re-converted to lead dioxide on the positive plate and lead on the negative plate. At the same time ionised, sulphuric acid is formed and

hydrogen and oxygen is released from the H2O. This causes electrolyte concentration and the specific gravity to return to approximately 1.26. The hydrogen emitted on charge is an explosive gas. Measuring the specific gravity of the electrolyte can therefore determine the state of charge of each cell of the battery.



In the battery above the six cells with a maximum of 2.1 volts are internally connected in series to give an output of 12.6 Volts (nominally 12 volts)

Alkaline batteries
Alkaline batteries are generally externally connected.
A variety is available including *Nicad* (Nickel Cadmium), *NiMH* (Nickel-metal hydroxide), *Nickel Zinc* and *Lithium.* The components of a *NiMH* alkaline battery are:

Positive plate (nickel hydroxide)
Negative plate (calcium hydroxide)
Electrolyte (potassium hydroxide)

They use alkaline instead of acid and the active materials do not dissolve in the electrolyte. The electrolyte transports ions between the positive and negative plates and the plates undergo changes in their oxidisation state. The specific gravity does not change between charged and discharged condition so it is necessary to use the terminal voltage to determine the state of charge. Alkaline batteries emit hydrogen/oxygen so avoidance of possible sparking should be taken when dealing with these batteries.

Deep cycle and cranking batteries
The plates of automobile batteries are thin and made of a porous loose active material so that maximum exposure to the electrolyte is obtained with a minimum internal resistance. This allows maximum chemical reaction to take place and allows maximum current availability for a short burst. Automotive batteries cannot withstand *cycling* (being run down to near discharge and then being recharged) and should be maintained at 95% charge. Few batteries will ever recover from more than nine complete discharges.

Similarly marine batteries dedicated to *cranking* (starting the engine) experience momentary high current drain and need wider space between the plates for the water created during high rates of discharge to disperse in the electrolyte.

Deep cycle batteries have thicker the plates made of denser active material sometimes separated by glass matting. They can withstand cycles of long continuous discharge and repeated recharging and are ideal to run house lights and the ship's general purpose outlets. They should be rated so that the discharge does not go below 50% of battery capacity. A higher charging voltage of approximately 14.5V may be required to achieve this. Marine deep cycle batteries have other features including greater plate coverage so when the vessel is heeled the plates are not uncovered - a process that would oxidize them with consequent rapid deterioration of overall battery performance.

Installation survey requirements
Batteries must be provided with isolation switches and preferably changeover switches to allow *cycling* of batteries (using one bank at a time to keep one spare). They must be secured to prevent movement at sea or objects falling onto the terminals to cause short circuit or even fire. They must be protected from mechanical damage and damage from water. Storage boxes must be acid resistant and ventilated to disperse the hydrogen gas. Battery terminals must be electrolyte resistant and cable ends sealed to prevent electrolyte entry.

Motor starters and solenoids must be covered and protected to prevent sparks. If alkaline batteries are fitted they should be installed to prevent short circuit from one case to another and between one case and the metal hull.

In a typical installation (low in an engine room next to the motor) thought must be given to how an emergency radio will work when if in-flooding occurs. Many vessels will have emergency batteries installed high in the vessel to mitigate that risk.

Alkaline Batteries
Terminal voltage is the only way to determine the level of charge. 1.3 volts is fully charged down to 1.0 volts being fully discharged. The charging voltage required for alkaline batteries is higher than that of acid batteries and is typically 15.5-16V for a 12V battery. The normal alternator's regulation set for lead acid batteries (usually set at 14 volts) will not deliver enough current to fully charge the battery but will only deliver a float charge.

Safe battery handling

Batteries must be handled with care as they are heavy, give off explosive hydrogen on charge and contain acidic or alkaline chemicals that can burn the flesh and eyes.

Wear safety goggles and rubber gloves to protect from the corrosive electrolyte.

Do not make sparks by touching leads on the battery terminals.
Be careful and use insulated tools when working on the battery.
Do not wear jewellery that can create a short circuit or sparks.

Avoid electrolyte spillage. It can mix with salt water and create chlorine gas.

Ensure you have sufficient ventilation around your batteries.

Never place acid batteries and alkaline batteries in the same compartment as the acid fumes will contaminate the alkaline batteries causing permanent damage.

Fit circuit breakers and correct fuses with additional electrical equipment fitted.

If battery fluid spills on your clothing or skin, wash immediately with cold water. A solution of baking soda and water can be used to rinse clothes or neutralise acid if a spillage occurs.

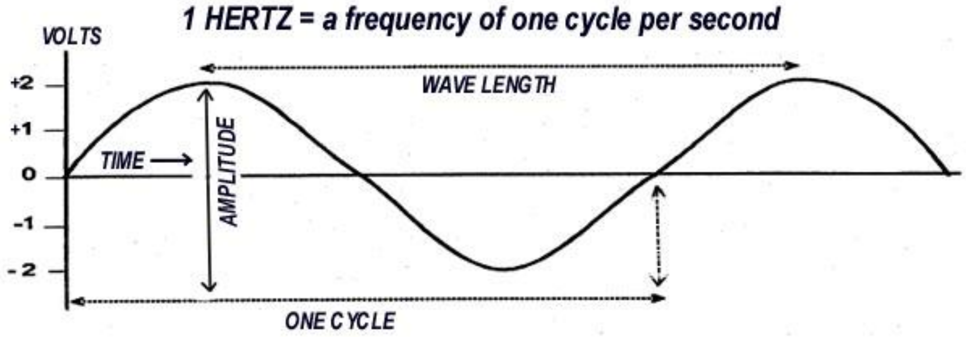
Battery testing of battery charge

The specific gravity of a lead acid batteries electrolyte is measured with a *hydrometer.* On battery discharge, the electrolyte becomes less dense, and the indicator in the hydrometer will sink. These batteries should be tested at least weekly. For safety, wait 30 minutes after charging/discharging and turn off all loads before taking measurements. Before removing the battery filler caps ensure adequate ventilation and remove naked flames. Insert the hydrometer it into each cell, squeezing its bulb to draw liquid into the chamber. Reading the scale at eye level will tell you the batteries condition. Typical readings are as follows:

Charge	***S.G.***	***Voltage***
100%	1.26	12.75
80%	1.22	12.55
60%	1.19	12.35
40%	1.16	12.1
20%	1.13	11.85
0%	1.1	11.65

7.3 Battery charging, generators and the starter motor

Electricity is electron flow along a conductor in the form of *DC* (direct current) or by *AC* (alternating current). DC is driven by a steady voltage in one direction only and is the product of the batteries described earlier. AC is a pulsing current driven by a voltage wave that alternates between a negative and a positive voltage.



Mains supply AC electricity is the product of an alternator resulting in a pulsing flow generated from their rotating windings within an electromagnetic magnetic field. This AC supply must be converted to extra low voltage DC supply to use in the vessels batteries, starter motor and lighting circuits. In mains supplied battery chargers this *voltage reduction* is achieved by the use of transformers and *rectification* (converted from AC to DC) is achieved with *diodes* (electrical one way valves). Alternators actually generate three pulses of electricity for each revolution of their generating rotors. These *phases* are more fully described in the next chapter.

Battery charging from the mains supply

It is safer to remove a battery from its battery box to the bench if there is risk of explosive of the hydrogen emitted on charge. Automobiles use the car body as the negative return. If their positive battery cable touches the car's body a spark will occur. Boats use a twin wire system with the metal hull insulated to limit electrolytic corrosion. Though not essential as with car battery removal, it is good practice to disconnect the negative battery cable first, secure it against contacting equipment, and then remove the positive lead and secure. This limits accidental sparking by touching leads. When reconnecting the battery to a car, attach the positive lead first and tighten the terminal clamp, and then the negative cable.

When connecting the battery to a charger, first remove the cell caps to ensure the electrolyte covers the cell plates to a height recommended by its manufacturer (usually 4 - 6 mm). Ensure that the positive wire and the negative wire are connected to the appropriate terminals before switching on the charger. Ensure that the charger is set on its appropriate 6 volt or 12 volt charge, depending on which battery you are about to charge.

Most chargers have a high amperage charge rate and a low amperage charge rate. Choose the lower rate over a longer period if time permits, or if the higher rate is selected, then frequently check that the electrolyte is not bubbling over. When the charger meter or indicator lamps show that the battery is fully charged, let it sit for 30 minutes as the electrolyte temperature has increased whilst charging. Cooling is required to take an accurate hydrometer reading.

BATTERY CHARGER

BATTERY TESTER

Battery charging from electrical generators

When a wire coil is moved through a magnetic field, a voltage is induced in that wire coil. Similarly if a magnetic field was passed over a stationary wire coil a voltage is induced in that wire coil. This principle enables electricity to be produced by a *motive force* (movement). Devices that produce electricity in this way are all commonly called generators, but there are several technical types as described below.

The magneto

A *magneto* is an electrical generator using wire coils and magnets to produce alternating current. It produces pulses of high voltage to activate the spark plugs of small petrol driven internal combustion engines such as light weight outboard motors and lawn mowers. The *shuttle magneto* variation spins a wire coil on its flywheel between the poles of a magnet whereas the *inductor magneto* spins the magnet around a static wire coil.

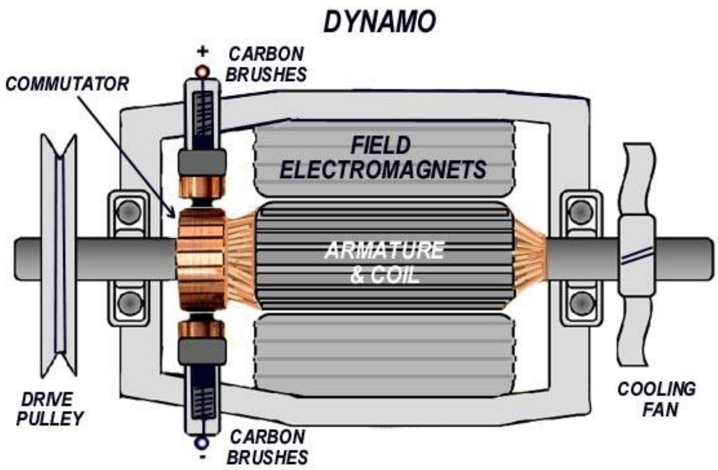
A cam on the drive shaft opens the *points* (contact breakers) momentary interrupting the current and collapsing the coil’s electromagnetic field. This induces a voltage across the coil, which in turn supplies the energy for the spark plug firing. To prevent high voltage arcing at the point’s contacts, leading to rapid decay, a *capacitor* (an electrical storage and smoothing device) is placed across the points to absorb the energy burst. (*Capacitors,* previously called *condensers,* are built from two films of electrical conductors separated by a film of electrical insulator).

The system is rarely used for vehicles or vessels that have electrical accessories, except for aero piston engines where simplicity and reliability are of advantage. The magneto is not used to charge batteries in marine systems but in old outboard motors may be wired to power an emergency light.

(Photo courtesy of www.forums.iboat.com)

The dynamo
A *dynamo* or *generator* is an electrical generator, belt driven by the motor, using wire coils and magnets to induce alternating electrical fields which are converted to direct current at the *commutator* (a segmented rotary electrical connection/switch using carbon brushes for continuous contact).

The dynamo has a stationary outer casing providing a magnetic field and a set of windings on an *armature* (supporting axle assembly) rotating within the field. The magnetic field is created with either permanent magnets or *electromagnets* (field coils). Dynamos use their rotary switch on the armature, the *commutator,* to output DC current, and an external voltage regulator to control output over the range of speeds of the driving motor.

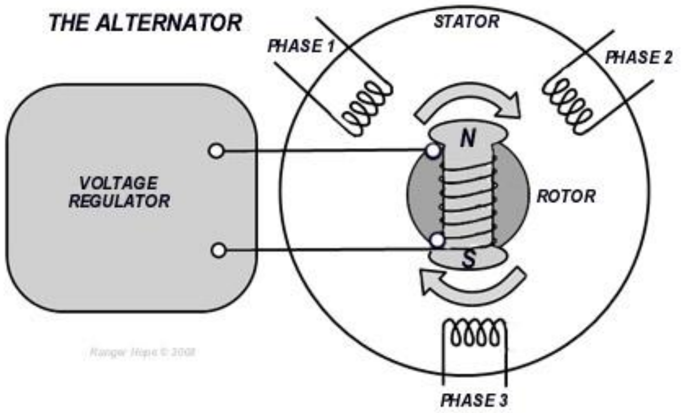


The dynamo operates at any speed with low output at engine idling. The alternator (described below) cuts in at a minimum speed but has greater output than the dynamo at idling. Additionally, the complexity and maintenance requirements of the dynamo's commutator and brush mechanism have resulted in it being largely superseded by the alternator for automobile and marine DC battery charging.

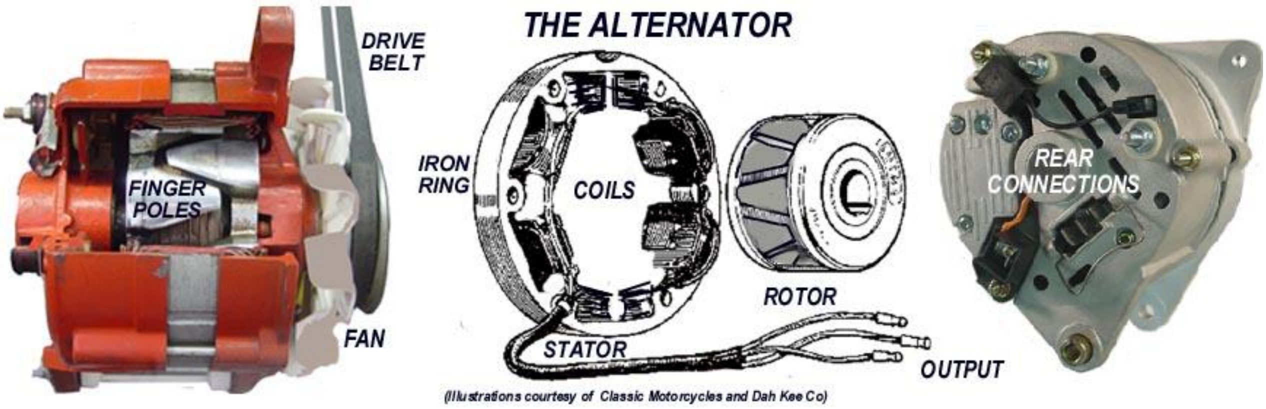
The dynastart
A dynastart is a combined dynamo/starter motor championed in *Stuart Turner*'s traditional marine petrol engines, renowned for their simplicity and reliability. The single unit with fields and coils can reverse switch its polarity connections to achieve both functions through a voltage regulator and control box.

The alternator, components and operation

The simple belt driven battery charging alternator consists of a *rotor* (a field winding assembly) rotating within a *stator (*a stationary induction winding assembly) so inducing alternating current in the stator's three sets of windings.



The batteries require DC for charging so a *rectifier bridge* (a diode assembly) converts this to AC while a *voltage regulator* (a voltage control device) ensures a steady supply output throughout the acceleration range of the driving motor. An integral fan or twin fans (depending on the model type) also provide internal cooling.



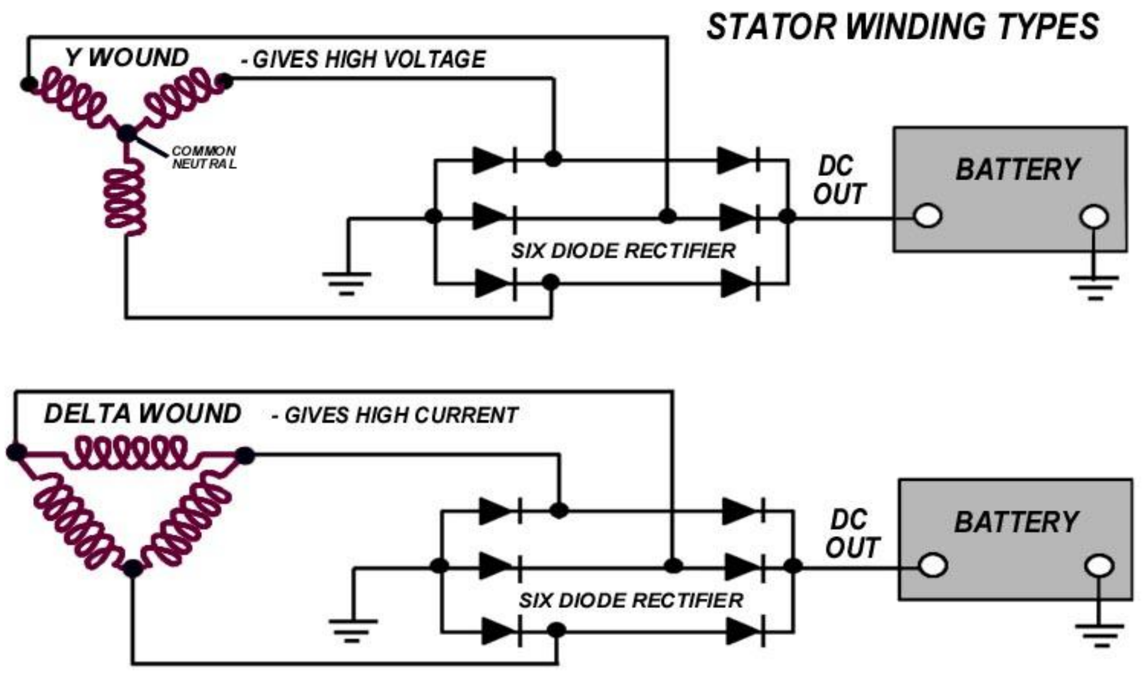
(Illustrations courtesy of Classic Motorcycles and Dah Kee Co)

Over the iron core of the spinning rotor shaft are the field windings surrounded by two claw-type finger poles. The ends of the rotor field windings are attached to twin slip rings that maintain contact during revolution by using *brushes* and allow current to flow through to the field windings.

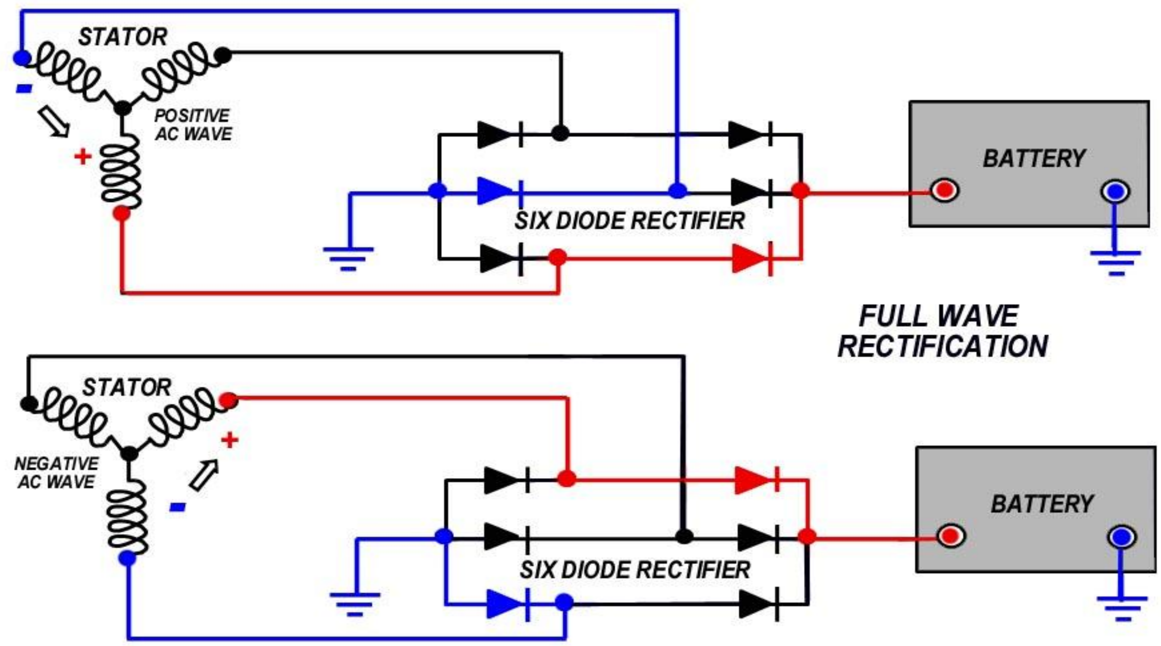
The stator- has three sets of winding coils evenly spaced around its core, its laminated iron ring concentrating the magnetic field. Two differing wirings arrangements are used:

Y - wound stators with three windings with a common neutral connection. They have three plus one (four) stator lead ends and provide high voltage output at low rpm. Two windings are in series at any time.

Delta - wound stators with three stator lead ends provide higher current flow at low rpm. The windings are in parallel.



The rectifier bridge - converts the stator AC output to DC output. Typically six diodes are sat on a heat sink that dissipates heat. A single diode would block half the output alternating current (either the positive or negative voltage section of the wave's cycle) so efficient rectifiers have both + and - diodes connected to each stator lead. As the rotor spins the current induced in the stator windings alternate in voltage polarity. The current paths available at the rectifier enable both the positive and negative polarity in the wave's cycle to be fed to the battery as DC output. *Full-wave rectification* describes this configuration (shown below).



The regulator- The regulator monitors battery voltage. It maintains a pre-determined charging system voltage level by increasing or decreasing the field current (and consequent magnetic field and alternator output) as is required. The regulator is usually internal but can be external. Two designs are commonly used:

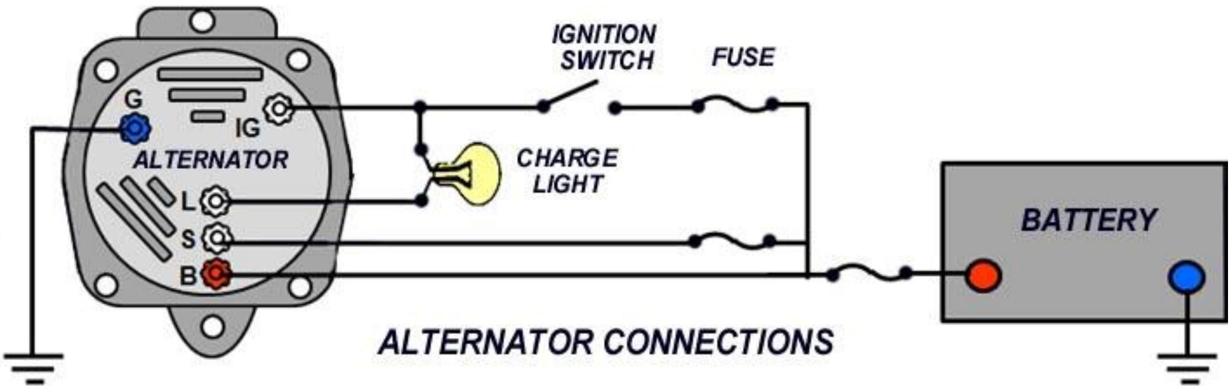
The *grounded regulator* controls the amount of battery ground (negative) going to the field winding in the rotor.

The *grounded field regulator* controls the amount of battery positive (B+) going to the field winding in the rotor.

Summary of the alternator's operation - As the alternator's rotor spins a magnetic field is generated that saturates the iron finger poles. One finger pole becomes a north pole and the other a south pole. An alternating magnetic field from north/south to south/north is created that induces voltage in the stator so current begins to flow.

The strength of the magnetic field and the speed of the rotor affect the amount of voltage induced into the stator. The voltage regulator monitors battery and stator voltages and will adjust the amount of rotor field current to control alternator output.

The resultant three overlapping output current waves from the three sets of winding coils make up the AC stator's output as three phase current. The stator output current is led to the diode rectifier bridge where AC is *rectified* (converted) to DC. Six (or eight diodes) are used, half on the positive side and half on the negative side.



Unlike the auto electrical system where the car body is itself the negative earth, the marine system is always a twin insulated wire system. The earth connections shown for simplicity above and in marine DC systems are fully insulated and connect to the neutral side of the battery. Four *terminals* connect the alternator to the charging system:

IG- *From the ignition switch that turns on the alternator/regulator assembly.*

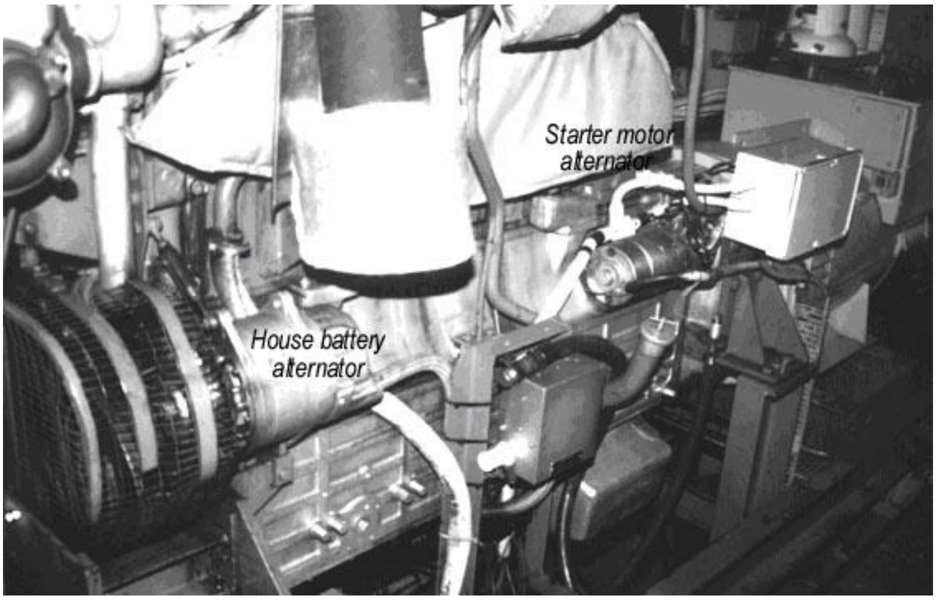
B- *The alternator output terminal that supplies current to the battery.*

S- *The battery voltage sensor used by the regulator to monitor charging at the battery.*

L- *Used by the regulator to ground the charge warning lamp.*

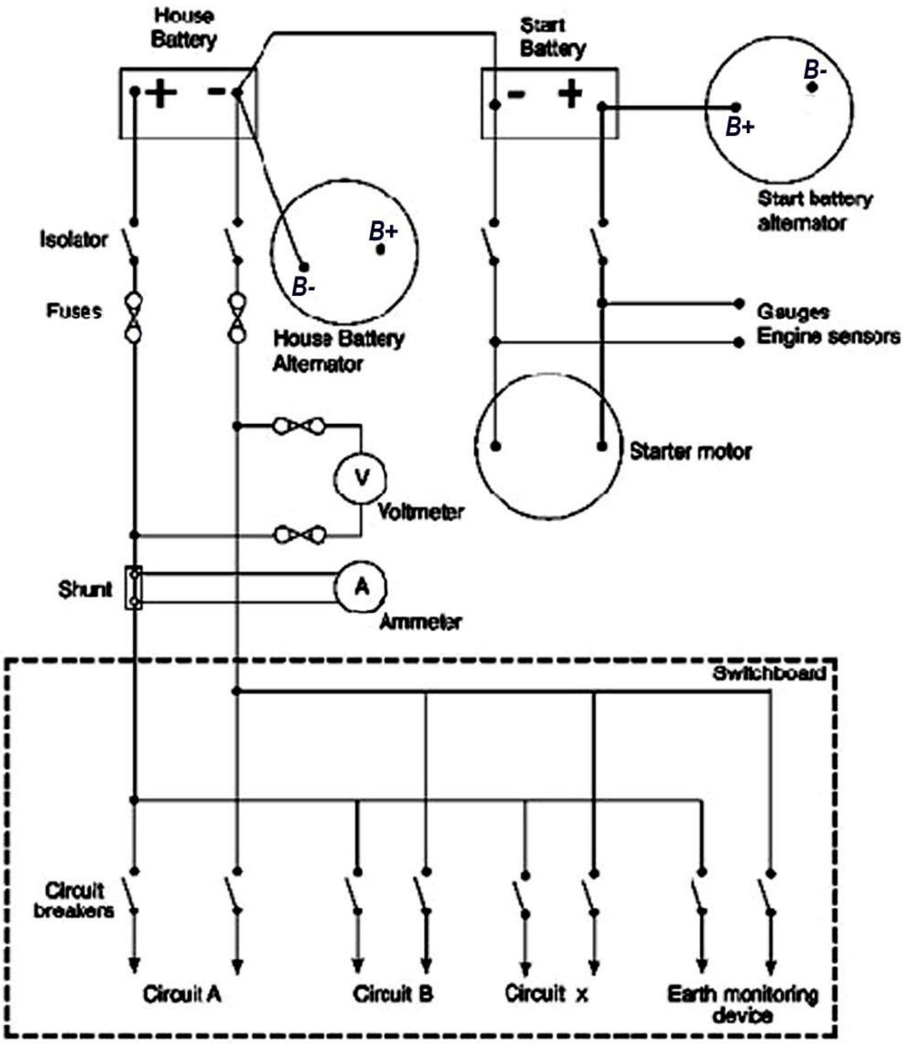
*The **F** terminal (not shown) is for a regulator full-field bypass.*

Twin battery bank charging alternators
Shown below two separate alternators are wired to charge the house (deep cycle) and the starter motor batteries (cranking). Battery charging alternators are 3 phase AC *alternators* producing DC output through a *diode/s* (an electrical valve that only allows one way flow). Most alternators have a charging voltage of 14V which is sufficient for lead acid batteries but insufficient for alkaline batteries which require 15.5V - 16V. The charging rate is controlled by the regulator which monitors the output voltage of the alternator and varies the field voltage in response to load variations.



Starting battery alternator - As with all alternators, the drive belt tension must be regularly checked to ensure charging. The alignment is also important to avoid bearing and belt wear. The battery will absorb a large current until the battery charge level is approximately 50%. When this is achieved the regulator starts to limit the voltage. The charge current will level off as the battery voltage level rises.

House battery alternator - A connection diagram below is shown for house and starter alternators with reversed belt drives. Larger and dedicated generator sets (alternators) associated with 240V supply are described in the next chapter.



PAIRED ALTERNATORS *(Drawing courtesy of ANTA publications)*

Charging system failures on a starting battery alternator

Initial output checks are shown by the lamp as determined by the regulator. Check that the voltage across the main and negative terminals rises to approximately 14V. No voltage indicates a total failure of the alternator or regulator. A lower voltage indicates that some diodes have failed or there is a regulator problem.

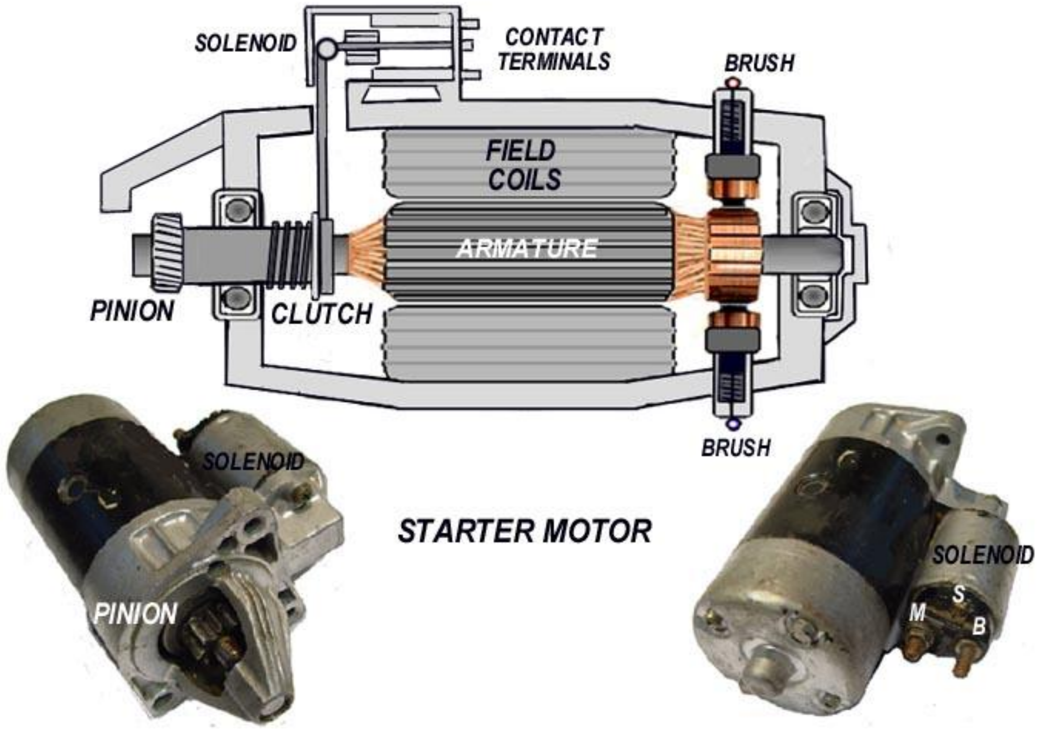
It is possible that the brushes in the alternator are not seated properly on the slip rings. If the voltage is correct, check the voltage at the battery and ensure that the terminal connections, leads and isolation diodes are satisfactory. There are two methods of regulator sensing:

The machine sensing method - monitors the output voltage and adjusts the alternator output value to approximately 14 volts. It does not allow for voltage drops in the charging circuit caused by terminal connections, undersized wiring or isolation diodes (if installed).

