Automatic control systems for ships fitted with podded propulsion drive (POD)

Czesław Dymarski, Assoc.Prof., D.Sc.
Karol Dąbrowski, M.Sc., Eng.

ABSTRACT

The paper shows purposefulness and possiblity of automation of ship propulsion systems , especially those of POD type, intended to be used on four Baltic navigation ships : a containership, ro-ro ship, product tanker, as well as river-sea-going ship, designed within the frame of the Eureka „Baltecologicalship" project. Requirements of ship classification societies, and general ones for modern ship control systems were presented, as well as a review and analysis of currently applied power plant automation systems for diesel- electric ships fitted with podded propulsion drive (POD), were performed. Moreover real ways and possibilities of controlling ship's course and speed were indicated. Information contained in this paper may facilitate selecting appropriate design assumptions for a propulsion control system to be applied on the above mantioned ships.

Keywords : ship propulsion, azimuthal propulsion, ship control systems

INTRODUCTION

The outfitting of ships with automatic control systems has already been a standard for many years. Such systems can be found practically in any shipboard device. However development of computer and data transmission technology has opened new possibilities for control systems. They are associated with joining control systems into large ones, which is a sucessive phase of development of automatic control for ships.

In a further prospect the development should lead to building ship power plants practically unmanned regarding their automation level. Unfortunately the goal is still very distant at the present development level, mainly due to too low reliability of mechanical devices.

The podded propulsion drive (POD) is a step forward in this respect as instead of a single high-output main engine a set of relatively low-output engines driving electric generating sets can be applied. A failure of one of the engines does not cause the blackout of the entire propulsion system to occur.

The other advantage of the POD system is a large number of electrical elements which can be easily automated.The devices are often fitted with its own microprocessor system and communication interface. This way vast possibilities have been opened for designers of automatic control systems.

The presented paper concerns the automatic control systems for four types of ships : a containership, ro-ro ship, product carrier, driven by azimuth propellers, as well as a river-sea-going ship driven by screw-rudder propellers. It can be assumed that a ship type only to a small degree influences overall structure of automation systems, therefore in this work no separate analysis for each of the ship types was performed.

REQUIREMENTS OF SHIP CLASSIFICATION SOCIETIES

The ship control systems are to provide high level of safety. The assumption has to be realized by satisfying a number of requirements established in the rules of ship classification societies. Below, the following requirements for ship control systems are formulated on the basis of the rules and publications of Polish Register of Shipping [11,12] :

- ensuring control of functioning and technical state of all important devices, i.e. electric motors installed in PODs, frequency converters, diesel engines etc, as well as generating appropriate signals and alarms to inform operators on occurrence of a malfunction
- making it possible to control ship's motion by influencing its propulsion system both from the bridge and other places on the ship, at which such need could appear
- ensuring an automatic response of the system in the case of hazardous situations.

ADDITIONAL REQUIREMENTS FOR CONTROL SYSTEMS OF POD-FITTED SHIPS

The PODs differ substantially from the classical ship propulsion system of a fixed or controllable pitch propeller and passive rudder system. Their essence consists in joining together propeller and rudder systems into the whole. In this case the propeller simultaneously fulfils the role of active rudder. Hence the automatic control system has to integrate both the function. Even if it is composed of two subsystems : steering and propelling, they will be expected to be functionally integrated into an entity. First of all they should be felt by the user as a single system. For this reason it is very important to appropriately design and locate control heads.

However the POD does not substitute all ship manoeuvring devices. For manoeuvring in ports bow thrusters are used. Therfore they are also provided on the designed ships in question. Because of high availability of electric energy on the ships it is recommended the thrusters to be electrically driven as it makes it possible to connect their control systems with the POD control system. This way ship's crew can have at its disposal a complete ship control system both during sea voyage and port manoeuvring, integrated in a single panel which makes it possible to control all propulsion and manoeuvring devices.

Such solution makes it necessary to design a superior system responsible for control of information flow within the entire system. It may be a separate computer which, on the one hand, could control communication between control systems of particular devices : i.e. frequency converters, main engines, switching devices etc., on the other hand it could serve as a module making it possible to hand-over control from one to another control heads. It is assumed that direct control over a given device can be executed from one control head only, hence a system giving assent for such control is necessary in this case.

