Journal of the Technical University of Gabrovo

https://mc04.manuscriptcentral.com/jtug

CALIBRATION OF TORQUE SENSOR PROTOTYPE USING COMMERCIAL TORQUE SENSOR

Branko Koprivica[1], Marko Sucurovic[2*], Vojislav Vujicic[3], Milos Bozic[4], Marko Rosic[5]

University of Kragujevac, Faculty of Technical Sciences in Cacak

[1]Department of Electrical and Electronic Engineering, [2]Department of Industrial Engineering,

[3]Department of Mechanical Engineering, [4]Department of Mechatronics, [5]Department of Power Engineering

Svetog Save 65, 32000 Cacak, Serbia

ARTICLE INFO

Article history:
Received 29 September 2018
Accepted 22 November 2018

Keywords:
torque sensor, prototype, dynamic load emulator, calibration, transfer function, relative deviation

ABSTRACT

The aim of this paper is to present the measurement method, measurement setup and results of calibration of torque sensor prototype under rotating operating conditions. By comparison with reference torque sensor, a transfer function is determined. Comparison of the calculated and reference torque is made and corresponding relative deviations are calculated. A proper discussion of all the results presented is also given in the paper.

INTRODUCTION

In some applications of rotating machines, measurement of torque is necessary in order to determine the mechanical power. For example, output mechanical torque of electrical motors or internal combustion engine could be measured using torque sensor. There are many torque sensors available on the market, based on different physical principles, which can be used in such measurements. Recently, novel design of torque sensor of magnetomechanical type has been proposed [1, 2].

Detailed information on static and dynamic testing of torque sensor are given in relevant standard and scientific papers [3-5]. All relevant information given are implemented in testing procedure for calibration of the proposed torque sensor.

This paper presents the results of the calibration of the proposed torque sensor under dynamic conditions, during rotational regimes. Commercial torque meter HBM TW22 [6] was used as the reference torque sensor. Both sensors are located on the same shaft, placed between induction motor and electromagnetic brake. The calibration was realised by direct comparison of the outputs of the tested and the reference sensor. Therefore, values of output voltage of the tested sensor and values of torque obtained from reference sensor are used for construction of calibration characteristic of the tested sensor. This characteristic is represented in analytical form as a fourth-order polynomial. This is used for calculation of torque according to the measured output voltage of the tested sensor and the obtained results are compared with the results obtained by the reference torque sensor. Relative deviations between results are calculated in order to examine the overall quality of the tested sensor.

A discussion of the obtained results is also presented in the paper.

EQIPMENTS FOR TORQUE MEASUREMENT

Testing and calibration of torque sensor based on the magnetomechanical effect was performed using the equipment presented in Fig. 1, numbered as follows: 1 - induction motor (creates torque), 2 - torque sensor under test, 3 - reference torque sensor, 4 - load emulator, 5 - data acquisition cards, 6 - DC power source, 7 - AC power source and 8 - PC with LabVIEW software.

The construction and the principle of operation of the tested torque meter are given in [1, 2].

The block scheme of the whole system is given in Fig. 2. Three-phase induction motor is powered directly from the electric network and the load torque is generated using the load emulator [2]. The control of load emulator is performed by adjusting the current of the DC source. The tested torque sensor is powered by a programmable AC voltage source APS-1102 with the stable sinusoidal voltage at a frequency of 100 Hz. A commercial torque sensor HBM T22 [6] was used as the reference torque sensor. Its output is DC voltage in the range from 0 V to 10 V in the torque range from 0 Nm to 20 Nm. Tested sensor also has a voltage output. NI 9215 acquisition card was used for measurement of these voltages. The temperature inside the tested sensor and ambient temperature were also measured. Measurement of temperature was performed using two thermocouples and NI 9211 card. The temperature may influence the value of the output voltage of the tested sensor, as it was previously examined [2]. LabVIEW

* Corresponding author. E-mail: marko.sucurovic@ftn.kg.ac.rs

application in a PC is used for presentation of all the results of interest, as well as for saving the data in its memory.

