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The hydraulic steering motor is fitted to the steering gear. Besides providing excellent manoeuvrability, maximum propulsive force can be obtained even in very shallow water. As no ballast time is required, this system is widely used as a thrusting system on freighters, cargo barges and passenger liners, and as the main propulsion system on fishing boats and work barges. The power from the horizontally mounted motor is transmitted to the horizontal input shaft of the Pump-Jet and via spiral bevel gears to the impeller. The spiral bevel gears of the SPJ gearbox are made of high quality case-hardened steel. The shafts are made of high grade steel and run in roller bearings. The shaft seals are made from seawater resistant material. Radial sealing rings are running on coated surfaces. A mounting flange is used for the installation of the Pump Jet, into the well. The Pump Jet has to be installed from underneath, into the vessel.

17.16.3.2 Self-cleaning of Pump-Jet

The SPJ is self cleaning by changing the rotation sense of the impeller and maximum speed of the propulsion motor should not be more than 50% of advance r.p.m. Flushing mode for self-cleaning should not be longer than 1-1.5 minutes.

17.16.3.3 Steering

The thrust can be directed to any desired direction through the SCHOTTEL-Pump-Jet, around its vertical axis. The SCHOTTEL units in Figures 17.34 and 17.35 are equipped with the following steering system: SCHOTTEL steering system SST 602, Copilot 2000 proportional; a way-dependent electro-hydraulic steering system.

The steering pump is electrically driven and must be connected to electric power supply 440 V / 60 Hz. The ingress protection standard of the electric motor must be at least IP 54. Power consumption is about 5 kW. The desired position of the SCHOTTEL-Pump-Jet is pre-selected by means of the control wheel of the co-pilot control unit. This activates the hydraulic motor transmitting the steering torque to the SCHOTTEL-Pump-Jet via an electronic control unit.

The proportional steering system works in such a way that with a small angle of steering, the corresponding steering speed is low and with a larger angle of steering, the steering speed is higher. In case of failure of the electronic steering system, the steering is automatically switched over to a time-dependent emergency steering system. This failure is indicated by a visual and audible alarm.

525(2)

The SCHOTTEL Pump-Jet position is indicated via an electric feed-back system by a SPJ thrust direction indicator.

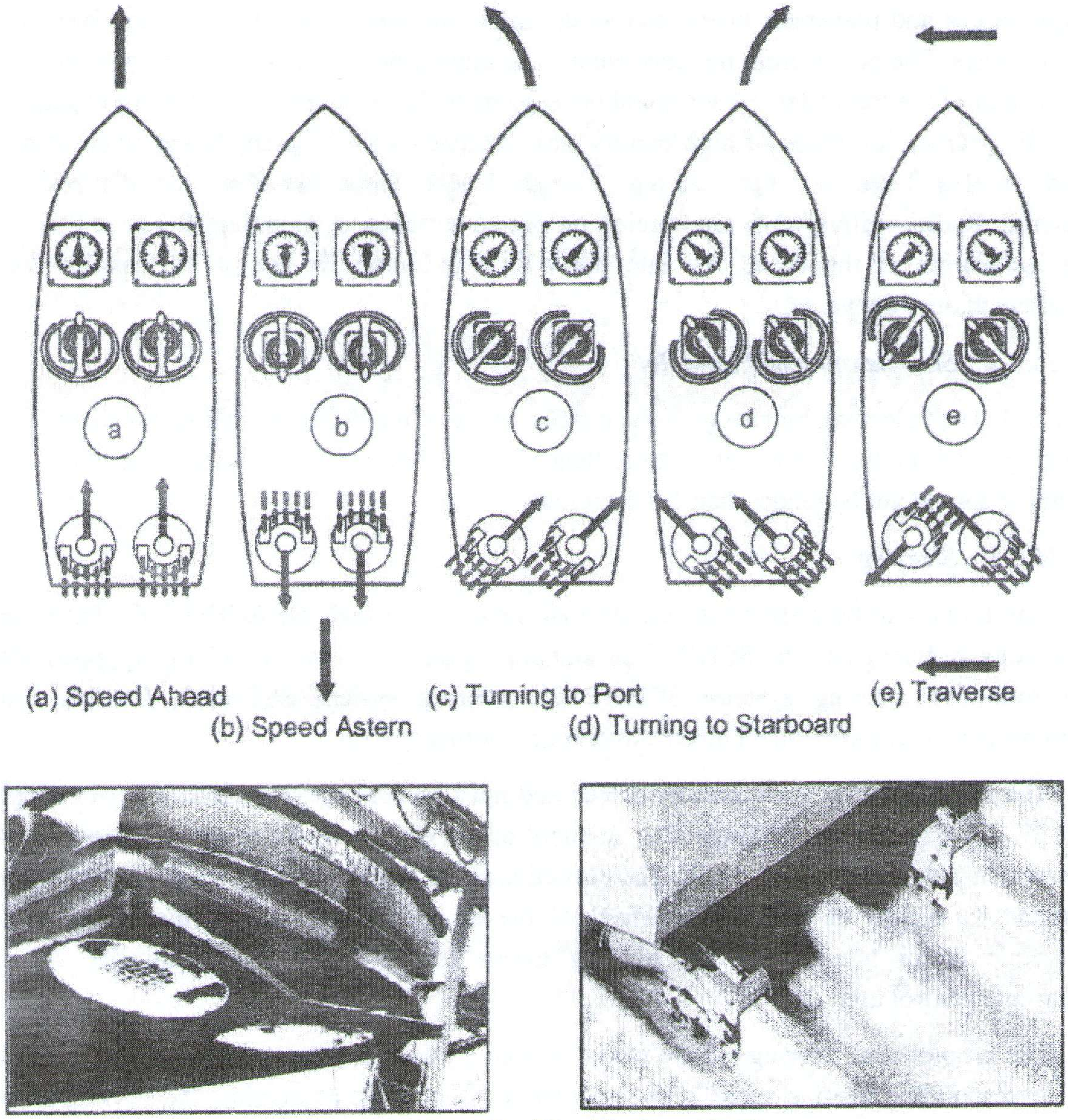
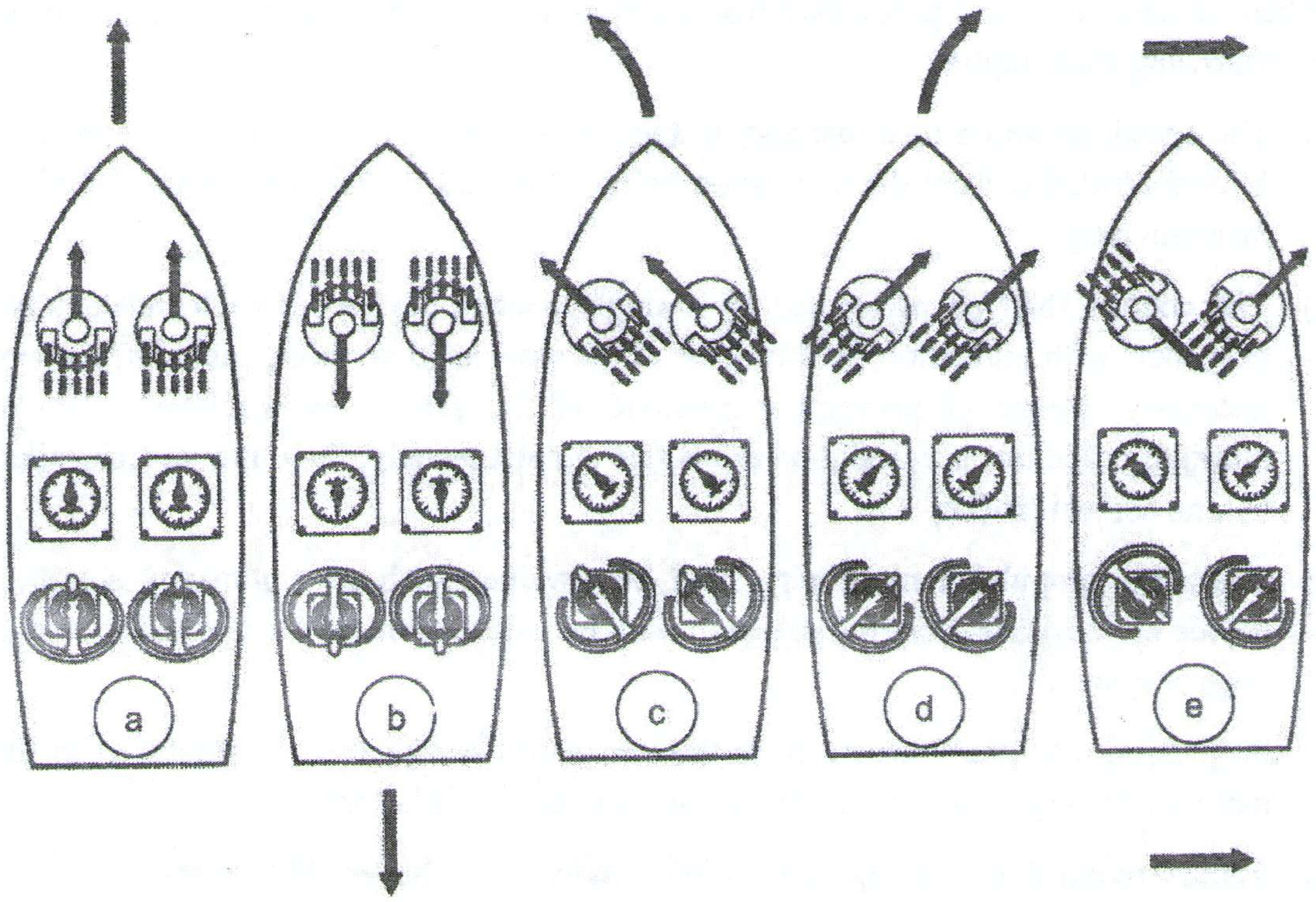


Figure 17.34 – The Double Stern Unit



(a) Speed Ahead (b) Speed Astern (c) Turning to Port (d) Turning to Starboard (e) Traverse

Figure 17.35 – The Double Bow Unit

17.17 Relevant Rules

17.17.1 Relevant SOLAS Regulations

Part C – Machinery Installations – Regulation 31 – Machinery Controls

Part E – Additional Requirements – Regulation 49 – Control of Propulsion Machinery from the Navigation Bridge

17.17.2 Summary of Regulations

1) Main and auxiliary machinery essential for the propulsion, control and safety of the ship shall be provided with effective means for its operation and control. All control systems essential for the propulsion, control and safety of the ship shall be independent or designed such that the failure of one system does not degrade the performance of another system.

S25(4)

2) Where remote control of propulsion machinery from the navigation bridge is provided, the following shall apply:

a) The speed, direction of thrust and, if applicable, the pitch of the propeller shall be fully controllable from the navigation bridge under all sailing conditions, including manoeuvring;

b) The control shall be performed by a single control device for each independent propeller, with automatic performance of all associated services, including, where necessary, means of preventing overload of the propulsion machinery. Where multiple propellers are designed to operate simultaneously, they may be controlled by one control device;

c) The main propulsion machinery shall be provided with an emergency stopping device on the navigation bridge which shall be independent of the navigation bridge control system;

d) Propulsion machinery orders from the navigation bridge shall be indicated in the main machinery control room and at the manoeuvring platform;

e) Remote control of the propulsion machinery shall be possible only from one location at a time; at such locations interconnected control positions are permitted. At each location there shall be an indicator showing which location is in control of the propulsion machinery. The transfer of control between the navigation bridge and the machinery spaces shall be possible only in the main machinery space or the main machinery control room. This system shall include means to prevent the propelling thrust from altering significantly when transferring control from one location to another;

f) It shall be possible to control the propulsion machinery locally, even in the case of failure in any part of the remote control system; it shall also be possible to control the auxiliary machinery, essential for the propulsion and safety of the ship, at or near the machinery console

g) The design of the remote control system shall be such that in case of its failure an alarm will be given. Unless the Administration considers it impracticable the preset speed and direction of thrust of the propellers shall be maintained until local control is in operation;

S2S(S)

h) Indicators shall be fitted on the navigation bridge, the main machinery control room and at the manoeuvring platform, for propeller speed and direction of rotation in the case of fixed pitch propellers and propeller speed and pitch position in the case of controllable pitch propellers

i) An alarm shall be provided on the navigation bridge and in the machinery space to indicate low starting air pressure which shall be set at a level to permit further main engine starting operations. If the remote control system of the propulsion machinery is designed for automatic starting, the number of automatic consecutive attempts which fail to produce a start shall be limited in order to safeguard sufficient starting air pressure for starting locally.

j) Automation systems shall be designed in a manner which ensures that threshold warning of impending or imminent slowdown or shutdown of the propulsion system is given to the officer in–charge of the navigational watch in time to assess navigational circumstances in an emergency. In particular, the systems shall control, monitor, report, alert and take safety action to slow down or stop propulsion while providing the officer in–charge of the navigational watch an opportunity to manually intervene, except for those cases where manual intervention will result in total failure of the engine and/or propulsion equipment within a short time, for example in the case of overspeed.

3) Where the main propulsion and associated machinery, including sources of main electrical supply, are provided with various degrees of automatic or remote control and are under continuous manual supervision from a control room the arrangements and controls shall be so designed, equipped and installed that the machinery operation will be as safe and effective as if it were under direct supervision for this purpose. Particular consideration shall be given to protect such spaces against fire and flooding.

4) In general, automatic starting, operational and control systems shall include provisions for manually overriding the automatic controls. Failure of any part of such systems shall not prevent the use of the manual over-ride.

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Chapter 18
Steering and Stabiliser Systems

At the end of this chapter you should be able to:

- ★ Explain the fundamental concepts of various types of steering systems
- ★ State the necessity and operating principles of some rudder position indicators
- ★ Explain the basic theory of a gyroscope and its applications
- ★ Identify the need for roll stabilisers
- ★ Comply with regulations governing steering systems

18.1 Fundamental Concepts

18.1.1 Steering Gear

It is the machinery, rudder actuators, steering gear power units, if any, and ancillary equipment and the means of applying torque to the rudder stock (e.g. tiller or quadrant) necessary for effecting movement of the rudder for the purpose of steering the ship under normal service conditions.

Elementary steering gear first of all comprises a steering wheel (or maybe a control knob) on the bridge, generally operated by the helmsman. The helm order or desired angle of the rudder is then transmitted from here to the steering control unit. This results in the operation of the rudder to which it is linked. A negative feedback signal of this ordered (or desired) angle is transmitted automatically through 'hunting gear' to the steering gear's control unit.

This (the negative feedback) gradually nullifies the control signal to the steering gear and causes the rudder to stop when the desired angle has been achieved. In the case of an electro-hydraulic system it is possible for the control unit to receive negative feedback signals through rotary transformers, potentiometers, etc. Now "helm angle" is the position of the steering wheel relative to the midship position. The steering control dials are normally graduated in such a manner that the rudder moves in tandem with it. For example, if the rudder is designed to move $\pm 35^0$, then the control wheel will also have a fixed dial and pointer arrangement graduated from 0^0 to $\pm 35^0$.

S25(7)

In some steering gear systems, be it a wheel, knob or handle, the steering control element does not maintain a one-to-one relationship with the rudder. In such an instance, an independent rudder indicator is deemed necessary and will be in the form of the type mentioned in article 18.8.

Instead of just a fixed dial and pointer, a two-element synchro chain (i.e., a pair of transmitting and receiving synchros) may be used to indicate to the operator the position that is desired of the rudder. Article 18.9 explains the theory behind synchros. The indicator is also called a helm indicator. Classification rules now specify that an independent rudder angle indicator be fitted when the rudder is power operated.

18.1.2 Steering Gear Power Unit

1. In the case of electro hydraulic steering gear, an electric motor and its associated electrical equipment and connected pump.
2. In the case of other hydraulic steering gear, a driving engine and connected pump.
3. In the case of electric steering gear, an electric motor and its associated electrical equipment.

18.1.3 Auxiliary Steering Gear

It is the equipment other than a part of the main steering gear necessary to steer the ship in the event of failure of the main steering gear but not including the tiller, quadrant or components serving the same purpose.