The remaining requirements for a control system one can describe by dividing it into the following constructional elements :

- **System's wiring** – should ensure fast and safe data transmission. Simultaneously, number of communication cables should be limited. The first postulate could be best fulfilled by lightguide connections having rotatable optical connectors installed in the places where the cables pass from PODs to the deck.The best way to limit number of cables is to apply data buses (e.g. profi-BUS, an up-to-date and still modernized solution). This solution has been used for many years and it has proved to be correct.
- **Drive control and supervison system** – should prevent against exceedance of limiting values in frequency converters. In the case when the control system covers a greater number of devices (e.g. thrusters) several drive systems are involved.
- **Drive system** – contains logic and drive supervision system. It analyzes operation of supply network, motor, transformers and remaining drive control elements. Its work is aimed at :
  - automatic switching-off in the case of exceedance of appropriate values in power supply circuit
  - safeguarding against overloads and shortings
  - checking the system before starting, generating availability signals and stopping the drive in case of incorrect values of operational parameters
  - control of starting and stopping the drive
  - rotational speed control of driving motor
  - communication with the remaining automation elements
  - switching on/off of activity of control panels on ship.

  Practically this is a management system which plays a decisive role in drive operating.
- **Data transmission control** – ensures distribution and recording of the data obtained from transducers and measuring instruments, moreover it makes communication between control heads and the drive control & supervision system, possible.
- **Operator panels, control heads** – serve as basic communication means between ship's crew and automation system. It should be remembered that to apply a POD system the ship is be fitted with an electric power plant , associated switching devices and a transforming station. They are also equipped with an automatic control system of electric power production and distribution. All the systems should be coupled together, and they should be made accessible from control heads grouped in one place. It is also crucial to design interfaces of operator panels in such a way as to ensure easy operation of the system, without any additional cost of ship's crew training.

A separate problem is to ensure cooperation with an autopilot. It can be realized by making use of a data transmission control system. The autopilot would be considered by such system as an additional control panel, without any possibility to control drive of thrusters. However the problem of a way of ship course-keeping remains to be solved. In the case of applying the POD system it can be attained in two ways :

1st – in the same way as it is realized in the case of the conventional propulsion system (screw propeller and passive rudder), i.e. by controlling direction of propeller thrust vector. The solution requires the entire POD to be rotated, but rotational speed of propellers can be maintained constant.

2nd – the other way is to change rotational speed, hence by changing the thrust delivered from the propeller of one POD only. Such action would produce a non-uniform propulsion generating a ship course changing moment. Choice of one of the possibilities should be based on an effectiveness analysis of both solutions and their energy efficiency. From the point of view of automatic autopilot system both the versions are rather easily realizable.

ANALYSIS OF POSSIBLE APPLICATION OF DIFFERENT CONTROL SYSTEMS

A system approach is necessary for designing a modern ship propulsion system fitted with electric power plant and switching station . An analysis of a ship as the whole , and not as a sum of its particular equipment elements, may help in lowering risk of malfunctioning, incorrect communication between devices etc. Also, users of such system may be easier and faster trained in operating it. In the case in question continuous development of user's interfaces (operator panels) is also of a great importance. It makes faster and more effective reacting by ship crew during ship operation, possible, as well as that special qualifications for operating automation devices by ship crew, are not required.

The ship electric power plant supplies all driving devices and delivers electric energy to the ship electric network. As all supply systems are mutually connected the intergrating of automation systems into a global system whose elements are capable of adapting their work to an energy situation of the entire ship, becomes rational.

Propeller thrust control

Two kinds of ship propulsion control are possible: maintaining a set value of ship speed, and maintaining a set value of power. In the first case a speed setting will be translated into an appropriate number of propeller rotations. It will cause demand for engine output changeable. In the case of the engine output control a reference value is the main shaft power, and the shaft rotational speed should be so changed as to maintain the power value constant.

Setting an appropriate speed value on the bridge should initiate a power changing program which determines slope values of power rising and trailing edges in function of the set value and current load. It has to prevent the propulsion system from an overload at too sudden speed change. An example diagram showing increase of main shaft power, speed and torque is presented in Fig.1.