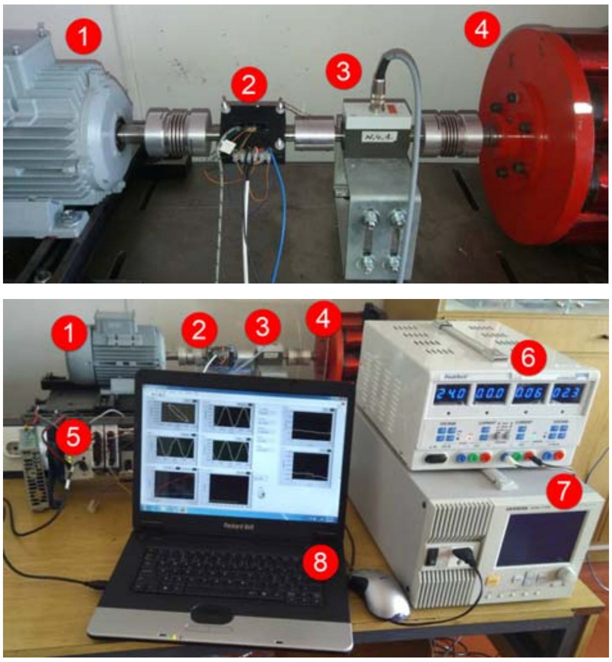

Fig. 1. Equipment for testing of magnetomechanical torque sensor

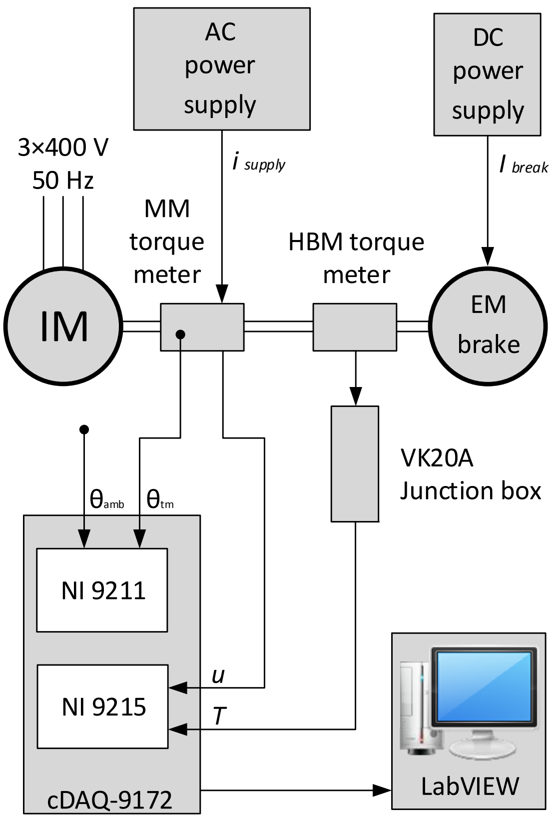

Fig. 2. Block scheme of measurement system

MEASUREMENT RESULTS AND DISCUSSION

Tested magnetomechanical torque sensor generates sinusoidal output voltage whose RMS value U is proportional to torque T (measured by the reference torque sensor) applied to its shaft. According to the calibration procedure [3], tested and reference torque sensor was subjected to the stepwise variable torque, produced by the gradual variation of the DC current of load emulator. Considering the fact that mechanical system used for making torque produces high vibration [4], in order to obtain as much as possible smooth output signals from both sensors, averaging has been applied, as well as polynomial fitting in case of measured voltage U. Thus, it is possible to observe variations in the output voltage created only by stepwise torque variations, while unwanted oscillations due to mechanical vibrations were not considered. This is needed for proper analysis of the results which includes calculation of the $U(T)$ characteristic of the tested sensor, calculation of torque according to that characteristic and calculation of the relative deviation between calculated torque and measured reference torque.

Stepwise variations of measured voltage U of the tested sensor and torque T from reference sensor are presented in Fig. 3. It can be observed from this figure that the output of both sensors effectively follows gradual variations of applied torque. It can be also seen that voltage U decreases with the increase of the applied torque. Also, this voltage varies between 4.58 V and 4.62 V for the applied torque in the range from 0.5 Nm to 8.2 Nm.

