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Ships and marine technology — Determination of the shaft power of ship propulsion systems by measuring the shaft distortion —

Part 3: Elastic vibration method

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Contents

Page

Foreword

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This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 2, *Marine environment protection*.

A list of all parts in the ISO 20083 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Selecting the optimum rating of a ship's main engines is important for ship owners, because it greatly affects the expenses of operations, maintenance and management as well as the ship's construction cost.

Measuring the output of the ship's main engine is important for confirming the ship efficiency, as well as for assessing the possible deterioration of the propulsion equipment or the accumulation of fouling on the hull over time. There are many methods of measuring an engine's output: (1) measuring the distortion of the shaft, (2) determining the fuel consumption, and (3) observing engine indicators such as cylinder pressure gauges.

Among these methods, ISO 20083 addresses the shaft distortion measurement with a shaft power meter, a method commonly used as the principal measurement of engine power output.

The purposes of shaft power measurement are:

— to provide a measurement of the ship's main engine output;

— to provide information regarding the ship's most efficient speed;

— to select optimum engine operational characteristics;

— to estimate maintenance and repair costs; and

— to monitor heavy propeller running.

Ships and marine technology — Determination of the shaft power of ship propulsion systems by measuring the shaft distorsion —

Part 3:
Elastic vibration method

1 Scope

This document specifies a procedure to determine the shaft power of engine ships, by measuring the shaft distortion using an elastic vibration type device. It gives the principles of the measurement, the components of the device and the calculation method. It also describes the factors for determining the measuring accuracy and specifies the on-board documentation for the device.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
shaft
propeller shaft or intermediate shaft which transmits the engine power to the propeller, and on which the shaft power meter is equipped

3.2
shaft torque
Q
turning moment transmitted to the shaft that is generated by the engine to rotate the propeller

Note 1 to entry: It is expressed in newton meters.

3.3
shaft power
P_S
power transmitted to the shaft that is generated by the engine to rotate the propeller

Note 1 to entry: It is expressed in kilowatts.

3.4
sensor
instrument containing elastic vibrating material whose natural frequency is altered due to a change in the length of the material

4 Principles of the measurement

The shaft power meter is a device that measures the shaft revolution and the torsional deformation of the shaft caused by the shaft torque. The shaft power, P_s [kW], is calculated using Formula (1).

$$Ps = \frac{2 \cdot \pi \cdot N \cdot Q}{60} \times \frac{1}{1\,000} \tag{1}$$

where N is the rate of shaft revolutions per minute[min^{-1}].

The shaft torque, Q [Nm], is calculated from the torsional deformation angle rate at unit length of the shaft using Formula (2).

$$Q = \frac{G \cdot Ip \cdot \theta'}{1\,000} \tag{2}$$

where

G is the G-modulus [N/mm^2];

I_p is the polar moment of inertia[mm^4];

θ' is the shaft torsional deformation angle rate at unit length [1/mm].

The polar moment of inertia, I_p [mm^4], is calculated using Formula (3).

$$I_p = \frac{\pi}{32}\left(D_o{}^4 - D_i{}^4\right) \tag{3}$$

where

D_o is the outer diameter of the shaft [mm];

D_i is the diameter of the hollow shaft [mm].

The shaft torsional deformation angle rate at unit length, θ' [1/mm], is calculated using Formula (4).

$$\theta' = \frac{\theta}{l} \tag{4}$$

where

θ is the shaft torsional deformation angle [rad] as shown in Figure 1;

l is the length between the shaft rings [mm].

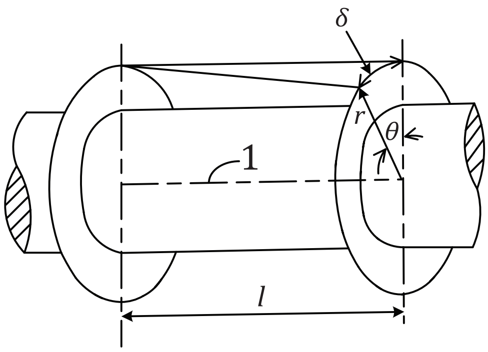
The torsional deformation angle, θ [rad], can be calculated from the displacement of the detecting point as given in Formula (5).

$$\theta = \frac{\delta}{r} \tag{5}$$

where

δ is the displacement of the detecting point [mm];

r is the distance of the detecting point from the shaft center line [mm].



Key

1 center line

θ shaft torsional deformation angle [rad]

l length between rings [mm]

δ displacement of the detecting point [mm]

r distance of the detecting point from the shaft center line [mm]

Figure 1 — Torsional deformation angle of a shaft

The elastic vibration type device calculates the displacement (δ) of a detecting point using the measured natural frequency of a sensor.

The relationship between the natural frequency and the tension of the sensor is given in Formula (6).

$$f = \frac{1}{2L}\sqrt{\frac{T}{\rho}} \quad (6)$$

where

f is the natural frequency [Hz];

T is the tension of the sensor [N];

ρ is the density of the sensor [kg/m];

L is the length of the sensor [m].

According to Formula (6), the tension (T) is proportional to the square of the natural frequency (f^2) of the sensor.

The tension (T) is also proportional to the displacement (δ) of the sensor because of the added tension being beyond the proportional limit of the material. Accordingly, the displacement (δ) of the sensor is proportional to the square of the natural frequency (f^2).

The relationship between the natural frequency (f) and the displacement (δ) of the sensor is given in Formula (7).

$$\delta = C \times \Delta f^2 \quad (7)$$

where C is a proportional constant defined as the sensitivity constant.

The sensitivity constant, C, is determined by the dedicated calibration device.

Δf^2 is the difference between the square of the natural frequency at displacement by (δ) and that at the initial condition.

