27. TESTING, COMMISSIONING AND CLASSIFICATION

Commissioning is the process of getting the installed equipment to work properly and fulfill its functions. It is done in steps, starting at the manufacturer's workshop where the essential equipment is tested before it is transported to the shipyard. These tests at the makers are called Factory Acceptance Tests (FAT) and certify that the equipment performs properly, when leaving the workshop.
Essential equipment includes generators, motors, switchboards and control gear assemblies, transformers, alarm and monitoring systems.

1 Factory acceptance tests (FAT)

1.1 Rotating machines

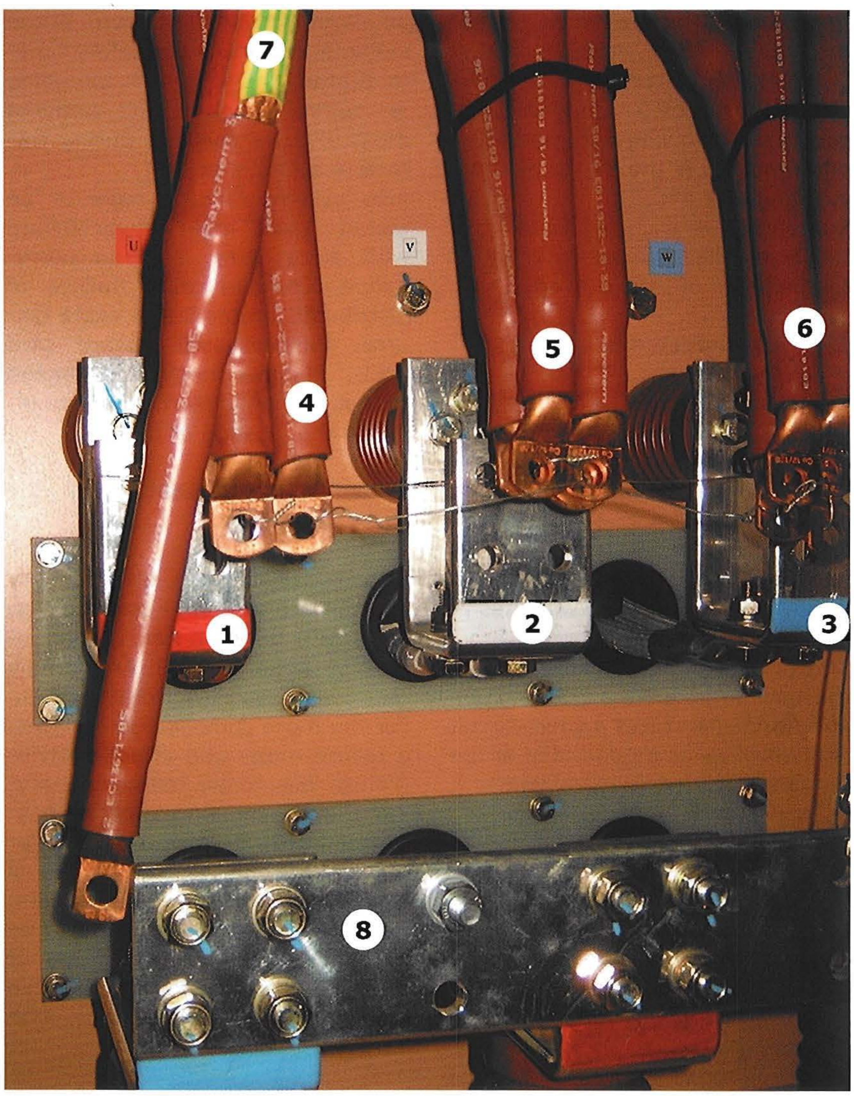
Generators and motors, usually identified as rotating electrical equipment, have to be subjected to a heat run test, to demonstrate that the rotating equipment can perform its duty within the temperature limits of the materials used.
Heat run tests can be performed under actual conditions, under load with the same characteristics and cooling conditions as the expected load in service. It is often simulated by a no-load test and a short-circuit test. The sum of the rise in temperature represents the actual temperature rise.
It is often limited to the electrical windings of a machine, but should also include mechanical parts such as bearings.
In addition, megger tests, insulation resistance tests and high voltage tests as well as overspeed tests at 120% for two minutes, are carried out. If possible, load steps and other dynamic tests are run.
If dynamic tests cannot be carried out in the workshop, they must be done during the harbour acceptance tests (HAT) or during sea trials.

High voltage connection box:
1. Terminal L1
2. Terminal L2
3. Terminal L3
4. Conductors L1
5. Conductors L2
6. Conductors L3
7. Earth conductor
8. Starpoint

1.2 Cables

Cables used onboard of ships must be type-approved, meaning that they have been subjected to a series of tests together with an approved quality assurance system of the manufacturer.
These cables are listed in the type-approved equipment of the various classification societies.
In general, these cables are specially designed and are suitable for conditions with respect to vibration. Thus, stranded conductors, fire retardant and low smoke and low halogen insulation.

Cables temporarily disconnected for testing purposes



1.3 Switch and control gear

Very few have type approval, but most switch gear and control gear assemblies have been built from type approved parts. All main and emergency switchboards must be factory tested to verify operational and insulation quality by Megger and high voltage tests.
The tests consist of checks of interlocks, synchronisation, autostart and autoclose of generators and circuit breakers, sequential restart, load shedding, depending upon the ship's specification.

1.4 Circuit breakers.

Circuit breakers have to be adjusted and tested by the manufacturers. Certificates of required settings and test results must be submitted and verified. Nameplates must be fitted adjacent to the circuit breakers in the switchboard referring to the adjusted settings to enable replacement.

1.5 Starting devices

Large starting devices (>100kW) must be tested at the manufacturer's workshop as far as practicable. The tests are more or less identical to the tests of switchboards.

1.6 Converting equipment

Large converting equipment (> 100kW) must be tested at the manufacturer's workshop.
For rotating converting equipment, the same tests are applicable as for rotating machines.
For static converting equipment, built from type-approved parts, functional tests have to be done simulating the performance of the converter and checking temperature rises of the approved parts in the assembly. This can be done during a full load test with the same cooling arrangements as in the ship's design standards.
This usually means cooling air of 45°C, cooling water, if direct seawater is used, of 32°C, but mostly freshwater through a heat exchanger of 37°C, or air, cooled by either sea or fresh water with maximum temperatures of 37 and 42°C respectively, allowing a temperature difference over the water/air heat exchanger of 5°C.
Sometimes, if a chilled water system is installed, chilled water with a temperature of 6°C is used.

1.7 Transformers

Large transformers (> 125 kVA or 100kW) with a power factor of 0.8 have to be tested at the manufacturer's workshop. The test must include a megger test, a high voltage test and a megger test again, as well as a heat-run determining the temperature rise of the windings at full load conditions.
Similar to rotating machines, often the test is done by a combination of a no-load test and a short-circuit test which gives a good idea of the temperature rise at actual load.

1.8 Automatic control systems

Large control systems, or better complicated control systems, have to be tested at the manufacturer's. This means building up the various components, such as equipment, control-stations and work-stations and connecting these, making it a complete system. It is more efficient to test a complicated system at the manufacturer's, as all control locations are close together and the changes of control positions are more easy to test. Transfer of control from one location to another shall be bumpless and accepted by the other location. This to avoid unacceptable surprises.
Failure of a power supply shall not cause change in control result or alarms only.

