Section 7

Cathodic Corrosion Protection

A. General

The design and arrangement of the cathodic protection systems shall take into account the specific requirements of the structure or the component. These protection systems must ensure the corrosion protection for the specified protection duration.

To be able to guarantee sufficient protection, the structure must be adequately polarized. The protective potentials specified in Table 7.1 shall be observed.

The cathodic protection systems must be compatible with the coating that is applied, i.e. their use must not lead to an impairment of the quality and functionality of the coating. Evidence of the durability should be provided in accordance with the requirements of STG Guideline No. 2220 or an equivalent standard.

The ship or the structure to be protected must be subdivided into a suitable and expedient number of cathodic protection zones (KSZs). These are surfaces of varying corrosive stress or different areas of action as a result of geometric conditions. The areas of the corresponding KSZs must be determined or estimated as precisely as possible. The necessary protective current density for a KSZ should be chosen in accordance with the recommendations of Table 7.2, and those of the corresponding protective potential in accordance with Table 7.1.

The required consumption of protective current for a KSZ (I_{KSZ}) is obtained from the product of the KSZ area (A_{KSZ}) and the corresponding protective current density (i_{KSZ}):

Equation I: $I_{KSZ} = A_{KSZ} \cdot i_{KSZ}$

For the outer shell of ships with the Class Notation **IW** and for seawater ballast tanks, the Rules for Classification and Construction, I – Ship Technology, Part 1 – Seagoing Ships, Chapter 1 – Hull Structures, Section 35 shall be observed.

Table 7.1 Protective potentials for the KKS of various metals in seawater

Material of the structure to be protected	Range of the protective potential (Ag/AgCI/seawater)	
	Negative minimum potential	**Negative maximum potential**
AlMg and AlMgSi alloys	– 0,80 V	– 1,10 V [1]
Steel / cast iron		
– Aerobic conditions	– 0,80 V	– 1,10 V
– Anaerobic conditions	– 0,90 V	– 1,10 V
High-tensile steels ($Rp_{0,2} \geq$ 700MPa) [2]	– 0,80 V	– 0,95 V
Stainless steels [2, 3]		
– Pitting resistance equivalent $\geq W_{min.}$ [4]	– 0,30 V	– 1,05 V
– Pitting resistance equivalent $< W_{min.}$ [4]	– 0,60 V	– 1,05 V

1 A possible cancellation through over-protection and also the risk of hydrogen embrittlement with higher-strength alloys must be considered.

2 With steel types that are sensitive to hydrogen embrittlement and crack initiation and with duplex steels which exhibit an unfavourable grain structure (e.g. because of incorrect application of heat), a protective potential of no less than – 0,83 V must be maintained.

3 Martensitic steels tempered for high strength (R_m > 1 000 MPa) should have a protective potential between – 0,50 and – 0,70 V.

4 See Section 3.4.2.1.1

Table 7.2 Protective current densities for various cathodic protection zones

Typical KSZ			Protective current density (i_S) (minimum value) [mA/m²]
Coated out shell [1] of steel ships with speeds	up to 20 kn		15
	20 – 25 kn		30
	over 25 kn		40
Coated outer shell of steel ships used for voyages in ice			60 [2]
Outer shell of ships made of aluminium alloys	Coated		4
	Uncoated		20
Outer shell of ships made of stainless steel	Coated		2
	Uncoated		20
Other uncoated underwater surfaces			200
Propeller surfaces			≥ 500
Trim, ballast water, slop and sludge tanks or similar	Coated surfaces		10
	Uncoated surfaces		120
Tank tops (inner bottoms), bilges or similar			20 – 100 (depending on loading, coating and accessibility)
Underwater zone of stationary steel structures (depending on the environmental conditions)	Uncoated	DTZ	80 – 130
		WTZ	Current density of the uncoated sustained submersion zone + 20 %
	Coated	DTZ	1 – 2 % of the uncoated sustained submersion zone + 1 – 1,5 % per year
		WTZ	2 – 5 % of the uncoated sustained submersion zone + 1 – 1,5 % per year

1 For service in primarily tropical waters, higher protective current densities can become necessary.
2 In the case, that GL approved ice-coatings have been applied the protective current density can be reduced to 40 mA/m².

B. External Protection through Sacrificial Anodes

1. Field of application

This section applies for the cathodic corrosion protection of the underwater surfaces of ships and floating units through sacrificial (galvanic) anodes (also termed "anodes" in the following) in seawater and brackish water.