The battery sensing method - measures the voltage at the battery and adjusts the alternator output voltage to compensate for voltage drops in the charging circuit. This ensures the correct voltage is supplied to the battery. If the warning light does not operate when the ignition is turned on, check for a lamp or connection fault at the lamp or the D+ terminal. If these are satisfactory, the alternator excitation diodes maybe faulty. In an emergency, if there is a faulty regulator or a partial diode failure, the regulator can be disconnected and a full field voltage connected to achieve maximum output.

The engine starter motor

The starter motor reverses the dynamo's principle of using motion within a field to generate electricity by using electromagnetism to create motion. These motors have very heavy work to do albeit for a short time so the cabling must be thick, of a short run and have clean contacts with large surface area to avoid resistance, sparking and consequent overheating.



The solenoid forces the pinion outward to temporarily engage with the engines flywheel. On the motors starting and release of the starter switch the pinion springs back clear. Common faults with starter motors are poor connections. The pinion can jam in engagement with the flywheel in older worn starters. If the solenoid indicates that it is working by a click on turning the ignition starting key then a tap on the rear end of the starter motor with a rubber hammer may free it until the required service and repair can be undertaken.

7.4 DC circuit protection

To protect circuits and users from electrical accidents a twin wire insulated return is used in marine applications. The insulation must be in good order and especially checked where routed through bulkheads (for cuts on sharp edges). Extra low voltage (ELV) marine systems are completely isolated including engine sensors, starter motors and alternators.

Preferably there should be a main *twin pole isolator* (switch to both positive and neutral wire) to close circuit with the battery bank and fuses to open circuit in case of overload. Pole switches are more fully described in the next chapter on AC current. They must be an enclosed type so sparks or arcs protect from explosion. An ammeter is installed here to verify safe battery discharge levels. A volt meter may be installed so that battery charger voltage and charge condition is monitored.

From the main switchboard, power is distributed to various switch/fuse combinations or circuit breakers which either supply circuits to items of equipment or other distribution boards. An earth indication system is also be fitted in this switchboard. All circuits should be protected with a twin pole isolator.

Short circuits
Short circuits can occur when the positive side of the battery is connected directly across to the negative side, bypassing the equipment itself. This causes an excessive current flow, generating heat and causing fire to occur (usually at the smallest wire in the circuit), unless fuses or circuit breakers are fitted. A dramatic short circuit will occur if you were to drop a metal tool onto your battery and it were to touch both battery poles at the same time.

Fuses and circuit breakers
Fuses are usually fitted to protect DC wiring and equipment from overload. Though usually reserved for AC wiring, circuit breakers may be found with specific DC applications.

A fuse - is a thin metal wire designed to *open circuit* (break) by melting if the current goes above a certain level, so stopping a surge continuing down the wiring system. A surge from a short circuit would otherwise cause equipment damage or electrical fires.

Engine room fuses must be ceramic or glass encapsulated to avoid being an open ignition source causing fire or explosion. If a fuse blows, it must be entirely replaced with the same amperage fuse. A fuse that continuously blows must never be replaced by a higher amperage fuse that does not, but rather the electrical problem causing the blow must be identified and repaired.

Circuit breakers - are load sensitive switches that *trip* (open circuit) if a predetermined excess current flows. They are more fully described in the next chapter on AC current.

Stray currents
Stray currents are leakage currents which occur when a conductor has an earth fault. They are often too small to trip circuit breakers or other protection devices.

These faults are usually caused by moisture in junction boxes or other components, and from damaged cable insulation. Also, when operating electric motors for pumps and other equipment, a magnetic field is produced around and about the motor. This field creates an electrolytic reaction with the sea water so electrolytic corrosion of the metal hull can follow.

It is for this reason that sacrificial anodes are located on the parts of the vessel most likely to be affected by this reaction. These anodes are made of materials such as zinc, which corrode before the metal hull or other parts. The anodes must be replaced regularly. Any faults which may produce stray current must be rectified as soon as possible.

Because of the serious effects of stray currents, it is necessary to regularly check the earth monitoring system as it is imperative that the earth faults be rectified as soon as practical.

The cause and cure of electrochemical corrosion is more fully described in Chapter 10, and isolation earthing in the next chapter on AC wiring.

Extra Low Voltage (ELV) systems
Any system with a voltage below 110 V is known as an Extra Low Voltage (ELV) system. Systems where the voltage is between 110V and 240V are known as Low Voltage systems. These are described in the next chapter.

Chapter 8: Marine AC electrical systems

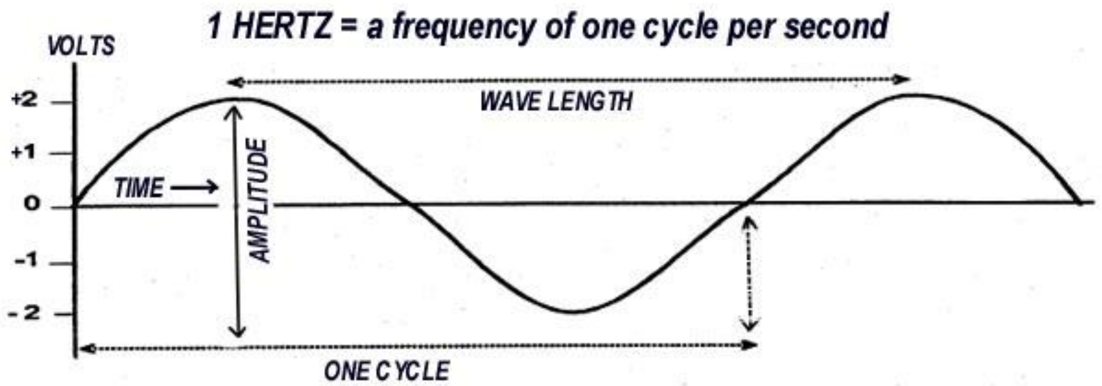
8.1 Electrical safety with AC

Extra Low Voltage Systems (less than 110V) were described in the last chapter. This chapter describes *Low Voltage* Systems (110V - 440V) and *Medium Voltage* Systems (over 440V).

DC and AC

Electricity is electron flow along a conductor in the form of *DC* (direct current) or by *AC* (alternating current). DC is driven by a steady voltage in one direction only and is the product of the batteries described in the previous chapter.

AC is a pulsing current driven by a voltage wave that alternates between a negative and a positive voltage. The frequency of this cycle is defined in units of *Hertz* (cycles per second), and in Australia domestic 240V electricity is supplied at 50 hZ. Beware, other countries such as America (and their ships) may use 60 hZ.



We are more familiar with higher voltage AC systems than higher DC systems. However, take care not to assume the low electrocution risk of 12V systems with higher DC systems. Even moderately higher voltage DC induces a clenched fist reaction that will make an electrocuted victim involuntary grip tight to a cable, whereas at a similar voltage AC may to throw the person off.

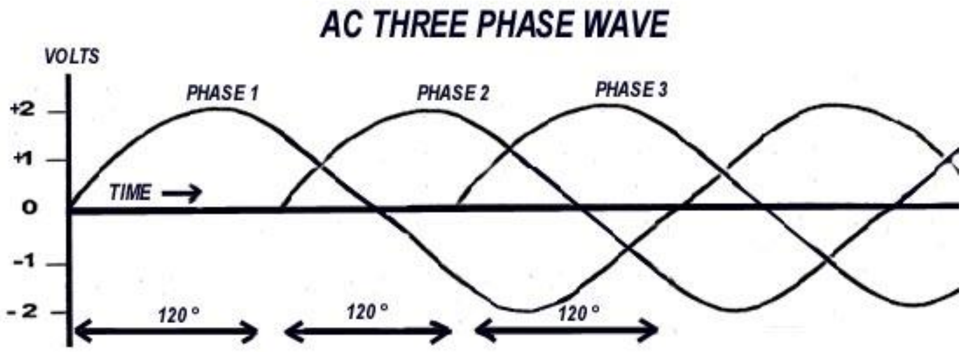
AC electricity is produced by an alternator and needs to be converted to DC to use in the vessels batteries, starting and lighting circuits. To do this a *diode* that only allows electrical flow only in one direction is incorporated in the charging circuit. Alternators also generate three pulses of electricity for each revolution of their generating rotors. These *phases* are more fully described below in the section *three phase*.

8.2 Single and three phase

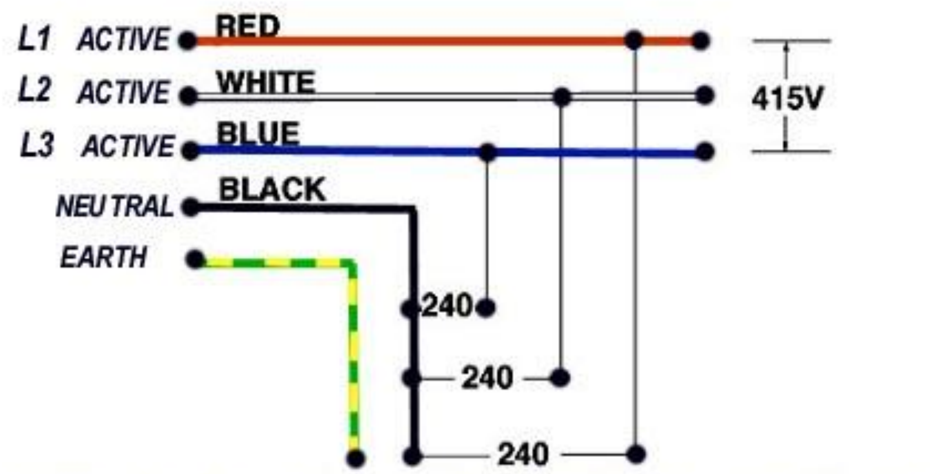
Ship's *Single phase* systems are normally 115V AC or 240V AC. These are twin wire systems consisting of one *active* (positive) conductor and one *neutral* (negative) conductor. Current standard single phase wire colours in Australia are:

Active - brown (older wiring was red)
Neutral - light blue (older wiring was black)
Earth - green and yellow (older wiring was green)

Three phase electricity is generated by an alternator. *Three phase* supply is much more efficient at transferring electricity over long distances than single phase and uses smaller cabling for the power carried. Due to the triple wave form generated at 120° electrical separation, it also provides a more constant current than single phase that dips through zero volts on every cycle.

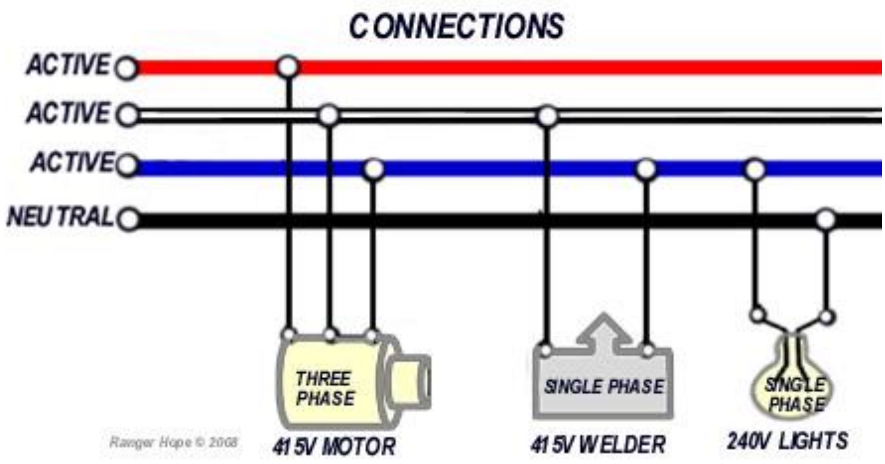


Three phase systems are triple wire systems consisting of three active conductors and one neutral. Different countries use different colour schemes to identify each wire. Older Australian colour coding may still be found in aged vessels.



THREE PHASE AUSTRALIAN COLOUR CODE TO AS/NZS 3000:2007

Three phase system enable a number of connection options. It can be used to run three phase equipment, or can be split up as 3 single phase systems using a neutral.



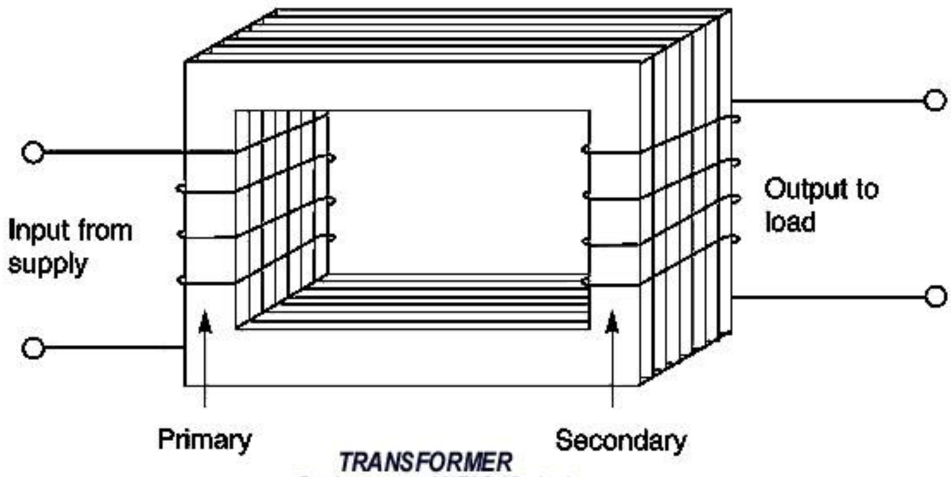
Using three phase without a neutral to obtain 240V single phase is achieved with a transformer.

Transformers

When a wire is moved through a magnetic field, a voltage is induced in that wire, the same thing would happen if the wire was stationary and the magnetic field was moved. This principle enables electricity to be generated.

Also, when a current flows through a wire, a magnetic field is produced around that wire. This principle enables transformers to change one voltage to another.
The transformer has no moving parts except for the magnetic field which is continually changing due to the alternating current. Transformers will not work on *direct current* (D.C.). They have three main components, the:

Primary coil
Secondary coil
Laminated steel core



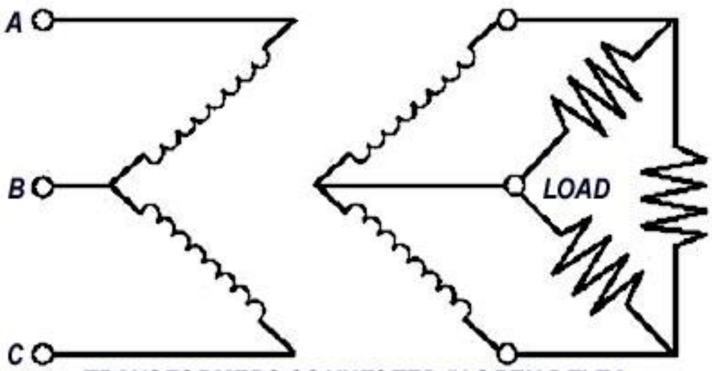
TRANSFORMER
(Drawing courtesy of ANTA Publications)

The primary and secondary coils are wound on a laminated steel core and insulated from one another. The supply voltage is connected to the primary coil and the load is connected to the secondary coil. The alternating current in the primary coil creates an alternating magnetic flux in the laminated steel core. This flux causes an electromotive force to be induced in the secondary coil.

Transformers can be used to step up or to step down voltages dependant on the ratio of wire turns in each of the opposing coils. (Never disconnect any transformers in the switchboard while the power is on).

Vessels will normally produce three phase 415V to drive motors. The reduced voltage from the transformer could be used at 240V to supply lighting circuits or at 24V to supply a rectifier for recharging batteries or DC lighting. To achieve this, the control circuit in the main switchboard is controlled by a step down transformer situated in the switchboard. Also in the switchboard you would find *current transformers* (CT's) which supply the *ammeters* and *potential transformers* (PTs) which supply the *synchroscope* (see paralleling alternators in next section).

Three phase transformers can be wound on to one core or they can be three single phase transformers. One advantage of using three single phase transformers is that if one fails, the remaining two can be connected in an emergency to still produce three phase at 57% of the initial capacity.



TRANSFORMERS CONNECTED IN OPEN DELTA
(Drawing courtesy of ANTA Publications)

Isolation transformers are used in shore power connection to galvanically isolate the vessel from its shore power. Eliminating the ground path ashore reduces electrolytic corrosion. In isolation transformers the secondary voltage equals the primary voltage.

ISOLATION TRANSFORMER

8.3 AC circuit protection

Main faults in an electrical system

Extra Low Voltage Systems (less than 110V), *Low Voltage* Systems (110V - 440V) and *Medium Voltage* Systems (over 440V) can kill by electrocution if unsafe electrical components and personnel make contact. Low Voltage and Medium Voltage Systems have the potential to arc over in close proximity without actual contact. Consequently it is vital for the *Marine Engine Driver* to visually check wiring and equipment on a regularly for faults or impending faults. If faults are found they should be referred to a licensed electrician for repairs. Common instances of faults include:

Insulation on cabling particularly where they pass through bulkheads

Conduits and glands on motors that have become loose or broken

Loose wiring connections (become hot and the wires will start to discolour or burn).

Switches and power points that are cracked or damaged

If any of the above conditions exist, they must be isolated and rectified as soon as it is practical. The result of a fault is usually:

Short circuit - a misdirection of the circuit due to faulty insulation of loose terminal wires.

Open circuit - a break in the circuit.

Overload - too much current drawn for the rating of the circuit.

Open circuits can be the result of short circuit or overload where the wires have blown apart. More difficult to find are intermittent open circuit faults, such as where a wire has broken hidden inside its covering insulation sheath - on heating contact is made and on cooling contact is lost.

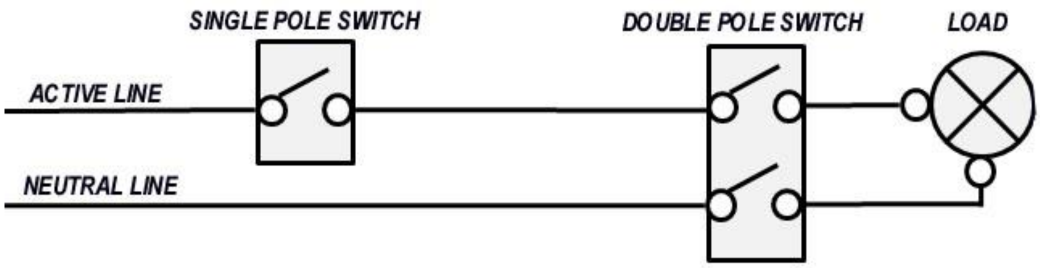
Electrical circuits must always be repaired by a licensed electrician. Before commencing work on any faulty circuit, it must be isolated. A test lamp or a multi-meter will confirm this. Always treat conductors as being live until you have confirmed otherwise. If *for the safety of the vessel at sea* you have to work on a circuit that you have isolated, always fit danger tags to the isolator so that no other person can inadvertently switch the isolator on. Never remove a danger tag or switch on an isolator that was tagged by somebody else. Always use insulated tools and wear rubber soled insulating shoes. When working on a switchboard, always remove the shore power lead.

Isolation

In marine applications to protect circuits and users from electrical accidents a twin wire insulated return is used. The insulation must be in good order and especially checked where routed through bulkheads (for cuts on sharp edges). The effectiveness of the rubber or plastic insulation can be found by inspection for bare wires and by checking the resistance of the insulation with an electronic circuit tester- a megger tester, so named as one million ohms of resistance is considered adequate for most 240 volt systems.

Preferably there should be a main *twin pole isolator* (switch to both positive and neutral wire) and fuses or circuit breakers to open the circuit in case of an overload. Engine room devices must be an enclosed type so sparks or arcs protect from explosive risks. An ammeter and volt meter can be installed to verify safe load and supply.

Single and twin pole switches
A two pole switch on AC power supply gives additional protection as it switches out both the supply power and eliminates any feedback of power on the neutral side, particularly in the case of reverse polarity with ship/shore power. A light switch is usually a single pole switch whereas a main isolator is usually a two pole switch.



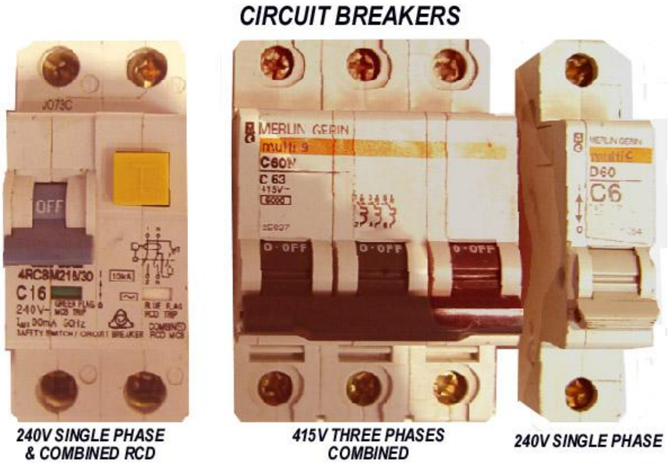
From the main switchboard, power is distributed to various switch/fuse combinations or circuit breakers which either supply circuits to items of equipment or other distribution boards. An earth indication system is also be fitted in this switchboard.

Fuses and circuit breakers
Fuses may be fitted to protect AC wiring and equipment from overload, though they are being superseded by the much improved system of circuit breakers. *Short circuits* can occur when the active cable is inadvertently connected directly across to the neutral side or through the hull. This can cause an excessive current flow, generating heat and causing fire (usually centred at the smallest wire in the circuit) or even cause electrocution to users, unless fuses or circuit breakers immediately open circuit to cut supply.

A fuse *-* is a thin metal wire designed to *open circuit* (break) by melting if the current goes above a certain level, so stopping a surge continuing down the wiring system. A surge from a short circuit would otherwise cause equipment damage or electrical fires.

Engine room fuses must be ceramic or glass encapsulated to avoid being an open ignition source that may cause fire or explosion. If a fuse blows, it must be entirely replaced with the same amperage fuse. A fuse that continuously blows must never be replaced by a higher amperage fuse that does not, but rather the electrical problem causing the blow must be identified and repaired.

A circuit breaker – is a load sensitive switch that *trips* (open circuit) if a predetermined excess current flows. Consequently they activate much more quickly than a fuse so ensuring greater protection for sensitive electronic equipment and personal protection for higher power situations. They are easily reset simply by re-switching them to the original position. They can be used as an additional circuit isolation switch.



Four types are commonly used.

Thermal - is tripped by a bi-metal contact strip that on heating expands differentially to cause a tripping lever to bend away from the contact with consequent open circuit. Small overloads with increasing heat build up over a period of time may trip this system.

Magnetic - all or part of the wiring passes through an electromagnetic coil that at a determined overload setting creates sufficient magnetic attraction to pull on the tripping lever and break contact. Usually a spring is incorporated to smooth out current fluctuations. High overloads will trip this system instantaneously.

Thermal and magnetic - combining the two above.

Solid state – immune to mechanical fault but restricted to smaller load applications.

An additional protective measure (in newer AC circuitry) is to make the casing of circuit breakers individually sized by their amperage rating, so a replacement cartridge cannot be mistakenly installed into an incorrectly rated socket.

Earth faults

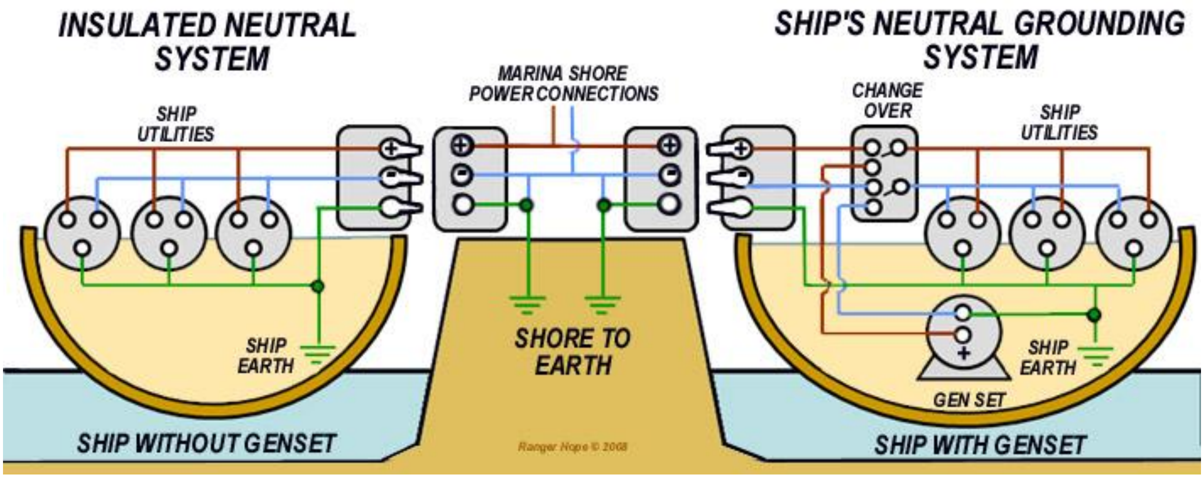
A stray electrical current will seek the path of lowest resistance to return to earth and find balance. Consequently safe electrical systems rely on good insulation and devices that provide better paths to earth than through the personnel contacting wiring. This principle is used in the *Earth Neutral Systems* of land based installations that earth to a metal post driven into the *ground*. A short circuit causes a high load to escape to earth that trips the circuit protection devices. Ship's earths are not connected in the same way. Metal hull vessels use a twin wire insulated return. In an *insulated neutral distribution system* no part of the ship's active or neutral circuit is connected to *ground* (earth) - the shipboard system is completely isolated, including engine sensors and starter motors. Only at the shore side is the shore neutral connected to the shore earth. This has twin benefits:

Prevention from receiving an electric shock

Limiting of electrolytic corrosion

Insulated neutral system - There is one main earth connection to the hull (vessel ground) which connects to an earth bus bar in the main switchboard. The earth is then fed to the distribution boards, outlets, and eventually to all items of equipment. All AC items of equipment must be earthed. The vessel ground system must never be interconnected to the DC system negatives. The earthing cable is connected to the neutral conductor only on the shore side (*mains earth neutral system)*, but no current flows through the ship earth conductor and as shown below, no current flows though the earth line.

Neutral grounding system - If a vessel has a *genset* (alternator) or *inverter* then a *neutral grounding system* is used. In this case the neutral and the ship's earth are connected at the *genset* only. These wires do not become current carrying as in a short to earth on shore, and merely bring the neutral voltage back to the earth levels required to drive electrical loads. Again, neutral to ground flow is only possible at the shore side earth.



Sometimes a cabling can break down or leak to earth from deterioration of the cable insulation itself or by moisture in junction boxes. These leakages can be very small and will not blow fuses or trip circuit breakers so we must rely on earth monitoring devices to check if conductors are breaking down as are described below.

Earth indication - All AC and DC systems should have some type of earth leakage monitor. This continuous monitoring enables an earth leakage to be immediately detected and rectified quickly. A common monitor used is the leakage test lamp type.

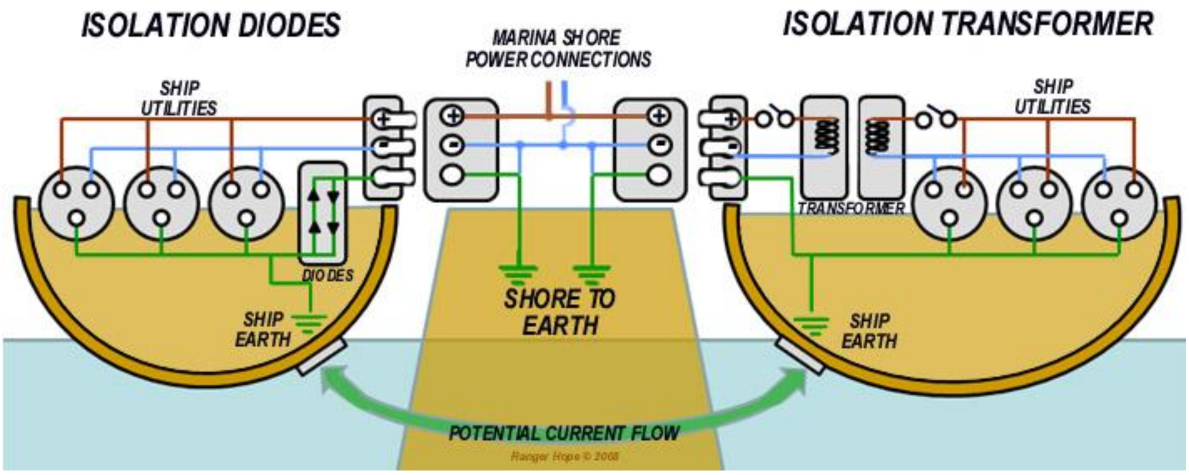
A 3 phase system uses 3 lamps and a test button located on the main switchboard of each system. When the switch is closed, the lamps will be illuminated. If there is a leak on a phase, the lamp on that phase will not be as bright as the others. Sometimes a meter is installed next to the lamps to indicate the degree of leakage and to activate an alarm at a preset value.

***Electrolytic corrosion* -** The linking a ship's underwater earth plate and the shore earth grounding gives excellent protection against electrocution. However if two ships are floating in an salt water (*an electrolyte*) each with slightly differing earth plates (*dissimilar metals*) a battery is formed, a stray current will flow between their earth plates and galvanic corrosion will occur to one of the vessels. This unfortunate by-product of earthing is dealt with by galvanic isolation by two primary arrangements:

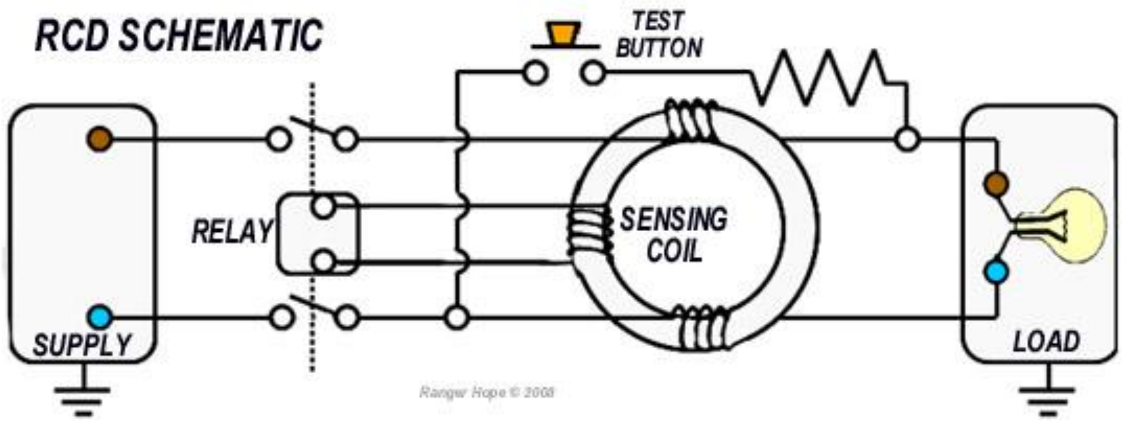
Galvanic isolators - A salt water battery is unlikely to generate more than 1 volt DC. An assembly totalling four 0.5 volt resist diodes are fitted to a heat sink and connected across the ships earth cable. A pair of diodes in series each requiring 0.5 volts (1 volt total) to start conducting prevent low (stray) current transmissions from ship to shore. Another pair of diodes placed in parallel to them on the same earth cable, prevent low (stray) current transmissions from shore to ship. At the same time in the event of higher voltage, as may result from an AC short circuit, the diodes will allow current passage safely to shore earth.