1.9 Alarm and monitoring systems

Alarm and monitoring systems must also be tested at the manufacturer's.
These include simulation of alarms, checking of group alarms at the bridge, and of engineer's alarms.
Duty selection, safety timer for not accepting alarms, safety timer for one person on watch, automatic change over from unmanned to manned operation when accepting an alarm in the engine room, at the same time starting the safety timer to protect the engineer attending an alarm. Graphics and trending must also be checked during this factory acceptance test.
Also system failures have to be tested. Thus, main power failure with alarm only, back-up power failure, communication failure of distributed systems and cable failures. Printed circuit board card (PCB) failures must be restricted to that part only. Alarms have to indicate the location of the fault.

1.10 Dynamic positioning systems.

Dynamic positioning systems vary from simple computer assisted systems with Notation AM, via redundant systems Notation AA, to fully redundant systems Notation AAA. For the more complicated systems, a failure mode and effect analysis (FMEA) has to be made, identifying the consequences of all possible failures. This is the basis for the test procedures. The functional tests are more difficult to simulate. As most of the systems have to be adjusted to the characteristics of the ship, especially for the first ship of a series, these are usually done during sea trials.

1.11 Systems in general.

It should be clear that all factory acceptance tests have one common purpose: that is to confirm the suitability of equipment to be installed onboard.
Every step in the FAT testing programme has one major purpose. This is to ensure performance during the harbour acceptance tests (HAT) and of course, during the final acceptance test, the sea trials. Consequently, the above testing must be executed with all new and essential equipment or systems working.

1.12 EMC/THD tests

All navigation and nautical equipment has been tested for electromagnetic compatibility during the type approval procedure. Interference between components should not exist as long as all equipment is installed in the original housing and in accordance with the instructions of the manufacturer.
When in the open deck area other sensitive equipment is installed, such as a frequency converter operated deck crane, controlled from a control cabin with many windows in view of the radar antenna beam, also this control cabin has to be tested for EMC.
Measuring the Total Harmonic Distortion (THD) for different operational conditions is particularly advised when large Variable Frequency Drives are installed. These measurements are sometimes also required by Class.

1.13 Step loads

After testing of the individual diesel generators for proper operation the sets are tested in parallel operation. With 3 sets, first 1 and 2 in parallel, thereafter 2 and 3 and finally 1 and 3. When current and kW loadsharing is in order the engines and generators have to be subjected to step loads.
A step load is a suddenly applied load on the generator, to check the performance of the generator AVR as well as the diesel governor.
Usual steps are from 25 to 50 % and 50 to 100 %, whereby the minimum voltage and the minimum frequency during the process have to be checked.

Testmatrix	VHF 1 and 2	VH Navtex	HF2182kHz homing device	MF/HF transceiver	DGPS 1and 2	GSM 1 and 2	AIS	SATCOM C1 and C2	SATCOM Mini-M	TV/FM/AM	X-band RADAR	S-band RADAR	Magnetic compass	Wind speed	Gyrocompass	EM Log	Echo-sounder	Steering system	Automatic Telephone	Batteryless telephone	Public address	Propulsion control
VHF 1 and 2	x																					
VH Navtex		x																				
HF2182kHz homing device			x																			
MF/HF transceiver				x																		
DGPS 1and 2					x																	
GSM 1 and 2						x																
AIS							x															
SATCOM C1 and C2								x														
SATCOM Mini-M									x													
TV/FM/AM										x												
X-band RADAR											x											
S-band RADAR												x										
Magnetic compass													x									
Wind speed														x								
Gyrocompass															x							
EM Log																x						
Echosounder																	x					
Steering system																		x				
Automatic Telephone																			x			
Battery-less telephone																				x		
Public address																					x	
Propulsion control																						x

Another test of the diesel and generator performance is the switching off of a certain load whereby the overvoltage and maximum frequency of the sets are checked during the process.
This is usually done in parallel, operating by switching off circuit breakers.

1.14 Example of EMC interference

EMC interference problems are sometimes hard to trace like in this example of an Offshore Construction Vessel.
When the ship got operational it appeared that the crane would not work although this had been succesfully tested during harbour trials.
It took a long time to find the reason for this failure of the crane but in the end it appeared that the beam from the radar disturbed the crane controls.
By screening some cables in the control cabin of the crane the problem was solved.
The test matrix for commissioning should include verification of this sort of interferences.

After the Factury Acceptance Tests are completed to satisfaction, the equipment has to be installed on board. When completed, a new series of tests has to be carried out: The Harbour Acceptance Test, or HAT.
Before this testing can be carried out, cables, pipes, safety systems, such as firedetection, bilgealarm, etc, have to be ready and have to be tested. This is in fact pre-testing, and part of the HAT. There is an overlap with the actual HAT, which is carried out when all systems and equipment is supposed to be ready.

2 General shipboard testing.

Before a new installation is put into service, the following tests are to be carried out. These tests are in addition to any acceptance tests which may have been carried out at the manufacturer's .

2.1 Insulation resistance

The insulation resistance of all systems and electrical equipment has to be measured using a direct current insulation tester, between:

a. connected current carrying parts
b. as far as reasonably practicable all current carrying parts of different polarity or phase.

The installation may be subdivided and equipment may be disconnected if initial tests produce resistance values lower than the required resistances.

2.2 Earth conductors

Tests are to be carried out to verify the effectiveness of the earth continuity conductor and the earthing of non-current carrying exposed metal parts of electrical equipment and cables.

2.3 Generators

Tests are required to demonstrate satisfactory performance of each generator and engine by means of a test run at full rated load and at 110% overload for at least 15 minutes. Engine temperatures should stabilize and not exceed the maximum figures as determined by the manufacturer.

27.1	INSULATION RESISTANCE	MEGGERREADING
	PROPULSION AUXILIARIES	MΩ
E310	Steering gear pump (1- MSB; 2- ESB)	100,00
E310	Steering gear pump (1- MSB; 2- ESB)	100,00
E310	Steering gear pump (1- MSB; 2- ESB)	100,00
E310	Steering gear pump (1- MSB; 2- ESB)	100,00
E317	Stabilizer hydraulic pump main	100,00
E317	Stabilizer hydraulic pump main	100,00
E317	Stabilizer hydraulic pump emergency	100,00
E317	Stabilizer hydraulic pump emergency	100,00
E347	Water mist Emergency supply	100,00
E610	Main engine Lub oil priming system	100,00
E610	Main engine Lub oil priming system	100,00
E610	Main engine Coolant pre heating unit	80,00
E610	Main engine Coolant pre heating unit	80,00
E650	Generator pre-heating	60,00
E650	Generator pre-heating	60,00
E650	Generator pre-heating	60,00
E650	Aux eng SW pumps exhaust	100,00
E650	Aux eng SW pumps exhaust	100,00
E650	Aux eng SW pumps exhaust	100,00
E710	Starting air comprssor	100,00
E710	Starting air comprssor	100,00
E714	Air Dryer	80,00
E720	Fuel oil booster pump	100,00
E720	Fuel oil transfer pump	100,00
E730	Lub oil transfer pump	100,00
E730	Gearbox Trailing pump	100,00
E730	Gearbox Trailing pump	100,00
E810	Fifi/ bilge pump	100,00
E810	Fifi/ bilge pump	100,00
E810	Emergency fifi pump	100,00
E815	Bilge water separator	100,00
E810	Bilge valves	100,00
	Engineroom fans	100,00
	Engineroom fans	100,00
	Supply fans technical spaces	100,00
	SHIPS SERVICE AUXILIARIES	
E250	HPP- Aft: Tenderdoors/ bulwark doors/ te	100,00
E250	HPP Stern door+ passarelle	100,00
E250	HPP Seaterrace crew door and boarding l	100,00
E250	HPP Foredeck hatches,crane mast and a	100,00
E320	Anchor/ mooring winches Fwd	80,00
E320	Anchor/ mooring winches Fwd	80,00
E322	Capstan Fwd Port; Stbd	80,00
E322	Capstan Fwd Port; Stbd	80,00
	THRUSTERS	
E645	Bowthruster AC heating	50,00
E645	Bowthruster Air injection unit	100,00
E646	Hydraulic unit+ control+ AC heating Stern	80,00
	Bow thruster	100,00
	Stern thruster	100,00

