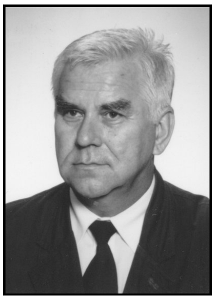
Leszek MORAWSKI[1], **Zbigniew SZUCA**[2]
[1] AKADEMIA MORSKA W GDYNI
[2] PRZEDSIĘBIORSTWO BADAWCZO PRODUKCYJNE ENAMOR SP. Z O. O., GDYNIA

The microprocessor device for measurements of torque and rotational speed on the propeller shaft of ship

D.Sc., Ph.D. Leszek MORAWSKI



He graduated from Warsaw University of Technology (Electronic Faculty) in 1969, obtainig M.Sc. degree in computers. In 1978 he gained PhD degree from Technical University of Gdańsk in automatics and in 1994 D.Sc. degree in automatics and robotics from Warsaw University of Technology (Faculty of Power and Aeronautical Engineering). His professional and research interests are in automatic steering of ship motion and in design and application of microcontrollers for industry measurement and control systems.

e-mail: lmoraw@am.gdynia.pl

Ph.D. Zbigniew SZUCA

In 1974 he graduated from Gdansk University of Technology, Faculty of Ship Technology, and then began to work in Polish Ocean Lines in Gdynia, first as a member of the company sailing crew, later as a supervisor in Technical Department. In 2000 he started working in Research & Production Enterprise "ENA-MOR" Ltd in Gdynia. In 2006 he gained PhD degree from Mechanical Engineering Faculty at Gdansk University of Technology.

e-mail: zbigniew.szuca@enamor.com.pl

Abstract

The paper presents the new model of torque meter designed in Gdynia Maritime University and Research-Production Enterprise for Maritime Industry "ENAMOR" Ltd., Gdynia. The general idea of measurement makes use of the torsion angle measured on a shaft section (400 mm) using the photo-optical technique. Torque meter unit is equipped with Programmable Logic Device (PLC) for calculations, external parameters acquisition (ex.: speed, trim, shaft generator power etc.) and measured data storage in memory. This unit (bearing a symbol ETNP-8) has also possibility to measure instantaneous fluctuations of the torque and engine rotational speed as a function of the shaft rotation angle. Displaying time-histories of those parameters on the monitor screen of an external PC computer gives the operator an opportunity to make a preliminary performance assessment for each individual cylinder in the engine, and for the drive system as a whole. As an example, the analysis and processing of the measured torque and rotational speed fluctuations are presented. The measurements were done on the training ship m/s Horyzont II, owned by the Gdynia Maritime University.

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

Urządzenie do pomiaru momentu i prędkości obrotowej na wale śruby napędowej statku

Streszczenie

Referat przedstawia urządzenie do pomiaru momentu i prędkości kątowej na wale śruby, wykorzystujące fotooptyczny pomiar kąta skręcenia wału. Na podstawie mierzonych czasów trwania zębów i szczelin dwóch tarczy zębowych wyznaczana jest prędkość obrotowa, moment i moc na wale oraz teoretyczne zużycie paliwa. Dołączony do urządzenia zewnętrzny komputer PC, z odpowiednim oprogramowaniem umożliwia pomiar wartości chwilowych momentu i prędkości obrotowej w funkcji kąta położenia wału korbowego. Pomiary wartości chwilowych zawierają informację diagnostyczną o pracy układu napędowego statku.

Słowa kluczowe: okrętowy układ napędowy, silnik napędu głównego, pomiar momentu, momentomierz.

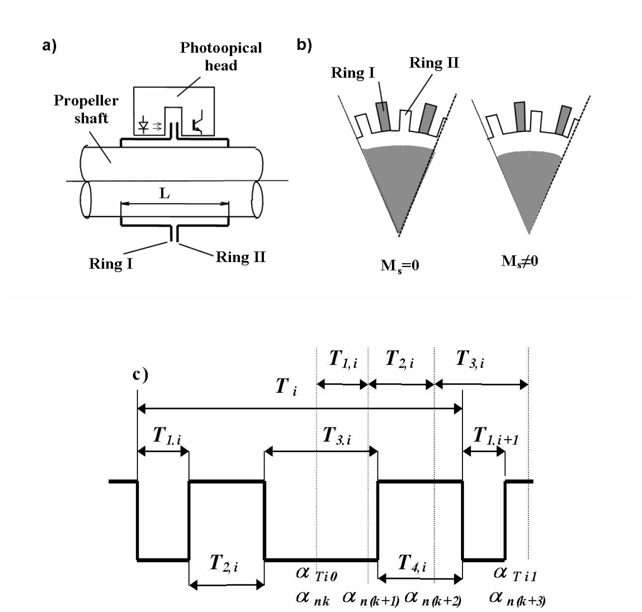
1. Introduction

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. A device providing those data is a torque meter. Its basic function is continuous assessment of load of the main propulsion engine, and signalling when permissible parameters have been exceeded.

