Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

THE MONITORING OF SHIP PROPULSION BY TORQUE AND ROTATIONAL SPEED MEASUREMENTS ON THE PROPELLER SHAFT

Leszek Morawski

Gdynia Maritime University
ul. Morska 83, 81-225 Gdynia, Poland
e-mail: lmoraw@am.gdynia.pl

Zbigniew Szuca

e-mail: zszuca@interia.pl

Abstract

In paper device for measuring of torque and rotational speed at the ship main drive propeller shaft transferred will be described.. This device connected to the power plant monitoring systemt. It may be used for continuous control of operating costs of the ship and for the choosing of safe and best engine operational parameters. It is possible to observe the actual point of engine's operational state marked against the mechanical characteristic chart. The limited, safe area of acceptable working points is displayed on the diagram as well. The presented torque meter has possibility to measure instantaneous fluctuations of the torque and engine rotational speed as a function of the shaft rotation angle. This is a piece of important diagnostic information for fast preliminary assessment of the load on a particular cylinder and of the quality of engine work.

Keywords: *ship's propulsion unit, main engine, torque measurement, torque meter*

1. Introduction

Safe and efficient operation of ship propulsion system requires accurate data on current load of the main propulsion engine. A device providing those data is a torque meter. Its basic function is continuous assessment of load of the main propulsion engine, and signaling when permissible parameters have been exceeded. The torque meter can be used also to economisation of ship's motion bases on selecting an optimal relation between the cost of consumed fuel and the obtained transporting result. Its measure can be the speed reached by the ship, for instance. Evaluating instantaneous fuel consumption requires accurate data on current load of the main propulsion engine.

Torque meters employed in practice on watercraft are used for measuring:

a) shear stresses – strain gauge torque meters;
b) shaft torsion angle - string torque meters and torque meters with toothed rings.

In described below a torque meter is applied photo optic method for measure a torsion angle of propeller shaft.

2. Characteristic of torque meter

The principle of operation of torque meters bases on photo-optical measurement of a torsion angle of the propeller shaft section. Two rings with machined teeth (usually 2.2÷2.4 teeth for 1 cm

diameter of shaft) are fixed on the shaft at a distance of abt. 400 mm. They are designed in such a way that their teeth are in the same plane, and are covered by one measuring head.

The average torque and power values, measured and calculated for the period of 4 to 240 sec (adjustment selected by operator), are displayed as percents of nominal parameters, with 0.1% resolution. At the same time the rotational speed is determined at the 0.1 rev/min resolution.

Fig. 1 shows a schematic block diagram of the entire configuration of the mentioned torque meter. The configuration includes the following basic components:

- photo optical measuring head – signals source;
- microprocessors main module – one-chip micro-computer;
- Programmable Logic Controller – basic signals acquisition, arithmetical calculations, communication with outer units, archive measured and calculated output data, tooth rings technical condition self test;
- Operating Panel (LCD colour touch panel) – displaying current results of the engine's load measurements (rotation speed, torque, power), data archived in memory, efficiency indexes; used by operator for communication and giving commands;
- LED display – displaying current results of the „rotational speed-torque-power" measurements on the navigating bridge.

The device has a modular structure. Its basic component is a programmable PLC controller that executes controlling and calculating functions for measurement and calculation data, as well as storing of part of them. By using proper interfaces, the controller communicates with an „intelligent" module used for preliminary processing of measurement signals, and with other terminals. It is connected with the operator's console, displays, PC computer and the system that monitors operation of the marine power plant.