2. Design fundamentals

The protection period should be designed for one drydocking interval, but at least for 2 years (17 520 h).

2.1 Protective current density

Reference values for the required protective current densities are given in Table 7.2. Protective current densities for non-specific areas or for CPZs which represent special areas from a corrosion protection viewpoint (bow thrusters, water-jet drives etc.) shall be determined individually in each case.

The calculated underwater area applies only for the hull; for the determination of the overall area A_G to be protected, the additional cathodic protection zones (such as the appendages, propeller and shafts) are calculated separately according to drawings and then added.

The protection of openings, e.g. sea cheats, and other KSZs lying outside the region of action must be calculated in addition.

2.2 Calculation of the protective current

The required total protective current is:

Equation II: $I_G = A_G \cdot i_S$

where:

I_G = total protective current

A_G = total area to be protected

i_S = protective current density

The protective current for cathodic protection zones to be handled separately must be determined by

Equation I: $I_{KSZ} = A_{KSZ} \cdot i_{KSZ}$

2.3 Calculation of the required anode weight

The required total anode weight is:

Equation III: $m_G = \frac{I_G \cdot t_S}{Q_g}$

where:

m_G = required total anode weight

I_G = total protective current

t_S = protective period

Q_g = electrochemical efficiency of the anode alloy

The required anode weight of a KSZ to be handled separately is:

Equation IV: $m_{KSZ} = \frac{I_{KSZ} \cdot t_S}{Q_g}$

If an area which has to be considered separately, such as a bow thruster, consists of several cathodic protection zones (impeller, bracket, tunnel), the required total mass must be calculated by addition of the individual values.

3. Anode selection

3.1 Anode materials

Concerning the materials for galvanic anodes, aluminium or zinc alloys as per the requirements set out in Table 7.3 or 7.4 or as per VG 81255, equivalent standards or specifications approved by GL must be applied.

Table 7.3 Sacrificial anodes of zinc alloys for applications in seawater

Element	GL-Zn1	GL-Zn2
Al	0,10 – 0,50	≤ 0,10
Cd	0,025–0,07	≤ 0,004
Cu	≤ 0,005	≤ 0,005
Fe	≤ 0,005	≤ 0,0014
Pb	≤ 0,006	≤ 0,006
Zn	≥ 99,22	≥ 99,88
Potential (T = 20 °C)	– 1,03 V Ag/AgCl/See	– 1,03 V Ag/AgCl/See
Q_g (T = 20 °C)	780 Ah/kg	780 Ah/kg
Efficieny (T = 20 °C)	95 %	

Table 7.4 Sacrificial anodes of aluminium alloys for applications in seawater

Element	GL-Al1	GL-Al2	GL-Al3
Si	≤ 0,10	≤ 0,10	Si + Fe
Fe	≤ 0,10	≤ 0,13	≤ 0,10
Cu	≤ 0,005	≤ 0,005	≤ 0,02
Mn	N/A	N/A	0,15 – 0,50
Zn	2,0 – 6,0	4,0 – 6,0	2,0 – 5,0
Ti	—	—	0,01 – 0,05
In	0,01 – 0,03	—	0,01 – 0,05
Sn	—	0,05 – 0,15	—
Other El.	≤ 0,10	≤ 0,10	≤ 0,15
Al	Residue	Residue	Residue
Potential (T = 20 °C)	– 1,05 V Ag/AgCl/See	– 1,05 V Ag/AgCl/See	– 1,05 V Ag/AgCl/See
Q_g (T = 20 °C)	2000 Ah/kg	2000 Ah/kg	2700 Ah/kg
Efficiency (T = 20 °C)	95 %		

Other material combinations, as specified in Table 7.3 and 7.4: Sacrificial anodes of aluminium alloys for applications in seawater, are only permissible for sacrificial anodes if their suitability and protective effect can be verified, either through successful and documented service over many years or through suitable testing methods.

Anodes of magnesium alloys are not permissible in ship and offshore technology, neither for cargo tanks and ballast water tanks nor for the protection of the ship's outer shell nor as a temporary protection. An exception here is presented by applications solely in fresh water.