However, the additional stray AC currents of over 1 volt often found around busy shore facilities will prompt the diodes to conduct both AC and DC currents. For this reason a capacitor is incorporated to block DC current flow.

Isolation transformer - The more expensive method of placing a transformer on the vessel between the shore power lead and the ship connection ensures that there is no physical cable connection. The current is induced electromagnetically between the two. The vessels earth system is fully insulated from the shore earth (eliminating a shore path for galvanic currents) and ship leakage is blocked at the ship side of the transformer.

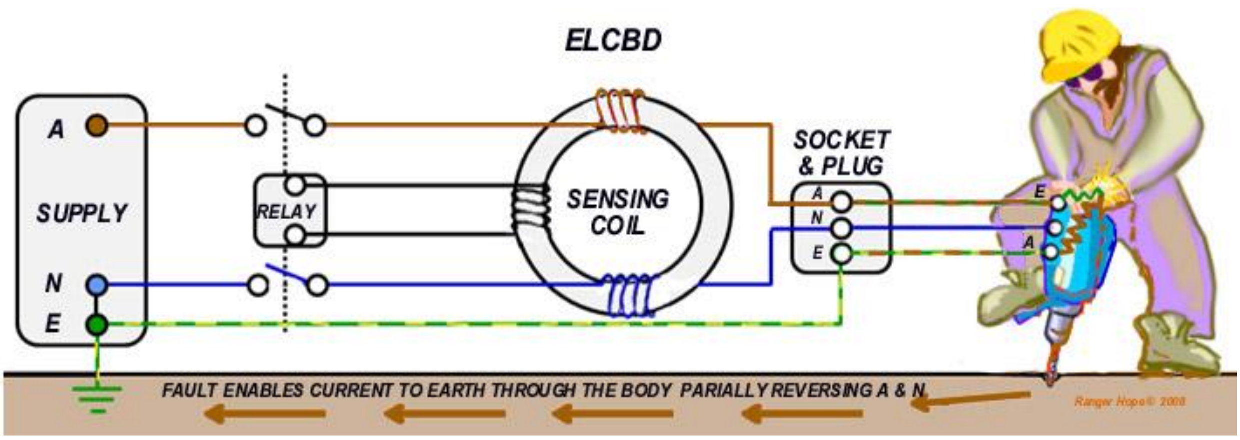


***Residual current devices* -** are increasingly being used in power supply systems in order to isolate the vessel from shore power if a shipboard fault occurs. A transformer is used to detect magnetic fields created by current flow in both the active and neutral wires of the circuit. Under normal current flow the positive and neutral fields should balance out so the residual current detected will be zero. If however a short (to earth) is occurring then one wire will pass more current and create more magnetic field than the other, so a *residual* *current* will be detected. This generates a tripping signal that activates a relay that in turn isolates the circuit providing protection. A test function is often installed.



Typically RCDs are set to trip at 30 milliamps within 200 milliseconds as is sufficient to protect human life. It must be noted that a load such as a light globe that is connected to both active and neutral simultaneously when its switch is closed will not trip the device, as the magnetic fields in each wire remain equal. Similarly a person who holds both wires as a switch is turned on can act as a load and not be protected. The *RCD* therefore does not replace standard overload protection, earths and sound electrical safety practice.

Earth leakage core balance devices - are particularly useful with extension leads for portable power tools used on shore. In the case of a leak from the active to earth through the operator the function of the earth and active are partially transposed. The result is an imbalance between the active and neutral that is detected by the sensing coil. This in turn activates a relay that trips the isolation switches.

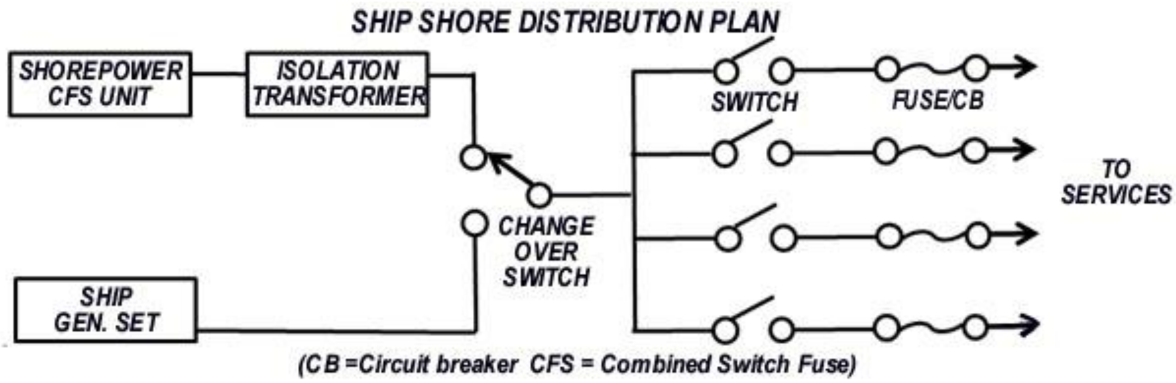


8.4 The genset (engine driven alternator)

Power Distribution

The power distribution of the ship is controlled from the main switchboard. Warning lights are incorporated to indicate the health and status of the electrical system. Here the ship's genset/s power and shore power supply can be isolated, monitored and selected through changeover contactors. These operate in the same way as two motor starters in parallel (See 8.4). If ship and shore power were both available it would be necessary to switch off one before switching on the other. The changeover contactors are electrically and mechanically interlocked to prevent both of them being energised simultaneously.

The load side of the changeover contactors connect directly onto *bus bars* (common connectors) at the main switchboard. These bus bars are then routed through fuses, circuit breakers and/or switches to feed various supply distribution boards. The sub-circuits from these distribution boards then supply lighting, power and utility circuits. There should be wiring schematics pasted inside these distribution board cabinets to identify each fuse/circuit breaker, its rating and which circuit each protects.



Connection to shore power

Precautions should be taken when connecting to shore power and before closing the breaker on the main switchboard, including specific checks for:

Voltage compatibility between shore and vessel (240V to 240V)
Polarity compatibility with your vessel. (Some vessels are wired with a reverse polarity)
Shore power supplies run through a fuse, RCD or circuit breaker
Connection lead is of correct current rating and is faults free (no cuts and abrasions)
Connection plugs are watertight and free of moisture

Additional precautions before connecting on a slipway include specific checks that the:

Connecting lead is secured safely and not lying around the deck area
Vessel shore plug receptacle (CFS) is the same rating as the one on shore
Vessel earth is not connected to the shore earth

The shore power supply may be less than that supplied by the gen set so avoid overload by switching off unnecessary items of equipment. First ensure that the 3 phases are available. This can be checked by lamps on each phase or by the volt meter and phase to phase switch. If the 3 phases are not available, do not connect the vessel to shore power. If the phases are okay, the next step is to check the phase rotation via the phase rotation meter, if the phases are reversed, it will be necessary to correct the phases using the polarity changeover switch.

Before bringing the shore power on line, switch off major items of equipment.

Ship/shore contactor

Switched/fused shore plug receptacle
The shore power can now be brought on line. This may entail switching off the ship power first, if the system is not an automatic changeover type.

The gen set's driving motor

The gen set or generator set is usually a diesel motor governed to drive an alternator at a set speed in order to produce the designed power requirement. Appropriate pre-departure checks need to be carried out before start up, including:

Step	Action
1	Check coolant and oil levels. Visually inspect electrical connections.
2	Open the sea cock to allow water sucked up by the pump to cool the system.
3	Ensure the fuel supply is turned on.
4	Ensure the main alternator isolator is switched to off.
5	Hold on the pre-heat switch (glow plug) for around 30 seconds.
6	Push the engine start button.
7	Check that sea water is being discharged or your engine will overheat.

When the motor has started, check the engine speed, oil pressure and alternator frequency and voltage. The frequency should be 50 Hz, so adjust the engine speed at the governor if required. The gen set's voltmeter should show 240 volts output. An ammeter should show how much current is being drawn.

Before *closing the main isolator* (switching in the alternator) turn of major items equipment. An overloaded generator will *hunt* (struggle to maintain speed) and decrease in RPM. It could trip the circuit breaker or stall even the motor. You can further reduce the load by shutting down unnecessary lights or utilities. Then close the main isolator.

Check the frequency and voltage at the main switchboard and ensure they are registering the correct readings. If everything is satisfactory, the rest of the load can sequentially be brought back on line. When shutting the alternator down, it is advisable to switch major items of plant equipment off first, again to reduce surges at change over to shore power.

The alternator

The components of a small alternator for battery charging, being a *rotor* (a field winding assembly) rotating within a *stator (*a stationary induction winding assembly) that generate AC electricity and convert to DC has been described in the previous chapter. The genset's large alternator uses the same components as its smaller cousin, but the output utilised is three phase AC (not rectified) that is used to power the ships heavy equipment or is transformed down to lower voltage for the ships utilities and general purpose outlets.

Paralleling Alternators
Alternators are inefficient when running small loads or if overloaded. If twin or more alternators are installed then another can be brought on line to meet periods of peak demand. Together they must produce exactly the same output (*line voltage*, *frequency*, *phase sequence*, *phase angle* and *waveform*) as the operating system - they must be *synchronised*. Waveform and phase sequence are fixed by alternator type and circuitry at installation. Alternator terminals and wiring are matched to the systems *phase sequence* (order of phase). Connection to the wrong phase sequence would cause a short circuit.

However voltage, frequency and phase angle must be controlled with each new alternator added. Modern systems are automatic, controlled by *Synchronization relays*, but manual synchronization is still available with *Synchronizing lamps* or the *Synchroscope*.

The following notes are general only so the users' manual must be consulted for operating instructions of your vessel's specific system. The synchroscope, engine speed governor, and automatic voltage regulator (AVR) are usually located on the main switchboard. The manual or automatic synchronization process is similar. The genset is brought up to approximate synchronous speed by progressively increasing throttle/governor settings. The alternator field is energized and the voltage at the terminals observed until it meets system voltage and phase angle, when it is switched into circuit. When synchronized, the frequency varies dependant on load. Large changes can cause the alternator to drop out of synchronism when circuit protective devices cut in to disconnect automatically.

Synchronizing relays - enable automatic and remote operation by the use of sophisticated microprocessors. A failsafe *synchro check* relay is installed that prevents connection beyond a few electrical degrees of in-phase with the system. Often manual override synchronizing devices are incorporated.

Synchronizing lamps - Three indicator lamps are connected between the alternator's (instrument transformer) terminals and the system terminals. As the genset's speed changes, the lights glow bright when the alternator voltage opposes to the system voltage (ahead or behind in-phase). When the alternator voltage matches the system voltage the lights go dim. At that instant, the alternator is switched into circuit and stays in synchronism.

Synchroscope - displays the relative frequencies of system and alternator. The pointer (or indicator lamps) indicate fast or slow speed of the genset compared to the system requirements. If the pointer rotates (or +/- indicator lamps show), the engine governor must be adjusted until the needle points vertically (or top lamp shows) and is steady.

An error of a few electrical degrees between the alternator and the system on connection will cause a severe drain with abrupt genset speed change or even stalling. To avoid this isolator is closed as the needle slowly approaches the in-phase point. Do not leave the synchro switched on as the synchroscopes are not designed to operate continually.

Alternator power ratings

The factors in rating an alternator are:

Frequency and speed

Kilovolt ampere output in a 3 phase circuit

Number of phases and terminal voltage

Frequency and speed - frequency varies with the speed and is controlled by the governor. It is calculated by:

$$\text{Frequency (Hertz)} = \frac{\text{Speed x Number of Poles}}{120}$$

120° is a constant, being 1/3 of the 360° electrical degrees of the three phase wave form. Most alternators are 4 pole machines.

Example - What speed must be achieved to develop a frequency of 50 Hertz using a 4 pole alternator:

$$\text{Frequency (Hertz)} = \frac{\text{Speed x Number of Poles}}{120}$$

$$\text{Speed} = \frac{\text{Frequency x 120}}{\text{Number of Poles}} = \frac{50 \times 120}{4} = 1500 \text{ rpm}$$

Phases and terminal voltage- Australian vessels commonly use 3 phase 415 volt. Larger motors are designed to run at these values. Lower voltage rated equipment of 240V, 115V, 24V use supply stepped down by transformers.

Alternators can be described by their Kilovolt Ampere output. In a 3 phase circuit this is calculated by:

$$\text{1 kilovolt ampere (KVA)} = \frac{\sqrt{3} \text{ x Voltage (V) x Current (I)}}{1000}$$

Example - How much current could a 20 KVA machine deliver at 415V.

$$KVA = \frac{\sqrt{3} \times \text{Voltage (V)} \times \text{Current (I)}}{1000}$$

$$I = \frac{1000 \times KVA}{\sqrt{3} \times V} = \frac{1000 \times 20}{\sqrt{3} \times 415} = 27.82 \text{ amps/phase.}$$

Sometimes alternators are rated in Kilo Watts (KW). A value called the *power factor* (cosine Ø) is introduced to moderate the previous formula.

$$kW = \frac{\sqrt{3} \times V \times I \times \cos Ø}{1000}$$

Simply put, the *power factor* is the ratio of True Power (kW) to Apparent Power (KVA). Resistive loads such as incandescent lights and heaters have a power factor of 1. Inductive loads such as motors and transformers have a power factor of approx. 0.8. Sometimes when the alternator is rated in KW, a power factor, usually 0.8, is specified. The power factor can be used to calculate unknown values in the formula:

Example - Calculate the current from a 20 kW 415V alternator with a power factor of 0.8:

$$kW = \frac{\sqrt{3} \times V \times I \times \cos Ø}{1000}$$

$$I = \frac{1000kW}{\sqrt{3} \times V \cos Ø} \qquad \frac{1000 \times 20}{\sqrt{3} \times 415 \times 0.8} = 34.8 \text{ amps/phase}$$

8.5 Motor starter isolation and fuses

Repair or decommissioning of electrical systems

Before repair, decommission or work on electrical equipment, the first priority of the *licensed electrical tradesman* is to isolate the system for personal safety from electrocution. If no local isolation switch is fitted, he/she must isolate the equipment at the distribution board supply and tag it to protect from inadvertent connection. After isolation he/she will use a test lamp or multi-meter to confirm that the power is actually isolated. If the equipment is to remain isolated or removed from service the relevant fuses and/or circuit breakers will be removed and disconnect from the wiring circuit. Any changes to the wiring plan should be updated in the wiring diagrams.

Motors *-* If a motor is to be reinstated, checks for loose connections are made. If the connections are tight, then a meter is used to check that the motor resistance between each phase is the same. This is done on the load side of the contactor or the thermal overload and from each phase to earth. If all of these are satisfactory, the motor is manually turned to ensure it is not jammed.

Having completed these checks, the fuse is replaced and power reinstated. Then using a Tong (clamp) type ammeter, the current drawn on each phase is checked to not exceed the current on the motor's name plate. A *thermal overload* protects the motor from exceeding the name plate amp rating and a fuse protects the cabling from short circuits. The fuse size can be equalled to the current rating of the cable.

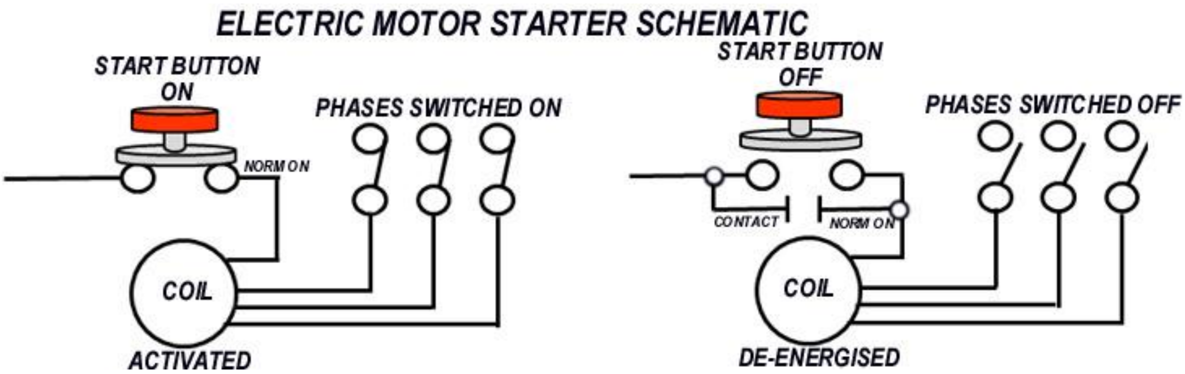
Motors fuses - If it is necessary to change a fuse in a motor starter it is first isolated and tagged. Isolating the starter a test lamp or multi-meter is used for confirmation. Finally the flow fuse is checked for the correct size.

Motor starters

Motor starters for electrical motors are used so that the control equipment of start/stop buttons, safety switches and control cabling can be kept to a minimum size. If a 20 KW motor was controlled without a motor starter a 50 amp three phase switch and six 40 amp cables plus similarly rated safety switches would be required. When installing a motor starter only two 1.5 mm cables and single pole 10 amp switches are required.

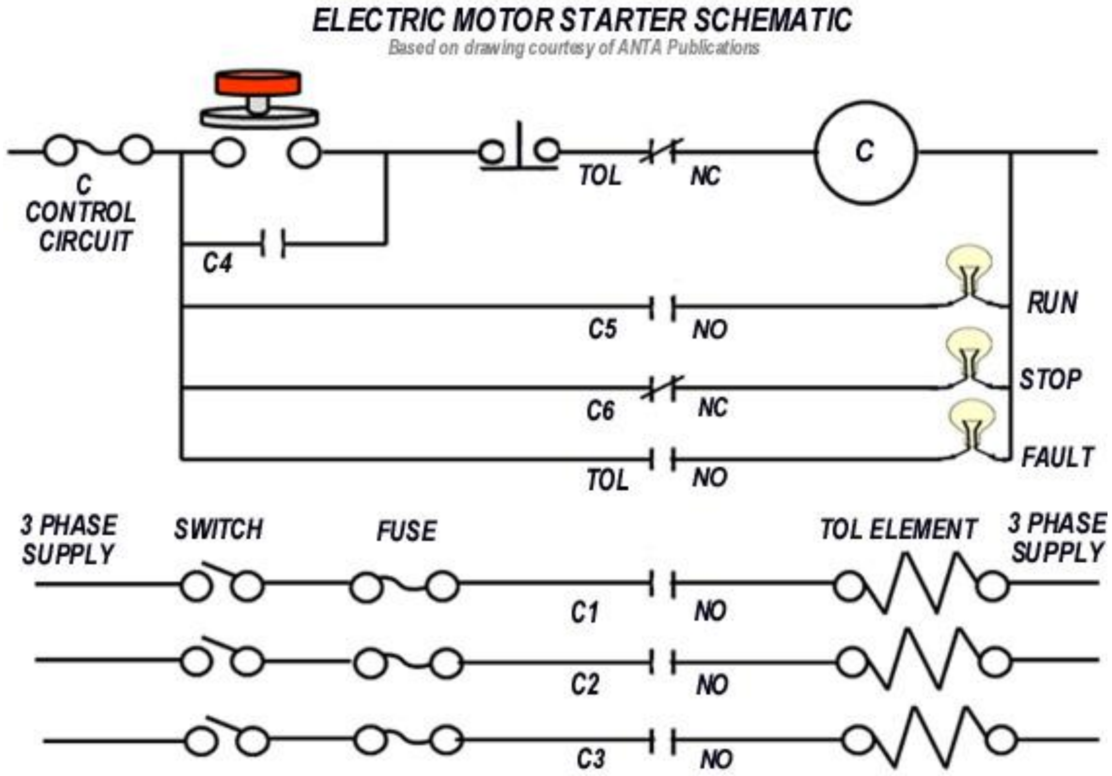
A motor starter control system

The motor starter stop/start button *contactor* is a magnetic switch. When power is applied to the coil, the *contacts* (switches) close and when the power is removed from the coil, the *contacts* open. There are generally three main contacts that switch the main load and four or more auxiliary contacts used for indication and control. These auxiliary contacts may normally be open or closed, that is, when the coil is de-energised, the contact is either open or closed.



If one of these normally open (NO) auxiliary contacts is connected in parallel with the push button, the contact will close creating a new path for the power to travel to the coil. If the button is released, the coil will still remain energised due to the power flowing through the *holding contact*. The only way to de-energise the coil is to interrupt the power supply. This can be achieved very easily by installing a stop push button in series with the start push button and the coil. In normal operation, this stop push button is closed but when the stop push button is pressed, the coil is de-energised and the holding contact returns to the normally open position.

Apart from the contactor, the other major element of the motor starter is the thermal overload (TOL). This normally fits directly onto the contactor and has two auxiliary contacts, one normally open (NO) and one normally closed (NC). This device is used to protect the motor from exceeding the main plate amperage, which can occur from various reasons, such as a seized motor or a jammed pumping impeller. The thermal overload will also cut out if the phases are lost due to a blown fuse, if there is a hot or loose electrical connection or a burnt out contact on the contactor. The thermal overload will normally need to be manually reset if it trips on fault.



Chapter 9: Refrigeration

9.1 Principles of refrigeration

Ship board cooling is required for air conditioning, freezing cargo and for cooling food stores sufficiently to slow the growth of bacteria (between 5° to 8° C) while maintaining a humidity sufficient to prevent its dehydration. Several devices are used including latent heat *bush coolers*, *air cycle*, *vortex tube*, and *thermoelectric refrigeration.* In remote areas *absorption refrigeration* and the *ice box* (esky), are utilised. However, the universal method for ship and shore refrigeration is by using the *vapour compression refrigeration cycle*.

Terminology

The transfer of heat energy enables refrigeration to occur, so a basic language of refrigeration is used to describe the principles that are involved.

Energy - is measured in units of *Joules* (J) being the work done in applying a force of one *Newton (*N*)* through a distance of one metre (equivalent to lifting an apple one metre). Energy cannot be created or destroyed, but it can change between many forms including *kinetic* (motive), *electrical*, *light*, *electromagnetic* and *heat*.

Heat - is measured in units *Celsius* (C), graded from 0° C when ice melts to 100° C when water boils, at atmospheric pressure. Heat is a form of energy that is the result of the molecules in a material being constantly in motion. The faster molecules move the greater the heat of the material. Only at minus 273.16° C do they stop, this temperature is the lowest that is possible and therefore called absolute zero. When the differences in a substances heat are compared for refrigeration calculations the units Kelvin from the absolute scale of temperature are used, where one degree K = 1° C + 273.16. The heat interval between a degree Kelvin (1 K) is equivalent to the heat interval between a degree Celsius (1° C).

Heat transfer- occurs through convection, radiation or conduction (see Chapter 3.1 Principles of fire control). Devices constructed to transfer heat are called a *heat exchanger* and they play a key role in refrigeration. A change of heat experienced by a material can either alter its temperature or, dependant on the pressure it is under, it can change its *phase* (state) from solid to liquid to vapour, and vice versa.

When change occurs in a material's measured temperature it is termed a *sensible heat* change. When heat energy causes it to change phase it is termed *latent heat* change.

When a liquid is frozen to a solid phase the process releases *latent heat of fusion*.
When a vapour condenses to a liquid phase the process releases *latent heat of condensation.*
A liquid change to a vapour phase requires boiling and uses *latent heat of vapourisation*.
This can be experienced by licking your finger and feeling it go cold as the fastest and hotter moving water molecules vapourise to the wind leaving the slower ones behind.

Pressure - is measured in *kilopascals* (kPa), in *pounds per square inch* (Psi) or in multiples of one *standard atmosphere* at sea level (Bars) being equivalent to 101.325 kPa. A vacuum can exist when the pressure within a space is lower than that of the atmosphere and it is measured in minus units.

The *gauge pressure* measured to monitor the system at the refrigeration servicing points is the pressure exerted by the refrigerant gas less that of the surrounding atmospheric pressure, i.e. they are set to read 0 kPa at atmospheric pressure. *Absolute pressure* is the total pressure experienced by a refrigerant and includes its own local pressurization within its pipe work (gauge pressure) added to that of the outside atmospheric pressure. Absolute pressure is always used in refrigeration calculations where one atmosphere is taken as 100 kPa. (E.g. with a gauge pressure 220 kPa, absolute pressure = 220 + 100 = 320 kPa).

Suction or *back pressure* refers to the low pressure side of a system, and *head* or *discharge pressure* to the high side.

Heat, pressure and refrigerants – Substances chosen for their ability to change phase within reasonable pressures and temperatures are selected for use to *charge* (fill up) a refrigeration system. Pressure plays a pivotal role in the process of change of phase. The higher the pressure on a refrigerant, the higher the temperature that is required for it to boil (vapourise) and vice versa, the lower the pressure the lower the temperature that is required for it to boil.

Saturation temperature - The energy required to heat a substance toward boiling point is far less than that required to achieve the boil over. *Saturation temperature* is the point when a liquid boils (*a saturated liquid*) or vapour condenses (*a saturated vapour*) and is dependent on the pressure experienced. Transfer of latent heat into a saturated liquid to boil, or out of a saturated vapour to condense creates not only phase change but results in high heat energy transfer.

Subcooled liquid - describes one that is between its freezing and boiling points and will change temperature with sensible heat without a change of phase.
Superheated vapour - describes when a vapour is above its saturation temperature and any change in heat will be sensible as a change in its temperature.

Principles of refrigeration

Refrigerant gasses are selected for their ability to readily change phase under reduced pressure, enabling heat transfer from the freezer using the physical principals of:

Energy cannot be destroyed, only changed into another form of energy.
(Electricity into heat or heat into movement).

Heat transfers from a material with a high temperature to one with a lower temperature.
(The rate of transfer is proportional to the temperature differential).

The boiling point (temperature) of a liquid rises with the pressure the liquid experiences.
(Water boils at a lower temperature on a mountain top and higher temperature in a car's radiator).

The boiling point of a liquid remains constant while boiling
(At boiling point vapour forms, but the unvapourised remnant does not continue to rise in temperature).

Liquids absorb considerable heat in boiling (the change from liquid to vapour) and vapour gives off heat as it reverts to a liquid.
(The states of ice, liquid and vapour are termed the phases of a material)

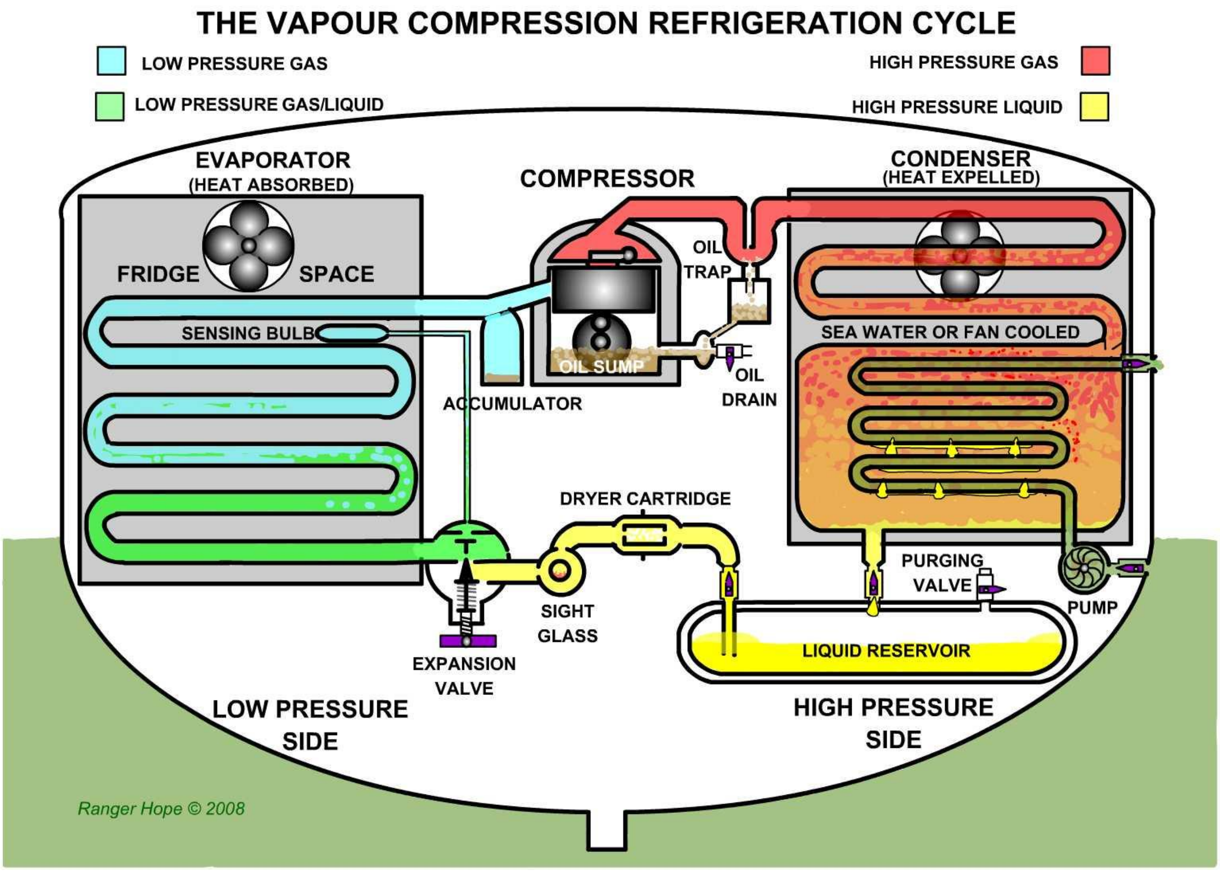
9.2 The vapour compression refrigeration cycle

The refrigeration system circulates a refrigerant gas through a high pressure section and a low pressure section. The refrigerant is converted from a vapour phase to a liquid phase, and heat is transferred as it experiences the four processes of:

Expansion - Vapourisation - Compression - Condensation

Expansion - High pressured liquid refrigerant that has been collected in the liquid reservoir is sucked towards the *refrigeration control device*. As it does so, a disposable cartridge or reusable filter drier unit removes any water contaminants that may later damage the compressor pump (water is not compressible). A sight glass enabling refrigerant quality to be monitored is also fitted.

A common *refrigeration control device* is the adjustable *TX* or *thermostatic expansion valve*. The expansion of liquid refrigerant reduces its pressure causing an amount of the liquid to vapourise. Its action can be likened to the spray nozzle on an aerosol can that allows a controlled escape of the high pressure liquid refrigerant to a lower pressure region as mist and vapour. This change of phase absorbs heat from the freezer cabinet through *latent heat of vapourisation.*



Vaporisation - As liquid refrigerant enters the lower pressure *evaporator* from the *TX valve* a temperature sensing bulb attached to the outlet of the evaporator sends feedback signals to adjust the flow rate. As it passes through the evaporator in the fridge/freezer cabinet the refrigerant absorbs heat and continues to changes phase as its temperature continues to rise. As the refrigerant leaves the evaporator it should have entirely changed phase to vapour.

Compression - Before entering the compressor an accumulator collects any remaining (uncompressible) liquid refrigerants or water contaminants that would otherwise damage the compressor pump. Knocking from the compressor termed *slugging* indicates liquid contamination. On entering the compressor the vapourised refrigerant is compressed, raising its pressure and temperature. The gas is then forced on to the condenser. Any oils leaked from the compressor are collected in the oil trap where they can be drained off.

Condensation - For the refrigerant to revert to a liquid phase it must give up its heat. The condenser allows for this heat to transfer to the sea (water cooled ship systems) or to the atmosphere (air cooled shore system). As the refrigerant cools to liquid it is consolidated in the liquid reservoir.