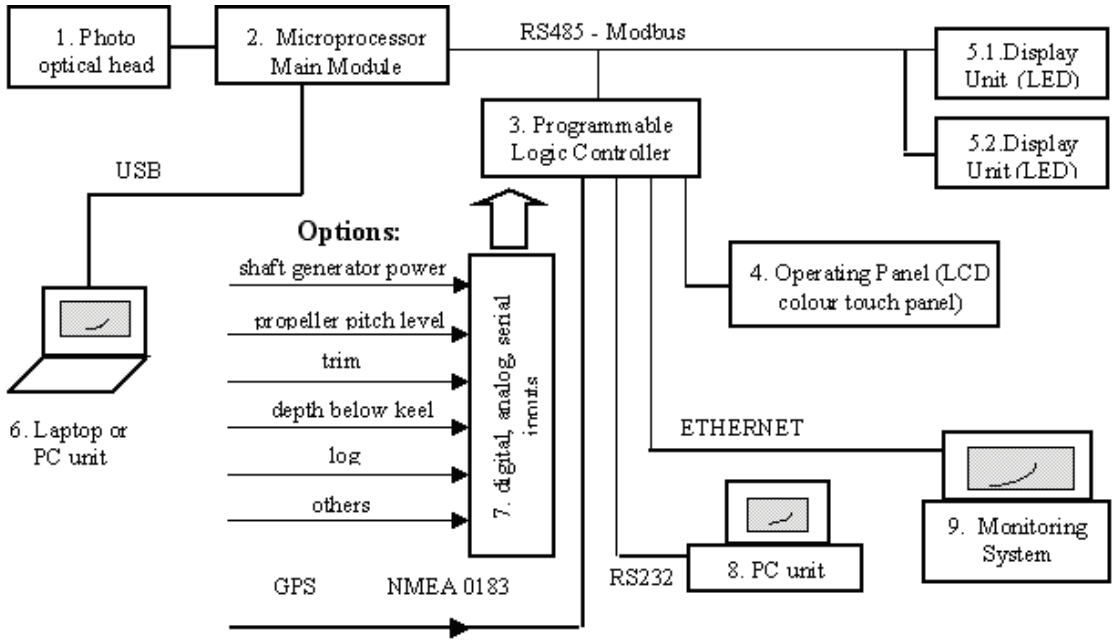

Fig. 1. Schematic block diagram of the entire configuration of torque meter

The module used for preliminary processing of measurement signals from a photo-optical head (laser measurement head) was designed using a fast micro-processor system that processes signals in a real time of an order of several milliseconds. The optional components of torque meter are:

- PC or Laptop unit equipped with special software for observe torque and shaft speed fluctuations which can help in diagnosing the engine. If PLC damage the measured torque, revolutions and engine power are show on PC/Laptop screen;
- analog and digital serial data inputs for acquisition additional data;

- PC unit for archiving the measured and calculated data and visualisation of actual point of engine's operation state, diagrams and trends (in case of lack of Monitoring System);
- Monitoring System – as above and communication with the owner's technical department.

In the presented torque meter, new technical solutions were applied that base on experience gained during design, production and use of previous versions of the device. So far, several dozens of torque meters have been produced and installed on merchant and training vessel, as well as in university laboratories. The novelty of the present design is the use of a programmable logic controller PLC along with own codes allowing easy integration of the torque meter with any computer system, or a special system for monitoring operation of marine power plant devices.

3. The torque meter as a device for efficient exploitation of ship propulsion system

The torque, power and rotational speed of propeller shaft are the parameters that carries important information about technical condition of the engine, and are sensitive to they changes. Therefore they can be considered as a diagnostic parameters, especially torque and rotational speed of shaft.

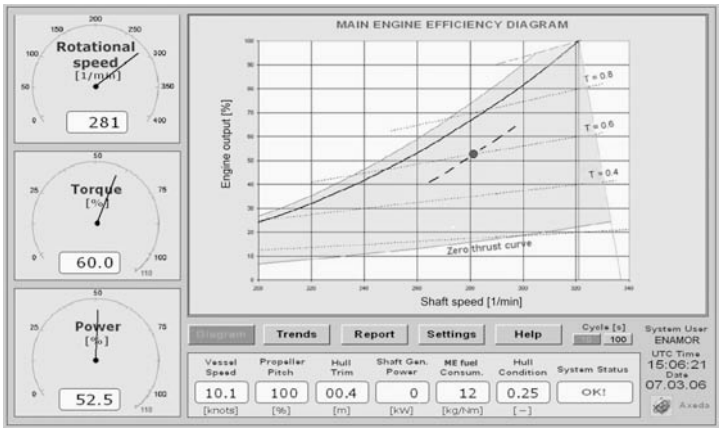

Fig. 2. The main engine efficiency diagram in power plant monitoring system on the training ship m/s "Horyzont II". Marked point of actual working state of main engine

The knowledge about the torque (or power output) and rotational speed unmistakably identifies a point in the propulsion engine operation area. On the Fig. 2 is presented the exemplary diagram with the actual point of engine's operational state marked against the mechanical characteristic chart. This example of efficiency engine diagram is taken from the monitoring system, which together with torque meter are installed on the training ship m/s "Horyzont II".

