Increasing demand for ever-higher nominal torque values- by the example of a marine application

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Abstract:

The world's steadily growing energy needs combined with increasing requirements on machines and drive systems in terms of economical use of resources and protection of the environment demand innovative technologies for running such systems. Power and efficiency are the main parameters of machines and drive systems. Driven by the need to increase efficiency and by international emission regulations, highly accurate and reliable torque measurement in both test bench applications and the monitoring of ships at sea are of high interest to ship's engine (marine) technology.

Key words: Drive systems, power, efficiency, accurate, torque measurement.

Industrial applications

The trend toward low emission, high power engines is also found in the marine industry. Fig.1 shows that high-torque applications are not only focused on ship's engine technology. Other fields of application, for example, power generation are of interest as well.

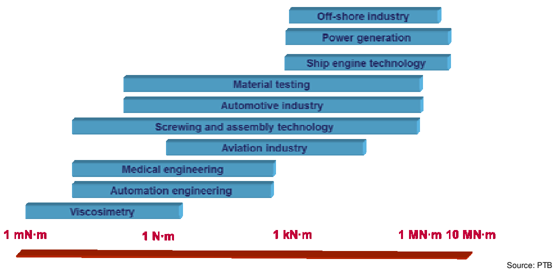

Fig. 1. Application and nominal torque ranges

The requirements for marine technology applications are constantly changing and becoming ever more stringent, so the demands on both test bench manufacturers and providers of systems for the monitoring of ships at sea are also increasing. Higher accuracy for enhanced efficiency and the demand for highly dynamic torque measurement to ensure sufficient engine control play a pivotal role in meeting the new challenges. The higher the demands today and in the future, the more critical is the measurement equipment, e.g. the torque transducer.

Torque measurement

A method for determining drive power is to measure torque M_t in the shaft train between drive side and generator which is used, together with the rotational speed n, to compute drive power.

$$P = \varpi \cdot M_t = 2 \cdot \pi \cdot n \cdot M_t \qquad (1)$$

This is done by measuring the input shaft torsion generated by torque on the driven side. There are several methods available which have in common that torque is not directly determined but indirectly via a torque-related parameter and subsequent calculation. The parameters to be considered in this calculation (e.g. material, shaft geometry) are subject to tolerances which ultimately lead to a relatively large measurement uncertainty in the torque parameter.

Indirect torque measurement

This method, for example, measures torsion via the strain on the input shaft surface. Strain gauges are glued directly onto the shaft for this purpose and then connected into a measuring bridge. The measuring bridge excitation voltage and the measurement signal are transferred contactless via a telemetry system from a stator to the rotating shaft and vice versa. Depending on the installation quality and the components used, this method provides very precise strain measurement values [1].

In case of a cylindrical shaft, the strain gauges measures the strain in direction of the principal strains ε_n acting at ±45° to the shear plane and to the axis respectively [2].

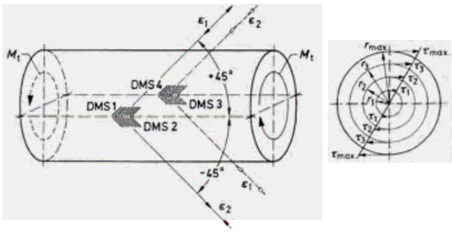

Fig. 2. Cylindrical shaft with strain gauges and cross section of shear stress distribution

The maximum shear stresses $\tau_{\max}$ occur on the outside fiber of the cylindrical shaft

$$M_t = \tau_{\max} \cdot W_t \qquad (2)$$

The shear stresses for a full bridge circuit can be calculated as follows:

$$\tau_{\max} = \frac{1}{2} \cdot \varepsilon \cdot G \qquad (3)$$

Equate (2) and (3) by using the equation for the section modulus W_t, and the shear modulus G results in

$$M_t = \varepsilon \cdot \frac{E}{(1+\upsilon)} \cdot \frac{\pi \cdot d^3}{64} \qquad (4)$$

When determining torque by measuring strain ε with strain gauges the tolerances of the gauge factor k also have to be taken into account (see Tab. 1).