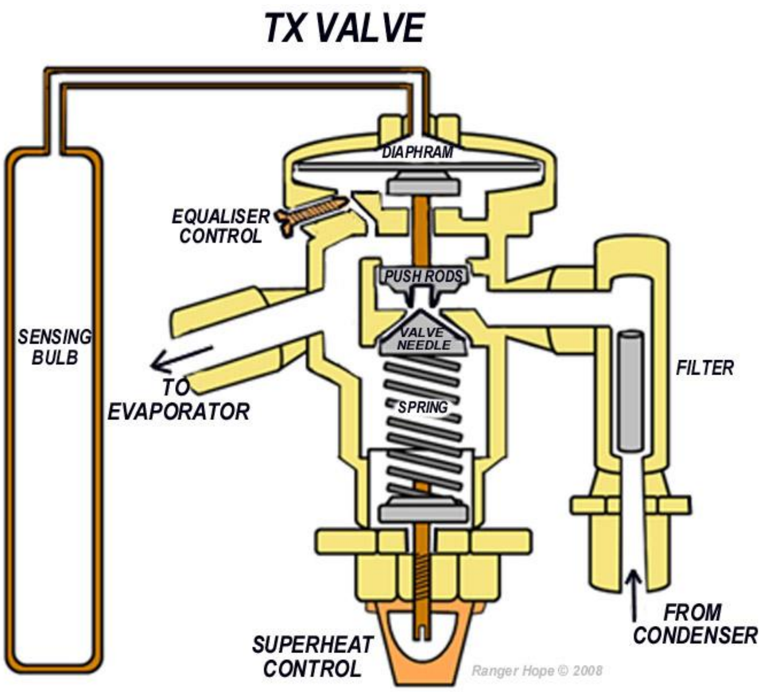
A purging valve is fitted at this point to remove contaminants that may have built up in the refrigerant, including air, oil or water and to allow a point to recharge the system with new refrigerant. A licence is required to handle or service systems. The refrigerant is directed to recommence the cycle, flowing through the evaporator and again to the compressor.

The basic components - of the *vapour compression refrigeration cycle* include:

Accumulator	It prevents liquid refrigerant from flowing into the compressor to cause knocking and damage. Liquid reaching the accumulator evaporates.
Cabinet	Provides cold storage and houses the cooler tubing and sensor bulb.
Condenser	It cools the refrigerant, transferring the heat away, returning it to liquid. Anodes may be fitted to ship systems.
Compressor	The compressor draws the gas refrigerant from the evaporator and forces it to the condenser.
Drier	Removes moisture from the liquid refrigerant and prohibit contaminants from blocking the Tx valve.
Evaporator	The cooling unit where heat is absorbed by the refrigerant, evaporating the liquid and turning it into gas.
Oil trap	Removes excess oil from the refrigerant returning it to the compressor. Oils of three types are used, including polyalkalylene glycol (PAG), polyol ester (POE) or alkybenzene (AB), each particularly suited to different refrigerants.
Refrigerant	The liquid used for heat transfers.
Reservoir	The container which holds the liquid refrigerant.
Control valve	This keeps the evaporator full of liquid refrigerant while the system is running, allowing for more efficient cooling.

Sight gauge – It is installed after the filter dryer and gives indication of the quality of the refrigerant. Bubbles seen through the sight glass may indicate air or shortage of refrigerant. Some sight glasses indicate when the system needs recharging. Streaks seen through the sight glass may indicate oil or water contaminating the refrigerant. A colour indicator may be fitted that is blue/green when dry and pink/yellow if moisture is detected.

TX Valve - Though not the only type of refrigerant control valve, the adjustable *thermostatic expansion valve* is commonly used to both maintain a pressure differential between the high and low pressure sections of the system and regulate the flow of refrigerant that can enter the evaporator. A sensing bulb that is positioned at the far end of the evaporator provides a feedback loop to fine tune the flow rate. TX valves are usually set to 10 degrees of superheat to ensure all uncompressible liquid refrigerant is fully vapourised before reaching and potentially damaging the compressor. *Flash gas* refers to the instant vapourisation of liquid refrigerant.

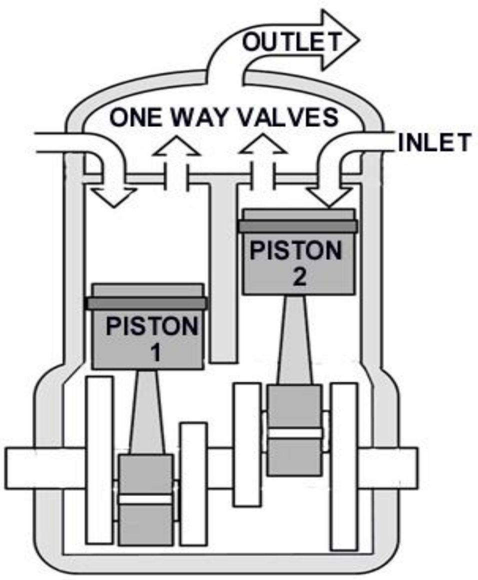


Evaporators - remove heat and so must be at a lower temperature than the freezer cabinet called the *evaporator temperature difference.* Evaporators can be of the *bare pipe* type (pipes running through the freezer cabinet) or *forced draft coil* type (pipes with fins subjected to a blast of air from a fan) that require regular defrosting. *Frost back*, ice forming on piping, is common in the suction line. The *plate surface type* of evaporator run through or form brine tanks in fishing vessels that use cold salt water to stow their catch.

Compressor – Several designs of reciprocating compressor pumps are available. The type shown below uses one way metal flap valves to hold pressure in a tank above the twin cylinders. The inlet metal flap valve opens on each piston's down stroke so gas enters the cylinder. As the piston rises the inlet valve is forced shut and the compression tank valve above opens. Compressed gas is forced up. A shut off or bypass arrangement is needed to avoid over pressurisation of the holding tank and subsequent internal damage.

The bottom of the pistons are splash lubricated from an oil sump containing customised oils but a separate oil pump may deliver lubrication through galleries to all wearing surfaces. An oil level sight gauge is often fitted. As liquids are non-compressible, measures need to be taken to avoid water, liquid refrigerant or lubricating oil entering the cylinders to cause *slugging* (knocking) or even more disastrous consequences.

The type below shows a *hermetically* (totally) sealed refrigeration pump but it is not uncommon to find belt driven systems in fishing vessels where drive arrangements need to be regularly serviced.



Condensers - give up heat and so must be at a higher temperature than the cooling medium called the *condenser temperature difference.* Cooling is achieved ashore by fans venting to the atmosphere or usually in vessels by salt water heat exchanger.

Shell and tube, *keel coolers* or *tube within a tube* heat exchangers are utilised.
In each case, to maximise heat transfer, the direction of the coolant flow is designed to be opposite that of the refrigerant. The refrigerant gas cools to become liquid in the liquid reservoir, the highest point of which is a convenient access point for purge and re-charge.

Service valves - are fitted at a number of critical points in the system to allow the fitting of gauges to monitor temperature and pressure, and to purge and re-charge.

Use of the manufactures *temperature pressure tables* (see next section) enables temperature pressure differentials to be calculated.

Safety devices - to assist to monitor and control the plant's performance and guard against system failure, damage and leakages include:

Electrical earthing	Electrical components must be grounded to prevent electrical shock.
Motor protection	Fuses/circuit breakers protect from overloading. Bi-metal switches (temperature opening) provide protection against overheating.
Pressure gauges	Used to indicate the pressure and consequent functionality at various locations within the system. They are calibrated in KPA and PSI and may incorporate maximum/minimum temperature record.
Pressure limiters	Are installed in systems where the evaporator pressure must not exceed a certain level.
Pressure switches	Are switches which react to a set range of pressure changes. They have a cut-out override control to shut down the system.
Relief valves	Prevent the build up of excessive pressures. These valves will generally only function after all other safety devices have failed.
Service valves	Access points on the low and high pressure side of the compressor to install gauges and take system readings.
Sight glass	This provides a visual check for the level of refrigerant in the system and for the presence of moisture.
Thermometer	Typically located inside the evaporator, cabinet, condenser or tubing.

9.3 Refrigerants

Many substances meet the primary requirement of a refrigerant in that it can readily absorb heat and transfer it to another location and then give up again. In choosing a refrigerant, other factors must be considered including the refrigerant's stability and cost, the fire, explosive or poisoning risks, the ability to detect leaks, the corrosive effect on plant or equipment and the overall effect on the environment.

Regulations and control

Some chlorine rich fluorocarbon refrigerants such as *chlorofluorocarbons* (CFCs) and *hydrochlorofluorocarbons* (HCFCs) cause severe environmental damage by depleting the earth's protective ozone layer. At the Montreal Convention in 1987, international action initiated banning or phasing out the worst of these substances. B*romofluorocarbons* (Halon) and *hydrobromofluorocarbons* (HBFCs) are now banned and signatory countries control use by restrictions on sales and operating requirements (licensing) for repairers.

The Commonwealth is a party to the international agreements to further controls. Since 1996 CFCs have been banned and HCFCs have been classified as controlled substances requiring special licences. A total ban of HCFCs is scheduled by 2020. The control is devolved to State and Territory governments whose enforcement agencies include their Environmental Protection Agencies, Workcover and Maritime Authorities.

Industry associations and manufacturers are sources for product information regarding usage restrictions and handling in product *hazardous material data safety sheets*. Some existing refrigeration plants will not be economic to adapt to the use of a newer compliant refrigerants. Awareness of the currently banned or restricted use refrigerants is critical in order to monitor compliance of the system on your vessel. While the refrigerants are carefully controlled so are repairers and refrigerant sales- both activities require licensing.

Refrigerants safety

When dealing with refrigerants special care must be taken to avoid both personal injury and environmental damage when filling or purging the system, or if a leak occurs. Detectors are available for refrigeration system leakage, the most common called a *halide leak detector.*

PPEs are advised while working on systems. All refrigerants on contact with the skin will cause a freeze burn. Due to its pressurisation, the possibility of squirts into the eyes with leaks is a high possibility. In the event of an accident immediate first aid will include irrigation and seeking medical assistance. Fluorocarbon refrigerants are heavier than air and can lead to asphyxiation and death in confined spaces. In affected persons fresh air and resuscitation will be required immediately.

Refrigerant storage cylinders should be stowed with their thread caps fitted to prevent damage, kept away from the sun or heat and never be more than ¾ full. Refrigerant storage cylinders are colour coded to Australian Standards for initial identification. The correct refrigerant and coloured cylinder *must* always be used appropriately. However, be wary that this precaution has carelessly not been observed.

To positively identify the refrigerant, a compound gauge can be fitted to measure the cylinder pressure and the temperature at the bottom of the cylinder. Using a *pressure temperature chart* the refrigerant can be identified.

Types of refrigerants

Different refrigerants are used dependant on the refrigeration system and its purpose. They are grouped under three main types:

Group One: *Safest of the refrigerants*
Group Two: *Toxic and some flammable refrigerants*
Group Three: *Flammable refrigerants*

Despite some of these refrigerants being called non-toxic, care must be taken when handling the material to avoid any possibility personal injury. By itself a refrigerant may be relatively harmless, but having been introduced to the air, flame or hot metal, the refrigerant may break down into dangerous by-products such as acid or gas.

Listed below are common refrigerants, their characteristics and associated hazards:

Group One
R12 Dichlorodifluoromethane -is a popular liquid refrigerant which is colourless and almost odourless. It is not toxic, does not irritate, does not corrode and is non-flammable. Found in air conditioning (especially in vehicles) and refrigeration systems.

R22 Monochlorodifluoromethane - is a synthetic refrigerant and is used in refrigeration systems which a low evaporating temperature. It is not toxic, does not irritate, does not corrode and is non-flammable. Used in air conditioners and domestic and commercial refrigeration systems.

R134a Tetrafluoroethane - is the common replacement for many R12 applications where a medium evaporating temperature is required.

R502 Azeotropic mixture - This is a liquid mixture of refrigerants and is non-flammable, non-corrosive and is generally not toxic. R502 is used in systems requiring low to medium evaporating temperatures. Generally used in commercial refrigeration systems.

Group Two
R717 Ammonia - is common in industrial applications and is a chemical compound. It is flammable and can form an explosive mixture with air. In small quantities R717 is not poisonous but will severely irritate the respiratory system. Large exposure must be avoided. The gas has a strong and ugly odour and is easily detected. Exposure can cause burns, eye injury and loss of consciousness. Protective clothing and breathing apparatus should be worn when dealing with this refrigerant.

Group Three
Include *R170 Ethane, R290 Propane, R600 Butane, R601 Isobutane and R1150 Ethylene. All are highly flammable.*

Temperature pressure tables

These tables are available from your refrigerant gas supplier and they show the pressure that a refrigerant requires to change phase - it indicates the saturation temperature of a number of common refrigerants at a given pressure and consequently can also be used to identify the type of refrigerant.

To determine the pressure for R22 to vapourise at -12°C, scan across from the tabulated temperature to the pressure reading of 229 kPa. To find the gauge pressure required from the absolute pressures tabulated, one atmosphere has to be subtracted:

229 kPa (absolute pressure) -100 kPa (atmospheric pressure) = 119 kPa (gauge pressure)

Refrigerant Pressure Temperature Chart

For example and study use only courtesy of Reece plumbing supplies http://www.reece.com.au

°C	R22	R134a	R507	R410A	R404A	R404A	R407C	R407C
	Saturated Conditions				Bubble	Dew	Bubble	Dew
	kPa	kPa	kPa	kPa	kPa	kPa	kPa	kPa
-40	4	-50	37	73	34	30	19	-16
-38	14	-45	50	90	47	42	30	-7
-36	25	-38	64	108	60	55	43	3
-34	37	-32	79	126	75	69	56	14
-32	49	-25	95	147	90	85	71	25
-30	63	-17	111	168	106	101	86	37
-28	77	-9	129	191	124	118	102	51
-26	92	0	148	215	143	137	119	65
-24	108	10	169	241	162	156	138	80
-22	126	20	190	269	183	177	158	96
-20	144	31	213	298	206	199	179	113
-18	163	43	237	329	229	222	201	132
-16	184	56	263	362	254	247	224	152
-14	206	69	290	396	281	273	249	172
-12	229	84	318	433	308	300	276	195
-10	253	99	348	471	338	329	303	218
-8	279	116	379	512	369	360	333	244
-6	306	133	413	555	401	392	364	270
-4	335	151	448	600	435	426	396	298
-2	365	171	484	647	471	462	430	328
0	397	191	523	697	509	499	467	359
2	430	213	563	749	548	538	504	392
4	465	236	605	804	590	579	544	427
6	501	261	649	861	633	622	586	464
8	540	286	696	921	678	667	629	503
10	580	313	744	983	726	714	675	544
12	621	342	794	1049	775	764	723	586
14	665	372	847	1118	827	815	773	631
16	711	403	902	1189	881	869	825	678
18	759	436	960	1264	937	925	879	727
20	809	470	1020	1342	996	983	936	779
22	861	507	1082	1423	1057	1044	995	833
24	915	544	1147	1507	1120	1107	1057	889
26	971	584	1214	1595	1187	1173	1121	949
28	1030	626	1284	1687	1255	1242	1188	1010
30	1091	669	1357	1782	1327	1313	1258	1075
32	1154	714	1433	1881	1401	1387	1330	1142
34	1220	761	1512	1984	1479	1464	1405	1212
36	1288	810	1594	2091	1559	1544	1483	1285
38	1359	862	1679	2202	1642	1627	1564	1361
40	1432	915	1767	2317	1728	1713	1648	1440

9.4 Common faults

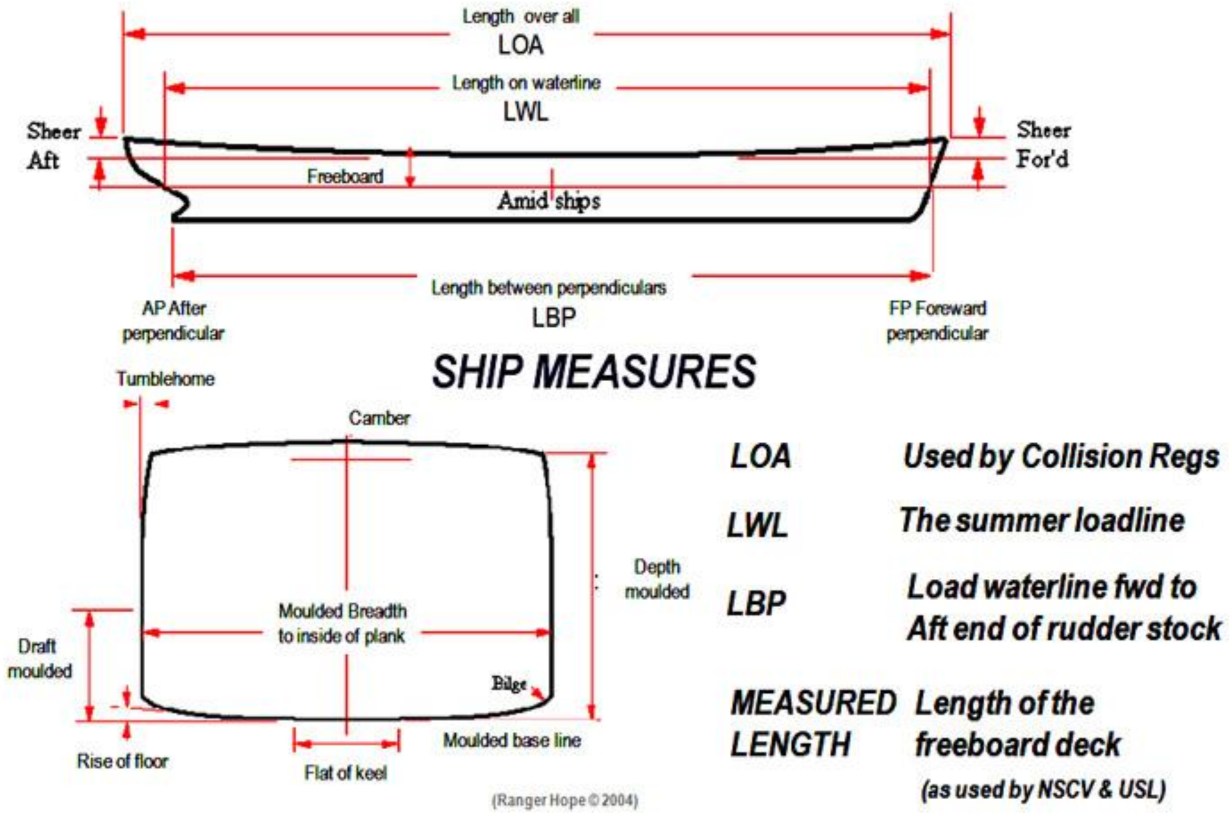
Modern refrigeration systems are highly reliable, so user servicing should primarily be that advised in the manufacturer’s operating manual. Maintenance will probably be limited to topping compressor oil levels, changing filter dryers, monitoring temperature pressure differentials in order to tweak superheat control and freezer cabinet temperature, the occasional defrosting and servicing of salt water cooling strainers and anodes. Any work planned beyond this must take account of the legislated requirement of a licensed operator to undertake any works where refrigerant leakage is conceivable. However, the following table summarises some of the more common problems.

Compressor motor faults	***Possible cause***
Will not start	Isolation switch is open. Circuit breakers are tripped. No immediate demand for the compressor. Anti recycle timer operating- wait until time out auto completes. Loose electrical contacts. Low oil pressure safety cut out. High refrigerant pressure safety cut out. Motor seized. Motor windings shorting or burnt out.
Hums but will not start	Over tight drive belts. Mechanical failure, bearing or frictional overload. Low voltage supply to motor. Operating on one phase due to broken connection.
Shuts down after start/short cycles	See pressure faults.
Motor runs continually	Too lower temperature set for conditions. Condenser cooler blocked.
Motor runs hot and is noisy	Low lube oil or worn compressor bearings. Overload.
Pressure Faults	***Possible cause***
Low pressure	Low refrigerant level. Check for leakages. There may be a blockage in the tubing. The could be a leak in the compressor. There is ice build up on the evaporator. There may be a blockage in the drier core. Moisture may have frozen in the thermostatic expansion valve.
High pressure	There is too much refrigerant in the system. There could be air in the system. There may be a blockage in the condenser unit.
Moisture	Could have entered the system on installation or on replacement of parts. Can result from leaks.

Chapter 10: Slipping, inspection and repair

10.1 Forces and stress

Terminology



The *bow* is the front and the *stern* is the back of a vessel. To move towards the bow is to go *forward* and move towards the stern is to go *aft*. To move along the length of a vessel is to go in a *longitudinal* direction. To move across a vessel is to go in a *transverse* direction. When facing forward, the left hand of a vessel is the *port side* and the right hand is the *starboard side*.

Amidships - is the vessel's mid length and defines the point at the centre of the *LBP*.

Freeboard - the distance from deck to waterline.

Sheer – is the vessel's the deck line curves forward and aft. It aids water runoff and contributes to reserve buoyancy.

Length Overall (LOA) - the length from the extreme tip of the bow to the aftermost point of the stern. This length used in the *International Regulations for Preventing Collision at Sea*.

Load on the waterline (LOL) - is dependent on the placement of cargo and stores (*the loading condition*). A vessel at the planned fully loaded condition is said to be floating at its *design waterline*.

Length between perpendiculars (LBP) – is a distance between two vertical lines at each end of a ship's profile plan that ship designers' use to space out regular sections (stations or frames). It is usually taken as a vertical line drawn through the point where the load waterline cuts the stem (the forward perpendicular) and a vertical line drawn at the after end of the rudder post (after perpendicular).

Measured length - is the distance from the front of the hull to the back of the hull, taken at the upper side of the uppermost watertight deck, or in open vessels, at the height of the gunwale. Specific vessel variations are found in *Part B NSCV*.

Moulded depth - is the internal distance from deck to keel plates or timbers.

Moulded breadth - is measured at the widest part of the vessel. It is the greatest width internally from one side of the vessel to the other.

Beam - is measured at the widest part of the vessel. It is the greatest width externally from one side of the vessel to the other.

Draught - is measured from the waterline to the bottom of the vessel. When the vessel is fully loaded it is termed the *loaded draught* or the *service draught*. Some vessels have a keel parallel to the design waterline while others one angled to it. In the latter case the angle is described as the *declivity of keel*.

Flat of bottom - is the area of the hull near the keel that in some vessels is flat.

Bilge - is the rounded hull where the side meets the bottom to provide strength and reduce hull stresses.

Rise of floor (*deadrise*) - is the area of the hull near the keel that in some vessels rises from the centre line to the turn of bilge.

Camber - is where the deck of a vessel has an upward curve to help water to run off and reduce deck stresses.

Tumblehome - describes where in some vessels the uppermost sides plates curve inwards to provide intrinsic strength and greater buoyancy on initial heeling.

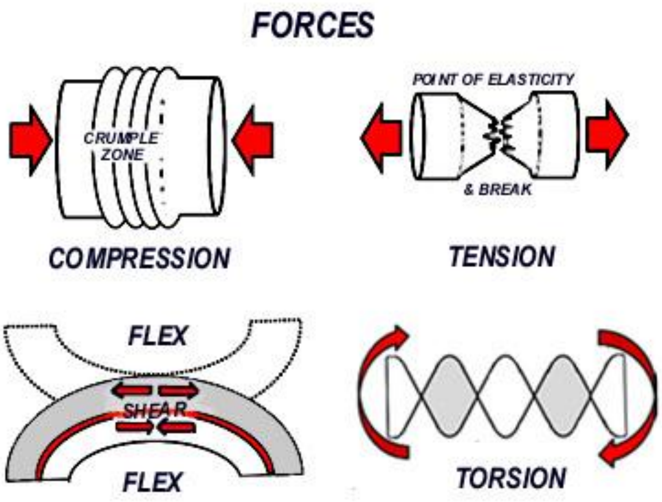
Flare - is the concave curving of the bow faces that drives water away from the vessel, promoting deck dryness but reducing intrinsic bow strength.

Bluff bowed - is the convex curving of the bow faces that forces water outwards, increasing intrinsic strength. They can be *wet boats* (take spray over the bow).

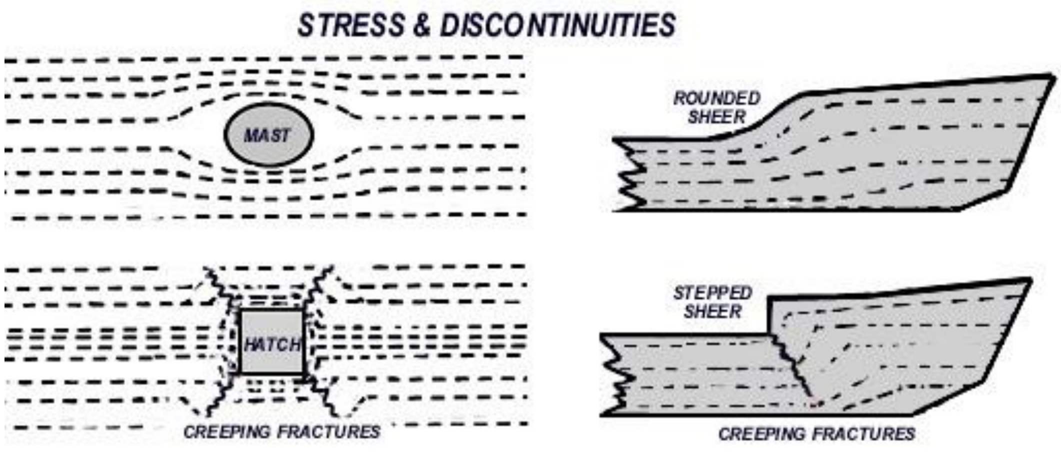
Rake - is any structure that is bent from the vertical, including bow, stern, mast , funnel etc.

Force and stress

Force can be experienced by a material as:
Compression - squeezing, such as experienced by a post supporting a weight.
Tension - the stretching of a material such as experienced by a cable lifting a weight.
Sheer - the tearing apart of a material such as experienced by ripping.
Torsion - the twisting action such as between a rotating engine and its support bolts.
Flex - the bending of a material such as experienced by a mast in the wind.



The evidence of *over compression* is indicated by buckling and *over tension* by stretching and thinning until a point of ultimate elasticity is reached and failure occurs (a break). In a *flexing* material the upper and lower sides alternate between compression and tension. The central zone between is experiencing *shear*.

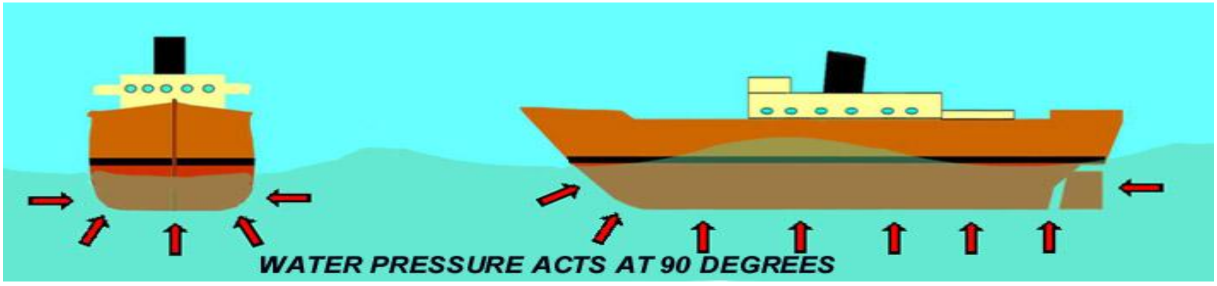


Stress is a force experienced over a determined surface area. If the force is concentrated over a small area, such as a heavy deck mounted piece of machinery, it is said to experience a *point load* or *point stress*. Often a force is spread over a wider area that be visualised as a radiating web of stress lines. Rounded shapes are capable of evenly distributing the stress, whereas (poorly designed) square edged structures create points of stress concentration. The weakness in the affected area from these *discontinuities* are more likely to be the starting point of creeping cracks or even structural fracture.

A vessel encounters particular stress from both sea conditions and its trading, including:

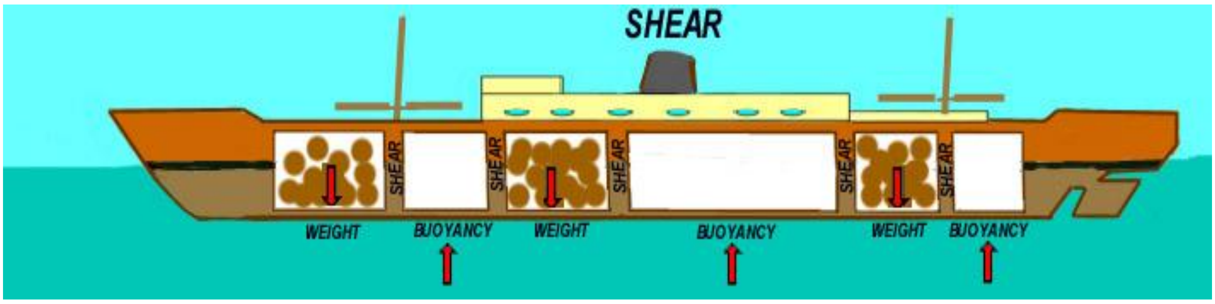
Static forces of water pressure resulting from immersion
Stress from unbalanced weight and buoyancy
Stress from the dynamic action of wind and waves
Stress from point loading such as cargo and machinery
Stresses from dry dock and slipping

Forces from static water pressure
Water pressure acts at 90° to the underwater hull surface. To counteract this constant pressure the hull is reinforced both longitudinally and transversely.



Stress from unbalanced weight and buoyancy
Uneven loading can cause flex over the length of keel but is more dramatically experienced as shear between compartments, as described below.

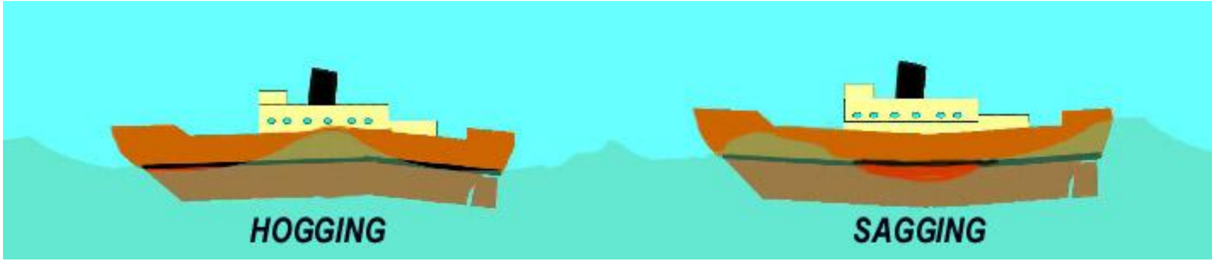
Shear - occurs when the vessel's spaces are unevenly loaded, and buoyancy and weight act in opposition along an adjoining surface (bulkhead). Adequately engineered bulkheads and planned loading are required.



Stress from dynamic wave action
Wave action dynamically acts at 90° to the underwater hull surface. To counteract this constant pressure the hull is reinforced both longitudinally and transversely.

Hogging - Is the longitudinal bending of the hull caused by a wave supporting the vessel on crest amidships or due to poor longitudinal weight distribution of the vessel.

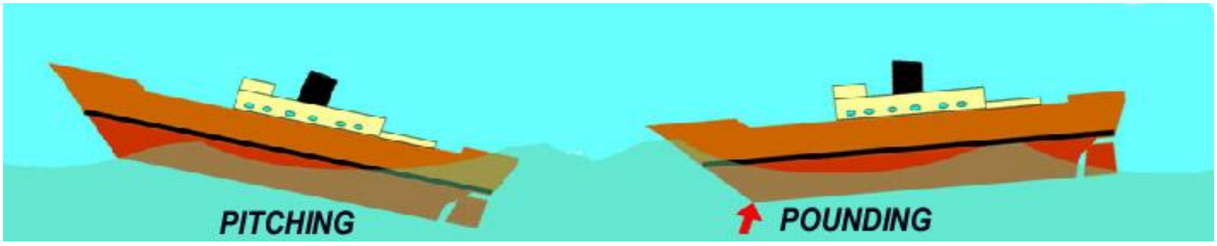
Sagging - Is the longitudinal bending of the hull caused by a wave supporting the vessel at bow and stern only or due to poor longitudinal weight distribution of the vessel.