In the case of ambient temperatures exceeding 25 °C, the reduced capacity and effectiveness of the sacrificial anodes must be taken into account for the design and arrangement. This is especially applicable to hot transverse bulkheads (e.g. walls adjoining fuel tanks). Conventional sacrificial anodes of zinc must only be used up to an ambient temperature of 50 °C for the protection of steel. If special alloys are to be used at temperatures exceeding 50 °C, their electrochemical characteristic and protective effect must be verified separately. The capacity of aluminium anodes is also reduced. In the case of high temperatures, it can be calculated as an approximation within the temperature range from T = 20 to 80 °C using the following equation:

Equation V: $$Q_g(t) = 2000 - 27 \cdot (T - 20\,°C) \quad [Ah/kg]$$

Experience shows that there are also special alloys for aluminium anodes which possess greater current capacities at high temperatures than the values calculated according to equation V. The manufacturer must then verify and guarantee these values.

3.2 Shape and mounting

The shape and size of the anodes must be suitable for the intended purpose. For the ship's outer shell, flat anodes must be specified, to keep the flow resistance to a minimum. Applicable instructions are given in VG 81257.

Here it must be ensured that the selected anodes provide the required protective currents and the calculated anode weight through their number and shapes.

Depending on the material to which the anodes are affixed, mountings of hull structural steel (H), stainless steel (SS), non-magnetic austenitic steel (NM) or aluminium (Al) must be used.

H = GL–B or equivalent type of steel with regard to strength and weldability

NR = X6CrNiMoTi17-12-2 (1.4571) according to DIN EN 10088-2 or equivalent type of steel with regard to strength, weldability and corrosion resistance.

NM = X2CrNiMoN18-14-3 (1.3952.9) according to WL 1.3952-1 or at least equivalent type of steel with regard to strength, weldability, corrosion resistance and non-magnetic properties

Al = AlMg4,5Mn (3.3547) or other type according to EN 573 that can be agreed upon when the order is placed

The mounting bracket of ship structural steel, zinc-plated with a thickness >25 µm, must be free of cracks and impurities. Zinc coatings are not suitable for aluminium anodes.

The mounting of stainless steel or non-magnetic steel must be pickled.

Mountings of aluminium must be free of impurities.

4. Arrangement of the anodes

4.1 Fastening the anodes

The connection between the anode and the area to be protected must be metallically conductive. For this reason, the anodes must be welded on.

In the case of low shell thicknesses, sensitive materials or platforms, mounted plates (doubling) of sufficient thickness must be welded on, with an extra border of 20 mm on all sides around the welding points of the anode.

If bolted connections cannot be avoided in exceptional cases – which must be agreed upon with the client – a metallically conducting connection, e.g. through welding points, must be provided.

4.2 Shadow effect and openings

The anodes must be arranged so that a shadow effect is largely avoided.

Openings in the outer shell, e.g. for sea cheats, lateral thrust propellers or similar, must be protected in addition. It must be taken into account that openings are protected by externally placed anodes only up to a depth of one to two times the opening diameter.

4.3 Anode-free areas

In order not to impair the inflow of water to the propeller, an area depending on the diameter of the propeller, according to Fig. 7.1, should be kept free of anodes.

The dimensions given are reference values which depend on the shape of the hull and the speed.

Areas in which the flow conditions must not be impaired (e.g. in the vicinity of sonar domes or openings for pitot heads) must be kept free of anodes according to the corresponding instructions of the manufacturer.

In the tunnel of bow thrusters, the anodes should be arranged by agreement with the manufacturer of the thruster unit.

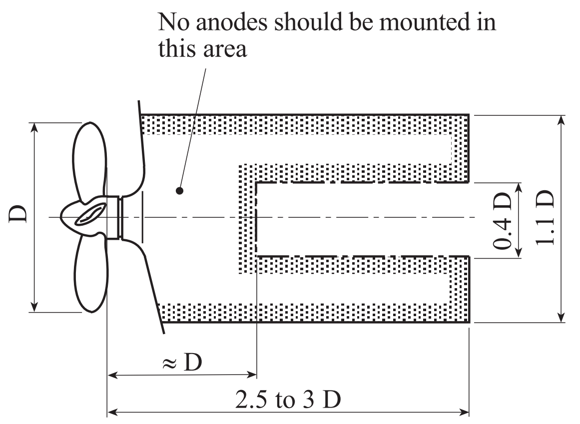

Fig. 7.1 Anode-free zone in way of the propeller (example) as per VG 81256-2

4.4 Complete protection

The anodes required according to B. serve to protect the entire ship and must be distributed over the entire underwater area of the vessel. For the stern area, about 25 % of the total anode weight must be used for single-propeller ships, and about 30 % for multi-propeller ships; for the arrangement, see 4.6.

