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5–11, 29–36, 37–53

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Chapter 1

Electrical Distribution.

1.1 Power Distribution

The function of a ship's electrical distribution system is to safely convey electrical power to every item of equipment connected to it. The most obvious element in the system is the main switchboard. The main board supplies bulk power to motor starter groups (often part of the main board), section boards and distribution boards. Transformers interconnect the HV and LV distribution sections of the system. Circuit breakers and fuses strategically placed troughout the system automatically disconnects a faulty circuit within the network. The main switchboard is placed in the engine controlroom and from there engineroom staf monitor and control the generation and distribution of electrical power. It is very important that every engineer has a profound knowledge of the electrical distribution of the ship's power. The only way to aquire this knowledge is to study the ship's power diagrams. Almost all oceangoing ships have an A.C. distribution system in preference to a direct current D.C. system. Usally a ship's electrical distribution scheme follows shore pratice. This allows normal industrial equipment to be used after being adapted and certified where and if necessary, so it can withstand the conditions on board of a ship (e.g. vibration, freezing and tropical temperatures, humidity, the salty atmosphere, etc. encountered in various parts of the ship). Most ships have a 3-phase A.C., 3-wire, 440V insulated-neutral system. This means that the neutral point of star connected-generators is not earthed to the ship's hull. Ship's with very large electrical loads have generators operating at high voltages (HV) of 3.3KV, 6.6KV, and even 11KV. By using these high voltages we can reduce the size of cables and equipment. High voltage systems are becoming more common as ship size and complexity increase. The frequency of an A.C. power system can be 50 Hz or 60Hz. The

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most common power frequency adopted for use on board ships is 60Hz. This higher frequency means that generators and motors run at higher speeds with a consequent reduction in size for a given power rating. Lighting and low power single-phase supplies usually operate at 220 V. This voltage is derived from a step down transformer connected to the 440 V system.

1.2 Grounding systems in shipboard electrical networks.

In electrical engineeering, the ground means reference in electrical circuits from which other voltages are measured. The earth point means a solid connection to the earth, which due to its massive section and mass has almost no resistance for electrical current. If the reference for your voltage mea-

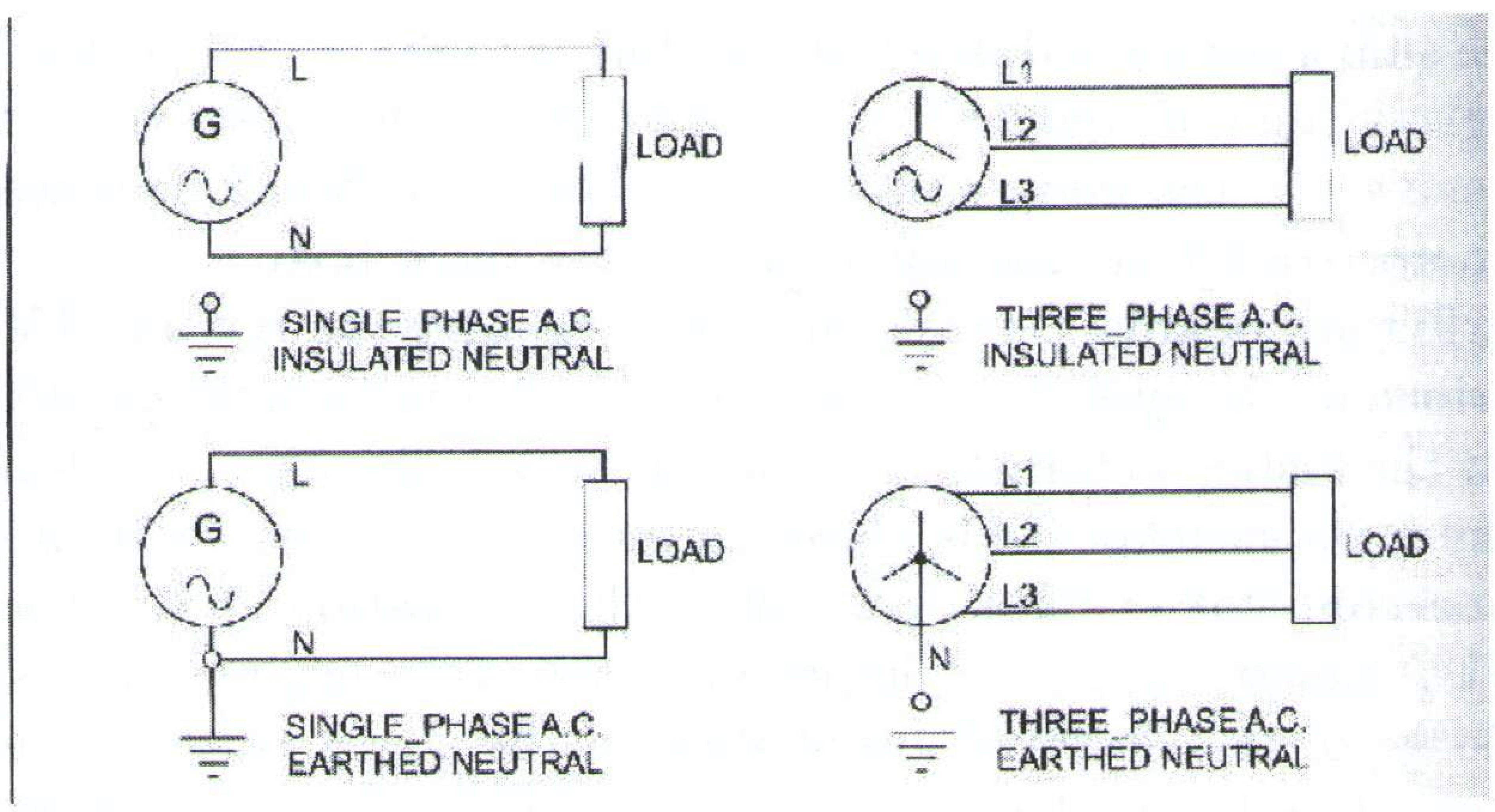

Figure 1.1: Insulated and earthed neutral systems.

surements is the earth the earth becomes your ground. By absense of the earth on board of a ship, the ship's hull can be used as a substitute for the earth. Depending on the construction of the electrical networks they may ar may not be connected to earth potential. In general we can have solidly grounded, reactance grounded, resistance grounded and isolated networks. In isolated networks there is the challenge to detect earth faults. Ships distribution systems are typically isolated in low voltage systems (¿1000V AC) and high resistance grounded in high voltage systems. High resistance grounding ensures the trip action in case of an earth fault and prevents short circuit faults in the network. High resistance grounding can therefore not guarantee continuity of service.

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Characteristics	Solid	Isolated	High resistance
High ground fault current	**Yes**	No	No
Possibility of multi-phase fault	**High**	Low	Low
Arc flash hazard risk level	**High**	Very low	Very low
Relative safety level (equipment and personnel)	**Low**	High	Very high
Fault location	**Yes**	No	Yes
Continuity of service	**No**	Yes	Yes
Possible selective tripping	**Yes**	No	Yes
Alarming without tripping	**No**	Yes	Yes
Cable insulation level (IEC 60502-2)	**1.0**	1.73	1.73
Surge protection level	**1.0**	1.73	1.73
Transient overvoltage level	**2.5x**	6x	2.7x

1.3 Electrical faults

There are three different kind of electrical faults.

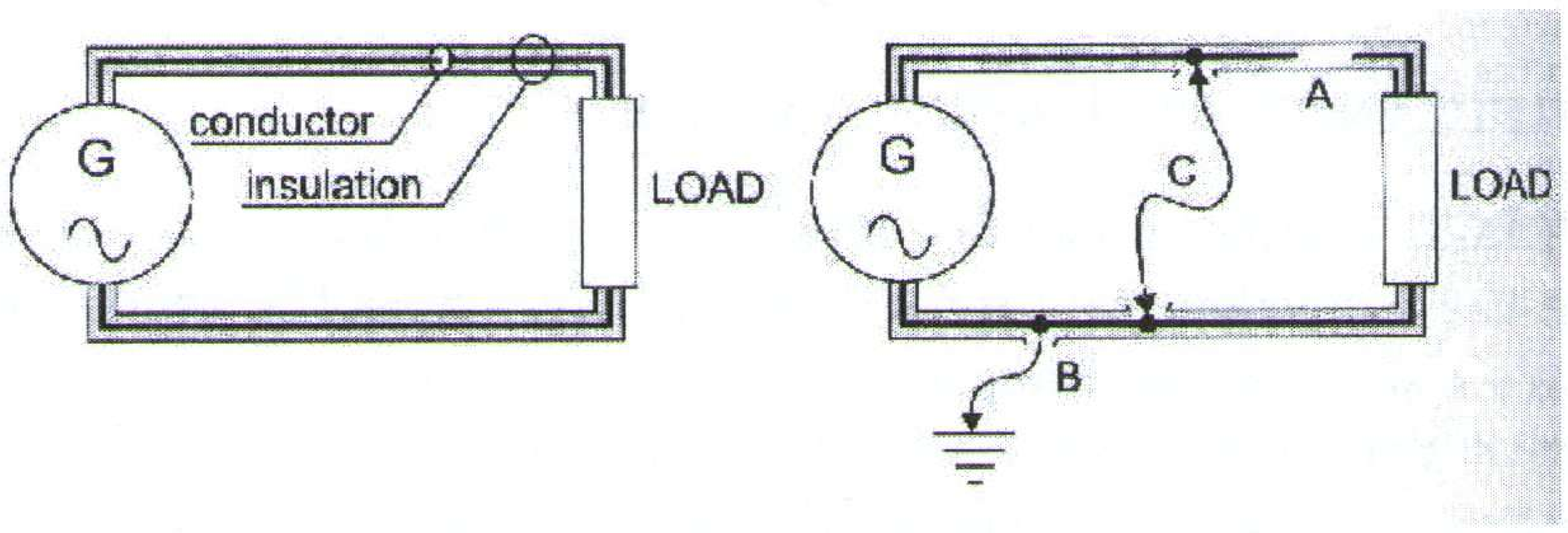

Figure 1.2: circuit faults

1.3.1 Earth fault

An earth fault is caused by loss of insulation allowing the current to flow to earth potential. Causes of earth faults are typically breakdown or wear of insulation. The majority of earth faults occur within electrical equipment due to an insulation failure or a loose wire, wich allows a live conductor to come into contact with its earthed metal enclosure.
To protect against the dangers of electric shock and fire that may result from earth faults, the metal enclosures and other non-current carrying metal parts of electrical equipment must be earthed. The earthing connector connects the metal enclosure to earth (the schip's hull) to prevent it from attaining a

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dangerous voltage with respect to earth. Such earth bonding of equipment ensures that its voltage in reference to earth always remains at zero.

1.3.2 Open circuit fault

An open circuit fault occurs when a phase conductor is completely or even partialy interupted. Causes of open circuit faults are bad connections or a break in the wire. Open circuit faults when intermittent can cause flashes. Open circuit faults when not completely open (bad connection) can cause a lot of heat and are a fire hazzard. Open circuits in three phase circuits can cause motors to run on only two phases and create a motor overload.

Short circuit fault

Short circuit faults occurs where two different phase conductors are connected together. This can be caused by double break loss of insulation, human error or another abnormal situation. A large amount of current is released in a short circuit, often accompanied by an explosion.

1.3.3 Significance of Earth Faults

If a single earth fault occurs on the live line of an earthed distribution system it would be the equivalent to a schort-circuit fault across the generator trough the schip's hull. The resulting large current would immediatly cause the line protective device (fuse or circuit breaker) to trip out the faulty circuit. The faulted electric equipment would be immediately isolated from the supply and so rendered safe. However, the loss of power supply, could create a hazardous situation, especialy if the equipment was classed essential(ABS part 4 chapter 8 table 1 and 2), e.g. steering gear. The large fault current could also cause arcing damage at the fault location. In contrast a single earth fault occuring on one line of an insulated distribution system will not cause any protective trip to operate and the system would continue to function normally. This is the important point: equipment continues to operate with a single earth fault as it does not provide a closed circuit so no earth fault current will flow. More important is that if a second earth fault occurs on another line of the insulated system, the two faults together would be equivalent to a short- circuit fault (via the ship's hull) and the resulting large current would operate protection devices and cause disconnection of perhaps essential services creating a risk to the safety of the ship.
An insulated distribution system therefore requires two earth faults on two

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different lines to cause an earth fault current to flow.
In contrast, an earthed distribution system requires only one earth fault to cause an earth fault current to flow.
An insulated system is, therefore more effective than an earthed system in maintenance continuity of supply to essential services. Hence its adoption for most marine electrical systems.
Note: Double-pole switches with fuses in both lines are necessary in an insulated single-phase circuit.

1.3.4 An Electric Power System's Reliability

Reliability of an electric system is obtained by sectioning of the distribution system and providing multiple power sources, by providing an emergency power system, subsectioning of the circuits, the choice of the earthing system and the selectivity of the protections.

1.3.5 Sectioning of the distribution system and providing multiple power sources

Providing multiple transformators can protect certain users against particular problems. An example can be computer systems wich are sensitive to harmonics.

1.3.6 Emergency power systems

Two independant high to low voltage power stations, emergency generators, UPS, independant emergency lighting a.o. have to be placed in well protected area's enabling them to function in case of an emergency and or accident.

1.3.7 Sectioning of circuits

Essential equipment can take there power from the main or emergency switchboard. This way a fault wich affects a secondary circuit doesn't influence a circuit with high priority. Sectioning of circuits is done as demanded by *The Rules* and the demands of exploitation, providing at least two power sources for all essential equipment.

1.3.8 Selectivity

If a fault occurs at any point in an electrical distribution circuit, it is essential that it does not interrupt the supply to essential services. This obvious

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requirement leads to the necessity of rapidly isolating the defective section without depriving the other users of electrical energy; this is in fact the principle of selective tripping.
The protective element (circuit breaker or fuses) wich is placed immediately up-stream from the part of the circuit where the fault has occured, and this alone element, must then operate; the other protecting elements must not trip. Conventional selectivity processes (overcurrent and time lag) fullfil these requirements to a more or less satisfactory degree.

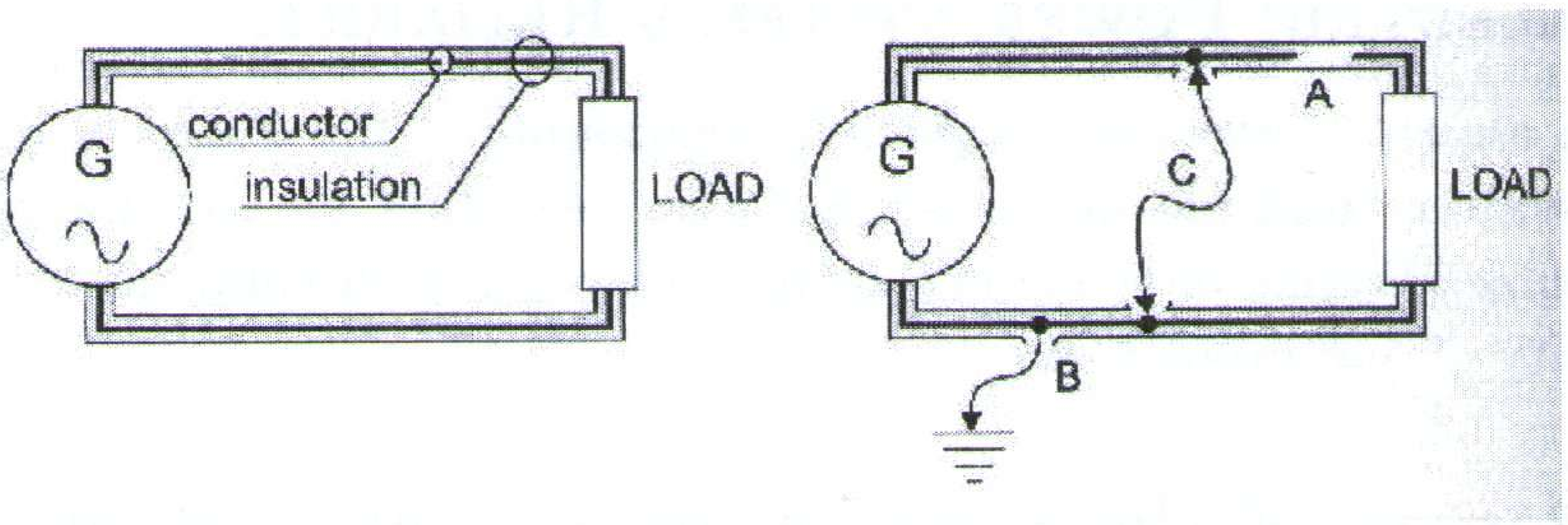

Figure 1.3: circuit faults

1.3.9 Overcurrent Selectivity

This makes use of protective equipment operating instantaneously (rapid circuit breakers or fuses). The selectivity is based on the fact that the short-circuit current decreases with increasing distance from the power source. It is thus especially for low voltages where the connecting impedances are not negligible.

1.3.10 Time lag selectivity

This can make complete selectivity by delaying the tripping of each circuit-breaker for durations all the higher as the circuit-breaker is nearer the source of energy.

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Chapter 2

A Ship's Electrical System.

2.1 Overview

2.2 Generators

In marine applications generators are always synchronous machines. Synchronous machines are excited by direct current. In all but very small generators the rotor is the exiter of the generator. The direct current can be supplied to the rotor from an external exciting device via slip rings (brushed excitation) or via a small AC generator and rectifier on the rotor shaft (brushless excitation). An automatic voltage regulator (AVR) controls de exciting current. The AVR keeps the generators voltage in the set value, regardless of changes in load, temperature and frequency.

2.3 Electric motors

Nowadays the most widely used electric motors in marine applications are 3-phase alternating current asynchronous motors with a squirrel cage rotor.

2.4 Starting devices

A starting device is the general term for a piece of equipment that allows the connection of a consumer to its main power supply. Starting devices can also be used to limit inrush current of a consumer to an acceptable value. An acceptable value is one that does not disturb the proper functioning of the power supply as this would also disturb other consumers on this supply. Limiting the starting current will also limit the starting torque of an electric

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3.3 Cathodic Protection For Ships.

3.3.1 History.

Cathodic protection was succesfully applied even before the science of electrochemistry was developed. It is particular to the shipping industrie to note that Humprey Davey first used cathodic protection on British navale ships in 1824.

3.3.2 A litle electrochemistry

The basis of corrosion in general:

- Hydrogen evolution

$$2H^+ + 2e \longrightarrow H_2 \tag{3.1}$$

- Oxygen reduction

$$O_2 + 2H_2O + 4e \longrightarrow 4OH^- \tag{3.2}$$

- Metal ion reduction

$$M^{3+} + e \longrightarrow M^{2+} \tag{3.3}$$

- Metal deposition

$$M^+ + e \longrightarrow M \tag{3.4}$$

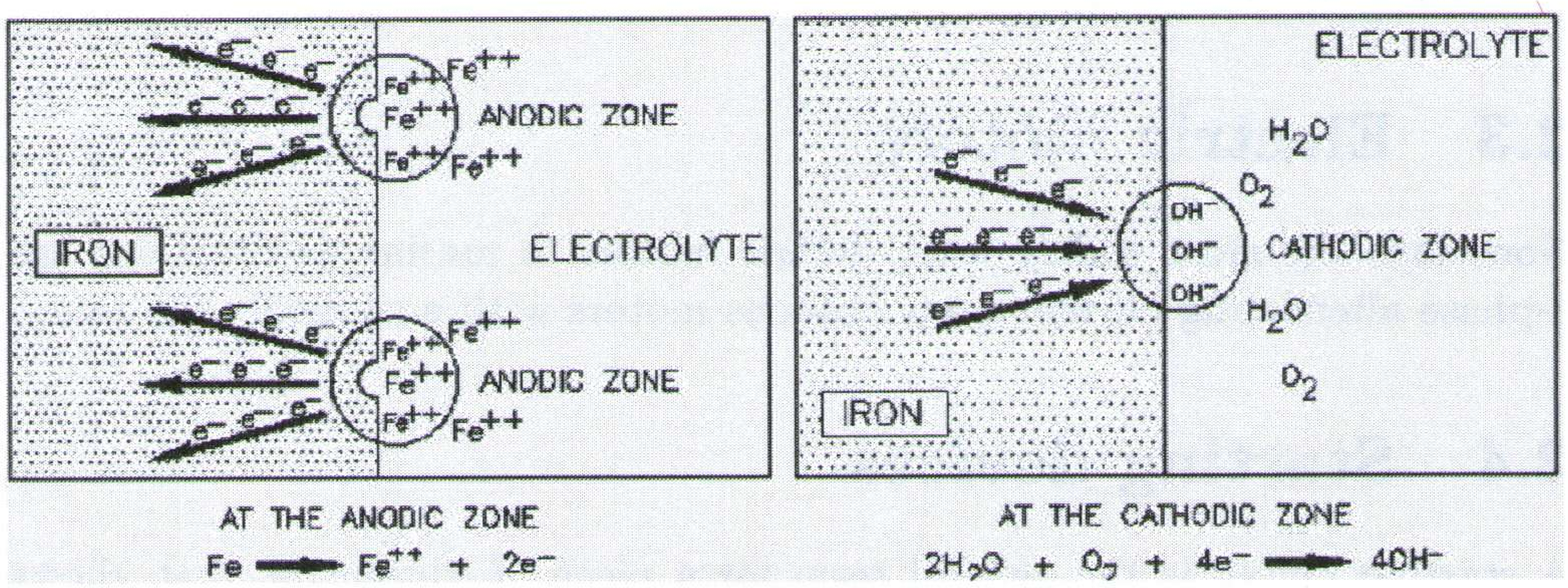

Figure 3.19: anodic reaction and cathodic reaction.

Metal ion reduction and metal deposition are less common reactions. All of the above reactions have one thing in common they use electrons. In

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addition, these reactions can largely be used to interpret most corrossion problems.
Consider what happens when iron is immersed in seawater that is exposed to the atmosphere - corrosion occurs. The anodic reaction is:

$$Fe \longrightarrow Fe^{2+} + 2e \tag{3.5}$$

Since the seawater is exposed to the atmosphere it contains dissolved oxygen and is nearly neutral, where the cathodic reaction is:(1.2)

$$O_2 + 2H_2O + 4e \longrightarrow 4OH^-$$

Keeping in mind that sodium and chloride ions do not perticipate in the reaction, the overall reaction is obtained by adding (1.2) and (1.5):

$$2Fe + 2H_2O + O_2 \longrightarrow 2Fe^2 + 4OH \longrightarrow 2Fe(OH)_2 \downarrow \tag{3.6}$$

In an oxygenated environment ferrous hydroxyde that precipitates from solution is unstable and further oxidises to the ferritic salt:

$$2Fe(OH)_2 + 2H_2O + \frac{1}{2}O_2 \longrightarrow 2Fe(OH)_3 \tag{3.7}$$

The final product is known as rust.