18.1.4 Steering Gear Control

A Steering gear control system is the equipment by which orders are transmitted from the navigation bridge to the steering gear power units and locally from the steering gear space. These may be any acceptable arrangement like manual operation of hydraulic valves, electrical or electro-hydraulic systems - with the help of an operating handle, wheel or joystick. Steering gear control systems comprise of transmitters, receivers, electro-hydraulic converters, hydraulic control pumps and their associated motors, motor controllers, piping and cables. For the purpose of the Rules, steering wheels, steering levers, and rudder angle feedback linkages are not considered to be part of the control system. A steering console that is installed on the bridge or wheelhouse of a ship is depicted in Figure 18.1.

The control system may comprise of the Auto-pilot / Follow-up type that has a console as shown in Figure 18.1 and/or the 'non-follow-up' type as depicted in Figure 18.2. Non-follow-up control units are also depicted in Figures 18.14 and 18.15.

S25(8)

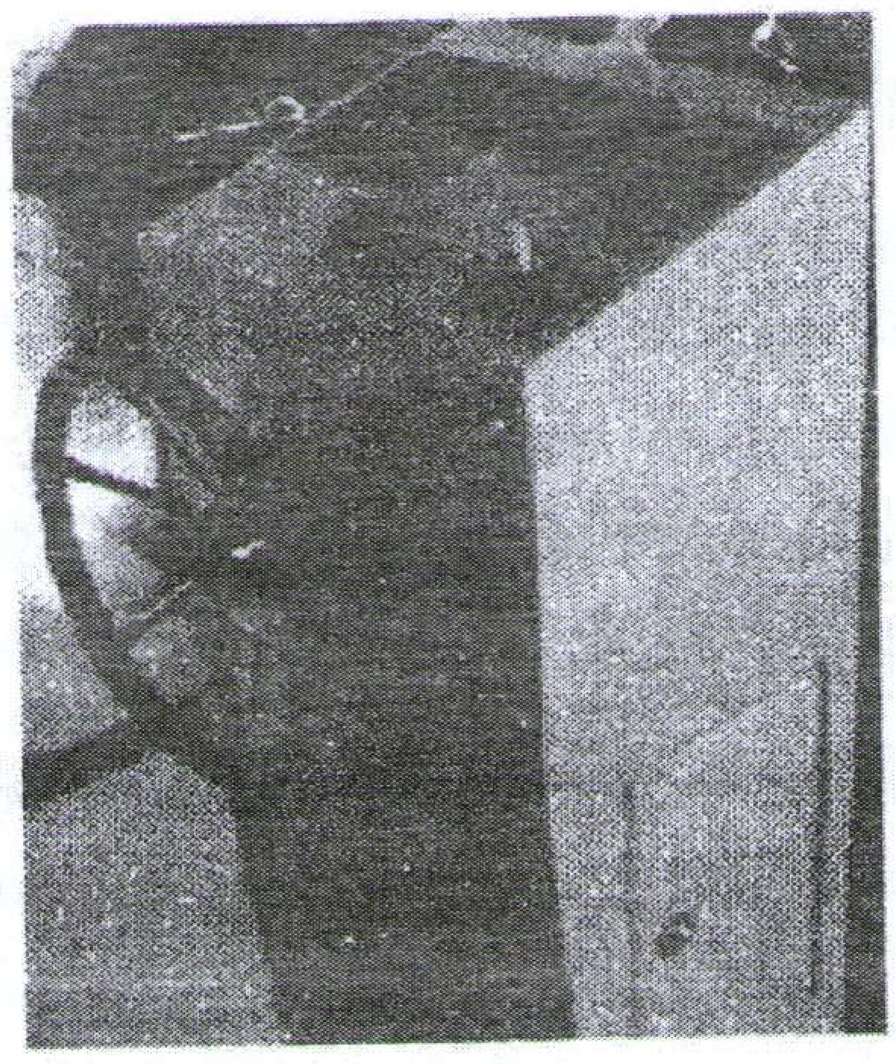

Figure 18.1 – AutoNav's Steering Console

In the non-follow-up mode, as long as a wheel / lever is held , or pushbutton is pressed, to energise the steering gear so that the rudder moves in one direction – either to port or starboard, the steering gear functions. It de-energises automatically at its mechanical limit – normally 30^0 to 35^0. The rudder may also be moved a few degrees at a time, either to port or starboard, by deflecting the control (off 0^0) for brief periods. The helmsman's keen sense of judgement is vital in order to ensure effective control of the rudder. Many a time, novices steer the vessel in a zigzag manner thereby wasting time and precious resources on board.

The second type of controller causes the rudder to automatically align amidships the moment the helmsman releases the controller. Refer article 18.3.2.2 titled *Dual Non-Follow-up (Dual NFU)* later in this chapter.

The third variant is the full follow-up system. It is also explained further on in this chapter. The modern version senses any existing error between the helm (the position of the rudder controller) and the rudder's true position with the help of a comparator. The error which is in essence an algebraic sum of the desired and true angles of the rudder is amplified and fed to the rudder control unit. This moves the rudder to the desired angle either port or starboard. As already mentioned, the rudder stops only when the negative feedback signal cancels out the desired angle signalled by the helm.

The rudder is held in position so long as the difference is equal to zero. The rudder will move once again when a difference arises by moving the helm or due to the drifting of the rudder on account of hydrodynamic forces.

S25(9)

18.1.5 Non – follow Up Steering (or Time Dependent Steering)

The following explanation supports the Non-follow-up Control Diagram depicted in Figure 18.2. As briefly mentioned earlier, we will understand that while using the 'Non-follow-up' (NFU) system, the steering gear will function as long as the controller is held in an actuating position i.e., either to Port or Starboard, and will only stop when it moves back to an 'Off' or the central position or until the steering gear has reached its mechanical limit.

The control from the bridge is by means of a NFU lever or sometimes a wheel that is spring loaded. Since the rudder movement depends on the duration that the control is held off-centre, this variant of a steering control system is sometimes called 'time dependent steering'.

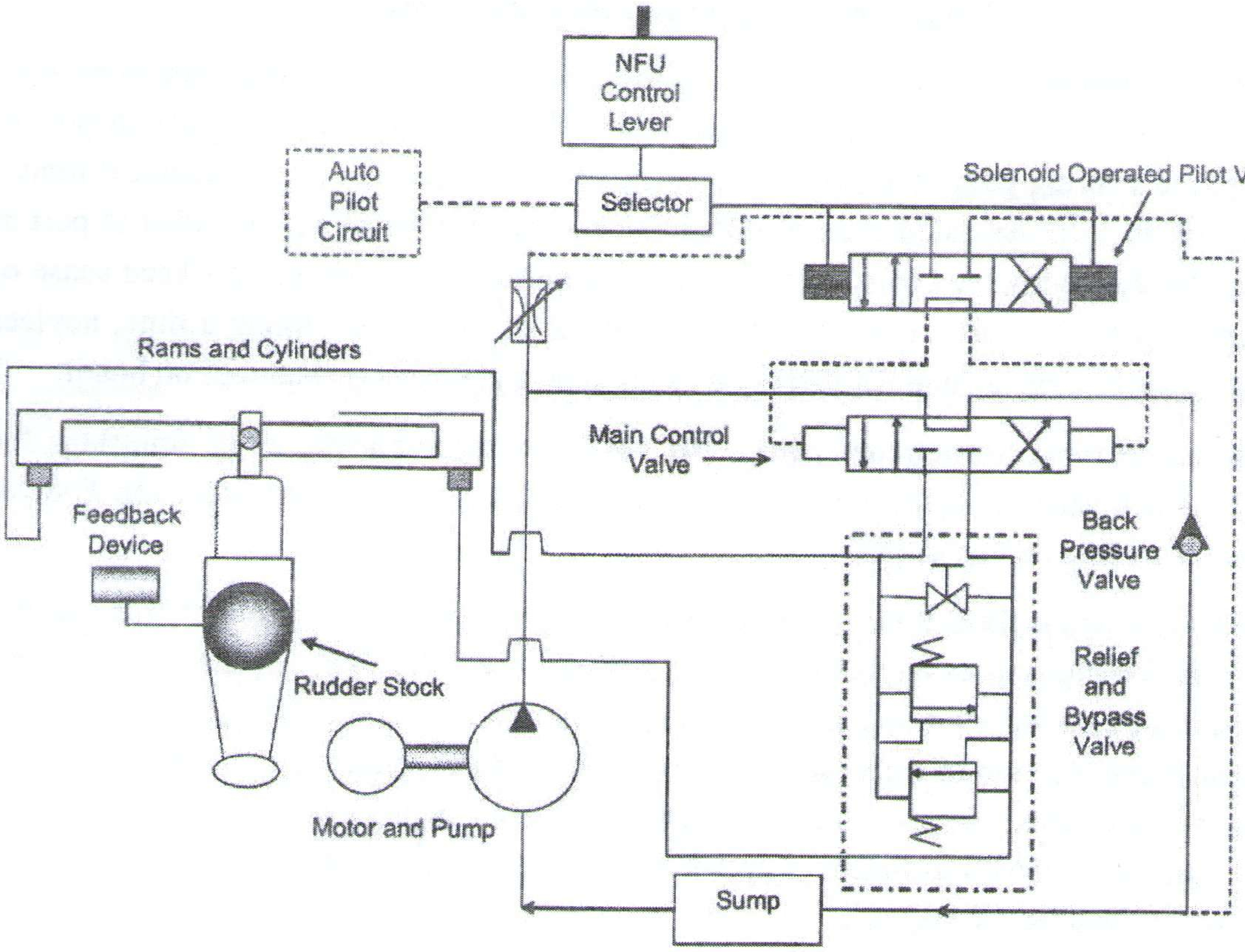

Figure 18.2 - Non-follow up Control Diagram of a Rudder

The NFU lever operates a switch that energises either a port or starboard solenoid, depending upon the direction of movement required. These solenoids in turn operate a pilot valve that brings about the operation of the main control valve.

525(10)

As seen in Figure 18.2, the solenoid-operated pilot valve is a two-way-three-position one. It is designed to divert hydraulic pressure through direct or cross-connected ports. A fixed delivery pump serves to deliver hydraulic pressure to the steering gear. Depending upon the application of pressure to a particular side or the ram, the desired direction of rudder movement is thus achieved. When the NFU lever is released, springs return it to the central position. This causes the control valve to return to its neutral position; the main control valve in turn also returns to neutral thus bypassing the pump delivery.

The steering gear stops for two reasons – first of all because there is no hydraulic pressure and secondly because, as we will see in Figure 18.2, the hydraulic fluid is trapped on either side of the ram due to the blind ports in the main control valve. The rudder indicator serves as a negative feed back device. It is capable of only serving as a visual feedback device. Thus the onus is on the helms-man to control the movement of the rudder. He is as an important link in the control chain and serves as a virtual hunting gear!

18.1.6 Remote Control Systems

In short they can relate to mechanical, hydraulic, electrical, and electronic subsystems. Ancients systems even resorted to using shafts, wire rope, sprockets and chains, push-pull flexible control cables, and their combinations to transfer motion proportional to that of the helm. This was connected from remote steering stations to the local control station of the steering gear but in most cases proved troublesome. These mechanical means are simple, reliable and still used in smaller vessels.

As will be mentioned later, the use of an electro-hydraulic unit can be used instead. The fundamental type of hydraulic control system is the hydraulic telemotor that has been in use for ages. It consists of a telemotor unit located in the wheelhouse and an aft unit in the steering gear flat. Pipelines are used to connect the units and cylinder. The pipelines of the cylinder are attached to the steering gear local control unit. The hydraulic pressure causes the steering gear to move the rudder in the direction chosen by the helmsman. Similar systems can be found in Figures 18.3, 18.5 and 18.6.

18.1.7 Electro-hydraulic Control

Turning a wheel causes a potentiometer in a balanced bridge network, to unbalance the electrical circuit. The error signal activates an intermediate powered servo that supplies the local control unit and moves a follow-up potentiometer linked to the rudder. This balances the circuit once again and cuts–off the servo, when the helm and relative servo angular positions neutralise each other.

S25(11)

The powered servo is in most cases a rotary electro-hydraulic unit that can be likened to a miniature steering gear. It is designed for application with any steering gear variant, and serves as one link in a chain of servomechanisms from the steering wheel to the rudder.

Several vessels achieve local (manual) control of the steering gear with the help of a mechanical differential control. This allows the helmsman to rotate the steering wheel at a desired rate. The helm signal is transmitted to the mechanical differential through the rotary electro-hydraulic unit and then to the steering gear pump's control.

The steering gear itself follows, moving the rudder at its pre-determined rate. A mechanical follow-up linkage feeds the rudder position to the mechanical differential. The reduction of the pump stroke is with the help of differential control, when it is within 5^0 of the ordered angle. It is fully off stroke when the ordered angle is reached.

Electro-hydraulic control has many variants. A twin-ram system is depicted in Figure 18.3. Hydraulic pressure can also be made available with the help of a dedicated hydraulic system's accumulators. This has many advantages, a few of which are:

- Compatibility with complex control systems
- Less running hours for pumps
- Increased reliability
- Easy and quick changeover to a standby hydraulic system
- Local control from the unit itself in case of an emergency

This method is much simpler and can be one of the many modes of operation in a complex auto pilot or electronically controlled steering system. The next sub-heading briefly explains an electronically controlled system where-in, though the use of electronics is resorted to, hydraulic pressure is required to move the rudder.

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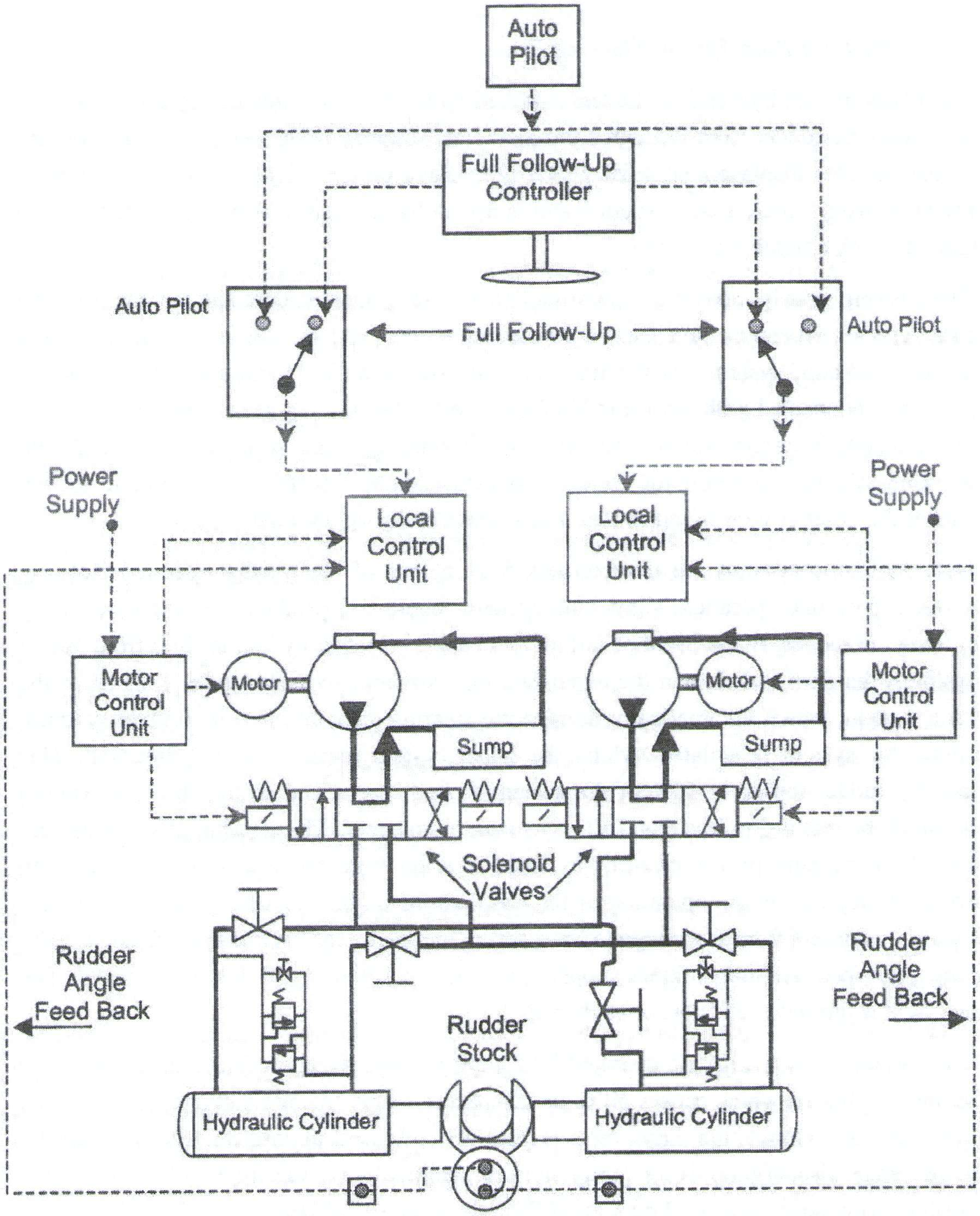

Figure 18.3 –Two-ram Electrically-controlled, Hydraulically-operated Steering System

525(13)

18.1.7.1 The Four Ram Type of Steering Gear

It consists of four hydraulic cylinders supplied with oil by two electrically driven pumps. Rams operate the rudder tiller through a crosshead and Rapson Slide mechanism. The pumps are of the variable displacement axial piston type. Each pump is located inside its own oil storage tank, from which it takes suction and is driven by an electric motor, mounted outside the tank, through a flexible coupling.

