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Investigation of Torsional Moments on Shafts using Telemetry Systems

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Abstract: The method for measurement of torsion moment on rotating shafts is described; some current telemetry systems, working on inductive and Bluetooth principle are shown and some application examples of torsion moment investigation used in VZÚ Plzeň at operation conditions are given.

Keywords: Torsion moment, telemetry system, strain gauge, shaft

1. Introduction

The torsion moment is one of the most important mechanical quantities in the field of design and operation of rotating parts of machines. In the power industry, most of machines producing energy are working on rotational principle. The exact measurement of torsion moment is conditioned due to the tendency of continuous increasing of operational parameters of rotating machines during their dimensioning and efficiency.

The principle of the torsion moment investigation is the measurement of elastic strain of the shaft, telemetry transferee of measured data and recalculation of the strain to the torsion moment. At present, the most widespread method for measurement of elastic strains is the method using strain gauges. The same measurement of torsion moment can be performed directly on the object under investigations or with the measuring part, inserted in series in to the measuring chain.

2. Principle of the torsion moment measurement

The shaft loaded with torsion is subject to biaxial stress state. The principal strains and stresses occur at angles of ±45° to the shaft axis. The maximum sheer stress τ_{max} lies at these planes, too. The relation between the torsion moment M_k and the maximum sheer stress is the function of the section modulus W_k, see Eq. (1). The sheer stress can be determined using measured strain $\varepsilon_{45°}$ in half-bridge or full-bridge strain gauge circuit (Fig. 1) with the help of sheer modulus G.

$$M_k = \tau_{\max} \cdot W_k ; \quad \tau_{\max} = \frac{2}{k} \cdot \varepsilon_{45°} \cdot G; \quad M_k = \frac{2}{k} \cdot \varepsilon_{45°} \cdot G \cdot W_k \qquad (1)$$

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The combined standard uncertainty of torsion moment determination, given in Eq. (4) can be derived from mathematical model of the evaluation function Eq. 1. It can be calculated from standard deviations of sheer modulus, section modulus, Eq. (3) and measured strain, Eq. (2). The last one includes the drift of measuring amplifier, uncertainty of measuring chain and the error caused by deviation of strain gauges position from principal directions.

$$u(\varepsilon)=\sqrt{u^2(\varepsilon_L)+u^2(\varepsilon_z)+4\varepsilon^2\cdot\sin^2 2\alpha\cdot u^2(\alpha)} \tag{2}$$

$$u(W_k)=\frac{\pi}{16}\cdot 3\cdot d^2\cdot u(d) \tag{3}$$

$$u(M_k)=0{,}5\cdot\sqrt{G^2\cdot W_k^2\cdot u(\varepsilon)^2+\varepsilon^2\cdot W_k^2\cdot u(G)^2+\varepsilon^2\cdot G^2\cdot u(W_k)^2} \tag{4}$$

Table 1. Example of computation of torsion moment uncertainty

Given values	M_k [Nm]	D [mm]	E [MPa]	μ [ ]		
	10000	200	2.10E+05	0.3		
Computed values	ε [m·m^{-1}]	G [MPa]	W_k [mm^3]			
	0.000158	8.08E+04	1570796			
Uncertainty estimates	$u(\varepsilon_L)$ [ ]	$u(\varepsilon_z)$ [ ]	u(α) [rad]	u(D)	u(E)	u(μ)
	3.15278E-07	1.00E-06	0.087	0.2	10000	0.003
Uncertainty computations	u(G) [MPa]	u(ε) [ ]	$u(W_k)$	$u(\varepsilon_\alpha)$		
	3.85E+03	2.6E-06	4712	2.39E-06		
Resulted values	2*$u(M_k)$ [Nm]	2*$u(M_k)$ [%]	Δ $M_{k,\ mean}$ [Nm]			
	1011	10.1	-102			