Example of part of Megger list

Rated voltage U_n V	Minimum voltage of the tests, V	Minimum insulation resistance, MΩ
$U_n \leq 250$	$2 \times U_n$	1
$250 < U_n \leq 1000$	500	1
$1000 < U_n \leq 7200$	1000	
$7200 < U_n \leq 15000$	5000	

Minimum test voltage and insulation resistance M_a

DIESELGENERATORS 1 + 2 PARALLEL						
Total Rating %	**Diesel 1**			**Diesel 2**		
	Kw	**A**	**Hz**	**Kw**	**A**	**Hz**
0	0	0	60	0	0	60
25	60	120	59.8	65	130	59.8
50	125	250	59.5	130	260	59.5
75	185	370	59.3	190	380	59.3
100	250	500	59	250	500	59
75	185	370	59.3	190	380	59.3
50	125	250	59.5	130	260	59.5
25	60	120	59,8	65	130	59.8
0	0	0	60	0	0	60

SINGLE DIESEL GENERATOR					
Power %	**Power**	**Voltage**	**Current**	**Freq**	**Speed**
	Kw	**V**	**A**	**Hz**	**RPM**
0%	0	455	0	60	
24%	60	454	125	59.8	1800
50%	125	452	250	59.5	
70%	185	452	375	59.3	1785
100%	250	450	500	59	
75%	185	451	275	59.3	1770
50%	125	452	250	59.5	
20%	60	454	125	59.8	
0%	0	455	0	60	1800

STEPLOADS								
Step 1 from 25 to 50% by switching off diesel 1								
Step 2 from 50 to 100% by switching off diesel 1								
Total Rating %	**Diesel 1**			**Diesel 2**				
	Kw	**A**	**Hz**	**Kw**	**A**	**Hz**	**min V**	**min Hz**
0	0	0	60	0	0	60		
25	60	120	59.8	65	130	59.8		
50	0	0	60	130	260	59.5	440	57
50	125	250	59.5	130	260	59.5		
100	0	0	60	250	500	59	435	56

STEPLOADS SWITCHING OFF							
Power %	**Power**	**Voltage**	**Current**	**Freq**	**Speed**		
	Kw	**V**	**A**	**Hz**	**RPM**	**max V**	**max Hz**
50%	125	452	250	59.5			
0%	0	455	0	60	1860	480	62
100%	250	450	500	59			
0%	0	455	0	60	1720	485	63

High Voltage test voltage depends on the nominal voltage of the system as in the following table:

Rated voltage, $U_n U_n$ V	Test voltage a.c. (r.m.s.), V
$U_n \leq 60$	500
$60 < U_n \leq 1000$	$2 \times U_n + 1000$
$1000 < U_n \leq 2500$	6500
$2500 < U_n \leq 3500$	10000
$3500 < U_n \leq 7200$	20000
$7200 < U_n \leq 12000$	28000
$12000 < U_n \leq 15000$	38000

2.4 Switchboards

During the full load tests, the temperatures of joints, connections, circuit breakers, bus-bars and fuses have to be monitored and may not exceed the maximum values.
For cables with XLPE insulation this value should be below 85°C.
Bus-bars in switchboards may reach 95 °C.

2.5 Synchronising equipment

During functional tests the operation of engine governors, synchronizing devices, overspeed trips, reverse-current relays, reverse-power and over-current trips and other safety devices must be demonstrated. Generators with a rating of more than 1500kVA must also be protected by a differential protection system, showing a possible current leakage.

2.6 Automatic Voltage Regulator

The voltage regulator of each generator has to be tested by opening its breaker when the generator is running at full load and also when starting the largest motor which is connected to the system.

Also the speed governor has to be tested by opening the circuit breaker at full load. This is not to result in overspeed trip. The minimum speed of a diesel generator has to be verified when starting the largest electric motor on board.

2.7 Parallel operation

Parallel operation and kW and kVA load sharing of all generators capable of being operated in parallel mode, at all loads up to normal working load, has to be tested.

2.8 Functional test

Essential equipment must be operated under service conditions, though not necessarily at full load or simultaneously, for a sufficient length of time to demonstrate that the temperatures stabilize and equipment does not overheat.

2.9 Safety systems

Fire, crew and passenger and ship safety systems must be tested for correct functioning.

2.10 General alarm systems

On completion of the general emergency alarm system and the public address system tests, the surveyor has to be provided with two copies of the test schedule, detailing the measured sound pressure levels. Such schedules are to be signed by the surveyor and the builder.

3 Harbour Acceptance Tests (HAT)

After the equipment is installed onboard the ship and connected, Harbour Acceptance Tests are carried out to prove that the equipment is capable of functioning properly.

3.1 Electric power supply system tests

An example is the load tests of the diesel generator sets in combination with the switchboard. Load tests are often done using a water resistance device that consumes electrical power by heating water.
A disadvantage of the device, is that it does not simulate the ship's load which is usually partially inductive. The power factor is 1 for a resistance load so that the maximum power for the diesel is reached at 80% current of the generator.
This is therefore, not a generator test where current is the limiting factor.
Load steps also give a good idea of the generator set's performance. Auxiliary engine protection and shutdown systems are to be tested as well as automatic starting of standby pumps and sequential restart of essentials after a blackout.

Further tests may include the load dependent start-stop by a power management system with automatic reduction of propeller pitch and/ or RPM of electric driven thrusters in case of overload of the generator plant. Much of this testing can be done in harbour as it does not require the ship to be sailing.

3.2 Engine protection systems tests

Tests of safety stops for diesel generator engines, propulsion engines, boilers and likewise.

PROPULSION SYSTEM			
MAIN ENGINES>1500K	SYSTEM	STATUS	RESULT
	LUBR OIL PRESS	LOW/LOW	STOP
	OIL MIST CONCENTRAT	HIGH	STOP
MAIN BEARING 1	TEMPERATURE	HIGH	STOP
MAIN BEARING 2	TEMPERATURE	HIGH	STOP
MAIN BEARING 3	TEMPERATURE	HIGH	STOP
MAIN BEARING 4	TEMPERATURE	HIGH	STOP
MAIN BEARING 5	TEMPERATURE	HIGH	STOP
THRUST BEARING	TEMPERATURE	HIGH	STOP
HT COOLINGWATER	HT CW OUTLET TEMP	HI/HIGH	STOP
ENGINE SPEED	OVERSPEED	HIGH	STOP
GEARBOX	LUBR OIL PRESS	LOW/LOW	STOP
AUXILIARY ENGINE 1	SYSTEM	STATUS	RESULT
	LUBR OIL PRESS	LOW/LOW	STOP
	HT CW OUTLET TEMP	HI/HIGH	STOP
ENGINE SPEED	OVERSPEED	HIGH	STOP
AUXILIARY ENGINE 2	SYSTEM	STATUS	RESULT
	LUBR OIL PRESS	LOW/LOW	STOP
	HT CW OUTLET TEMP	HI/HIGH	STOP
ENGINE SPEED	OVERSPEED	HIGH	STOP
AUXILIARY ENGINE 3	SYSTEM	STATUS	RESULT
	LUBR OIL PRESS	LOW/LOW	STOP
	HT CW OUTLET TEMP	HI/HIGH	STOP
ENGINE SPEED	OVERSPEED	HIGH	STOP

Example of test sheet of safety systems of main and auxiliary diesel engines (see 27.2.2)

3.3 Automation system tests

Systems to be tested are the bridge control systems for main engines/ clutches/propellers, transfer from engine room to bridge, bridge to bridge-wing and back, emergency stops, thrusters' start-stop and controls and pitch and RPM indicators. This can all be done at reduced load along the quay.
Additional testing is required for steering gear systems' pump start/ stop with alarms, rudder position indicators, autopilots and propulsion safety systems, such as rudder limiters, interlocks between bowthruster and stabilizers.
The above tests have to be carried out prior to sea trials.