Alternation between hogging and sagging creates flex along the keel. Large steel tankers travelling between tropical and winter zones may experience differential heating between deck and underwater zones sufficient to hog or sag the vessel and alter the apparent position of the amidships summer load line. Care must also be taken when slipping to adequately support the full keel length to avoid permanent deformation. Longitudinal constructional fortitude of the keel, hog, side plate and deck resist hog and sag.

Pitching - is the action of the vessel being longitudinally lifted by a wave and then dropped into the next trough. This stresses both the stem and the stern structures which are reinforced accordingly.

Pounding - is heavy pitching assisted by heaving as the whole vessel is lifted out of the water and slammed on top of the next wave, causing stress to the stem and forefoot. Similarly, with an overhanging counter type stern, its underside being hit on re-entering the water is termed *slapping*. Doubling of floors and plate is utilised to reinforce structure.

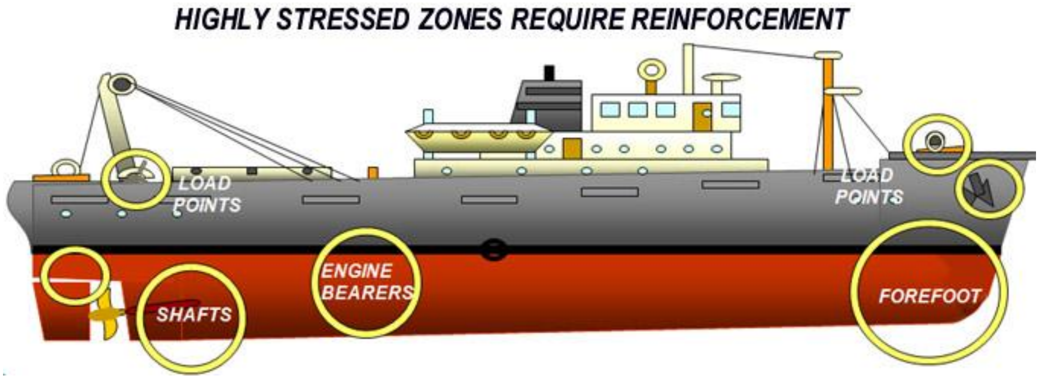


Panting – is the result of water pressure variations on the end hull plating of the vessel when pitching heavily in a seaway. If uncontrolled the waves may actually deflect the hull plate, especially if the vessel continues to make headway, resulting in plate flex and a possible pumping action that can suck sea water into the vessel.

Racking - occurs to the body of the vessel rolling in a seaway due to water pressure variations on the hull plating. The waves act to deflect the hull out of the square. Brackets and knees are used to counteract this force.

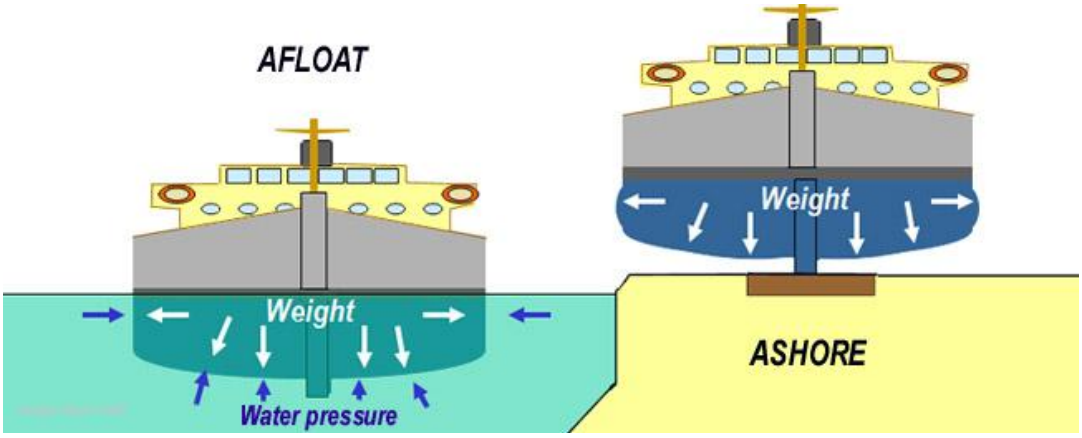
Stress from point loading such as cargo and machinery

Under any winches, windlasses, hawse pipes and masts the supporting deck experiences point loads are that are typically resisted by doubling the thickness of the deck plating and/or by supportive underdeck posts or pillars. The bow and forefoot must bear the first impact of a collision and the stern area must resist the continuous stresses of torsion around the propeller shaft, rudder post and engine bearers.



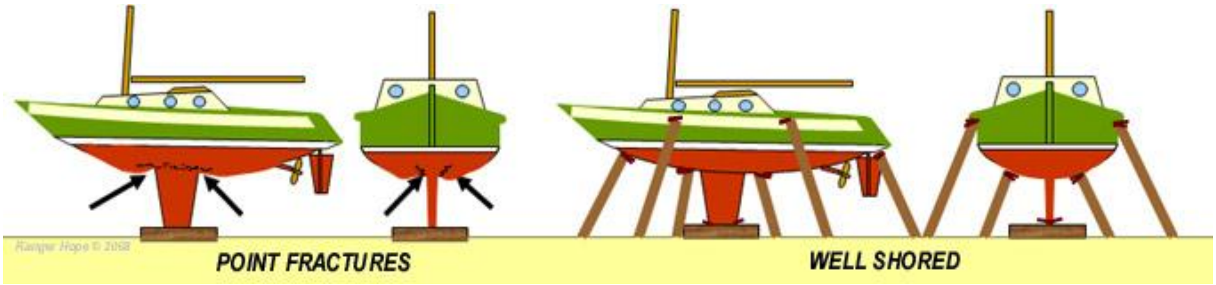
Stress caused by dry dock and slipping

The vessel is built to withstand the forces of water pressure pushing inward. In water the weight of the vessel is balanced by the external water pressure. When removed from the water to the slip these forces are removed so it must be well supported by toms or chocks.



Poor support on the slip can result in permanent hog or sag particularly with elderly timber vessels where the continuous working of fastenings to widen their driven holes and/or the corrosion of fastenings themselves has created the terminal condition called *nail sickness*.

Particular care needs to be taken if vessels have extreme overhangs as much of the weight must be supported over a concentrated area, a point load, such as with fin keeled yachts. As shown below are the tell tale fractures at discontinuities in a fin keeled hull that has been badly propped or has grounded, and the method to shore and prop correctly.



10.2 Structures of a vessel

Vessels are constructed as a floating platform (*hull*) with enclosed areas for stowage and machinery (*holds and spaces*). Open work areas (decks) and accommodation (*super structure)* are built over the hull.

The hull

A variety of hull materials can be used, each with structural properties that are described in the next section. The hull may be of *monocoque* construction, having a continuous watertight skin as with fibreglass vessels, or be built from component parts, as with a planked timber vessels. Some vessels are built from components and then fused into a *monocoque* structure such as welded steel vessels. Monocoque construction creates a rigid hull while component vessels have *give* (flexibility), but also the inherent weakness of seams that will leak if the joint sealant fails.

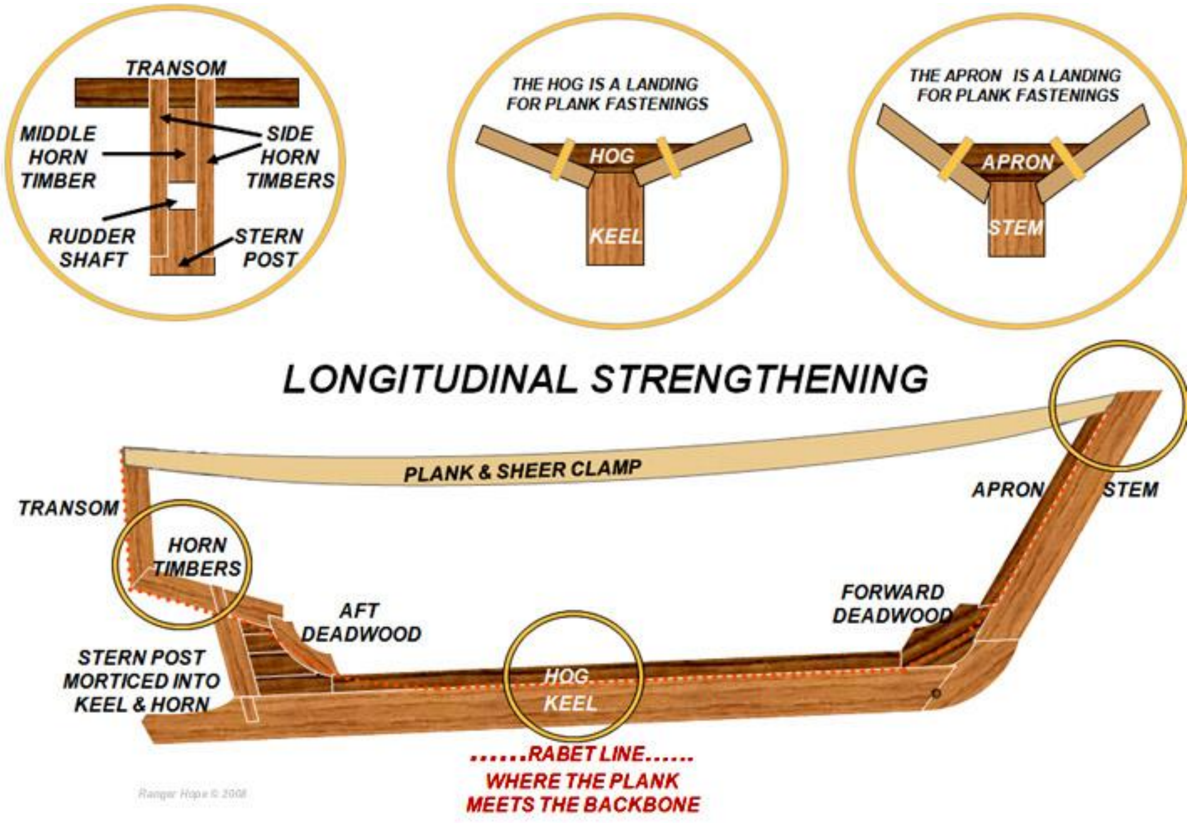
Hull designs include *flat bottomed*, (the simplest), *round bottomed* or *chine* construction. Chined uses two flat planes of material such steel or plywood sheets bonded create the vessel's body. If the angle at the bow is sharp it is called *hard chined* or a *v bottom* construction, noted for an ability to drive through waves. If multiple sheets are used, this build resembling the continuous curve of a *round bottom* construction is called *multi-chine.*

Whatever method used, the hull must resist the longitudinal and transverse stresses of hogging, sagging and racking. Component construction solutions include additional, doubling or thickening of strengthening members and monocoque solutions include local thickening of hull and intelligent use of design shape to optimise stress resistance.

Timber construction - longitudinal strengthening

Being the earliest of constructional materials used, the solutions found and names given have evolved as almost another language to the landsman. Some structures have several alternatives names or are even named entirely differently dependant on locality or material of construction. However the underlying principles to resist stress remain the same.

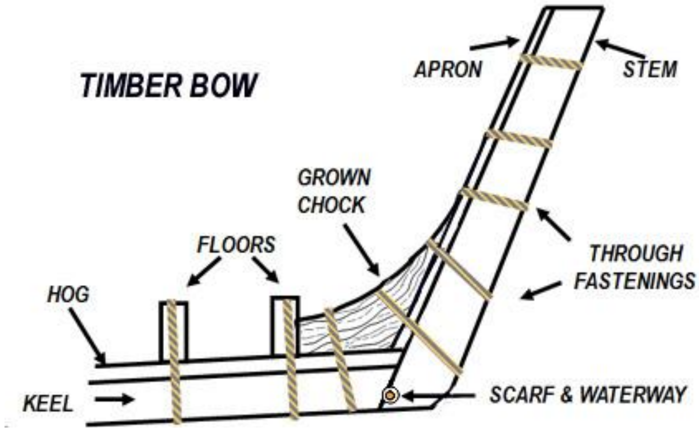
The *keel* is joined to the *stem* by a scarfed joint and at the *stern* by a mortise and tenon joint. A dowel pulls the tenon tight into the mortise and a *fish plate* (a shaped and rebated joining plate) keeps it there. Brackets reinforce the back of the keel to stem and stern joins. The strongest type is shaped from the natural curve of a *compass timber* (a tree's bough) and is termed a *grown chock*. One that is sawn diagonally from a standard plank to follow the grain is called a *sawn chock*. Another method is to sandwich several boards together, shape them and then drift bolt them together. This type of bracket has little intrinsic strength and relies on its fastenings; hence it is named *a deadwood*.



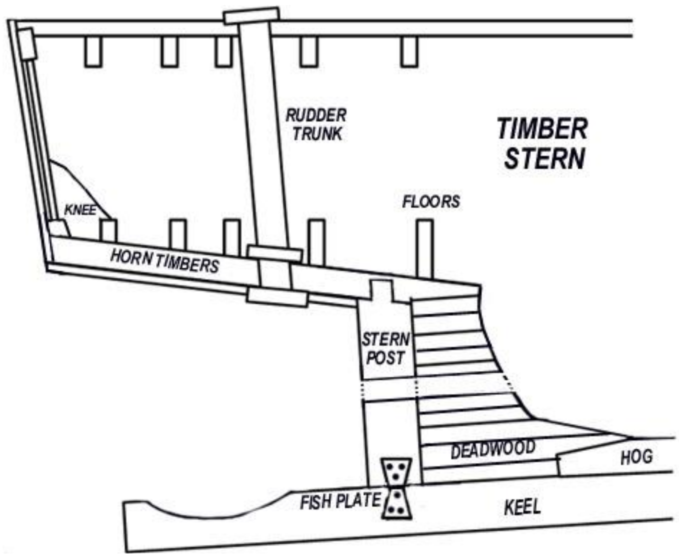
Where the side planks meet the backbone the keel, stem and stern post have to be longitudinally rebated (*the rabet*) to accept the plank edge's changing angle of incidence. At amidships the edge of the plank is nearly parallel to the side of the keel, but at the bow and stern it *lands* at an acute angle. That angle of incidence would make it difficult to skew in a plank fastening to attach to the backbone without the common solution of fitting a *hog* and *apron* to provide the *landing* (point of attachment) for fastenings.

Stem is the extreme forward member of the backbone of a vessel and has to be very strong to resist pitching and pounding stress as well as that from potential collision.

The strongest type of bracket to reinforce the bow scarf is the *grown chock* shown below. Good practice is to drill a transverse hole through the scarf and drive through a *waterway* (dowel) that swells and seals the scarf's join from seeping all the way into the *hog*.



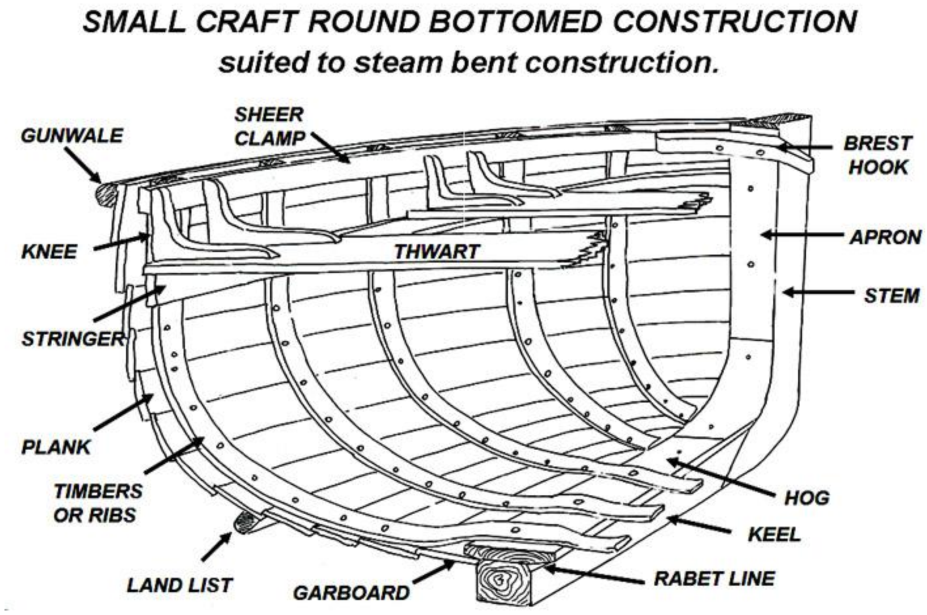
Panting stress is addressed in larger timber vessels by spacing the frames so close that they are fitted literally side by side. The upward extension of the foremost group of these frames is called the *knights head* and this supports the bow sprit.



Stern Post is mortised into the keel below and sandwiched between the twin horn timbers above. A fish plate secures its bottom end. Stern deadwood is massive to allow for the stern tube tunnel to be drilled for the propeller shaft.

Timber construction - transverse strengthening

The compressive forces from water pressure are resisted by *thwarts* (seats) and *ribs* in small craft and *deck beams* and *sawn frames* and/or *bulkheads* in larger vessels. In the *round bottom construction* shown below, this small vessel's ribs may be laminated and glued or bent by applying steam (*steam bent*) when they are called *timbers*.



In the *chine* construction *sawn frames* are more common and *webs* (built up frames) provide additional rigidity. The labour intensive steam bending process is only required at the forward plank ends. The bottom short cross-plank makes for economic use of short boards of timber. The transverse section is built from *floors* and *brackets* (knees). *Limber holes* drilled through the floors allow bilge water to flow to the lowest point and bilge pump.

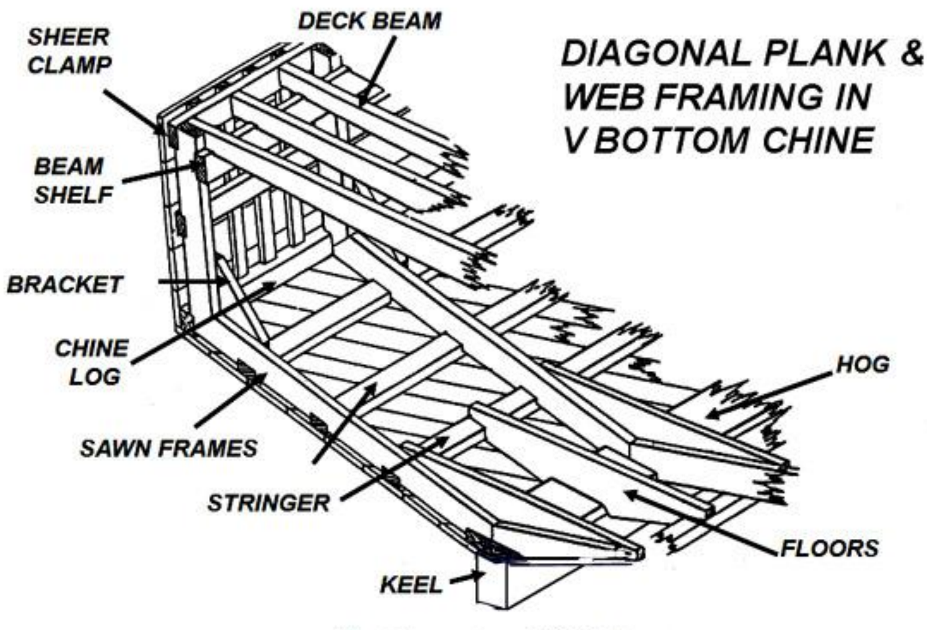
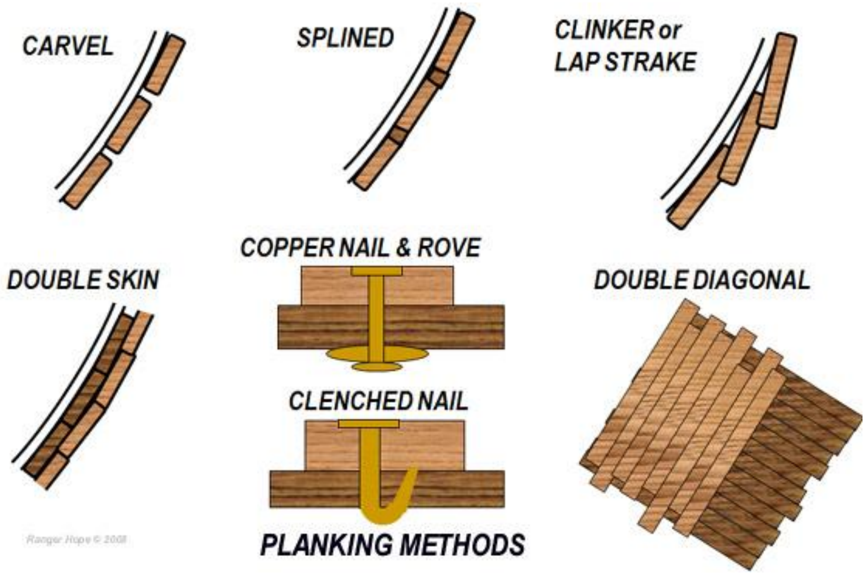


Illustration courtesy of USL Code,

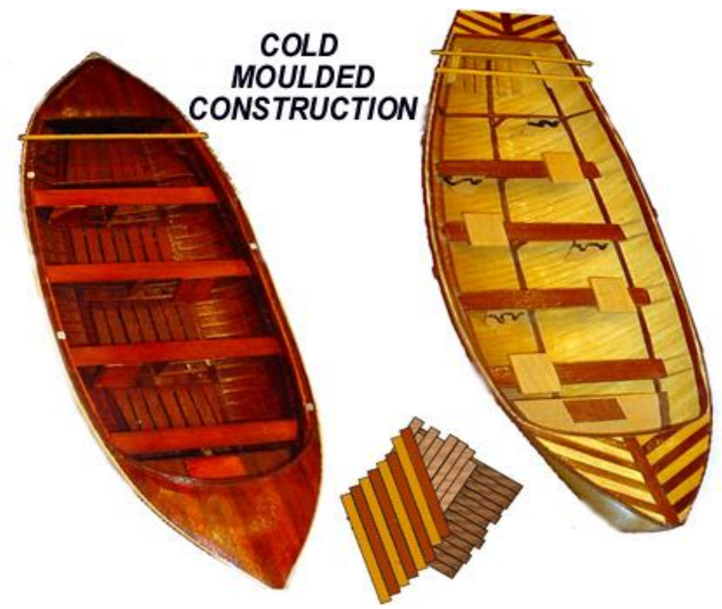
In this construction the deck beams are supported by the longitudinal *beam shelf*, and the frame tops tied together by the longitudinal *sheer clamp.* This poorly ventilated area can be prone to rot especially at the vessel's ends and where excessive tumblehome occurs.

Timber construction – planking - The *deck*, *rails*, *sheer clamp,* and *side planks* also contribute to longitudinal strengthening. The lowest and first side plank fitted beside the keel is called the *garboard.* Differing planking methods are used.

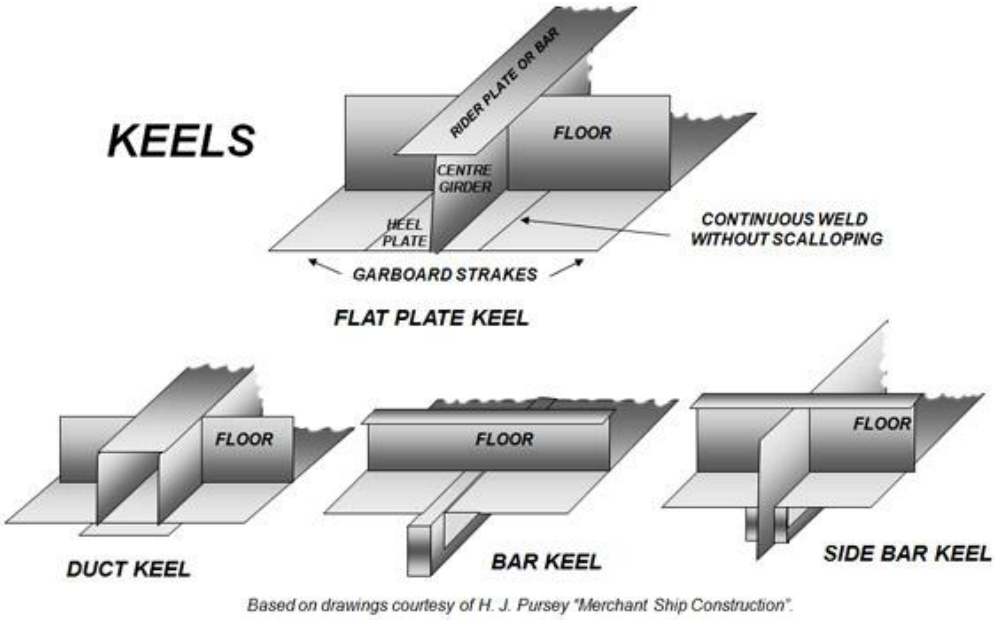
The lightest and most flexible method is the traditional *clinker* build. The carvel system requires the plank *seams* (gaps) to be packed with *cotton* fibres or *oakum* (hemp fibres) to keep them watertight. This is called *caulking*. Oakum should always be used under engine rooms as the diesel and oil weeps rots cotton quickly. In tropical Australia open boats that are left out under the hot sun are often partial double skinned by backing over the seams of their carvel construction with thin stringers. Though if properly executed the *clenched nail* (worked into a U shape by counter hammering) is strong, the *copper nail and rove* (worked rivet) is a superior method allowing tightening with progressive ageing.



The modern technology of superior waterproof epoxy glues, resins and varnishes has been harnessed in a variation of the double diagonal system called *cold moulding.* Cold moulded vessels are built with layers of thin laminations separated by waterproof membranes. They can be round bottomed with all the superior strength and light weight achieved by plywood but are monocoque with the great advantage of no seams to pack to prevent leaking. However, repairs to impact damage are problematic.

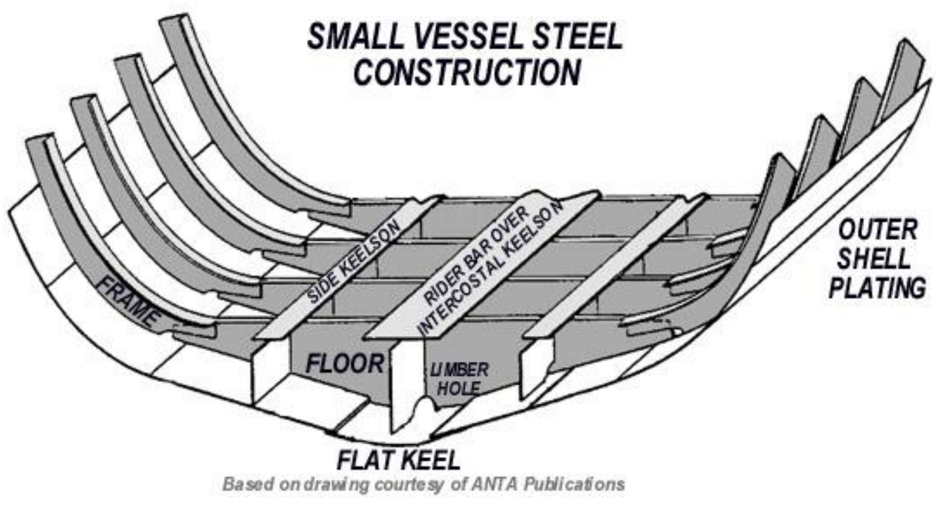


Steel construction - longitudinal strengthening
Principles of steel construction mimic those of timber but with some significant changes in terminology. Steel construction calls major longitudinal members *girders*, minor ones *longitudinals*, and major transverse members are called *floors* and *beams.*



Steel construction utilised various types of centrally placed keel to resist bending of the hull in a longitudinal direction. A small vessel may use a *bar keel* but *flat plate keels* are standard construction. A longitudinal *centre girder* runs along the ship's centre line fitted at right angles to the flat plate keel. If a *side girders* or side *keelson* is fitted parallel to the *central girder* it may be constructed of many short plates individually slipped in between the *floors*. A rider bar is welded over the top to join the component plates. The whole then welded together is called an *intercostals side keelson*. Larger vessels may use a duct keel that forms an internal watertight passage used for carrying the vessel's pipes and shafting.

Steel construction - transverse strengthening
The bottom shell plating is stiffened by means of transverse members called *floors.*

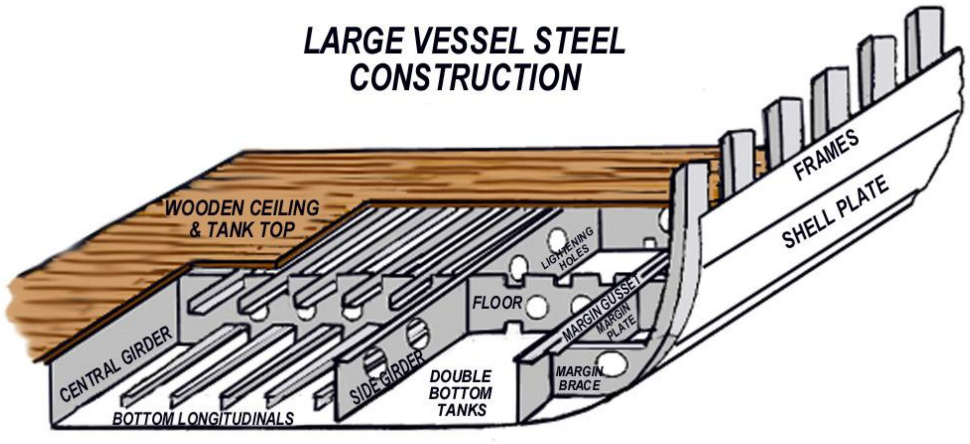


The floors support the base of the frames at the zone where the hull shell plates change from side plates to bottom plates at the *turn of the bilge*. This area may be supported against *racking* by additional brackets.

Steel construction - watertight subdivision - The greatest transverse strength is provided by *bulkheads* (solid walls between a vessel's compartments). Bulkheads have great resistance to *racking,* provide watertight zones (that limit flooding) and fire check zones (that limit fire spread). The number, position and construction of bulkheads according to the vessel's measured length is specified in USL, NSCV or Classification Society Rules (see Chapter One)

USL vessels of 12.5 metres and over in measured length must have a watertight bulkhead at each end of the engine room (except where it is located at the extreme end of the vessel). The bulkhead at the back of the engine room is called the *aft peak bulkhead*. Vessels of 16 metres or over measured length must have a dedicated watertight bulkhead called a *collision bulkhead* fitted at the bow. An intervening space between two bulkheads is called a *cofferdam* when it is used to stop contamination seepage between close tanks such as oil tank and a fresh water tank. Alternatively a *cofferdam* can be filled with water to improve fire control between two fuel oil tanks.

Steel construction - double bottom - construction is used on larger vessels to act as tank space for fuel, ballast and fresh water. Additionally it provides an extra safety, since in the event of bottom plate holing only the double bottom tank is flooded. The girders and floors are perforated with holes called *lightening holes* both to reduce weight and to provide access to and between the double bottom tanks. The *turn of the bilge* is reinforced at the margin with a composite longitudinal *margin plate* with *braces* (*brackets)*. The tanks are plated over with a steel top with strategically placed entry manholes. At the margin a *gusset* is used to reinforce the top of the margin tanks. The tank top can be lined with a *ceiling* (timber deck planking).

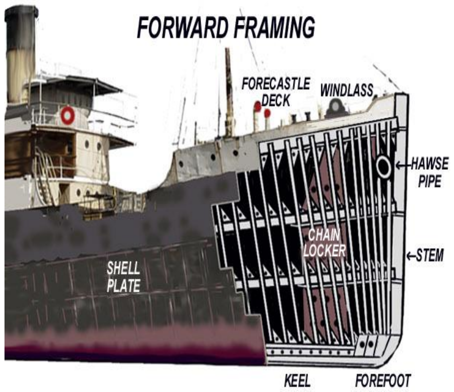


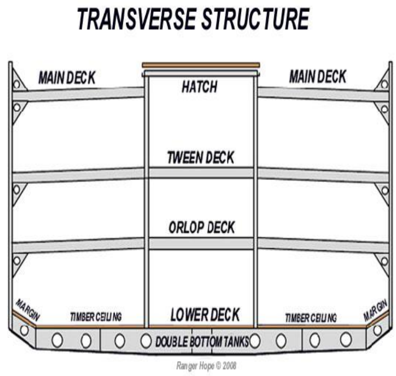
Based on drawing courtesy of ANTA Publications

The condition of the tanks is critical so the tank tops and valves into the tanks must be routinely inspected for deterioration. A small undetected leak from the bottom plate will initially struggle to enter the vessel against the pressure of the tank, but if a corroded tank top is traumatically breached the leak may become a torrent. It is common for vessels to be detained by harbour authorities due to tank top and/or valve corrosion issues.

