CONTROL ENGINEERING ON BOARD

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Abstract: *Control engineering embraces instrumentation, alarm systems, control of machinery and plant previously known under the misnomer of automation. Control engineering can be applied not only to propelling and auxiliary machinery but also to electrical installations, refrigeration, cargo handling (especially in tankers) and deck machinery, e.g. Windlass control. Opinion still vary on such matters as the relative merits of pneumatic versus electronic system and whether the control center should be in the engine room or adjacent to the navigating bridge. Arguments against the exclusion of the engineer officer from close contact with the machinery are countered by the fact that electronic systems are based on changes other than those of human response. Automated ships (UMS) operate closer to prescribed standards and therefore operate with greater efficiency. The closer control of machinery operating conditions, e.g. cooling water temperatures and pressures, permits machinery to be run at its optimum design conditions, making for fuel economy and reduced maintenance. Automation can carry out some tasks far more effectively than men. In other areas it is less effective. For example, the monitoring of machinery operating conditions such as the temperatures and pressures can be carried out by a solid state alarm scanning system at the rate of 400 channels/sec., giving a degree of surveillance which would be impossible by human observation. Conversely, the detection of noisy bearing, a leaky gland or cracked pipe is scarcely possible by automatic means. The balance between the possible and the necessary would be achieved in this case by combining automatic monitoring of all the likely fault conditions, with routine machinery space inspection say twice a day.*

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1. Introduction

If a ship's engine room is to operate unmanned for specific periods, certain requirements must be met. Firstly, control of engine speed and direction (or propeller pitch) must be made available at the bridge. In order to avoid placing any additional work load on the bridge watchkeeper, who is concerned essentially with what is happening outside the ship, the engine remote control system should carry out instructions signaled by the bridge watchkeeper at a simple telegraph type control. No demands for engineering skill should be placed on the bridge personnel. The application of starting air, then fuel and the subsequent rate of acceleration to demanded speed should be functions of the control system rather than of the operator.[1],[2].

Having removed the need for engineers to respond to possible telegraph orders at any time, the next important step is to provide automatic control of main engine services such as cooling water, lubricating oil, fuel and air systems. These functions are carried out by means of automatic controllers and control valves, which maintain system pressures, temperatures etc. at predetermined values despite load changes. The response rate, stability and accuracy of these control loops are dependent not only on the quality of the components but more important, on the matching of the dynamic characteristics of the control system to the requirements of the particular service.[3],[4],[5].

The third requirement for unattended machinery operation is the provision of an alarm system to monitor all the important operating conditions. These include temperatures and pressures of the fuel, air, lubrication and cooling systems for the main engines and generators, tank level alarms and many others such as bearing temperatures of equipment capable of carrying out these tasks, and some typical systems will be described later.

The most important feature of an unattended machinery complex is the fire alarm system, in which sensors are placed around the engine room and associated spaces in order to detect combustion at the earliest practicable time.

Finally, it is necessary to provide for the continuity of electrical power for essential services in the event of failure of the duty generating equipment. In its simplest form, this may be limited to starting the emergency generator to provide power for essential lighting, but other services such as steering motors, machinery and fire alarm systems may also be provided with emergency power.

These are the five keystones of an automated machinery space, upon which all classification societies agree-remote engine control, automatic control of engine room services, a machinery alarm system, fire alarm system and emergency electrical power.

2. Planning the system

Planning of the automation system [3], by which is meant the total complex of remote and automatic controls and plant instrumentation must take account of several basic parameters:

1. The intended service of the ship.
2. The intended manning arrangements.
3. The type of propelling machinery.
4. Ship maintenance policy.
5. Classification society and notation required.
6. Ship resale value.

The above list of "design inputs" is by no means complete, but represents the major factors, which should influence the design of the automation system.

Experience has shown that where there has been some failure to achieve all that was expected it is largely due to lack of planning. Successful planning involves integrating and coordinating the system as a whole and this cannot be achieved if sections are in different hands. Haphazard methods by independent concerns have resulted in conflicting and unworkable systems. For example, sensors have been used at the instigation of one interested party and without consultation with, for example, the supplier of the computer or the data-logger only to find later that the output is incompatible.

It is also essential the control engineer should have practical knowledge and experience of the plant to be controlled and that the plant supplier should concur regarding facilities for accommodating and positioning the sensors.

A procedure, which has been advocated for ensuring success, is that the ship-owner should, at the outset, state in broad terms what he requires. The shipbuilder should then prepare an outline specification to meet the owner's requirements and from this the control engineer can prepare a detailed specification. All three parties should then get together and agree the control specification. Hitherto there has been too little feedback information and experience from the ship but control engineers and ship-owners are now appreciating that this is important. If owners or builders have preferences for any particular make of component for any particular make of component; it is at the planning stage that agreement should be reached.