Another method for determining torque on a cylindrical shaft is through measurement of the torsion angle φ.

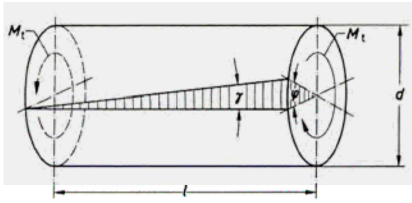

Fig. 3. Schematic image of torsional deformation of a cylindrical shaft

Both angles φ and γ of a cylindrical shaft subjected to torsion have the following correlation [3]:

$$\varphi \cdot r = \gamma \cdot l \qquad (5)$$

Applying Hooke`s law to the deformation angle $\gamma = \tau_{\max} / G$ and using equation (1) the torque M_t can be calculated as follows using the correlation $W_t \cdot r = I_P$

$$M_t = \frac{\varphi}{l} \cdot G \cdot I_p \qquad (6)$$

Applying the equations for the shear modulus G and the polar moment of inertia I_P, the torque M_t can be calculated as follows:

$$M_t = \frac{\varphi}{l} \cdot \frac{E}{(1+\upsilon)} \cdot \frac{\pi \cdot d^4}{64} \qquad (7)$$

Both methods offer some advantages, for example, that already existing systems can be fitted with these measurement systems at any time. However, the torque value to be subsequently calculated has a relatively high uncertainty because of the tolerances (see Tab. 1) of the parameters to be taken into account [1].

Tab. 1: Estimation of tolerances

Parameter	Symbol	Approx. tolerances / %
Speed	n	0.1
Shaft diameter	d	0.01
Young's modulus	E	5…10
Poisson's ratio	υ	3…5
Gauge factor	k	1
Torsional angle	φ	0.1
Shaft length	l	0.01

By simply considering the measurement uncertainty using the values given in Tab. 1, you obtain a result ranging between 3-5% at best, due to the influence of Young's modulus E and the Poisson`s ration υ respectively. Additional sources of error resulting from lacking or insufficient temperature compensation need to be taken into account, as the case may be. The uncertainty that can be achieved for the torque parameter and power measurement respectively, however, no longer meets the current requirements for new drive systems.

Direct torque measurement

The described challenges can be solved by considering, already in the design phase, installation of an inline torque transducer in the drive shaft (see Fig. 4).

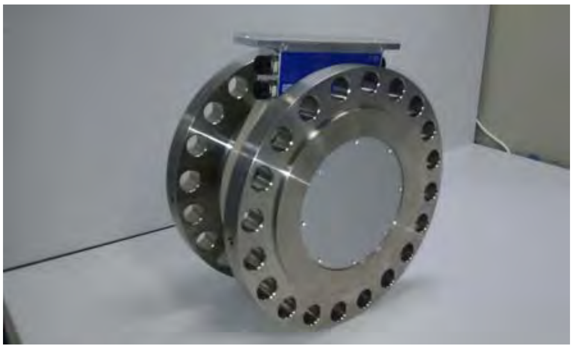

Fig. 4. Marine torque flange for direct installation into the drive shaft

The advantage of this solution is that the inline torque transducer can be calibrated at the manufacturer’s site using appropriate calibration machines. The required quantity (torque) is then calibrated and certified. The transducer can be easily installed, removed, replaced and recalibrated. With the inline torque transducer for marine applications a accuracy class of 0.1 to 0.3 is standard. The requested measurement uncertainty for this application is <1,0%. Even taking side effects like e.g. temperature into account, it is obvious that this level is achievable with the torque transducer inline solution.

The inline torque transducer solution ensures that users in the marine industry can rely on their measurements, due to the fact that the technology is fully traceable to national standards (see Fig. 5).

Fig. 5. Calibration pyramid - Traceability of the quantity torque

References

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