Speed change versus load		Power change versus load	
Range	Slope of characteristics	Range	Slope of characteristics
0-50%	10%/s	0-5%	5%/s
50-80%	1%/s	5-50%	1.25%/s
80-100%	0.7%/s	50-100%	0.5%/s

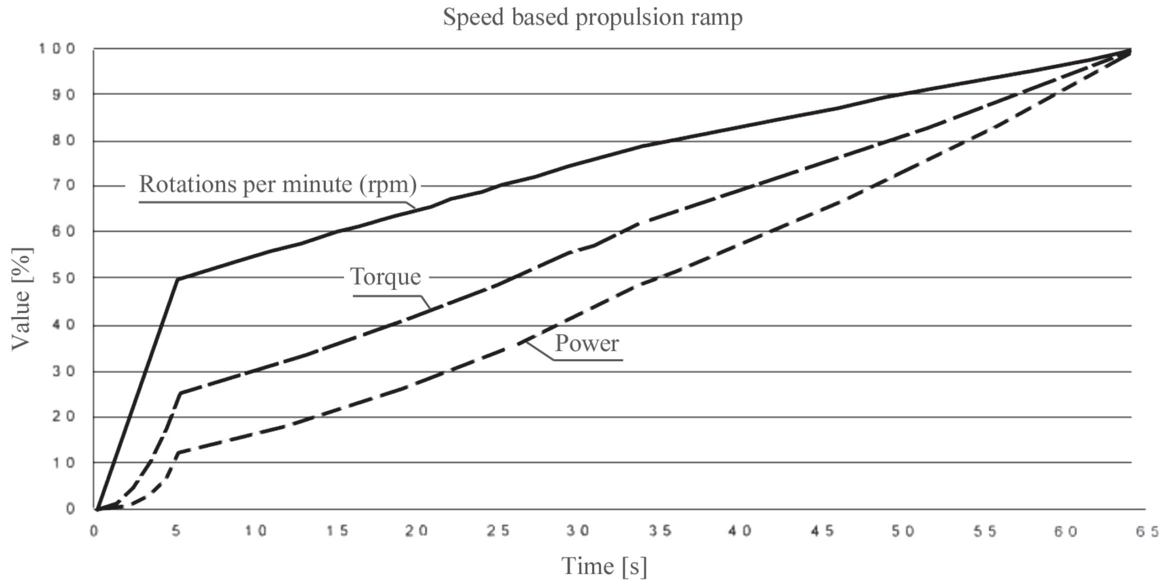

Fig. 1. *An example diagram showing increasing course of main shaft power, speed and torque in function of time*

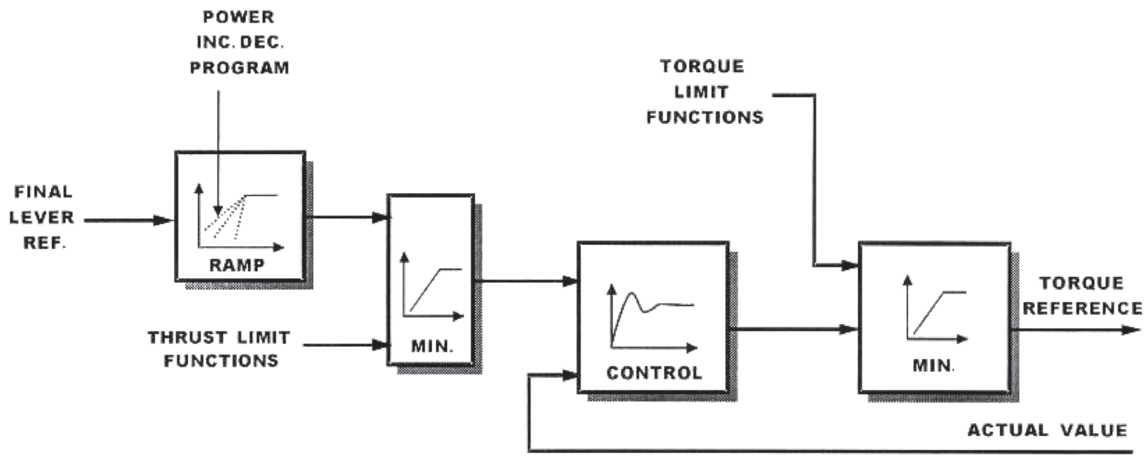

Fig. 2. *Schematic diagram of the ship speed control procedure*

As soon as a power level becomes steady a limiting value of propeller thrust is checked. The maximum set value of ship speed will be hence dependent on limitation of propeller thrust force. Next the system checks a value of engine shaft torque and adjusts its rotations in such a way as not to exceed the maximum shaft torque. After performing the procedure an appropriate value is sent to the engine.

A sudden drop of rotational speed of the engine should cause the engine passing onto generating work mode and transferring a part of its output to an inverter and network, and a power surplus to a resistor.

