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Computer simulation of control processes of ship power plant auxiliary systems

SUMMARY

In the paper a way of forming numerical models of some ship power plant systems is presented, which makes it possible to monitor work of the entire system, control it, simulate failures and analyse phenomena occuring within the entire system. Particular elements of a simulated system are modeled by using theoretical description of physical phenomena occurring in it. Final result of such simulation obtained from a synthesis of basic elements is presented, as an example, for B672 ship systems.

INTRODUCTION

Comprehensive automation of the ship power plant has led to a change in the mode of operation of engineering staff. In the extreme case the engine room is unattended and control functions are taken over by the officer-on-watch located on the bridge. Ship engineers realize only essential current maintenance, being kept in reserve for the case of a failure in any of the power plant systems. In the less advanced power plants the engineers work in the central control stations, steering the power plant remotely. In both situations the ship engineer has become essentially an operator of a automated complex system. This situation generates new problems for engineer's education processes. Far from the controlled object they are forced to control it by means of available sets of its state signals usually presented on a computer screen. Their decisions are sent to the engine room also by using a computer. It is considered that they should have at their disposal an „internal model" of the controlled object, to be able to act effectively [6]. The ship power plant simulators, today standard equipment of maritime schools worldwide, have to ease creating such models.

The simulators can also be useful in investigating the reliability of the ship power plant human operator. In that role the simulators are employed e.g. in nuclear energy industry [4]. Data on that reliability are necessary for predicting and assessing ship safety [3] as 70-80% ship accidents are considered as resulting from human errors, inclusive of those caused by power plant operators.

A single simulator does not satisfy all arising demands. It is necessary to elaborate their new versions to be able to assimilate all technical novelties in the area in question. Hence the idea emerged of modelling the elements of ship systems, suitable for digital simulation. In result it would be possible to „assemble" future installations from such element models.

BASIC ASSUMPTIONS

Elaboration of a computer simulator of a given process consists of the following steps :

- definition of a simulated object and process
- recognition of them
- modelling the process
- programming the model
- checking the model suitability.

The modelling can be realized by applying the heuristic methods or those based on the theoretical premises. The heuristic approach may be illustrated by application of the two-element model consisting of an inertialess block of statical characteristics and a linear inertial block. The theory-based approach can obviously provide more correct results making it possible to analyze the simulated process more thoroughly.

Such theoretically justified, computer simulation models of functioning of some ship engine auxiliary systems were presented in [5].

- ❖ The models are assumed operating in real time to make it possible to represent static and dynamic characteristics of the modelled installations in the full range of their loads and consequences of failures of their elements.
- ❖ Control of the models is performed in a way similar to that used in the ship power plant automation digital systems, i.e. on the basis of computer graphics.
- ❖ The models should be simple for the sake of a limited computation time, and should represent possibly complete set of the

operational states of an installation (which can be generated by its element failures and external disturbances in service).

❖ The modelled installations are assumed fitted with DSC computerized intermediate control systems as they would be probably applied to ship installations in the future.

The following assumptions have been made as to the modelling methods of the installations :

★ the theoretical models of the installation elements will be elaborated to be next simplified to a form suitable for real-time computations
★ thermodynamical phenomena and processes occurring in the installations will be modelled as linear and dynamic
★ hydraulic phenomena and processes will be modelled as nonlinear inertialess
★ identification of installation element failures will be performed by means of the Failure Mode and Effects Analysis method (FMEA) on the basis of expert opinions [8]
★ adequacy assessment of the simulation models will be made by analyzing correctness of their responses to selected inputs, and subjective correctness assessment of regulation time periods (the assessment will deal with an example model of the cooling and lubricating systems of 6ZA40S medium-speed main diesel engine installed onboard B672 ship)
★ only that part of the systems will be modelled which co-operates with the diesel engine.

DESIGN SOLUTIONS OF THE COOLING AND LUBRICATING SYSTEMS OF THE MARINE MEDIUM-SPEED DIESEL ENGINE

The cooling system of the piston combustion engine is intended for preventing against excessive temperature increase of its elements and minimizing average temperature variations within different parts of one and the same element. The cylinder liners and heads, exhaust valve bodies, turbo-blowers, pistons and injectors require cooling. Such objects of the other group as the lubricating oil systems of gears, shaftline bearings and compressor casings also require cooling. A schematic diagram of the cooling and lubricating system of the main diesel engine is shown in Fig.1.