The remaining anode weight must be distributed over the midbody and the forebody.

In way of the bilge, the anodes must be arranged so that they cannot be damaged when the ship is berthed. In the case of bilge keels, the anodes must be arranged in alternation on their upper and lower sides; if the bilge keel height is not sufficient for this, the anodes must be arranged on the hull near the bilge keel in alternation above and below the bilge keel.

The anodes near the bows must be arranged in the direction of water flow and placed so that they cannot be damaged by the anchor chain.

4.5 Part protection (stern protection)

For ships where only the aftship is protected, about 25 % or 30 % of the total anode weight must be applied within the scope of the complete protection according to 4.4. With this partial protection of the ship, at least 2 anodes of the same shape, or 10 % of the actual stern protection must be applied in addition. These additional anodes shall be fixed 3 to 8 m in front of the front anode of the actual stern protection. In case of the Class Notation **IW** the complete underwater hull has to be protected in any case.

4.6 Arrangement at the stern

When determining the anode arrangement in the stern area, the local flow conditions must be considered and the following points must be taken into account:

– Above the propeller well and the heel piece just before the propeller well, at least one anode just be mounted on each side.

– In way of the stern tube exit, the necessary anodes must be arranged (at least one on each side), whereby special attention must be paid to the anode-free area according to 4.3 and Fig. 7.1.

– To protect the shaft brackets, anodes must be applied near their mountings on both sides of the hull; size and material of the shaft brackets must be taken into account for the number of anodes.

– As a rule, propellers and shafts should be included in the cathodic corrosion protection of the outer shell. These parts must be connected conductively with the hull by means of sliprings on the propeller shafts and brushes. To achieve a low-impedance connection, the split bronze or copper ring must have a rolled-in silver layer, on which the brushes of metallic graphite run. The transfer voltages should lie under 40 mV. For monitoring purposes, a measuring instrument must be installed permanently via a separate carbon brush.

– It is possible to cathodically protect the propeller and shaft solely through a zinc ring mounted on the propeller hub or on the shaft.

– The rudders of fast ships (speeds over 30 knot) should as a rule only be protected by anodes adapted to the rudder profile, e.g. shape RA according to VG 81257. If this is not possible, the rudder must be included in the complete protection scheme by cable or copper-band connections to the hull.

– Rudder heels must be given one anode on either side. The width of the anode should be smaller than the height of the rudder heel.

4.7 Special aspects

4.7.1 Metal ships with special features

For ships with special propulsion systems (e.g. Voith-Schneider drive) and for ships with special rudder shapes (e.g. Kort nozzle or rudder propellers), certain measures that must be agreed upon with the corresponding manufacturer and GL are necessary.

For special hull types (e.g. hydrofoils, ships with water-jet drives, catamarans), the structural design and the flow rate must be considered for the arrangement of the external protection.

4.7.2 Ships with a non-metallic hull

For the protection of the metallic appendages, anodes applied to the hull must be conductively connected (using either welding straps or cables) with the parts to be protected, whereby in each case care must be taken to ensure a metallically conducting connection.

If there is no central cathodic protection system, rudders must be cathodically protected by anodes, and propellers and shafts by zinc rings affixed to the propeller hubs or shafts.

C. Internal Protection through Sacrificial Anodes

1. Field of application

This section applies for the cathodic corrosion protection of the internal areas of ships and floating units by means of sacrificial anodes.

The specification applies only for surfaces which have been exposed to an electrolytic solution of sufficient conductivity – at least brackish water – for a sufficient length of time – at least 50 % of the service time. The effect of the anodes is limited in fresh water and river water.

2. Design fundamentals

2.1 Protective current requirement

2.1.1 Protective current density

Reference values for the required protective current densities are given in Table 7.2.

2.1.2 Protective duration

The protective duration should be set to 5 years (43 800 h) or defined by agreement with the client.

2.1.3 Loading factor

The size of the loading factor (f_B) depends on the period in which the surface is covered with the electrolytic solution.

In the case of constant loading (filled tanks/cells), the factor must be set to 1.

2.1.4 Total area to be protected

The maximum surface area covered by the electrolytic solution is used for the calculation.

2.2 Anode weight

The required anode weight per KSZ is obtained by

Equation VI: $$m_{KSZ} = \frac{I_{KSZ} \cdot t_S \cdot f_B}{Q_g}$$

f_B = loading factor

3. Anode selection

With regard to the anode materials, the notes under item B.3. must be observed.