The steering gear is capable of operating as two totally independent and isolated steering systems. The second pump unit can be connected at any time by starting the motor. No.1 pump has a hydraulic system which connects it with No.3 and No.4 hydraulic cylinders whilst No.2 pump is connected with No.1 and No.2 cylinders. The steering gear is provided with an automatic isolation system which is actuated should there be a pump failure or oil loss from the working system; the automatic isolation system isolates the defective hydraulic system and makes the other system sound so that it can remain fully operational.

Both hydraulic systems are interconnected by means of electrically operated isolating valves that, in normal operation, allow both systems together to produce the torque necessary for moving the rudder. In the event of failure that causes a loss of hydraulic fluid from one of the systems, the float switches in the expansion tank are actuated. This gives a signal to the isolation system, which automatically divides the steering gear into two individual systems. The defective system is isolated, whilst the intact system remains fully operational. This reduces the rudder torque to 50% of the system's rated torque and so the ship's maximum speed should be reduced to less than half of its maximum speed. The steering gear is remotely controlled by the auto pilot control or by hand steering from the wheelhouse. Emergency control is carried out by the operation of the pushbuttons on the solenoid valves on the auto pilot units. All orders from the bridge to the steering compartment are transmitted electrically. Steering gear feedback transmitters supply the actual position signal for the systems. The rudder angle is limited to 35^0 port or starboard.

The variable flow pumps are operated by a control lever, which activates the tilting lever of the pump cylinder, which causes oil to be discharged to the hydraulic cylinders. When the tiller reaches the set angle, the tilting lever is restored to the neutral position, which causes the pump to cease discharging. No.1 pump unit is supplied with electrical power from the emergency switchboard and No.2 pump unit from the main switchboard.

Under normal circumstances, all four cylinders will be in use, with one pump unit running and the second pump unit ready to start automatically.

S2S(14)

18.1.7.2 *Procedure to Put the Steering Gear into Operation*

1. The system valves are assumed to be set for normal operation.
2. Check the level and condition of the oil in the tanks and refill with the correct grade as required.
3. Check that the control lever is correctly set for operation from the bridge and not locally from the steering flat.
4. Ensure the rudder is in the mid position.
5. Start the selected electro-hydraulic pump unit.
6. Carry out pre-departure tests.
7. Check for any abnormal noises.
8. Check for any leakages and rectify if necessary.
9. Check the operating pressures.

18.1.8 *Automatic Isolation System*

This steering gear is so arranged that in the event of a loss of hydraulic fluid from one system, the loss can be detected and the defective system automatically isolated within 45 seconds. This allows the other actuating system to remain fully operational with 50% torque available.

18.1.8.1 *Construction*

This system consists of the following equipment:

(a) Two isolating valves

(b) Two oil tank level switches with low and low-low level positions; one for each system tank

(c) An oil tank divided into two chambers for level switches and system test valves

(d) An electrical control panel for automatic isolation system

(e) An alarm panel for the automatic isolation system

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18.1.8.2 Operation

If failure of one of the systems occurs, the ship's speed should be reduced, as only 50% of the torque for the steering gear operation is available.

18.1.8.3 Failure Sequence with One Pump Running

If any loss of oil occurs with say, No.1 pump running and No.2 pump stopped, the following sequence will take place:

1. The oil level in No.1 oil tank goes down to the "Low" level; audible and visual alarms are activated on the navigating bridge and in the machinery space.
2. At the same time the No.1 automatic isolating valve, is energised and the hydraulic system associated with No.2 pump is isolated.
3. If the oil loss is in the hydraulic system associated with No.2 power system, the steering process is continued by No.1 power system and with the No.2 system isolated, there will be no further oil loss.
4. If the oil loss from the system is associated with No.1 power system, the tank oil level will continue to fall and when it reaches the Low-Low position. No.1 automatic isolating valve will be de-activated and No.1 pump is automatically stopped.
5. System No.2 automatic isolating valve is activated and No.2 pump is automatically started. The hydraulic system associated with No.1 pump is isolated and so no further oil loss will occur. Steering is now being carried out by No.2 pump and its two related cylinders (No.1 and No.2).
6. If the oil loss occurs in No.2 tank, steering is continued to be carried out by No.1 pump and its two related cylinders (No.3 and No.4) with 50% torque.

18.1.8.4 Failure Sequence with Both Pumps Running

If oil the level in No.1 tank goes down first:

1. Oil level in No.1 tank goes down to the Low position and the audible and visual alarms are activated on the navigating bridge and in the engine room.
2. No.1 automatic isolating valve is energised and the hydraulic system associated with No.2 pump is isolated.

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3. If the oil loss is associated with No.2 pump system, the oil level in No.2 tank will fall to the Low-Low position and No.2 pump will be automatically stopped. No further oil loss will take place and steering will continue at 50% torque with No.1 system working alone.
4. If the oil loss is associated with No.1 pump system the oil level in No.1 tank will fall to the Low-Low level and No.1 automatic isolating valve will be de-energised thus isolating No.1 system. No.1 pump is stopped and No.2 automatic isolating valve IV-2 energised. No.2 pump and its associated cylinders No.1 and No.2 provide 50% of the normal rudder torque.

18.1.8.5 System Testing

The oil tank float chamber can be isolated and drained to test the system's automatic isolating operation. This should be carried out as part of the pre-departure checks.

18.1.9 Electronic Steering Control

This method may use a microprocessor-based circuit to receive the helm order and the rudder position feedback and compare them. The AutoNav Autopilot Model A-1500, to be explained later in this chapter is one such example. In other cases an operational amplifier could also be used instead. Cumbersome mechanical linkages and differential controls are replaced by quick-response electronic servo control valves on the hydraulic pump, which receive the order from the microprocessor and stroke the pump in the direction and the degree requested.

The variant of this is a system where the electronic signals from the controller and the feedback device are compared, amplified by the power amplifier whose output controls solenoids within the electro-hydraulic unit. The electro-hydraulic unit serves as an interface between the computing circuit and the hydraulically-operated rams. It directs the hydraulic pressure to the cylinders (Refer Figure 18.4).

The follow-up element, which is either a potentiometer or a rotary transformer, is moved in direct proportion to the motion of the rudder-stock or simpler said, the ram itself. It provides the negative feedback signal to the control circuit to de-stroke the pump and stop the rudder at the ordered angle or, in the other case, to nullify the output of the operational amplifier which in turn forces the output of the power amplifier to zero. This brings the solenoid valve to the neutral position. The blind-ports are then aligned with the hydraulic lines leading to the rams; this action results in holding the rudder in the desired position by trapping the hydraulic fluid within the cylinders.

525(17)

An error in the feedback system caused by a new helm or autopilot order (in the case of operating in the automatic mode as shown in Figure 18.5) or by motion of the rudder due to external dynamic forces reactivates the control system; other signals that influence the control of the rudder are:

- The ship's speed;
- The turning radius (may be set manually also);
- The set course;
- The rate of change of course;
- The present position of the rudder itself.

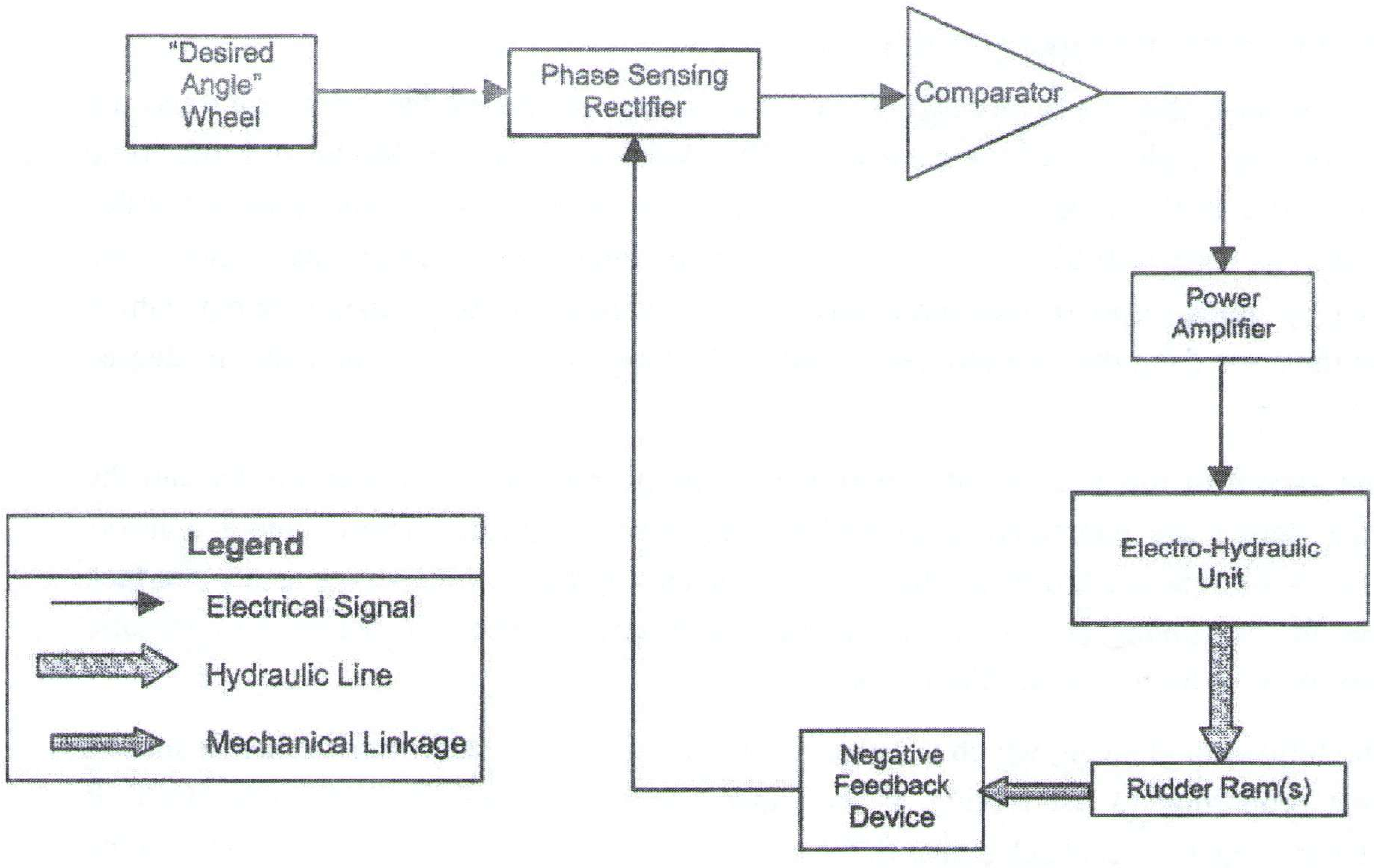

Figure 18.4 - Electronic Steering Control - Manual Mode

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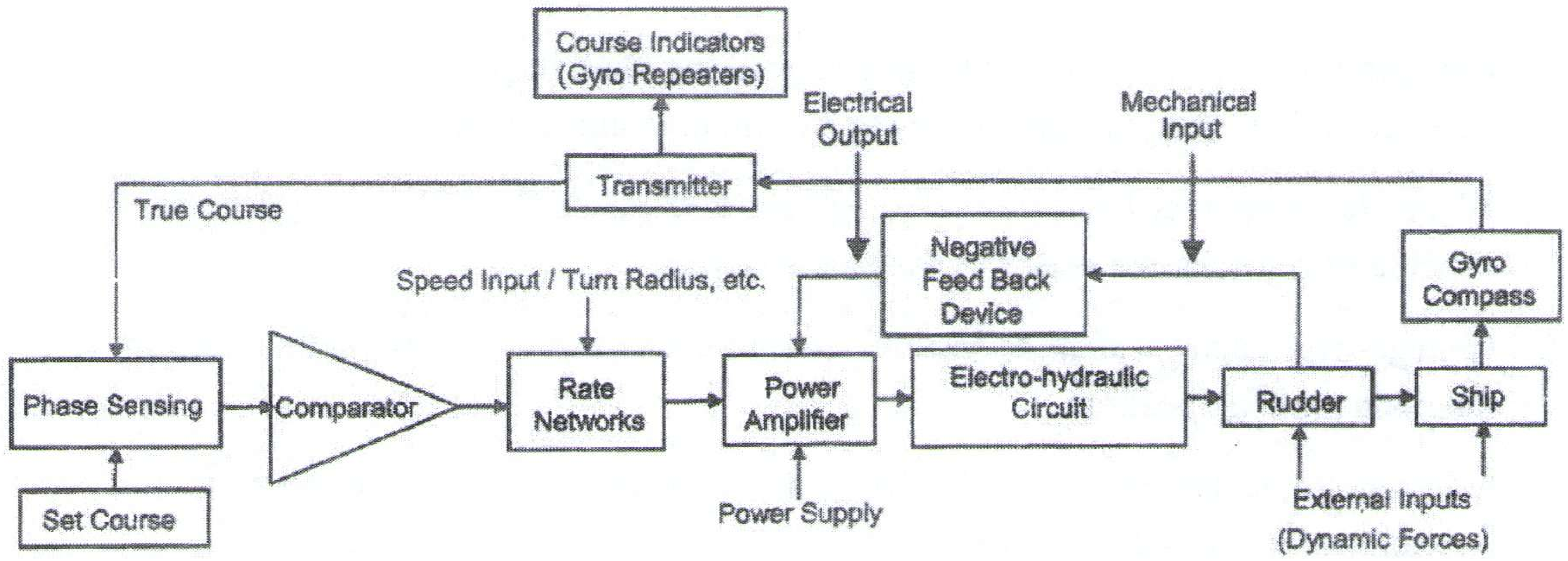

Figure 18.5 - Electronic Steering Control – Auto-pilot Mode

18.1.10 Indicators for Monitoring the Operating Conditions of the Steering Gear

The indicators for monitoring the operating conditions of the steering gear, provided in the wheel house and ECR are designed to comply with SOLAS Regulations 29 and 30. They are as follows:

a) Phase failure – in case of single-phasing of the pump's motor, an alarm is activated

b) Motor overload – especially when the winding is overheated (the motor's control circuit is to have short circuit protection)

c) Isolation (auto shut-off) valve operated e.g., in case of excessive flow rates

d) Hydraulic Oil tank level low

e) High oil temperature

Note: Some steering systems have an air-cooled system that ensures the system will not be activated until the fan is started.