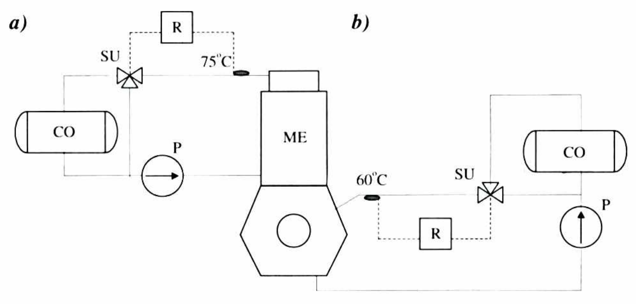

Fig.1. Schematic diagram of the auxiliary systems of the main diesel engine
***a)** cylinder block cooling system, **b)** lubricating oil cooling system*
***Notation :** CO – cooler, SU – setting unit, P – pump, R – regulator, ME – main engine*

For many years the typical ship power plant cooling system was applied, where the cylinder block together with cylinder heads was fresh-water cooled, and the fresh-water installation itself and the installations of the second group - by using sea water (Fig.2.)

Disadvantages of that system led to applying a new *central cooling system* of the ship power plant [1]. Its idea consists in using solely fresh water for cooling all ship power plant devices. The installation consists of two circuits :

➢ high-temperature one (HT) for cooling cylinder liners and heads
➢ low-temperature one (LT) for cooling the circulating oil, engine supercharging air, air compressors, shaftline bearings, devices connected with operation of auxiliary engines etc.

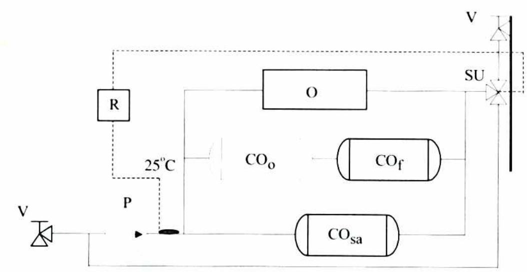

Fig.2. Schematic diagram of a sea-water cooling system
***Notation :** CO_{sa} – supercharging air cooler, CO_o – lubricating oil cooler, CO_f – fresh-water cooler, SU – setting unit, O – cooled objects of the second group, P – pump, R – regulator, V – valve*

The main advantage of such system is its higher reliability. Three different versions of the central cooling system can be distinguished :

◆ the integral system in which the HT - circuit fresh water is cooled by mixing it with the LT - circuit fresh water
◆ the installations of the separate HT - and LT - circuits, and the separate HT - circuit cooler cooled by sea water
◆ the installation in which HT - circuit fresh water is cooled by LT - circuit fresh water, in a separate cooler.

The integral central cooling system is reduced to short piping segments and one or more central coolers. From two to four pumps are usually installed, some of them can be two-step. An appropriate choice of pump capacity, depending on the load and sea-water temperature, ensures the integral control of auxiliary devices.

One of the newest regulation systems is Alfa-Laval Engard system [2] intended for automatic controlling the central-cooling-system working parameters. It consists of a micro-processor controller connected to temperature gauges of HT - and LT - circuits, final control elements and sea-water pumps. A scheme of the central cooling system controlled with the use of Engard system is shown in Fig.3. Temperature of each fresh-water circuit and opening degree of the setting unit is recorded and compared with the preset temperature at a given flow rate. The controller, apart from the temperature regulation, is able to switch sea-water pumps on a smaller or greater capacity depending on varying fresh-water temperature.