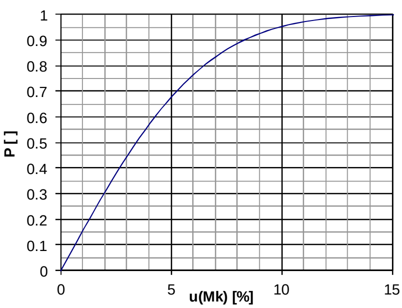

Fig. 1. Probability distribution of M_k uncertainty

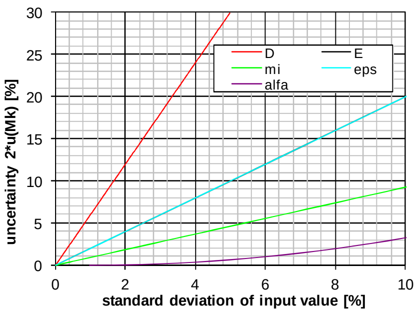

Fig. 2. Sensitivity analysis of input values

An example of calculation of torque uncertainty for some given input values is presented in Table 1. The distribution function for this uncertainty expressed in [%] is provided in Fig. 1. Here it can be seen, that the torque uncertainty is approximately 3.5 % for P = 50%. How the resulted uncertainty is influenced from input values is shown in Fig. 2. Note that the most influence is from correct estimations of shaft diameter. This can be often problem, when the inner diameter is not correctly known.

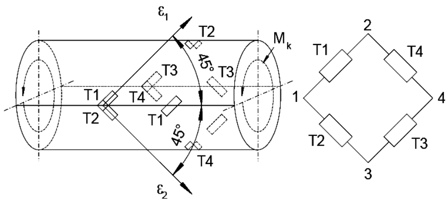

Fig. 3. Strain gauge layout at the shaft

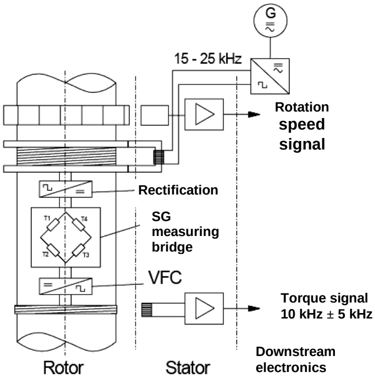

Fig. 4. Scheme of induction torque measurement system

3. Used equipment for torsion moment measurement in VZÚ Plzeň

3.1. Inductive principle of data transferee

The principle of based torque telemetry system including rotation speed measurement is shown in Fig. 4.

One system from Kraus Messtechnik GmbH (KMT) and two from Manner Sensortelemetrie GmbH (Manner) are used for various investigation tasks in VZÚ Plzeň. All the systems have the bandwidth approx. 0 ÷1000 Hz.

One channel 16 bit PCM RMC telemetry system made by Manner is equipped with Ethernet interface as well as analogue output ± 10 V. It contains programmable rotating measuring amplifier and enables remote zero point, amplification and calibration adjustments. The amplifier is assembled to special aluminium ring, which carries also a rotor antenna. The powering and data transferee is performed with a power head. The system enables relatively large shift between the antenna and the head.

The second one, made also by Manner, is equipped with two-channel interface, however has only analogue output ± 10 V. The offset and sensitivity can be changed in small ranges with the potentiometers on receiving unit. The large sensitivity change (0.125 and 4 mV/V) and offset shift change can be adjusted using external resistors. The technical parameters are the same as at the one channel system. Instead of power head, the stator antenna formed from copper band is used, which have to be mounted directly over the rotor antenna.

The last inductive system from KMT is marked TEL1-PCM. The system contains one rotation strain gage transmitter dimensions 35×18×22 mm. Power supply of the transmission part and the digital data transfer between transmitter and receiver is realized inductively through an induction winding around the rotating shaft and with the help of pickup power head. The receiving unit with the possibility of gain and auto-zero setting has an analogue output ± 10 V. The one disadvantage of this system is relatively small gap between the power head and the induction coil. The coil same have to be separated from the shaft with two windings of special ferrite coil or with 20 mm high non-conducting ring.

3.2. Bluetooth principle of data transferee

Microlog, made by firm JR Dynamics Ltd., is a self-contained instrumentation and data analysis system comprising of 2 channel strain gauge signal conditioning, accommodating full-, half- and quarter-bridge gauges or other transducers at 4 kHz low pass active filter on each channel.

System has independent signal offset, software gain (1 to 4×) and shunt calibration facility on each channel; temperature and battery level monitoring; comprehensive data handling and storage including rainflow counting (64×32) and time at level, short bursts of time domain data, storage of 100 highest events recorded in time domain, including accurate time stamp. Data is downloaded to a PC over a high-speed, robust Bluetooth pairing, giving a range of up to 100 m, just through thick walls of measured devices, when mounted inside.