4. Arrangement of the anodes

4.1 General

The anodes must be arranged so that a shadow effect is avoided to a large degree, even in areas with a complex structure.

Because of the unknown filling level, the anodes must be assigned primarily to the lower parts, i.e. the areas most likely to be wetted.

It must be noted that several smaller anodes provide a better current distribution than one large anode of the same weight.

In addition to the notes given in B., it must be noted that there may be a necessity to increase the number of anodes assigned to the internal spaces, for the following reasons:

– The effective zone of the anodes may be limited due to low water levels.

– Internal structures can cause a shadow effect.

– The effect of noble materials (formation of galvanic cells) must be compensated locally.

In extreme cases, it may even be necessary to apply extra anodes in addition to the total anode weight calculated according to 2.2, in order to achieve the required number of anodes needed for a uniform distribution of the protective current.

4.2 Fastening the anodes

The connection between the anode and the area to be protected must be metallically conductive. For this reason, the anodes must be welded on.

In the case of low material thicknesses, sensitive materials or platforms, mounted plates (doubling) of sufficient thickness must be welded on, with an extra border of 20 mm on all sides around the welding points of the anode.

If bolted connections cannot be avoided in exceptional cases – which must be agreed upon with the client – a metallically conducting connection must be provided, e.g. through welding points.

4.3 Aluminium anodes

Aluminium anodes must only be affixed so that they do not exceed a drop energy of 275 J, i.e. to take an example, an aluminium anode with a weight of 10 kg must not be mounted any higher than 2,75 m over the bottom.

This limitation does not apply for ballast water tanks.

D. External Protection through Impressed Current

1. Field of application

This section applies for the cathodic corrosion protection of the underwater surfaces of ships and floating units through impressed current in seawater and brackish water.

2. Design fundamentals

The same design fundamentals apply as set out in B.2.

Openings in the outer shell – e.g. sea chests, overboard discharges, stabilizer boxes, thrusters, scoops, parts not conductively linked, Voith-Schneider propellers, shaft penetrations, and other cathodic protection zones which lie outside of the zone of action – must be protected additionally with sacrificial anodes.

3. Arrangement of anodes and reference electrodes

The impressed-current cathodic protection system is designed for a specific ship or structure. In general, the following design criteria must be observed:

– The impressed-current system must be symmetrical, i.e. for the port and starboard sides, the same number of impressed-current anodes and reference electrodes must be arranged at the same positions. Damage to the ship must be expected for an asymmetrical arrangement.

– At least one anode each must be arranged to port and to starboard in the stern area of the ship – preferably in way of the engine room.

  – At both sides, at least one reference electrode must be arranged for either side; this electrode must be located between the anode and the propeller and be as far away as possible from the associated anode (minimum distance approx. 10 % of the ship's length).

  – Vessels with a length (L_{pp}) of more than 175 m shall be equipped with a second impressed-current system in the bow area.

  – If there are two impressed-current systems, the system for the bow area must be arranged so that the control electrode is located between the anode and the bows.

– The structural inclusion (cofferdam) of the anodes in the outer shell must be carried out in a technically competent manner. In case of ships with GL Class, this is object of the drawing examination.

– The anodes exhibit a relatively high current delivery which could lead to damage to the coating if no suitable countermeasures are taken. For this reason, a protective shield of adequate coating thickness and size must be built up around the anodes to ensure a favourable distribution of current.

  – At a distance of at least 0,8 m from the anode edge, an FRP coating or a filler compound or an equivalent coating with a dry film thickness of at least 3 mm at the anode and 2 mm at the outer border of this area shall be applied. For the remaining area of the protective shield, a coating with a dry film thickness (without antifouling) of at least 500 µm can be used.

  – The protective shields of GRP coatings, filler compounds and/or coating systems must be resistant to the loads occurring in the "potential funnels" (e.g. elementary chlorine), must not become brittle, must exhibit adequate ductility and must not change even after lengthy docking periods.

  – The protective shields must have a target lifetime of 10 years.

– The rudder must be included in the cathodic protection scheme with an appropriate cable connection, and the propeller with a shaft slipring. (See also item 4.6.)

– The capacity of the rectifier must be designed so that the required protective current requirement is ensured in all cases and so that a reserve capacity at least 1,5 times of the normal service value is available to accommodate the coating damage which is to be expected.