2. Measuring torque and rotational speed fluctuations

The general idea of the torque and rotational speed measurement makes use of the torsion angle measurement executed on a shaft section using a photo-optical technique. Two rings with machined teeth are fixed on the propeller shaft at distance L (approx. 400 mm). They are designed in such a way that their teeth are in the same plane. The teeth of these two rings can rotate in (and through) a gap of a transoptor based measuring head (Fig. 1a). The shaft torsion, proportional to the loading torque, makes the teeth of the two rings move with respect to each other, as is shown in Fig. 1b. At the output of the measuring head a rectangular wave is obtained with variable pulse-width modulation (Fig. 1c).

The torque measurement bases on measuring the difference in the time duration of two successive pulses, recorded by the transoptor head, that correspond to the clearances between the ring teeth.



Rys. 1. Zasada pomiaru kąta skręcenia wału:
a) usytuowanie pierścieni zębatych na wale;
b) przekrój w płaszczyźnie położenia zębów;
c) przebieg sygnału z fotooptycznej głowicy pomiarowej

Fig. 1. Principle of the shaft torsion angle measurement:
a) method of ring fastening on the propeller shaft;
b) cross sections of toothed ring portions;
c) time-history of output signal from transoptor head

One tooth on one ring has a narrow gap to mark a selected shaft position angle [1]. Other shaft position angles are determined by counting pulses transmitted by the transoptor head (Fig. 1c). When the pulse from the narrow gap is estimated, the torque meter starts measuring the passing times T_1 i, T_2 i, T_3 i, T_4 i (Fig. 1c) of consecutive clearances between the teeth during a given number of revolutions. The results of the time measurements are stored in the RAM memory of the torque meter electronic unit. Then, after the measurement is completed, the data are transmitted to the external computer. Actual values of the torque and rotational speed fluctuations are computed in the off-line mode [2, 3].

Assuming that the values of the torque and rotational speed are constant during the time when the transporting head passes two consecutive teeth and two clearances, the instantaneous torque is determined from the formula:

$$T_T(\alpha_{Ti,j}) = \pm k_T \cdot \frac{\left|T_{3,i} - T_{1,i+j}\right|}{T_{1,i+j} + T_{2,i+j} + T_{3,i} + T_{4,i}} = T_{Tj,i} + T_{Tj,ip} \ [\%] \quad j = 0,1 \tag{1}$$

while the instantaneous rotational speed of the shaft is computed from the formula:

$$n(\alpha_{nt,i}) = \mathrm{k}n \begin{cases} 1/(T_{1,i} + T_{2,i} + T_{3,i} + T_{4,i}) & t = 0 \\ 1/(T_{1,i+1} + T_{2,i} + T_{3,i} + T_{4,i}) & t = 1 \\ 1/(T_{1,i+1} + T_{2,i+1} + T_{3,i} + T_{4,i}) & t = 2 \\ 1/(T_{1,i+1} + T_{2,i+1} + T_{3,i+1} + T_{4,i}) & t = 3 \end{cases} \quad [\text{rev/min}] \tag{2}$$

where:

- i - number of teeth in one ring,
- k_T - proportionality coefficient resulting from the nominal torque, the amorphous elasticity coefficient of the shaft, the shaft diameter, the length of the twisted shaft section, and the unit scaling,
- kn - proportionality coefficient resulting from the unit scaling;
- $\alpha_{Tj,i}$ - torque measurement angles (j=0,1),
- $\alpha_{nt,i}$ - rotational speed measurement angles (t=0,1,2,3),
- $T_{Tj,i}$ - torque resulting from the shaft tension angle,
- $T_{Tj,ip}$ - average torque correction resulting from the distribution of clearances in the rest position.

It should be stressed here that the number of points corresponding to one shaft revolution during which the torque is measured is equal to the double number of teeth (i) in one disc, while for the rotational speed the number of points is four times as big as the number of teeth. The mean values of the shaft torque and rotational speed are calculated as the mean value of all measurements, using formulas (1) and (2) for an integer number of shaft revolutions.

3. Results of measurements on real object

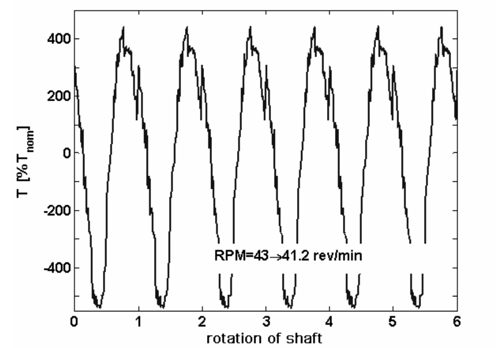
The measurements were done on the training ship m/s Horyzont II [4], owned by the Gdynia Maritime University (L=56m; main engine: 4-stroke SULZER–Cegielski 8S20U, nominal power 1280 kW, nominal rotational speed 1000 rev/min; reduction gear 3.115:1; propeller shaft diameter 180 mm; four-blade variable pitch propeller D=2.1m; number of teeth of the torque meter ring 48).