18.1.11 Procedure for Change-Over from Normal to Emergency Mode of Operations

18.1.11.1 Requirements

1. Changing over from automatic to manual steering and vice versa shall be possible at any rudder position and be effected by one, or at the most two manual controls, within a time lag of 3 seconds.

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2. Changing over from automatic to manual steering shall be possible under any conditions, including any failure in the automatic control system.
3. When changing over from manual to automatic steering, the automatic pilot shall be capable of bringing the vessel to the preset course.
4. Change-over controls shall be located close to each other in the immediate vicinity of the main steering position.
5. Adequate indication shall be provided to show which method of steering is in operation at a particular moment.

18.1.11.2 Basic Actions

a) Establish communication between the navigation bridge and the steering flat
b) Changeover to the manual mode (not auto pilot);
c) Set the wheel to the midship position;
d) Switch off the telemotor i.e. disconnect the remote control circuit.
e) Steer from the steering flat by operating the manipulators or similar arrangements; this will be as effective as the NFU mode except that it is done locally and the operator may have to resort to monitoring the rudder angle with the help of the mechanical pointer on the rudder stock itself if the helm indicator too is not operational.

18.2 Anschütz Auto Steering

The variety of devices required for navigation and monitoring in the bridge area necessitates a functional design meeting work-sequence-oriented and ergonomic demands. For more than 75 years, Anschütz has been accumulating experience in this field. In 1969, Anschütz introduced modular equipment technology in the area of steering control. Today approximately 10,000 ships use Anschütz steering control all over the world.

A typical system is depicted in Figure 18.6. Figure 18.7 is an example of a control system on the bridge.

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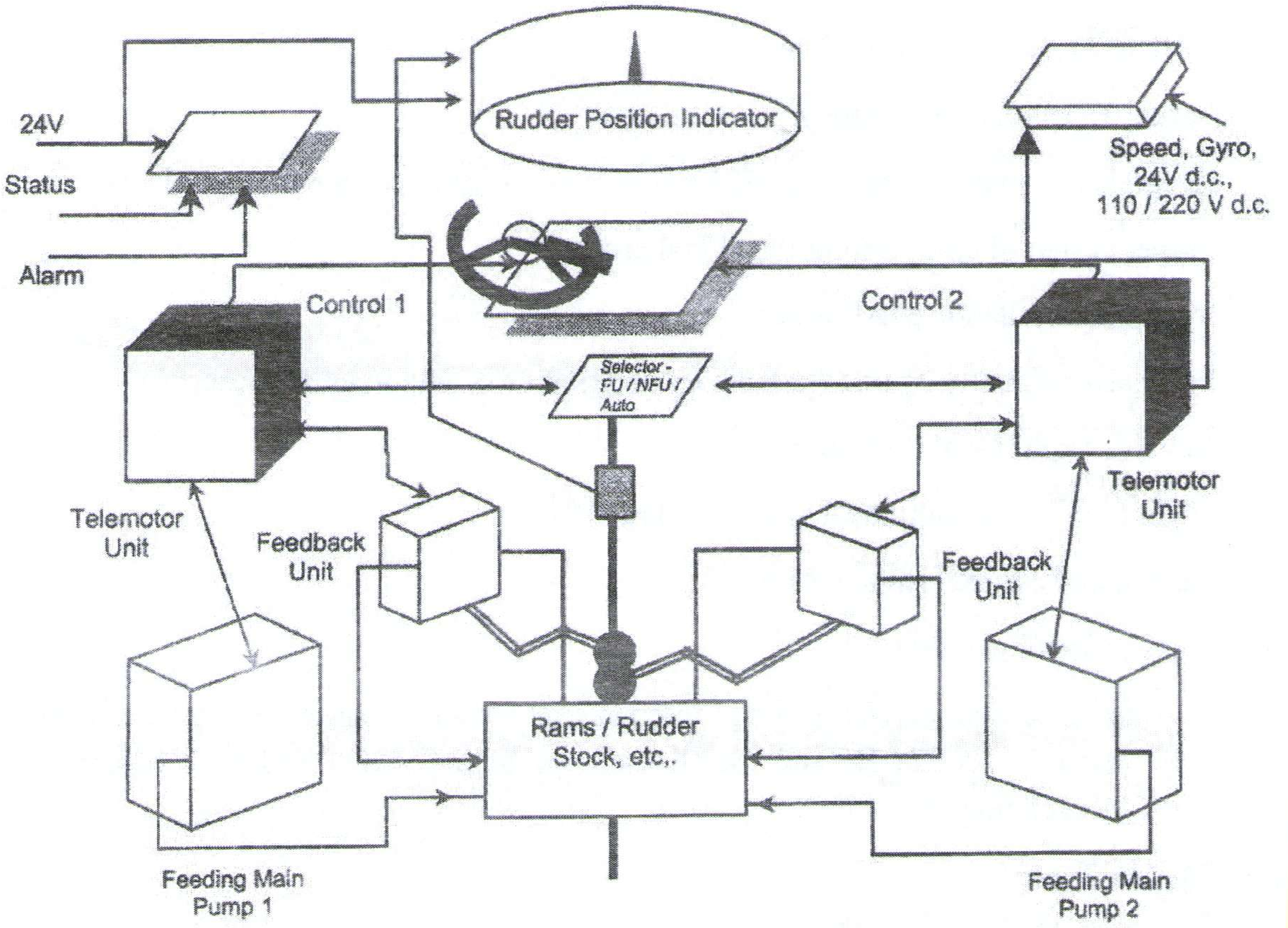

Figure 18.6 - Anschütz Auto Steering

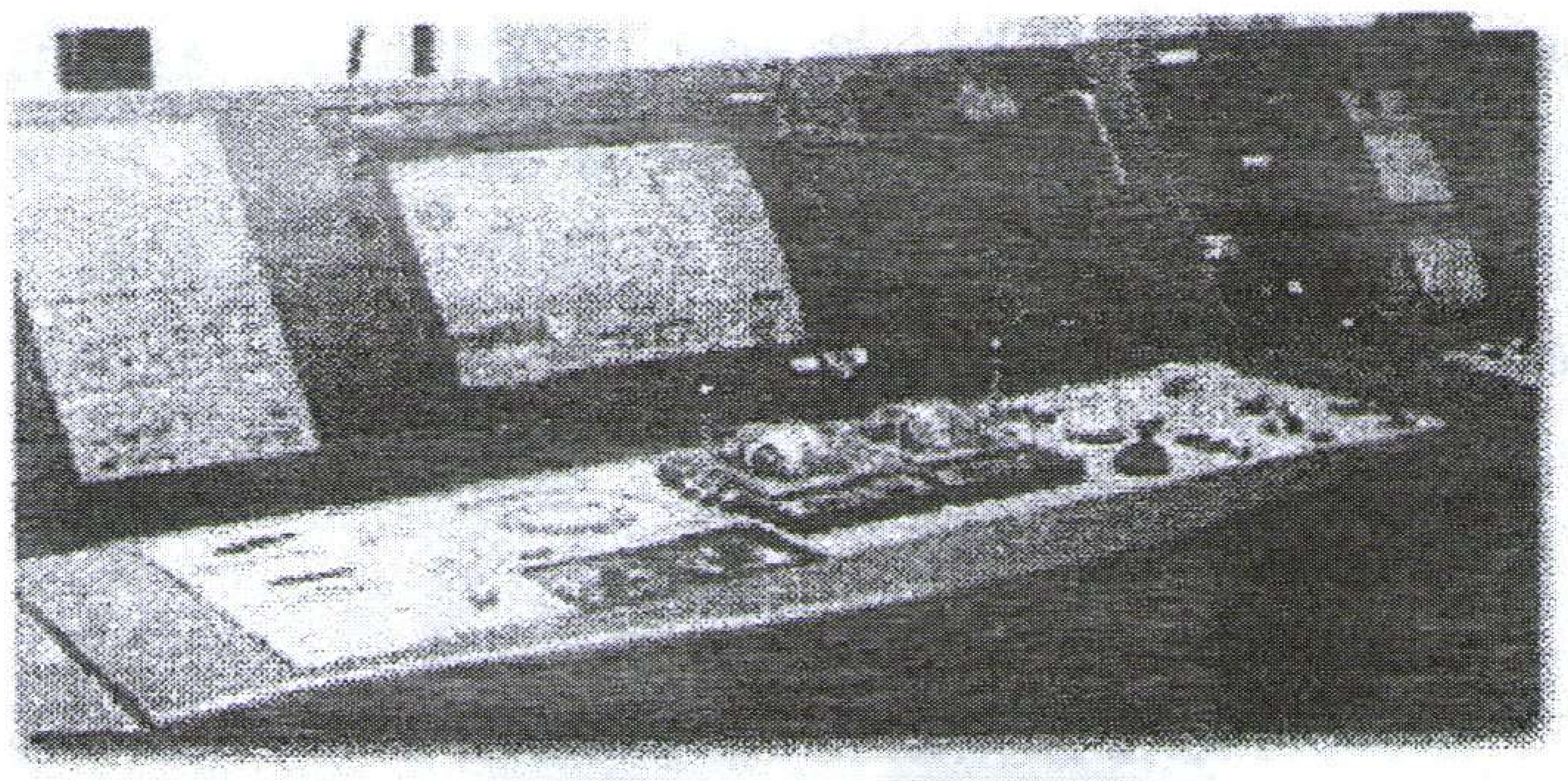

Figure 18.7 - Steering Control System – *NautoSteer*

(This figure includes other systems too)

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18.2.1 Salient Features of NautoSteer

- Safety, reliability, redundancy.
- Integral component of the Integrated Navigation and Bridge System, expandable.
- Proper design of co-operating functional groups.
- Versatile installation possibilities.
- Increased reliability by self-explanatory designation of important sequences.
- Reliable legibility of instruments.
- Night design with individual or central dimming.
- Neutral and non-reflective colours.
- Service-friendly design.
- In compliance with all National and International Classification Rules, especially the IMO resolution A.325 IX and the SOLAS resolution MSC.1 (XLV), Chapter II, Part C, Regulation 29.

18.2.2 System Types

18.2.2.1 Dual Follow-Up (Dual FU)

The required rudder angle is selected on the mechanical rudder position indicator at the follow-up hand wheel or tiller (Refer Figure 18.8). One amplifier operates the servomechanism of the steering gear and the rudder is moved until it reaches the required angle (1 amplifier per pump or valve according to IMO or SOLAS). The feedback unit transmits the actual rudder position (Refer Figure 18.12).

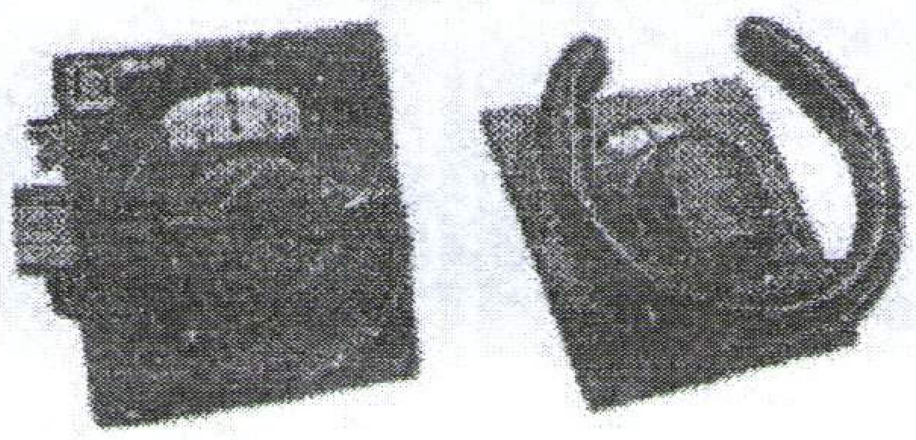

Figure 18.8 - Rudder Angle Indicator and Tiller

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18.2.2.2 Dual Non-Follow-Up (Dual NFU)

To command a rudder, electrical movement contacts are made by moving the NFU hand wheel or the NFU tiller. The rudder position is changed as long as the contact is held. The steering gear is controlled according to IMO or SOLAS (1 contact set per pump or valve). During the steering process, the actual rudder angle should be checked on the rudder position indicator.

18.2.2.3 Follow-Up/Dual Non-Follow-Up

Depending on the type of steering selector at the steering mode selector switch, the steering gear is controlled by the follow-up or the non-follow-up control system. Each of the two steering systems is able to control both pumps of the steering gear. Due to the redundant (dual) design of the non-follow-up controls, this system is the main steering control in this configuration according to IMO or SOLAS.

18.2.3 System Structure

18.2.3.1 Control Components

❋ ***Follow-up (FU) controls*** - *Contact steering is by a follow-up amplifier.*

Figure 18.9 - FU Hand-wheel Unit

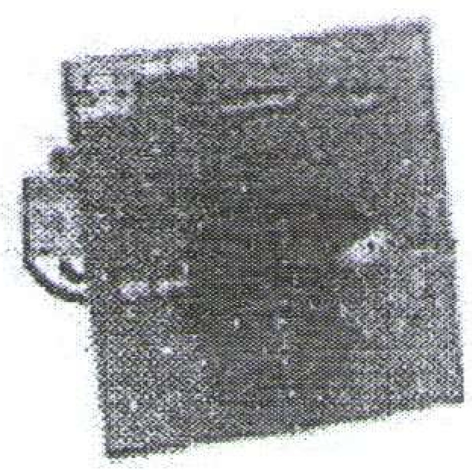

Figure 18.10 - FU Tiller

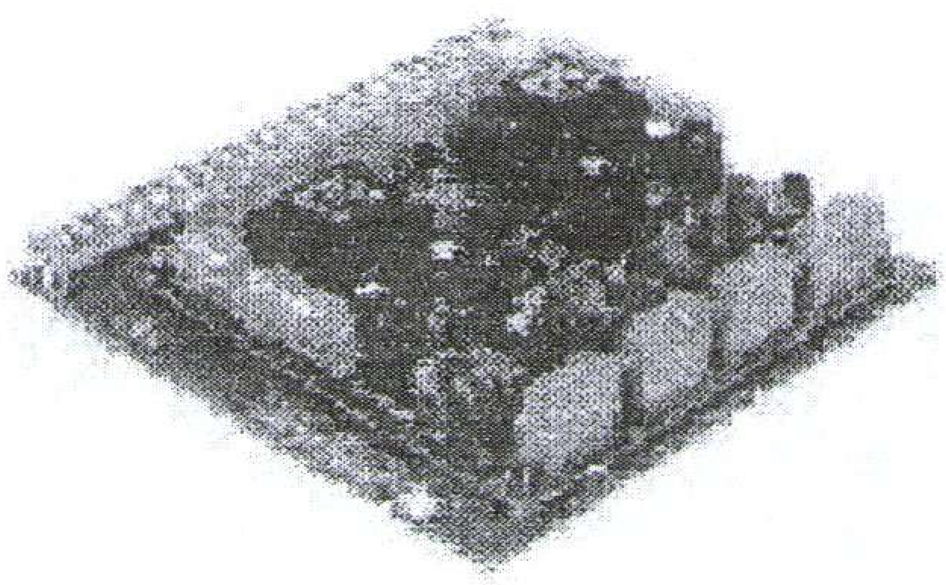

Figure 18.11 – Follow-up Amplifier

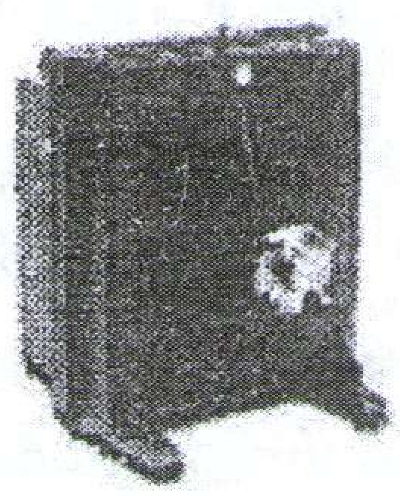

Figure 18.12 - Feedback Unit

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- *Actuator*

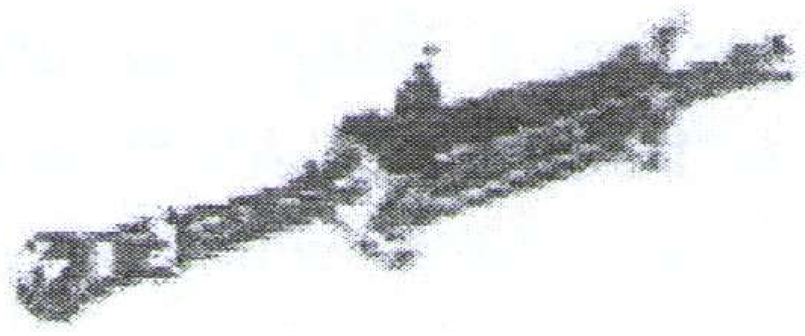

Figure 18.13 - Solenoid Valve with On/Off Function

- *Non-Follow-up (NFU) Controls*

Direct contact steering elements:

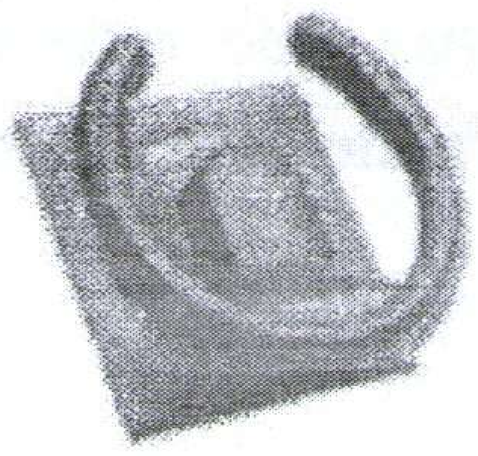

Figure 18.14 - NFU Hand-wheel Unit

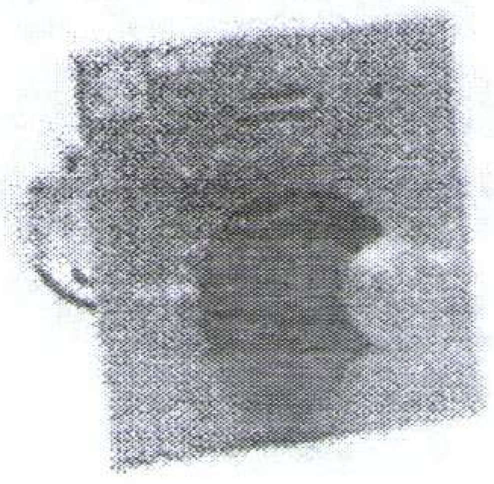

Figure 18.15 - NFU Tiller

- *Actuator*

Proportional valve or torque motors

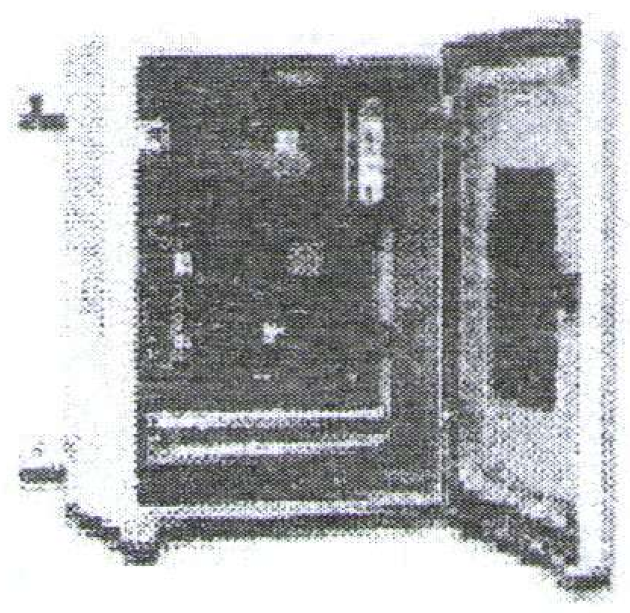

Figure 18.16 - Proportional Steering By Analogue Amplifier/Main Pump

- *Selection of Remote Steering Stands*

In principle, all basic steering control systems (dual FU, dual NFU, and dual FU/NFU) can be extended by remote steering stands. The steering stands, e.g. bridge wings, are selected by a steering mode selector switch and by the electronic 'Take-over System'. The steering mode selector switch has an additional position '*Remote*' by which all remote steering stands can be activated (Refer Figure 18.17).

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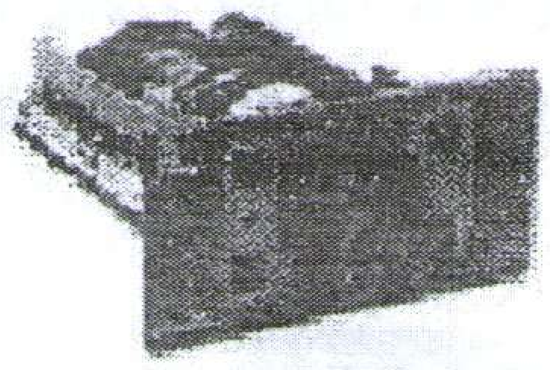

Figure 18.17 – Steering Mode Selector Switch

* ***Rudder Position Indicator***

The scope of supply of the Raytheon Marine steering control system includes the feedback unit, which is usually installed on the rudderstock. In addition to the limit switches, this feedback unit includes various potentiometers. One of these potentiometers is used as a transmitter for the actual electrical rudder position indicators (Refer Figure 18.18). Hence, no additional feedback unit and no additional mechanical connections are required at the rudder stock.

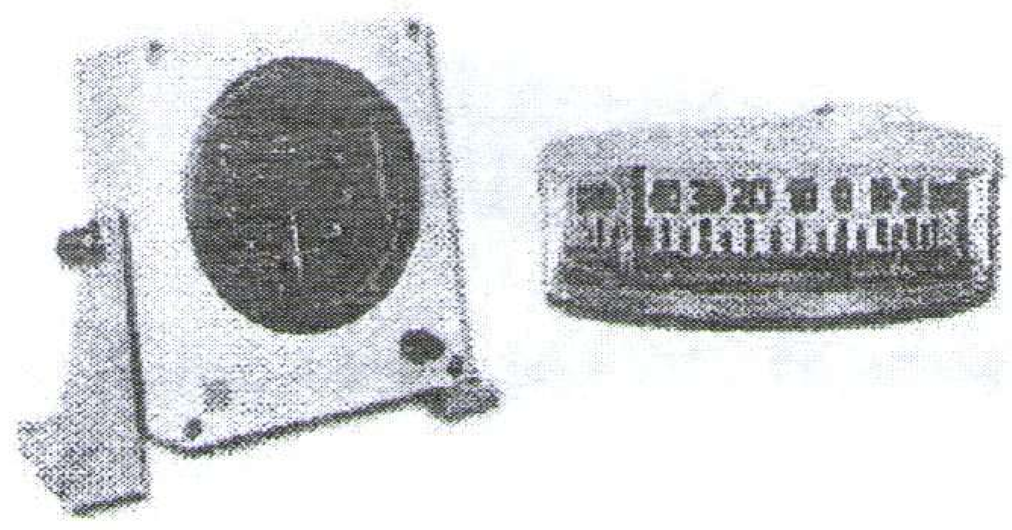

Figure 18.18 – Rudder Position Indicators

* ***Universal Signal Device***

Up to 15 alarm and status indications of the steering gear system can be free configured as the Nautoalarm. The steering mode selector switch can also be supplied with illuminated status information on steering control modes (Refer Figure 18.19).

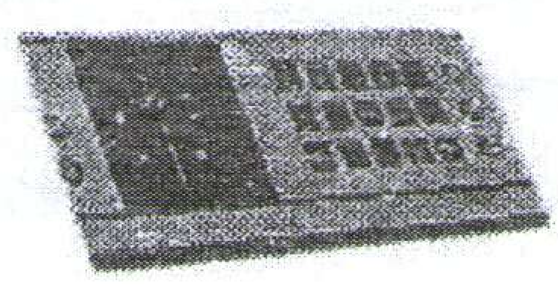

Figure 18.19 - Universal Signal Device

* ***Over-ride Control***

FU and NFU tillers can be extended by an over-ride function if desired by the customer. 'Over-ride' means an immediate disconnection of the automatic mode, such as autopilot or track control and the activation of manual control (Refer Figure 18.20).

The override signal unit indicates this mode visually and audibly. It enables a return to the automatic mode on completion of the manual steering manoeuvre via a push-button switch.

Figure 18.20 - Override Control

- ***Monitoring System***

The steering failure alarm device offers online monitoring from the rudder order element of the FU steering control to the rudder blade as well as synchronisation monitoring of mechanically independent double steering gears (Refer Figure 18.21).

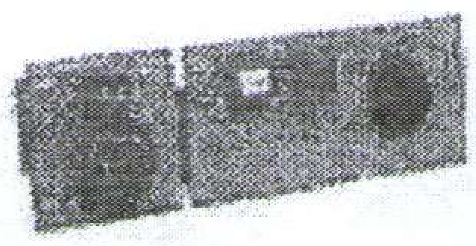

Figure 18.21 - Monitoring System

- ***Emergency Controls***

Some classification societies require a dual emergency control in the steering gear room. A separate change-over switch - 'Bridge / Steering Gear' in the steering gear room as well as a dual FU tiller meet this task in connection with a steering repeater compass (Refer Figure 18.22). The changeover switch can be locked against unauthorised use. It electrically isolates the steering control in the steering gear room from all other steering controls on the bridge. This ensures galvanically separated operation. If the mechanical rudder position indicator cannot be seen on the stock, the Raytheon Marine electric rudder position indicator can be introduced as an additional feature.

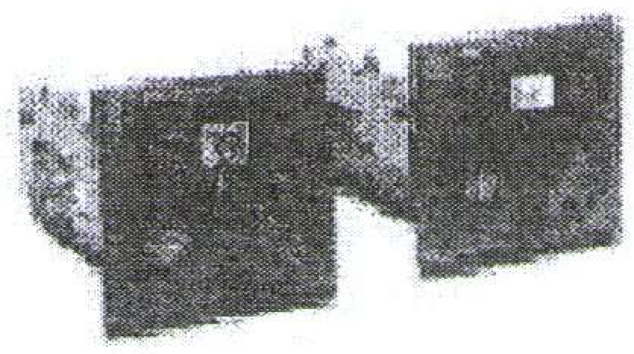

Figure 18.22 - Emergency Controls

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The following article is an extract from www.sperry-marine.com and a related website (Sperry Marine, with worldwide headquarters in Charlottesville, Va., is part of Northrop Grumman's Electronic Systems sector). These have been inserted for the sheer simplicity, yet rich content that is capable of letting the reader practically visualise whatever is explained!

18.3 Sperry Marine Steering Gear

This steering system is provided to control the rudder in response to helm commands from the bridge. The system consists of the following subsystems:

Steering commands are given to the *dual-control gyro pilot steering stand* located on the ship's bridge. In the steering engine room the commands are received by two *linear hydraulic power units* and *compensated hydraulic pumps* and transmitted to two *Heleshaw radial piston pumps*. The radial piston pumps direct pressurized hydraulic oil to four hydraulic rams which moves the rudder. Precise control of the rudder position is accomplished by means of a *differential gear train* and *follow-up mechanism*. An *emergency hand pump* is supplied for use in the event of failure of the normal hydraulic system and also for filling and draining the system, and all hydraulic components of the system are coupled together with *high and low pressure piping systems*.

Each of the above mentioned components will be discussed in detail as follows:

18.3.1 Steering Design Specifications

Max. Rudder Torque-Ahead at 35^0 Rudder Angle	3,048,000 in-lbs
Max. Rudder Torque-Astern at 35^0 Rudder Angle	4,370,000 in- lbs
Max. Pressure-Ahead at 35^0 Rudder Angle	735 psi
Max. Pressure-Astern at 35^0 Rudder Angle	1055 psi
Relief Valve Setting	1300 psi
Rudder Angle Hard Over (H.O.) to Hard Over	70^0
Time - H.O. to H.O. (One Power Unit Operating)	2^0 per second
Time - H.O. to H.O. (Both Power Units Operating)	4^0 per second
No. of Turns for Trick wheel (70^0 H.O. to H.O.)	9.1

18.3.2 Dual Control Gyro Pilot Steering Stand

The Sperry dual control gyro pilot steering stand provides three types of rudder control: automatic control using the gyrocompass input to maintain the selected heading, hand steering with follow-up, and hand steering without follow-up. The rudder control selector switch on the steering stand is used to change from one mode of rudder control to the other.

Regardless of which mode of rudder control is utilized, an electric signal is sent to one of the two independent electro-hydraulic steering controls located in the steering engine room.

The heart of each automatic steering system (port or starboard) is a potentiometer bridge. Each bridge contains two potentiometers connected in a balanced Wheatstone bridge arrangement. One potentiometer of each bridge is called the control potentiometer. It is located in the steering stand, and is positioned by both the steering wheel and the gyro compass which acts on it through a mechanical differential gear train. The other potentiometer of each Wheatstone bridge is called the follow-up or repeat-back potentiometer. It is located in the linear hydraulic power units and controlled by the rudder positioning equipment.

When the control potentiometer is turned by either the steering wheel or by the gyro-compass, a d.c. signal called the course error signal is sent to a solenoid-operated directional valve located in each linear hydraulic power unit. The polarity and magnitude of this course error signal indicates the direction and amount of corrective rudder action required.

When the linear hydraulic power unit transmits this rudder order to the radial piston pumps the follow-up or repeat-back potentiometer generates a d.c. signal opposite in polarity to the control signal. When the magnitude of this opposite signal increases to equal the value of the course error signal, the effective signal level to the hydraulic power unit reduces to zero, and rudder action ceases. Thus, full follow-up control is provided.

Double cabling connects the steering stand in the wheel house with the hydraulic power units located in the steering engine room. Indicating lights on the steering stand show which system is operating and whether the other system has power available.

18.3.3 Linear Hydraulic Power Unit

The linear hydraulic power unit consists of a double ended hydraulic control cylinder, manifold-mounted directional and bypass valves, parallel rack, outside limit switches, inside limit bypass relay and repeat-back potentiometer.

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The power unit receives electrical signals from the dual control gyro pilot steering stand. In response to these signals, the piston rod is positioned by means of hydraulic fluid delivered under pressure by the Vickers hydraulic pump units. The position rod, in turn, is directly connected through a differential gear train to the floating ring of the radial piston Hele Shaw pump. The amount of travel of the piston is made proportional to the order of the dual-control gyro pilot steering control. Also, limits are provided to prevent over-travel of the piston.

18.3.4 Piston Operation

The controlling element of the linear hydraulic power unit is the directional valve which is a solenoid-controlled, pilot-operated, four-way valve. A control signal from the steering stand energizes one of the solenoids in the valve. The solenoid pushes the pilot spool off-centre, thus porting pilot fluid to offset the main spool valve. This connects one side of the cylinder to the input pressure and the other side to the return line, causing the piston rod and hence the floating ring of the Heleshaw pump to move.

The direction of flow, and thus the direction of the control cylinder movement, will depend upon which solenoid is energized by the steering control. A parallel rack, which activates the repeat-back potentiometer and limit switches is attached to and moves with the piston. When the piston rod reaches the ordered position, the electrical follow-up signal balances the control signal thereby de-energizing the directional valve.

A bypass valve in the power unit opens when the automatic or hand-electric controls are not in use, allowing oil to flow freely from one end of the power unit cylinder to the other. The ship's steering mechanism can then be operated by separate means with the hydraulic power unit still connected. When the system is energized, hydraulic pressure closes the valve to permit operation. The bypass valve is a hydraulically pressure-operated, spring-offset four-way valve requiring at least 50 psi of pressure for its operation. Although the bypass valve is a four-way type, its use in this system is limited to either the open or closed position. This is accomplished by blocking one set of ports.