3.4 Fire protection

Safety systems such as fire detection, fire alarms, fire doors and shutters and fire fighting systems are to be tested before going on sea trials.
The fire detection in engine rooms consists of three types of sensors:
- Smoke detectors
- Flame detectors
- Heat detectors

Each type needs to be tested in its own way. See pictures.
During sea trials this test is repeated with engines and engine room ventilation running.

Smoke, heat and flametests.
Realistic test of the smoke, heat and flame detection is done by burning diesel oil in a drum.
Such tests are only carried out during sea trials to test the whole system.

Adequate precautions as a fire extinguisher and people with fire resistent clothing is a must.
During normal operation smoke detection is carried out using a spray can with a special testing liquid on a broomstick.

Flame detectors can be tested with a good torchlight, heat detectors with an ordinairy hair dryer.

3.5 Safety of people on board

Personal safety systems, such as internal communication, general alarm systems and public address systems have to be tested prior to leaving to sea.

Smoke test in progress

3.6 Alarm and monitoring system tests

See table on the right side.

3.7 Emergency Power

Autostart of the emergency generator, the transitional source of power, emergency lighting, escape lighting, lifeboat preparation lighting and lights required to launch the boats, are to be tested.

3.8 External Communication

External communication systems must be tested and certified by or on behalf of the national authorities.

3.9 Nautical systems

Radars, gyrocompasses, echosounders, speed log, DGPS positioning reference systems and vertical reference units must be functionally tested so far as is possible during quayside testing.

3.9. Lighting

Functional tests of emergency lighting, navigation lighting, signal mast lighting and anchor lights also have to be carried out.

After successful completion of the HAT, the ship will receive a temporary certificate of seaworthiness by the authorities and is allowed to go to sea.

Sea Acceptance Tests (SAT) complete the program by executing those tests which require sailing, including manoeuvring tests, stop tests and likewise.
All these tests must be well documented with values, figures.
in order to be available as a reference. Normally a booklet is produced by the shipyard with these data.

PROPULSION SYSTEM			TEST SHEET					
MAIN ENGINES > 1500 KW	SYSTEM	STATUS	RESULT	YARD	DATE	OWNER	DATE	CLASS
	LUB OIL SUMP LEVEL	LOW	ALARM					
	LUB OIL PRESS	LOW	ALARM					
	LUB OIL PRESS	LOW/LOW	STOP					
	LUB OIL TEMP	HIGH	ALARM					
	LUB OIL FILTER DIFF	HIGH	ALARM					
	OIL MIST CONC	HIGH	STOP					
MAIN BEARING 1	TEMPERATURE	HIGH	STOP					
MAIN BEARING 2	TEMPERATURE	HIGH	STOP					
MAIN BEARING 3	TEMPERATURE	HIGH	STOP					
MAIN BEARING 4	TEMPERATURE	HIGH	STOP					
MAIN BEARING 5	TEMPERATURE	HIGH	STOP					
THRUST BEARING	TEMPERATURE	HIGH	STOP					
HT COOLING WATER	HT CW OUTLET TEMP	HIGH	ALARM					
		HI-HIGH	STOP					
	HT CW INLET PRESS	LOW	SLOW					
	HT CW EXP TK LEVEL	LOW	ALARM					
LT COOLING WATER	LT CW OUTLET TEMP	HIGH	ALARM					
	LT CW OUTLET TEMP	HI-HIGH	SLOW					
	LT CW INLET PRESS	LOW	ALARM					
FUEL OIL	FO PRESSURE	LOW	ALARM					
	FO TEMPERATURE	HIGH/LOW	ALARM					
	FO LINE LEAKAGE	LEAK	ALARM					
START AIR	START AIR PRESSURE	LOW	ALARM					
CONTROL AIR	PRESSURE	LOW	ALARM					
ENGINE SPEED	OVERSPEED	HIGH	STOP					
CYLINDER 1	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 1	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 2	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 2	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 3	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 3	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 4	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 4	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 5	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 5	EXH GAS TEMP	DEVIATION	ALARM					
CYLINDER 6	EXH GAS TEMP	HIGH	ALARM					
CYLINDER 6	EXH GAS TEMP	DEVIATION	ALARM					
TURBO CHARGER	EXH GAS IN TEMP	HIGH	ALARM					
TURBO CHARGER	EXH GAS OUT TEMP	HIGH	ALARM					
TURBO CHARGER	LUB OIL PRESS	LOW	ALARM					
TURBO CHARGER	LUB OIL SUMP LEVEL	LOW	ALARM					
ENGINE OUTPUT	OVERLOAD	HIGH	ALARM					
GEARBOX	LUB OIL PRESS	LOW	ALARM					
	LUB OIL PRESS	LOW-LOW	STOP					
	LUB OIL TEMP	HIGH	ALARM					
	LUB OIL SUMP LEVEL	LOW	ALARM					
PROPELLER CONTROL	HYDR OIL PRESS	LOW	ALARM					
	CONTROL AIR PRESS	LOW	ALARM					
	ELECTRIC SUPPLY	FAIL	ALARM					
AUX DIESEL NR 1	LUB OIL PRESS	LOW	ALARM					
	LUB OIL PRESS	LOW-LOW	STOP					
	LUB OIL TEMP	HIGH	ALARM					
	CW OUT TEMP	HIGH	ALARM					
	CW OUT TEMP	HIGH-HIGH	STOP					
	CW INLET PRESS	LOW	ALARM					
	FO LINE LEAKAGE	LEAK	ALARM					
	OVERSPEED	HIGH	STOP					
	EXH GAS INLET	HIGH	ALARM					
	EXH FGAS OUTLET	HIGH	ALARM					
AUX DIESEL NR 2	SEE ABOVE							
BOILER	WATER LEVEL	LOW	ALARM					
	WATER LEVEL	LOW-LOW	STOP					
	WATER TEMPERATURE	HIGH-HIGH	STOP					
STEERING GEAR	ELECTRIC POWER	FAIL	ALARM					
	CONTROL EL POWER	FAIL	ALARM					
	HYDR OIL TANK LEVEL	LOW	ALARM					
	MOTOR OVERLOAD	HIGH	ALARM					
	PHASE FAIL		ALARM					
	HYDR. LOCK		ALARM					
ELECTRIC SYSTEM	Bus-bar VOLTAGE	HIGH / LOW	ALARM					
	Bus-bar FREQUENCY	HIGH / LOW	ALARM					
	OVERLOAD	NON-ESSENTIALS TRIP						
	Bus-bar INSULATION	LOW	ALARM					

On completion of the HAT, the ship goes for trials. At sea for large ships, inland at sufficient deep and wide water for smaller ships. The electrical installation can then be tested under 'normal' conditions and/or full load, on full speed, without ground or channel effect, what is normally not possible at the outfitting quay. Without speed, alongside, the propulsion system quickly comes in overload conditions.