In Fig. 7.2, Fig. 7.3 and Fig. 7.4 the impressed-current protection for a ship is shown in schematic form.

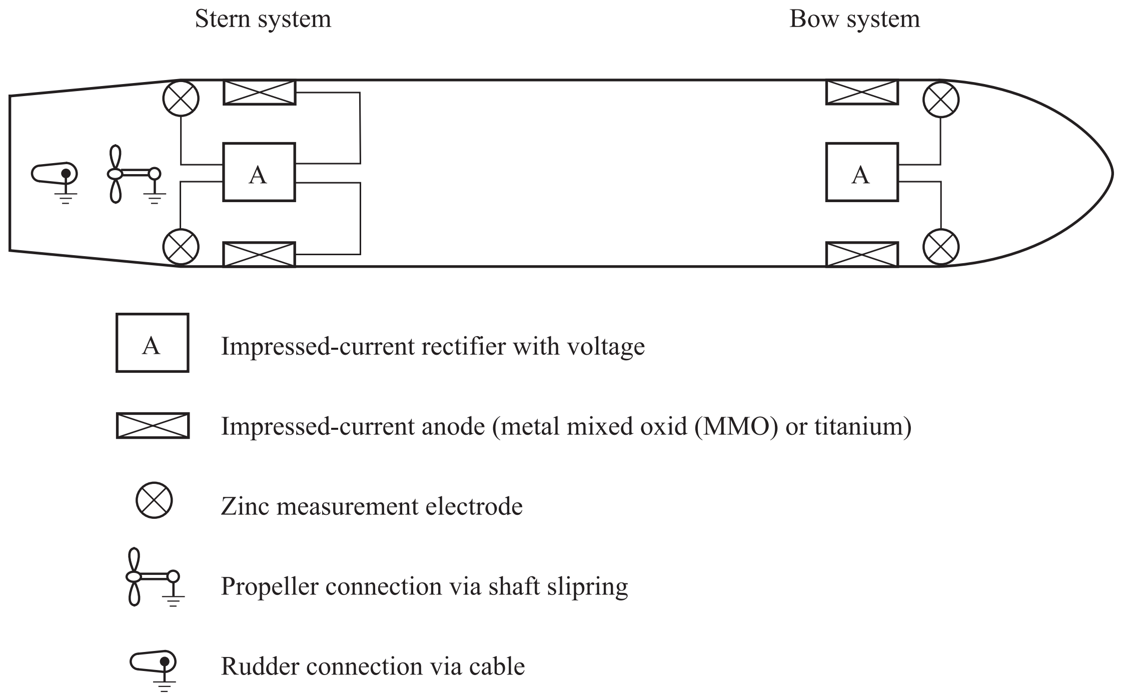

Fig. 7.2 Schematic arrangement of an impressed-current system

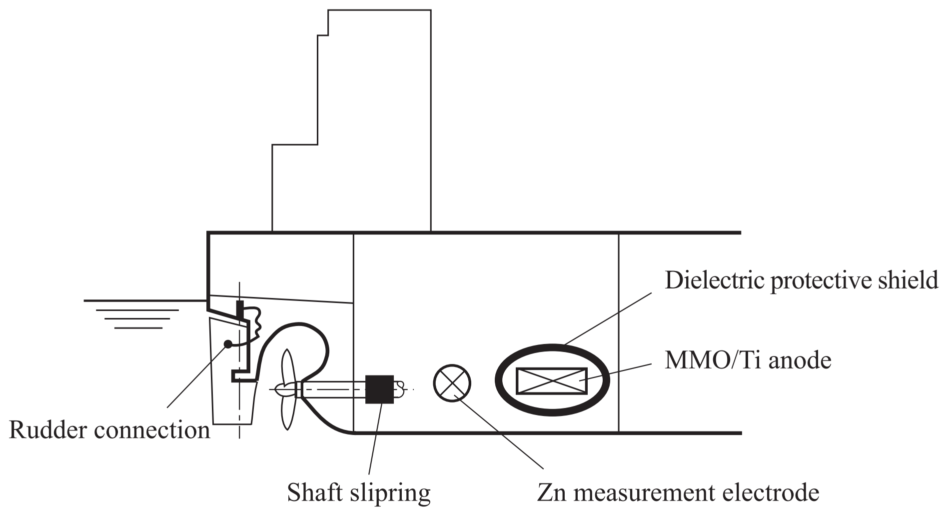

Fig. 7.3 Schematic arrangement of an impressed-current system (stern area)