3.3.3 What is cathodic protection.

Cathodic protection is achieved by supplying electrons to the metal structure to be protected. The addition of electrons to the structure will tend to suppress metal dissolution and increase the rate of oxygen evolution.
In conventional electrical theory current is considered to flow from (+) to (-) and as a result a stucture is protected if current enters it from the electrolyte (seawater). Conversely accelerated corrosion occurs if current passes from the metal to the electrolyte (seawater). Cathodic protection of a structure can be achieved in two ways, namely:

- by application of an external power supply (impressed current)
- by application of an appropriate galvanic system (sacrificial anode)

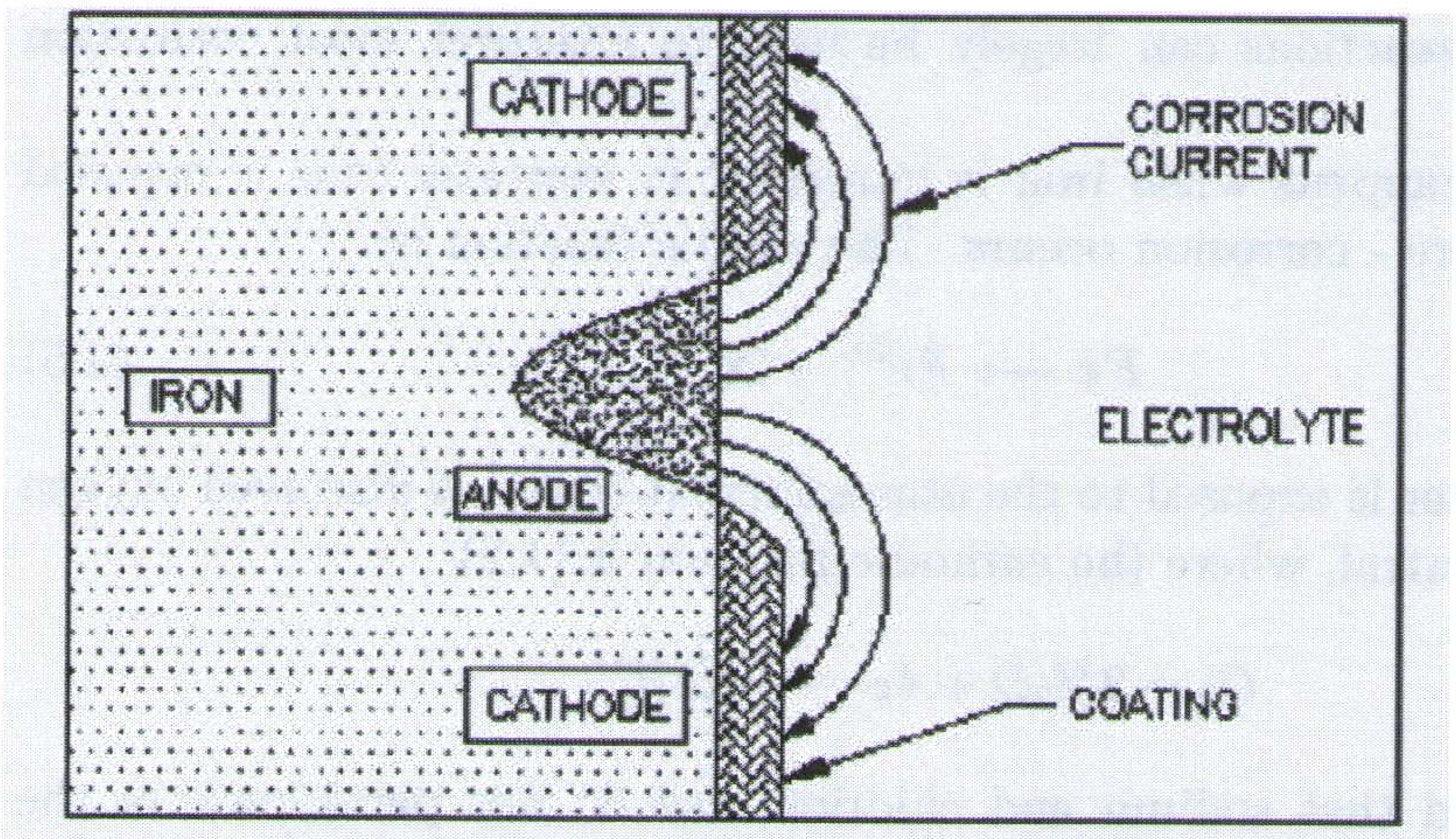

Figure 3.20: No protection at all.

3.3.4 Cathodic protection in human language

When two dissimilar metals are immersed in sea water and connected together a current will flow through the water from the more reactive (anodic) to the less reactive (cathodic). Due to the electrochemical action the anodic metal will tend to go into solution (ie corrode) whilst the cathodic metal will remain stable (ie protected by the anodic metal).
Similar reactions occur at numerous places on a steel structure due to the potential difference between areas (anodic cathodic) for a veriety of reasons eg lack of chemical uniformity of the steel, breaks in paint coating. The reaction also occurs in the presence of a different (coupled) metal (eg welds; brackets). Variations in sea water flow and aeration can also give rise to potential differences on a plate surface causing current flow which will result in corrosion.
The principle of cathodic protection is to swamp these localised corrosion currents by applying an opposing current from an external source. (Either the sacrificial anode system or impressed current system may be used). For the structure to be adequate protected the potential of all areas of metal must be depressed to a value more negative than any natural anodic area. This potential may be measured against a standard reference electrode in sea water.
The current density required to protect a ship's hull will depend on a number of variables such as, speed of ship, condition of outer bottom paint, salinity, temperature of sea water etc. Currrent density requirements are based on the following assumptions:

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- About 32 mA/m^2 is needed for adequate protection of painted steel.
- About 110 mA/m^2 is needed for adequate protection of unpainted steel.
- About 150 mA/m^2 is needed for adequate protection of non-ferrous metal.
- About 540 mA/m^2 is needed for adequate protection of propellers.

To determine wether complete protection of the underwater structure has been achieved it is necessary to measure the potential difference against a reference electrode. For adequate protection the painted steel must have a potential of 750 to 850mV negative with respect to a silver/silverchloride reference electrode. Below 750mV the risk of corrosion is increased. Above 850mV there is a danger of damage to paint coating caused by hydrogen evolution from protected surface.
To ensure protection of rudders and stabilizer fins it is necessary to provide each with a low resistance connection to the hull. This bonding is achieved by means of a flexible cable fitted between rudder (or stabiliser) stock and a convenient point on the hull.
The propeller shafting may require bonding to the hull.

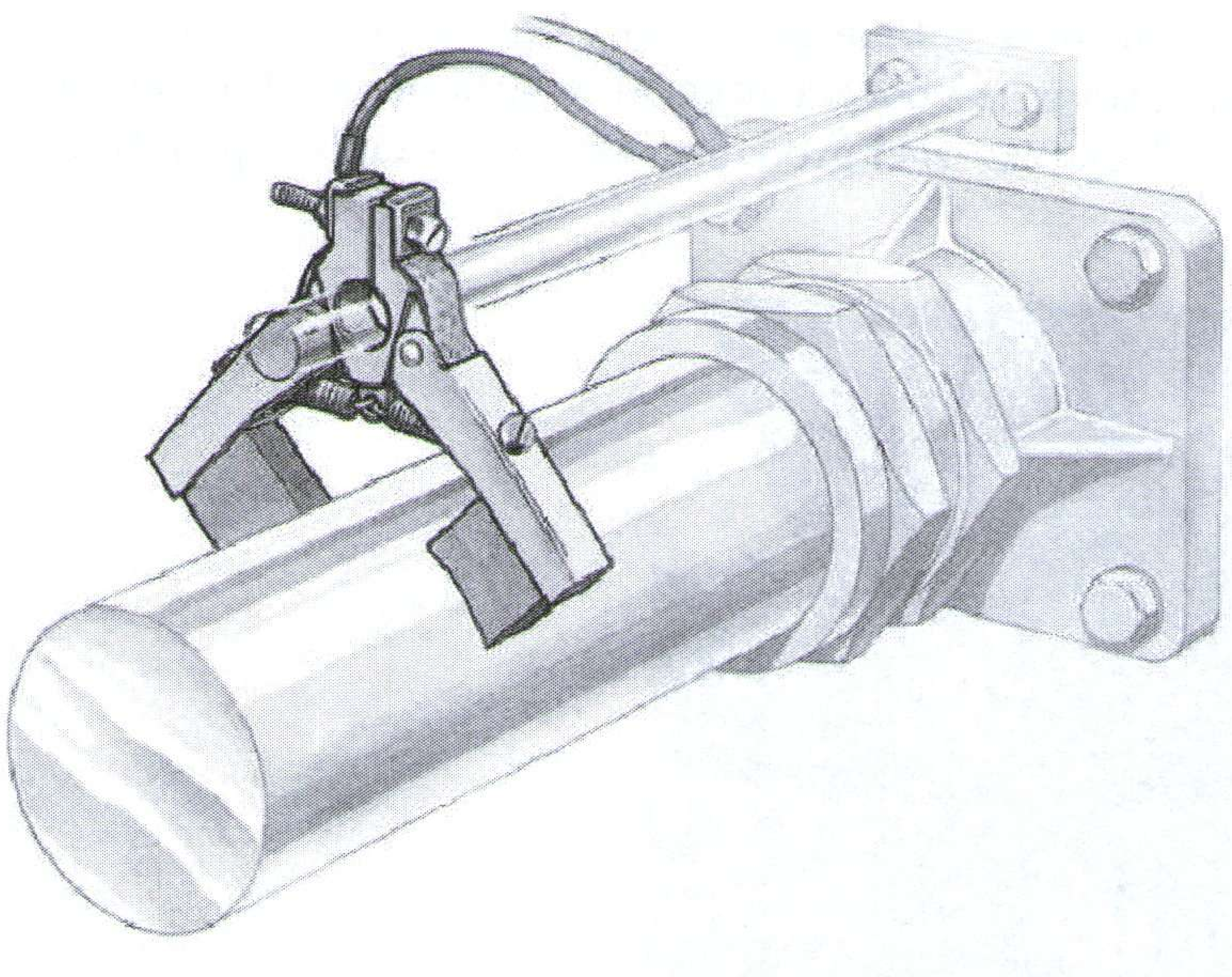

Figure 3.21: Propeller shafting may require bonding to the hull.

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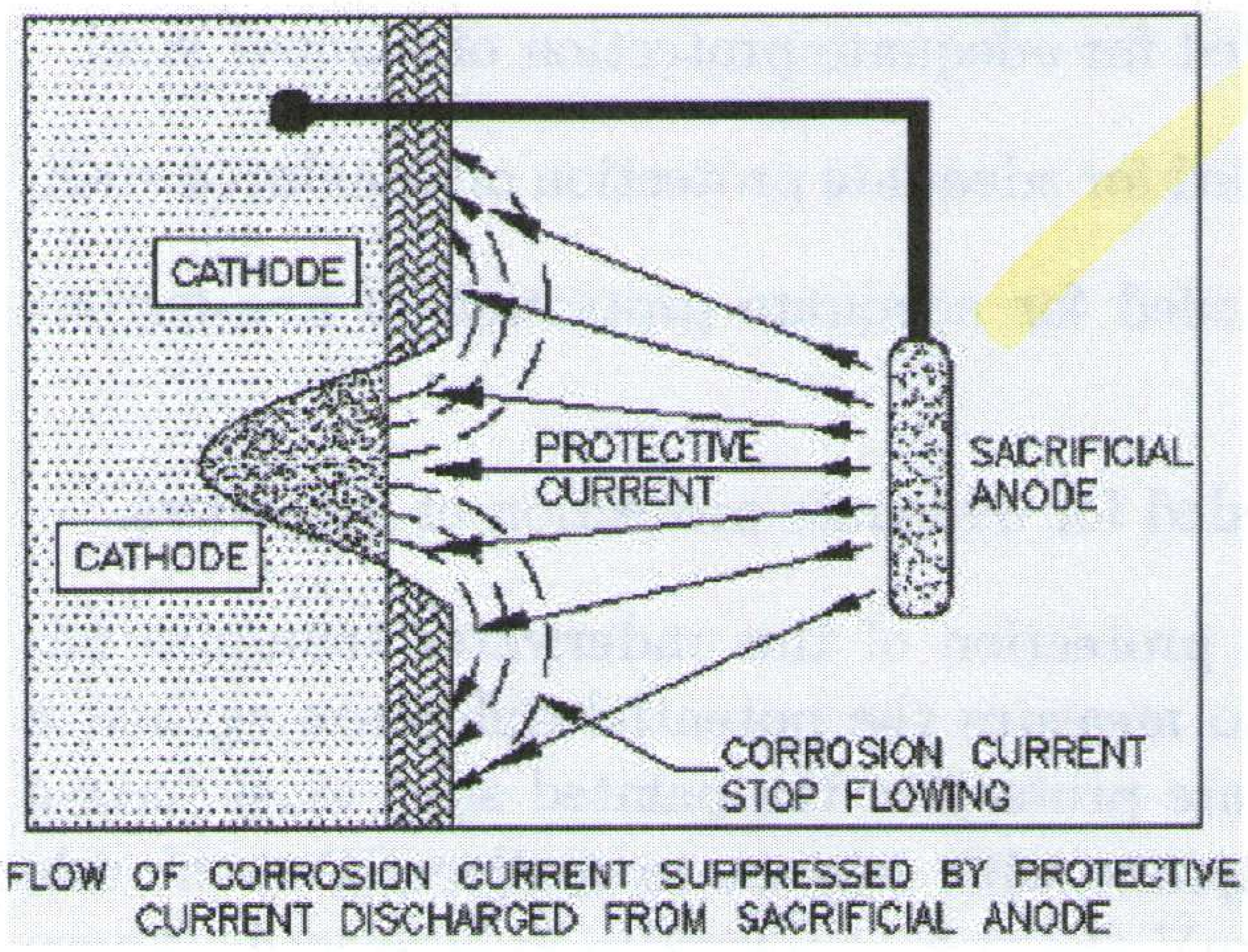

Figure 3.22: Sacrificial cathode system.

Sacrificial anode cathodic protection

?? shows sacrificial cathode protection applied to a ship's hull. Galvanic coupling is shown between the ship's hull and a zinc anode. The zinc is anodic (+) with respect to the steel and corrodes preferentially when coupled with steel.
Corrosion takes place all over submerged steel. But, if the steel has been coated, the corrosion attack is concentrated at points of paint breakdown and takes the form of deep pits weld grooving ore even complete penetration of the plate.

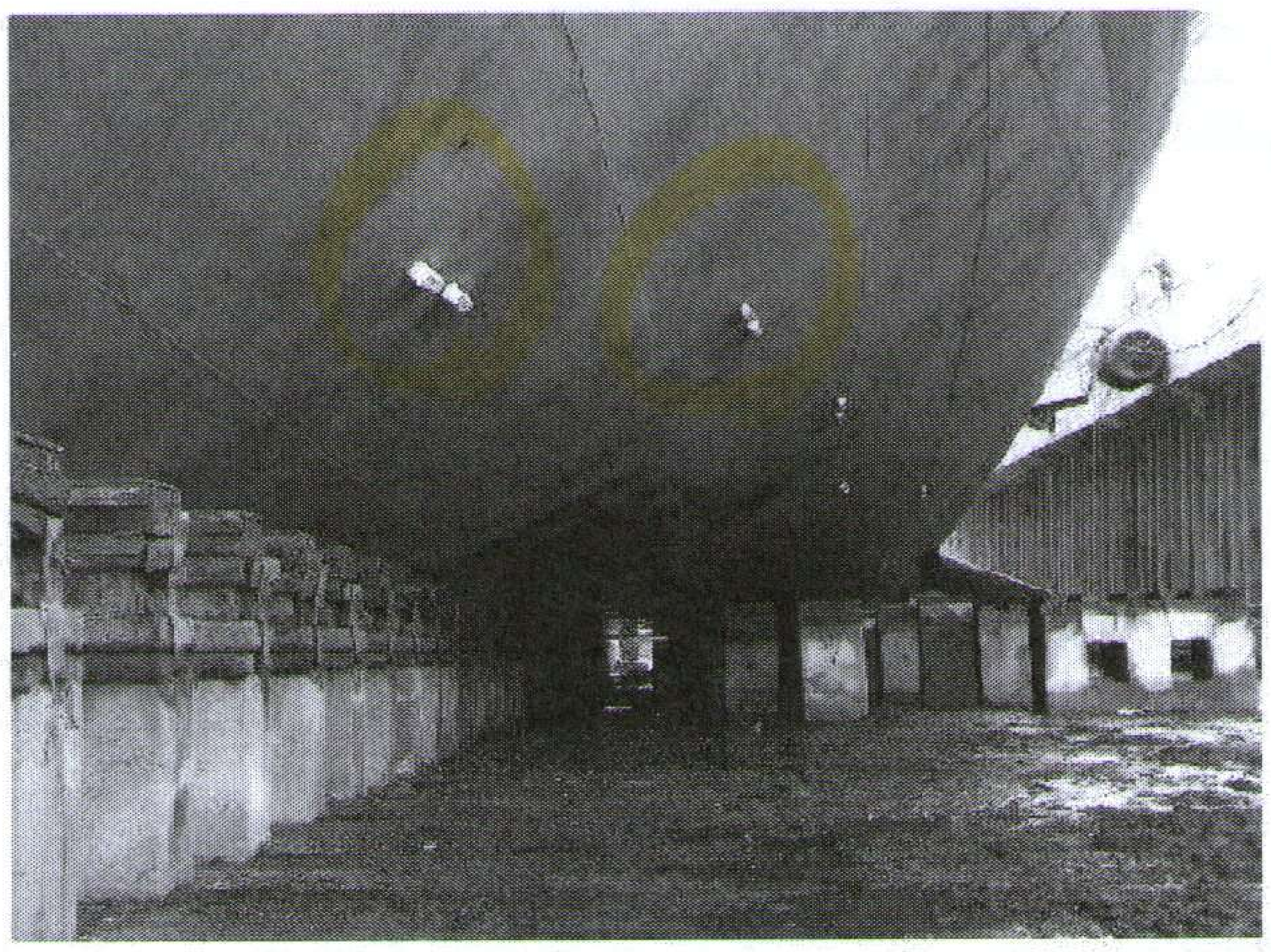

Figure 3.23: sacrificial anodes on a ship's hull.

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Impressed current protection system.

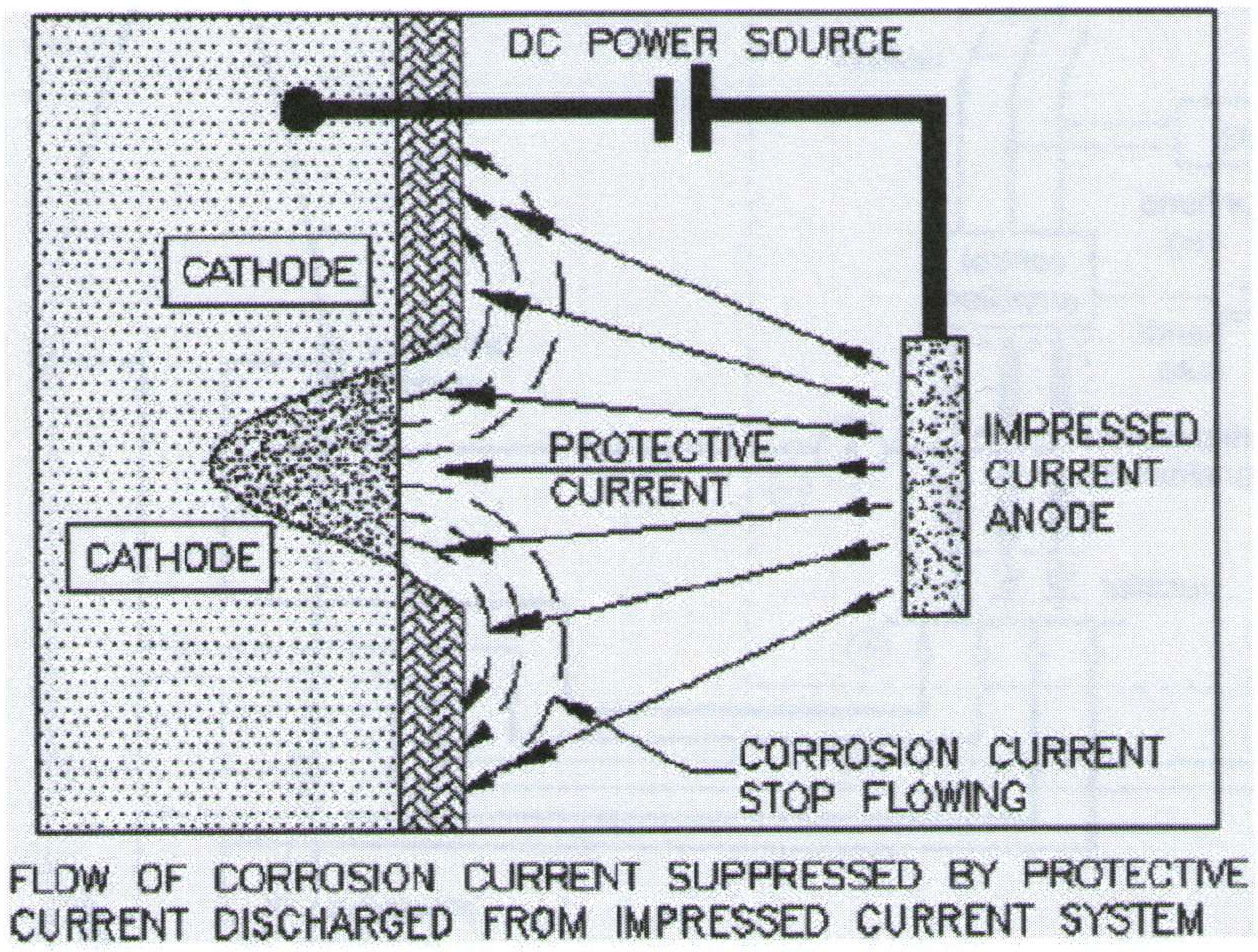

Figure 3.24: Impressed current system.

Impressed current cathode protection systems fitted in ship's consist of a number of anodes (lead or platinised titanium) fitted to the hull at selected places below the waterline, and control equipment wich automatically regulates the anode current to the required value. Direct current is supplied to the anodes, after transformation and rectification, from the ship's 440 V 60 Hz 3-phase a.c. distribution system. The control equipment comprises reference electrodes, an amplifier assembly and one or more transformer rectifier units.

Current control is usually regulated by electronic thyrister controllers and the diagram in the next fig. outlines a typical scheme.

The control equipment automatically monitors the size of anode current required wich will vary with conditions as there are; sea water temperature, ship's speed, condition of the coating and salinity. Typical anode current density range from 10 mA/m^2 to 40 mA/m^2 for the protection of painted surfaces and 100 to 150 mA/m^2 for bare steel surfaces. The total impressed current for a hull in good condition may be as low as 20A. Maximum controller outputs may be up to about 600 A at 8 V.

Measurements should regularly be logged together with the ship's operating conditions as there are; sea water temperature and salinity, draught, speed at sea or berthed.