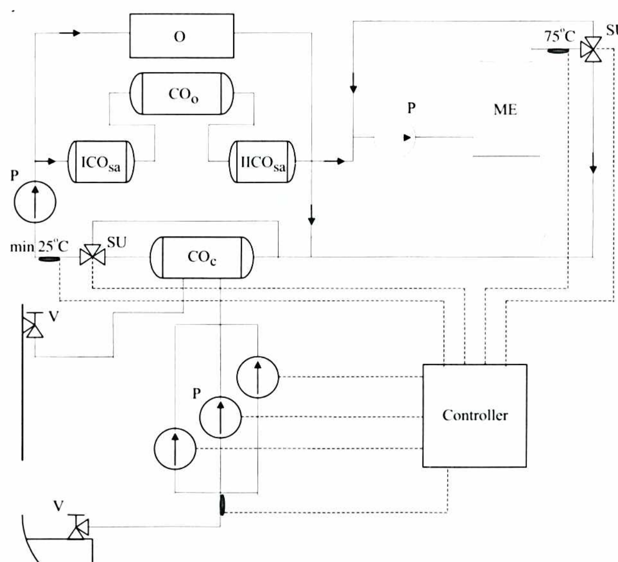

*Fig.3. Schematic diagram of the central cooling system controlled by the Engard system. **Notation :** CO_c – central cooler, CO_o – lubricating oil cooler, I, II CO_{sa} – supercharging air coolers, SU – setting unit, O – cooled objects of the second group, P – pump, ME – main engine, V – valve*

ASSUMPTIONS FOR SIMULATION AND CONTROL ALGORITHM OF THE INSTALLATIONS

- A simulation program structure should contain ready-made elements of the installations, which could be parametrized and then linked into a required configuration.
- A programming platform equipped with a database of installation elements should be at disposal in order to make updating easy and simulation of similar systems possible.
- Moreover, possible co-operation of a seperate installation with the entire power plant simulator is required.

The simulation object is a system consisting of mutally coupled installations. Fig.4 presents a general simulation and control scheme of a separate installation.

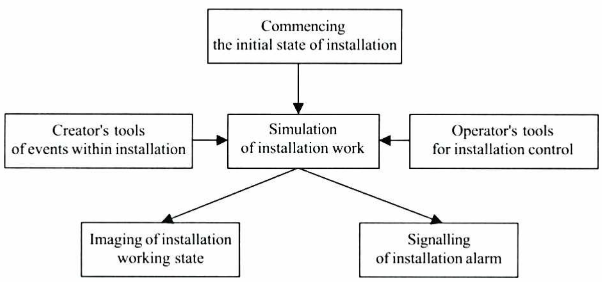

***Fig.4.** General simulation and control diagram of the installations*

Delphi 3 code (a new Turbo Pascal version) was selected for programming. It makes it possible to code mathematical operations in a broad range, create own graphical elements and co-operate with a network database.

BLOCK DIAGRAMS OF INSTALLATION MODELS

The diesel engine auxiliary installations considered as the regulation objects are complex, nonlinear systems. In each of them two mutually interacting sub-systems can be distinguished: thermodynamic and hydraulic. A model scheme of a typical **fresh-water cooling system** of the main engine is shown in Fig.5.

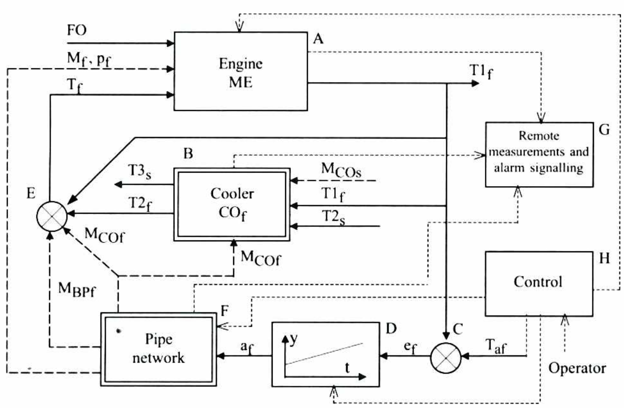

***Fig.5.** Model scheme of a typical fresh-water cooling system of the main engine*
***Notation :** - - - - hydraulic signal, —— thermal signal*
········ measurement and control signals
Other notations in the text below and in the nomenclature

The fresh-water pressure p_f at the inlet to the engine is controlled and the water temperature $T1_f$ at the outlet from it is regulated. Several parameters are remotely measured and exceedances of their limiting values are signalled. The fuel oil charge FO of the engine is an input value to the model. At the same time the pumps should be in an operation state. Within the block „A" of the model the static increase of cooling water temperature is determined. The heat inflow to the installation is inertial.