The owner will need to consider operational and economic issues to decide how far to go and what financial benefits he can expect from each section. For example, in a refrigerating plant, push-button starting from the control console may not be justified as it is an infrequent

operation, which can be performed manually, and so centralization can be confined to instrumentation and alarms. The essential factors for successful systems are:

1. Reliability.
2. Simplicity.
3. Ease of operation and maintenance.
4. Suitability for marine conditions.
5. Facilities for servicing (especially in foreign ports).

Marine conditions involve not only ambient temperatures, humidity, vibration and saline atmospheres but also the physical conditions inevitable during construction, installation and trials. These apply to all parts of the system-sensors, instruments, consoles, computers, etc. Paint spraying, asbestos lagging, welding, staging and dirty surroundings can play havoc.

Fitters and erectors have no respect for such equipment and many sensors have served as a footstep. Systems must embody "fail safe" features and this aspect must be studied analytically in the planning stage. All possible sources of failure and their consequences must be covered. For example, if a fuel injection system is such that a spring is balanced by fluid pressure acting on a piston then loss of fluid may result in full fuel admission to the engine and a dangerous condition exists.

The arrangements must ensure that failure of the controlling medium will result in either the speed remaining constant or that is reduced.

Fail safe principles can be interpreted in different ways, such as complete stoppage of an operation or reverting to some other (safe) state. In suitable cases it can mean "fail-as-set", i.e. continue as at the time of failure, sometimes referred to as "failed-as-is". This essential that an alarm be operated to direct attention to the failure.

A vital part of planning procedure is planning the pre-commissioning trials and calibration. This must be considered and agreed by the builder at an early stage so that he can include it in his overall program and delivery date and, when the time comes, provide the essential facilities.

It is not unusual for a comprehensive system to include 300-400 control points widely distributed and each requiring individual checking for operation and possibly calibration. This is time consuming and can only be done when installation is complete and ship's services are available. It cannot be postponed until after the sea trails. A detailed test program and timetable, agreed by the shipbuilder is therefore essential. Whit all systems there is an initial period of teething troubles and these must be tracked down as far as possible before the sea trials. This applies particularly to closed-loop systems.

Simulators can be provided in some cases, which make possible to test the entire electronic equipment by providing similar responses to those anticipated under service conditions. They can form part of the permanent installation so that, for example, prior to arrival in port, the navigating officer can himself simulate operation of the engine telegraph.

3. Control system

The simple control loop has three elements, the measuring element, the comparator element and the controlling element. The loop may be effected pneumatically, electronically or hydraulically. In some instances the control loop will be a hybrid system perhaps utilizing electronic sensors, a pneumatic relay system and hydraulic or electric valve actuators. Each system has its strengths and weaknesses:

Pneumatics- require a source of clean dry air-can freeze in low temperature, exposed conditions, but equipment is well proven and widely used. Most engineers naturally favor pneumatic control, as it is effective and relatively easy to maintain. Nevertheless electronic systems can be equally reliable and in fact become indispensable for sophisticated systems especially those incorporating computers and data loggers. Pneumatic systems can give a speed of response sufficient for marine applications and have been used for example for fuel and lubricating -oil temperature recording, boiler control and in numerous other directions. *Electronics*- good response speeds with little or no transmission losses over long distances, easily integrated with data logging system, requires to be intrinsically safe in hazardous zones. Advantages are low power consumption, reduced size and cost of components, high speed of response.

Hydraulics- require a power pack, may require accumulator for fail-safe action - compact and powerful and particularly beneficial in exposed conditions.

4. Measurement of process conditions

The range of parameters to be measured in merchant ships includes temperatures, pressures, level, speed of rotation, flow, electrical quantities and chemical qualities. Instrumentation used for remote information gathering purposes invariably converts the measured parameter to an electrical signal which may be used to indicate the measured value on a suitably calibrated scale, provide input information to a data logger or computer, initiate an alarm or provide a signal for process controller.[6]. As stated earlier however the more favored means of providing process control information (as opposed to information display only) is to use a pneumatic system.

4.1. Sensors.

Sensors play an essential role in all systems for transmitting information to control and other remote positions. The quantities necessary to sense include counting, fluid flow, humidity, liquid levels, noise, position, pressure, salinity, smoke density, speed, strain, temperature, viscosity, torque, power, etc.

The type of sensor must take into account the relative importance of the effect of its presence on the quantity to be measured, together with the extraneous effects by or on the sensor. For example:

1. It should not effect the quantity to be measured, e.g. flow metering.
2. The effect of ambient and adjacent temperatures should be either known or be capable of elimination.
3. Speed of response in respect to rapid changes.
4. Independence from magnetic fields, humidity, barometric pressure, local heat.