4. Examples of operational tests using telemetry systems

4.1. Torsional vibration monitoring in nuclear power station Temelín

The one channel Manner system is used at present for long term monitoring of steam turbine-generator torsional response during operation in ETE TG1 on generator shaft of diameter 560 mm, $n = 3000\ \text{min}^{-1}$, $t = 60°\text{C}$. Position of the antenna ring and power head is at generator shaft just at the coupling with LP shaft, see Fig. 5. The controlling electronics is situated 15 m from the shaft in power station engine hall.

Torsional vibration will damage turbine-generators if the vibratory response is high enough to result in stresses that exceed the fatigue limit of the materials involved. High stresses relative to the high cycle fatigue strength from torsional vibration can occur at or near the roots of the turbine blades in the last few stages of the LP turbines and in the machine shafts at areas of stress concentration.

For shafts this occurs at locations such as keyways or radial holes, and the effects can be amplified if local fretting or other surface phenomena occur, reducing the fatigue strength. An applied torque occurs that is due to an abnormal event that the design is not capable of sustaining without experiencing fatigue damage. One example of measured transient torsional event is presented in Fig. 7. Its representation in frequency domain is shown in Fig. 8.

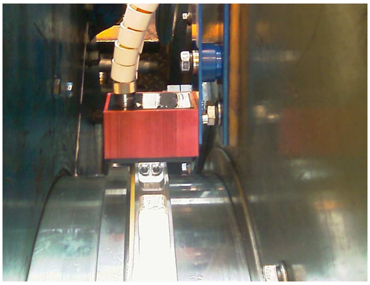

Fig. 5. Power head and antenna ring of Manner system installed on ETE TG1 shaft

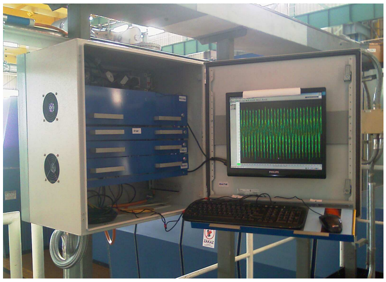

Fig. 6. Control electronics on ETE TG1 engine hall

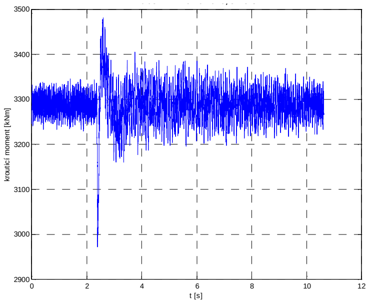

Fig. 7. One of torsional events, that occurred during TG1 operation

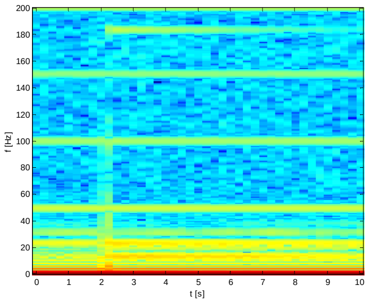

Fig. 8. The frequency of 183 Hz, excited as a result of transient event

4.2. Monitoring of transmitting power on rolling mill

Measurement of the torque was performed at the shaft coupling of the tube rolling mill in Chomutov for assessment of transferred power between primary and rack gear box of the piercer. The installation of KMT system on the coupling shaft is shown in Figure 7. It was found, that the maximum measured torque considerably exceeds the design power values of both gear boxes.

In Fig. 8, there is shown the torque during the milling cycle of one tube. The higher frequency component is caused due to the impacts of punching stud. It causes the high dynamic load of the gear boxes and is the reason for the fatigue failure of tooth system.

4.3. Determination of power distribution to two arms of the gear box

The side drive gear boxes are produced by firm Wikov Ltd. (Fig. 12). They are used for driving the cement mills just from the side of the mill, removing the long shafts used with conventional gear boxes. The mill is turned in parallel with two arms of the gear box. The task was to estimate, if the power distribution in both arms is the equally divided.