The internal tank surfaces of large vessels are traditionally coated with concrete screed to reduce corrosion. Modern mastic based materials are available. If it is necessary to enter such a confined space, make sure that it is absolutely safe to do so. Ensure occupational health and safety requirements have been addressed including isolating services into the tank, venting, testing and issue of gas free and permit work certificates, posting a sentry and providing rescue apparatus.

Steel construction - **aft and forward ends -** The aft end of a vessel experiences torsion stresses from both the propeller shaft and rudder stock. Any overhanging structure can experience severe slamming forces in heavy weather so the structure is suitably stiffened by doubling the floors and providing brackets. The shell plating terminates at a massive stern frame structure which in single screw vessels has a tunnel for the propeller shaft. Multi screw vessel's stern frames can be much smaller and use *A* or *P* shaped brackets to hang the propeller shafts outer bearing clear of the hull's bottom and similarly protruding skegs for the twin semi-balanced rudders.

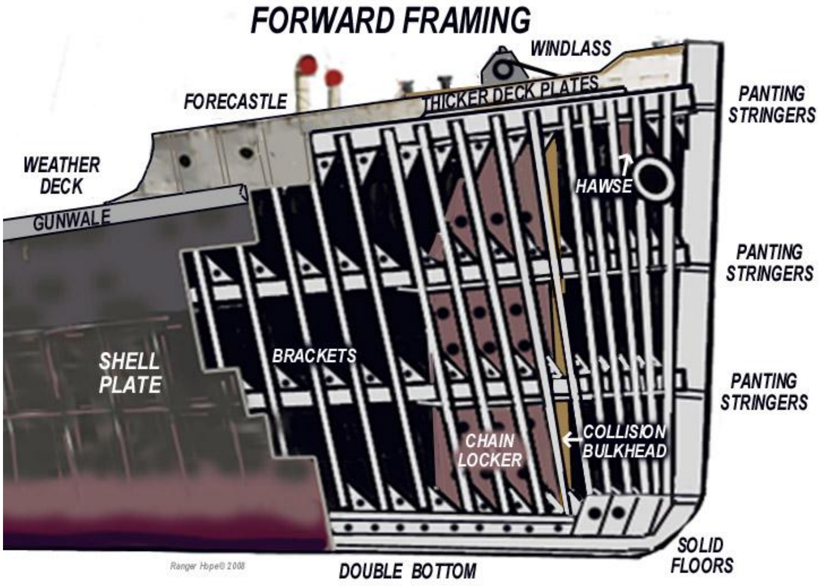




The *stem* (forward most part of the vessel's hull) is constructed of a stem bar from keel to water line and a stiffened plate structure up to the forecastle deck. The side shell plating may be flared outward to increase the deck area and to deflect spray away from the ship. Some vessels are fitted with a *bulbous bow* (a protrusion below the waterline) designed to increase the vessel's speed by throwing water away from the remainder of the square hull.

Steel construction - panting and pounding - Stiffening structures are provided to strengthen the bow. To resist *pounding* the frame spacing is reduced, additional side girders and doubled or solid plate floors are fitted. The anchor chain leads through the *hawse pipe* to the *windlass* that is mounted on double thickness deck plating. A *bow stopper* is fastened to a strong point in order to take the strain off the *windlass* when the vessel is riding to its anchor chain. Below the windlass's *gypsy* (its chain sprocket), the chain is passed through the *spurling pipe* into the *chain locker*. The above strengthening and collision bulkhead incorporated with the chain locker forms a solid skeleton to attach the thickened bow plating.

To resist *panting* horizontal plates (*panting stringers*) are welded to the sides of the vessel, *panting beams* are fitted transversely and partial bulkheads may also be added. *Perforated flats* (partial decks with holes cut in them) are also provided in some vessels. The whole welded together is called a *panting frame* and with the collision bulkhead and chain arrangements forms a structure of massive strength.



Steel construction - shell plating and decks - The decks, bottom and side shell plating form the watertight skin providing buoyancy and longitudinal strength. While some old timers are still around that were built from iron plates riveted together, modern vessels are all of steel plate. The steel shell plating is built from many welded *strakes* (sheets). The greatest bending stresses are experienced along the weather deck edge that is also subject to impacts when berthing. Here an additional longitudinal member called the *gunwale* can be fitted. Deck plates are typically supported by deck beams. In larger vessels those beams may be supported by longitudinal girders.

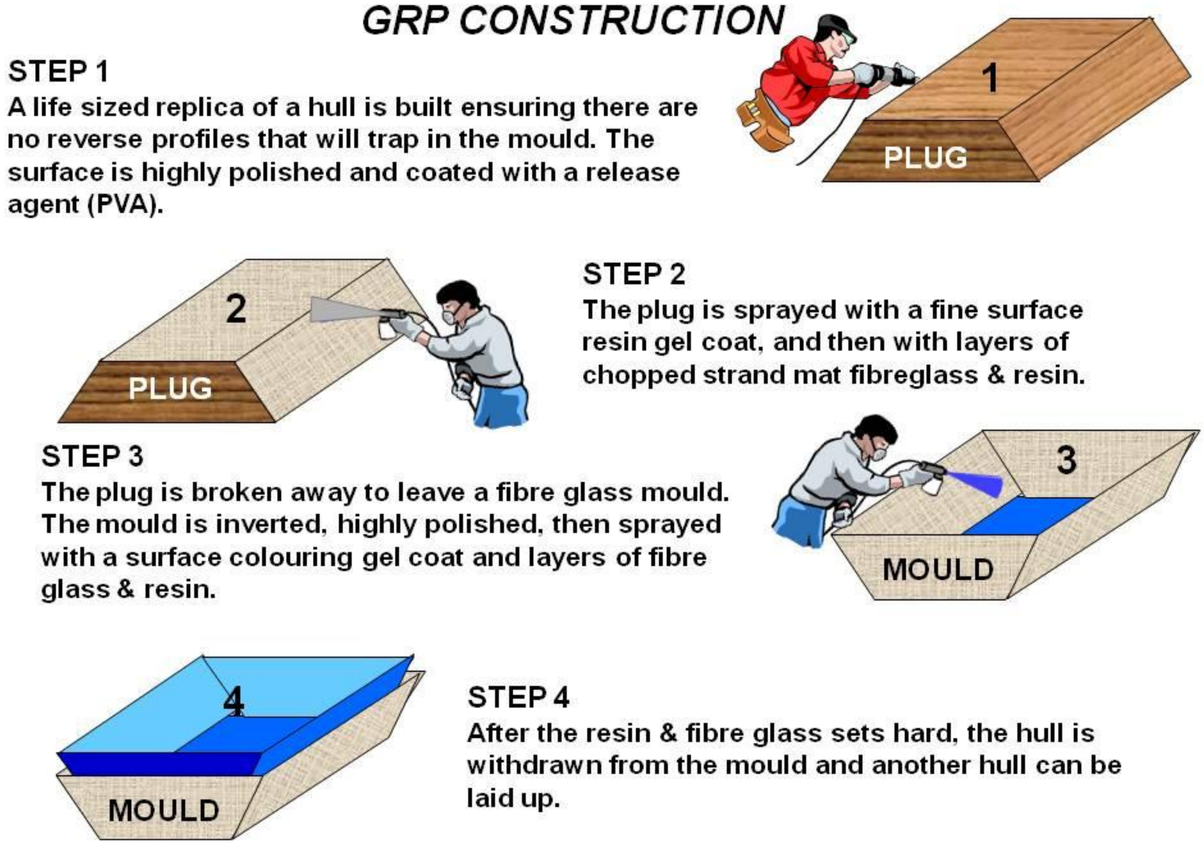
Additional strengthening is provided on deck where heavy loads over a small area (*point loading*) may be anticipated. Such areas include the bases of deck machinery, hoists, masts, helipads and high weight cargo stowage zones. The weight of containers is transmitted through the stacking points at each of the four corners. Incorrect stowage of high density cargoes will cause distortion of the ship's structure. The vessel's loading plan will provide information regarding load limited areas. Sensitive deck zones must be painted yellow with "do not stow here" or with the maximum load limit stress in kilo newtons.

Steel construction - superstructure - The *superstructure* describes the major construction above the freeboard deck that usually provides deckhouses, accommodation, stowage space and work stations. Structural discontinuities (sharp corners) that could result as the starting points for cracks are avoided by designing the superstructure in curved rather than abrupt terminations both transversely and longitudinally. Where aluminium deck structures are mounted, gaskets are used to provide insulation from the steel decks to limit galvanic corrosion. The base of the superstructure is normally the boundary of the watertight and the weathertight zones of the vessel, by virtue of the many openings required here to provide access and ventilation.

Glass reinforced plastic construction
GRP or fibreglass construction uses a substrate of hollow glass fibres that are covered with a mix of liquid resin, catalyst and hardener. The resin mix impregnates the hollow fibres and hardens to form a solid mass. A "one off" vessel can be built over a temporary former to create a replica with a smooth internal surface but an exterior requiring fairing.

More usually however, a plug is created which in turn is used to create a mould. Inside the mould, many identical copies of the original with a smooth textured exterior can be easily replicated making the process ideal for mass production.

Polyester resin is commonly used, but this has inferior waterproof properties over extended periods of immersion (decades) to the more expensive alternative of epoxy resin. The glass fibres can be sprayed with the resin into the mould or, for course hand layup, *chopped strand matting* is cut to size, coated with the resin that is subsequently dabbed or rolled into the fabric of the glass fibres. Woven strands of glass called *woven rovings* and woven rovings *tape* can be applied where a finer surface finish is required or reinforcement is necessary. Other fibres such as *kevlar* or materials such as *polyurethane* fillets can be glassed into the hull to improve structural qualities or weight in what is called *composite* construction.



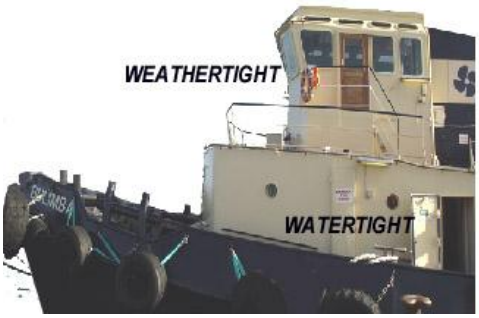
Standard layup techniques include solid resin/glass and sandwiched foam (or balsa wood) between an inner and an outer glassed layer. In sandwich construction the designer must include solid areas of glass or packing pads for point loads such as a mast or winch, and for through hull drilled holes such as for skin fittings. Stiffening is added to the inside of the hull with glass floors and less commonly stringers and ribs may be fitted. Bulkheads or even prefabricated fibreglass shower or whole galley units are installed and epoxy resined to the hull. Plywood bulkheads must be fully coated with an epoxy barrier coating (*Everdure*), especially along the edges. Production vessels are universally made with a hull section from one mould and a deck/superstructure section from another. The hull and deck are then bonded, the unsightly join being covered with tape or a gunwale.

Even without point thickening and reinforcement the monocoque construction of GRP and ferro-cement vessels provides a seamless hull of great strength, particularly when intelligent design of shaped deck camber, topsides tumblehome and convex bow/stern sections are applied.

Weathertight and watertight integrity

Weathertight doors and vents are fitted above the weather deck into the superstructure to provide access and ventilation. They will resist water ingress but if fully immersed, air will escape and water will enter. Typical structures include a raised *threshold* (step), splash guards and rubber seals with sliding or hinged doors. Vent pipes may terminate with a swan neck or gravity flap valve to minimise rain or spray entry. Such openings are best positioned in a shielded position rather than facing the weather.

Watertight portholes, bow doors, side doors and hatches are designed to provide watertight integrity by preventing water ingress even if fully immersed. Watertight doors can be likened to valves whose closing mechanism can be firmly seated onto a seal. Typical structures include a raised threshold or hatch combing with rubber seals that mate with the internal face of a multi hinged door. The hinge position can be adjusted to ensure even mating as multiple *dogs* (adjustable levers) clamp the door with its sealant strip. The seals should not be painted. An alternative type of door slides vertically down into a tapered base slot similar to a gate valve. Debris build up here can interrupt full closure.



Doors and hatches can be tested for serviceability by a *chalk test* (rubbing chalk on one surface and checking that after closing its impression is fully transferred to the mating surface) or by a pressure water hose test of 80 psi.

Internal bulkhead doors also enable passive fire control by containment. Such bulkheads may additionally be coated with fire resist paint or sheathed with steel or steel gauze. The bulkhead doors may be edged with an additional intumescing sealing strip that expands in contact with fire to further seal the door frame. Openings that allow the passage of pipes or cables must be actually flanged to the bulkhead not just passed through a drilled hole.

Strategic hull opening and bow doors must be fitted with audio visual alarms at the helm station and internal subdivision watertight bulkheads required to be closed at sea should be fitted with a visual monitor.

10.3 Materials and preservation

Common construction materials

Steel ***Timber*** ***Glass Reinforced Plastic (GRP)*** ***Aluminium*** ***Ferro-Cement***

Timber and timber products have unique qualities making it the most flexible of all construction materials. If properly constructed and maintained timber vessels routinely outlive their metal fasteners, notable examples still sailing after a hundred years.

Timber	
Advantages	*Disadvantages*
Light weight for high strength	Expensive - requires skilled shipwrights
Aesthetically pleasing to human	Aesthetically pleasing to vermin
Corrosion resistant	Rots
Flexible and non magnetic	Burns

The ability to weld new repairs as strong as or stronger than the old (even to lengthen ships) has seen mild steel replacing both timber and iron plate as the premier shipbuilding material. However it rusts rapidly requiring rigorous surface coatings maintenance, even so few large steel vessels are economic to keep at sea for more than thirty years.

Steel	
Advantages	*Disadvantages*
Cheap	Corrodes readily
One piece hull, no seams	Heavy
Not easily holed	Inflexible
Good fire resistance	Magnetic - affects the compass

The resistant aluminium oxide that rapidly coats the bare metal provides decks and topsides not requiring surface coatings. Its low position in the galvanic scale promotes electrolytic corrosion when in contact with nobler metals such as stainless steel or bronze.

Aluminium	
Advantages	*Disadvantages*
Light	Expensive
Does not rust - low maintenance	Corrodes on lead, copper, bronze contact
Easy to work	Comparatively easily damaged
One piece hull, no seams	Low melting point - poor fire resistance

Ubiquitous for today’s small craft, production vessels are cheaply built with low user maintenance requirements. Impact damage and osmosis are problematic after a few decades, particularly for vessels built in the early days of the technique (1970-80’s).

GRP	
Advantages	*Disadvantages*
Corrosion free	Osmosis and chipping
Easy maintenance	Easily damaged on impact
One piece hull, no seams	Inflammable
Cheap in mass production	Skilled construction required

A cheap and solid hull built as a wirework basket and then finally rendered with specialist cement screed. Some barges and floating wharfs are still floating after a century, albeit looking shabby, a quality shared with some new amateur built ferro-cement yachts.

Ferro-cement	
Advantages	*Disadvantages*
Cheap	Chips easily
One piece hull, no seams	Skilled plaster of hull required
Not easily damaged - easily repaired	Heavy
Fire resistant	Magnetic

Corrosion and deterioration

Deterioration of timber
Despite its resilient qualities timber will quickly deteriorate in the presence of fresh water or insect infestation. Two distinct types of rot can be identified, being wet rot that will be cured if the timbers are dried out and dry rot that is the product of persistent fungal infection requiring chemical fumigation.

Fungal infestation - occurs when the moisture content rises above 20%. The fungi spread as airborne microscopic spores so areas prone to condensation, freshwater leaks or low ventilation are most at risk. Under the beam shelf along the deck edge meets all these conditions. Warning signs of onset of fungal infection include:

Surface coating failure
A musty mushroom like smell
Softening, cracking or disintegration of timbers
Fruiting fungal bodies, incrustations or mycelium (white threadlike growths)

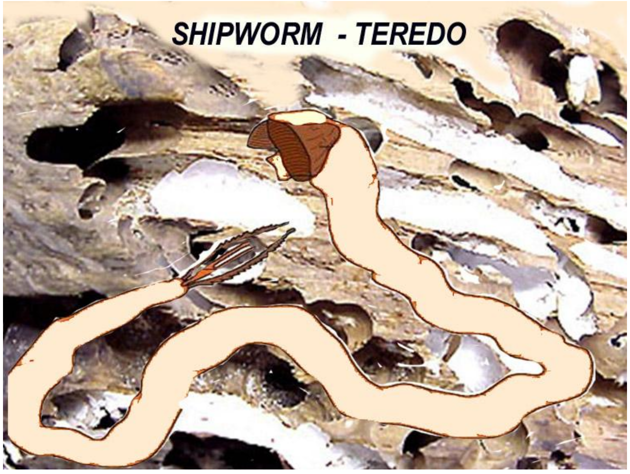
In older vessels that have experienced alterations be wary of low points on the deck where surface water accumulates. These points must be provided with drains or scuppers.

Insect infestation - Timber is devoured by termites, white ants and borers. The *lyctus borer* attacks hardwoods with high starch content but many Australian hardwoods are immune. A telling sign of infestation is a floury dust on the timber's surface. Insects can be effectively exterminated by fumigation with poisons such as *pyrethrum*.

Marine Borers infestation - Crustaceans such as the pill bug or gribble will attack the softwood of timbers seen in old wharf pilings, but in southern waters the mollusc called a *shipworm* or *toredo* is the most destructive. It larval stage is free swimming before it attaches to any submerged timber, bores into it and grows as a worm. Beneath the surface of the planking they can grow to over a metre in length and twelve millimetres in diameter. They can honeycomb the plank with their tunnels to completely destroy its integrity, unseen and unsuspected unless they break the internal surface of the plank creating a spurting leak perhaps metres from the initial entry point.

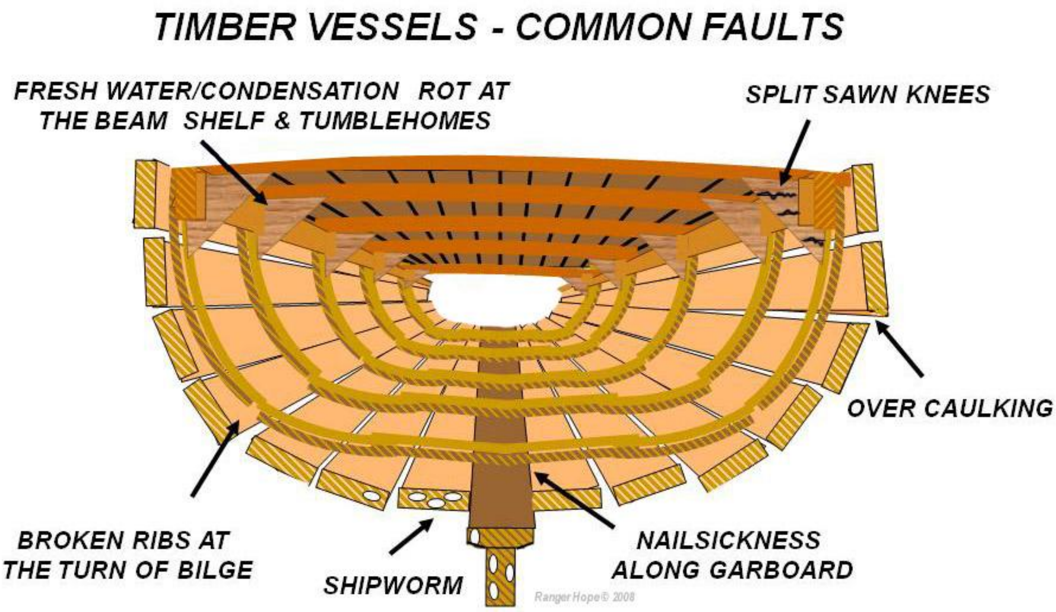
Prevention of attack is possible by impregnation of the timber with creosote or chemical preservatives. Sheathing the underwater hull with a fibreglass skin (dynal sheathing) is an alternative to the traditional protection of copper plate over tar sheathing.

Infestation is best treated by thoroughly drying out the vessel on the slip for several weeks and removing and replacing all damaged timbers.



Timber structural aging - A number of common faults can occur including:

Nail sickness – The working of fastenings or nails in their pre-drilled holes along with the corrosion of the fastenings themselves results in a loosely fastened vessel described as being *nail sick*. Zones that take a lot of fastenings and/or experience flex such as the *hog*, the *sheer* and the *turn of the bilge* are particularly affected. The condition can give rise to a permanent hog of the keel. It is unusual to find this condition when the traditional practice of using *treenails* (wooden dowels) for fasteners has been used.



Broken ribs - are often found at the turn of the bilge at the point of a nail hole. Due to the need to remove the deck and beam shelf to replace a whole rib it is common to install an additional *sister* (partial rib) with significantly less strength than the original.

Split knees - the economy of using sawn knees rather than grown or laminated knees often results in splits along the grain, particularly around any fastening drill hole.

Caulking damage - the convex surface of the outer planking results in the plank edge seams being wider at the outside than the inside creating a wedge shaped longitudinal seam. Because of this it is possible to drive in the *oakum* (seam caulking) and ram it home. If the back edge of the plank is broken away, by too enthusiastic and inexperienced caulkers, then the caulking will be pushed straight through and out the other side. There is no easy solution to this common fault other than to router out a wider seam, slip in *splines* (softwood strips of western red cedar) and *dynal* (epoxy sheath) over the whole.

Preservation of timber - As freshwater is the agent for rot in wooden vessels, make sure rainwater cannot get into the timber. This can be achieved by two principle strategies:

Firstly ensure tight deck seams and engineer solutions to deck areas where rain water puddles (drains and scuppers). Prevent condensation by ensuring through ventilation, particularly when it is lying idle. Secondly, where rain or condensation is unavoidable such as the insides of windows or under deck edges use water-repellent preservative or surface coatings.

Water repellents are deep soaking oils (such as *Teak Oil* or *Deks Olje*) or epoxy soaks such as *Everdure*. Both processes need multiple coats paying particular attention to the end grain. Unlike the oil soaks, surface coatings such as paint or varnish need to be fully sanded back before reapplication with at least a primer, an undercoat and twin topcoats of suitable marine and UV resistant quality.

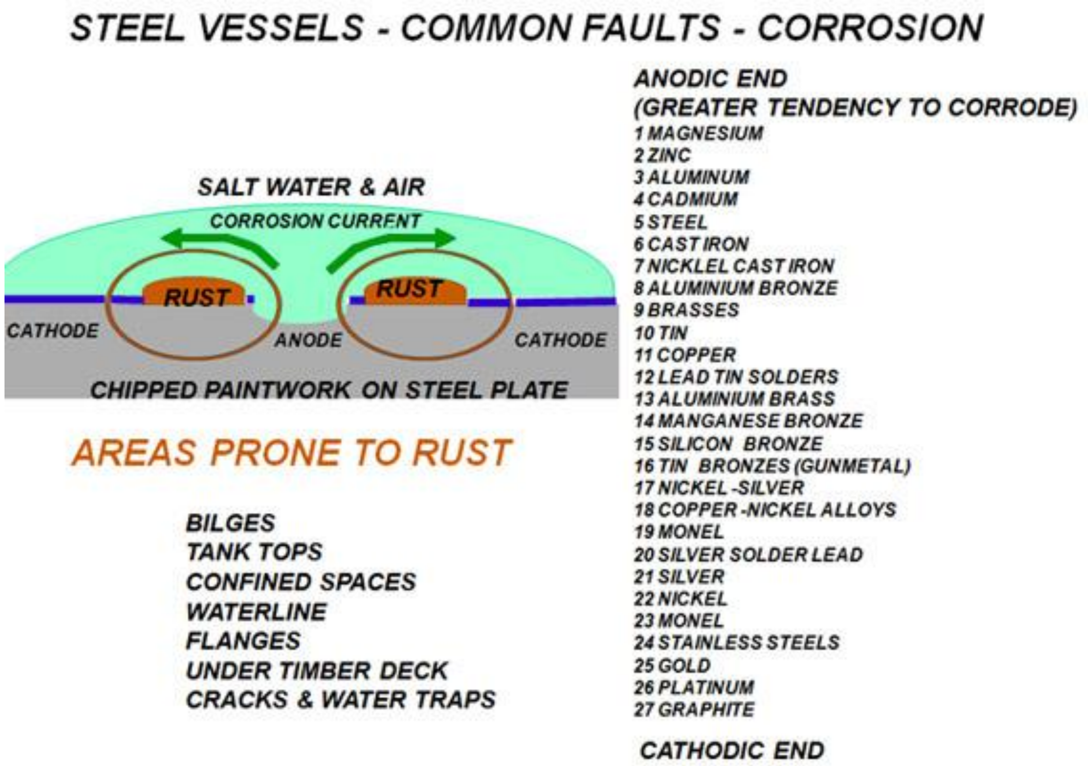
Fungal infection can be controlled with a water soluble preservative in the bilge of 0.65 Kg of borax and 0.45 Kg of boric acid in four litres of hot water. This traditional mixture is non-corrosive and harmless to animals but check with your Marine Authority that this meets the current environmental protection regulations in your operating location. Regularly inspect your vessel's timbers for decay and if found act at once using the recommended proprietary preservative or poison for marine insects extermination.

Deterioration of metal

Corrosion is indicated by the wastage and decomposition of metals by chemical attack or by electrochemical reactions. Hence it is the result of either *chemical corrosion* or *electrochemical corrosion*.

Chemical corrosion - Solutions of acid (such as sulphuric acid and hydrochloric acid) or alkali (such as caustic soda and lime) dissolve metal by chemically combining to form oxides, other compounds and gasses. Typical areas of attack are at the engine room battery banks, in storage cupboards and toilets (leaking cleaning products) or where hazardous cargo packaging is breached. Great care must be taken in clean up due to the potential for personnel injury and environmental damage. The chemical's Hazardous Material Data Safety Sheet must be consulted for the appropriate first aid response and emergency management schedule. The *IMDG Code* also contains this information.

Electrochemical Corrosion - Electrochemical corrosion is caused by electrical currents flowing between physically close but galvanically dissimilar metals when both are bathed in an electrolyte. (See pages 142 and 164). Saltwater plays the part of the electrolyte and the steel hull the part of the anode. A small current will be created as the bare steel is stripped and redeposited as rust at the edges of the paint chip. The *Galvanic Scale* of metals shown below indicates the comparative reactivity of differing metals, and their differing readiness to corrode.



Note that all the corrosion resistant marine grade metals and alloys that we use for fastenings and utilities (apart from aluminium) are closer to the cathodic end of the scale than steel. On exposure to air aluminium rapidly forms an aluminium oxide coating that is very resistant to corrosion. Copper is a *ductile metal* (bends easily without breaking) that is used for nails. Brass is an *alloy* (mixture) of copper and zinc used for handles, hinges and wood screws. Although it is partially resistant to corrosion, over time the zinc will leech out of the screws making them brittle and easily broken. Over long exposure to the marine environment bronzes are superior to brass. They are alloys of copper and tin with traces of nickel. Other metals can be added with bronze for specialist uses such as in manganese bronze bearings and annular nails (of phosphor bronze). Stainless steel is available in many grades, but the high nickel content marine quality of *SS 603* does not rust and is non magnetic. It is however very brittle and will not bend readily without snapping.

If two galvanically dissimilar metals are placed together in an electrolyte, it is the one at the anodic end of the galvanic table that will corrode with material from it migrating to the cathodic end (to the more noble metal). Hence the use of a *sacrificial anode* made of zinc is fitted near the costly bronze propeller, bearings and stainless steel shaft to corrode in their place. It must also be noted that where, for instance, a stainless steel shaft is selected to run in a bronze bearing the cheaper bearing that will corrode not the more expensive shaft - a better result than if the selection had been reversed.

Preservation of metals - Corrosion is controlled by addressing electrolysis and/or by the use of surface coatings.

Sacrificial anodes - are the tried and tested means used to address electrolysis. Usually sacrificial anodes of zinc, but recently aluminium alloy, are available in a variety of shapes and sizes including those dedicated to clamp around exposed shafts and to fit as terminals for propellers. It is vital that the anode makes electrical contact with the hull so it must be a clean metal to metal initial fitting. Clearly anodes should be masked off on slipping and not over painted with anti-fouling. Don't forget to unmask them before launching. Lead contacting an aluminium vessel will cause rapid hull corrosion. Lead based paints must never be used on aluminium hulls and all non aluminium skin and deck fittings must have gaskets to prevent electrical contact.

Larger vessels may also be fitted with an *impressed electrical current* network of transponders on the bottom of the hull designed interrupt the electrolysis process.

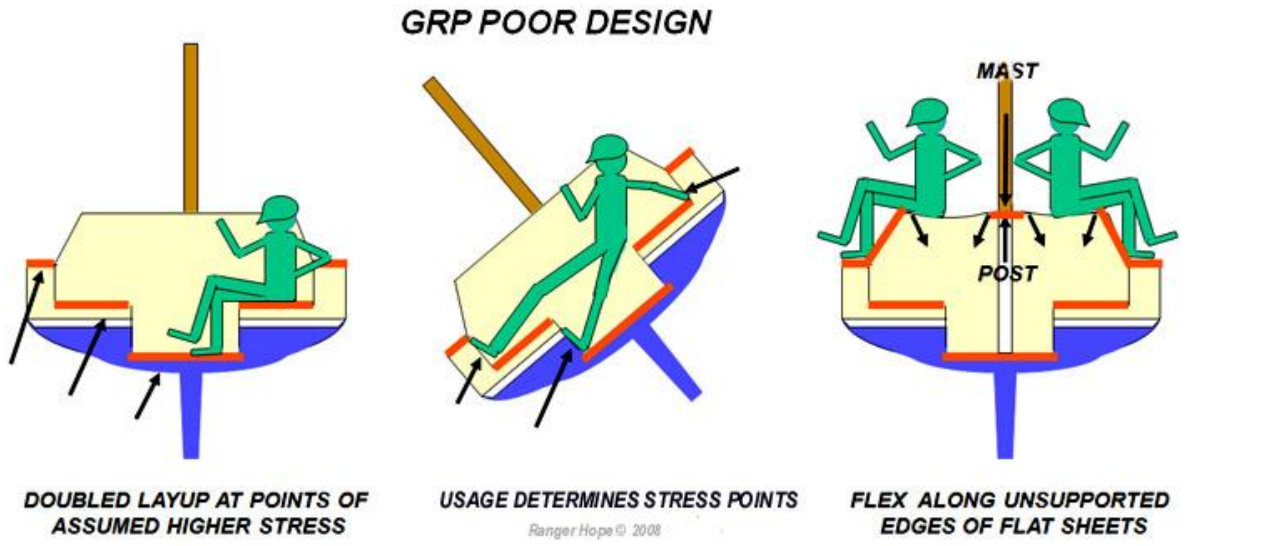
Surface coatings – rely on the bond between the paint and the surface so the surface must be corrosion free, thoroughly clean and degreased ready for the initial primer. Techniques are more fully described in the following section on *paints and surface coatings.*

Deterioration of GRP

GRP is a comparatively new boatbuilding material that in the short term has shown itself to be remarkably free from the drudgery of continuous maintenance due to weathering as required by timber and steel construction. GRP may only need antifouling every few years and a polish every decade to look almost as good as new. However it requires good fenders and rope leads to limit abrasion damage and care to avoid impact with the consequent chips and radiating star cracks. Particularly in older vessels, it can suffer the consequences of poor design and inexperienced construction.

Design - and construction has come a long way since the earliest fibreglass vessels of the late 1960-1970s. Flex in sheets of fibreglass easily develop creeping fracture lines between a supported and unsupported edge. Wide T shaped terminals to posts and pillars are required to support by spreading the loads bearing experienced by large flat areas.

Some earlier designs assumed loads to be gravity produced failing to recognise that the stressed areas of the vessel at rest were not the same as those of the same vessel in its working state. Modern design has greatly improved structural performance and optimised accommodation space and layout.