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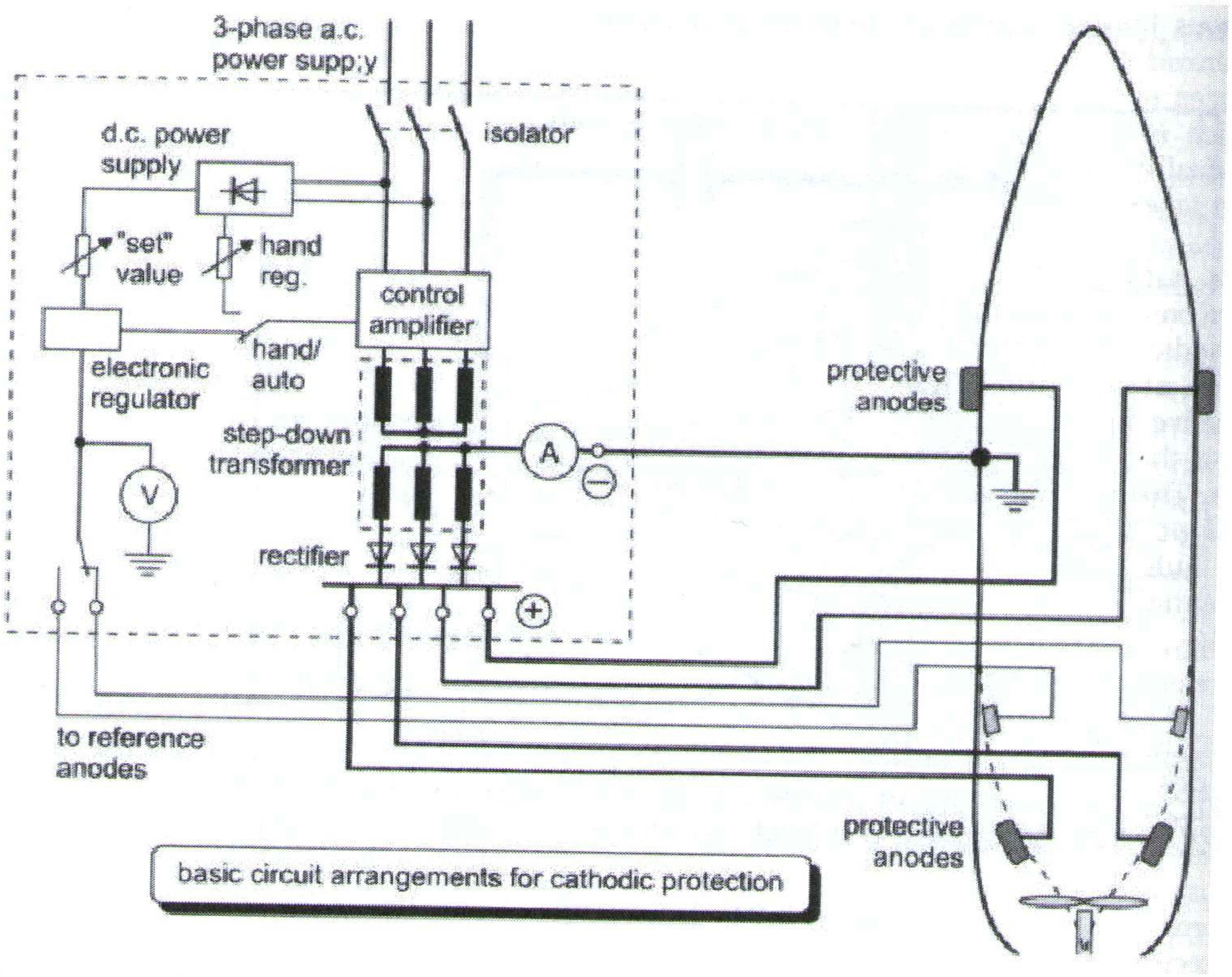

Figure 3.25: Ships anodes and impressed current control system.

When the ship is stopped at sea, voltage reading can be taken between a reference anode and the ship's hull. Check the manufacturer's instructions regarding the manipulation of the reference electrode.

Safety

It is always wise to turn of the impressed current cathodic protection system when divers have to work in the vincinity of the hull.

applications

Cathodic protection on ship's is not only used to protect the outer hull, we can find sacrificial anodes in seawater systems, bun coolers, fresh water heaters, coolers and even in ballast tanks.

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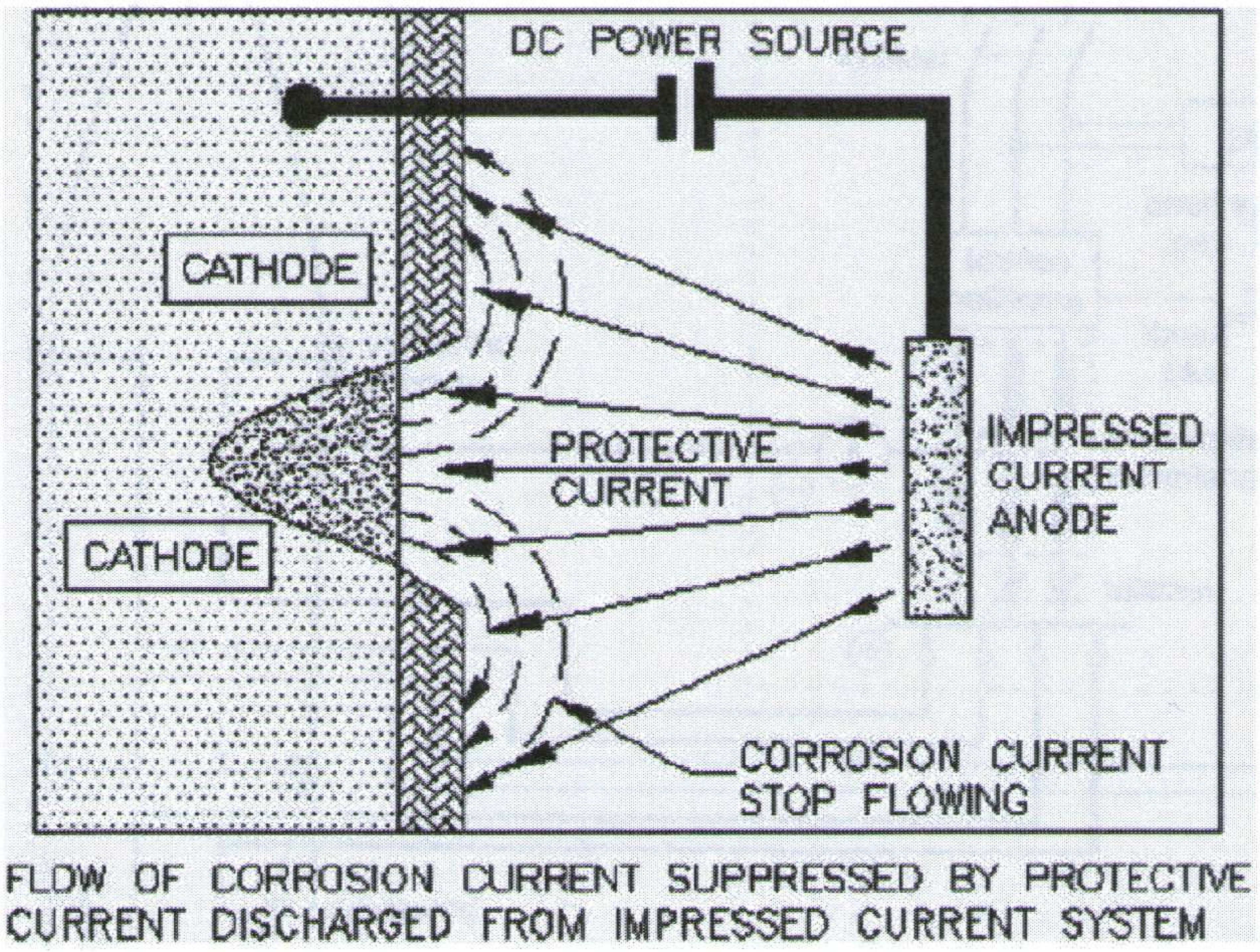
Impressed current protection system.



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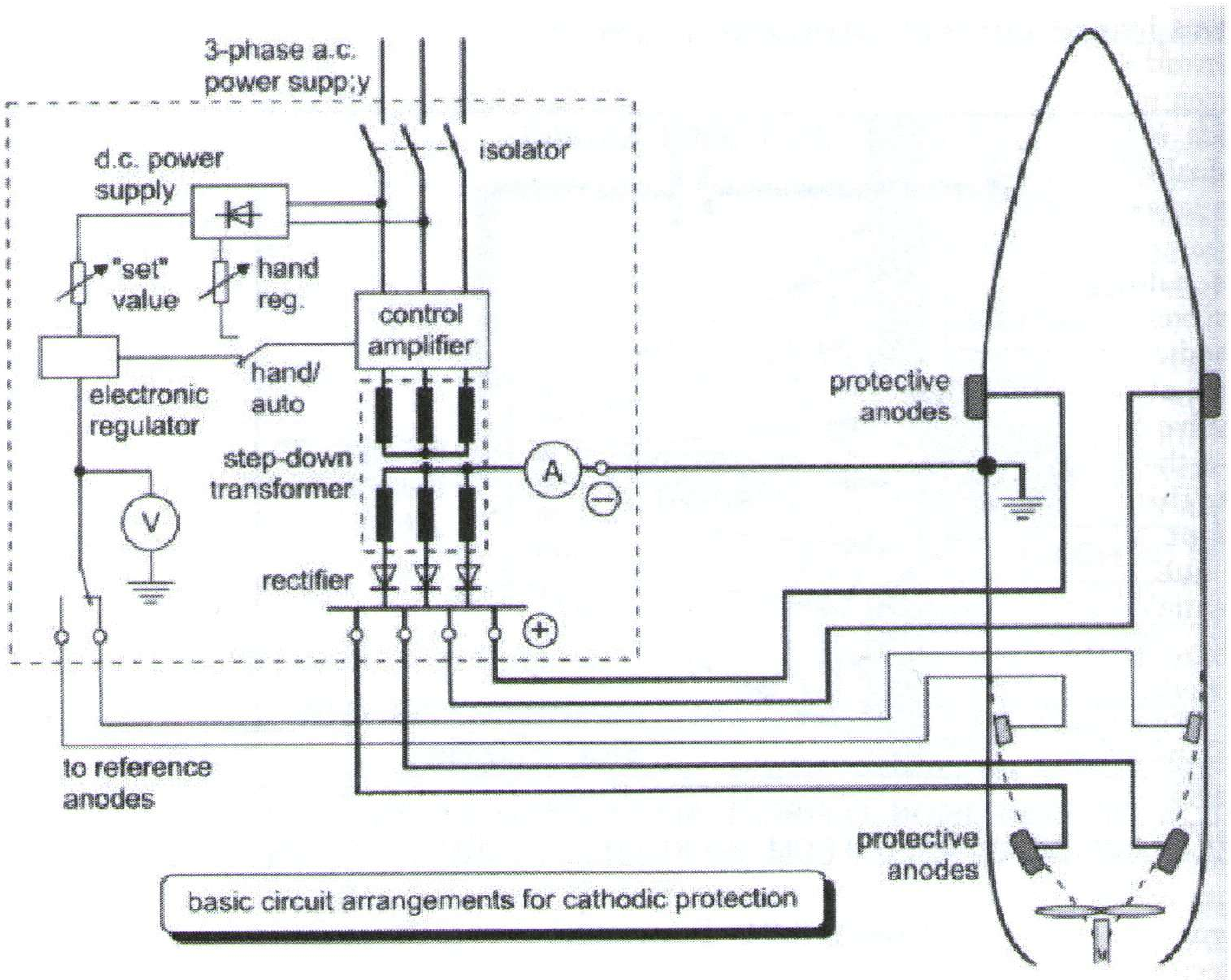

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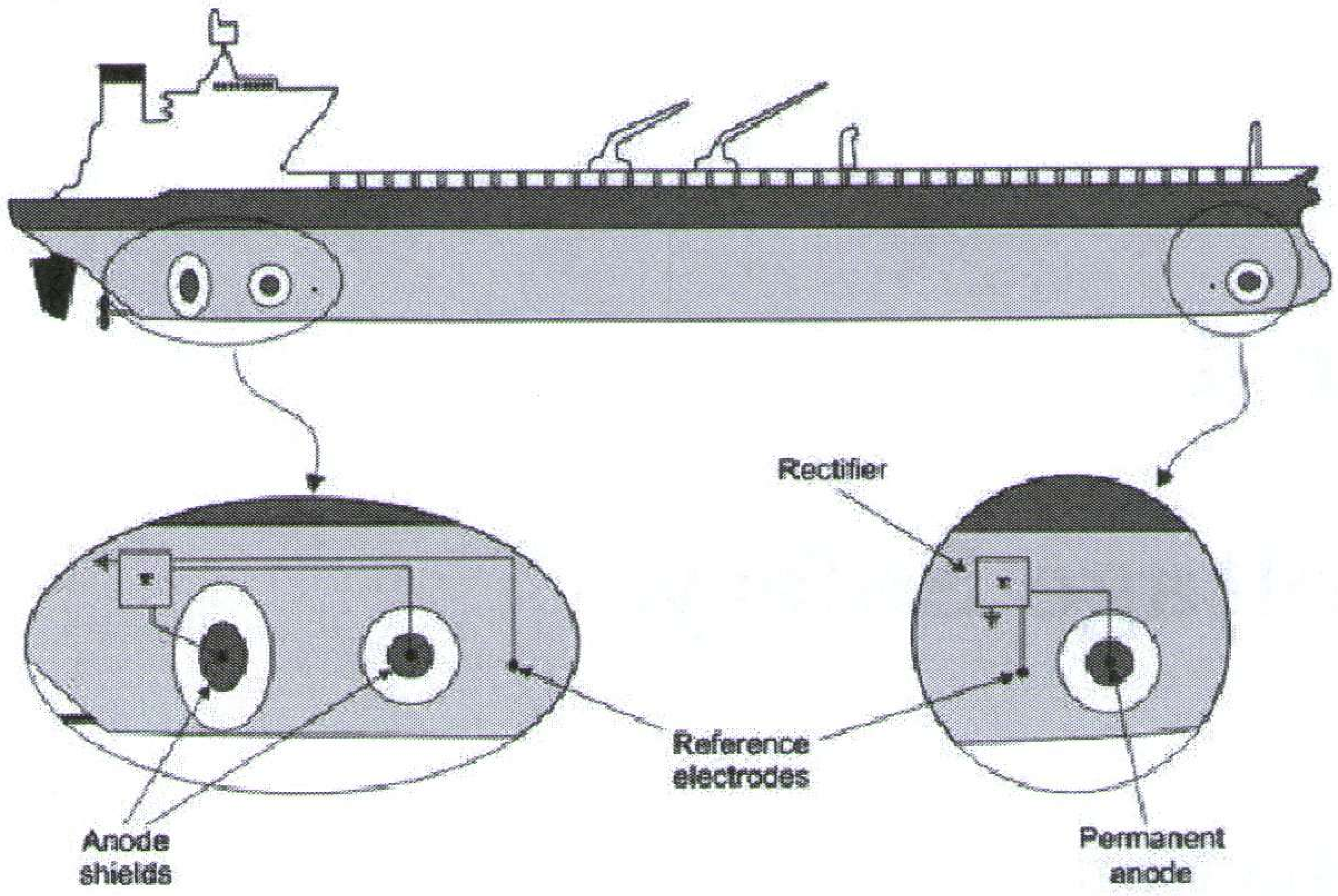
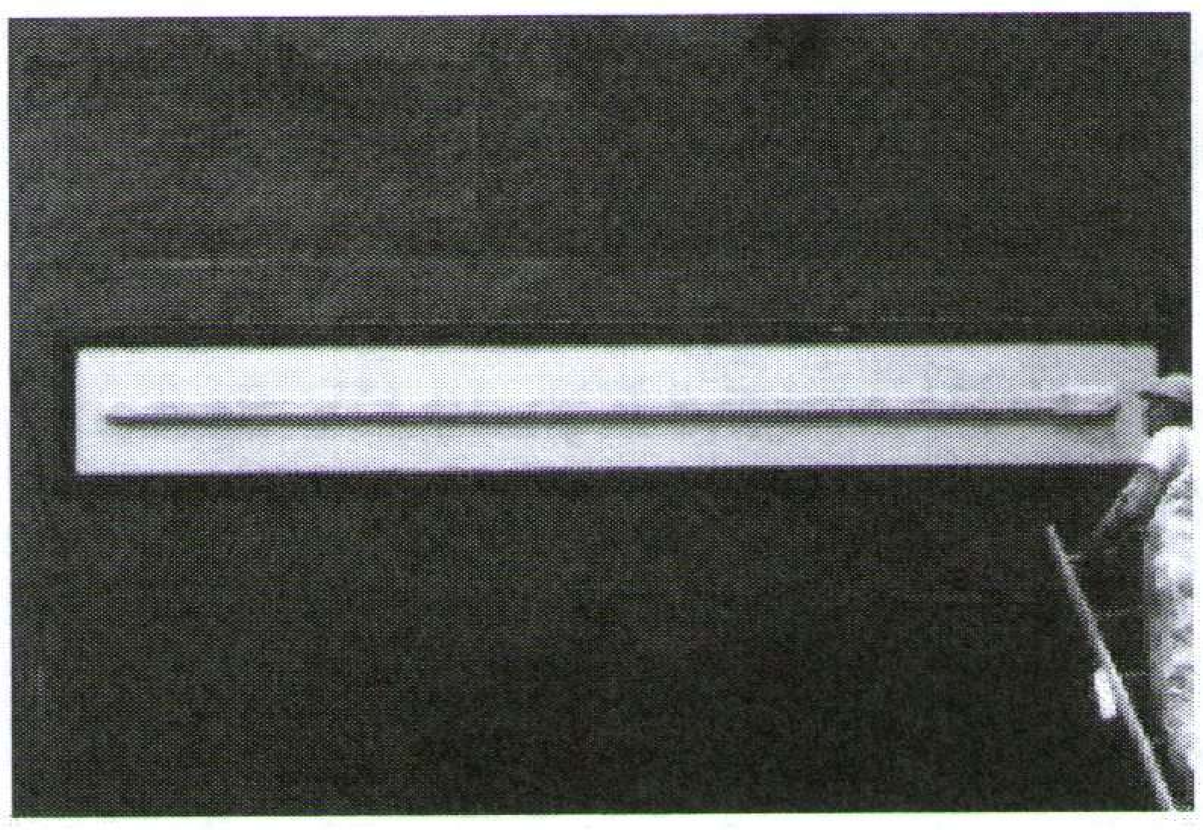


Figure 3.26: Impressed current system on a tanker.



Typical Hull Mounted ICCP Anode - Primary Dielectric Shield (Courtesy Deepwater)

Figure 3.27: Impressed current anode.

Figure 3.28: Sacrificial anodes in a ballast tank.

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Chapter 4

High Voltage Safety.

4.1 introduction

As the demand for electrical power increases on vessels the supply current ratings becomes too high at the usual 3phase 440 V.
To reduce the size of both steady state and fault current levels it is necessary to specify a higher power system voltage at the higher power ratings.
In marine practice voltages below 1000 V are considered LV (low voltage). HV (high voltage) is any voltage above 1 KV.
Typical marine HV system voltages are 3.3 KV and 6.6 KV. 10 KV Systems are emerging with the still increasing power demands. By generating electrical power at 6.6 KV instead of 440 V the distribution and switching of power levels above about 6 MW becomes more practicable and manageable.
By generating electrical power at 440V from 3 x1 megawatt, 0.8 power factor diesel generator sets, each generatorr main cable and circuit breaker has to handle a full load current of:

$$Power(watt) = \sqrt{3} \times Voltage(volt) \times Current(amp) \times Powerfactor(cos\phi)$$

$$P = \sqrt{3} \times U \times I \times cos\phi$$

Which returns a current of:

$$\frac{1000000}{\sqrt{3} \times 440 \times 0.8} = 1640amps$$

If a short circuit fault occures on one of the outgoing feeder cables from the

main switchboard the feeder circuit breaker would need to be rated to break a prospective fault current of about 65 KA.
For the same system at 6.6 KV the full-load current of each generator is:

$$\frac{1000000}{\sqrt{3}} \times 6600 \times 0.8 = 109A$$

Also, the fault level at the main board would be as low as 4.5 KA.
In addition to the above, the power loss in an HV installation may be calculated by:

$$P = I^2 \times R$$

Power loss is reduced if the voltage is stepped up and thus it is always efficient to transmit power at a higher voltage. Thes are a few mayor reasons why vessels have shifted towards high voltage systems.

4.2 Training

The 2010 Manilla Amendments to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) introduced revised competence standards for the engine department, including a new additional requirement for engine personnel to have undergone training and education in HV systems.

The Mannila Amendments entered into force on 1 January 2012. Seafarers who started their training before 1 july 2013 may continue to meet the previous training requirements until january 2017. However, from 1 january 2017, engineering personnel wil have to demonstrate that they meet the new HV requirements. Companies should confirm individual flag state requirements, but it is likely that, when it comes to revalidating their certificate (every 5 year), engineering officers who are unable to provide documentary evidence of previous sea services on ships fitted with HV systems or of having completed an appropriate HV course will have an HV limitation placed on their Certificate of Competency.

Companies will also need to confirm any national requirements for the approval of HV courses, but for engineering personnel at the management level, an approriate course is likely to have to cover as a minimum:

- The functional operational and safety requirements for a marine HV system.

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- Assignement of suitably qualified personnel to carry out maintenance and report of HV switchgear of various types.
- Taking remedial action necessary during faults in a HV system.
- Producing a switching strategy for isolating components of a HV system.
- Selecting suitable apparatus for isolation and testing of HV aquipment.
- Carrying out a switching and isolation procedure on a marine HV-system.
- Performing tests of insulation and resistance on high voltage equipment.

4.3 Definitions

4.3.1 Additional earth

An earth connection applied to apparatus after application of a CME, normally applied at the point of work if not already fitted with CME.

4.3.2 Approved

A type of form sanctioned for use by the DPA/superintendent/senior electrical engineer.

4.3.3 Authorised person (AP)

An authorised person is appropriately trained and appointed in writing by the superintendent/electrical engineer to carry out work as permitted by these rules.

4.3.4 Caution notice

A notice conveying a warning against interference with the apparatus to which it is attached.

4.3.5 Chief engineer

Senior engineer onboard the vessel responsible for all vessel technical operations and maintenance.

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4.3.6 Circuit main earth (CME)

An earth connection applied for the purpose of making apparatus safe to work on before a permit to work or sanction for test is issued and which is nominated on the document.

4.3.7 Competent person

A competent person is appropriately trained and has sufficient technical knowledge or experience to enable him to avoid danger. It is the duty of the authorised person issuing a permit to work to satisfy himself that the persons are competent to carry out the work involved.

4.3.8 Danger notice

A notice calling attention to the danger of approach or interference with the apparatus to which it is attached.

4.3.9 Dead

At or about zero voltage and disconnected from all sources of electrical energy.

4.3.10 Earthed

Connected to the general mass of earth in such a manner as will ensure at all times an immediate discharge of electrical energy without danger.

4.3.11 High voltage (HV)

All voltage exceeding 1000 V ac.

4.3.12 High voltage apparatus

Any apparatus, equipment or conductors normally ooperated at a voltage higher than 1000 V ac.

4.3.13 Isolated

The disconnection and separation of the electrical equipment from every source of electrical energy in such a way that this separation and disconnection is secure.

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4.3.14 Key safe

A device for the safe retention of keys used to lock means of isolation, earthing or other safety devices.

4.3.15 Limitation of acces (LoA)

A form issued by an authorised person to a competent person, defining the limits of the work to be carried out in the vincinity of, but not on, high voltage electrical apparatus.

4.3.16 Live

Electrically charged from a supply of electricity.

4.3.17 Permit to work (PTW)

A form of declaration signed and given by an authorised person to a competent person in charge of the work to be carried out on or in close proximity to high voltage apparatus, making known to him the extend (in time and space) of the work, exactly what apparatus is dead, is isolated from all live conductors, has been discharged and earthed and, insofar as electric hazards are concerned, on wich it is safe to work.

4.3.18 Safety lock

A lock used to secure points of isolation, safety devices and earth circuits, being unique from other locks used on the system.

4.3.19 Sanction for test (SFT)

A form of declaration, signed and given by an authorised person to another authorised person in charge of testing high voltage apparatus making known to the recipient what apparatus is to be tested and the conditions under which the testing is to be carried out.