When the system is not in operation, or in the event it should become inoperative, the bypass valve allows oil to flow from one side of the control cylinder to the other so that the piston rod may be moved by an alternate means of steering such as a trick wheel or telemotor. When the pump is turned on to start the system in operation, there is an immediate pressure build-up in the system, due to the check valve. This pressure closes the bypass valve thus allowing the control cylinder to respond to the operation of the directional valve.

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18.3.5 Limit Switches, Relay, and Follow-up Potentiometer

The hydraulic power unit contains two pairs of limit switches, designated "inside limit switches" and "outside limit switches". The inside limit switches restrict electrical operation normally to ten degrees of rudder motion in either direction in order to optimize performance when steering automatically. Thus, when an error signal tends to drive the cylinder beyond moderate rudder angles, an inside limit switch opens the circuit to the energized solenoid of the directional valve. The outside limit switches are set to open the solenoid circuit at the hard over rudder positions. Also, these switches are always set to prevent the piston from hitting its mechanical stops. In the hand-electric mode of steering, a relay in the power unit, controlled from the steering stand, closes the circuits across the inside limit switches and allows movement of the rudder up to the angle determined by the outside limit switches.

In the normal mode of operation both pairs of limit switches are closed. A control signal is applied to one or the other solenoid of the directional valve depending on the direction of the rudder order. The valve operates to port in order to move the piston and rod. This also moves the attached rack. The rack drives a pinion which couples through a gear train to the limit switch cam shaft. The gears are chosen at the factory in accordance with the travel distance of the piston rod, so that the cam shaft rotates 270^0 when the piston rod moves from one position to the other. The cams are set on the shaft during installation for the specific limits required by the particular vessel.

18.3.6 Inside Limit Switches

When the piston rod has moved sufficiently to produce a rudder angle of about 10^0 either side of amidships, a cam opens the limit switch in series with the energized solenoid valve and the steering mechanism is held in this position until control current is applied to the other solenoid. If less than 10^0 of rudder were called for, an inside limit switch would not operate.

18.3.7 Outside Limit Switches

In the hand-electric mode of operation, a cam operated switch in the steering stand energizes the inside limit bypass relay in the power unit when a rudder order of approximately 8^0 is applied by the helmsman. A few degrees short of maximum travel, a cam opens the normally closed snap-action outside limit switch thereby de-energizing the directional valve solenoid and holding the steering mechanism in position until the helmsman orders a return of the rudder toward amidships. Thus the outside limit switches determine hard-over rudder angles and prevent the power unit from operating to its mechanical limits of travel.

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The camshaft also drives the rotating wiper of a 5000-ohm wire-wound oil-filled potentiometer. This potentiometer is accurately positioned so that when the piston rod is at its mid position, the wiper of the potentiometer is at "mid resistance". In this way the potentiometer provides an electrical signal proportional to the power unit position for connection into the follow-up circuit of an automatic or hand-electric steering control. In other words, this repeat-back potentiometer generates a follow-up signal which is sent to the steering stand. The directional valve solenoid is de-energized when the follow-up signal cancels the control signal.

Both ends of the power unit piston rod carry a clevis, one of which is connected mechanically through the differential gear train to the Hele Shaw rotary pump crosshead. The power unit is capable of transmitting a force of about 6,800 pounds, either as a push or a pull.

18.4 Gyroscopes

18.4.1 Definition

A gyroscope is any device consisting of a rapidly spinning wheel set in a framework that permits it to tilt freely in any direction i.e., to rotate about any axis. The momentum of such a wheel causes it to retain its attitude when the framework is tilted; from this characteristic a number of valuable applications are derived. Gyroscopes are used in such instruments as compasses and automatic pilots onboard ships and aircraft, in anti-roll equipment on large ships, inertial guidance systems and many other systems where stabilisation is a mandatory requirement.

The marine gyrocompass is a three-frame gyroscope with its spin axis horizontal. In order to achieve the north-seeking and actual location (or meridian settling) properties of a gyroscope, use is made of the tilting effect of the spin axis when it is not pointing to the true north. As soon as tilt develops, a pendulum type device introduces torques that precesses the spin axis towards the meridian, causing it to describe a spiral with an ever-decreasing radius.

When stabilised, the spin axis is maintained in the meridian plane by a precession equal but opposite to the drift at the particular latitude. When there is no tilting effect the marine gyrocompass will lose its directional properties and become useless. This is the case at the poles and also when a vehicle moves due west with a speed equal to the surface speed of the Earth. Because the latter condition can easily exist in an aircraft in the middle and upper latitudes, it cannot be used for air navigation. Vertical three-frame gyroscopes with pen-recorder attachments are often used to analyse rolling and pitching movements of ships.

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18.4.2 The Three-Frame Gyroscope

If the base of a three-frame gyroscope is held in the hand with the rotor spinning and turned about any of the three axes, the rotor axle will continue to point in the original direction in space. This property is known as *gyroscope inertia.* If the speed of the wheel decreases, the gyroscope inertia gradually disappears, the rotor axle begins to wobble and ultimately takes up any convenient position.

Rotors with a high speed and concentration of mass towards the rim of the wheel display the strongest gyroscopic inertia (Refer Figure 18.23).

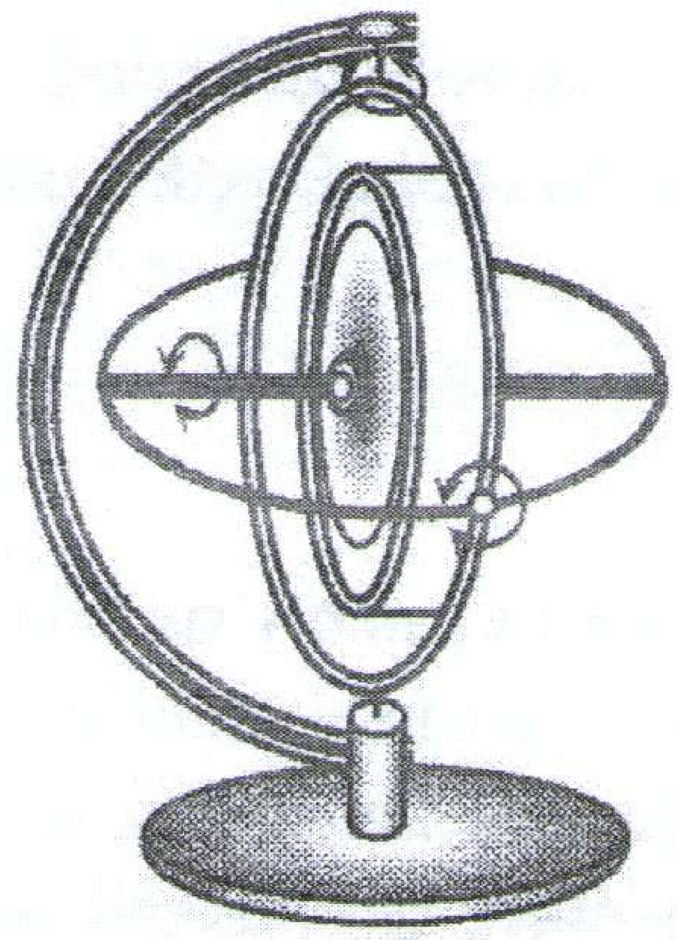

Figure 18.23 – The Three-framed Gyroscope

It is apparent that gyroscopic inertia depends on the angular velocity and the momentum of inertia of the rotor, or on its angular momentum. The rotor (wheel) is subject to the laws of rotational motion and inertia in that a freely rotating, well-balanced body, whose mass is equally distributed along its circumference, will maintain a fixed direction in space, tends to preserve its angular momentum, or spinning action, unless acted upon by some external force.

The consequence of gyroscopic inertia is that to the observer on Earth, the spin axis of a gyroscope makes an apparent movement over a period of time, although this apparent motion merely reflects the revolution of the Earth about its axis.

There is one exception to this, that when the spin axis points towards the polar star, there is no movement of the spin axis with respect to the observer's surroundings, as the axis is parallel to the Earth's axis and points toward the Celestial poles.

As the direction of the Earth's rotation is counter clockwise when seen from above the North Pole, the relative direction of this end will change through Northeast, East, Southeast, South, etc.

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This clockwise movement will continue until, at the end of one period of rotation of the earth (23 hours 56 minutes), the rotor and spin axis revert to their original position with respect to the observer on the Earth's surface. While this is taking place, the top end is apparently tilting upward. The change in azimuth (direction) of the spin axis is often referred to as *drifting*. Sometimes *tilting* and *drifting* are collectively called *apparent wander*.

If, while the rotor of a three-frame gyroscope is spinning, a slight vertical downward or upward pressure is applied to the horizontal gimbal ring at the top, the rotor axle will move at right angles in a horizontal plane. But no movement will take place in the vertical plane. Similarly if a sideways pressure is applied at the same point the rotor axle will tilt upward or downward. This second property is called *precession.* A precession or angular velocity in the horizontal plane is caused by the application of a couple, i.e. parallel forces equal and opposite, in the vertical plane perpendicular to that of the rotor wheel. Precession is the tendency of the rotor's axis to move at right angles to any perpendicular force that is applied to it.

The unrestrained or *free* three-frame gyroscope has little practical use because its spin axis is subject to tilting and drifting owing to the rotation of the Earth. In the controlled state it is widely used. The term control of a gyroscope implies that the spin axis, by small continuous or intermittent application of torque (twisting force), is made to precess so that it oscillates around a mark fixed in relation to co-ordinates on the Earth rather than in relation to space.

18.4.3 Controlled Gyroscopes

Controlled gyroscopes fall into three categories:

- The north-seeking gyroscope is used in marine applications. In the settling (or normal) position the spin axis is kept horizontal and in the plane of a meridian.
- The directional gyroscope is used in aircraft and is sometimes called a self-levelling free gyroscope corrected for drift. With its spin axis horizontal it has directional properties but does not automatically seek the meridian.
- The gyrovertical has its spin axis vertical and is used to detect and measure angles of roll and pitch.

These types of three-frame gyroscopes are called *displacement gyroscopes* because they can measure angular displacements between the framework in which they are mounted and a fixed direction - the rotor axis.

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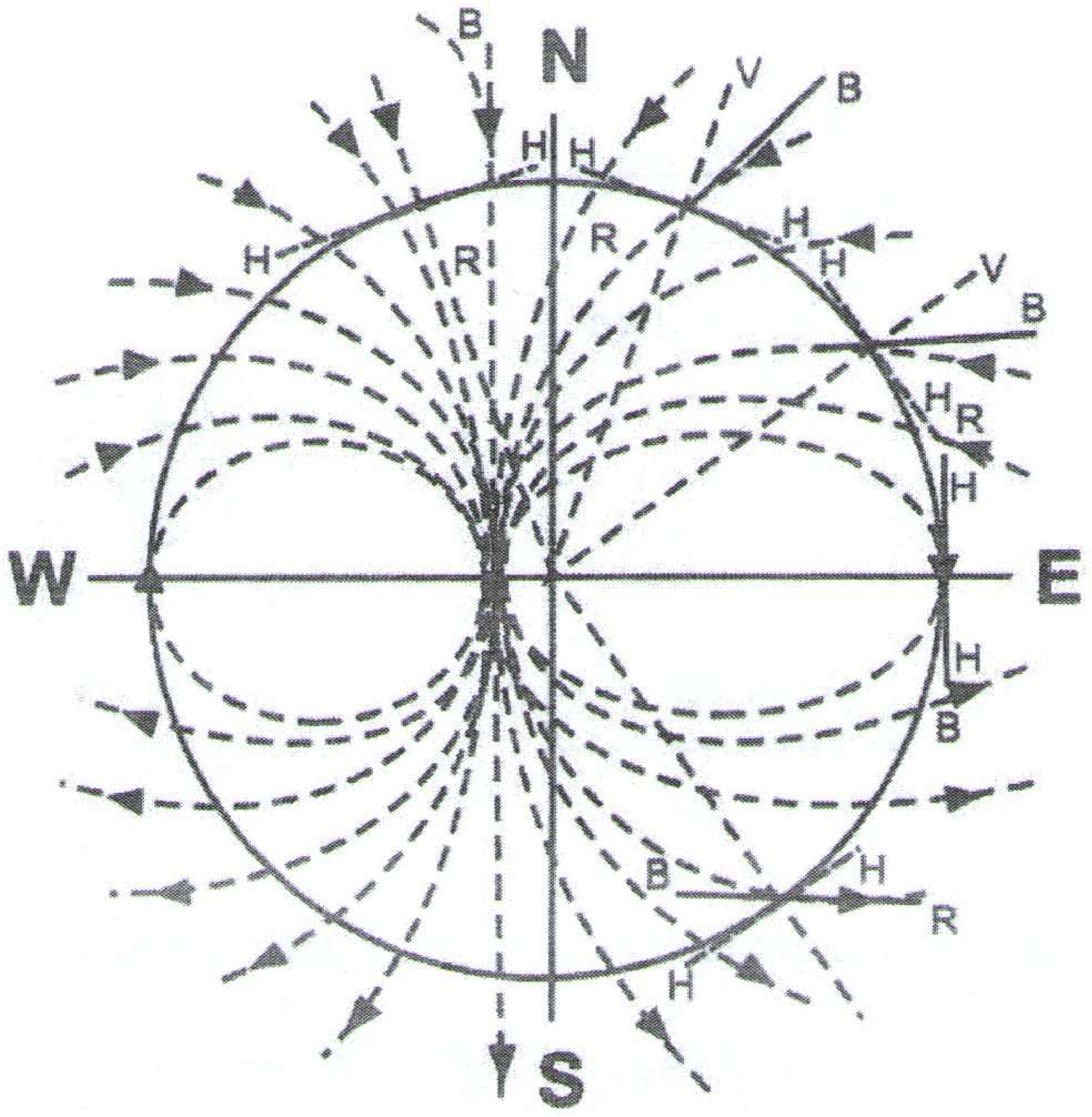

Figure 1 - Simplified section through the Earth's magnetic field.
B and R signify blue and red poles. The lines marked V and HH show the vertical and horizontal directions in various latitudes.

At mid latitudes in the U.S., one degree of sensor tilt off horizontal will have an apparent two-degree shift in indicated heading, even though the vessel is still on course.

In higher latitudes where the horizontal field decreases in strength and the vertical field increases, one degree of tilt can cause over 10 degrees compass error. The Great Lakes and Eastern parts of Alaska are particularly bad areas in this regard (see figure 2).

A few electronic compass manufacturers fill their compass sensor with a heavy oil to dampen the gimbal action and minimize these vertical field errors. Others resort to electronic damping, which either increases the compass dead band (lowers its sensitivity) or averages the heading (delays the availability of current heading information). Some designs use more sophisticated signal processing, but the end result is roughly the same.

Any delay in autopilot response to heading changes, especially in quartering seas, results in excessive yaw and the need for excessive rudder corrections. Some electronic compass manufacturers recognize this deficiency by offering a rate gyro which provides a more current short-term heading reference than their sluggish and over damped electronic compass is capable of.