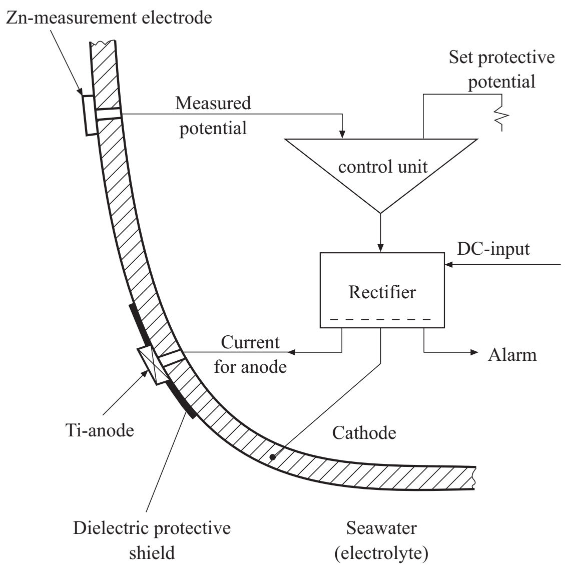

Fig. 7.4 Schematic circuit diagram for an impressed-current system

4. Monitoring and control

4.1 Impressed-current protection systems must be fitted with voltage-controlling power supply units which may exhibit a slow control characteristic. It must be possible to read the control electrodes individually, so that the protective current can be adjusted independent for port- and starboard side.

4.2 The possibility of switching over from automatic to manual operation must be provided.

4.3 The following indicators must be provided as a minimum:

- Indicator light "On"
- Indicator light "Manual Operation"
- Common indicator light "Malfunction"
- Indicator "Anode failure or anode group failure"
- Measurement units for "Anode current", "Anode voltage" and "Potential" (input impedance of the measurement circuit: ≥ 1 MΩ)

4.4 The target-value transmitter for setting the required potential must be fitted with a locking arrangement.

4.5 Automatic limiters for anode current and anode voltage must be provided.

4.6 In the event of wire break or short circuit at the control electrodes, the protective current must be switched off automatically or regulated down to zero when in automatic mode.

4.7 For alerting purposes, each group alarm must be routed via a potential-free contact (change-over) to the terminal strip of the power supply unit.

4.8 The control precision of the set voltage for the control electrodes (target value) must be within ± 10 mV during automatic operation.

4.9 The measurement units must be arranged so that it is easy to read off the measurement values regularly.

4.10 The potential values, the voltage difference at the shaft slipring and, if applicable, the anode current and anode voltage must be recorded at regular intervals.

E. Maintenance of the Cathodic Protection System

During docking periods, the sacrificial anodes must be checked for excessive metal loss, damage and for possible passivation, and also for uniformity of the metal loss. Furthermore, the mountings of the sacrificial anodes must be checked for proper electrical contact.

In the case of impressed-current systems, the condition of the reference electrodes, the impressed-current anodes and the anodic protective shield must be checked for damage.

During abrasive-blasting and high-pressure washing work at the outer shell, the reference electrodes, the impressed-current anodes and the anodic protective shields must be protected against damage.

The voltage difference between the slipring of the propeller shaft and the brushes must not exceed 40 mV, in order to prevent damage to the propeller bearings and the propeller shaft. Any instructions issued by the manufacturer must be observed.

F. Documentation of the Cathodic Protection System

The installed cathodic corrosion protection system must be described by appropriate documentation and can be presented to GL for examination. In the case of ships with the Class of Germanischer Lloyd that are to bear the Class Notation **IW**, the following documents shall be submitted, see GL Rules for Classification and Construction, I – Ship Technology, Part 1 – Seagoing Ships, Chapter 1 – Hull Structures, Section 35. The documentation must, insofar applicable, cover the following points:

- Design data of the system (selected protective current densities and potential ranges for specific areas for the ship, for each KSZ)
- Arrangement of the sacrificial anodes on the ship
- Specification of the sacrificial anodes, i.e. type or chemical composition, mass, capacity, manufacturer, acceptance certificate

– Type and arrangement of the reference electrodes and the impressed-current anodes as well as the rudder and propeller connections

– Type and design data of the rectifier

– Specification of the anodic protective shield

– Specification of the control unit

– Design of the cofferdams