4.3.20 Designated person ashore (DPA)

A senior electrical/mechanical engineer suitably qualified and appointed in writing by the company to be responsible for compilation and administration of procedures for high voltage installations and operations.

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4.4 What is classed high voltage onboard a vessel

In marine practice, voltages below 1000V ac are considered LV (low voltage). HV (high voltage) is any voltage above 1000V. Typical marine HV systems are 3.3KV, 6.6KV and 11KV.

4.5 HV Equipment

The principal items of a high voltage electrical system would be:
The main generating sets.
The main and auxillary HV switchboards with associated switchgear, protective devices and instrumentation.
High voltage cables.
HV to LV transformers.
HV to HV transformers typically step down or isolating transformers supplying propulsion converters and motors.
HV motors for propulsion, thrusters, ballast-pumps, cargo-pumps and compressors.

4.5.1 HV Insulation Requirements

The winding arrangements for marine HV generators and motors are similar to those at LV exept for the need for much better insulating materials such as Micalastic or similar.
The windings of HV transformers are usually insulated with an epoxy resin and quartz powder compound. This is a non-hazardous material wich is maintenance free, humidity resistant and tropicalised. Insulation for the HV conductors requires a more complicated design than is necessary for LV cables. Buth HV cables provide a significant saving in weight and space, leading to easier installation and a more compact result. Where air is being used as the insulating medium between bare copper busbars and terminals, the creepage and clearance distances between live parts and earth are greater on HV systems.

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4.6 Major features of a HV system compared to a LV system

- HV systems have more extensive and complex networks and aonnections.
- Acces to HV areas is strictly limited and securely controlled.
- Isolation procedures are more involved and switching strategies have to be formulated and recorded.
- Isolated equipment must be earthed down.
- Appropriate test probes and instruments should be used.
- Diagnostic insulation resistance testing is necessary.
- HV systems may sometimes be earthed neutral and use current limiting resistors.
- Special HV circuit breakers should be installed.
- Current magnitude and time is used for discrimination in protection/monitoring devices.

4.7 Dangers when working on HV equipment

4.7.1 Electric shock

Making personal contact with any electric voltage is potentialy dangerous. At high voltage levels the electric shock potential is lethal. Body resistance decreases with increased voltage level wich enhances the current flow. Remember that an electric current shock of as low as 15mA can be fatal. The risk to people working in HV areas can be greatly minimized by the diligent application of sensible general and company regulations and procedures. Factors likely to increase the risk of receiving an electric shock include the following.

- HV work on board du to limited space may be carried out in close proximity to a person(s) not familiar with HV hazards. Therefore the area must be properly cordoned off from surrounding work that may be going on and danger notices well posted.

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- There will be large areas of earthed metal that can be easily touched, increasing the possibility of electrical shock from an HV conductor.
- High voltage isolation testing can be particulary hazardous when several parts of the equipment are energised for a period of time.
- Some equipment could be using water in its operation which can lead to an increased risk of injury. In general, water conducts electricity and reduces the resistance of the skin.
- The use of instruments when taking measurements of high voltages can increase the risk of injury if they are inadvertently used without the earth (protective) conductor connected. This can result in the enclosure of the instrument becoming live at high voltages.
- High voltage equipment will store energy after disconnection. For example, on a 6.6KV switchboard a fatal charge may still be present on the equipment hours or even days later.
- If during maintenance an HV circuit main earth (CME) is removed from the system, it must not be worked on, as the HV cabling can recharge itself to a high voltage from induced voltages from nearby live HV cabling.

4.7.2 Arc

- An arc is a discharge of electrical current across a gap.
- An arc fault is a high power discharge of electricity between two or more conductors.
- The radiation of heat in an arc is very high and it can very easily set a persons clothes on fire.

4.7.3 Arc Blast

- Arc blast pressure derives from two things. First, the expansion of metal in a boiling, vaporising state, and second the heating of ambient air by passage of the arc.
- The mixture of vaporised water and metal in air near the arc generates a rapidly expanding plasma of ionized vapor, which can lead to extensive injuries.

4.8 Electrical Permit Work System

The access procedure to HV switchboards and equipment must be strictly controlled by using a Electrical-Permit-Work-System(PTW), isolation procedure involving a safety key system, and Earthing Down.
The format of a permit will vary for different companies and organisations. Before work is commenced on HV equipment an PTW must be issued. This permit is usually the last stage of a planned maintenance task organised and approved by the authorising officer to be carried out by the responsible person.

4.9 Additional procedures to be implemented for HV systems

For HV systems, additional procedures and precautions should be taken. These are as follows:

4.9.1 Sanction-to-test system

Usually testing on an HV system can only be carried out after the circuit main earth (CME) has been removed. An example of this can be insulation testing as it involves the system being checked for insulation to earth.
A sanction-to-test should be issued in a similar manner to a permit-to-work. A sanction-to-test should never be issued on an apparatus on wich a permit-to-work is still in force, or on wich another sanction-to-test is in force.
Note: Maintenance and repair cannot be carried out under a sanction-to-test.

4.9.2 Limitation of acces form

When carrying out HV maintenance, it may be dangerous to allow unrestricted work be carried out nearby. Workers carrying out maintenance nearby may not have HV training and may not be familiar with the risks involved when working on or near HV equipment. Due to these risks the Limitation of acces form should be used. This form states the type of work that is allowed to be carried out nearby the HV work, the limitations imposed (space and time) and the safety precautions taken. The form is to be issued and signed by the authorised person (AP) and a confirmation of receipt signature by the person carrying out the work. The form should include a sign off and a cancellation section.

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4.9.3 Earthing Down

Earthing Down is required to ensure that any stored electrical energy in the inherent capacitance of the epuipment insulation after isolation is safely discharged to earth. The higher values of insulation resistance required on HV cabling leads to a high value of insulation capacitance (C) this coupled with the high voltage means the energy stored (W) in HV equipment is far greater than that in LV systems.

$$\frac{C \times V^2}{2} joules$$

Earthing down also ensures that isolated equipment remains at a safe potential during work procedures.
Earthing down at a HV switchboard is of two types. **Circuit Earthing:** an incoming ore outgoing feeder cable is connected by a heavy earth connection from earth to all three conductors after the circuit breaker has been racked out, this is done at the circuit breaker using a special key. The key is then locked in the key safe. The circuit breaker cannot be racked in until the circuit's earth connection has been removed. **Busbar Earthing:** when it is necessary to work on a section of busbars they must be completely isolated from al possible electrical sources. This will include generator incomers, section or bus-tie breakers and transformers on that bus-bar section. The busbars are connected together and earthed down using portable leads which give visible confirmation of the earthing arrangement.

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Chapter 5

Classification and Certification

Repair and maintenance.

- Use of the equipment
- Fault finding
- Planned maintenance
- Who will do it?
    1. competence
    2. confident
    3. familiar with equipment
- Equipment specific instructions
    1. Makers instruction books, manuals
- Regulations and work standards
    1. Shipowner's book
    2. Class rules
    3. Flag regulations

Generally, work onboard ships is subject to local circumstances.
Since the actual electric work is not defined as on land, company practises prevail. All personnel needs to know the risks and operational requirements on electrical equipment.
The amount of electrical work has steadily increased day by day.
The allocation of electrically educated people is usually lagging behind.

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In the meantime, trained people have become rare, why??
The everyday organisation and monitoring of the work requires competent and responsible decisions on task allocation.
Misunderstanding between the different proffesional groups involved have to be minimized:

- Electricians
- Mechanics
- Administration office people

5.1 classification and certification for the equipment

- Equipment is generally classed according to IEC standards.
- The national Flag Rules may ask for certification.
- The major Ship Classification Societies group up as the members of IACS (International Association of Classification Societies). The member societies may cover for each other in some cases of equipment approvals.
- Classification societies approve delivered equipment as:
  1. Type/ standard approved, or
  2. Case-by-case approved (routine tests)

5.2 Mechanical Standards

5.2.1 ISO

The International Organisation for Standardisation, is a world- wide federation.

- The scope of ISO covers standardisation in all fields except electrical and electronic engineering standards, wich are included in IEC-standards.

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- Almost everything from drawing sheet size to the welding strenght calculation and re lubrication nipple dimensions has an appropriate ISO standard. The sound pressure level test is also included in ISO standards as are transportation package and container construction.

5.2.2 DIN

Deutsches Institut fur Normung.
DIN standards are old and generally used in Europe.
In DIN standards have been defined dimensional standards for bolts, screws, nuts and accesories for bolt nut assemblies. Also different type of shaft end, material requirements and couplings are standardized in DIN standards. Examples of DIN standards are:

- DIN 476: international paper sizes (now ISO 216 or DIN EN ISO 216)
- DIN 946: Determination of coefficient of friction of bolt/nut assemblies under specified conditions.
- DIN 1451: typeface used by German railways and on traffic signs
- DIN 31635: transliteration of the Arabic language
- DIN 4512: A definition of film speed
- DIN 72552: electric terminal numbers in automobiles

5.2.3 ANSI and ASME

Also inch-based mechanical standards have been defined. For example ANSI (American Standard Institution) and ASME(American Society of Mechanical Engineers) Standards define inch screw threads and give inch based bolts, screws, nuts and bolt/nut assemblies.

5.3 Electrical Standards

5.3.1 IEC

- The International Electrotechnical Commision is the organisation responsible for standardisation in the electric al and electronics field.

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- IEC is composed of 44 National Committees wich collectively represent some 80 percent of the worlds population that produces and consumes 95 percent of electric energy.
- The main problem with the IEC standards is that their status in the world is not strong enough. In many countries national electric standards are in common use.

IEC 92

- IEC 60092 Electrical installations in ships
- This standard, forms a series of international standards for electrical installations in seagoing ships, incorporating good practise and co-ordinating, as far as possible, existing rules.
- The standard is said to form a code for practical interpretation and amplification of the requirements of the international convention on Safety Of Life At Sea (SOLAS).

5.3.2 IEEE 45

What is IEEE 45?

It is the recommended standard for electrical on-board installations based on USA practices. The scope of this standard covers oceangoing vessels and vessels for use on rivers, lakes, bays, etc. It is considered an alternative standard to the IEC 60092, wich are part of ABS rules.

Where is it used?

The IEEE 45 electrical practice is often applied to offshore GOM (Gulf Of Mexico) support vessels and drill ships especially those that are US-build. Outside the US and for non US-flag vessels operating outside the GOM, electrical equipment vendors more frequently adhere to IEC standards.

Can IEEE 45 be used in place of IEC standards to meet ABS Rule requirements?

Both IEEE 45 and IEC standards can be used to meet ABS rules. Equipment, components and systems for which ABS has specific requirements may comply with an alternative standard such as IEEE 45, in lieu of the IEC-based requirements in the Rules. It is essential, however, that IEEE 45 *or*

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any other alternative standard proposed for use is determined by ABS to be *no less effective* than the Rules.

Can parts of IEEE 45 be coupled with parts of IEC standards for meeting ABS Rule requirements

When IEEE 45 is proposed as an alternative, all equipment must fully comply with the IEEE 45 standard.**Coupling sections of several standards together can result in less effective electrical requirements**, and thus, cannot be accepted as being in compliance with ABS Rules. Although ABS has been migrating towards IEC-based rules, it continues to recognize American equipment and practices.

5.3.3 Other international electrical standards

- VDE (German Association of Electrical Engineers)
- CENELEC
- ANSI/ASME
- IEEE(Institute of Electrical and Electronics Engineers)
- NEMA (National Electrical Manufacturers Association)
- BS (British Standards)
- JAS (JAPAN)
- CSA (Canadian Standarts Association)
- AS (Australian Standards)
- API (American Petroleum Institute)

Most national standards cover things like terminal markings, direction of rotation and minimum creepage distances, which affects machine construction but not performance.
In many cases API-standard refer to NEMA standard.*The most frequently used national electrical standard replacing IEC is NEMA*

5.3.4 Marine Standards

The International Asociation of Classification Societies (IACS) is an association representing the world's major classification societies.

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IACS Members

- ABS American Bureau of Shipping
- BV Bureau Veritas
- China Classification Society
- DNV Det Norske Veritas
- GL Germanisher Lloyd
- Korean Register of Shipping
- LRS Lloyd's Register of Shipping
- Nippon Kaiji Kyokai
- Polski Rejestr Statkow
- Registro Italiano Navale
- RS Register of shipping (Russia)

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Chapter 2
Electrical Safety

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

★ Comply with regulations governing electrical safety

★ Avoid electrical accidents by adopting adequate safety measures

★ List the fundamentals requirements for safe installation of equipment

★ Identify safe electrical equipment for hazardous areas

★ Render first ... unfortunate event of electrical accidents

2.1 Compliance with Regulations

Practically every ocean-going ship is registered with a Classification Society and is therefore required to comply with the Rules of the relevant Society. These Classification Societies are members of the International Association of Classification Societies (*log on to www.iacs.org.uk for detailed information*). Dedicated to safe ships and clean seas, IACS makes a unique contribution to maritime safety and regulation through technical support, compliance verification, research and development. More than 90% of the world's cargo carrying tonnage is covered by the classification design, construction and through-life compliance Rules and standards set by the ten Member Societies and one Associate of IACS.

Ship Classification, as a minimum, is to be regarded as the development and worldwide implementation of published Rules and/or Regulations which will provide for:

1. the structural strength of (and where necessary the watertight integrity of) all essential parts of the hull and its appendages,
2. the safety and reliability of the propulsion and steering systems, and those other features and auxiliary systems which have been built into the ship in order to establish and maintain basic conditions on board, thereby enabling the ship to operate in its intended service.

The achievement of these goals is conditional upon continued compliance with the Rules and / or Regulations and proper care and conduct on the part of the Owner and Operator (Refer the IACS' Guide to Managing Maintenance in Chapter 26).

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A ship built in accordance with a Member Society's Rules and/or Regulations, or in accordance with requirements equivalent thereto, and fulfilling the applicable stability requirements will be assigned a class in the Register Book of the Society. For ships in service, each Member Society maintains the provisions of class by way of periodical visits by its Surveyors to the ship as defined in its Rules and/or Regulations in order to ascertain that the ship currently complies with those Rules and/or Regulations. Should significant defects become apparent or damages be sustained between the relevant visits by the Surveyors, the Owner and Operator are required to inform the Society concerned without delay. Similarly any modification which would affect Class must receive prior approval by the Society.

A ship is said to be in Class when the Rules and/or Regulations which pertain to it have, in the opinion of the Society concerned, been complied with. Individual Societies are to explain by an additional note as to how they deal with items, either statutory or class, beyond the basic definition. The Members and Associates are as follows:

Classification Society	Email	Website
	Members	
American Bureau of Shipping	abs-worldhq@eagle.org	http://www.eagle.org
Bureau Veritas	veristarinfo@bureauveritas.com	http://www.veristar.com
China Classification Society	ccs@ccs.org.cn	http://www.ccs.org.cn
Det Norske Veritas	iacs@dnv.com	http://www.dnv.com
Germanischer Lloyd	headoffice@gl-group.com	http://www.gl-group.com
Korean Register of Shipping	krsiacs@krs.co.kr	http://www.krs.co.kr
Lloyd's Register of Shipping	Lloydsreg@lr.org	http://www.lr.org
Nippon Kaiji Kyokai	xad@classnk.or.jp	http://www.classnk.or.jp
Registro Italiano Navale	info@rina.org	http://www.rina.org
Russian Maritime Register of Shipping	004@rs-head.spb.ru	http://www.rs-head.spb.ru/
	Associate	
Indian Register of Shipping	ho@irclass.org	http://www.irclass.org

Courtesy – International Association of Classification Societies (www.iacs.org.uk)

Table 2.1 – International Association of Classification Societies

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The International Electrotechnical Commission (IEC) Publication No. 92, *Recommendations for Electrical Installations in Ships*, gives guidance to national bodies, classification societies and all involved in the marine industry. Increasing adoption of these recommendations will lead to a greater level of international standardisation.

Offshore installations involved in the exploration and / or production of hydrocarbons may not be subject to classification requirements, but will be subject to regulatory requirements of the country within whose waters the operation is being conducted, e.g., Certificate of Fitness. Some vessels are subject to both classification and national offshore regulatory requirements.

In addition to classification requirements, there are statutory international requirements, namely the International Convention for Safety of Life at Sea (usually referred to as SOLAS) which is produced by the International Maritime Organisation and administered by National Governments.

Ships with British registry, for example, are required to comply with the Department of Trade (Marine Division) regulations. Similar is the case for other countries too.

Note: *The International Electrotechnical Commission is the authoritative worldwide body responsible for developing consensus global standards in the electrotechnical field. It is based in Geneva, Switzerland. It writes standards for electrical and electronic equipment practices. It is dedicated to the harmonisation and voluntary adoption of these standards, supporting the transfer of electrotechnology, assisting certification and promoting international trade. Since 1906, it has served the world's electrical industry, developing international standards to promote quality, safety, performance, reproducibility, and environmental compatibility of materials, products, and systems. It has also published standards for the electronics and telecommunications industries. The IEC's present membership of more than 60 participating countries includes most major trading nations with their goals being:*

- *Define requirements for making the global market world wide efficient*
- *Improve efficiency in industrial processes*
- *Improve human health and safety*
- *Protect the environment*

IEC standards are widely adopted as the basis of national or regional electrotechnical standards, and are often quoted in manufacturers' specifications and by users when calling for tenders. Over 2000 standards cover virtually every topic of electrotechnology from acoustics, to medical devices, to insulating materials, to aircraft, to nuclear instruments.

2.1.1 Other Important International Organisations

- **Underwriters Laboratories (UL)** is a private company that is nationally recognized as an independent testing laboratory. UL tests products for safety and products that pass UL tests can carry a UL mark.
- The **National Electrical Manufacturers Association (NEMA)** is an organization that, among other things, develops standards for electrical equipment.
- The **National Fire Protection Association (NFPA)** is a nonprofit organization which publishes the *National Electrical Code®* (*NEC®*). The intent of the *NEC®* is to describe safe electrical practices.
- The **American National Standards Institute (ANSI)** is a nongovernmental organization that facilitates the development of standards by establishing a consensus among qualified groups.
- The **Institute of Electrical and Electronic Engineers (IEEE)** is an organization open to individual membership and provides a variety of services for its members. It also develops numerous standards for electrical and electronic equipment and practices.

There are two outstanding considerations in the selection and installation of marine electrical equipment: firstly, outstanding reliability and freedom from breakdown for those services which are essential for safety, navigation (steering, navigation lights, radio services, etc.) and propulsion; secondly, freedom from fire risks. Both these conditions demand a well-found installation with first-class materials and, above all, good workmanship and maintenance. In the following chapters, some of the factors that contribute to these requirements will be dealt with more fully, and a better understanding of installations by the marine engineer and electrical officer will, it is hoped, lead to more efficient maintenance and operation. Some factors are common throughout and to save repetition may be summarised here. All materials should, as far as possible, be non-flammable, but some insulating materials cannot be made to meet this requirement and the nearest approach is that they should be flame-retardant, i.e. they will not continue to burn when the flame is removed.

2.1.2 Relevant SOLAS Regulations (Chapter II–1)

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

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2.1.2.1 Summary of Regulations

1) Exposed metal parts of electrical machines or equipment which are not intended to be live but which are liable under fault conditions to become live shall be earthed unless the machines or equipment are:

   a) Supplied at a voltage not exceeding 50 V direct current or 50 V, root mean square between conductors; auto–transformers shall not be used for the purpose of achieving this voltage; or

   b) Supplied at a voltage not exceeding 250 V by safety isolating transformers supplying only one consuming device; or

   c) Constructed in accordance with the principle of double insulation

   d) Additional precautions for portable electrical equipment for use in confined or exceptionally damp spaces where particular risks due to conductivity may exist.

2) All electrical equipment shall be so constructed and so installed as not to cause injury when handled or touched in the normal manner.

3) Where necessary, non–conducting mats or gratings shall be provided at the front and rear of switchboards

4) No electrical equipment shall be installed in any space where flammable mixtures are liable to collect including those on board tankers or in compartments assigned principally to accumulator batteries, in paint lockers, acetylene stores or similar spaces, unless the Administration is satisfied that such equipment is:

   a) essential for operational purposes;

   b) of a type which will not ignite the mixture concerned;

   c) appropriate to the space concerned; and

   d) appropriately certified for safe usage in the dusts, vapours or gases likely to be encountered.

Note: *In addition to the above, relevant safety guidelines have been included in all chapters*

2.2 The Inherent Dangers and Avoidance of Disastrous Consequences

At the outset, it is worth reproducing a few excerpts from "A Guide to Risk Assessment in Ship Operations" (Published by IACS - Date: 26/03/2004 - Revision: 0)

Quote

"The best safeguard against accidents is a genuine safety culture - awareness and constant vigilance on the part of all those involved, and the establishment of safety as a permanent and natural feature of organizational decision-making".

IMO defines risk as:

"The combination of the frequency and the severity of the consequence."

(MSC Circ 1023/MEPC Circ 392)

In other words, risk has two components: likelihood of occurrence and severity of the consequences.

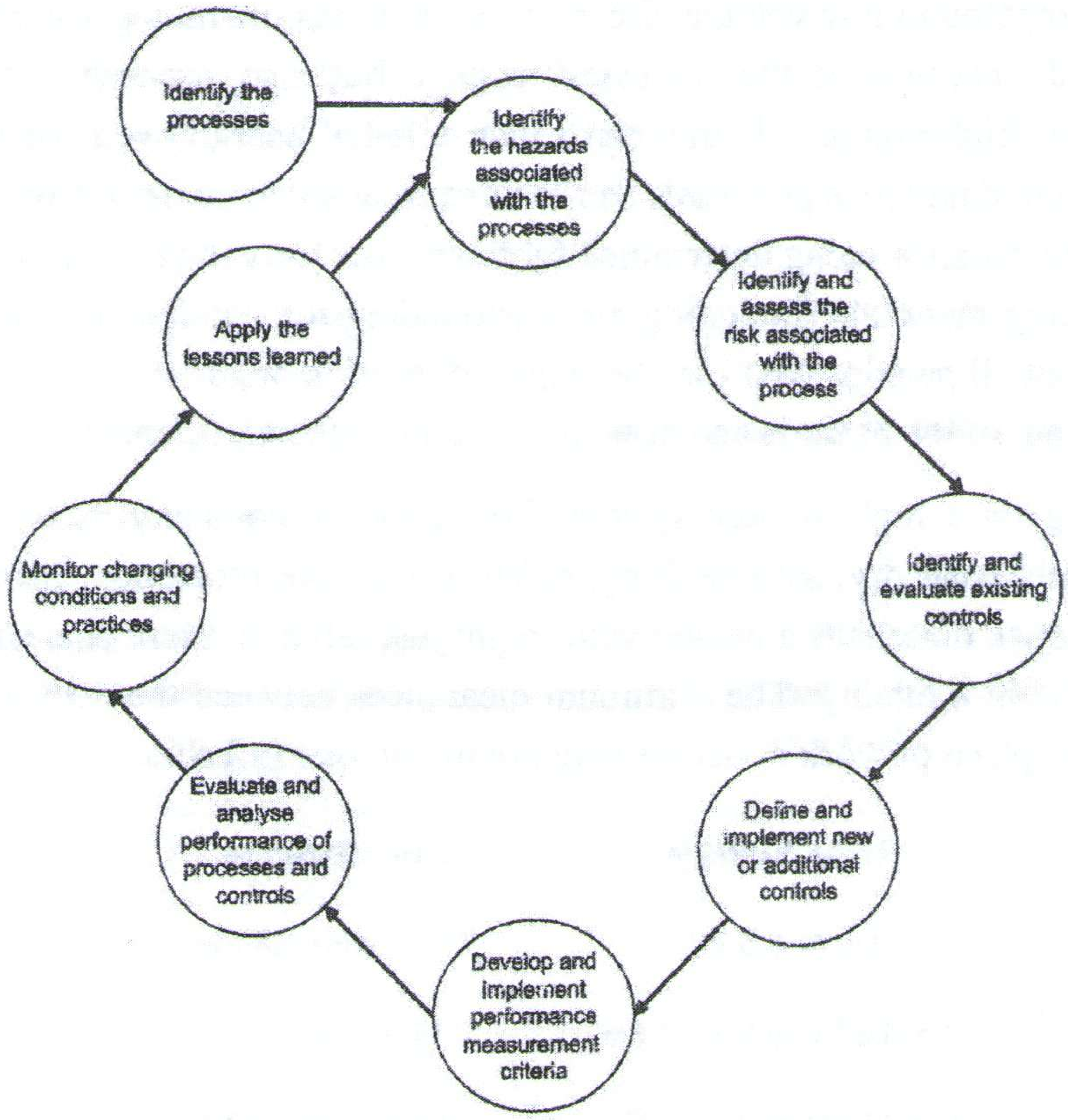
A hazard is a substance, situation or practice that has the potential to cause harm. Briefly, what we are concerned with, therefore, is:

- The identification of hazards
- The assessment of the risks associated with those hazards
- The application of controls to reduce the risks that are deemed intolerable
- The monitoring of the effectiveness of the controls

The controls may be applied either to reduce the likelihood of occurrence of an adverse event, or to reduce the severity of the consequences. The risks we are concerned with are those which are reasonably foreseeable, and relate to:

- The health and safety of all those who are directly or indirectly involved in the activity, or who may be otherwise affected
- The property of the company and others
- The environment

The risk management process may be summarized by the flowchart below.