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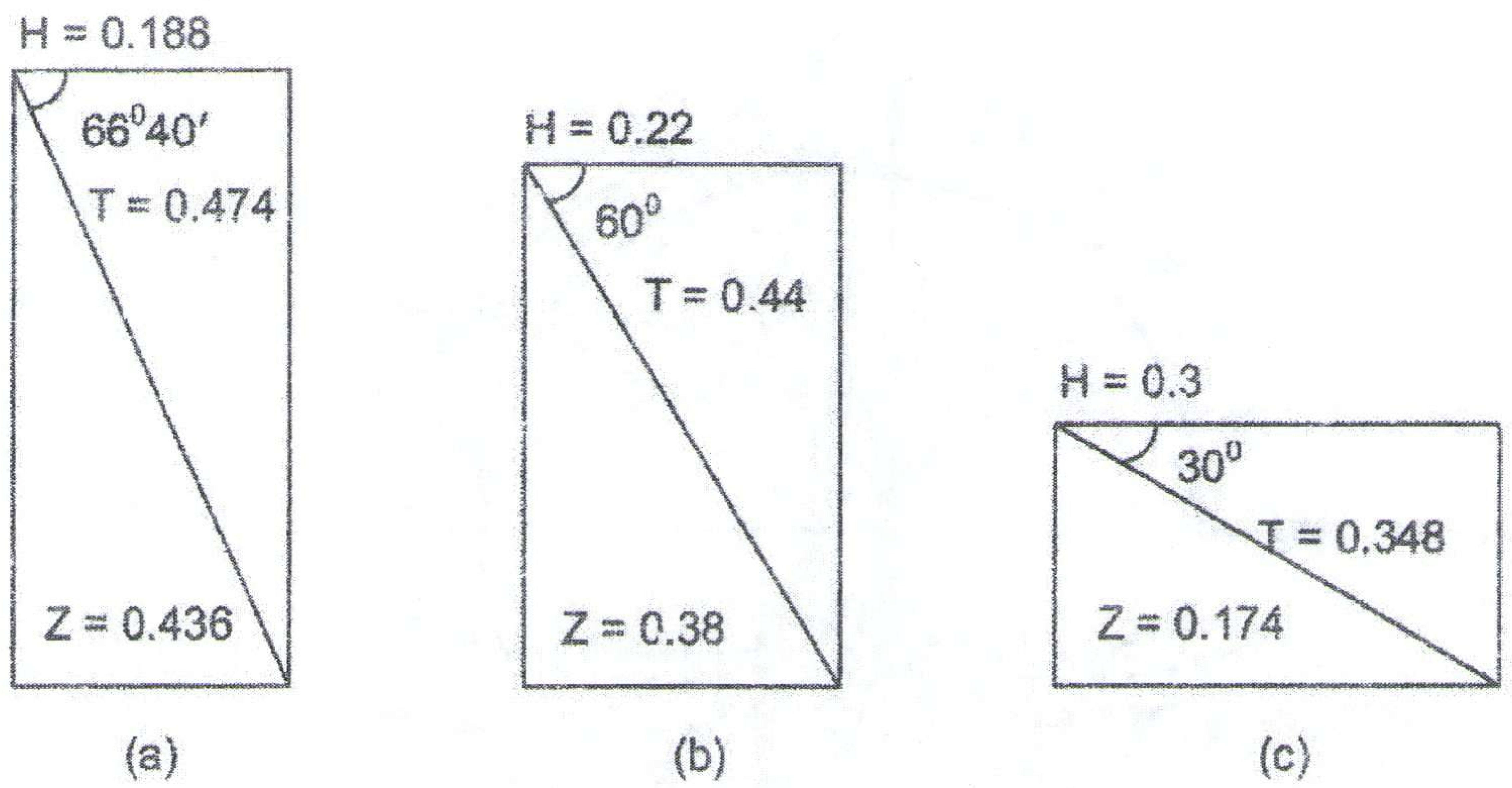

Figure 2 - Horizontal and vertical components of the Earth's magnetic field.

H, Z, and T are respectively the horizontal component, the vertical component, and the total force, all expressed in oersted units. The field is shown for (a) London; (b) Northern Spain, and (c) the Sahara Desert.

Another electronic compass manufacturer has a "turn" button on the compass display. They recommend that this button be activated when a change of course is made. This button simply changes the compass damping to minimum and is a tacit admission that the normal amount of damping, which is required to provide a steady display, causes such a delay in heading indication that the helmsman would overshoot a course change. Clearly, any autopilot using this heading information would have great difficulty steering in quartering seas where immediate correction of course changes is essential.

To verify the severity of compass errors induced by electronic compasses, a simple test can be made using a well-known brand of hand-bearing compass which uses an ungimbaled flux gate sensor in a flat hand-held digital readout configuration. The user must maintain this sensor perfectly horizontal to avoid errors induced by sensing the earth's vertical field. I am not sure how this is to be achieved on a heeled and rolling deck! To measure the tilt errors, hold the hand-bearing compass down flat on the edge of a seat with the vessel at the dock, i.e., no vessel motion to confuse the measurement. Take a reading, and then, without rotating the compass to a different heading, tip it a few degrees up or down and note the change in indicated heading. If this compass were controlling your autopilot, you may appreciate the resulting sloppy steering.

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Chapter 19
Deck Machinery

At the end of this chapter you should be able to:

- ★ Explain the basic operation of windlasses
- ★ Explain the basic operation of cargo winches
- ★ Explain the role of electrical equipment in deck machinery
- ★ Trace basic control circuits
- ★ Comply with regulations governing deck machinery

19.1 The Anchor Windlass

The basic dimensions of an anchor windlass depend on the anchor weight and chain size. The size of the vessel, the nature of the service, and the desired anchor handling and stowage arrangements also contribute to the choice of an anchor windlass. It is also usual to involve capstans for warping. Combination windlass mooring winches / warping head systems have often been supplied for large ships as will be explained in article 19.1.2.

19.1.1 The Horizontal Windlass

One of the two fundamental configurations of anchor windlasses is the horizontal windlass that is in fact a specialised winch, powered by a hydraulic or electric motor or in rare cases, by a steam engine.

The motor is then connected to a gear train that drives one or more chain sprockets, called wildcats, through sliding-block locking heads or comparable jaw clutches. Figure 19.1 depicts a pictorial diagram of a windlass, Figure 19.2 depicts a typical electric windlass and Figure 19.3 is a schematic diagram of a horizontal electro hydraulic type of windlass.

The specification for cargo vessels often require the combination of a horizontal mooring winch with a clutched drum driving a chain wildcat through an auxiliary reduction gear and jaw clutch or sliding pinion. The chain-lifting unit consists of a rigid framework holding an axle for the support of the integral gearwheel wildcat brake rim and the pinion shaft with bearings.

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Chapter 14
Electric Cables

At the end of this chapter you should be able to:

- ★ State the significance of temperature coefficients of metals used for conductors
- ★ Compare various ratings and sizes of cables in use
- ★ Describe the importance of cable testing
- ★ Apply proper wiring procedures on board a ship
- ★ Comply with regulations governing the installation and use of cables

14.1 The Basics

A ship's wiring cables form an integral part of the electrical system on board a ship. Selection of cables for particular applications is an important task for a designer as they are sometimes the weakest link in the system.

They also have to withstand a wide variety of environmental conditions e.g., extremes of temperature, humidity and salinity of atmosphere, as mentioned in Chapter 1. Improved materials have led to obtaining cables of a fairly standard design that are safe, durable and efficient under all conditions in both hazardous and non hazardous areas.

The normal voltage on ships is 440V and cables for use at this voltage are designated 600 / 1000V – 600V to earth or 1000V between conductors. Higher voltages require cables rated at 1900 / 3300V for 3-phase, earthed neutral systems and cables rated at 3300 / 3300V for 3-phase insulated neutral systems.

Electric cables comprise of two basic materials namely insulating and conducting materials, the former of which is the outer covering of the metallic conducting part. Understanding their physical, chemical, electrical and mechanical properties are important. In the case of the conducting material, conductivity, mechanical strength, ductility, and corrosion resistant properties are most important; this is the reason why copper and aluminium cores are very popular – to name a few.

Where insulating materials are concerned, dielectric strength, thermal strength and moisture resistant properties are some of the most important factors. This chapter deals with cables in general and conductors in particular; Chapter 15 deals with insulating materials.

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14.2 Conductors

Many factors determine the type of electrical conductor used to connect components. Conductors may either be "solid" or "stranded" in nature. "Stranding" makes cables more flexible, allows higher current carrying capacities, easy to handle, and easy to solder. Some of these factors are the physical size of the conductor, the type of material used for the conductor, and the electrical characteristics of the insulation. Other factors that can determine the choice of a conductor are the weight, the cost, and the environment where the conductor is to be used. Although silver is the best conductor, it is costly and hence is only used in special circuits; it is used where a substance with low resistivity is needed (its resistivity known to be as low as 1.64×10^{-8} ohm-metres at 20^0C).

Copper is the next option for the following reasons:

- It possesses low resistivity - for annealed (softened) copper it is 1.72×10^{-8} ohm-metres at 20^0C.
- It is more ductile (can be drawn out into fine strands).
- It has relatively high tensile strength (the greatest stress a substance can bear along its length without tearing apart) and it can also be easily soldered.

The copper conductor is tinned or alloy-coated to ensure compatibility with its insulation. Conductors are normally made of annealed stranded copper, which may be circular or specially shaped. Cables with shaped-conductors and cores are usually smaller and lighter than cables with circular cores. (Refer Figure 14.1)

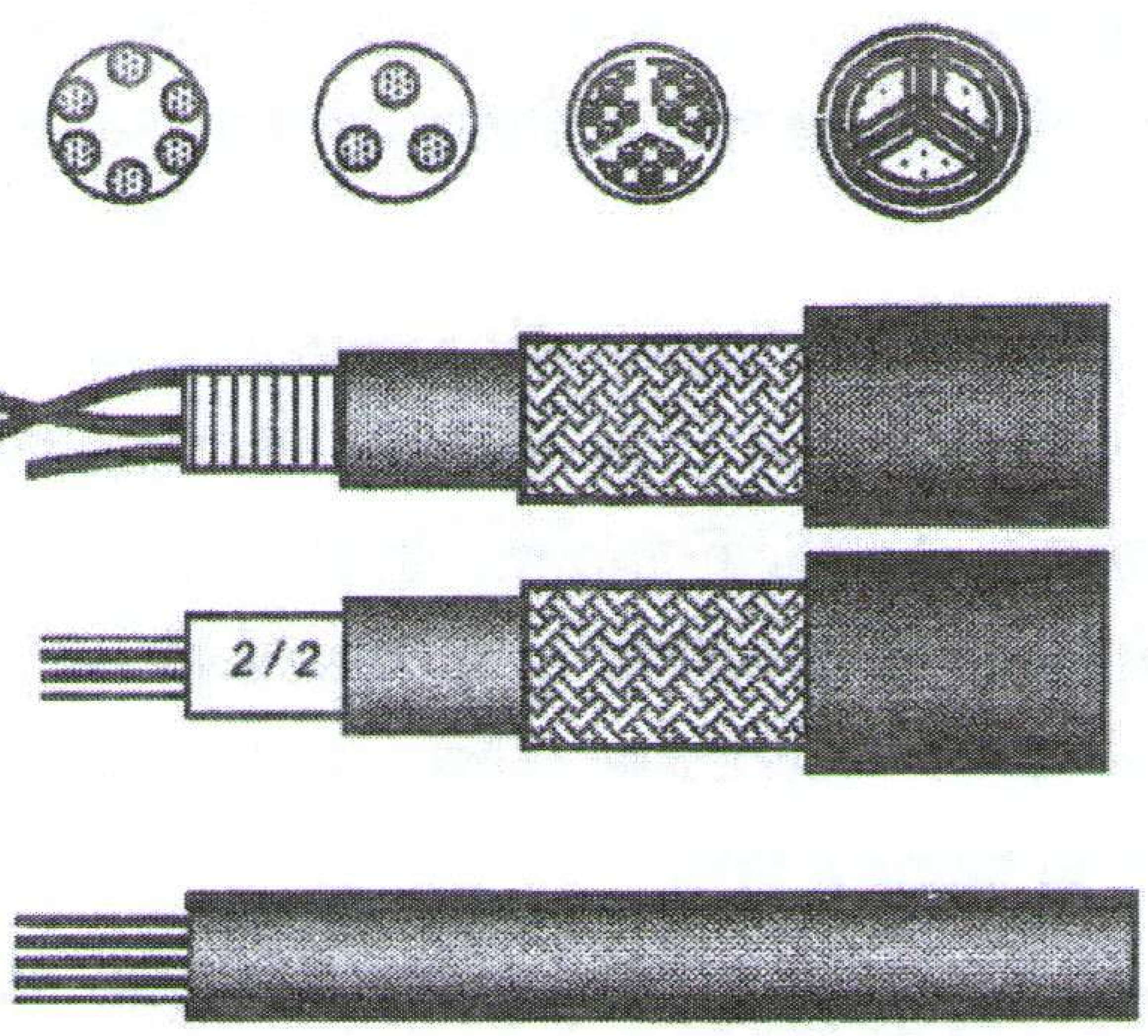

Figure 14.1 - Cable Cores

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14.3 Temperature Coefficient

Pure metals, such as silver, copper, and aluminium, have positive temperature coefficients i.e., their respective resistances increase along with a rise in temperature. The resistance of some alloys, such as constantan and manganin, changes very little as the temperature changes.

Measuring instruments use these alloys because the resistance of the circuits must remain constant in order to achieve accurate measurements. The positive temperature co-efficient of a material maybe defined as *the rise in resistance per ohm original resistance per ^{0}C rise in temperature*. It is denoted by the symbol α, which is equal to 1/234.5 = 0.00427 for copper at 0^{0}C. Though it is expected to remain constant, it does vary at different temperatures i.e., it is 0.00393 at 20^{0}C, 0.00378 at 30^{0}C and 0.00352 at 50^{0}C and so on. This and more is taken into account when designing the electrical distribution system of the vessel. A wire is *not just any wire*; there is a reason and a purpose for the entire electrical system. The only changes in the electrical system should be for expedient repairs and approved modifications; do not modify electrical systems without proper authority.

14.4 Current Rating and Voltage Drop

The current rating of a cable is the current that the cable can carry continuously without the conductor exceeding 80^{0}C with an ambient air temperature of 45^{0}C (i.e. a 35^{0}C rise). This rating must be reduced (de-rated) if the ambient temperature exceeds 45^{0}C, or when cables are bunched together or enclosed in a pipe or trunking which reduces the effective cooling. MICC – Mineral Insulated, Copper Covered cable current ratings are based upon a copper sheath temperature of 150^{o}C (maximum).

For all types of cables the size of conductors required for a particular installation is estimated from standard rating tables. The voltage drop in cables from the main switchboard to the appliance must not exceed 6% (in practice it is about 2%).The cables installed must comply with both the current rating and the voltage drop limitation. Voltage-drop only becomes a problem in very long cables. Continuous current ratings for groups of circuits (up to 6 cables bunched) for twin and multi-core Ethylene-Propylene (EP) rubber insulated cables, run open or enclosed are shown in Table 14.1.

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Conductor Nominal Cross-Sectional Area	Twin Cables			Three and Four Core Cables	
	Current Rating DC or Single Phase	Voltage Drop per Ampere per Metre		Current Rating 3-ϕ AC	Voltage Drop per Ampere per Metre
		DC	1-ϕ AC		
mm2	A	mV	mV	A	mV
1.0	13	54	54	11	47
1.5	17	35	35	14	30
2.5	24	18	18	20	16
4	32	12	12	27	10
6	41	7.8	7.8	34	6.7
10	57	4.6	4.6	47	4.0
16	76	2.7	2.7	63	8.3
25	100	1.7	1.7	84	1.5
35	125	1.2	1.2	100	1.1
50	155	0.98	1.0	125	0.89
70	190	0.68	0.70	160	0.64
95	235	0.49	0.53	195	0.50
120	270	0.39	0.43	225	0.44
150	310	0.31	0.36	225	0.38
185	350	0.25	0.32	290	0.34
240	415	0.19	0.27	345	0.31
300	475	0.15	0.24	390	0.29

Cooling air temperature	35°C	40°C	45°C	50°C	55°C	60°C	65°C	70°C	75°C
Rating factor	1.12	1.06	1.00	0.94	0.87	0.79	0.71	0.61	0.50

Table 14.1 – Cross Section versus Current Ratings and Voltage Drops

Rating factors are based on cooling air temperature

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14.5 Cable Sizes

The Following methods are adopted for determining cable sizes:

1. Use of a standard wire gauge.
2. According to the diameter of the cable
3. According to cross sectional area of cable (i.e. its core)

Table 14.2 is an example of a selection guide for a 3-ph motor whose rating is 400 / 440V.