4 Sea trials

During sea trials the final tests are carried out before delivery of the ship to the owner.
Sea trials prove the specified performance of the ship to the owner as well as demonstrate that the ship is capable of performing conformto the minimum requirements as determined in SOLAS.

Propulsion equipment is to be tested under working conditions and operated in the presence of the surveyors to their satisfaction.
Owners' requirements, such as speed, fuel consumption, noise levels, etc. are to be tested at full operating conditions or at whatever agreed figures or circumstances provided in the building contract.
For cargo ships maximum figures for sound or noise are given in SOLAS; for yachts and passenger ships there is a totally different list of figures.

Sound and vibration levels form a great part of the conditions for people's comfort onboard ships and these have to be verified under operational conditions.

All necessary parameters such as pressures, temperatures under different load conditions of the main engine are collected and recorded. A booklet with all these data is produced and remains the reference throughout the lifetime of the ship.

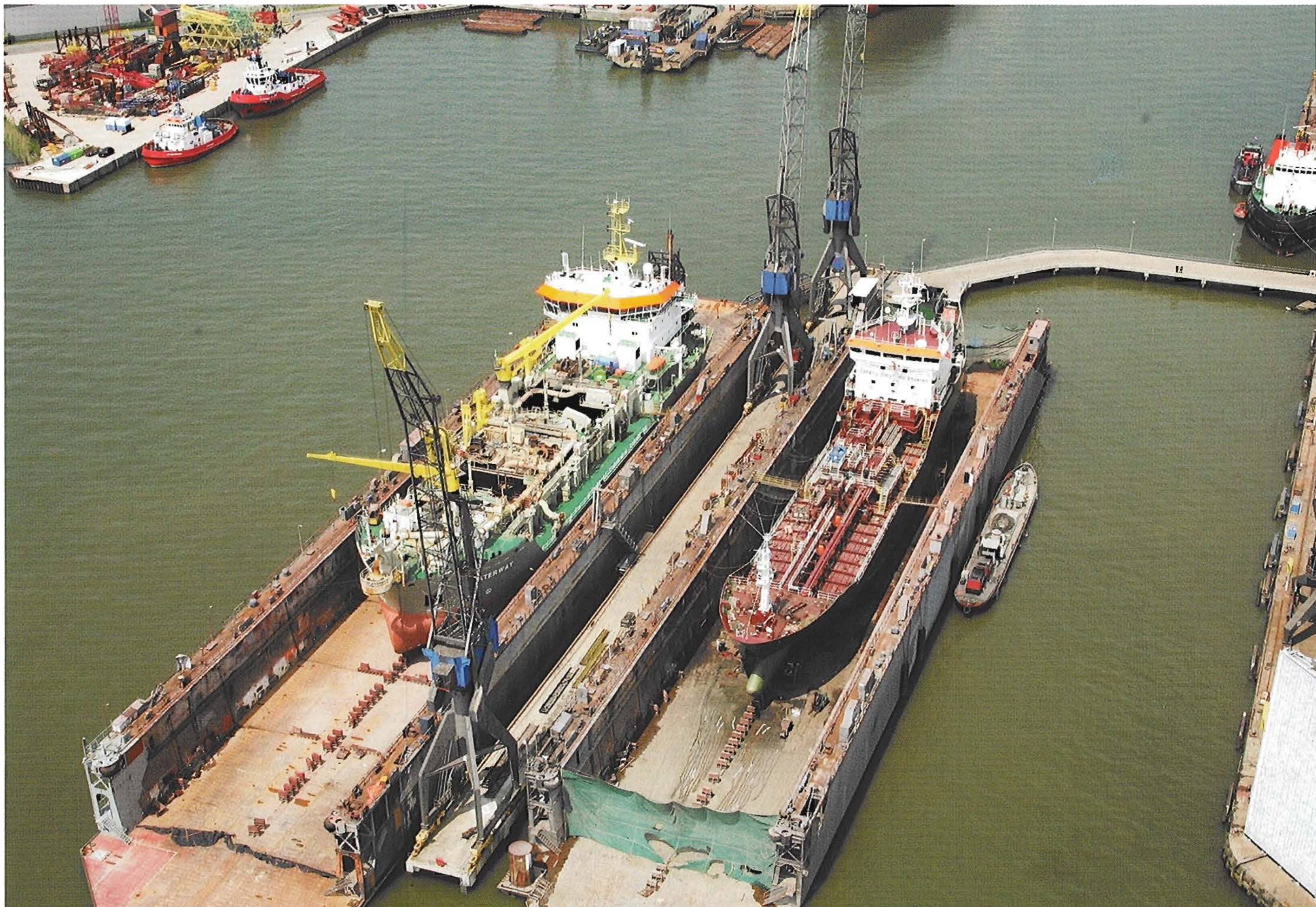
On completion of the seatrials, the SAT, when the ship is considered completed is all respects, the cerificates are issued, as far as not already issue for completed items. With the necessary egards and often festivities, the initial Class certificates for Hull and Machinery are handed over. When all necessary other certificates are on board, the ship is allowed to take cargo and to leave port.

5 Periodical surveys

However when the ship is in service, to maintain the validity of the certificates, periodical surveys have to be carried out. Annuel survey, intermediate survey, and special survey, together with other compulsary certificates in a five years cycle. The basic annual electrical survey consists of the following tests and inspections, depending on the type of ship. For example:

5.1 General

- Testing of all bilge level alarms
- Testing of all watertight doors (operation and alarms), general survey conditions of watertight sealing of electrical equipment when this is intended to be used in submerged conditions
- Testing of main and auxiliary steering gear systems inclusive of alarms
- Survey of all escape routes, route signs, illumination low level lights
- Testing of communication systems between bridge and engine room and emergency control positions
- Testing of remote controlled valves and indications
- Inspection of main and emergency switchboards and associated cables. Examination under normal operation conditions. Testing of automation, black-out start, power depending start, power management systems, automatic sequential restart systems, non- essential tripping systems. Electric safety inspection, earthing of electrical equipment, especially in wet or dangerous areas
- All ships: General inspection of alarms and safety devices as well as autostart of standby generator and sequential restart of essential auxiliaries under normal service conditions
- UMS ships: General inspection under working conditions of automation systems such as standby pumps and auxiliaries. Sample tests of alarms inclusive of bridge, mess room and cabin alarms. Safety timer/dead man alarm systems. Survey as per approved test schedule. Testing of bridge control systems and bridge engine room communication systems.
- Navigation and nautical equipment. General inspection of all equipment under normal operation
- NAV 1 Ships, In addition to general inspection under working conditions of bridge equipment additional alarms and indications, also safety timer and cabin alarms. Survey as per approved test schedule.
- Radio / GMDSS / External communication survey
- Crew safety systems. General alarm and emergency lighting system, emergency generator automatic start and if emergency source of power is a battery, a load test of this battery.



Futher in addition to 5.1:

5.1.1 Ships transporting dangerous cargo in bulk

- Dangerous cargoes in bulk. Inspection of equipment in dangerous areas in relation to the gas group, temperature class and external damage, if any.
- Dangerous dusty cargoes. Inspection of equipment in dangerous area, type of enclosure, protection class, eventual external damage.