5. Independence from variations of electrical supplies (e.g. frequency and voltage) or be provided with means for compensating for variations.
6. Linearity, hysteresis, repeatability and zero-point drift are also important.

Sensors may be required to initiate mechanical operation, for example, such as the high forces required operating cargo valves in tankers and for hatch closing and opening and as most sensors cannot provide the mechanical effort required this can be provided via transducers. The electrical or pneumatic signals obtained from them can in turn operate alarms, relays or instruments. Bourdon tubes, diaphragms and floats can provide sufficient power to operate instruments directly or can act as transducers. [6]

4.2. Alarm systems and data loggers

The first step towards centralized control of marine machinery was simply to extend the conventional control and instrumentation facilities to a central control console, which was housed in a special control room. Consequently, the resulting consoles were very large and presented a great mass of information on gauges. In later installations and the wide spread use of microprocessors it became the practice to integrate the three basic instrumentation functions - alarm monitoring, display of data and recording - within one electronic system.

Alarm scanning is the most important function performed by this type of equipment. Scanning speeds vary between one and 400 channels per second for analogue parameters, and the accuracy of alarm comparison is generally within one per cent of the measurement range. An extremely complex machinery arrangement can be checked for mal function twice every second, and alarm thresholds can be set very close to normal operating conditions, so giving practically instantaneous response to potentially dangerous situations. The development of high -reliability alarm-scanning systems is an important accompaniment to the increasing use of multi-engined propulsion systems, higher b.m.e.p.'s and the growing practice of operating ships with unattended engine rooms.

Several types of equipment are employed in ships, and while the details of operation vary, the basic arrangements are similar. Such equipment may be regarded as comprising four sections; primary measurement, signal selection, signals processing and control of out-put units.

4.3. Signal selection

The basic principle of scanning systems is that a number of measurements are evaluated sequentially by one high-quality signal processing system. The transducer signals are selected singly for evaluation by means of relays or solid-state switching networks. The relays or transistor switches are operated by signals from a scan control unit, which is generally regulated by an electronic clock. Scanning speeds vary according to the type of signal selection system used, and on the speed of response of the signal processing equipment. Relay scanners are usually limited to about 10 channels per second because of limited relay life and the delay required for the signal to stabilize after switching. Solid state scanners do not suffer these limitations to any great extent, and analogue scanning speeds of 400/or more channels per second are thus made possible.

A high scan rate gives the system a very short response time to alarm conditions, which is very important with modern high-rated machinery. It also enables the logging system to tabulate a cascade of faults in proper chronological order, enabling the operator to identify the source of trouble when presented with a complex fault situation. For the engineers it can show trends, which require action and vital conditions requiring urgent attention. By automatically recording conditions at predetermined intervals, transient states are revealed which would not otherwise be observed.

4.4. Signal processing

The first stage in signal processing is amplification of the low-voltage transducer signal, which is typically in the range 0-100mV. The most important part of signal evaluation is comparison of the signal level with upper and/or lower alarm limits.
The digital section of the system converts the analogue data into digital form for presentation on the multi-point indicator or printer.

The digitized transducer signal is referred to a scaling unit which multiplies the signal by an appropriate constant so that its numerical value corresponds to engineering unit such as °C. The scale unit or computer may therefore be called upon to perform addition, multiplication, linearisation and combination of all three, changing its routine as each transducer signal is processed.

One disadvantage of alarm scanning systems is that a failure in the central sections of the equipment can cause loss of all facilities on all channels. For this reason they must be made to a very high standard of reliability which makes them relatively expensive. Also, it is advisable for the ship to carry a fully comprehensive spares kit if it is engaged in deep sea trading.

Generally, the more channels that are monitored by such equipment, the more cost-effective they become, as the cost per channel is reduced. For smaller ships, where the data logging facility is not important, parallel entry instrumentation system may be employed. The essential difference is that alarm comparators and alarm lamp drive circuits are provided for each channel, instead of being shared by all inputs.

In addition to the conventional measurements such as have already been mentioned, small sub-systems are employed for special functions such as fuel viscosity control, turbocharger vibration alarms, being wear-down alarms, flame failure devices for boilers, fire alarm systems, etc.

5. Engine room control

5.1. Bridge control for diesel engines

Remote control of large diesel engines requires consideration not only of the normal functions of starting and reversing but also the conditions imposed on the engine when reversing while the ship is under way. Account should also be taken of critical running speeds, which may be barred because of torsional vibration.

It is essential, particularly with bridge control, that all the operations should take place automatically without intervention by the officer in control, and that he should receive a signal confirming that the order has been obeyed.