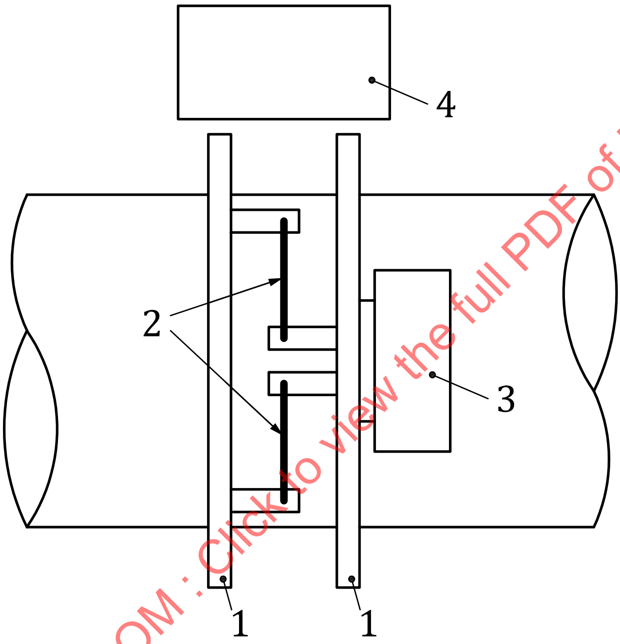
Since two sensors are used as shown in Figure 2, the average of Δf^2 of the two sensors is actually used for the calculation in Formula (7).

The two sensors are mounted between the shaft rings where the natural frequency increases and decreases when torque is added to the shaft. The temperature change, centrifugal force and shaft bending have an equal effect on the two sensors. By using two sensors, such influences are offset.

5 Components of the device

5.1 General

An elastic vibration type device is basically composed of a shaft ring, two torsion sensors, a transmitting/receiving component and other peripherals including a power supply system, as shown in Figure 2.



a shaft ring
b sensor
c transmitting/receiving components
d peripherals (including power supply system)

Figure 2 — General composition of an elastic vibrating type device

5.2 Shaft ring

The shaft ring consists of two split rings. The split rings are clamped onto the shaft independently at a specified distance. The fitting blocks to mount the sensors are attached to each shaft ring.

5.3 Sensor

As shown in Figure 2, two sensors are used. Each sensor has two magnetic coils that are located close to the elastic vibrating material, such as string or strip. One of the magnetic coils acts as an exciter and the other acts as a pick-up. The magnetic coils cause the elastic vibrating material to vibrate at the natural frequency.

5.4 Transmitting/receiving component

The following functions shall be performed by the transmitting/receiving component, that is attached to the shaft rings:

a) it shall receive electric power;

b) it shall transmit the sensor signal to the receiving antenna in the power supply system facing the shaft.

5.5 Peripherals

The following functions shall be performed by the peripherals:

a) they shall supply electric power to the receiving unit in the shaft rings;

b) they shall perform as an antenna to receive the sensor signal;

c) they shall transmit the sensor frequency and rate of the shaft revolution to the data processing unit.

The power supply system shall be installed on the dedicated stand facing the shaft.

The power supply and the signal receiving shall be performed without contact with the shaft.

6 Calculation of the shaft power

6.1 Shaft torque

The shaft torque, Q [Nm], is calculated from the displacement of the detecting point and the length between the shaft rings using Formula (8).

$$Q = \frac{1}{1\,000} \times \frac{\pi\left(D_o^4 - D_i^4\right)G}{32} \times \frac{\delta}{lr} \tag{8}$$

where

G is the G-modulus [N/mm²];

D_o is the outer diameter of the shaft [mm];

D_i is the inner diameter of the hollow shaft [mm];

r is the distance of the detecting point of the shaft center line [mm];

l is length between the shaft rings[mm];

δ is the displacement of the detecting point[mm].

The displacement, δ [mm], is calculated using Formula (9)

$$\delta = \frac{C_1\left(f_1^2 - Z_1^2\right) + C_2\left(Z_2^2 - f_2^2\right)}{2} \tag{9}$$

where

f_1 is the frequency of sensor 1 [Hz];

f_2 is the frequency of sensor 2 [Hz];

Z_1 is the frequency at the initial condition of sensor 1 [Hz];

Z_2 is the frequency at the initial condition of sensor 2 [Hz];

C_1 is the sensitivity constant of sensor 1 [mm/Hz^2];

C_2 is the sensitivity constant of sensor 2 [mm/Hz^2].

6.2 Shaft power

The shaft power, P_S [kW], is calculated using Formula (10).

$$Ps = \frac{2 \cdot \pi \cdot N \cdot Q}{60} \times \frac{1}{1\ 000} \tag{10}$$

where N is the rate of shaft revolutions per minute [min^{-1}].

7 Factors for determining the measuring accuracy

7.1 General

The accuracy of a shaft power meter is based on the accuracy of the individual components in the shaft torsion detection part including the sensors and the reliability of the G-modulus of the shaft. The sensor sensitivity (see 7.2) and zero adjustment (see 7.4) are essential factors for shaft power measurement that affect the measurement accuracy.

7.2 Sensor sensitivity

The sensitivity constant shall be determined from the displacement of the sensor and the difference of the square of the natural frequency in the elongated condition and that in the initial condition. The sensitivity constant of each sensor differs slightly even though the same material is used. As a result, every sensor shall be given its inherent sensitivity constant. The material used for the sensor should ensure stable sensitivity. The re-calibration of the sensitivity shall be carried out by the dedicated calibration device at regular intervals.

7.3 G-modulus

If no actual shaft torsional test certificate for the G-modulus is available, a G-modulus of 82 400 N/mm^2 shall be used.

NOTE A G-modulus of 82 400 N/mm^2 is also given in ISO 15016:2015[1].