5.1.2 Tankers

- Dangerous liquid cargoes. Inspection of equipment in dangerous areas, in relation to gas group, temperature class and eventual external damage. Gases from some cargoes are heavier than air and thus form a layer on deck or in any space under the deck.
- Liquefied natural gas and liquefied petroleum gas carriers (LNG and LPG ships).
- Liquefied natural gas is lighter than air, while liquefied petroleum gas is heavier than air. Inspection of equipment in dangerous areas gas group and temperature class to be verified as well as inspection for damage to ship or equipment.

5.1.3 Passenger ships

- Ship safety systems
- Passenger safety systems. General alarm, public address, emergency lighting, transitional lighting systems and low level lighting systems. Batteries and UPS capacity tests are required. Automatic start of emergency generator and operation of associated equipment as fans, fire flaps, air louvres. to be demonstrated.

5.1.4 Car ferries with bow and stern doors

- Door alarms and indications, water level alarms, closed circuit TV monitoring systems (CCTV)
- Additional lighting systems for crew and passengers
- Equipment in dangerous areas, for instance the lowest 45 centimetres above the car decks where cars are stowed with petrol in their tanks are considered dangerous areas. Also attention for equipment under ramps and swing decks where cars can be stowed. Minimum requirements for equipment on cardecks, etc. above this 45 centimetre layer is protection class IP 55. Car deck ventilation must have at least 10 air changes per hour.

5.1.5 Dynamic positioned ships

Annual Survey under operational conditions, which means an annual DP trial at a convenient location, to demonstrate the operation of the control system completed with a survey of the total propulsion system, often diesel electric. Surveys and tests have to be carried out as per ship-specific approved test schedule. Special attention for UPS capacity tests. The basis for the tests is often the FMEA, failure mode and effect analysis.

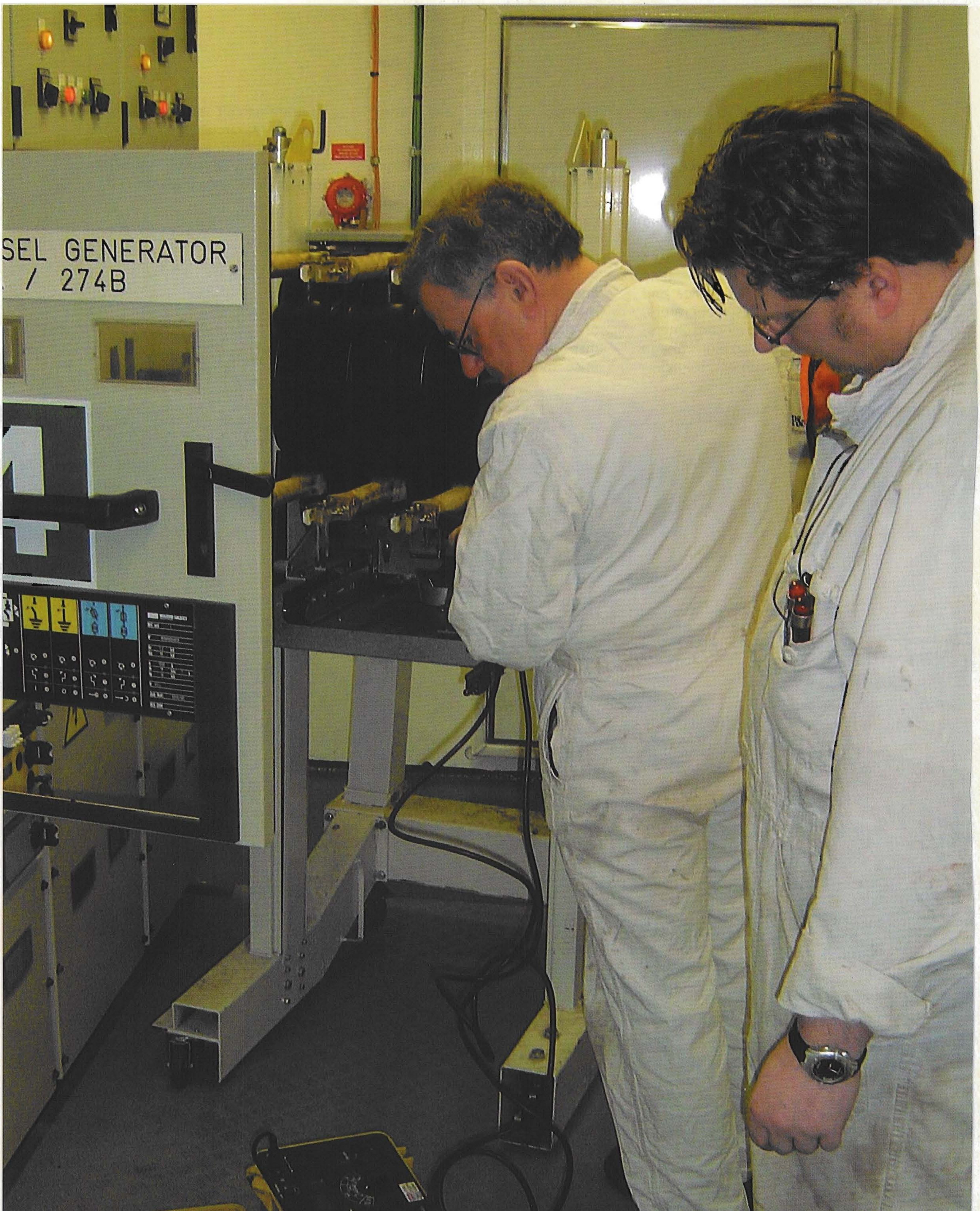
5.1.6 Small ships and yachts

- Basic electrical installations
- Automation
- Equipment in dangerous areas, where all sorts of equipment running on petrol, is stored. For requirements see the ferry car decks. The ventilation must perform at least 10 air changes per hour. Gas detection must be fitted to an alarm and all equipment not suitable for this environment must be switched off.

5.2 Complete five year survey electrical installations

Every five years the electrical installation of a ship must be subjected to a special survey, equal to an annual survey along with the following tests and inspections:

- Electrical insulation resistance measurement of all cables and equipment, motors, generators, switchboards and all consumers, galley, laundry. Also high voltage cables and consumers, if any.
- Fittings of main and emergency switchboards to be inspected, which means checking of connections either by torque wrenches or by thermal inspections under load, using infra-red camera. Copper bus bars are relatively soft, the torque when setting bolts is therefore, important. Checking of bus-bar resistance by special low resistance measuring equipment. Testing of circuit breaker settings and inspections of contacts. Resistance measuring of contacts of vacuum circuit breakers. Calibration of circuit breaker settings and testing of non-essential tripping circuits. General inspection of switchboards.



28. MAINTENANCE

Maintenance onboard modern ships has to be planned very carefully. The required checks and tests are spread over the total maintenance period.

1 General

Maintenance is an essential part of a ship's installation; Planned Maintenance Systems (PMS) are designed to prevent failures.
A Failure Mode Effect Analyses which is a requirement for the higher classes of DP-notations also provide insight into the effects of single failures and methods to prevent unwanted consequences. Monitoring and collecting data of failure, parts involved, alarms prior to the failure, help to improve planned maintenance.
To aid maintenance, more and more ships have computer systems on board for remote monitoring and life cycle management.
Such a system is linked to the alarm data computer memory, coupling the type of alarm to the running hours of the relevant item, in order to generate maintenance planning.
By means of satellite communication equipment suppliers can monitor equipment on board and advise the crew or materials can be ordered to be available in the next port of call.