The area of safe and acceptable working points is displayed on this diagram. This field is marked darker colour. The borders of safe and acceptable area of engine working mark: power characteristic for nominal or exploitation fuel supply set, propeller characteristic in captive test of ship, control characteristics for minimal and maximal rotational speed and characteristic of minimal torque (in that case zero thrust curve) [5]. The nominal propeller characteristic is marked as a fat line. The dashed lines are the lines of solid torque. The power and torque actual values are expressed as percents of nominal parameters, with 0.1% resolution.

Along with the fuel consumption basing upon the engine characteristic, stored in the device's memory, it is possible to calculate theoretical fuel consumption in each measuring cycle. The volume of this fuel consumption is also summed up in a "Last 24hours fuel consumption" counter. The result showed by the counter represents sum of power produced by the propulsion engine. Pulses delivered from GPS satellite navigation system or from a log, allow assessing a valuable, from the point of view of fuel economization, factor referred to as "normalized fuel consumption per 1 nautical mile". This factor immediately responses to any change in parameters of ship's

motion, as well as and to changes in trim, wind direction with respect to ship's course, propeller pitch (if CPP applicable), etc.

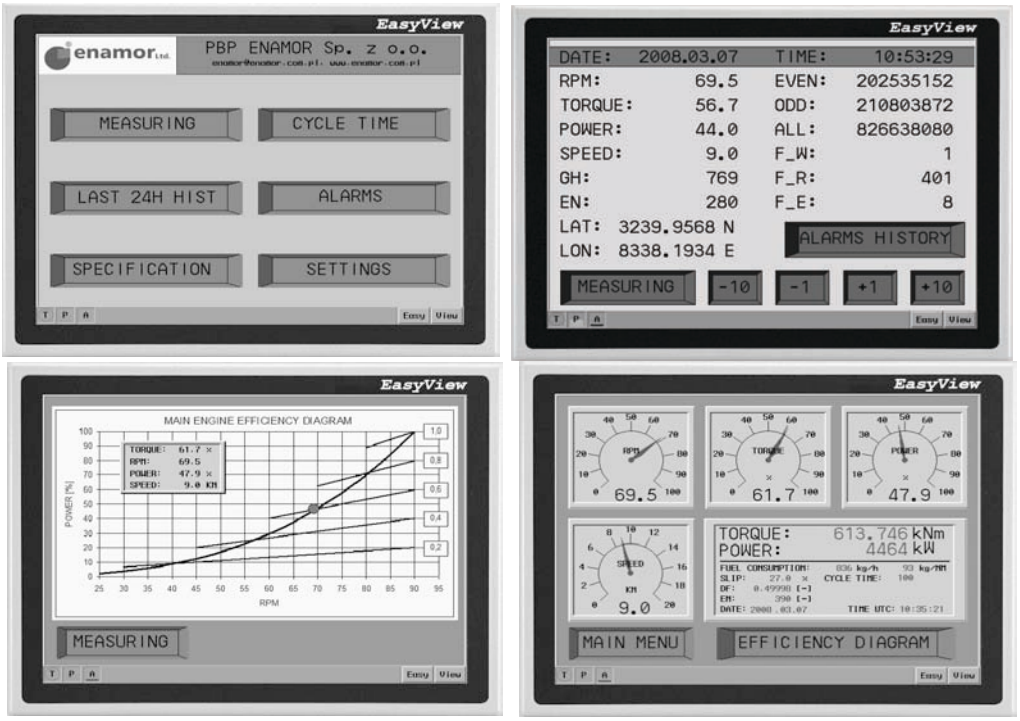

Fig. 3. The examples of the diagrams on the LCD operating panel

Mentioned above exploitation parameters are displayed not only on the efficiency diagram but also on the LCD handy operating panel (Fig.3). It is possible through the operating touch panel to put to the torque meter necessary parameters of engine, propeller shaft, number of teeth on ring and threshold values of signalling alarms. Reading the current measurements other exploitation and diagnostic parameters and their history, trends from the last 24 hours it is possible also.