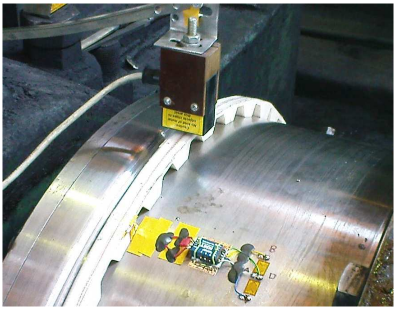

Fig. 9. Installed one-channel KMT system

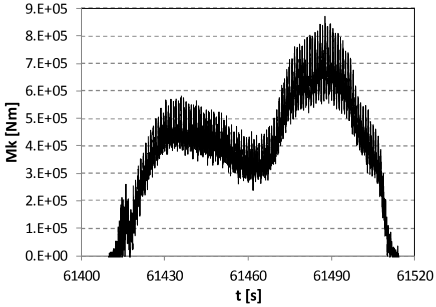

Fig. 10. Time history of one milling cycle

The strain gages were distributed round the shaft at 90° on both sides of the gear, the connecting cable was led in the bottom of tooth space (Fig. 11). The Microlog amplifier was supplied from two lithium batteries, which covered several days of measurement. The conclusion was that the distribution of the torque is very complicated, but the integral of transferred power (i.e. the distributed energy) at each arm are approximately the same.

Fig. 11. Instrumented shaft of the gear box

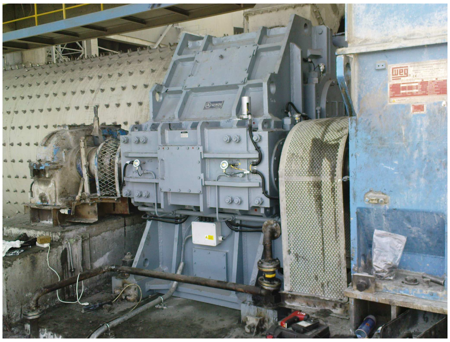

Fig. 12. Gear box at cement mill in Adocim, Turkey

4.4. Estimations of torque and axial force at trolleybus cardan shaft

Measurement of torsional moment and axial force for estimation of dynamic loading of the used traction engine bearing was set as a standard series test on ŠKODA trolley busses. For the data acquisition and storing the on-line measuring system for long-term data monitoring was developed, situated on the trolleybus roof. The Manner two channel system is used for this task. The instrumented cardan shaft is presented in Fig. 13 and one of tested trolleybuses in Fig. 14. Time history of measured data during a short part of a service with passengers is shown in Fig. 15. Some statistical distributions of measured data were created between two terminal trolley bus loops. The distribution function of effective value of torsional moment at one loop is shown in Fig. 16.

Fig. 13. Instrumented cardan shaft of 25Tr

Fig. 14. Measured trolleybus 25 Tr

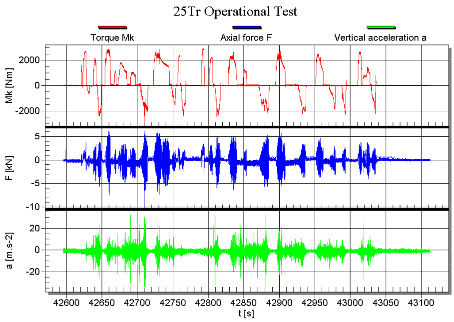

Fig. 15. An example of measured values during service of trolleybus 25 Tr

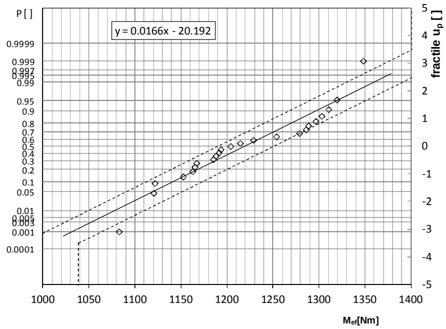

Fig. 16. Estimated probability distribution curve of measured effective torque

5. Conclusions

The theory and some examples were given in the field of measurement torque with telemetry systems. The systems, used in VZÚ Plzeň, work reliably even during long-term monitoring. The main disadvantage is relatively low accuracy, when the direct calibration of the measuring chain is not possible and relatively large necessary space for the antenna for powering the inductive system.

Acknowledgements

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References

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