Propeller thrust direction control

Rotation of propeller's POD makes it possible to produce large forces transversally directed to ship's longitudinal axis. It may be hazardous as a large heeling moment appears in such situation. Apart from a large heel of ship, which itself is hazardous (possible shipping of water on deck) it generates large accelerations which may cause a shift of cargo and – in consequence – trigger other hazards including loss of stability and ship's capsize. Hence the control system is required not only to control a propeller thrust value depending on a value of POD's rotation angle, but also to limit speed of its rotation. The speed limitation should not be dependent on an actual thrust value. At its low values the POD's rotation can be executed rather fast. Greater thrust values should cause POD's rotation speed lowering.

Limitation of power level in the system

A number of generators running in the system depends on an actual power input. Appropriate limits for power input after exceedance of which the number of running generators is changed by one, are established. This way the energy production becomes adjusted to the power demand from the side of ship's network.

Limitation of engine output

In the case of sudden manoeuvres it may occur that engin's output or torque reaches its respective maximum value earlier than set speed value. In the situation the system should be capable of stopping the rotational speed increasing.

Besides, in the case of automatic switching - off the generators the control system reduces engine output to such an extent as to adjust its value to the power available in the network.

Requirements for safeguarding system

It is necessary to control the following :

- pump operation parameters of cooling system
- temperature of stator's winding of electric motor
- temperature of lubricating oil or bearing
- temperature of transformer's winding
- overloads of frequency converter
- temperature of frequency converter's cooling medium.

If any of the above enumerated parameters is not contained within its permissible range the system has to start procedure of propulsion power lowering.

The control system should be capable of auto-diagnosing. Due to the function it is possible to monitor : all programs executed by the system, values of voltage on auxiliary devices, supervision over communication system , I/O panel of frequency converter, as well as analogue input signals. Besides it is important to ensure possiblity of recording course of the system's operation in order to perform later its analysis in the case if ship's crew is not able to cope with a failure.

Starting and stopping main drive

Starting the engine is usually executed from Central Control Station (CCS). All auxiliary devices such as :

- cooling water pump of engine cooling system
- cooling water pump of inverter cooling system
- fan of engine cooling system
- auxiliary voltage source of inverter
- pumps and fans of cooling system

are to be started separately before starting the main engine.

The following sequence of the main drive starting operation should be realized :

- switching-on an appropriate number of generating sets
- starting auxiliary devices
- releasing the engine's breaking system
- starting the main engine.

Stopping the engine should consist in lowering its rotational speed up to zero and next in the following :

- switching-on the breaking system
- switching-off auxiliary devices
- successive switching-off the generating sets.

Synchronization of drives

In the case of applying a greater number of drives on a ship it is necessary to synchronize their work to avoid beating which happens if their rotational speeds are incompatible. To synchronize their work the following conditions are to be complied with :

- synchronization function is to be activated by means of a graphical operator panel
- difference between the reference rotational speed and actual speeds of drives cannot be greater than the value established by their producer
- value of the reference rotational speed of each drive cannot differ by more than the number of rotations per minute (rpm) established by its producer
- actual values of rotational speed of drives cannot differ by more than the number of rpm established by their producer
- communication between drives is to be realized through a data bus.

However if synchronization of drives were necessary then it would be rather impossible to keep the ship on a set course by changing the rotational speed of one of the drives only.

POSSIBLE CHOICE OF A CONTROL SYSTEM

During the analysis of control and automation systems for a POD-fitted ship the following products of two leading producers were considered :

- PodCon and Marintronics™ systems of ABB firm
- Alstom - Mermaid™ system of Rolls-Royce Group.

All the products totally cover the automation system of ship propulsion and manoeuvring, and they are intended for POD drives. Additionally the products can be shaped into many configurations and matched up to specific features of a ship. More information on the systems can be found in [14] and the producer technical pamphlets referred to in the below attached Bibliography.

From the information contained in the sources it results that both firms : ABB and Rolls-Royce-Alstom intend to introduce the global supervising systems. It makes it possible to greatly improve efficiency of a power system, and to reduce number of ship's personnel in the future. Even a not large decrease of shipping costs may improve competitiveness of a given shipowner.

It is very important to correctly manage the power in changeable load conditions (frequent speed changes, switching on/off the thrusters etc), as then profits associated with lowering fuel oil consumption will be manifested the most. Correct adjusting a number of generating sets which supply the network, depending on instantaneous power demand is the area of the greatest possiblities in improving the power system effectiveness.

In such waters as the Baltic Sea, time of sea voyage of a ship is rather short, hence the share of duration time of port manoeuvers is substantial. Therefore application of an integrated ship management system may bring in measurable profits in the form of lowering operational costs to such an extent as to cover initial cost of the system.

Choice of a definite system is not easy; however the problem goes beyond the scope of this paper.

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