Characteristics of the cooler are represented by the non-linear unit „B" which obtains the signals (on the temperature $T2_s$ and water flow rate M_{COs}) from the modelled and the sea-water installation. The signal on the temperature $T1_f$ is put into the summation node „C" where it is compared with the signal on the set value T_{af}. The regulation deviation signal e_f is passed to the proportional-plus-integral controller „D" which forms the steering value a_f thus influencing position of the setting unit. The setting unit „F" is contained in the piping model and flow rates in the setting unit channels are determined there. The summation node „E" collects the determined flow rate signals (M_{COf} - through the cooler, and M_{BPf} - through the bypass) and temperature signals, and it determines the input water temperature to the engine, T_f, thus closing the computation loop. In the unit „G" results of parameter remote measurements are collected, and alarm signals are generated in case any of them exceed limit values. Commands from the operator are put into the unit „H".

The lubricating oil cooling system is fitted with the same units as those of the fresh-water cooling system. It differs from the latter only in the place where the temperature T_o is regulated, which, in this case, is located at the inlet to the engine. A model scheme of the lubricating oil cooling system of the ship main engine is shown in Fig.6.

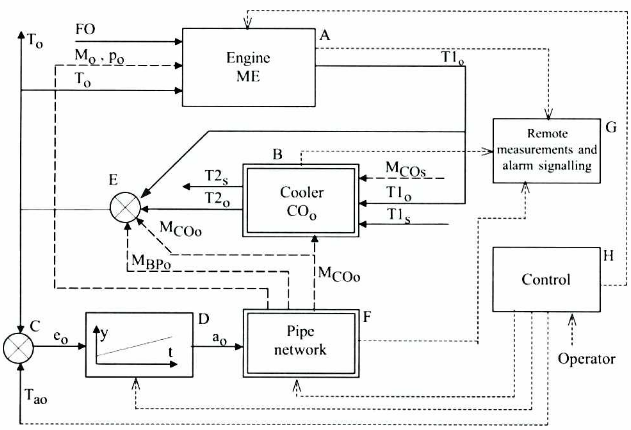

***Fig.6.** Model scheme of the lubricating oil cooling system of the main engine*
***Notation :** - - - - hydraulic signal, —— thermal signal*
········ measurement and control signals

The sea-water cooling system takes over the heat absorbed from the main engine by both above considered installations. The installation is also equipped with a typical temperature control system intended for moderating disturbances due to changes of overboard sea-water temperature. A scheme of the system's model is presented in Fig.7. The units „B_o" and „B_f" represent the coolers which belong to the fresh-water and lubricating-oil cooling installations.

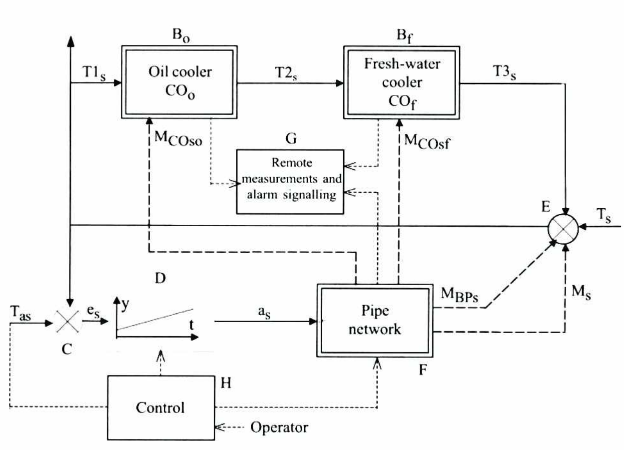

***Fig.7.** Model scheme of the sea-water cooling system of the main engine*
***Notation :** - - - - hydraulic signal, —— thermal signal*
········ measurement and control signals

AN EXAMPLE OF COMPUTER SIMULATION OF SHIP MAIN ENGINE AUXILIARY SYSTEMS

The example of computer simulation was elaborated for the auxiliary systems of 6ZA40S medium-speed main diesel engine installed onboard B672 fishing trawler STROJNIK [5]. Three integrated cooling installations were simulated (but limited to their parts directly connected with the main engine) :

- of fresh-water (FWI)
- of lubricating oil (LOI) and
- of sea-water (SWI).

Operation of the installations was analyzed by changing CP propeller pitch during STOP - FULL AHEAD - STOP manoeuvre at the constant engine speed of 466 rpm. At the STOP - FULL AHEAD cycle the engine torque is almost directly proportional to its fuel oil charge. At the FULL AHEAD - STOP cycle the engine load fast drops to zero and remains at this level. The ship is dragged by her hull resistance and not by CPP action.

Therefore the recorded pitch characteristics at increasing and decreasing CPP pitch are not to be compared because of a non-linear character of the object. Below, some selected results of the simulation are presented.