Unquote

Successful completion of everyday activities depends on safe execution; preparation and conduct during these activities reflects on performance. In no other field is this more significant than in the marine field. Today most marine installations are a.c. based, but there may still be a few operating on d.c., which under certain conditions can be lethal. Generally speaking, the danger of a d.c. shock is not nearly as severe as compared to one from a.c. supplies.

2.2.1 High Voltage Safety

In recent years there has been an increasing use of high-voltage systems on board ships, particularly for cruise liners, some LNG carriers and specialist offshore support vessels.

While working on a high voltage system, we should pay more attention to safety because we know that any voltage above even as low as 55V can also be fatal.

High-voltage circuits (i.e., above 1000 V up to and including 15 kV AC), are potentially more dangerous as compared to low voltage circuits (i.e., up to and including 1000 V AC and 1200 V DC), not only because of the increased voltage but also because under certain common circumstances high-voltage circuits can retain a lethal charge even when they are switched off. In addition, dangerous potentials can exist even at some distance from live high-voltage conductors, the distance being determined by the conductor voltage and the dielectric strength of the insulating materials (including air) surrounding the conductor. It is therefore considered essential that all persons who may be required to work on, or operate high-voltage apparatus are fully aware of the hazards and how to avoid the associated danger.

Personnel working on a high voltage system should follow company safety rules and procedures. They should wear dry, safe clothing, safety shoes, eye protection, hard hat, etc., as even the slightest shock disorients a person who might just fall and injure oneself but more often than not it results in a fatality. The minimum clearances between the nearest exposed, live conductors and the place of work or access way are mentioned in Table 2.2.

Rated Voltage	Safe Distance
Up to 6.6 kV	2.56 metres (8'5")
V > 6.6 kV to V < 11 kV	2.59 metres (8'6")
V > 11 kV to V < 22 kV	2.64 metres (8'8")
V > 22 kV to V < 33 kV	2.74 metres (9')

Table 2.2 – Safe Distances for HV Systems

When work is carried out on a high-voltage system, it is highly desirable that a previously prepared program incorporating a checklist be strictly followed to ensure that the work is correctly performed without mistakes considering their inherent danger. In order to operate a high-voltage system safely, it is necessary to ensure that all persons concerned are suitably qualified for the duties they are to perform. Before attempting any electrical work, there are some basic safety precautions one must bear in mind. The possible dangers arising from the misuse of electrical equipment are well known.

An electric shock or fire can cause loss of life and damage to equipment. Where danger arises it is usually due to an accident, neglect or some other contravention of the regulations. Hence it is important to ensure that appropriate safety measures are always adopted.

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2.3 Passive Safety Measures

This is the highest level of safety for personnel, when all systems are in normal operation. Avoiding failure is therefore a primary goal. The basic design philosophy of and electrical system must, when built according to SOLAS Requirements, Classification Rules, Regulations or Standards, have an inherent ability to withstand stresses generated externally and within the system. This ability must give each particular function, for example, a power supply for a pump, a defined quality or reliability level. The level is reached through correct system design, application or use of suitable equipment, correct rating and correct installation procedures. Some of the passive measures are mentioned in the following paragraphs.

2.3.1 Component Quality or Reliability Level

The following measures must be adopted and adhered to:

i. Components must be selected according to their actual use. The rules mention requirements regarding ambient conditions and design specifications.

ii. The rating must be selected according to the prospective stresses applied on the component by the system at the location where it is installed.

iii. The component must be installed in such a way that its properties as defined above are maintained. The rules specify requirements regarding installation. Some examples are as follows:

a) Cables are very important in a ship's electrical system's installation. They are usually of specialized construction and incorporate properties in conformity with IEC recommendations such as flame retardant capabilities and a high resistance to humidity, oil, vapour and ageing.

b) Large switchboards are normally to be divided into several cubicles. One of the reasons is to allow for maintenance work while the rest of the switchboard is in operation and, in high voltage switchboards the equipment in each cubicle is to be interlocked so that no live parts are accessible until they are isolated from the network and solidly earthed. The other reason for adapting to cubicles is that if a mechanical fault were to occur on one of the components, damage can be alleviated to a great extent. They also serve as magnetic shields, thus reducing the effects of electro-magnetic interference.

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iv. Enclosures are normally specified according to IEC 529. This standard gives requirements against intrusion of solid objects and against ingress of water. When an electrical component is given a degree of protection, this describes the protection required for personnel and the protection necessary to ensure reliable electrical operation. This is explained in article 15.18. Two examples are mentioned below:

a) Rotating machinery mounted in an engine room is to have protection to at least IP 22. IP gives the reference to IEC 529, the first numeral (2) indicates that the motor must be protected against intrusion of solid objects larger than 12 mm and the second numeral (2) indicates the protection against ingress of dripping water when tilted up to 15 degrees.

b) A machine mounted on an open deck is to have a degree of protection to at least IP 56. The first numeral (5) means dust protected and, the second numeral (6) means protection against heavy seas.

2.3.2 Protection against Erroneous Operation

As far as is possible safeguards are built into the electrical system so that a system, component or machine will be 'fail safe' when operational conditions exceed set limits, in terms of voltage, current, temperature, speed, etc.

2.3.3 Maintenance

There must be an organised system of maintenance applied to the whole electrical installation. This involves inspection and testing at regular intervals, and the repair or replacement of any component or part which is found to be defective or malfunctioning. Only in this way can the electrical installation be relied upon in order to supply electrical energy safely and as demanded by operational requirements.

2.3.4 Personnel Protection

All protective measures applied to eliminate potential failures are in fact elements in a personnel protection scheme, as any abnormal situation will reduce the actual safety level. A number of rules are however, directly aimed at protecting personnel. The most important requirements and their purpose are aimed at the prevention of accidentally touching live parts. Electrical shocks can be lethal, even at voltages as low as 220V. In switchboards the wrong use of tools and other objects can also cause arcs, exposing personnel to short-circuit and similar effects.

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Important requirements in the rules are therefore related to:

i. ***Enclosures***

Minimum requirements are given for most electrical equipment, for example, terminal boxes, distribution boards and starter enclosures.

ii. ***Screening***

Screens are often required for equipment which cannot be enclosed, for example, the bus Bars.

iii. ***Warning Signboards***

These must be prominently and permanently displayed at all locations where potential electrical hazards exist for personnel.

iv. ***Limited Accessibility***

For high-voltage equipment, special tools must be available to open, for example, terminal boxes on motors. High voltage transformers are to be installed in locked rooms.

v. ***Accidentally Touching Rotating and Movable Parts***

Minimum enclosures are specified to provide protection against rotating parts in motors and generators.

2.4 Active Safety Measures

When a failure occurs in the electrical installation, the philosophy is that the installation shall only suffer minor operative consequences due to any single system failure. Measures are also to be taken to limit secondary effects from any system failure, to a minimum.

The most important measures adopted to fulfil these requirements are as follows:

2.4.1 Redundancy Requirements

For particular functions where the reliability level is not considered high enough, the level is normally increased by the introduction of redundant systems

Example:

In a lubrication system there are two electrically-powered pumps; where both pumps have sufficient capacity to maintain adequate lubrication alone, and the pumps are supplied from independent power supplies, it is said that the pumps are redundant.

The Classification Rules list a number of users defined as essential and important for the operation of the ship:

a) *Essential users* are for example: steering gear; auxiliary machinery for main and auxiliary engines.

b) *Important users* are, for example, windlasses, bilge and ballast systems and thrusters.

In addition to these users, there are a number of functions which are connected to the emergency system. A typical emergency system arrangement is shown in Figure 4.1. Such functions are emergency lighting, navigation lights, steering gear, fire detection/alarm system and fire pumps. These functions are duplicated.

As an example, normal lighting is supplied from the main system, but in case of a main system blackout, the emergency lighting will be supplied from the emergency system. Based on these considerations, the normal system solution in marine installations, for redundancy, is as follows:

2.4.1.1 Essential Users

Users which need to be in continuous operation are duplicated. These users have separate supplies from the main switchboard. Consequently, a main system blackout will interrupt the operation of these users. Such failures are very rare and if they do occur they are not considered likely to cause major dangers in most installations.

For special installations, for example, on diving vessels where continuous thrust is vital for the safety of the divers, other arrangements must be sought.

With reference to Figure 4.2, this installation can be operated with bus tie breakers open, permitting one section of the system to remain in continuous operation even when a main switchboard failure occurs. Article 1.3.2 also explains the importance of essential users.

2.4.1.2 Important Users

Users which are necessary to maintain the main functions of the installation are very often duplicated or partly duplicated. They are normally supplied directly from the main switchboard or from dedicated distribution switchboards.

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Example:

There is a main switchboard failure leading to a main system blackout. There is only a short period where battery-backed systems are alive.

After 5-20 seconds the emergency diesel will start, and users fed from the emergency switchboard will come alive. For most purposes a 5-20 seconds' power interruption will have no consequences, and the power supply is therefore considered "continuous".

If no major damage is present in the main system, the main system can now be re-started and normal operation resumed, provided that functions necessary to start the main system's diesels are supplied from the emergency system or can be activated by other sources.

There are a number of other general redundancy requirements in the Rules:

a) Safety of supply

A ship must be provided with both main and emergency sources of electrical power supply.

b) Main generators and prime movers

There is a requirement for at least 2 (two) generating sets. With any unit out of service the rest of the generators must be capable of supplying all the systems necessary for the operation of the vessel and maintaining a minimum habitable condition.

c) Power transformers

Transformer installations supplying essential and important users must be designed so that with any transformer out of service other transformers will be capable of maintaining normal operation.

d) Cable installation

Cables for redundant users must have separate routing. Cables for the emergency system must be separated from the main system. The intention is that no single incident damaging the cable installation shall cause failures in redundant circuits. The main electrical supply must be independent of the emergency supply in such a way that a fire or other casualty in the spaces containing the main source of supply will not render the emergency source of supply inoperative.

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e) Main lighting system

A main lighting system must be provided and supplied from the main source of power. The arrangement of the main lighting system must be such that a fire or other casualty in the spaces containing the main source of power, associated transformer, main switchboards and lighting switchboards will not render the emergency lighting inoperative.

2.4.2 Circuit Protection

We know that a basic circuit consists essentially of two parts:

(a) The *conductor* – which carries current around the circuit; and

(b) The *insulation* – which confines the current to the conductor itself.

Here, only two types of circuit faults can occur, i.e. either a break in the conductor, or a break in the insulation (Refer Figure 2.1). The complexity of other faults is beyond the scope of this chapter. However, Chapter 13 deals with various faults and fault protection devices in detail.

- An *open-circuit fault* is due to a break in the conductor, so that current cannot flow.
- An *earth fault* is due to a break in the insulation, allowing the conductor to touch the hull or an earthed metal enclosure.
- A *short-circuit fault* is due to a double break in the insulation, allowing both conductors (of different potential) to be connected thereby resulting in a very large current that bypasses or short-circuits the load. The magnitude of 'fault current' that will flow depends on the overall impedance left in the circuit under such conditions.

In order to minimize the operational consequences and secondary effects of system failures, the electrical network is equipped with automatic disconnecting devices. The integrity principle as described in IEC Publications and the classification rules is of major importance when selecting protective devices for an installation is 'short-circuits'

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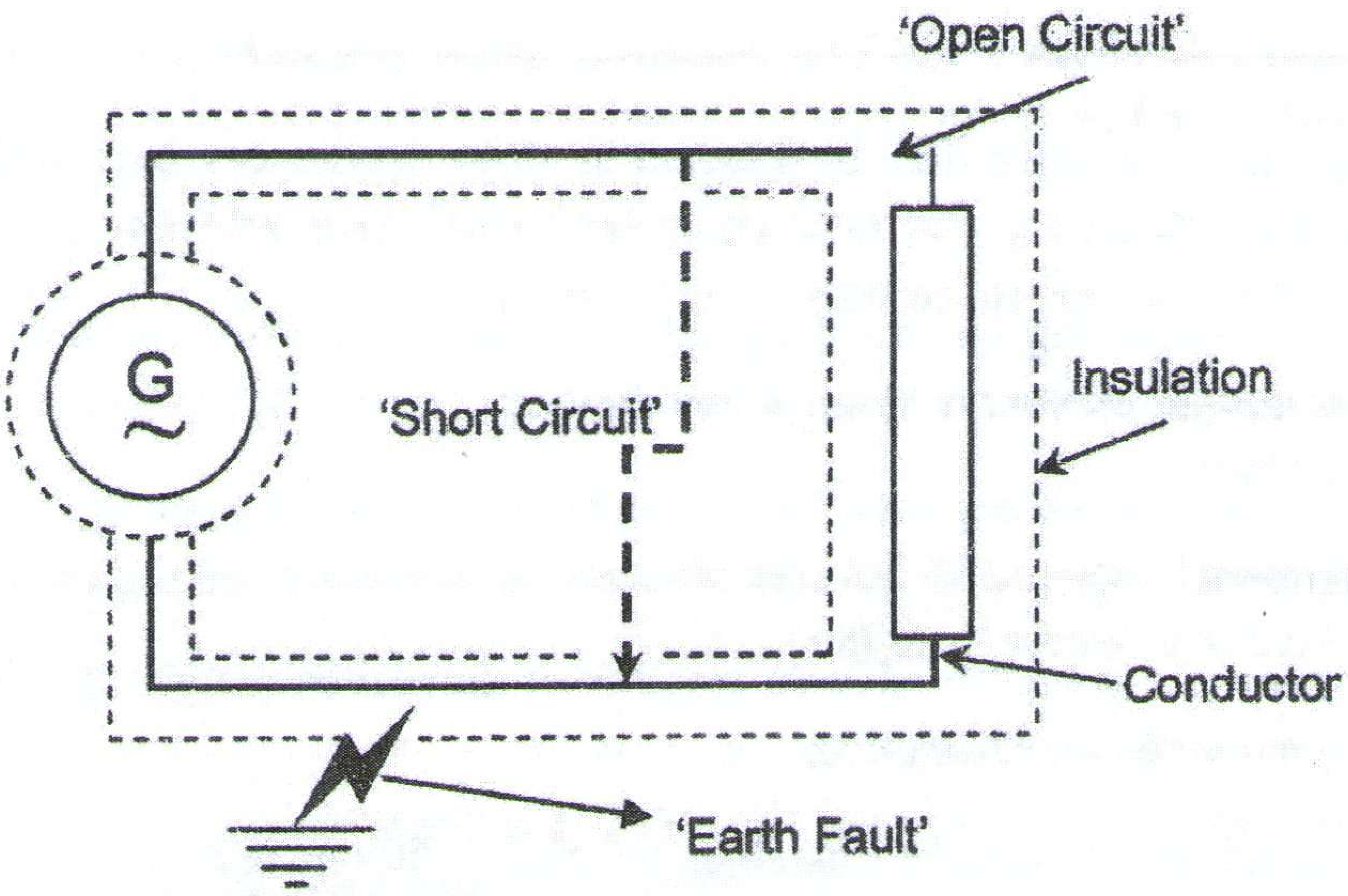

Figure 2.1 - Common Circuit Faults

2.5 Fundamental Requirements for Safe Installation of Equipment

From the very early days of electricity there has been an essential requirement for electrical installations to be installed safely, as well as being suitable for the purpose for which they are designed. Some guidelines are as follows:

- Good workmanship and proper materials shall be used throughout the installation;
- The equipment shall be installed in such a way as to be accessible for testing, inspection and maintenance as far as is practical;
- Joints and connections shall be properly constructed, regarding conductance, insulation, mechanical strength and protection;
- Wherever necessary, circuits shall have suitably rated automatic protective devices especially for protection against overcurrent;
- Whenever a prospective earth fault current is insufficient to operate the above, a residual current device shall be fitted;
- Electrical equipment shall be earthed in such a manner that earth leakage currents will be discharged without danger;
- If metal parts of other devices can be touched simultaneously with the above, then they should be earthed;

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☞ Single pole switches shall be inserted in phase conductors, only with the exception of linked switches;

☞ Circuits supplying electrical equipment shall have effective means of isolation as necessary, to prevent or remove any danger;

☞ Safe means of access shall be ensured for persons to operate or attend to installed equipment;

☞ Equipment exposed to adverse weather or corrosive conditions shall be designed to prevent any danger from this;

☞ No additions to installations shall be made without ascertaining there is sufficient spare capacity for it and that the earthing arrangements are adequate;

☞ Testing shall be carried out on completion of the installation, to the requirements as specified in relevant regulations.

The ships' staff must also operate equipment in a safe manner and maintain them in a safe condition at all times. Failure to do so will cause danger with possible disastrous consequences.

2.6 Dos and Don'ts While Working With Electrical Equipment

Do...

☺ ... get to know the ship's electrical system and equipment. Study the ships' diagrams to pinpoint the location of switches and protection devices, distribution boards and essential items of equipment. Write down this information in a notebook. Note the normal indications on switchboard instruments so that abnormal operation can be quickly detected.

☺ ...operate and maintain equipment according to the manufacturers' recommendations.

☺ ...ensure that all guards, covers and doors are securely fitted and that all bolts and fixings are in place.

☺ ...inform the Officer of the Watch before shutting down equipment for maintenance.

☺ ...remember that it is mandatory to obtain a work permit prior to carrying out any work on equipment that is supplied with voltages greater than 1000 volts. In fact most vessels insist on work permits for electrical equipment that operate at even less than 1000 volts. An example of such a permit is mentioned in article 26.2.1.1.

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☺ …switch off and lock all supplies[1], remove fuses and store them in a safe place. It is mandatory to display warning notices before removing covers of equipment for maintenance; refrain from asking others to do this; do this yourself as you are going to work on the equipment.

☺ …confirm that circuits are *dead* (by using a voltage tester[2]) before touching conductors and terminals. Never rely totally on switches, etc, as sometimes they may be defective or could have been wired or labelled wrongly, such that when indicating 'Off', they could actually be 'On' thus completing the power supply to the circuit.

☺ …make contact with the conductor(s) of a supposedly dead power system, first with the back of one hand. Even if a shock should still occur, an involuntary reaction will cause the fist to be clenched, thus moving the fingers *away* from the conductor – rather than involuntarily gripping the live circuit, which has sometimes resulted in many fatalities.

1 *Proper and foolproof electrical locking would not merely mean switching off the supply by operating the isolation switch / switch fuse handle but by removing the fuses or by mechanically locking the handle in the "Off" position.*

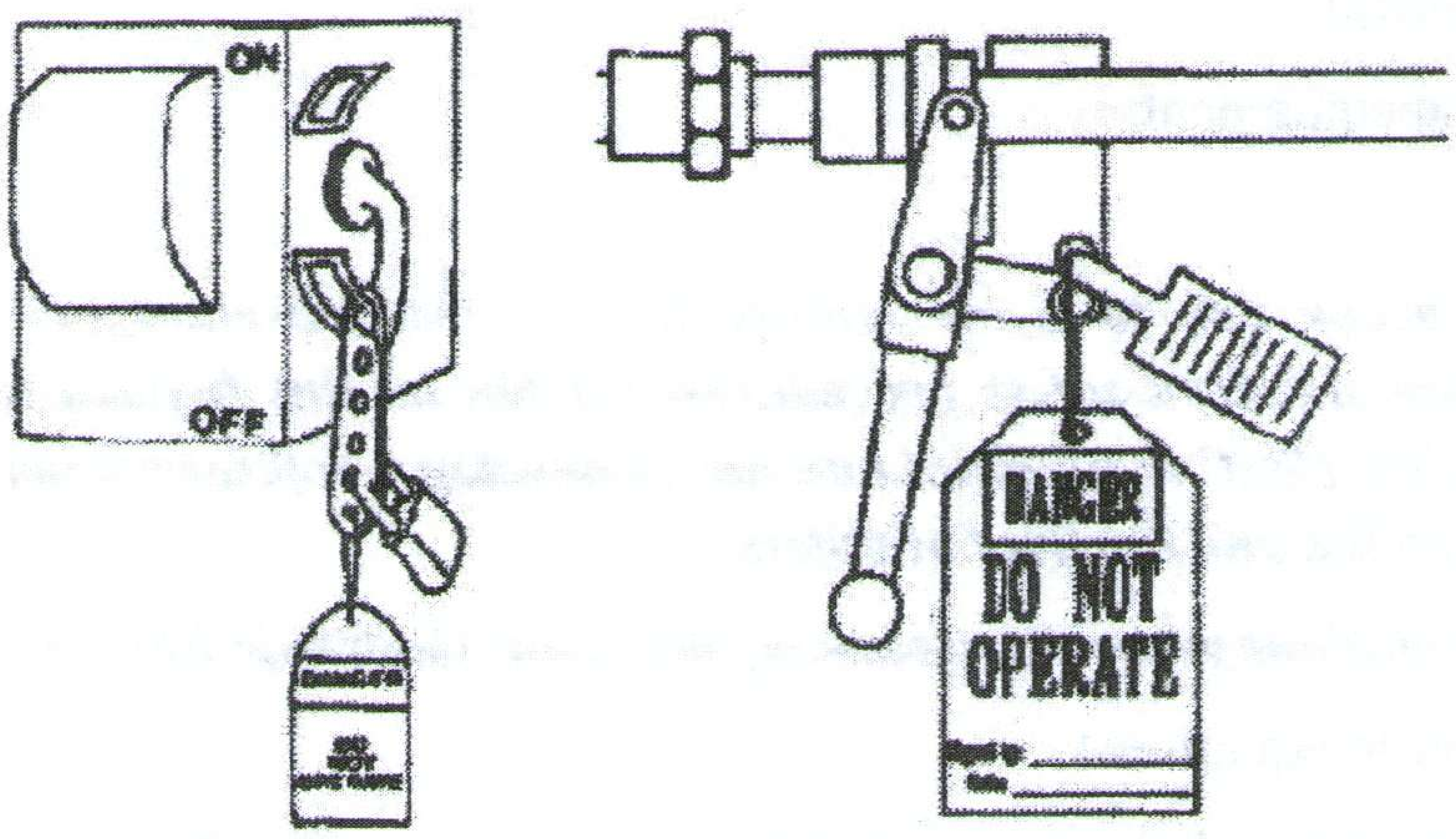

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Figure 2.2(a) - Foolproof Locking

2 *Check the instrument used for testing (to ensure that it is working); next check the equipment which has been made dead (for any presence of electricity); finally check the instrument on a live circuit so as to ensure that it is still working*

Don't…

- …touch live conductors under any pretext – especially when wearing damp clothing or perspiring.
- …remove earth (ground) connectors on power cords and within equipment.
- …touch rotating parts as depicted in Figure 2.2(b).