The torque meter has a memory for automatic storing and reading the results of measurements and calculations covering several hundreds of consecutive measurement cycles. This function is of essential applicability on ships on which a computer system for data storing has not been installed.

Storing and analysing data from long time intervals, together with other parameters normally recorded during marine power plant operation, brings information of great value. Observation of trends in those data allows preparing long-term reports, as well as assessing changes in technical condition of propulsion system components and the risk of their possible failure. Their correlation with fuel consumption at given changes of operating conditions, like state of the sea, wind direction and force, draught and trim, propeller pitch, etc., help to make a sensible decision on the main engine operation. The analysis of costs resulting from changes in technical condition of the propulsion system facilitates making important decisions on repair, cleaning of underwater hull parts without docking, or modifying its components. In case of malfunction or worsened technical condition of any component of the propulsion system, it is possible to gain information of the possible location of its origin. As a result, all this simplifies and shortens servicing and diagnostic actions during ship operation. These characteristics of the torque meter allow considering it a valuable diagnostic tool.

Essentially helpful is the torque meter in propulsion systems equipped with the controllable pitch propeller, as this provides opportunities for evaluating the most favourable parameters of engine operation for a given propeller pitch. A new design of the torque meter makes it possible to take into account additional engine load caused by the operation of a shaft generator. In this case, along with operating parameters of the main engine, the engine-propeller co-operation point is

evaluated as well.

The torque meter is equipped with procedures that detect and signal failures, or dirt on the photo-optical head and toothed rings.

Optional codes are being prepared for a PC computer that will allow evaluating time-histories of shaft torque and angular velocity in a single turn (for a slow and medium rotational speed engines). This is a piece of important diagnostic information for fast preliminary assessment of the load on a particular cylinder and of the quality of engine work [1]. On the basis of these data one can conclude about the power transmitted by particular cylinders to the propeller shaft. Also, a "piston-cylinder" system can be identified which reveals visible differences from standard performance [2], [6].

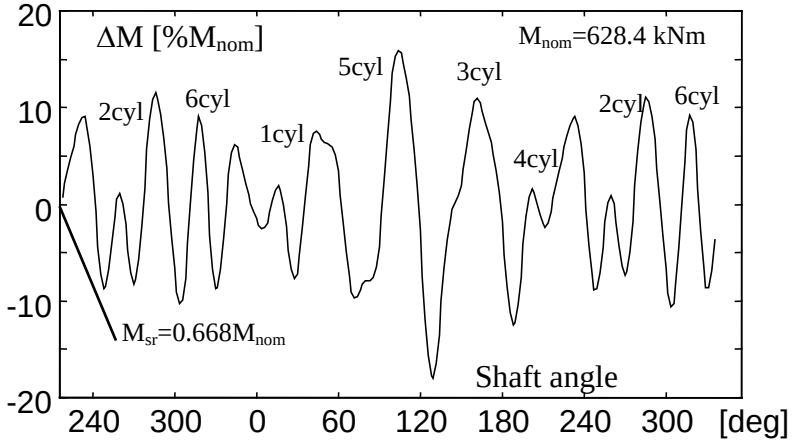

Fig. 4. Instantaneous torque fluctuation curve, reconstructed from the frequency spectrum. (the bulk carrier m/s "Powstaniec Listopadowy")

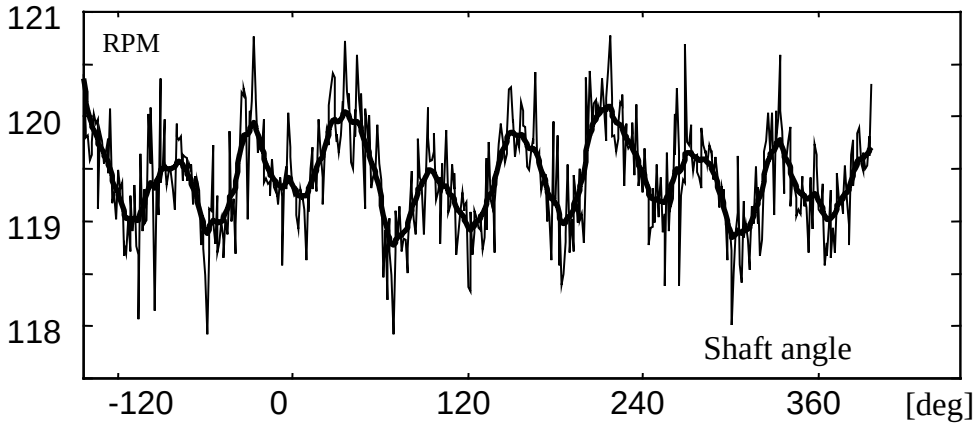

Fig. 5. Propeller shaft rotational speed computed and filtered at RPM=118.8 rev/min, torque $M_{śr}$=66.8%$M_{nom.}$ (the bulk carrier m/s "Powstaniec Listopadowy")