The torque fluctuation curves computed, using formula (1), for two different loads and shaft rotations, are shown in Figs 2 and 3.

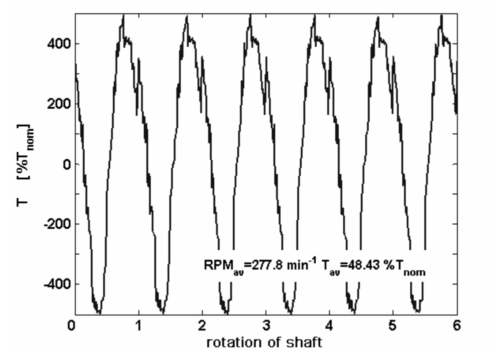
The second case corresponds to the situation when the shaft was decoupled from the engine and the shaft rotation was only provoked by the moving ship. The value of the torque was near zero. The both presented signals are significantly deformed. The main source of deformations is an inaccuracy in manufacturing and installing the toothed discs on the shaft, but it can also include possible resonances of free torsion vibrations of the propeller shaft, vibrations of the shaft deflection, propeller load fluctuations, etc. The possibility of free resonances of mechanical parts of the torque meter cannot be neglected as well.

The two presented torque time-histories are similar to each other, with the first harmonics being the dominating component. Its most possible source is the lack of symmetry in fastening of the two halves of the toothed disc, cut apart before the assembly, on the shaft. As is seen in Fig. 2, this component exceeds 400% of the nominal torque. This and other spectrum components deforming the measurement results can be eliminated using a method of spectral analysis which was presented in [1] and [2].

a)



b)



Rys. 2. Pulsacja momentu na wale:
a) gdy n_{av} = 277.8obr/min, T_{av} =48.43 % T_{nom} ;
b) gdy n_{av} = 41.2-43 obr/min, T_{av} =-0.32 % T_{nom}

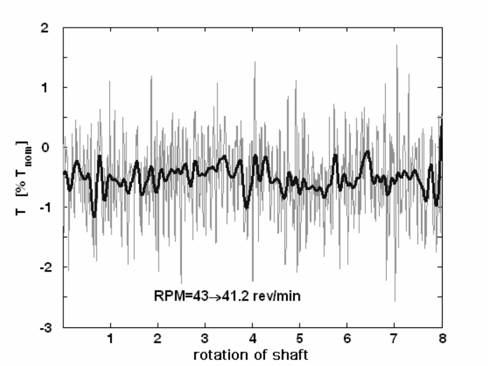
Fig. 2. Propeller shaft torque fluctuations:
a) for n_{av}=277.8 rev/min, torque T_{av}=48.43 %T_{nom} ;
b) for n_{av}=41.2-43 rev/min, T_{av}=-0.32 %T_{nom}

Low-frequency disturbance was eliminated by using the torque corrections which correspond to the distribution of gaps and teeth of two rings when load is zero. High-frequency deformations was eliminated using a forward-backward type filter, which gives zero phase shift due to double filtering.

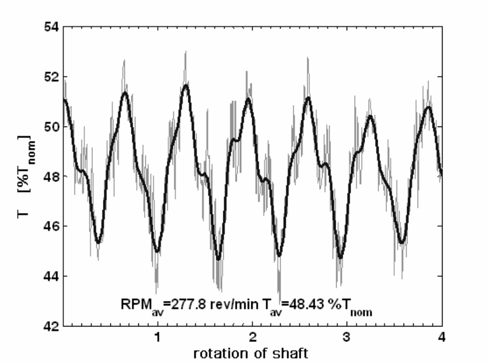
The filtered torque time-histories are marked in Fig. 3 as thicker lines. What is noteworthy is torque fluctuations with the amplitude of about 2.5% of the nominal torque (Fig. 3a). Those fluctuations are generated by the running engine and residual torque fluctuations on the engine crankshaft, which were not completely damped.