Early construction techniques did not fully appreciate the requirements for humidity control during the curing of the GRP process, or that polyester resins are not ultimately waterproof. The earliest beefy hulls built with cheap resin and gave way in the mid 1970-80s to a decade of soaring resin prices and thinner sometimes poorly cured hulls. A decade or two later it is not uncommon for this era of GRP vessel to exhibit the deterioration called *osmosis*.

Osmosis - occurs when two differing concentrations of solutions that are separated by a semi- permeable membrane develop sufficient difference in pressure to force particles from the more concentrated solution through that membrane towards the less concentrated solution.

Poor humidity control on build can allow moisture to contaminate the resin so pockets of the resulting high concentration mixture become encapsulated close to the *gel coat* surface (the hull's thin outer layer). The polyester *gel coat* becomes the semi-permeable membrane that is under pressure from the underlying pockets of contaminated resin to burst through into the salt water beyond. In fully developed cases the hull becomes full of blisters and the gel coat breaks away leaving bare glass fibres to absorb seawater, expose deeper encapsulated pockets and spread further deterioration.

Attempting to build an impervious surface coating over osmosis blistering fails to address the root cause that is the remaining pockets of contaminated resin trapped within the layup. The blisters must to be ground out one by one with an angle grinder, the hollows thoroughly washed clean and then fully dried. In serious cases it may be necessary to have the gel coat shaved (with an electric plane like shaving tool), the hull sprayed with water for many weeks to purge it of resin remnants and then dried out for many months.

Once a clean dry hollow is prepared and locally degreased with acetone, a marine grade filler paste of polyester resin reinforced with fine fibreglass stands can be applied.

The hollow should be under filled so sanding back with the inevitable exposure of fibre ends is not required. A reasonable surface can be achieved by smoothing over some a temporary plastic sheet. When the resin has cured a smooth layer of marine grade epoxy paste can be applied and subsequently sanded back fair.

In completion to resurface a two pack epoxy paint spray coated will provide both a durable surface coating and a watertight membrane, albeit not as glass like as the original gel coat finish.

Glue, sealants, preservatives and surface coatings (paints)

Glues and sealants - compounds traditionally used as glue included water soluble vegetable bases, oil based rosin varnishes or spirit based shellacs. While *shellac* (ground beetles) and oil provided some waterproof qualities all these glues were brittle when dried out. Organic oils and resins, gum arabic, bog pitch and tars provided semi drying seals with greater flexibility and consequent sealant qualities. In the construction and maintenance of a wooden sailing ship, tonnes of pitch would be melted into the deck seams, barrels of linseed oil putty and *white lead* (lead oxide) mix pasted into every hull seam, creosote sloshed over any unpainted timber that was not *brightwork* (varnished) and very rope hanging from a forest of mast and spars was tarred. Not surprisingly uncontrolled fire engulfed many ships.

Traditional modern animal glues and tars have been replaced by chemical compounds of greater bonding strength, water resistance and versatility or specialty so much so that for full product information it is imperative both to read the products label and the material data safety sheet. In a small vessel solvent stowage remains a major fire risk. Always read the instructions carefully before opening the container.

Modern *PVA* glue (polyvinyl acetate) used for interior house joinery is not waterproof. Neither are the *contact adhesives* used for linings when rapid assembly is needed (both surfaced are pre-coated before pressing together in situ). This adhesive bond can let go in a summertime heat wave. The development of water resist *Cascamite* like (melamine-urea powder/water mix) and *Cascophen* like (resorcinol two pack resin/catalyst mix and liquid hardener) provided a leap forward in marine and aviation timber bonding. The later in improved mix shelf life, convenience of assembly and immersed bonding performance.

Two pack polysulphide compounds replaced pitch for ship scale deck seam caulking with the convenience of cold application, ability to sand back, over paint and form into rubber like gaskets. Oil mastic sealants (that skin over but do not dry) have been superseded by extremely flexible cartridge applied silicon sealants (cannot be over painted) and polyurethane sealants (can be over painted). The boundaries between glue and sealant are now indistinct with adhesives like the *Sikaflex* range for specialist applications, and the *West System* merging timber build, epoxy resin bonding, filling and final surface coating.

Preservatives - The greatest enemy of timber is rot caused by fresh water. A soak in a preserving *Teak oil* or *Deks olje*) or an epoxy soak such as *Everdure* is effort that will be rewarded. Both processes need multiple coats paying particular attention to the end grain. If possible, sit the end grain in a pot of oil to fully soak. Unlike surface coating that requires sanding back between layers, soaks only require a wipe back sufficient to key the surface. To preserve the historic vessels SVs Mary Rose and Batavia specialist silicon epoxies were sprayed over them that wicked up into the damaged timber fibres to set hard.

Proprietary timber preservatives contain poisonous and/or carcinogenic copper sulphate and arsenic so they should be used with extreme care. Fungal infection can be controlled with a solution of borax and boric acid described earlier in the timber deterioration section. *Oxalic acid* is affective in cleaning up beech decks but check with your Marine Authority that any chemical used meets the current environmental protection regulations in your operating location and plan to avoid any run off into the watercourse.

Surface coatings (paints) - paints are made from pigments and drying agents mixed with a solvent. For cleaners and solvents marine paints use water (acrylic paints), white spirit or turpentine (oil based paints), or acetone thinners (two part epoxy paints). Oil based paints are usually successful if over painted on top of an acrylic undercoat - the opposite is rarely successful.

Specialist paints use custom ingredients such as *marble dust* for ultra violet resistance, *oils* for flow qualities, metals for corrosion protection or a *catalyst* to prompt the reaction process. Specialist application paints include:

Anti-corrosive - used on metal surfaces to prevent corrosion

Anti-fouling - used on hulls to prevent marine organism growth

Barrier coatings - to over coat differing paint systems without sand blasting back to bare surface it is essential to apply a barrier layer between the old and the new. With differing anti-fouling systems the remnant solvents can interact so reducing the surface concentration of the active anti-foul ingredients. Similarly, twin pack over layers may chemically attack single pack under layers.

Heat resistant - of aluminium and graphite

Fire retardant - that give off gasses as they burn to smother localised flames

Primer - the initial surface coat that may contain anti corrosive metals

Quick drying - for intertidal applications

Non skid - to prevent slippage in key zones

UV resistant — particularly for *brightworks* (varnish)

Surface preparation - is the key to a lasting paint job. Timber must be scraped back and abraded to a solid surface. A *sanding sealer* is often used to fill the grain and give a better bond to the timber. On steel hulls old paint and rust is first removed with a rattle gun or sandblaster. Persistent low spots may require wire brushing or abrasive disc grinding back to bare metal. When all paint and rust is removed a degreasing agent such as *Prepsol* is used to wipe down the hull. On fibreglass vessels an acid etch primer may be required to give a key for subsequent over coats.

Paints can be applied by brush, roller or spray gun. Use the largest brush you can reasonably handle with a liner brush handy for finishing to a fine edge. Quality brushes produce quality work, but with some two pack processes it is impractical to clean a brush without using buckets of thinners costing more than the brush, so a disposable may be more economic. In all cases you should refer to the manufacturer's instructions on the recommended procedure, materials and safety precautions. Safety information is also available in the material data safety sheet. Paint instructions will include the acceptable temperature and humidity range for application, the thickness required for each layer and the maximum/minimum over coating time period. Minimal paint regimes will require at least a primer, an undercoat and two top coats.

Paint is expensive - do not waste it. Prepare in advance a convenient access to the whole job, mask off splash zones and only mix up sufficient paint for what can be achieved before it begins to harden, particularly in hot weather. Have solvent and clean up rags ready in advance and disposal plan for the rubbish. On commercial jobs a quality control procedure will require an accurate log of instrument readings to be maintained (ultrasound, thermometer, and dewpoint) and volumes applied.

10.4 Slipping operations

Slipping methods and devices

A variety of methods and devices can extract a vessel clear of the water to enable out of water surveys or repairs, these include:

Careening - requires driving the vessel ashore to gain access to the underwater hull. This procedure is rarely attempted except in the remotest of areas with no slipping facilities or in the case of a dire emergency. Environmental considerations must be addressed.

Ideally a flat sand or mud beach or river bank clear of obstructions is selected when the tidal range is greater than the vessel's draught. This will usually mean a position parallel to the water's edge where the incline is least steep. Care must be taken that the vessel does not become be-neaped (caught in the monthly tidal cycle when progressive lower tidal heights occur). Grounding in part ballast will give the flexibility to settle the vessel at a chosen point by pumping onboard or pumping out to float free. The vessel should be adequately propped to remain safely upright or at least heeled over away from the direction of the next rising tide. If the lower side faces the incoming tide and its incoming waves the vessel could flood before the rising tide can lift her.

Heaving down - the vessel is heeled over while afloat using tackles acting on its mast from the shore or another ship. While the chances of hull grounding damage are less than careening the underwater area exposed is less and the repair crew must work in the water.

The floating cradle (patented slipway) - is a set of railway tracks fixed to a sloping base extending from deep water to above the high tide level. A *cradle (*wheeled carriage) with adjustable vertical arms runs on the tracks and supports the vessel's hull as it is winched clear of the water. Multiple carriages can be linked together to form a cradle appropriate for the size of vessel. A pollutant trap is incorporated to trap sediments and potential spills.

Smaller vessels may only need two cradle beams to support the keel but with larger vessels the exact keel shape must be known to the slip master so that keel blocks and packing pieces can be set up give continuous support. Plans or photos are a great help as he/she places a taut piano wire over the cradles length and places packing timbers to the calculated distance below the wire. Often a final crushable plank of soft timber is placed as the uppermost packer just in case the measurement is imprecise.

The vessel is driven or warped onto the cradle and secured with springs. The vessel's trim is sighted to make sure that it is not listing as the adjustable arms are wound inwards to support the gunwales. As the vessel settles onto the cradle, divers can check that the slip master has got the packers right, or alternatively wedges can be inserted as required. The cradle is slowly winched shoreward. Once the vessel and cradle are winched clear *toms* and *shores* (support posts) can be positioned under hull overhangs and at the turn of the bilge. A safety securing chain is attached to the cradle and the slip master removes the docking plugs to drain remaining bilge water. This potentially oily water must be drained into drums for proper disposal. The docking plugs remain in the possession of the slip master who must re-insert them as the final check before re-launching can proceed.

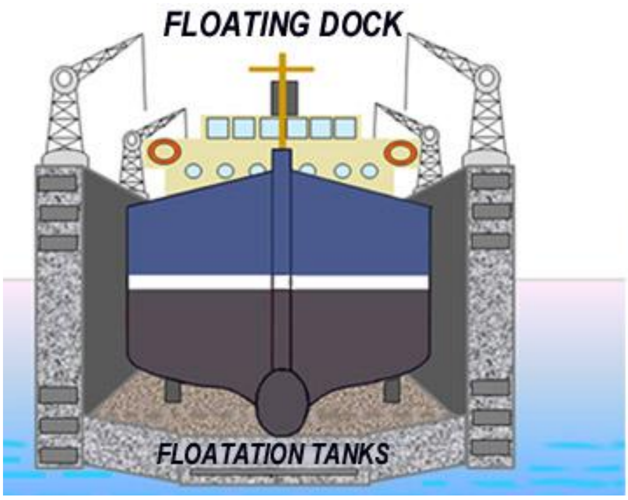
The travel lift – The travel lift enables a rapid lift at any state of tide and can move the vessel to any position on a hardstand for propping. Unlike the patent slip that is burdened by the slipped vessel until its re-launch, the travel lift can execute as many lifts as there is hard stand space available. Originally for small operations, that shown below courtesy of Sydney City Marine has a 100 ton capacity.

The travel lift can be driven out over a purpose excavated narrow dock. Twin webbing strops hang down into the dock and the vessel is driven into position over the top of them. The strops are then hauled up by powerful winches. The positioning of the strops is critical, needing a skilled travel lift operator. They must be placed so the load is evenly shared, but also close to the bulkheads to prevent crushing the hull, and away from impellors or transducers that are easily damaged. If all is satisfactory on inspection after a partial haul then the vessel can be fully hauled clear of the water and driven to the desired location for propping and stowage.

The dry dock - The dry dock or graving dock is created by excavating a short canal (dock) into the river bank. It has a concrete floor gently sloping down towards the entrance where fixed lock gates are positioned over a sunken sill. Alternatively a *caisson gate* (a submersible gate) can be towed into position, sunk so the entrance is fully sealed.

The dockmaster sets up keel blocks the entire length of the dock's floor to support the intended vessel's keel. Once the vessel has been warped into the dock it is positioned over these keel blocks, the gates are closed and the dock water is pumped out, back into the river. The mounting pressure of the river water keeps the gates ever more tightly pressed against the sill and frame. To open, the the dock has to be re-flooded to equalise the pressure on both sides of the gates or caisson before either will open.

As the dock empties the stern touches the keel blocks first (called *seeding the keel*). At this point divers will be sent down to ensure that the vessel's keel continues to seed fully supported all along its length. As the water level continues to drop *bilge blocks* or *side blocks* are built up and wedged tight. At critical points support props are also wedged under the hull. The sides of the dock are constructed in tiers not only to provide several levels of access to support scaffolding but also for side shores that can easily be positioned at various heights along the vessel's sides. After inspection, repairs and cleanup the launch is the reverse procedure.



The floating dock - The floating dock acts as a mobile dry dock that can be moved to the ship rather than vice versa. It consists of a bottom platform built over a floodable double bottom tank. The two side walls act as side tanks that can also be flooded.

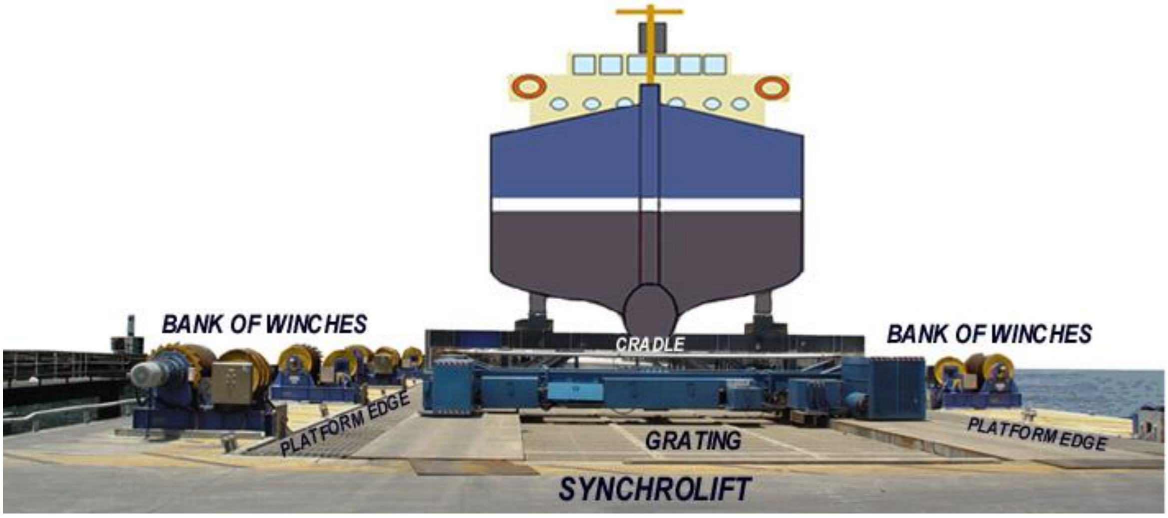
The floating docks tanks are flooded so it sinks to a pre-determined level. The vessel is warped into position and support jacks are pressed up to support the length of the keel and turn of the bilge. Great care has to be taken to ensure even loading and stability. As the tanks are slowly pumped dry the vessel and dock rises clear of the water. Side shores are wound in from positions embedded along the side walls. After inspection, repairs and cleanup the launch is the reverse procedure.

The ship transporter - The floating dock principle has been developed to its ultimate conclusion with the ship transporter that is able to be submersed below other ships, oil rigs or other structures and then refloated to pick them up as cargo to deliver them worldwide.

The super yacht industry is served by ship transporters carrying dozens at a time of these small ships to their seasonal cruising grounds. Though high cost, it can be less than the fuel, crewing and stores required for a super yacht's self propelled passage. It is also faster and can avoid the need to slip the vessel for repairs and maintenance on route.

The synchrolift - The synchrolift or ship lift is created by excavating a short canal (dock) into the river bank. A platform is suspended from the dock's side walls that can be lowered or raised by banks of synchronised winches.

The dockmaster sets up keel blocks the entire length of the platform's floor to support the intended vessel's keel. Once the vessel has been warped into the dock it is positioned over the platform, cradle and keel blocks, and the powerful winches wind all clear of the dock water. As the dock empties the stern touches the cradles keel blocks first (called *seeding the keel*). At this point divers will be sent down to ensure that the vessel's keel continues to seed fully supported all along its length. As the platform continues to rise *bilge blocks* or *side blocks* are built up and wedged tight. At critical points support props are also wedged under the hull.



The lift shown above can accept vessels of up to 800 tonnes. Once the platform is level with the hard standing of the ship yard the cradle and vessel can be hauled clear so the platform is free for another lift and the vessel is under cover.

Slipping preparation

The slipping of a vessel is expensive and fraught with dramas unless well planned, organised and executed. The reason for slipping and therefore the priority of works must be well understood by all. This will normally be in consultation with the survey authority and according to the survey schedules previously discussed from pages 8-12.

Job sheets - must be drawn up in advance to ensure that the inspection, repair and compliance re-inspection can occur within the time frame of the slipping. If the substance of works are known in advance then labour, tradesmen, the repair materials and the access scaffolding can all be ordered in advance and be on site when required. Areas that require repair should be discussed with the dockmaster so props and blocks are not placed in the way.

Structural concerns - When slipped the weight of the entire vessel will be supported at a few localised points. It is clearly better to slip with empty tanks than with full ones, though half full tanks present issues of free surface risks. If the support points are chosen well, under bulkheads, frames/floors or other strong points, the vessel will have sufficient strength to withstand the localised stresses. Pay particular attention to the position of hull fittings such as keel coolers, sounders, log and sonar transducers that could be damaged and tell the dockmaster of your concerns.

With timber vessels there is the potential for a slight change in shape of the vessel sufficient to jamb wooden doors and drawers. If these need to be opened for access or works make sure all are so before slipping, and re-opened before re-launch.

Stability concerns - as the vessel is removed from the water its trim changes. Therefore all potentially mobile weights should be lashed down or unnecessary weights removed. In changing trim, any tanks that are inter-connected may result in syphoning through the equaliser valves. Close them as soon as they are not required.

The patented slipway and travel lift constrain the vessel with arms and webbing strops, but other methods can be more problematic. The stern area seeds first, rising higher than the stem as the water recedes in the dry dock or on the synchrolift. The weight distribution of the vessel changes and can significantly raise the centre of gravity of the vessel. In the process of repairs new materials to install and waste removed tend to build up on the decks awaiting completion. Often large low components such as engines, chain and ballast may be entirely removed. These changes can reduce the overall stability of the vessel with disastrous consequences.

Crewing concerns - Your crew will be well drilled at the normal operations of the vessel, but not necessarily in the heavy industry environment of a busy shipyard. They will need induction for appropriate risk management including PPE's, manual handling and use of power tools.

Slip and splash procedures and summary checklists

The procedures must be customised for the slipping method of but generic checks include:

Step	***Actions when slipping***
1	Negotiate the plan with the surveyor, dockmaster and crew.
2	Empty or press full tanks and avoid liquid transfers during slipping.
3	Lash down or secure all loose gear.
4	Trim the vessel with no transverse list.
5	Trim the vessel to seed by the stern close to the line of the support blocks.
6	Shut down all machinery not required and close sea cocks.
7	Ensure the vessel is supported and stable on all the support blocks.
8	Connect safety chain when slipped position is reached.
9	Fit props to support overhangs and turn of the bilge.
10	Check for hull weeps, remove docking plugs and record their placement.

Precautions on the slip - Ensure that pollution and waste management controls are in place before water blasting the hull. Provide safe access and appropriate Ppes. While ashore the vessel may not be able to fully utilise its fire fighting system, so run hoses to the shipyards fire hydrants and position fire extinguishers at accessible points.

If tanks or void spaces are to be opened and inspected then isolate the tank's services, purge, vent and arrange issue of a confined space *gas free* and *permit to work* certificate. If welding or cutting are planned then a *permit for hot works* will be required.

Transducers and anodes must be masked off as should anywhere where drips or over painting could reach, as it almost surely will. The maintenance and repair plan will drive the schedule, examples of which are discussed in the following section *10.5 Maintenance, inspection and repairs.* However, because of drying and over coating time frames the painting regime is usually the critical determinant of when the vessel is ready to splash (and how many extra days of fees become due to the shipyard).

Step	***Actions for splash***
1	Confirm the paint is dry and transducers/anodes are un-masked.
2	Re-fit docking plugs, check that skin fittings and intake gratings are replaced.
3	Check that the anchors and chain are secured but ready to go.
4	Remove any tools, equipment, scaffold, shore power and remove safety chain.
5	Establish the same stability and trim conditions as at slipping.
6	Check the slip is clear and sufficient tide has flooded to float.
7	Check for leaks at sea suctions and discharges, side valves and stern gland.
8	Test that the bilge and deck hose system is in working order.
9	Test that the steering system is operating correctly.
10	Open the salt water cooling sea suction valve and start the genset.
11	Open the salt water cooling sea suction valve and start the engine.
12	Check both for discharge overboard.
13	Allow engine to idle for a short period.
14	Check ahead and astern and depart the cradle.

10.5 Maintenance, inspection and repairs

Maintenance

The value of maintenance is to ensure the continuous trouble free operation of equipment for the maximum duration before the expensive replacement with new is required. Daily use equipment is monitored in the pre-departure checks and obvious symptoms usually indicate when servicing is needed. Maintenance records not only schedule precautionary servicing but also tell a story of performance trends. However, emergency equipment may not be used in anger for years if at all. Such equipment, sitting in its highly corrosive marine atmosphere, cannot be relied upon to work when needed unless test operated as part of the maintenance schedule.

Maintenance schedules are also one of the essential *safety management procedures* that aim to identify hazards and reduce risks. A fuller description of example schedules is found at *Section 1.2 Survey Page 8*, the following information concentrating on methodology.

Maintenance records - may be kept by a number of methods including:

Verbal, or scribbled notes - unreliable and do not capture performance trends
Chalk or white boards - visible but impermanent
Loose leaf record sheets - entered into a folder on completion but subject to loss
Card systems - data cards recording servicing for each piece of equipment
Maintenance logbooks - effective tracking & diagnostic books that don't go missing
Computer data bases - facilitates cross referencing but unavailable at sea

Most vessels use a maintenance log book with a chalk board to highlight regular servicing due date items (such as oil change, coolant/fuel additives) and current status (such as fuel stowed and pre-departure draught marks). Whatever method or combination of methods you adopt, it must be *clear, concise and accurate.*

Maintenance checks - can include:

Primary consumables - Pre-departures, such as fuel, gas, fresh water
Ancillary consumables - Pre-departures, such as lubricant, coolant, electrolyte levels
Performance - Start up such as power, flow rate, pressure checks, brightness
Diagnostic indicators - Operating such as gauges, noise, exhaust
Service items - Filters, belts, globes, sharpening, replacement impellers

During this process, it may become evident that some equipment is:
Loosing performance or becoming dirty.
Operates ineffectively or inoperative.
No longer fit for the purpose due to many defects or many anomalies.

The development of these problems must be reported to the chief engineer or master/owner to ensure timely repairs/replacement. Let *everyone* know if equipment is removed or unserviceable by *tagging*.

Inspection

While the term inspection can be used in a general sense, it is useful to distinguish between visual inspection, examination, survey and audit. The defined use of those terms would be:

Visual inspection - A thorough visual check of the visible parts of equipment
Examination - A thorough visual and performance testing of accessible parts
Survey - Dismantling, measuring, performance testing and reassembling
Audit - Cataloguing the organisation's resources and their functionality

The obvious purpose of *inspections* is the identification of faults to promote timely repair, so maintaining equipment readiness. The process is continuous, but there are levels of thoroughness that are appropriate. Pre-departures checks will include *visual checks* of the overall readiness for the operational requirements. It might be at the *visual inspection* that a failure or potential for failure is identified. This would require an *examination* to resolve the problem and mend the utility. Normally, the more complete general *examination* of utilities will await the maintenance schedule and its list of weekly, monthly, three monthly and six monthly jobs. Others jobs will be determined by the manufacturer's recommended maintenance schedules.

Testing

When all the cleaning, maintaining and servicing has been completed, you must ensure that the item of equipment works satisfactorily, to the standards, by testing. The two basic strategies for testing are:

Proof tests - As its name suggests, proof testing is putting the equipment under load pressure and seeing if it is up to the strains of service (in fact, usually considerably more than would be encountered during normal use). An example would be a bosun's chair and lift that Marine Orders 32 (Cargo Gear) specifies should support four times the intended usage weight. The advantage of this type of testing is its low tech confirmation of the fitness of the equipment for the user's purposes. The disadvantage is that the equipment may well be destroyed, damaged or distorted in the testing process.

Specification (performance testing) - Usually requiring a degree of technical skill and testing apparatus to ascertain if the equipment meets the specification standards. Unlike proof testing, performance testing is not destructive. The specifications standards can be found by researching the:

The Australian Standards
National Standards (National Standards for Commercial Vessels/Marine Orders)
Manufacturer's Guidelines

Having identified the standard to which the equipment should match in performance, you check your manufacturer's guidelines to identify the approved procedure of the testing.

Disassembly and reassembly - **Specification** testing often requires taking the equipment apart. Examples include removing a prop shaft to set up on a centre lathe for testing wear or dissembling a stainless steering ram and die testing for signs of fatigue fractures. Conforming to a procedure of disassembly will save a lot of grief when reassembling.

Safety is a key issue and the importance of *isolating* power and fuel supply and appropriate use of personnel protective equipment cannot be over stated. Good lighting and a scrupulously clean dismantling area (perhaps a dust cloth below) will limit the loss of parts that resist coming loose only to fly off and disappear in the dirt. Contamination by oils and dirt is also reduced by attention to cleanliness.

Using the *correct tool* for the purpose it was designed for will avoid burring and damaging nuts, and probably avoid slicing the skin off your knuckles if the spanner slips. Marine components are often corroded and can be extremely resistant to separate. It is not unusual to resort to ever longer spanners, bigger hammers, soaking overnight in diesel or even heating with a blow torch. In the increasingly wilder efforts and mounting frustration resulting from such situations, it is well to pause and reconsider appropriate PPEs (visor, boots, gloves, dust mask). In removing a reluctant propeller, it is wise to remove the retaining split pin and propeller nut, and then loosely refit the nut so that when the prop suddenly pops off the shaft, it does not fall on your toe.

Even though your manufacturer's manual with its engineer's exploded component diagram is a guide for reassembly, bearing wear often results in couplings and flanges needing to be reassembly as was. Before disassembly it is a good precaution to scratch aligning marks on both meeting surfaces. Likewise, a method of removing nuts, washers, springs, and laying them out in the order of disassembly will greatly assist reassembly.

Equipment may contain extremely complex assemblies. It is a brave or foolish person who attempts to dismantle a diesel rotary fuel pump and its many components. The questions must always be asked, *"Have I got the skill and spares?"* or "*Is this a job for an expert?"*

Test result records - As well as tracking maintenance carried out, we also are obliged to maintain a record of the equipment being tested before being put back into service.

Defective equipment reports - The result of tracking is of great benefit to the company purchasing officer. If items manufactured by a certain manufacturer are consistently failing, it is important to look for an alternate product. The company can purchase wisely when such documented knowledge is readily available.

Gauges, measuring and testing tools

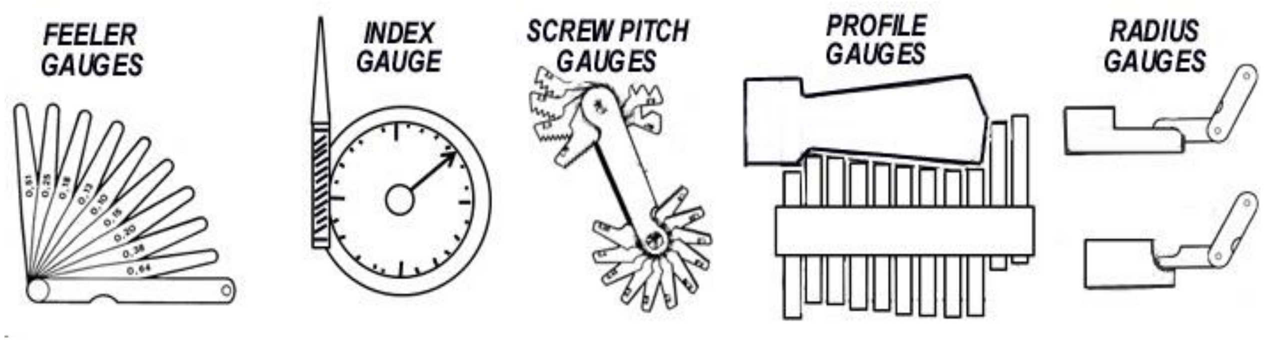
Inspection and testing will require fine tolerance gauges and measuring tools. These are liable to damage if bumped or dropped so they must be carefully stored, kept clean but oiled and regularly checked against *working standards of measurement* (precisely made steel gauge blocks). Getting the best out of tools is a learnt skill requiring practice. In use, holding the test item and gauge in directly in front of you against a light background allows you to take clear readings without *errors of parallax* (reading at an angle).

Feeler gauges - are used to measure clearances gaps between mating parts such as spark plug electrode gaps, mating surfaces between couplings or valve tappet's clearance. When using the thinner gauges pull the gauge through a gap rather than push, to avoid bending and permanently kinking it.

Depth gauge - is a stylus that can be inserted into a hole or slot, or between an edge and another surface.

Index or dial gauges - are used to measure the variation in diameter of material using a fixed dial/gauge body with a plunger indicating its distance from a test piece. An application will be a fixed gauge measuring the trueness of a propeller shaft mounted on a centre lathe.

Screw pitch gauges - for finding the pitch of a bolt they consist of a series of marked blades with teeth matching various thread systems. They are available for the common thread metric systems of *UNC* (Uniform National Coarse) and *UNF* (Uniform National Fine) and imperial measures of *Whitworth* (coarse), *BSP* (British Standard Pipe) and *BSF* (British Standard Fine).



Profile gauges or form - are used to compare shapes. They can be a fixed shape or profile, or an adjustable type with multiple sliders as shown.

Radius gauges - check internal and external radii. They are sets of marked blades with a *convex* (external) and *concave* (internal) radius of the same size on each blade.

Callipers - are used to transfer measurement by closing their jaws between two fixed points. There is an internal and external type. The calliper gap is then compared to a graduated steel rule and the dimension read. It is bad practice to use callipers on a rotating work piece (on a lathe) as it will mark the work or wear the tool's meeting surfaces.

Measuring tapes - a flexible steel tape is sprung loaded within a protective shell. The tape must be cleaned as it retracts into the housing to avoid subsequent jamming or the printed graduation marks being scratched away. These tools are not marine tolerant and will be destroyed with single salt water immersion. Regularly coat the tape with oil or WD 40.

Graduated steel rules - steel rules enable measure lengths to an accuracy of approximately plus or minus 0.5 mm. The end of the rule must be maintained with its edge square and sharp. A common error is caused by *parallax error (*not sighting across the rule at right angles to the graduations).

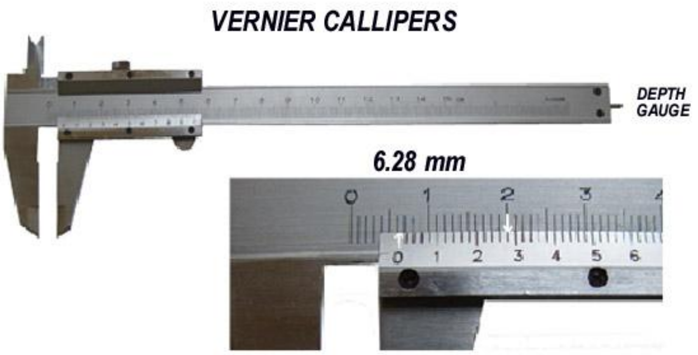
Vernier callipers - standard *vernier callipers* (with an engraved graduation scale) measure to within 0.05 mm, though *digital callipers* (with an electronic graduation display) are available with an accuracy up to 0.01 mm. *Verniers* measure *OD* (outside dimensions) with their main jaws, *ID* (inside dimensions) with a pair of upper tangs and can be used for depth readings with the protruding foot. Care must be taken to avoid wear on their measuring surfaces or bending the thin protruding foot. They must be stored lightly oiled in a protective case to ensure that their accuracy is maint**a**ined.