Movement of the control from stop must first initiate checks that turning gear is disengaged, starting air is available at the correct pressure, cooling water, lubricating oil and fuel oil supplies are in order before the starting sequences begins.

5.2. Boiler control systems

Automatic control of boilers and turbines is a much more complex problem than that of diesels and does not lend itself to any precise directions. Nevertheless it offers the greatest scope for efficiency and economy in both manpower and fuel consumption. Dealing first with steam raising, the efficiency of modern complicated high-efficiency steam and feed-water systems depends on the correct relationship and operation of a large number of independent controls. They are all inter-related and each variation of main engine load, sea temperature, etc. requires a different combination of values and optimum efficiency is rarely achieved without some form of automatic control.

The principal items requiring control in an automatic system may be grouped as follows:

Boiler system	*Turbine and reduction gear*
Steam pressure	Speed
Steam temperature(super-heat)	Bleeder valve control
Water level	Lubricating-oil temperature
Feed pump	Over-speed
Feed water temperature	Condensate system
Fuel-oil	Temperature of astern turbine
Forced draught fan	
Air heater	
Smoke density	

5.3. Controls for generators

In unattended machinery installations it is necessary to provide certain control facilities for the electrical generating plant. These may vary from simple load sharing and automating starting of the emergency generator, to a fully comprehensive system in which generators are started and stopped in accordance with variations in load demand. Medium speed propulsion plants normally use all diesels generating plant. Turbine ships obviously use some of the high quality steam generated in the main boilers in condensing or backpressure turbo generators, with a diesel generator for harbor use. The usual arrangement on large-bore diesel propulsion systems is a turbo generator employing steam generated in a waste-heat boiler, plus diesel generator for maneuvering, port duty, and periods of high electrical demand. Diesel generators. The extent of automation can range from simple fault protection with automatic shutdown for lubricating oil failure, to fully automatic operation. For the latter case the functions to be carried out are: Preparation for engine starting.

Starting and stopping engines according to load demand.
Synchronization of incoming sets with supply.
Circuit breaker closure.
Load sharing between alternators.
Maintenance of supply frequency and voltage. Engine/alternator fault protection.

Preferential tripping of non-essential loads and restoration when sufficient power becomes available. It is necessary to provide fault protection for lubricating-oil and cooling services, and in a fully automatic system these fault signals can be employed to start a stand-by machine, place it on line, and stop the defective set.

Turbo-generators. The starting and shutdown sequences for turbo-generator are more complex than those needed for a diesel-driven set, and fully automatic control is therefore less frequently encountered. However, the control facilities are often centralized in the control room, together with sequence indicator lights to enable the operator to verify each step before proceeding to the next. Interlocks may also be employed to guard against error.

The start up sequence given below is necessarily general, but it illustrates the principal and may be applied to remote manual or automatic control:

Reset governor trip lever.
Reset em'cy stop valve.
Start auxiliary L.O. pump.
Start circulating pump.
Apply gland steam.
Start extraction pump.
Start air ejectors.
Open steam valve to run-up turbine.

Where a waste-heat boiler is used to supply steam to a turbo-alternator, control of steam output is normally controlled by a three-way valve in the exhaust uptake, the position of which is regulated in accordance with steam demand. Surplus waste-heat is then diverted to a silencer.

5.4. Automation on tankers

Automation and computers play an indispensable part in tanker operation, particularly in the super-tankers now in service. It is of vital importance, for instance, to take account of stresses raised in the hull due to bending moments resulting from unequal buoyancy. These may arise from ballasting or from different grades of oil or may occur during loading/discharging. It will be apparent that with modern tankers a large number of valves are involved which must all be operated in a logical sequence. Not only is this important from considerations of hull stress, but also when a mixed cargo of different grades is involved. For protection against incorrect operation some valves require sequence interlocking. Trim and list must also be controlled. There is obviously a fertile field for centralized control and for computer operation.

6. Conclusions

A large number of ships have been fitted with computers which are programmed to carry out a great variety of tasks embracing satellite navigation, ship's housekeeping, crew wages, machinery surveillance, weather routing, cargo-loading calculation and ballasting, satellite communications, e-mail, etc. General-purpose industrial computers have also been employed or the single task of machinery alarm scanning and data logging.

Computers offer very important and unique benefits when they are applied with due regard to cost-effectiveness. Particular areas in which the computer may excel are the control of advanced steam generating plant, marine gas turbines, and performance monitoring of diesel engines.[7], [8], [9]

Progress is now being made towards machinery component condition monitoring, which could result in diesel engines only being stripped down for repair of known defects, rather than on the present basis of hours run. If classification societies are prepared, in the fullness of time, to relax periodic survey requirements as a result of this development, then these systems will be widely fitted.

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