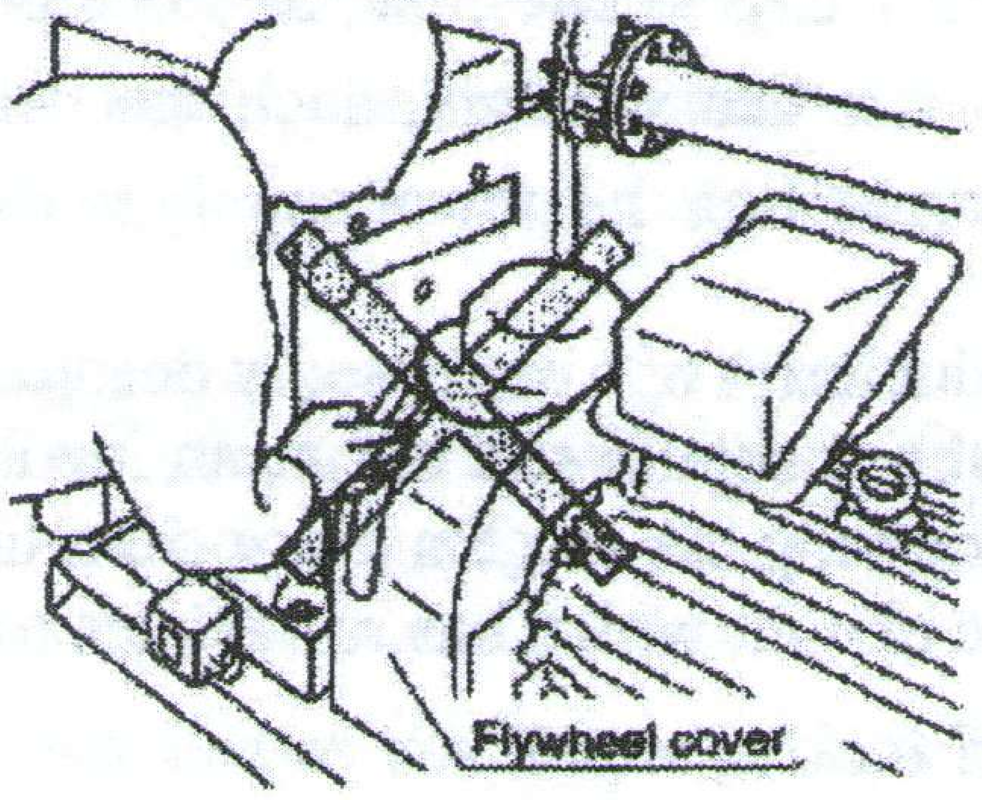

Figure 2.2(b) – Caution for Rotating Machinery

- …leave live conductors or rotating parts exposed.
- …overload equipment.
- …neglect or abuse equipment.

Remember!

- ***Most accidents occur due to a momentary loss of concentration or attempts to overlook or ignore standard safety procedures. Do not let this happen to you! You should think 'Safety First' at all times and hence develop a safety conscious attitude. This will save your life and the lives of others.***

2.6.1 Additional Precautions when Commencing Work on Electronic Equipment

1. Switch off the power to equipment
2. Select and use adequately-rated test and measuring devices that are both safe for the environment in which work is to be carried out and for the equipment too.
3. Personnel working on electronic equipment should wear electrostatic discharge straps on the wrist and ensure that the grounding connection (to a good earthing point on the ship) does not hinder safe working procedures.
4. Ensure that the equipment is also grounded at a good earthing point.
5. Electronic components and printed circuit boards, etc, must be stored in anti-static bags and similar storage devices.

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2.6.2 *Special Protection Scheme for Workshop Machinery*

1. A circuit breaker with a no-volt coil for workshop machinery ensures that if the power supply fails, the machine(s) will shut down and will not automatically start once the supply is restored; it has to be manually re-started.
2. The power supply from the Main Switchboard will be routed through a Distribution Board very close to the workshop and its equipment. This contains miniature circuit breakers for various machines; in addition there are overload and short circuit protection circuits; an emergency stop arrangement will also be installed on the machine itself.
3. Lathes have a foot pedal switch to isolate the equipment in case of an emergency

2.7 Danger Signals

Be constantly alert for any signs that might indicate a malfunction of electrical equipment. When any danger signals are noted, report them immediately to the chief engineer or electrical officer. The following are examples of danger signals:

- Fire, smoke, sparks, arcing, or an unusual sound from an electric motor or contactor.
- Frayed and damaged cords or plugs.
- Warm receptacles, plugs, and cords.
- Slight shocks felt when handling electrical equipment.
- Unusually hot, running electric motors and other electrical equipment.
- An odour of burning or overheated insulation.
- Electrical equipment that either fails to operate or operates erratically.
- Electrical equipment that produces excessive vibrations.

2.8 Precautions for Preventing an Electric Shock

Take the following precautions when working on electrical equipment:

- Remain calm and consider the possible consequences before performing any action.
- When work must be done in the immediate vicinity of electrical equipment, check with the senior engineer responsible for maintaining the equipment to avoid any potential hazards. Stand clear of operating radar and navigational equipment.
- Never work alone. Another person could save your life if you receive an electric shock.

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- Never enter a flooded compartment that has a generator actively producing power. Transfer the load and secure the generator before entering.
- Never work on electrical equipment while wearing loose-fitting clothing. Be careful of loose sleeves.
- Never work on electrical equipment while wearing rings, watches, identification tags, or other jewellery.
- Wear safety goggles. Sparks could damage your eyes. The sulphuric acid contained in batteries and the oils in electrical components can cause blindness.
- If possible, de-energize the circuit before using test equipment, especially a megger.
- Discharge capacitors before working on de-energized equipment. Take special care to discharge capacitors properly. Injury or damage to equipment could result if improper procedures are used.
- Work on energized circuits only when absolutely necessary. The power source should be tagged out at the nearest source of electricity for the component being serviced.
- Ensure that all tools are adequately insulated when working on energized electrical equipment.
- When working on energized equipment, stand on a rubber mat to insulate yourself from the steel deck.
- When working on an energized circuit, wear approved electrical insulating rubber gloves. Cover as much of your body as practicable with an insulating material, such as shirt sleeves. This is especially important when working in a warm space where you may perspire.
- When working on energized electrical equipment, work with only one hand inside the equipment. Keep the other hand clear of all conductive materials that may provide a path for current flow.
- Keep covers of all fuse boxes, junction boxes, switch boxes, and wiring accessories closed. Report if any cover is not closed or missing, to the senior engineer responsible for its maintenance. Failure to do so may result in injury to personnel or damage to equipment if an accidental contact is made with exposed live circuits.

Alternating current produces a continuing spasm in the muscles through which current passes, with its change from forward to reverse flow at the rate of 50 or 60 cycles per second. Alternating current has the ability to stimulate nerves directly. It finally results in the unfortunate victim tightening his / her grip. Most victims of 'serious shock' will have been in contact with a.c. Serious shock results in unconsciousness or worse conditions, requiring resuscitation and medical care.

Alternating current, which takes a path through the chest area, can, by contraction of the chest and diaphragm muscles, stop the breathing directly and possibly also indirectly by interfering with the functioning of the respiratory control nerves. Similarly, shock in the region of the chest can have direct consequences for the heart, causing stoppage of contraction of the heart's muscles. Lesser alternating currents can upset the heart's pumping action by destroying the co-ordination between the walls of the ventricles (ventricular fibrillation).

It must be remembered that fibrillation is unlikely to occur if the current in mA is less than 116/t where t is the shock duration in seconds; thus even though the current may be lower it may lead to this unpleasant condition if the victim is exposed for a longer time.

Current Level	Effect on Victim
1 mA	Sensation that shock is occurring
5 mA	Upper limit of safe or harmless range
10 to 20 mA	Let-go threshold – the victim cannot shake loose from the source of shock and perspires
30 to 40 mA	Sustained muscle contraction and cramping
50 to 70 mA	Extreme pain, physical exhaustion, fainting, irreversible nerve damage; possibility of ventricular fibrillation (shocking of the heart into a useless flutter); respiratory arrest with possible asphyxiation
100 mA	Ventricular fibrillation (of the heart) and death if the current passes through the body trunk
>100 mA	Fibrillation, amnesia (memory loss), burns, severe electrolysis at contact sites
>5A	Little likelihood of survival

Table 2.3 – Electric Shock Currents and Physiological Effects

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Regulations and practices applied to the installation of electrical equipment in tankers specify the types of safe equipment that can be fitted in the areas where flammable gas and air mixtures may be present. The degree of risk is not the same throughout the hazardous areas, which include cargo tanks and the spaces above them, pump rooms, cofferdams and closed or semi-enclosed spaces with direct access to a dangerous zone (Refer Figure 2.4).

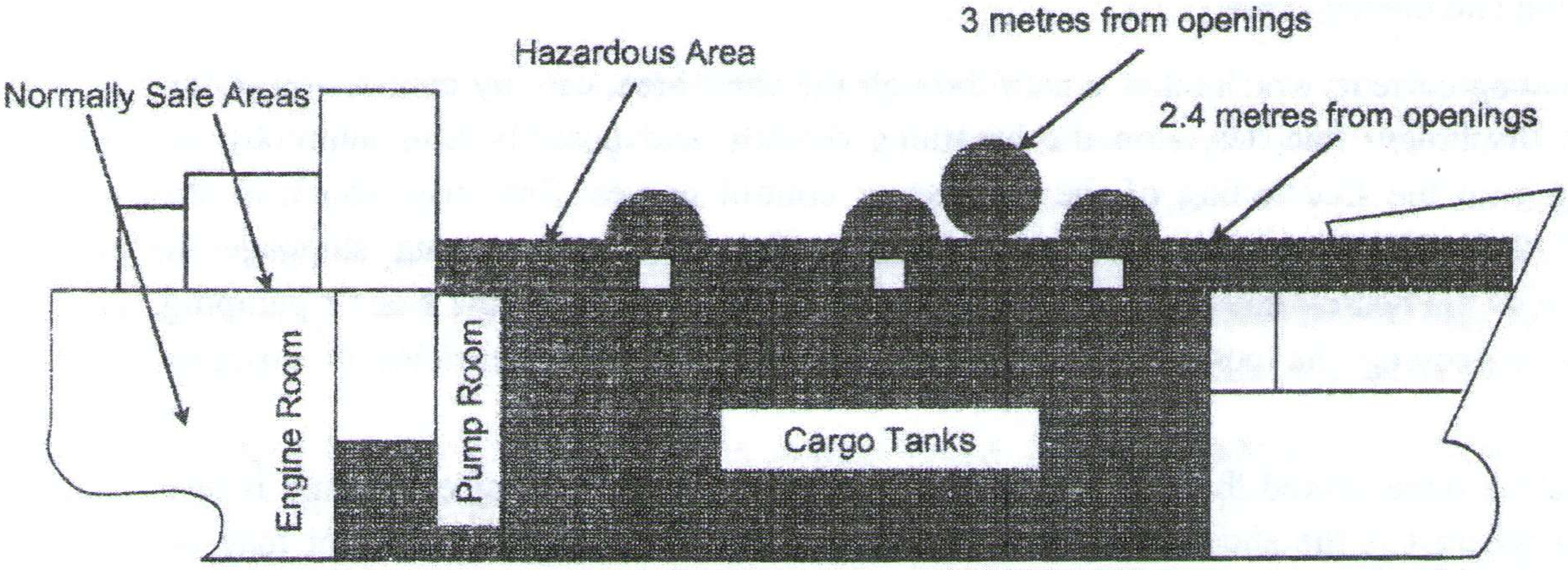

Figure 2.4 – General Tanker Arrangement
Showing Hazardous Areas and Normally Safe Areas

Cargo tanks are permitted to have only intrinsically safe apparatus which is certified to the higher Ex i(a) standard. Pump room lighting must be flameproof (Ex d) and arranged with two separate and independent circuits. Intrinsically safe apparatus to Ex i(a) standard is also allowed. Cofferdams adjacent to cargo tanks can be fitted with intrinsically safe equipment.

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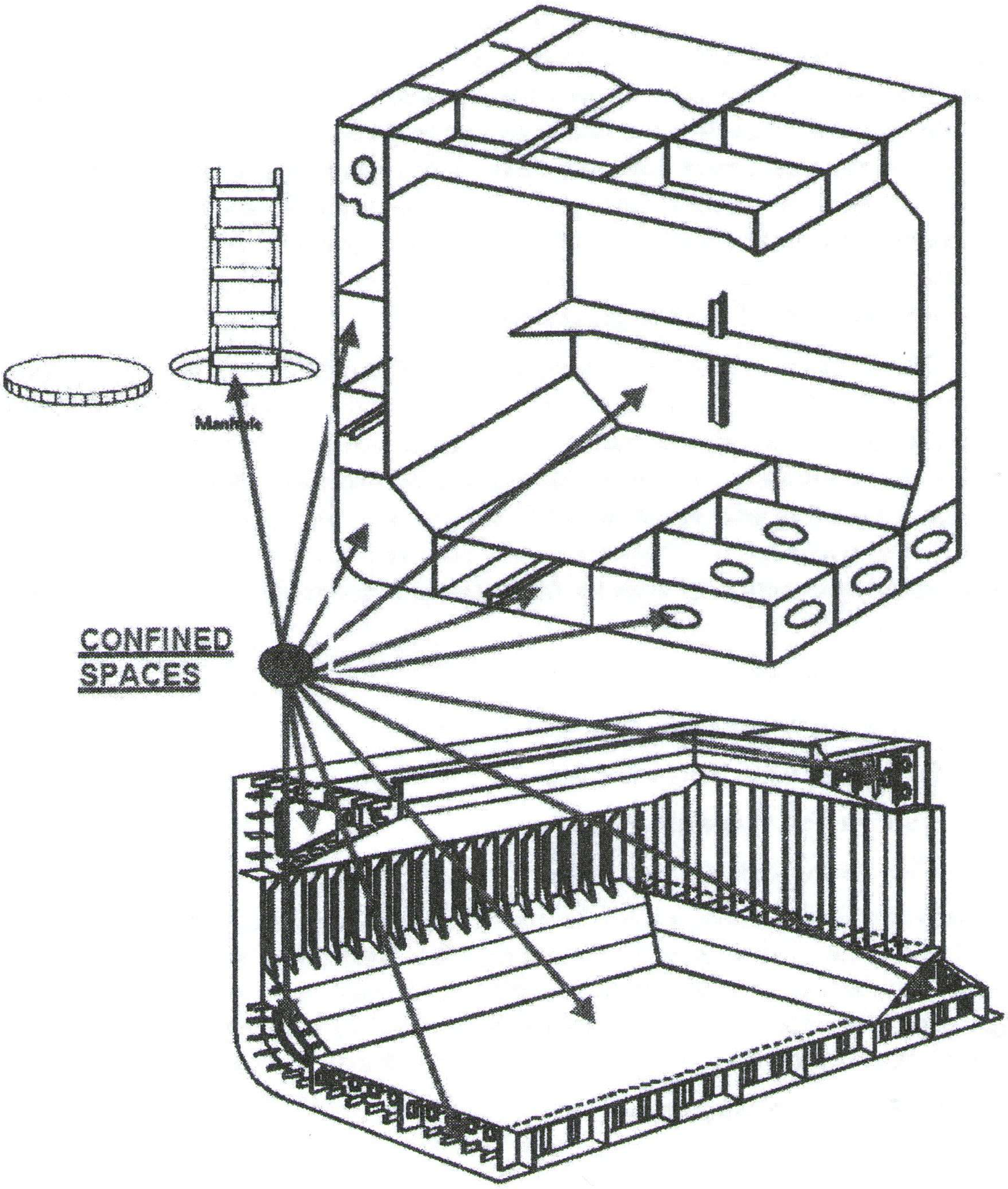

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Figure 2.5 - Examples of Confined Spaces

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The MSA tankscope is sensitive to tilt, so it is important to keep the instrument in a normal, upright position during operations or there may be a significant error in instrument readings.

24.2.2 Guidelines for use

1. Attach the sampling line to the inlet and the aspirator bulb to the outlet of the instrument. Check the air-tight integrity of the system by pinching a bight on the sampling line and squeezing the aspirator bulb. The bulb should not expand as long as the sampling line is pinched. If the bulb expands, re-check connections and non-return valves on the aspirator bulb.
2. Place the instrument in fresh air.
3. Turn the selector switch to 'Check'.
4. Switch 'On' the unit by lifting the switch on the top left hand corner of the instrument.
5. Flush fresh air through the tankscope by squeezing the rubber aspirator bulb and allowing it to expand completely. 8 to 10 squeezes are sufficient to flush the chamber. If the sampling line is used, two additional squeezes will be required for every 3 metres of line.
6. Adjust the meter pointer to the 'Check' position marked on the dial, using the 'Voltage Adjustment' knob.
7. Turn the selector switch to 'Gas'.
8. Adjust the meter pointer to 'Zero'.
9. Place the end of the sampling line where the sample is to be taken. Aspirate the sample through the instrument. The aspirator should be operated (squeezed) until the meter pointer comes to rest on the scale. With 2 metres of sampling line and probe, the meter pointer should rise on the scale within fifteen squeezes – otherwise the sample point may be considered gas free.
10. Stop aspirating and note the final reading. The reading should be taken with zero flow through the instrument and with the gas at normal atmospheric pressure. Small deviations from the normal atmospheric pressure in the instrument produce significant differences in the indicated gas concentration. If a space under elevated or reduced pressure is sampled, it is important to detach the sampling line from the MSA tankscope when aspiration is stopped; this allows the instrument to attain atmospheric pressure before the reading is noted.

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11. After each reading flush the sampling line and instrument with fresh air.

12. Recheck 'Volts' and 'Zero' controls at frequent intervals (steps 5, 6 and 7).

13. Protect the instrument from weather as much as possible and avoid exposure to very wet conditions.

24.2.3 Trouble-shooting

1. *If the meter pointer goes below the scale when the selector switch is turned to 'Gas' and cannot be adjusted to 'Zero' with the zero adjustment control:*

- The batteries may require replacement.
- The thermal conductivity filament (detector filament – white housing) may be defective and requires replacement.

2. *If the tankscope is sluggish and requires more than the specified number of aspirations for maximum deflection of the meter pointer:*

- The flashback arrestors may be clogged.
- There may be an obstruction in the aspirator coupling's flow orifice.
- The cotton filters may be choked.
- There may be a leak in the flow system.

If service other than that outlined is necessary, send the instrument ashore for repair and maintenance.

24.3 Thick Film Technology Gas Analysis

The reaction of a combustible gas with oxygen on a catalyst is used to give an extremely sensitive measurement of the concentration of that gas. Thick Film technology is used in combustion gas analysis applications to allow users to enhance combustion efficiency, saving fuel and reducing emissions (Refer Figure 24.5). This technique relies on the combustion of carbon monoxide and oxygen over a catalytic surface.

A four quadrant track is precision-printed onto a substrate using platinum ink. Each quadrant forms one leg of a Wheatstone bridge circuit (Refer Figure 24.6).

A layer of protective glaze, having a consistent thickness, is printed over the complete circuit and the catalyst which also has a consistent thickness, across two of the quadrants.

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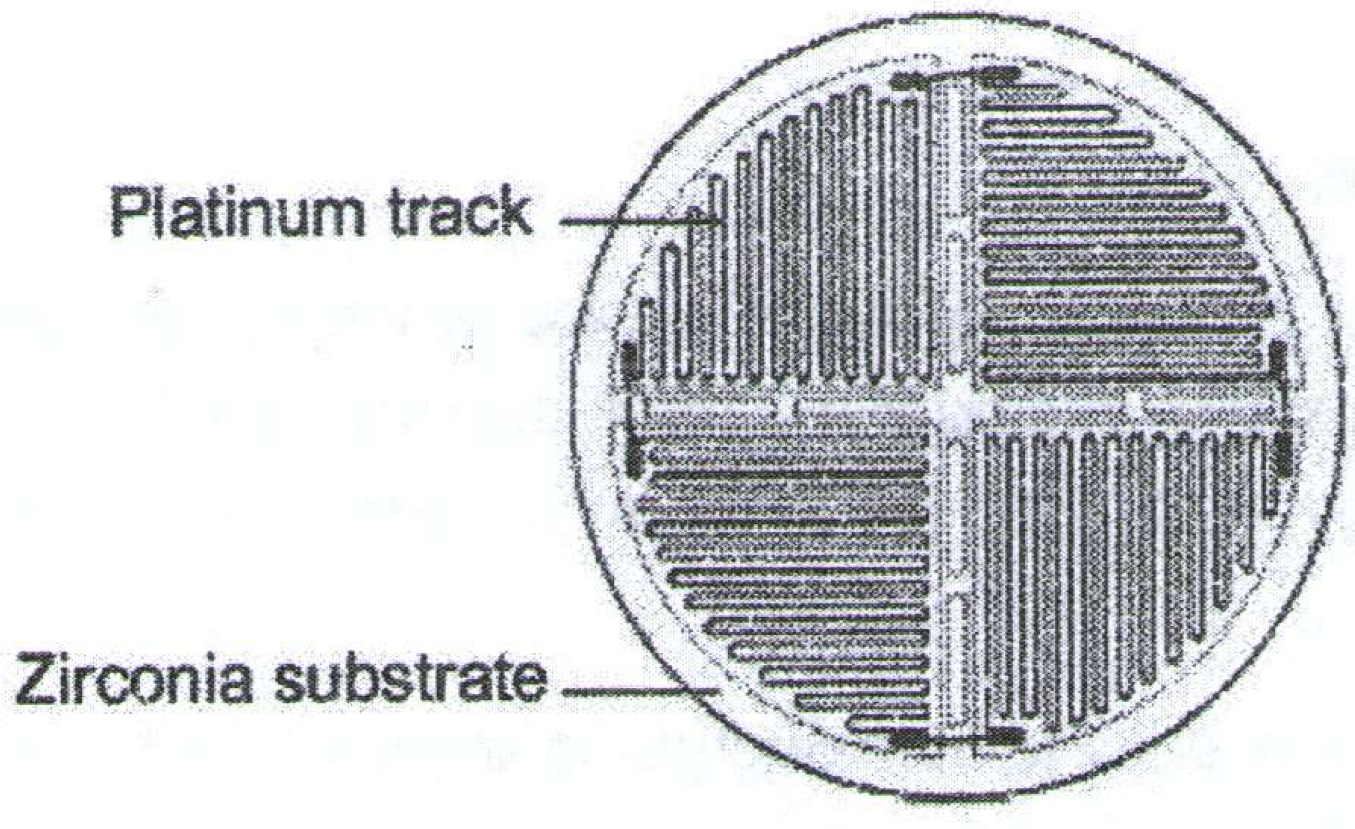