The main arm of the tool consists of a metal rule of up to 250 mm long (the example shown below is160 mm) graduated in centimetres and millimetres. The main graduated scale indicates at its 0 mark the thickness to the millimetre (in the case shown a gap of a bit over 6mm). As the tool's jaws are opened around an item to be measured, a sliding carriage moves with them. This carriage's graduated scale is a *vernier* scale that enables accurate determination of that "bit over the millimetre".

The lower carriage vernier scale is marked from 0 to 10 and divided into fifty graduations each representing 1/50th (0.02 mm) of the millimetre scale above. In the photo shown at a point of + fourteen graduations of the lower scale the marks on the main precisely align (28 aligns with 2). The tool is then reading 6 whole millimetres plus a bit that equals:

14 x 0.02 = 0.28 and in total thickness ***6 + 0.28 = 6.28 mm***

Metric calliper shown below has a lower vernier scale marked from 0 to 10 (with fifty graduations) can be read without resorting to calculations but other models with a vernier scale of 0 to 5 (with fifty graduations) have larger marks display. However, in each case a graduation represents 0.02 mm of the whole millimetre scale above. Do pay close attention to the number of graduations on the vernier scale, 0 to 25 (with fifty graduations of 0.02 mm) are also common but other graduated tools out there are from the days of imperial measures with differing fraction intervals



Micrometers - enable very accurate measurements of *OD* (outside diameters) and length of smaller parts. They are available in various sized *frames* (the bowed body) and with imperial or metric *spindle and thread (adjustable rod)* and *barrel* (measuring scale). No matter what the *frame* size and distance across the *anvil* (the internal measuring surfaces) all are limited to the length of the thread on the spindle. This is typically up to one inch or up to up to 25 mm. With frames designed for over 25 mm work pieces additional 25 mm *spacers* are provided that can gap fill and still allow the frames use for less than 25 mm work pieces.

The barrel scale measures from 0 to 50 in 25 graduated marks. When rotated twice the spindle widens by 1 mm. Each graduation therefore represents 0.02 mm.

MILLIMETERS to INCHES (mm x 0.03937 = inches)							
mm	in.	mm	in.	mm	in.	mm	in.
.1	.0039	25	.9842	58	2.283	91	3.582
.2	.0078	26	1.024	59	2.323	92	3.622
.3	.0118	27	1.063	60	2.362	93	3.661
.4	.0157	28	1.102	61	2.401	94	3.701
.5	.0197	29	1.142	62	2.441	95	3.740
.6	.0236	30	1.181	63	2.480	96	3.779
.7	.0275	31	1.220	64	2.519	97	3.819
.8	.0315	32	1.260	65	2.559	98	3.858
.9	.0354	33	1.299	66	2.598	99	3.897
1	.0394	34	1.338	67	2.638	100	3.937
2	.0787	35	1.378	68	2.677	101	3.976
3	.1181	36	1.417	69	2.716	102	4.016
4	.1575	37	1.456	70	2.756	103	4.055
5	.1968	38	1.496	71	2.795	104	4.094
6	.2362	39	1.535	72	2.834	105	4.134
7	.2756	40	1.575	73	2.874	106	4.173
8	.3149	41	1.614	74	2.913	107	4.212
9	.3543	42	1.653	75	2.953	108	4.252
10	.3937	43	1.693	76	2.992	109	4.291
11	.4331	44	1.732	77	3.031	110	4.331
12	.4724	45	1.772	78	3.071	111	4.370
13	.5118	46	1.811	79	3.110	112	4.409
14	.5512	47	1.850	80	3.149	113	4.449
15	.5905	48	1.890	81	3.189	114	4.488
16	.6299	49	1.929	82	3.228	115	4.527
17	.6693	50	1.968	83	3.268	116	4.567
18	.7086	51	2.008	84	3.307	117	4.606
19	.7480	52	2.047	85	3.346	118	4.645
20	.7874	53	2.086	86	3.386	119	4.685
21	.8268	54	2.126	87	3.425	120	4.724
22	.8661	55	2.165	88	3.464	121	4.764
23	.9055	56	2.205	89	3.504	122	4.803
24	.9449	57	2.244	90	3.543	123	4.842

INCHES to MILLIMETERS (inches x 25.40 = mm)							
in.	mm	in.	mm	in.	mm	in.	mm
.001	.025	.6	15.240	1 15/16	49.21	3 5/16	84.14
.002	.051	5/8	15.875	2	50.80	3 3/8	85.72
.003	.076	11/16	17.462	2 1/16	52.39	3.4	86.36
.004	.102	.7	17.780	2.1	53.34	3 7/16	87.31
.005	.127	3/4	19.050	2 1/8	53.97	3 1/2	88.90
.006	.152	.8	20.320	2 3/16	55.56	3 9/16	90.49
.007	.178	13/16	20.638	2.2	55.88	3.6	91.44
.008	.203	7/8	22.225	2 1/4	57.15	3 5/8	92.07
.009	.229	.9	22.860	2.3	58.42	3 11/16	93.66
.010	.254	15/16	23.812	2 5/16	58.74	3.7	93.98
1/64	.397	1	25.40	2 3/8	60.32	3 3/4	95.25
.020	.508	1 1/16	26.99	2.4	60.96	3.8	96.52
.030	.762	1.1	27.94	2 7/16	61.91	3 13/16	96.84
1/32	.794	1 1/8	28.57	2 1/2	63.50	3 7/8	98.42
.040	1.016	1 3/16	30.16	2 9/16	65.09	3.9	99.06
.050	1.270	1.2	30.48	2.6	66.04	3 15/16	100.01
.060	1.524	1 1/4	31.75	2 5/8	66.67	4	101.6
1/16	1.588	1.3	33.02	2 11/16	68.26	4 1/16	102.19
.070	1.778	1 5/16	33.34	2.7	68.58	4.1	104.14
.080	2.032	1 3/8	34.92	2 3/4	69.85	4 1/8	104.77
.090	2.286	1.4	35.56	2.8	71.12	4 3/16	106.36
.1	2.540	1 7/16	36.51	2 13/16	71.44	4.2	106.68
1/8	3.175	1 1/2	38.10	2 7/8	73.02	4 1/4	107.95
3/16	4.762	1 9/16	39.69	2.9	73.66	4.3	109.22
.2	5.080	1.6	40.64	2 15/16	74.61	4 5/16	109.54
1/4	6.350	1 5/8	41.27	3	76.20	4 3/8	111.12
.3	7.620	1 11/16	42.86	3 1/16	77.79	4.4	111.76
5/16	7.938	1.7	43.18	3.1	78.74	4 7/16	112.71
3/8	9.525	1 3/4	44.45	3 1/8	79.37	4 1/2	114.30
.4	10.160	1.8	45.72	3 3/16	80.96	4 9/16	115.89
7/16	11.112	1 13/16	46.04	3.2	81.28	4.6	116.84
1/2	12.700	1 7/8	47.62	3 1/4	82.55	4 5/8	117.47
9/16	14.288	1.9	48.26	3.3	83.82	4 11/16	119.06

In using the micrometer, first wipe the face of the anvils with a piece of clean cloth. The *thimble* (a torque set spindle winder) is turned until the anvils fully close or close onto an inserted test spacer trapped between the rod and anvil. As the torque setting is exceeded the sprung thimble assembly clicks over as it declutches from the spindle.

A spindle locking lever is activated as the thimble clicks to indicate declutching to prevent further movement of the spindle while the micrometer scale is read. This test measure should read zero on the scale, but due to wear on the spacers, micrometer or torque setting of the thimble there may be a plus or minus scale error of 0.05 or more. The force applied to the thimble to ram home the spindle requires a delicate touch and if over done can alter the reading by 0.01 mm. So note both the appropriate energy to exert and record the scale error to correct future readings.

This micrometer shown above has a frame enabling work pieces of up to 25 mm being measured. In taking a test measure between the anvils it is found that it is reading 0.003 mm when it should be 0.000 (measuring high). This is noted. A work piece is measured and found to have a thickness of 6 mm and a bit over. That bit over was the equivalent of winding the barrel scale past 6 mm once to the approximate mark of 28 (14 graduations x 0.02 = 0.28) with again a bit over. In the photo shown at a point of + thirty two graduations of the barrel scale the marks on the frame precisely align (32 aligns with 3). The tool is then reading 6 whole millimetres plus a bit that equals:

(14 x 0.02) + 0.003 = 0.283 and in total reading ***6 + 0.28 = 6.283 mm***

However, the micrometer was reading 0.003 high so the corrected thickness is:

6.283 mm – 0.003 = 6.280 mm

Disassembly and repair tools

There is a right tool for every job that can make the difference between a simple operation or a drama when alternative makeshift contingencies are resorted to.

Operations, servicing and damage control - The slipping plan should identify what specialist tools or equipment needs to be on site. If forgotten, while on the slip access to tools, equipment are spare parts will inconvenient but not be over problematic. However, it does provide an opportunity to review the tool kit carried as may later be required at sea, particularly if new plant is installed. Most vessels less than 24 metres will carry a tool kit with spare parts for routine servicing and at best a work bench with some additional hand and portable power tools. Most vessels less than 35 metres will be better equipped with at least limited workshop facilities hopefully including a bench grinder, drill press, welding and even thermal cutting gear. The traditional saying that there is the right tool for every job is as true as the frequency of having to improvise when at sea. The skill of the marine engineer will be to ensure that the minimum required to complete routine tasks at sea is carried as well as sufficient to deal with emergencies to enable a safe haven to be reached.

Audit of the tools and spares carried should look at preparedness for:

Operations - are specialised operational tools readily available for routine operations, such as fuel sounding rods, filler cap spanners, LPG cylinders, hatch wedge mallets, anchor shackles, cargo hooks, locks and keys, etc.

Servicing - are adequate servicing tools and spares available for scheduled operations, such as changing oils and filters, fuses and breakers, belts and impellers, ropes and hawsers, wire cables and hooks, etc.

Damage control - are adequate operational tools available and stowed where they are needed in an emergency, such as fire axes and extinguishers, hull wedges and shores, collision blankets, wire cutters, etc.

That correct tool to include in the tool kit will be either a hand tool or a power tool (electrical, combustion or compressed air dealt with later on page 228) designed to optimise work performance related to work holding and forming, impact or torque, scraping or cutting, surface coating, or jointing.

Work holding and forming devices - These are fixed vices, machine vices, portable clamps and anvil formers. The two basic types of fixed vice are the *soft jawed* (wooden) carpenters’ bench vice and the cast engineers’ vice. The latter may have a mini anvil flat and/or horn. Clearly they must be well bolted down onto a stable bench or foundation. Disposable jaw covers can be inserted to avoid marking the work piece. Care must be taken not to damage the clamping thread when though drilling held work or from weld spatter.

Portable clamps include G clamps, long sash clamps, mole grips, plyers and sprung welding hand clamps. The latter can have surprisingly strong spring action that can bite.

The blacksmiths anvil is a heavy iron casting intended as a multi surfaced forming device for red hot metal pulled directly from the blacksmith's forge. It has a squared body with a flat top for *plannishing* (hammering metal smooth) and forming angles in steel plate or bar. A tapered horn is fitted on one end for forming curves in bar, and at the other an extension has a number of sockets that will accept specialty formers. These are not usually carried on small vessels, in part replaced by mini versions or adaptions to the engineers vice.

Impact or torque devices - A number of impact hammer types are available including the heavy long handled sledge hammer, small lump hammer, the carpenters claw hammer (for extracting nails), the engineers rounded ball peine hammer, plannishing hammers and tack hammers for small work. In operation the best efficiency is gained by holding the end of the handle. For nail driving operations the head of the hammer needs to be kept clean to minimise glancing blows while for shaping operations the piene must be occasionally reground back to smooth to prevent marks being imprinted in the work's surface. Flying splinters, sparks and being dropped onto personnel below are all risks with these tools.

The spanner improves the torque that can be applied to loosen or tighten a bolt. They are made in imperial measure or metric with the size stamped on them or sizes if they are often double ended. The size refers to the diameter of the bolt thread, except in the American system where *AF* is used (this is the distance across the flat part of the bolt head). The jaws of a spanner are often cranked at a slight angle to its body. Where access only allows minimal rotation of the bolt head, this enables the spanner to shift the bolt fractionally then to be turned over for another fractional rotation. Where access space is not a problem it is good practice to hold the spanner with the crank placing the spanner body furthest away from the operator. Not only does this provide better torque, but the operator's grip is less likely to slip with a consequent bruised and bloody hand. Using the correct size of spanner is critical to avoid burring the bolt head or nut's faces. Spanners are open ended or ring design, the latter more suited to tight access spaces and less likely to fly off of the sudden release of a bolt under pressure.

A variety of adjustable spanners are available including the *stilson* (toothed plumbers pipe wrench), *shifter* (with knurled screw jaw adjuster), *mole grip* and adjustable *pliers*. Ensure the best fit before rotating to avoid slipping and burring.

Barrel sockets are made in sets of imperial measure or metric with the size stamped on them. Typical *wrenches* (driving arms) are made with 1/4 inch, 3/8 inch and 1/2 inch or 6 mm, 10 mm and 13 mm driving pins. Though cheap socket sets are readily available, they break quickly and are a false economy. Various ratchets, extensions and offset drive devices can fit into the tightest spots that conventional spanners would never reach. Torque measuring extensions are available enabling assembly to a manufacture's specifications.
If these cannot be determined at sea, disassemble with the torque wrench and record the measures for reassembly.

The screw driver is available for the common slot headed screws, phillips headed screws and hexagonal headed screws. Hand and power screw driver insert sets with custom tip bits and sockets are now common for a wide diversity of screw and bolt heads types.

An exact fit between screw head type and screw driver tip is essential, especially where a power tool is the driver. A variant of the conventional screw driver is the push spiral drive or *yankee* screw driver now largely superseded by the battery operated cordless screw driver or the *pneumatic* socket driver. The more robust *impact* screw driver works on the same principle that when belted with a hammer dives a spiral thread to rotate the screw driver bit or socket.

Scraping or cutting devices - Though in operation the distinction blurs between scraping and cutting the required sharpening angle of tool bits is quite different. Scraping tools require a very flat edge that may be improved with a burr. Their action is to tear a fine layer off a surface to leave a smooth finish. They should be applied to the work piece at close to 90º. Alternatively, cutters have a tapered sharp edge that slices through the surface and deflects the cut portion away for the cutting blade. They should be applied to the work piece at fine angles. Using the cutting blade at a skew will provide a greater length of blade edge to bear on the work piece with even better cutting effect.

Scrapers include hand scrapers, finishing centre lathe tool bits, power timber planer thicknessers, power routers and abrasive discs. Unless very tough material such as high carbon steel or tungsten is used for scraper blades they will lose their edge rapidly. Cutters include rasps and files, roughing centre lathe tool bits, hand timber planes, saws, knives, chisels and oxy acetylene cutting. With any cutting of scraping tool it is important that it is sharp. This is particularly so with power tools that must never be forced.

Drills are essentially scrapers of hard materials with a cutting action on soft material. Metal drills are shaped with a flat edge to chip off material and remove it from the tip through the spiral flute. Wood drills have a sharper tip angle, and wood augers have a honed leading edge blade. Blade angle charts are available at your hardware store.

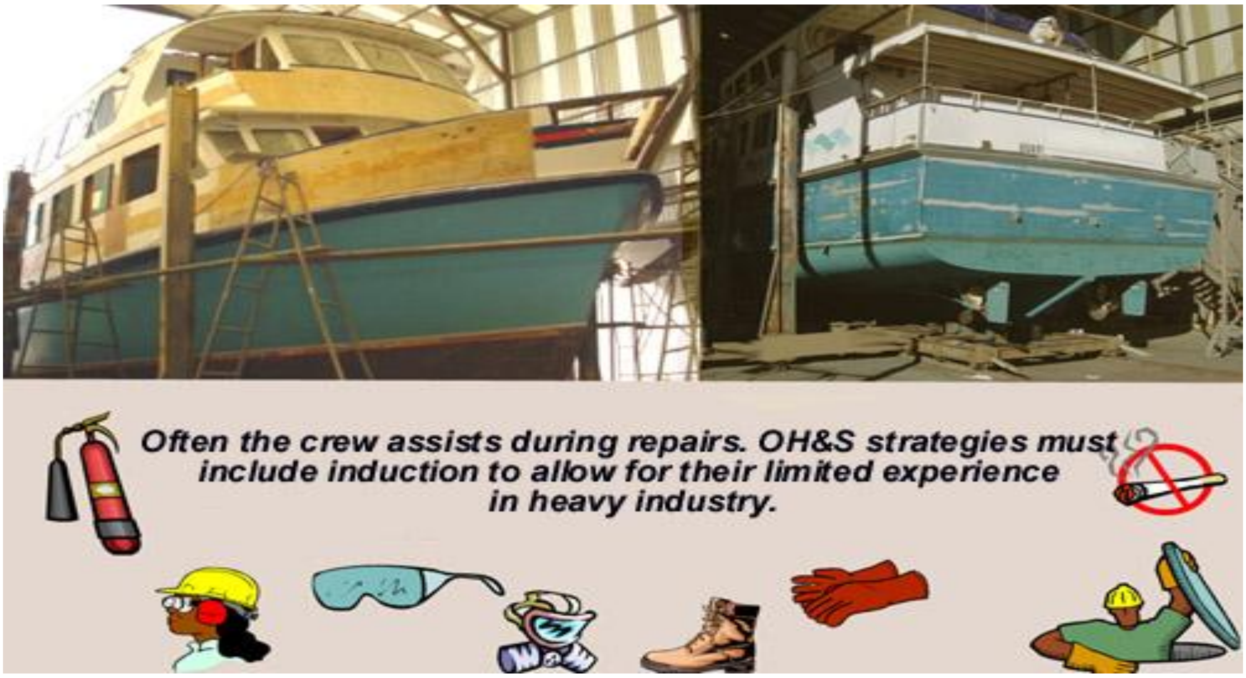
Surface coating or jointing devices - Surface coating tools are described at P 213. Jointing devices include mechanical types such as riveting, pop riveting and stapling. Thermal methods include arc welding, oxy welding and braising.

Hand tools and power tools - Clean up the work area so you are working on a dry non slip surface. The operator's position is all important for the use of tools. You must be stable over the full passage of the tool over the work surface so that if there is a sudden release of resisting pressure you do not topple over. It is important to determine if the work of the tool is achieved in the push or return stroke for flowing movement, as it is to ensure that any cutting actions are away from the operator's body. In works aloft or where tools can be dropped into inaccessible voids it is essential that *lanyards* (safety ties) be fitted to your tool belt. Sharp power tools are very important as over working a blunt power tool will lead to its demise or an accident.

Power tool electrical leads must be inspected and tagged at six monthly intervals, and be checked before every use for damaged insulation. Ensure earth and surge protection devices are fitted, and that the slipway power supply matches that of your power tool. Do not have cords lying on wet surfaces, wrapped around scaffolding or have large lengths coiled tightly during use. Support them above the ground with warning tape where required. Try to arrange for the cords of portable power tools not to lead to below your feet where you will be trading on them. Clear away waste, shavings and swarf as it builds up around the work piece. Always use personnel protective equipment with power tools.

Personnel protective equipment

Proper work wear includes wearing appropriate footwear, head gear, safety clothing and removing/mitigating long hair, jewellery and loose clothing. Safety ppes include hard hats, visors, earmuffs, dust masks or breathing apparatus, gloves, aprons, overalls, work boots and sun protection as shown below. Your crew will be trained in their job at sea not on the slip. Induction by safety briefing is required.



Repairs

Checking for hull defects – The corrosive effects of sea water and the attack by marine organisms will cause deterioration in a vessel’s hull. The build up of marine growth and flaking paint will be noticed as a reduction in performance after time. The continuous minor impacts from flotsam will contribute to defects requiring repairs to meet survey including:

Shell plating cracks, plank rot, worm or loose caulking
Leaking shell plate or planks
Loose or corroded fastenings
Impact damage that distorts two or more frames more than 25mm
Stern frame distortion or stern affecting tail shaft or rudder alignment
Areas of corrosion including expired anodes

On coming out of the water the hull should be checked for the tell tale signs of exterior weeps from the bilge water. After pressure washing these points and other detected damage zones should be chalk marked for closer inspection. Sighting along the hull close to its surface will reveal any spots of unfairness in the plate or plank that may be due to detached or misplaced support structures below. The state of the anodes will indicate what new to order. Final arrangements for the surveyor inspection should now be confirmed.

***Tail shaft inspection* - Shafts** should be withdrawn for inspection every 4 years (*USL*). If the vessel is slipped within that period it is wise to check the *weardown* of the aft bearing as *shaft sag* (due to propeller weight) increases stress in the shaft. The *weardown* is a measure of the *sag* (deflection). Increased vibration at the vessel's stern and persistent stern gland leaks (despite adjustment) are symptoms of excessive tail shaft or stern bearing wear. If exceeded, the consequences include fracture of the shaft with propeller loss. *Weardown* allowance is determined by the manufacturer, but rules of thumb range from 3% of diameter due for replacement to 6% being condemned (3% of a 50mm diameter shaft is 1.5mm permissible movement within the bearing). The outer bearing can be checked on the slip, by lifting the propeller or inserting a feeler gauge between the bearing and the shaft. If over worn, the tail shaft should be removed for inspection and workshop repair. Sometimes the rudder will restrict the tail shaft from moving aft and will also need to be removed. This is described earlier in Section 6.4.

Propellers can be very heavy and have sharp edges. As the propeller becomes free, it can quickly slide along the shaft causing personal injury or damage.

To remove a large propeller first fit lifting arrangements to support the prop. To remove a small propeller remove rope guard and fairing piece from propeller nut, then remove locking device and nut. The prop may be stuck fast on the shaft. That means that when it does come off it may do so suddenly, so refit the prop nut and tighten for a loose fit sufficient to stop the prop jumping off the shaft when it finally becomes free.

To loosen the propeller fit a *puller* or *drawing gear* (two or more long threaded rods tensioned between a plate positioned forward of the propeller boss and a *strongback* (a solid piece of timber) aft of it. Place the *strongback* over the studs so that it bears on the end of the shaft and evenly tighten the nuts on the threaded rods. At some point, the load will overcome the friction between propeller and shaft taper and the propeller will dislodge. If the propeller remains seized on, a sharp hit with a large hammer on the strongback can produce results. In extreme cases, heat may be needed to break the corrosion seal.

With the propeller and the inboard shaft coupling removed and clamps on the stern tube, packing and seals released, the tailshaft can be withdrawn. It will be heavy so strops and lifting equipment will be necessary. It may be wise to erect a scaffold to support the shaft as it is withdrawn and to guide it back in again when re-installed. While the tailshaft is out any seals, bearings and packing should be replaced.

The shaft is then sent for inspection for wear and trueness on a centre lathe. It may also be dye stained show up stress fractures. If there is minimal wear away not by the bearings it may be possible to end for end the shaft and refit it. It is not acceptable to weld on additional material and turn the shaft back to the specified diameter. If anywhere over its length the shaft is over worn a new shaft will have to be made up.

With the shaft *drawn* (removed) gear box to shaft alignment can be positively checked by stringing a taut piano wire through the dead centre of the outer bearing, the dead centre of inner bearing and carried on to the gearbox coupling. The gearbox coupling's dead centre must accurately line up with the shaft coupling position (the inboard end of the taut piano wire). If the taut wire does not meet the dead centre of the gearbox coupling then either the engine/gearbox unit must be moved, or the outer bearing bracket moved (the latter being more problematic). The engine/gearbox unit position can be adjusted by loosening its mounting bolts to rotate the longitudinal alignment, and adding or removing *shims* (metal spacers) to lift/lower the gearbox and coupling for *correct tilt and elevation*. Reinstalling the shaft is the reverse of drawing, much assisted by the drawing support guides.

Re-packing the stern gland - Packing material inside the stuffing box of the stern gland partially seals water from entering the vessel around the propeller shaft. Water is designed to enter the outer stern tube for cooling and lubrication so a regular drip into the vessel indicates that it is correctly *nipped up* and not over tight. Some arrangements also have coolant water piped to enter behind the gland and others grease nipples that can supply into the gland. This is described earlier in Section 6.4. As the packing wears tightening the gland nut/nuts will not stop water from pouring into the vessel. The stuffing box must be repacked and this is most conveniently done on the slip. The procedure is as follows:

Remove nuts that tighten the *collet* (gland packer slide assembly) and withdraw it away from the packing gland. This will expose any remaining packing. Using a fine hook pull out any remnant packing fibres from the *housing* (back of the gland). Count the number of remnant coils of packing (usually 3 - 4). Wipe clean to fully exposed the shaft's surface and inspect for any over wear that may require a new shaft.

Select the correct size of gland packing material. If in doubt as to the correct size then measure the gap between the shaft and the housing. Prepare the packing by cutting it to make coils of a few millimetres less than the shaft circumference. Each coil must be cut obliquely at its ends to overlap rather than butt when wrapped around the shaft. Cut 3 - 4 coils or the same number of packing lengths that were removed. Lightly grease the shaft surface and fit each coil over the shaft ensuring that the cut ends are staggered. Though with worn systems it is common to see heavy greasing, this is a mistake, particularly in sandy areas where the grease and sand form an abrasive paste to exacerbate wear.

With all coils inserted and pushed back into the housing, there should be 5 -15 mm under fill that allows the collet to be slid back along the shaft and meet with the packing. Finger tighten the collet tightening nuts. Ensuring that the collet remains square on the shaft, continue tightening the nuts to compress the packing until resistance is felt (about 20%) but the shaft can still be turned by hand.

After relaunching the gland should be inspected immediately and at ten minute intervals for the incorrect conditions of badly leaking and heat of friction from an overtight gland.

By tightening or loosening to correct to a condition of a slow drip and a cool bearing, the inspection schedule can be eased back to daily pre-departure checks.

Rudder bearings - Steering and rudders with their common problems have been discussed in Chapter 5.4. The rudder itself must be able to turn reliably from 35º to 35º, and on the slip the opportunity arises to check wear and serviceability. Areas prone to deterioration are:

Shafts or pintles bearings wear
Rudderstock to rudder attachment
Erosion and corrosion of rudder nosings
Cracks causing leakage into hollow steel and GRP rudders evidenced by leaks on the slip

The two common types of rudder are the *heel supported* and the *hung* rudder. The hung rudder may be semi balanced or balanced.

The *heel supported* or *pintle* type arrangement is securely mounted by bearings at the deck, under the hull and under the rudder at the *heel* or *sole* (an extension to the keel). The condition of the sole requires inspection for structural integrity, as does the condition of the pintle and its lower support bearing. Any weardown here can cause a drop in the position of the rudder itself with the possibility of its lower edge fouling the sole. The wear at the bearing points needs to be established either crudely by attempting to wobble it and measure bearing clearance with feeler gauges, or more precisely by pressuring the rudder with portable jacks at differing helm positions and recording the rudder stock displacement with a dial indicator. The dismantling of the rudder and sole assembly may be required to draw the rudder stock, though in some arrangements it is possible to loosen the deck upper stock, hull lower stock bearings and pintle bearing sufficient to slide the rudder stock past the sole. Over wear requires bearing or rudder stock replacement.

The *hung* type arrangement is checked for bearing and shaft wear in the same manner as above. Especially with the balanced type there is enormous stress where the rudder stock meets the lower stock bearing. Constant flex at this concealed point within the bearing can weaken a stainless steel shaft by progressive fracture, only to be revealed when the rudder and lower shaft fall off. Fortunately, withdrawing the rudder stock is much easier with this type as usually only the tiller has to be removed for it to fall away, so this precautionary inspection should be carried out every four years.

Deck equipment - Deck equipment includes the machinery, fittings and anchor chain as well as standing rigging and running rigging and is fully described in Chapter 4. Deck machinery is robust but it is exposed to weather, can be mishandled, overloaded and can suffer poor maintenance.

Ground tackle - The anchor cable should be removed from the vessel every 4 years (USL), ranged on the ground and inspected for deterioration and serviceability. Chain wear of more than 10% in link diameter is condemned. The swivel pins of anchors must move freely. The chain locker should also be inspected (a *confined space*) as well as all associated fairleads, rollers, hooks and restraints. Common service and repair issues for windlasses include corrosion of supporting deck, bent shafts due to overloading (from allowing the load to be carried by the windlass at anchor) and lack of maintenance resulting in bearing and shaft wear, worn linkages and brake wear.

Lifting equipment - Common service and repair issues for winches include corrosion of supporting deck, bent shafts due to overloading, standing rigging corrosion and running rigging wear.

Windlass/capstans, winches and other machinery must be serviced and repaired to standards including those listed in *Marine Orders 32 Cargo Gear* and the *NSCV Part C Section 7 Subsection 7D-Anchoring and Mooring Equipment*. Older vessels may comply with *USL Code Section 9 Engineering.* It should be noted that lifeboat davits and other mechanical launching arrangements are also deck machinery. The requirements can be found in *NSCV Part C Subsection 7A-Safety Equipment.* Older vessels may comply with *USL Code Section 10 Lifesaving Appliances.*

Confined and void spaces

It may be required that entry inspection and works are required in void spaces, holds, tanks or coffer dams that are not designed as a place of work where access is restricted - in *confined spaces*. Putting your head or upper body inside a confined space can be dangerous due to a number of hazards including fire, electrocution, noise, or obstructions, or even fatal if there is an insufficient or contaminated atmosphere.

Risks management – Confronted by a confined space the employer and employee have a duty of care to identify the *hazards* (what could happen), assess the *risk* (the likelihood, severity and duration of exposure to the hazard), develop a *management plan* and lastly *monitor and review* the adequacy of the plan. Consideration must be given to *eliminating the hazard* perhaps by not entering the tank at all, but instead using remote cameras and servicing equipment from outside the space. If the hazard cannot be eliminated then consideration must be given to *minimising the risk* by*:*

Substitution - by using a safer working chemical or applicator (e.g. a brush not spray can).
Isolation - shutting valves that allow contaminants or services enter the space.
Engineering - detectors, alarms, lockout mechanisms and alternative entry point.
Administration - safe work practices including, training, *tagging* (recording workers movements in and out of the workspace), a *sentry* (person standing by outside to raise alarm), *entry permits* rules, signage and personnel protective equipment.
Rescue - suitable procedures are in place for rescue, first aid and fire suppression.

Risk increases with low visibility, extremes of temperature, gravitational hazards, room to move, nature of work (welding, electrical, or motive equipment), physical activity (worker's fitness, skills and experience) and the length of time spent inside the space

To enter, a confined space an *entry permit* must be signed off by a competent person (trained and certified) who has ensured that all the steps of the written requirements of substitution, isolation, engineering, administration and rescue have been satisfactorily met. To ensure a safe atmosphere the steps may include that the space is *purged*. This may be done by filling and emptying with water or with an inert gas. The space will then have to be *vented* for a specified duration. Lastly a gas monitor must be lowered into the space for a *gas free certificate* to be issued for a defined duration. Additional permits may be required such as *permit to work* and *permit for hot work*.

Acknowledgements

References are attributable to the USL Code, the National Standards for Commercial Vessels, Australian National Training Authority's Maritime National Module Learners Guides, Caterpillar, GM Detroit, Bosch, Reece Plumbing Supplies, Wikipedia, Norglass, and International Paints. Other sources include but are not limited to;

H. Chappell - Boatbuilding,
H. Chappell - American Small Sailing Vessels,
P. Clisshold - Basic Seamanship,
Basil Greenhill - Merchant Schooners,
Kemp & Young - Ship Construction,
H.J. Pursey - Merchant Ship Construction.

In addition to the sources quoted I thank Richard Sprogue, Vikram Malhourta, Harry Machin and Atef Jaber for their expert advice.