The diagrams presented in Fig.8 to 13 demonstrate temperature changes with time in the FWI, LOI and SWI installations at the overboard sea-water temperature of 10 deg C and operating sea-water temperature control system with its preset value of 25 deg C (Fig.12), and at the sea-water temperature elevated to 30 deg C and non-operating sea-water temperature control system (Fig.13). During the analyzed situation all elements of the installations operated correctly. No large pressure fluctuations were observed, and those of about 0.01 MPa were due to changeable position of the setting unit.

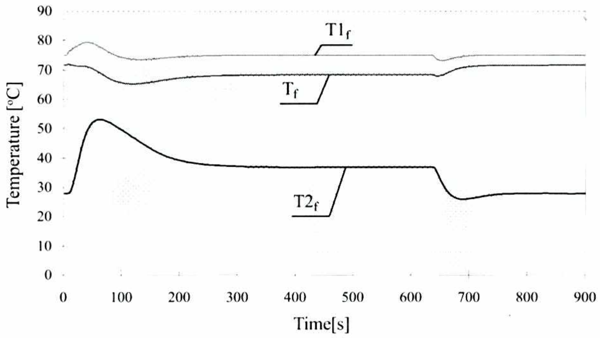

Fig.8. *Course of temperature changes versus time within the fresh-water cooling system (FWI) for a signal given from the ship motion system and the conditions : sea-water temperature of 10 deg C sea-water temperature control system under operation*

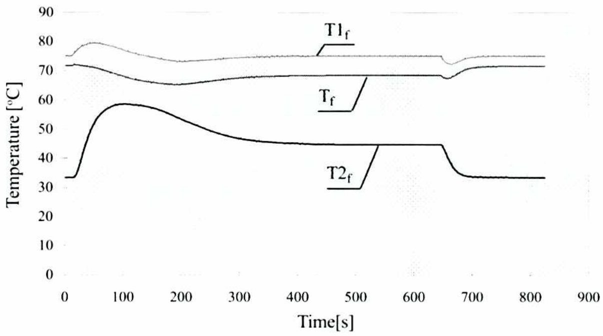

Fig.9. *Course of temperature changes versus time within the fresh-water cooling system (FWI) for a signal given from the ship motion system and the conditions : sea-water temperature of 30 deg C sea-water temperature control system not operating*

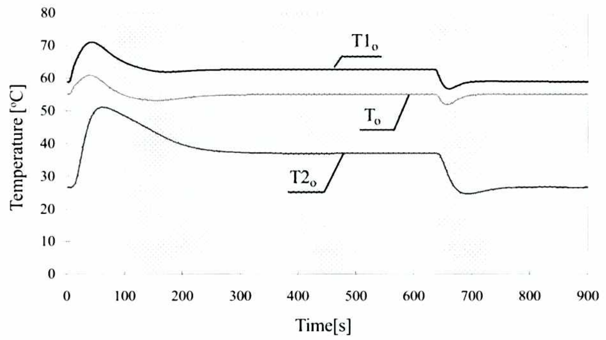

Fig.10. *Course of temperature changes versus time within the lubricating oil cooling system (LOI) for a signal given from the ship motion system and the conditions : sea-water temperature of 10 deg C sea-water temperature control system under operation*

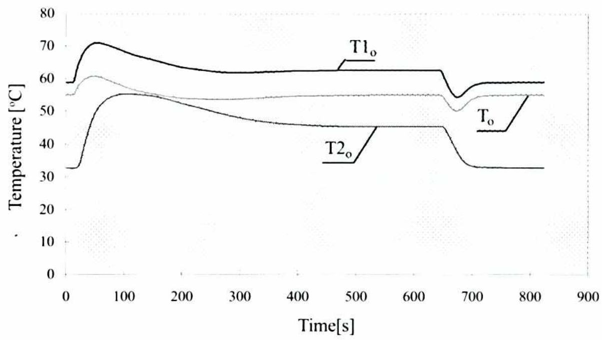

Fig.11. *Course of temperature changes versus time within the lubricating oil cooling system (LOI) for a signal given from the ship motion system and the conditions : sea-water temperature of 30 deg C sea-water temperature control system not operating*