Figure 24.5 – The Thick Film

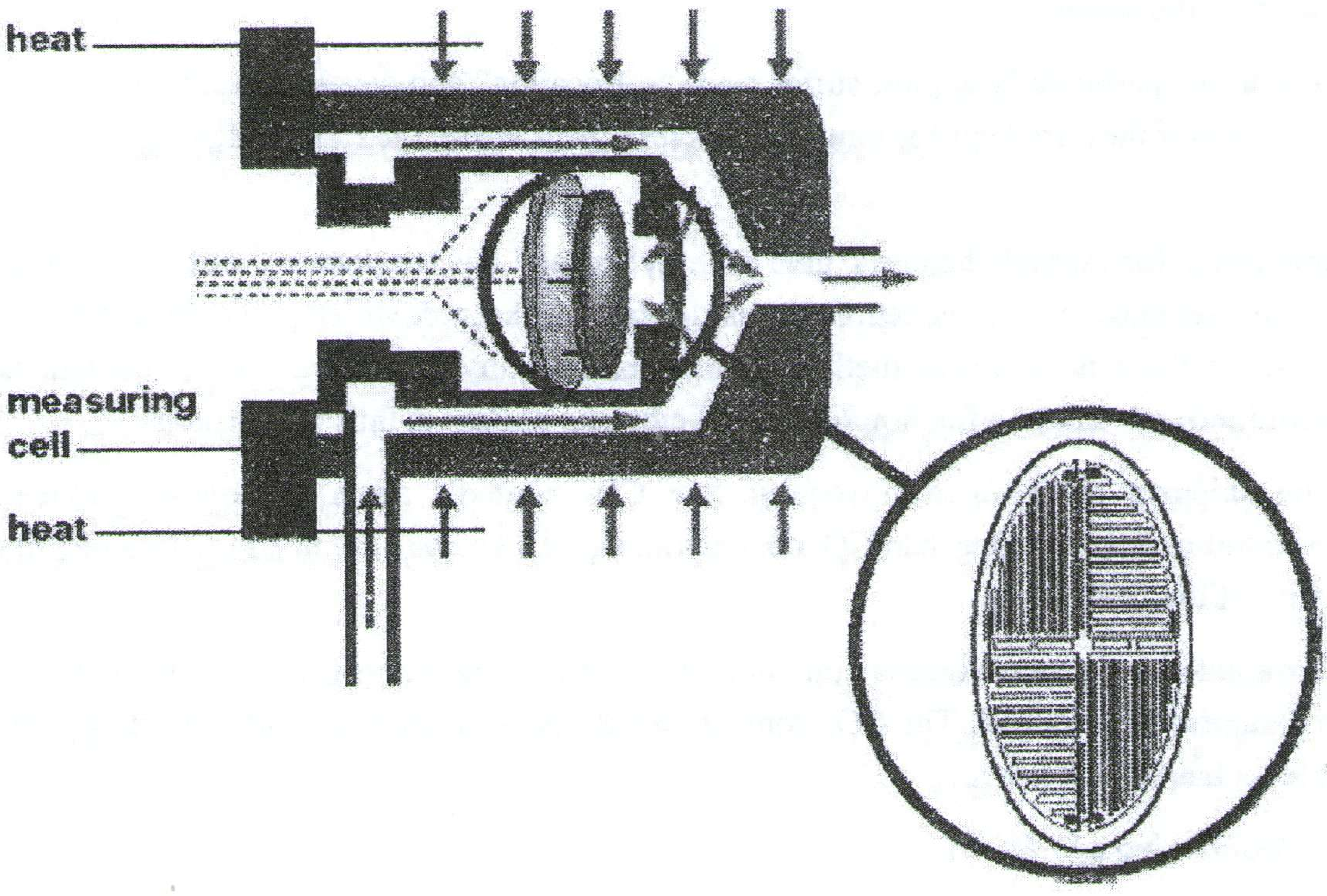

Figure 24.6 – The Sensor

The disk is mounted in a measuring cell and heated to 300°C at which stage the gas sample enters. Any carbon monoxide in the sample will burn on the catalytic surfaces, causing a heating effect. This alters the current in the circuit to produce an output that is proportional to the carbon monoxide concentration in the sample.

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24.4 Carbon Dioxide Analysis

24.4.1 Influence of Carbon Dioxide

Most fruits continue to live after picking, and breathe even when carried under chilled conditions. In breathing they absorb oxygen and release carbon dioxide into the storage space. The CO_2 content must be controlled by ventilating the space with outside air for the following reasons:

i) CO_2 content in excess of 5% with its associated reduction in oxygen content is dangerous to human life, and levels must be kept below this in case the space has to be entered;

ii) Some port authorities require the CO_2 content to be below 0.5% before men are allowed to work in the space;

iii) Many fruits, particularly apples, suffer from "suffocation" and develop internal browning of the flesh if they are kept for long in an environment where the CO_2 content is in excess of 2%;

iv) Some fruits, for example bananas, give off ethylene and this ethylene can initiate ripening of other bananas. Vigorous ventilation is desirable to keep down ethylene concentration levels. As there is no ready method of determining ethylene content, CO_2 content is determined and kept to a fraction of 1% and ethylene present is thus proportional;

v) Some shippers of citrus fruit request low CO_2 contents again to control ethylene concentration levels rather than CO_2 concentration, as they consider this may improve the quality of the fruit.

CO_2 production is most vigorous on completion of loading warm fruit, and decreases as temperatures are reduced. The CO_2 contents should be measured daily after loading until the level has settled down.

24.4.2 Monitoring of CO_2

Portable instruments for measuring CO_2 are electrical-types (based on measuring changes in thermal conductivity of the gas sample) or chemical-types (based on absorbing the CO_2 in a cartridge or solution of caustic soda).

They are used with a short length of rubber sampling tube, which can be lowered down an exhaust ventilator (or coupled to a sampling pipe if one has been built into the cooler room) and a hand aspirator.

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As portable instruments, the chemical types are more robust, although the electrical types are often used as permanently installed instruments in the engine room, from which a pipe leads to each cargo space. Permanent installations include a suction pump and manifolds for measuring each space in turn. Whatever instrument is used, it is good practice to carry a gas bottle of known concentration of CO_2 for calibration purposes. In the absence of such a bottle a rough check is to breathe into the instrument; a reading of about 5 % should be obtained.

24.5 Portable Oxygen Analyser - *Model: Draeger E-11*

The oxygen analyser is used to evaluate the O_2 content in the atmosphere. The most important part of the instrument is the sensor, which can be of different types in different makes such as

1. Electrolytic cell (Refer Figures 24.7 and 24.8)
2. Paramagnetic sensor
3. Chemical absorption sensor

24.5.1 Operation of the Electrolytic Cell Type

1. Prior to use, check the battery by changing over the 'Battery Check' switch to 'Battery Check' mode. The meter pointer should lie within the black band marked 'Batt'. It is not necessary to switch the instrument 'On' to check the battery. When it is released, the battery check switch being spring-loaded will return to its normal position.
2. Connect the remote head (sensor) to the instrument via the cable. Switch the instrument 'On' and allow it to stabilise for 10 minutes. At the end of this period, the reading should be 21% $\pm$ 1% oxygen (Provided the head is in open air). If not, it should be set using the panel potentiometer 'Set 21%' to read 21% oxygen in open air.
3. Just above and below the 21% mark there is an upper and lower alarm level. These alarms must be tested by turning the 'Set 21%' potentiometer on the front panel above and below the 21% mark until the respective alarms are activated. The instrument must then be returned to read 21% oxygen in air prior to use.
4. When moving its location, it is recommended that the instrument be kept 'On' owing to the necessary stabilisation time required for the next measurement.
5. Ensure that the alarm switch (on the rear of the instrument casing) is set to 'Operate' when an audible alarm is required, and not to 'Mute'.

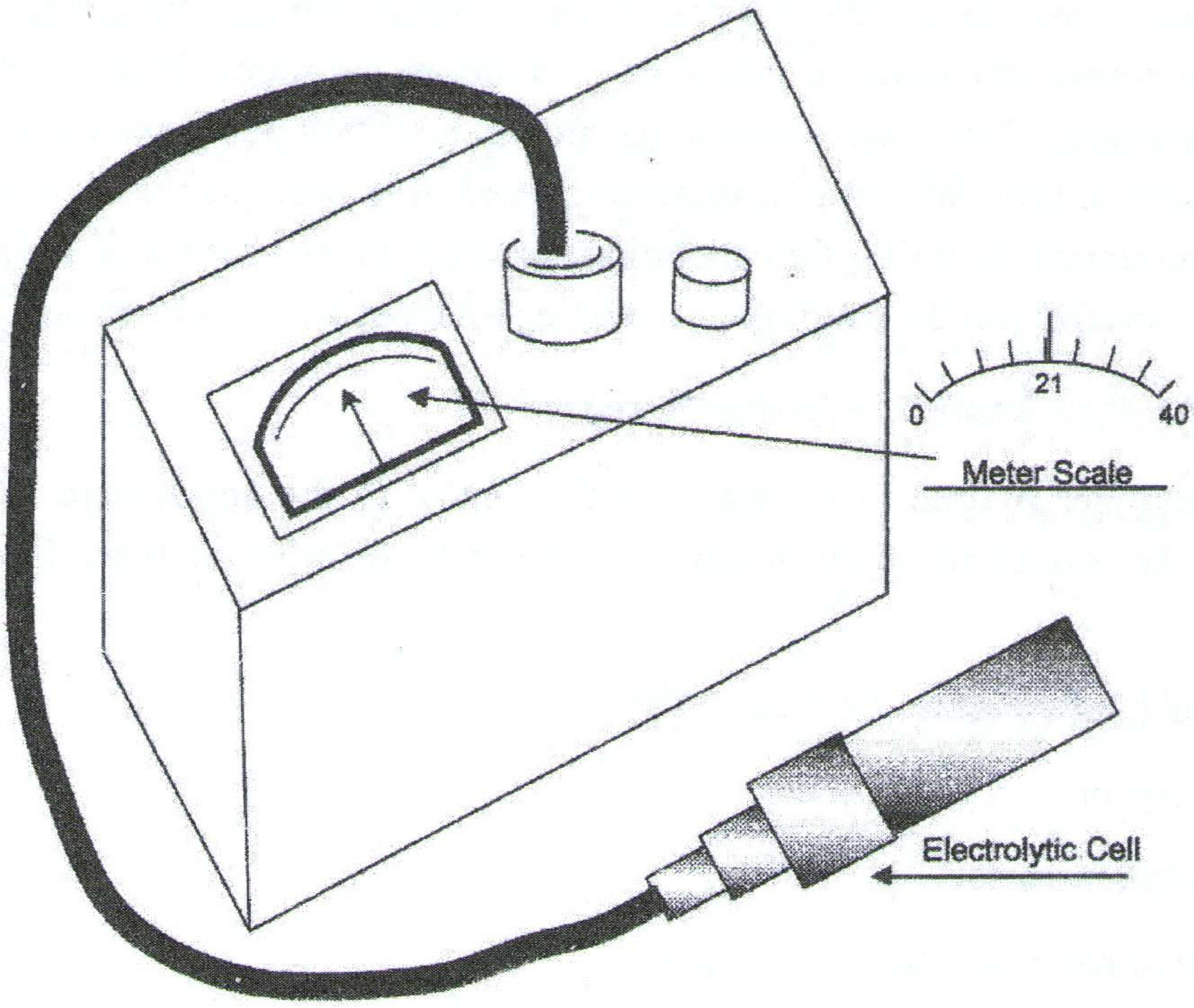

Figure 24.7 – E-11 Draeger Oxygen Analyser

24.5.2 Technical Specifications of the E-11 Draeger Oxygen Meter

1. Storage temperature: -3^0 to 50^0 C.
2. Meter display: 0 to 40 % oxygen.
3. Batteries: 2 x TR 132N Mallory Mercury Cells.
4. Maximum warm-up time: 5 minutes.
5. Accuracy: $\pm$ 5% of the reading.
6. Speed of response: 8 seconds to reach 90% of the reading.
7. Cell life: 130,000% oxygen hours at 20^0 C (Guaranteed 6 months of continuous use in 21% oxygen)
8. Remote head: Standard cable length – 10 meters; other lengths are available on demand.
9. Weight: Total weight of sensor and instrument is 2.6 kg.

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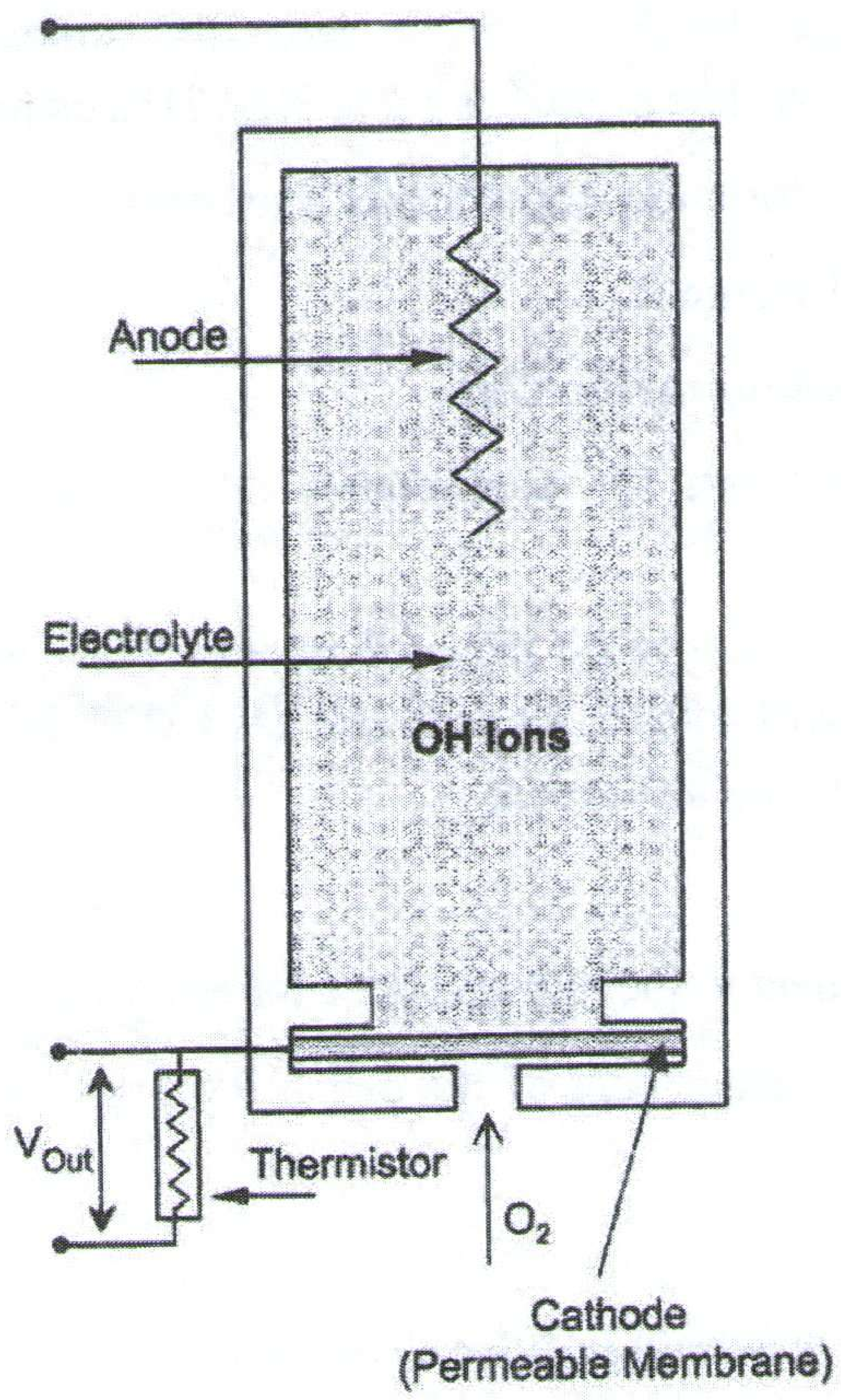

Figure 24.8 – Draeger Oxygen Analyser E-11 Probe (Electrolytic Cell)

24.5.3 Calibration

It is important that the 0_2 meter be calibrated before use. The E-11 is calibrated by using the aspirator attachment to create a flow system for calibration.

1. Open the front panel by removing the four securing screws. Take care not to break the connections to the alarm isolation switch on the rear panel, which should be set to 'Mute'. Locate the 4 potentiometers – 'A', 'B', 'C', 'D'.
2. Connect the sensor to the instrument, connect the aspirator attachment to the remote head, switch 'On' the device and leave it for 20 to 30 minutes.
3. Permit the nitrogen to flow through and leave it for approximately 10 minutes. Using potentiometer 'B' set the instrument to read 0% oxygen.

4. Place the sensor in a suitable concentration within the range of the instrument and leave it for approximately 1 minute. Fresh air drawn from the atmosphere is ideal and the instrument can be set for 21%. The pointer is set to read 21% using potentiometer 'A'.
5. Repeat steps 3 and 4 and perform any adjustments if necessary.
6. Replace the front panel and secure it.

24.5.4 Replacement of the Polarographic Cell

The polarographic cell will last for a minimum of six months in 21% oxygen at atmospheric pressure.

When the instrument can no longer be adjusted to read 21% oxygen, the cell must be replaced. Replacing the sensor will suffice. As each cell has a slightly different 'oxygen zero', it will be necessary to recalibrate the instrument.

The vessel can either:

- Return the complete instrument to the manufacturer for replacement and calibration.
- Return the sensor only for replacement of the cell if the vessel has adequate calibration facilities.

24.5.5 Fault Finding

1. *Meter pointer deflects over (extreme) positive or negative limits in all ranges of oxygen :*
   - ✓ Ensure that the batteries are firmly held in the pressure contacts; secure loose batteries or replace them.
   - ✓ Check the continuity of the cable and replace it if necessary.
2. *Meter goes to some position and does not respond to oxygen :*
   - ✓ Check the continuity of the cable and replace it if necessary.
3. *Instrument cannot be set to 21% in air:*
   - ✓ Inspect the batteries and replace them if necessary.
   - ✓ Inspect the polarographic cell and replace it if necessary.
4. *Alarm does not sound:*
   - ✓ The alarm mute switch may not be changed over to 'operate'.
   - ✓ Inspect the batteries and replace them if necessary.

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24.5.6 *Setting the Alarm Level*

1. Using potentiometer 'A' set the pointer to read the required lower alarm level setting of oxygen. Then alter potentiometer 'C' so that the alarm just sounds.
2. Using potentiometer 'A' set the pointer to read the desired upper level alarm setting. Then alter the potentiometer 'D' until the upper level alarm just sounds. Reading of the instrument should then be returned to 21% oxygen in air.

24.6 Fixed Oxygen Analyser - *Beckman Oxygen Analyser (Pauling Cell Type)*

24.6.1 *Principle of Operation*

The strong magnetic property of oxygen is virtually unique compared to other gases. Its attraction into a magnetic field (paramagnetism) is the basis for high accuracy oxygen analysis, when fast and reliable measurements are needed. On the other hand, Nitrogen is diamagnetic i.e. it is repelled by a magnet. Other paramagnetic gases are NO, and NO_2.

24.6.2 *Construction*

Two diamagnetic spheres of glass filled with nitrogen are mounted at the ends of a bar to form a dumb-bell. This dumb-bell is suspended horizontally from a quartz fibre. It operates in a strong non-uniform magnetic field. The spheres are repelled from the strongest part of the field and so rotate, twisting the suspension to its zero position when 100% nitrogen is made to flow across the field. The deflection of the pointer from zero is proportional to the force acting on the two spheres, which in turn is proportional to the oxygen content in the sample. If the O_2 content in the field changes, the force acting would change and the dumb-bell will attain a new position proportional to the O_2 change. The limitation of this type of instrument is that the deflection with a change in O_2 content is not linear and so the calibration of the scale is also non-linear. Hence although zero setting with nitrogen flow and 21% oxygen setting with airflow can be done, the scale cannot be divided into 21 equal divisions.

24.7 Beckman Oxygen Analyser *(Munday Cell Type)*

24.7.1 *Principle of Operation*

The 'Zero' position of the dumb-bell is sensed by a split photocell. This cell receives light reflected from a mirror, which is fixed on the suspension. The output from the photocell is amplified and fed back to a coil wound on the dumb-bell so that a restoring torque due to feedback current balances the torque due to oxygen in the sample.

The measuring system is thus 'null balanced' and has all the inherent advantages of this type of system. This electro-magnetic feedback also stiffens the suspension damping it heavily (Refer Figures 24.9(a) and 24.9(b)).

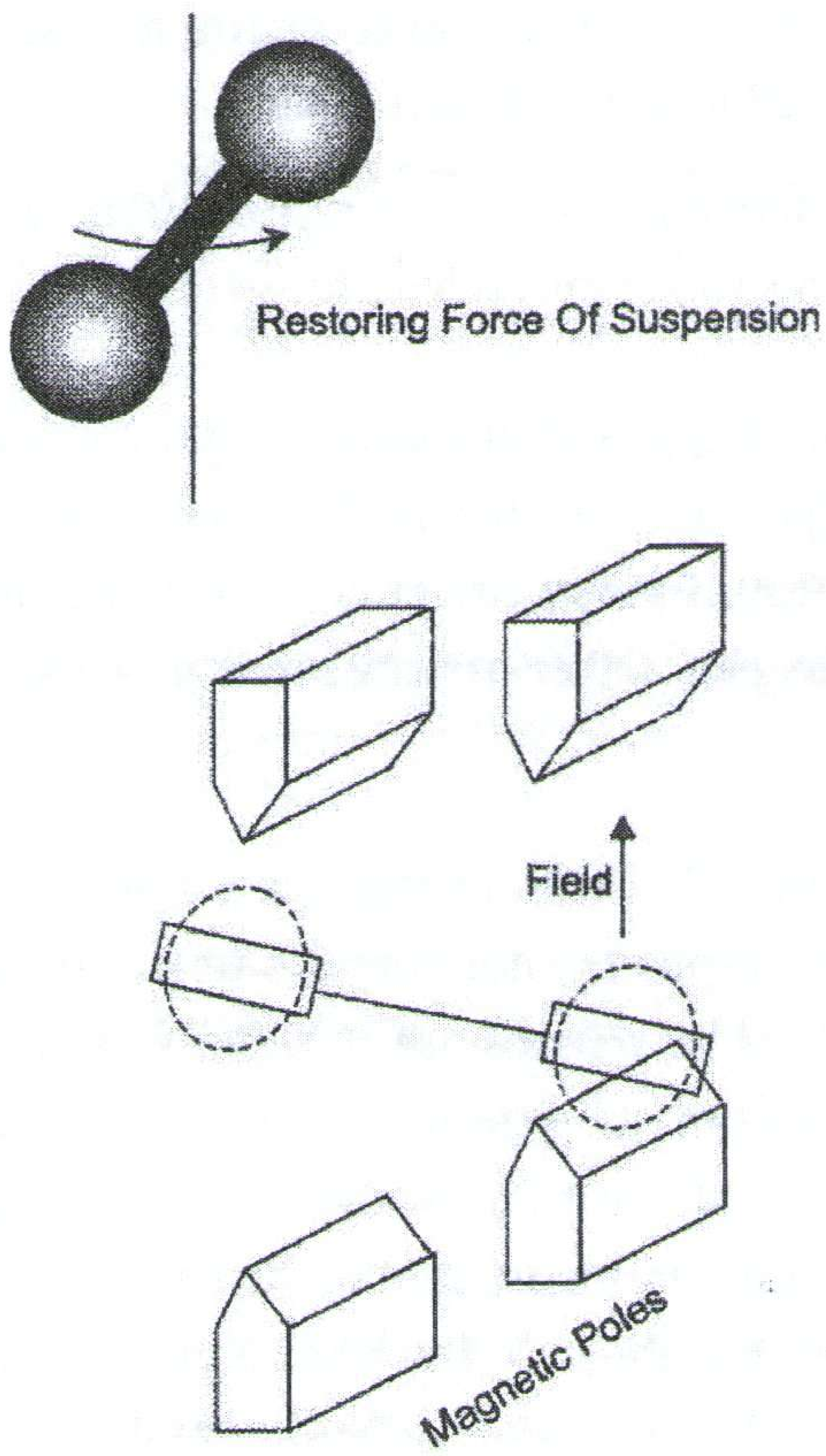

Figure 24.9(a) – Sensitive Element of the Munday Cell

Because of a linear relationship between feed-back current and the susceptibility of the sample, a proportional voltage can be developed, and various ranges can be obtained. Linearity of its scale also makes it possible to calibrate the instrument for all ranges by checking it at only two points, i.e., for 'zero' using pure nitrogen and 21% using air and dividing the scale into 21 equal divisions unlike the earlier model.