Figure 3b shows the time-history of the instantaneous torque measured on the propeller shaft 50 seconds after decoupling it from the propulsion engine. The propeller is rotated, together with the shaft and the gear, by the water flowing down the ship's hull, which moves by its own inertia. That is why the fluctuations caused by the engine in operation are missing in Fig. 4b. The observed low fluctuations are likely to be generated by irregular stream of water flowing down the propeller and friction torques in shaft bearings. The load was approximately equal to 0.4% of the nominal torque.

a)



b)



Rys. 3. Filtrowany przebieg momentu na wale śruby po uwzględnieniu niedokładności wykonania i montażu pierścieni:
a) sprzęgło silnika załączone - RPM_{av}=277.8 rev/min;
b) sprzęgło wyłączone - $RPM_{av}\approx$41-43 rev/min

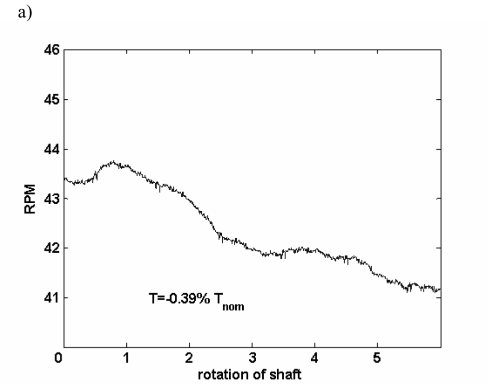
Fig. 3. Torque time-histories in consecutive shaft revolutions, taking into account corrections from inaccuracy of toothed ring machining and assembly and after filtering:
a) the ME drive coupling connected - RPM_{av}=277.8 rev/min;
b) the coupling disconnected - $RPM_{av}\approx$41-43 rev/min

A similar methodology of measurement data analysis was applied for shaft rotational speed time-histories using formula (2).

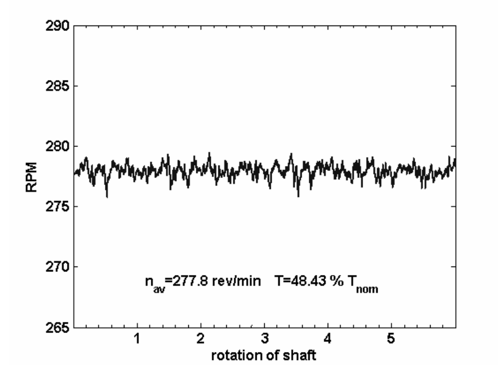
The rotational speed time-histories taking into account the calculated corrections are given in Fig. 4. The figure purposely preserves the same scale of the Y-axis to better illustrate the scale of fluctuations of torque.

The propeller shaft rotational speed fluctuations shown in Fig. 4a result from power transmission from the engine to the propeller.

a)



b)



Rys. 4. Przebieg prędkości obrotowej wału śruby po uwzględnieniu niedokładności wykonania i montażu pierścieni:
a) sprzęgło silnika załączone;
b) sprzęgło wyłączone

Fig. 4. Time-histories of the propeller shaft rotational speed after taking into account the correction from inaccuracy of toothed ring machining and assembly:
a) the ME drive coupling connected;
b) the coupling disconnected

4. Final conclusions

The presented results of measurements of instantaneous torque and rotational speed, and the methodology of their processing confirm much higher measuring potential of the newly developed torque meter ETNP-8. The ship on which the measurements were done has a 4-stroke medium speed engine and the power transmission system which to a considerable extent damps torque and rotational speed fluctuations. The analysed time-histories reveal basic harmonics corresponding to the full cycle of engine operation (2 crankshaft revolutions). The components corresponding to the operation of individual cylinders are not recognised in the analysed spectra.

The experience gained from numerous measurements of operating parameters of the power transmission system, performed with the aid of specialised measuring instrumentation on sea-going cargo vessels, allows concluding that along with typical application for continuous measurements of moment and rotational speed, the presented torque meter can also be used by the measuring staff for diagnostic measurements. Easy use in the operating mode „Diagnostics" allows the machine crew to perform on-line measurements, with their immediate analysis, data storage, and transmission to the shipowner.

5. References

[1] L. Morawski, Z. Szuca: Urządzenie nowej generacji do pomiaru momentu i prędkości obrotowej na wale okrętowego silnika średnio/wolnoobrotowego, z możliwością identyfikacji zmian stanu technicznego zespołu napędowego oraz wstępnej diagnostyki silnika napędu głównego. Raport końcowy - Projekt celowy KBN Nr 6T12 2003C/06267, Akademia Morska w Gdyni, PBP ENAMOR, marzec 2006.

[2] L. Morawski L., M. Sikora: Wykorzystanie mikroprocesorowego urządzenia mierzącego moment i prędkość obrotową wału śruby do monitorowania pracy układu napędu głównego statku. Pomiary Automatyka Kontrola, nr 7 (lipiec) 1998, str.272-277, rys.10 bibl. 6.

[3] L. Morawski, Z. Szuca: 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, Explo-Diesel & Gas Turbine '07. Gdańsk-Stockholm-Tumba, may 11-15, 2007.

[4] Dokumentacja techniczna urządzeń na statku Horyzont II, Stocznia Północna, Gdańsk 1998.

Artykuł recenzowany