2 Rotating machines

2.1 Air-cooled machines.

Cleaning or replacement of air filters, visual inspection of windings of stator, visual inspection of windings of rotor.

Special attention for loose fixings of wires between rectifiers and windings on poles.
General cleaning when found dirty inside. Grease (roller) bearings as per maker's instructions.

2.2 Water-cooled machines.

As 2.1 air-cooled machines. In addition the testing of the cooling water leakage detection and alarm.

2.3 Large machines with sleeve bearings.

Check the circumferential clearance of the rotor in the stator. Register data and check bearing clearance and lubrication system

2.4 Machines with roller bearings.

Roller bearings have to be greased as per maker's instructions.

2.5 Insulation resistance

Measure insulation resistance and register data and conditions, i.e. warm after running, and/or cold after a longer period of standstill.

2.6 Slip rings and brushes.

Visual inspection to check for scratches and excessive brush wear

3 Cables

3.1 Cables in hot areas.

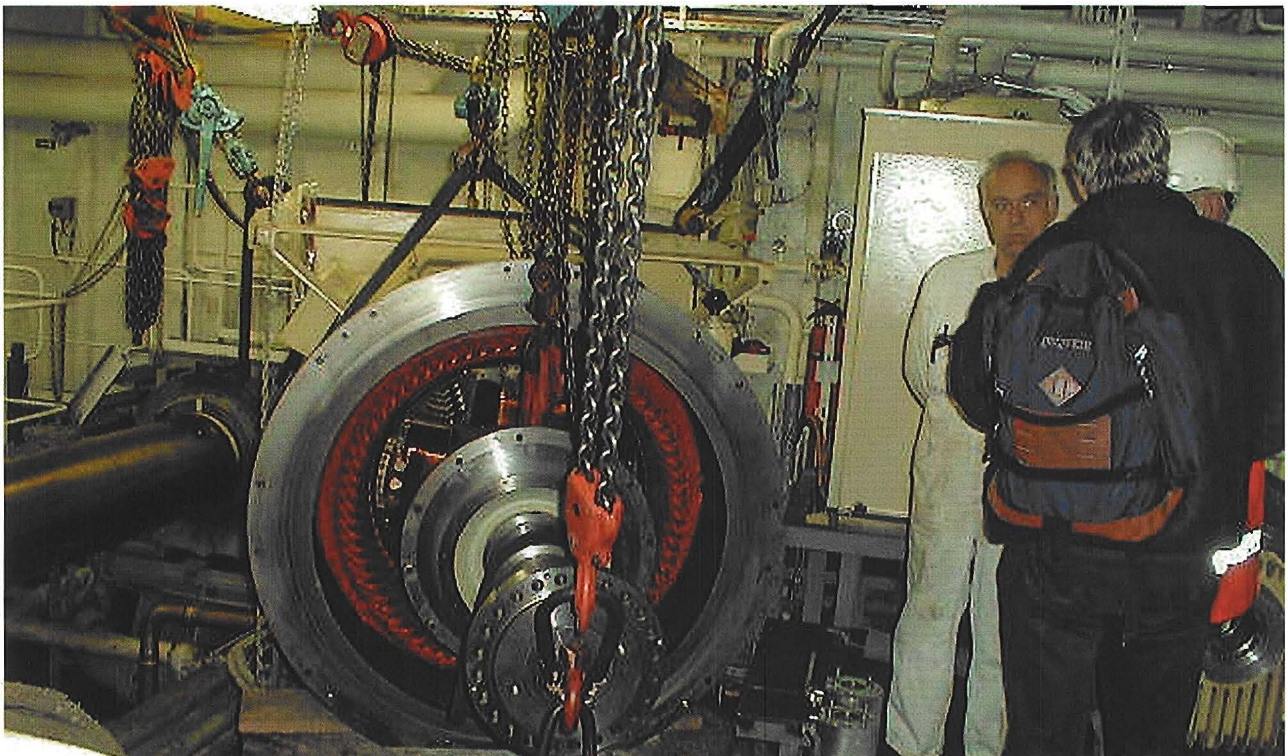
Visually inspect cables routed in hot areas, look for colour changes due to overheating of wires. Replace cables by heat resistant types if necessary.

3.2 Cables in dangerous zones.

Inspect cables for damage of outer sheaths. Repair if possible to avoid corrosion of metallic braiding underneath. Check glands of certified safe equipment for tightness.

3.3 Insulation resistance.

Measure insulation resistance of all cables in safe areas. Measure all outgoing groups of the power distribution system, inclusive of consumers. Use megger-list as provided at new building for reference.



4 Switchgear

4.1 Visual inspection for dirt

Cleaning or replacement of air filters, visual inspection of connections for discolouring of wires by overheating, visual inspection of bus-bars.

4.2 Visual inspection movable connections

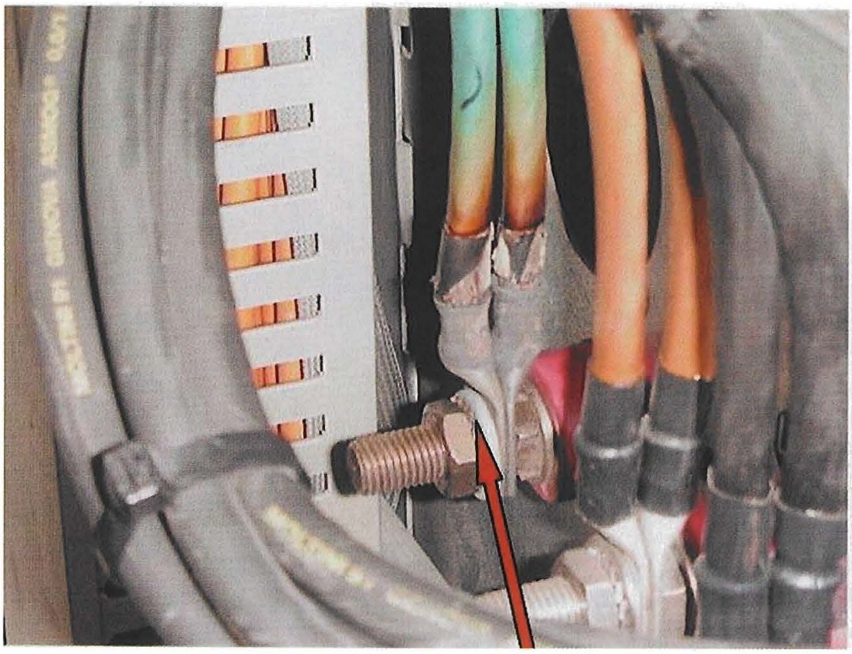
This is applicable to tulip contacts of withdrawable circuit breakers and starters. Check for proper working springs, if not accessible carry out conductivity tests.