The instrument continuously monitors the oxygen percentage in the inert gas at a point after the blowers. There are displays in the cargo control room (CCR), engine control room (ECR) and locally at the instrument. An alarm is incorporated to ring when the O_2 content goes above 8%. The oxygen content can also be recorded continuously.

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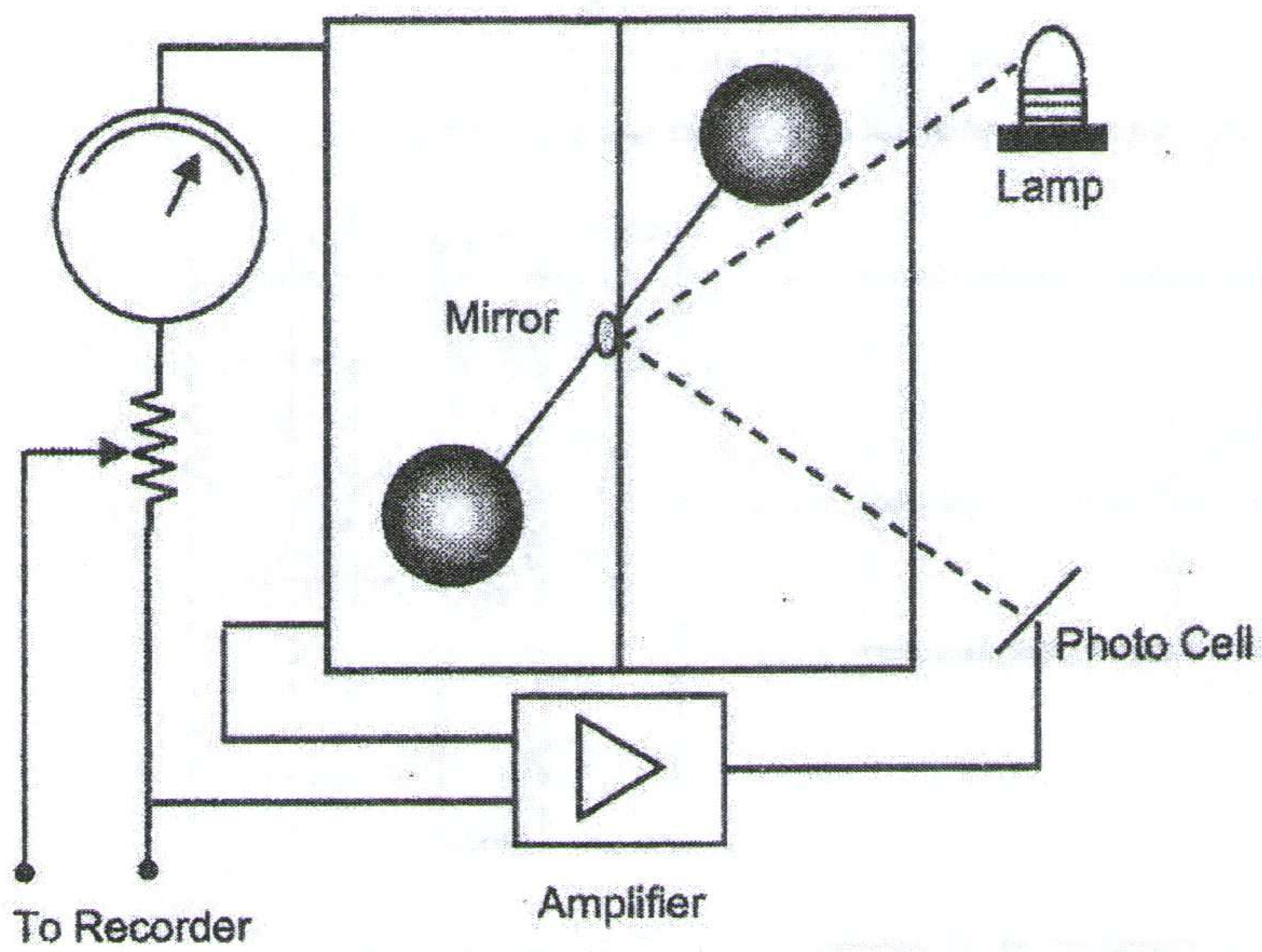

Figure 24.9(b) – Basic Circuit of the Munday Cell

24.7.2 Construction

This differs from the Pauling cell type wherein a platinum ribbon suspension is used and facilitates a considerable increase in physical strength (Refer Figure 24.10).

In addition, an electro-magnetic feedback is used to maintain the dumb-bell at its zero position. In a sample containing oxygen, the dumb-bell tends to deflect. The current required to maintain the dumb-bell at its zero position is measured and shown on the scale. The greater the deflection, the greater will be the current required to restore the dumb-bell to its zero position. Thus, this current represents the magnetic susceptibility of the gas present in the cell and therefore the O_2 concentration.

The advantages of this instrument are:

- Calibration is simple – nitrogen is used for zero calibration and air for span at 21% oxygen.
- There is virtual independence from variations in the sample gas composition.
- The scale is linear over the complete range (0 – 100 % oxygen), although the meter itself may only be graduated up to 21% or 40% oxygen.
- Response time is fast as there is no heating or cooling of filaments.
- The analyser is not sensitive to tilt.

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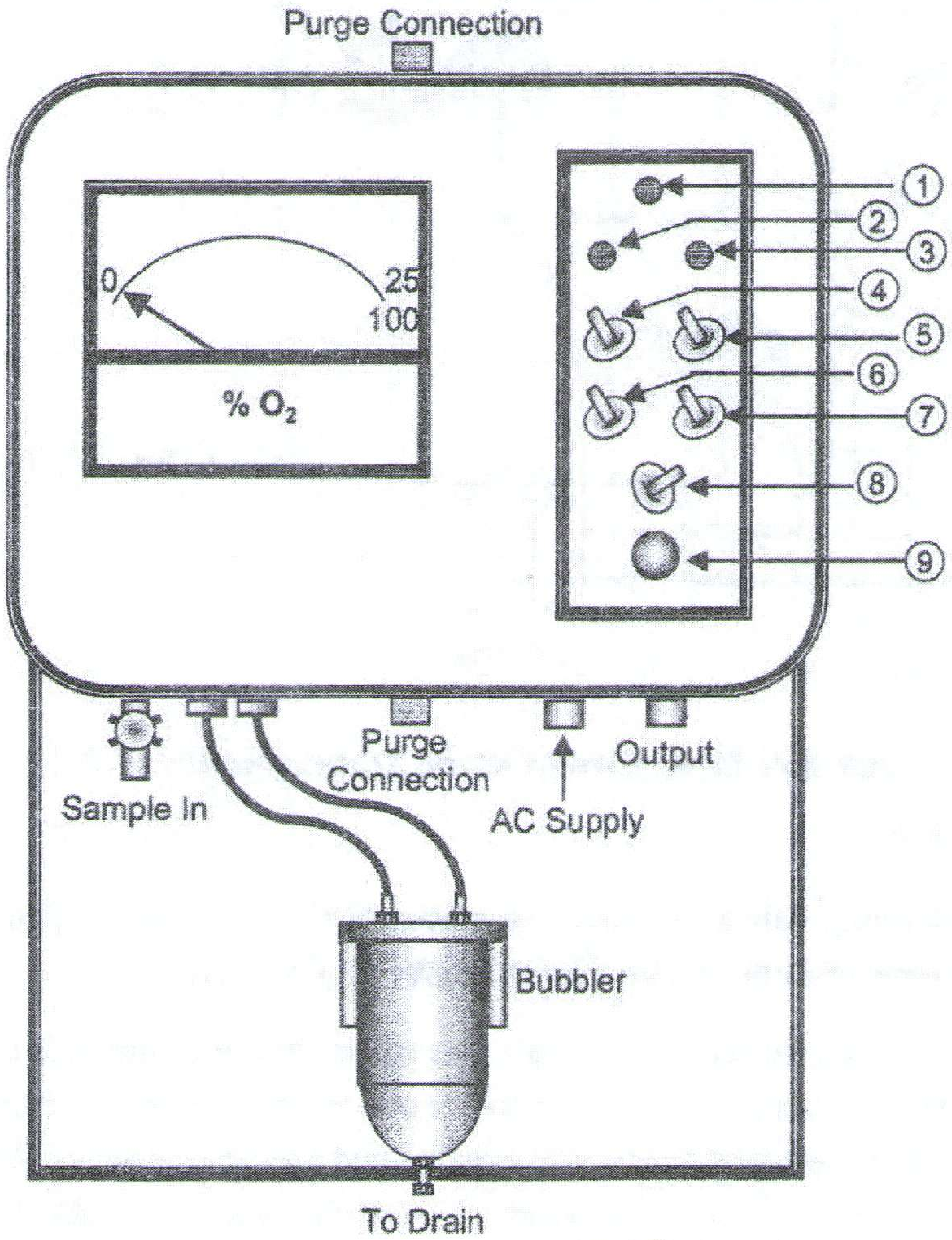

1 - Set Temperature
2 - Span Adjustment
3 - Zero Adjustment
4 - Lamp On
5 - Feedback On
6 - Power On
7 - Reset
8 - Range (%O_2)
9 - Lamp

Figure 24.10 – An Oxygen Analyser

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24.7.3 Starting Procedure

- Switch on the supply (the supply is pre-set to 110 or 220V).

Note: A voltage set higher than this will reduce the life of the lamp.

- Allow at least 2 hours (or as instructed by the manufacturers) for the analyser to warm up before passing the sample through it. This helps the instrument to attain proper sensitivity and prevents condensation of moisture in the instrument.
- A green indicator lamp glows when the heater is on. The lamp will go off when:
    1. Power supply fails.
    2. Temperature exceeds the cut-off point (around 60^0 C).
    3. The thermal fuse fails.
- Open the sample flow valve to obtain the normal operation flow rate of 100 cc/min; a total inert gas flow rate between 100 cc/min - 1500 cc/min is acceptable but the instrument should be preferably set at 200 cc/min of which 100 cc passes through the instrument and the excess 100 cc bypasses to the bubbler unit.

24.7.4 Shut-down Procedure

- Shut off the sample gas supply by closing the gas inlet valve.
- Flush out the sample system with instrument quality dry air for 6 hours or flush with dry nitrogen for 3 hours.
- After flushing for an appropriate time, switch off the main electric supply and allow the analyser to cool.
- Maintain flushing until the analyser has cooled internally to within 2^0 C of the ambient temperature. This is to avoid condensation of corrosive moisture of the gas trapped in the instrument.

24.8 Zirconia Oxygen Analysis

Zirconia is a ceramic that conducts electricity at high temperature by the movement of oxygen ions. This property is used in oxygen measuring cells for applications such as combustion gas analysis or gas purity measurement. This technique gives a robust way of accurately measuring oxygen.

It is used in combustion gas analysis in power stations where aggressive, hot gas mixtures are the norm and other industrial gas applications along with medical and physiological applications where extremely fast response times are paramount.

Some ceramics conduct electricity at high temperature through the movement of charged oxygen ions; zirconia is such a ceramic.

This ability can be used to measure oxygen in a gas mixture especially for direct measurement of hot flue gases; thus the need for sample conditioning equipment in combustion applications is reduced (Refer Figure 24.11).

A zirconia disk is mounted between the gas to be measured and a reference gas (usually air), inside a heater. Electrodes are connected to either side of the disc (Refer Figure 24.12). If there is a difference in oxygen concentration between the two sides of the disk, a voltage is generated and detected by the electrodes.

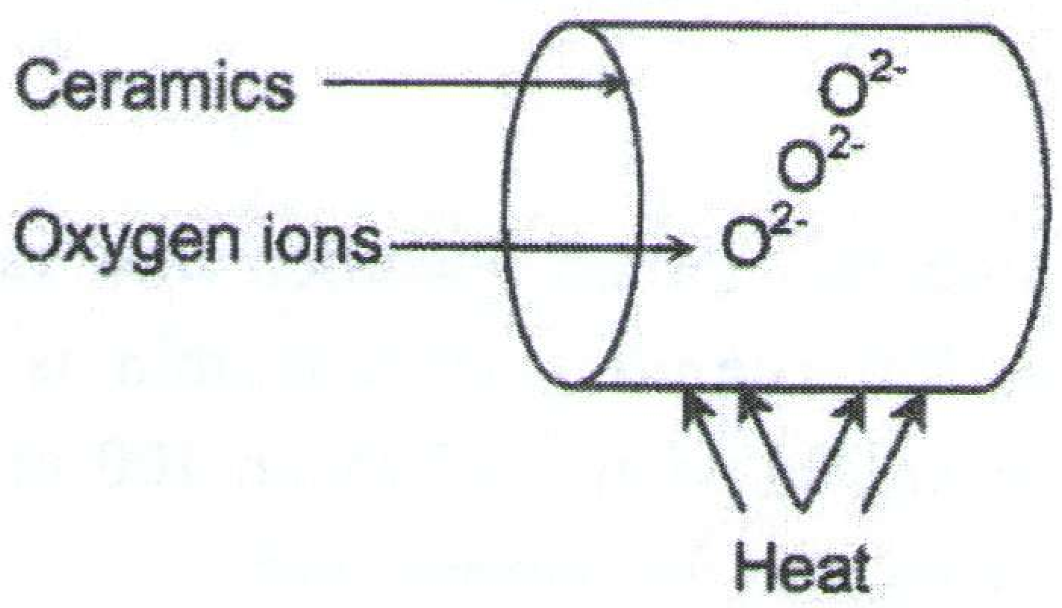

Figure 24.11 – The Basic Device

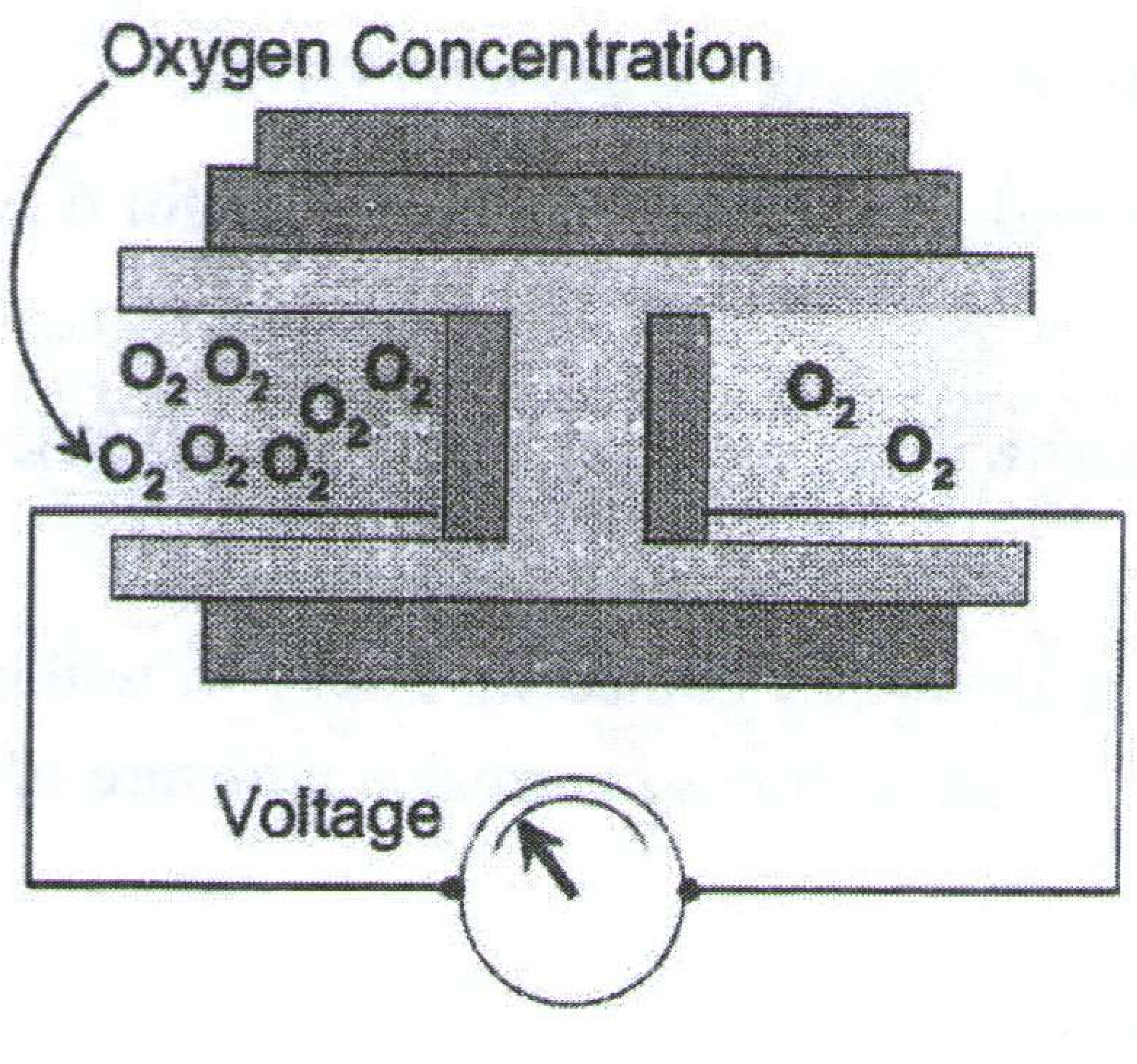

Figure 24.12 – Construction of the Sensor

In use, the zirconia disk is mounted on a flexible diaphragm in a rugged body - making it resistant to both thermal and mechanical shock (Refer Figure 24.13).

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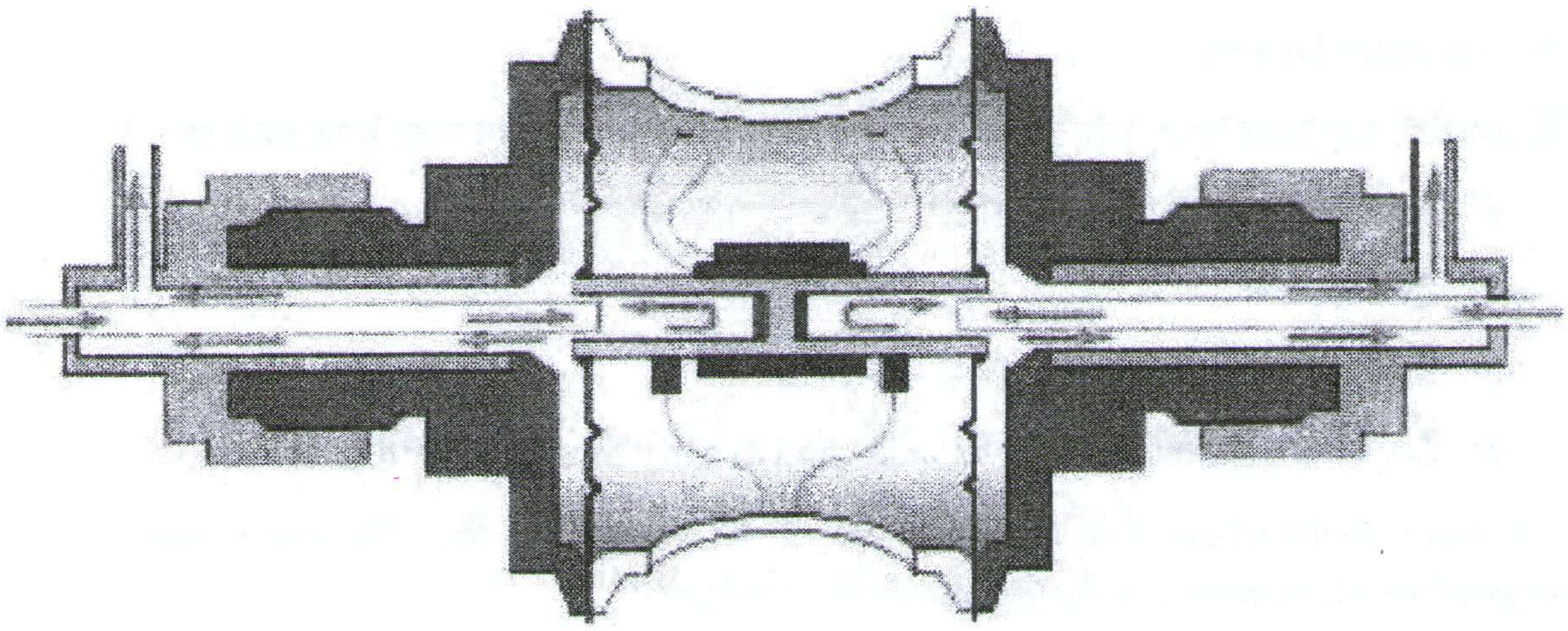

Figure 24.13 – The Device in use

24.9 Things to Remember

24.9.1 Presence of Gas

There may be flammable gas in the tank; it may be at any opening to the tank -

- After loading or discharging volatile petroleum
- After loading non-volatile petroleum into a tank which is not gas-free

24.9.2 Pressure

- Vapour in tanks may be under pressure

24.9.3 In Spaces Declared Gas-Free, Further Gas may be Released…

- After loose scale or sludge is disturbed
- After a heating coil is opened up
- When a pipeline or valve is opened up
- When a cargo pump or valve is opened up
- When a cargo vent line is opened up

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24.9.4 In Other Spaces…

Flammable gas may be in any space into which volatile petroleum may leak such as -

- Pump rooms
- Cofferdams
- Ballast tanks
- Empty compartments next to tanks used to carry low flash point petroleum

Note: *A space declared gas-free is free of gas at the time of the test. The space may not remain gas-free. Remember that further gas may be released.*

The absence of flammable mixtures does not necessarily mean the space is gas-free and safe.

Remember: *toxic gases are not necessarily flammable.*

Before you open a tank, any pressure must be released. This has to be done very carefully under controlled conditions.

Openings must be re-closed as soon as possible. A space may be certified gas-free and be:

- ✓ Safe for men and cold work (includes jobs which can cause sparks or enough heat to ignite any nearby vapour e.g., hammering).
- ✓ Safe for hot work (work that is so hot that it can actually cause dirty parts of a tank to give off vapour e.g. welding. This vapour can of course be ignited by the work).

24.10 Relevant Rules

24.10.1 Relevant SOLAS Regulations

Chapter II – 2 – Part B – Prevention of Fire and Explosion – Regulation 4 – Probability of Ignition and Chapter VI – Part A – General Provisions – Regulation 3 – Oxygen Analysis and Gas Detection Equipment.

24.10.2 Summary of Regulations

1) Tankers shall be equipped with at least one portable instrument (and means for its calibration) for measuring flammable vapour concentrations, together with a sufficient set of spares. Suitable means shall be provided for the calibration of such instruments.