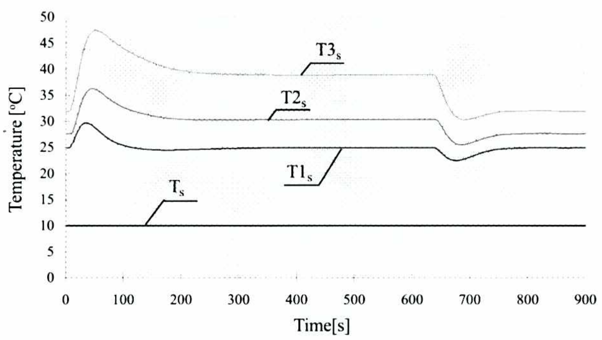

Fig.12. *Course of temperature changes versus time within the sea-water cooling system (SWI) for a signal given from the ship motion system and the conditions : sea-water temperature of 10 deg C sea-water temperature control system under operation*

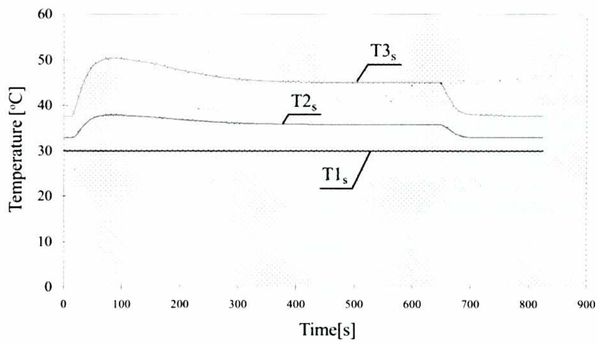

Fig.13. *Course of temperature changes versus time within the sea-water cooling system (SWI) for a signal given from the ship motion system and the conditions : sea-water temperature of 30 deg C sea-water temperature control system not operating*

ASSESSMENT OF THE SIMULATION RESULTS

- ➔ The simulated course of temperature changes seem to be correct as regards the regulation process duration, expected temperature deviation and co-operation effects of the relevant installations.
- ➔ The proposed element models correctly represent work of the installations in the steady states and transient states caused by changing the engine load as well as external factors.
- ➔ The preset sea-water temperature should be so selected as not to worsen regulation effects in warm waters and to improve them in cold waters. A low sea-water temperature increases effectiveness of coolers and can cause large fluctuations of regulated parameters, even an unstable operation.
- ➔ Sea-water temperature regulation limits detrimental effects of the object's non-linearity. Regulation time duration is of secondary concern as ensuring small regulation deviations is more important. Even the simplest system of water temperature stabilization is able to limit disturbance caused by its changes. The recommended preset temperature of the seawater amounts to 25 deg C.

FINAL REMARKS

The example investigations of the cooling and lubricating systems of 6ZA40S diesel engine lead to the following general conclusions :

- ❍ The obtained static characteristics of the modelled systems are fully appropriate within the entire range of their service loading.
- ❍ The transient state characteristics can be justified on the basis of relevant physical phenomena and their asymptotic values are realistic.
- ❍ The order of the recorded regulation times is deemed correct.
- ❍ Carrying out thorough analyses of the simulated phenomena and processes is possible. They can deal with the regulation processes as well as diagnosing the technical state of installation elements. It seems that possible range of such analyses is much broader than that available by means of a simulator based on heuristic models.

Appraised by Alfred Brandowski, Prof.,D.Sc.

NOMENCLATURE

a	-	position of setting unit
CO	-	cooler
e	-	control error
FO	-	fuel oil charge
M	-	liquid mass flow rate
M_{COsf}	-	sea-water mass flow rate through fresh-water cooler
M_{COso}	-	sea-water mass flow rate through lubricating oil cooler
ME	-	main engine
O	-	cooled objects of the second group
p	-	pressure
P	-	pump
R	-	regulator
SU	-	setting unit
t	-	time
T	-	temperature
V	-	valve
y	-	control value
1, 2 ...	-	node numbers of installation
I, II	-	numbers of coolers

Indices

a	-	assumed value
BP	-	of cooler bypass
c	-	central
CO	-	of cooler
f	-	of fresh water
o	-	of lubricating oil
s	-	of sea water
sa	-	of supercharging air

Acronims

FWI	-	fresh water cooling installation
HT	-	high-temperature circuit
LOI	-	lubricating oil installation
LT	-	low-temperature circuit
SWI	-	sea water cooling installation

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