Horse Power	Aluminium Cable Sizes			
	Supply connection		Star-Delta Starter to Motor Connection	
	Preferred Area	Alternative Area	Preferred Area	Alternative Area
1	1.5 mm^2	2.5 mm^2	1.5 mm^2	2.5 mm^2
1.5	1.5 mm^2	2.5 mm^2	1.5 mm^2	2.5 mm^2
2	1.5 mm^2	2.5 mm^2	1.5 mm^2	2.5 mm^2
3	1.5 mm^2	2.5 mm^2	1.5 mm^2	2.5 mm^2
4	1.5 mm^2	2.5 mm^2	1.5 mm^2	2.5 mm^2
5	1.5 mm^2	2.5 mm^2	1.5 mm^2	2.5 mm^2
6	2.5 mm^2	4 mm^2	1.5 mm^2	2.5 mm^2
7.5	4 mm^2	6 mm^2	1.5 mm^2	2.5 mm^2
10	6 mm^2	10 mm^2	2.5 mm^2	4 mm^2
12.5	6 mm^2	10 mm^2	4 mm^2	-
15	6 mm^2	10 mm^2	4 mm^2	-

Table 14.2 - Rating versus Cross-sectional Area for Motors

14.6 US and British Comparative Sizes for Cables and Lines

There are different standards of "wire gauges". AWG i.e., the American Wire Gage is also known as the "Brown and Sharpe Gage"; it was devised in 1857 by J.R. Brown. As will be seen from Tables 14.3 and 14.4, a larger number denotes a smaller wire and follows a mathematical law upon which the gauge is founded.

SWG i.e., the Standard Wire Gauge is also known as New British Standard Gauge, English Legal Gauge or Imperial Wire Gauge (adopted in 1883). The other common unit is the millimetre wire gauge denoted in mm^2.

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The following tables (14.3 and 14.4) are made with reference to Technical Data from Maryland Metrics, Maryland, USA (www.mdmetric.com) and are inserted with permission.

In the US, sizes of copper conductors for high current and telecommunication purposes are usually stated in American Wire Gauge (AWG) numbers. The following comparisons apply:

AWG	Diameter (mm)	Section (mm^2)
500	17.96	253
350	15.03	177
250	12.70	127
4/0	11.68	107.2
3/0	10.40	85
2/0	9.27	67.5
1/0	8.25	53.5
1	7.35	42.4
2	6.54	33.6
4	5.19	21.2
6	4.12	13.3
8	3.26	8.35
10	2.59	5.27
12	2.05	3.30
14	1.63	2.09
16	1.29	1.31
18	1.024	0.824
20	0.813	0.519
22	0.643	0.325
24	0.511	0.205
26	0.405	0.129
28	0.320	0.0805
30	0.255	0.0511
40	0.079	0.00490
42	0.064	0.00322
44	0.051	0.00204

Table 14.3 – US and British Comparative Sizes

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AWG	mm^2
30	0.05
28	0.08
26	0.14
24	0.25
22	0.34
21	0.38
20	0.50
18	0.75
18(UL)	1.0
17	1.0
16	1.5
14	2.5
12	4
10	6
8	10
6	16
4	25
2	35
1	50
2/0	70
3/0	95
4/0	120
300MCM	150
350MCM	185
500MCM	240
600MCM	300
750MCM	400
1,000MCM	500

Table 14.4 - Cross Reference Guide for AWG to mm^2

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Cables in exposed and damp situations, e.g., for deck lighting, may develop a low insulation resistance. Usually this is a result of mechanical damage, or a faulty gland permitting the ingress of water or just moisture.

Injecting a heating current from a welding set can dry out cables. The procedure requires care not to overheat the cables, which could cause further damage. The cable should be disconnected at both ends from the equipment, and connected as shown in Figure 14.3. The injection cables must have good connections at each end. The current flow and cable temperature should be carefully monitored. When satisfactory insulation values have been restored, a final check should be made with the cable at the normal (ambient) temperature.

Remember that the injected heating current must never exceed the rated value of the cable. It is advisable to use an ammeter and to start at the lowest setting on the welding set. The voltage should be in the region of 30V to 55V depending upon the current setting. The cable temperature can be measured with a stem thermometer (mercury in glass) secured to the cable and should not exceed a temperature rise of 30^0C (86^0F) from the ambient value. Readings of temperature and insulation resistance should be recorded every hour and a graph plotted.

14.8 Electrical Cable Codes

The following cable codes are those adopted by three countries. Such documents can be found on ships too.

The table below on Japanese Industrial Standards and relevant examples contain extracts from shipboard manuals.

Japanese Industrial Standards *(applicable for shipping too)*

Symbols for the number of cores and main uses:

S	Single Core for Lighting and Power	M	Multi Core for Control and Signals
D	Double Core for Lighting and Power	TT	Twisted Pair for telephones and instrumentation
T	Three Core for Lighting and Power	P	Portable or Flexible
F	Four Core for Lighting and Power	STW	Switchboard
L	AC 250V	H	AC 0.6 / 1kV

Extract from Paper No. 12

"The Future of the Automated Ship - The Role of Classification Societies"

By A Trousse [Head of Electrical and Automation Department Bureau Veritas, Paris].

Quote

France

0.6 / 1 kV or 0.44/0.75 kV	Rated Voltage
M	Marine Cable
Insulation	
Pr 85^{0}C	Cross-linked Polyethylene
Pr 95^{0}C	Cross-linked Polyethylene
Th	Thermoplastic Compound, Common Quality T75
	Thermoplastic Compound, Heat Resistant Quality T85
	Thermoplastic Compound, Extra Heat Resistant Quality T90
Armour	
A	Metal Braid Armour
	Metal Tape Armour
	Metal Wire Armour
Sheaths	
N	Synthetic Rubber (Polychloroprene)
G or Th	Thermoplastic Compound
H	Chlorosulphonated polyethylene (Hypalon)

Example: 0.6/1KV M Pr Th A G

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Germany

0.6 / 1 kV or 0.44/0.75 kV	Rated Voltage
M	Marine Cable
Insulation	
G	Epr 85 Ethylene – Propylene Rubber
	Epr 90 Ethylene – Propylene Rubber
Armour	
C	Metal Wire Armour (Copper)
D	Metal Wire Armour (Galvanized Steel)
Sheaths	
G	Synthetic Rubber (Polychloroprene)
Y	Thermoplastic Compound

Example: MGCG 0.6/1KV

Insulation(*)		Outer Covering(*)	
P	Ethylene Propylene Rubber	L	Lead Sheath
SR	Silicone Rubber	Y	Polyvinylchloride Sheath
Y	Poly Vinyl Chloride (PVC)	N	Polychloroprene Sheath
		D	Braid

Continued...

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Armouring(#)		Protective Covering	
C	Galvanised Steel Wire Braid	Y	Polyvinylchloride
B	Copper Alloy Braid	N	Polyvinyl chloroprene Sheath
FR	Fire Resistant	S	Copper wire Shield against noise
FA	Flame Retardant	*(*) For telephone cables, switchboard wire and PVC cords, the insulation symbols are omitted. The outer covering symbol of switchboard wire is also omitted*	
-S	Individual Core or Pair Shield		
E	Earth Wire	*(#) Wire braid shall be made of steel wires. In case of copper alloy wire braid, the letter B shall be suffixed to letter C*	

Example 1 – H-FR-FA-DPCY-2.5: 0.6/1kV, Fire resistant, double core, ethylene propylene rubber insulated, polyvinylchloride sheathed, steel wire braided, polyvinylchloride protective covering, 2.5mm^2 conductor cable

Example 2 – L-FR-FA-MPCYS-4: 250V, Fire resistant, multi core, ethylene propylene rubber insulated, polyvinylchloride sheathed, steel wire braided, common shielded, 4 core cable. 1.0mm^2 conductor cable

However, abbreviations like DY-2 are used for H-DPCY-2.5 and LMYS-4 for L-MPYCYS-4; such abbreviations are adopted for other codes too.

Unquote

14.9 Practical Tips on Wiring

Wiring is not always difficult, but there are some special considerations afloat. Corrosion is a major problem. That's why only marine-grade tinned wire and cables are used. It lasts longer and provides better service in the process. Use a crimping tool rather than solder for connections. A good crimping kit is inexpensive, convenient, and easily replenished with new connectors. When you 'heat shrink' crimped connections, you've made a permanent fix.

Wire size is important, too. Some power loss occurs in virtually every wire - but like plumbing and water pressure, the bigger the carrier, the less the power loss. For electric motors and critical uses (bilge pumps, electronics, navigation lights, etc.) no more than 3% voltage drop at the appliance is suggested. For cabin lights, etc., 10% is acceptable.

Alternating current cables should contain all three current-carrying conductors (*in a single cable*) in order to cancel out heating caused by inductive effects.

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Anchor windlasses are a particular challenge. These motors are much like automobile starters, and use tremendous amounts of current. Follow the manufacturer's recommendations on wire sizes completely! Don't use welding cables!

Cables for areas like the galley are prone to damage by fumes, varying temperatures, water vapour and grime. The sheaths of such cables must be heat, oil and chemical resistant and also flame retardant (HOFR). The sheath must also be tough and flexible. It is advisable to also ensure that they are braided to prevent any mechanical damage.

Remember, the longer the cable-run and the smaller the size (conductor cross-sectional area), the greater will be the voltage be drop. Conversely, the shorter the cable-run and the larger the wire size (conductor cross-sectional area), the lower will the voltage drop be experienced. So, use the shortest run and the largest diameter (largest wire gauge size) wire you can to reduce the voltage drop.

Where the American Wire gage or AWG is concerned, there are three points to be kept in mind; they are as follows:

1. An increase in 3 gauge numbers (e.g., from Number 10 to Number 7 will result in doubling the area which obviously doubles the weight and halves the DC resistance.
2. An increase in 6 gauge numbers e.g., from Number 10 to Number 4 doubles the diameter.
3. An increase in 10 gauge numbers e.g., from Number 10 to Number 1 will multiply the weight by 10 approximately times and obviously divide the resistance value by 10 times.

14.9.1 Minimising Electromagnetic Interference

A method employed in power cables to minimize radiation and pickup of spurious signals when running adjacent to a receiving antenna is to ensure that shielded / armoured cables are only used.

In earlier times, lead-sheathed cables were used but modern means are being adopted to reduce weight and prevent coupling of unwanted signals with adjacent circuits. It is also advisable to properly ground the armoured braid at regular intervals.

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Run your connectors as high as you can and try to keep electrical connectors away from compasses and sensitive electronic components (such as electronic compass sensors). If you can't avoid it, use twisted pair conductors within three feet of these devices. This avoids the creation of a magnetic field that normally arises from current flow.

We know that reducing electromagnetic interference means aiding electromagnetic compatibility (Refer Chapter 6). Colour coding of course will enhance the value of your vessel when the time comes to sell (and survey) it; it also makes troubleshooting much easier. It is also necessary to ensure that power and signal conductors cross each other at 90^0 if they ever have to...

14.9.2 Simple Daily-Use Terms Related To Cables

14.9.2.1 Cable Tags

Embossed metal tags are used to identify cables throughout the vessel. The tags are located at the distribution panel and the component. Tags are also attached to the cables where penetration of the bulkhead is necessary.

The first part of tag code indicates the type of circuit. In many cases, the cores are also numbered and they correspond to those given in the manuals.

14.9.2.2 Distribution Cables

These cables are used for power distribution up to the rated voltage and current of the cable. Low-voltage (600-volts) cables are generally found on ships for this purpose. They are used for most electrical connections.

14.9.2.3 Control Cables

These are multiple parallel conductor multi-coloured cables used for:

- Control circuits where an electrical signal energizes a magnetic control device to physically open or close the main contacts of a motor. The control cable does not carry the motor's operating current, but only the current used in energizing the coil of the magnetic control device (found in switchboards too).
- Indicating circuits in meters and other audio and visual indicating apparatus.
- Communication, electronic, and other similar circuits.

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14.9.2.4 *Signal Cables*

Signal cables of twisted pairs of conductor cables are used for signal transmission. Each twisted pair of conductors will have a shield to prevent interference. They may be single-cored, screened, co-axial cables too.

14.9.3 *Portable Cords*

Portable cords are used for the temporary connection of portable appliances. They are not to be used for fixed wiring.

14.9.4 *Other Important Points to Bear in Mind When Working on Your Electrical System*

※ All marine electrical equipment must have a breaker or fuse to protect the wiring as well as the product. Don't use breakers or fuses larger than those recommended by the manufacturer, or you may find yourself with 'fried' equipment.

※ Don't tap into other wires, no matter how tempting! Go directly to a terminal block and circuit breaker, as well as directly to a grounding bus.

※ Turn off all power before starting any work.

Maintaining good "grounds" is critical. Avoid unnecessary stray current.

14.9.5 *Determining a Cable's Reaction to Flames*

One method adopted is that a standard 4 feet length of cable is held vertically and burnt by a flame of known strength;

(a) If the flame travels the full length the cable is graded as "flame extending", (not in common use).

(b) If the flame is extinguished before it reaches the top end, it is classified as "flame retardant".

(c) If a cable is graded as flame retardant it must be able to resist the flame, and also after cooling be able to withstand an a.c voltage of twice the rated voltage for one minute.

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14.10 Relevant Rules

14.10.1 Relevant SOLAS Regulations (Chapter II–1)

Part D – Electrical Installations – Regulation 45 – Precautions against shock, fire and other hazards of electrical origin

14.10.2 Summary of SOLAS Regulations

1) All electric cables and wiring external to equipment shall be at least of a flame-retardant type and shall be so installed as not to impair their original flame-retarding properties; the use of special types of cables such as radio frequency cables, which do not comply to the above specifications may be permitted.

2) Cables and wiring serving essential or emergency power, lighting, internal communications or signals shall so far as practicable be routed clear of galleys, laundries, machinery spaces of category A and their casings and other high fire risk areas.

3) Cables connecting fire pumps to the emergency switchboard shall be of a fire–resistant type where they pass through high fire risk areas. Where practicable all such cables should be run in such a manner as to preclude their being rendered unserviceable by heating of the bulkheads that may be caused by a fire in an adjacent space. Thus cables should not be laid behind thermal insulation of bulkheads, etc.

4) Cables and wiring shall be installed and supported in such a manner as to avoid chafing or other damage.

5) Terminations and joints in all conductors shall be so made as to retain the original electrical, mechanical, flame-retarding and, where necessary, fire-resisting properties of the cable.

6) All cables on tankers must be either lead-alloy sheathed and armoured, mineral-insulated and copper-sheathed (the ends must be sheathed to prevent moisture being absorbed by the hygroscopic insulation material) or non-mineral impervious-sheathed and wire-braided so long as they are laid in a pipe (the curved surface area of the wire must be less than 30% of pipe bore so as to prevent overheating).

7) Glands fitted to bulkheads must allow for expansion and be weather-tight, water-tight bulkheads should only be penetrated by a suitable gland.

8) Cables should be laid away from hot surfaces.

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9) Cables installed in locations exposed to damp or wet situations, in machinery compartments, refrigerated spaces or exposed to any harmful vapours including those from oil, are to have the conductor insulating material enclosed in an impervious sheath of material appropriate to the expected ambient temperatures. Cable sheathing, unless galvanised, should have a rust-preventative coating.

10) Metal casings should be adequately rust-protected and earthed. PVC conduits must not be used in fridge spaces or on deck unless specially approved as liable to breakdown in cold weather conditions.

Find the Answers

1) For a power supply voltage of 440V, a cable is designated a value – 600/1000; this means ________.

2) The resistivity of silver is ________ at 20°C.

3) The resistivity of copper is ________ at 20°C.

4) The current rating of a cable is ________ (complete this sentence).

5) MICC means ________.

6) The voltage drop from a main switchboard to an appliance must be less than________.

7) A cable is used in stranded form to ensure ________.

8) The current rating of a cable is ________.

9) Selection of cables for installations is based on ________.

10) Write short notes on: (a) Conductors (b) Current Rating (c) temperature co-efficient

11) How are cables tested periodically?

12) List the common configuration of cabling in power distribution of 3 phase supply.

13) What are the type of cables suitable for use in wet or damp locations?

14) List the identification scheme employed in cabling systems.

15) State safe method of inspection of cables and connectors.

16) List a method employed in power cables to minimize radiation and pickup of spurious signals when running adjacent to a receiving antenna.