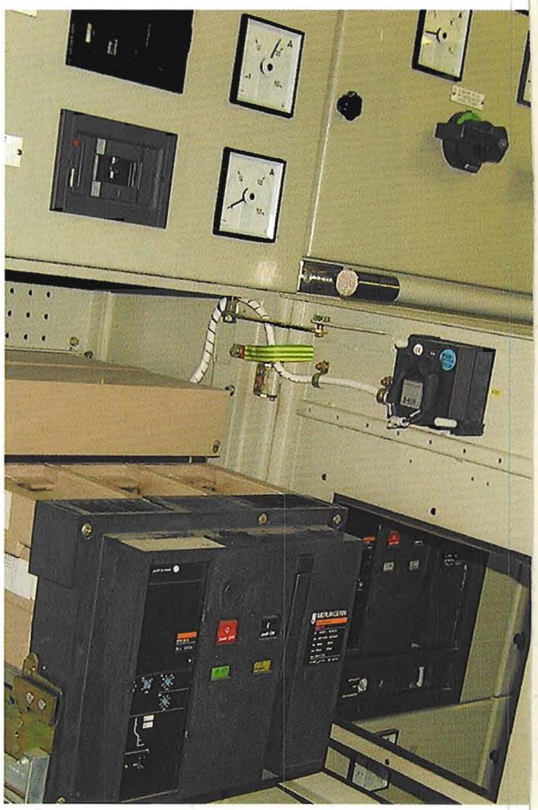
4.3 Thermal photography.

Thermal photography with an infrared camera is a quick way to find bad connections. It has to be carried out with the circuits under load or shortly after having been under load. When a hot spot is found, also a colour image has to be made of the same location to identify the hot spot. Some thermal cameras adapt the scaling of their pictures to the hottest spot in that picture. So a bright yellow part can be 35 °C in one picture and 135 °C in another. Some switchboards have not sufficient access to photograph all possible hot spots. Those switchboards also have to be visually inspected after switching off and opening of the doors.
See pictures below.

4.4. Bus-bar connection conductivity and insulation resistance.

Bus-bars are usually made of electrolytic copper, a good conducting but rather soft material.
Bus-bar connections are made with steel bolts, nuts and spring washers. Bus-bars can have a temperature of 125° centigrade under full load. Locking nuts with PVC or nylon locks have to be suitable for this temperature. Nuts to be fastened with a torque wrench to avoid overstressing of the copper. Overstressing above the yield stress of the copper results in loose connections. Checking all the connections in a switchboard bus-bar system with a torque wrench is a lot of work, not to mention the opening and closing of the bus-bar compartments.
Another way to check these connections is to measure with a low resistance measuring device from one outgoing group at the cable connections to the second outgoing group at the cable connections. Followed by the second to the third and so on.
With all circuit breakers open the insulation resistance of the bus-bar system can be measured.





5 Circuit breakers.

5.1 Low Voltage

Most LV circuit breakers are air circuit breakers with main contacts, arcing contacts and arc extinguishing chambers. Arc chambers to be taken off and inspected for debris.
Arc contacts and main contacts to be inspected for damage. Interval time annually or after clearance of a serious fault.

5.2 High Voltage

Most HV circuit breakers are either gas filled or vacuum and cannot be opened for contact inspection. There, with the same current injection set as used for the bus-bar conductivity tests, the resistance in micro-ohms of the closed contacts can be measured.

5.3 Functional tests.

Check the circuit breakers in the test position for correct closing and opening. Check remote controls and check the synchronising mechanism (closing at the correct moment by the synchronising device as observed by the Synchronoscope).

5.4 Calibration of protection devices.

Calibration of protection devices such as over-current, short-circuit current, under voltage trip, reverse power, differential protection and their timing requires special tools and specialists. The interval between tests is usually five years.

6 Starting devices

Starters to be visually inspected for cleanness and cleaned if necessary. Also inspection for hot spots:
- low voltage
- high voltage
- choke type
- autotransformer type.

7 Converting equipment

7.1 Air-cooled

Cleaning or replacement of air filters, visual inspection of windings, visual inspection of connections, checking for hot spots.

7.2 Water-cooled

Cleaning of heat exchanger, testing of leakage alarms, visual inspection of windings, visual inspection of connections, checking for hot spots.

7.3 Electronic components

Sensitive electronic devices such as printed circuit boards (PCB's) in rectifiers and converters must be kept clean of dust, salt deposits, and checked on a regular basis.

8 Transformers

8.1 Air-cooled

Cleaning or replacement of airfilters, checking of fans, if any, visual inspection of windings, visual inspection of connections, checking for hot spots.

8.2 Water-cooled

Cleaning of heat exchanger, testing of leakage alarms, checking of fans, visual inspection of windings, visual inspection of connections, checking for hot spots.

9 Emergency generator

The emergency generator has to be started every week. Both the first (battery) and second means of starting (usually another way, such as by spring or hydraulic power) are to be checked.
Automatic starting on the first starting arrangement by simulating no-voltage of the feed from the main switchboard to the emergency switchboard has to be tested.

10 Alarm and monitoring systems.

Correct functioning of temperature, pressure and flow switches to be checked.
This is a time-consuming process, as pressures, temperatures and flow have to be simulated.
Analogue transmitters are easier to check: with an engine stopped, all actual temperatures are indicated at the engine temperature panel, or the preheating temperature of the motor.
With running engine bearings, pressures and temperatures can be compared and faulty sensors are easily found. Same goes for exhaust gas temperature transmitters, from no load to full load all of them should indicate temperatures in the same range.
The list of inputs as from the commissioning shall be used as a reference

11 Batteries.

Batteries are to be checked for:
- correct liquid level
- corrosion-free connections
- cracks in the housing.

Also the battery capacity is to be checked by discharging the battery partly and measuring the battery voltage. Results depend on rating and type of battery. Data to be registered and by comparison the end of the life time can be predicted.

As the battery capacity is related to the ambient temperature the environmental conditions must be checked on a regular basis and through the seasons, especially during winter time.

29. APPENDIXES

1 Formulas

A formula is a concise way of expressing information symbolically or give a general relationship between quantities.

Formulas are used to solve equations with variables. For example the formula that describes the current flowing through a resistor when the voltage and resistance are known parameters is:

$$I = \frac{U}{R}$$

In which:
I representing the current in Ampere (A)
U the voltage in Volts (V)
R the resistance in Ohm (W)

In a general context a formula is applied to provide a mathematical solution for a real world problem. Formulae form the basis for all calculations.

Formulae are internationally standardized and enable professionals around the world to understand and use them appropriately.

Below is a selection of formulae, including those used in this book, with an explanation of their purpose. Also included are some short explanations of key parameters.

Some **common electrical units** used in formulas and equations are:
V = Volt, the unit of electrical potential.
W = Ohm, the unit of resistance.
A = Ampere, the unit of current
W = Watt, the unit of electrical energy or power.
VA = Volt Ampere, the product of volts and amperes.

Explanation: in direct current systems the volt ampere is the same as watts or the energy delivered. In alternating current systems the volts and amperes may not be 100% synchronous. When synchronous the volt amperes equals the watts on a wattmetre. When not synchronous volt amperes (VA) exceed watts (W)
cosφ = power factor, in short the ratio of watts to volt amperes or the ratio of the active (true or real) power to the apparent power.

Explanation: as this is an important issue in AC networks this is some explanation of the forms of power. There are three distinctive forms of power:
Active Power (P), measured in watts (W), is the power drawn by the electrical resistance of a network doing the actual work.
Apparent Power (S), measured in volt-amperes (VA), is the voltage on an AC network multiplied by all the current that flows in it. It is the vector sum of the active and the reactive power.
Reactive Power (Q), measured in volt-amperes reactive (VAR), is the power stored in and discharged by for instance inductive motors, transformers and solenoids. Reactive power is required for the magnetization of the steel cores but does not perform any action.

The power factor can be calculated from:

$$\cos\varphi = \frac{P}{S}$$

In which P = active power (W)
S = apparent power (VA)

Low power factors should be avoided as the circuit's wiring has to carry more current than what would be necessary with a normal power factor of around 0,8.