It should be stressed here that the number of points corresponding to one shaft revolution in which the torque is measured is equal to a double number of teeth in one ring, while for the rotational speed the number of points is four times bigger than the number of teeth. The torque and speed rotations fluctuation curves computed from the measured data are significantly deformed. It is affected by deformations caused by, among other things, an inaccuracy in manufacturing and installing the toothed discs on the shaft, resonances of free torsion vibrations of the shaft, vibrations of the shaft deflection, propeller load fluctuations and etc.

The deformations of measurements of low-frequency can be eliminated using a method of spectral analysis which was presented in [3] and [4]. A high-frequency deformation was eliminated using a forward-backward type filter. As example, on the Fig. 4 and 5 are presented

reconstructed and filtered time-histories of torque and rotation speed fluctuations in consecutive shaft revolutions. The presented measurements was made on the bulk carrier m/s “Powstaniec Listopadowy” (33767DWT, L=185m, main engine SULZER 6RL66, 8160 kW, 124 rpm).

5. Conclusion

Concluding, it should be stressed that described the torque meter can bring measurable profits resulted from safe and efficient exploitation of ship propulsion system. This opinion is backed up by the following arguments:

- continuous torque control helps operate the propulsion system without the effect of increased current repair cost;
- current control of mutual relation between real and calculated fuel consumption, the latter being indicated by the torque meter, allows evaluating changes in internal efficiency of the engine, thus avoiding the effect of increased repair costs and fuel investments;
- the knowledge of calculated fuel consumption used for covering 1 nautical mile make possible to select the most profitable parameters of the propulsion system (most significant – controllable pitch propeller), for instance with respect to the fuel consumption.
  More important: immediate feedback of any action taken to improve vessel operation – this is a potential source of fuel economisation;
- the combined knowledge of the torque and ship’s speed allows controlling changes in technical condition of hull and screw surfaces. This, in turn, allows making decisions on possible cleaning of those surfaces;
- the information of shaft torque and rotational speed fluctuation in a single turn makes a form of preliminary diagnostic of the propulsion engine operation;
- storing results of measurements and calculations, along with other parameters kept in the device’s memory, allows the ship owner to evaluate, and possibly correct, the way in which the vessel is operated.

References

[1] Fehrenbach H.,.Quante F., *Diagnosis of Combustion Engines by the Analysis of the Crankshaft's Rotational Speed*, VDI-Berichte, no 644, pp. 72-80, 1987.

[2] Morawski L., Szuca Z., *The new device for measuring torque and rotational speed on the propeller shaft of ship with possibilities of diagnostics and estimation of ship propulsion system state, Report of Project KBN Nr 6T12 2003C/06267* (in polish), Gdynia Maritime University, PBP ENAMOR Ltd, 2006.

[3] Morawski L., Sikora M., *The microprocessor device measuring torque and rotational speed on the propeller shaft of ship applied for monitoring of the ship propulsion system*, (in polish), Pomiary Automatyka Kontrola, nr 7, pp272-277, SIGMA Warszawa 1998.

[4] Morawski L., Szuca Z., *The application of the photo optic torque meter to estimation of torque and rotational speed fluctuations on the propeller shaft of a ship*, Journal of Polish Cimac, Vol.2, No.1, 2007.

[5] Włodarski K, Witkowski K., *The combustion engines of ship*, (in polish), Gdynia Maritime University, Gdynia 2006.

[6] Morawski L., *Measurements of instantaneous fluctuations of torque and rotational speed on the propeller shaft for diagnosis of ship propulsion system*, (in polish), Automatyka i Informatyka Technologie Informacyjne Diagnostyka, PWNT Gdańsk 2007.