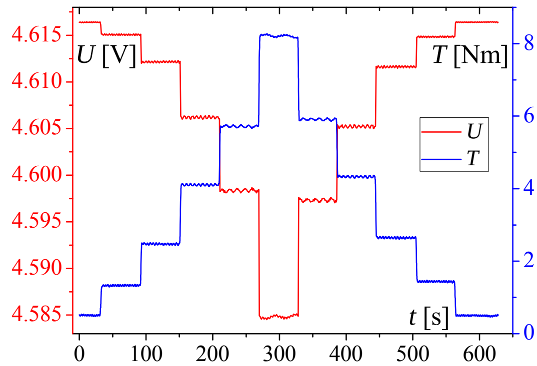

Fig. 3. Stepwise variation of measured torque T and voltage U.

The dependence of the torque T on voltage U is presented in Fig. 4. Black rhombuses represent measured values and blue line represent best polynomial fit to measured values. Therefore, $T(U)$ characteristic was obtained as fourth-order polynomial:

$$T(U) = \sum_{0}^{4} a_i U^i , \qquad (1)$$

with known coefficients a_i, i=0, 1, …, 4.

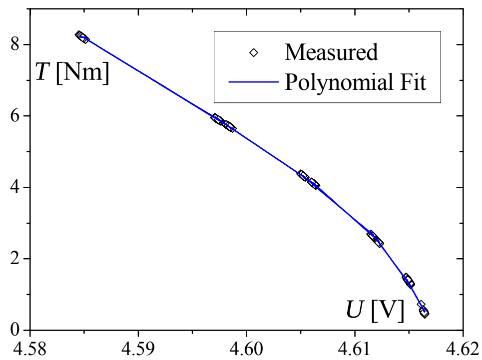

Fig. 4. Measured $T(U)$ characteristic and its best fourth-order polynomial fit

Further, torque calculation has been made according to (1) and by using measured voltage U (Fig. 3). The obtained values of torque are compared to the measured values and their comparison is presented in Fig. 5. Blue dots represent measured torque and the red line represents calculated torque. Accordingly, very good agreement between measured and calculated results has been achieved.

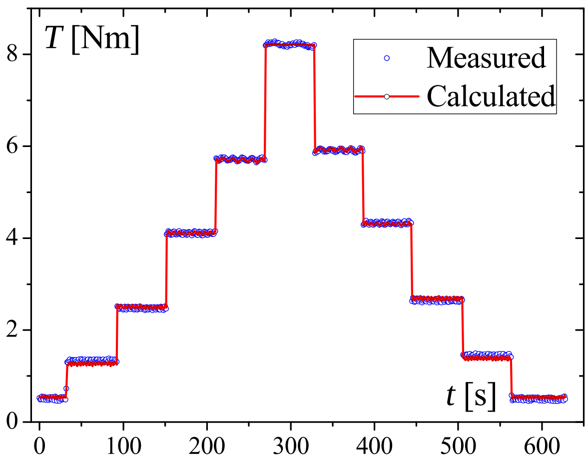

Fig. 5 Comparison of measured and calculated torque

It is better to represent the differences between measured torque T_{meas} and calculated torque T_{calc} as relative deviations with respect to the full scale T_{fs} (taken to amount 10 Nm). Relative deviations δ_{fs} were calculated as:

$$\delta_{fs}[\%] = \frac{T_{calc} - T_{meas}}{T_{fs}} \cdot 100 \, . \tag{2}$$

Fig. 6 presents values of calculated relative deviations for results presented in Fig. 5. It can be observed that in a whole range of applied torques these deviations are below ±1 %. This value of measurement error is acceptable for practical application in engineering practice.

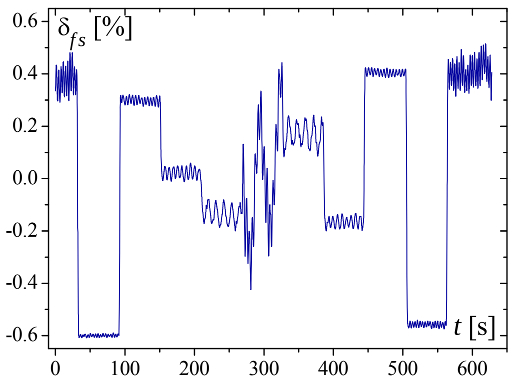

Fig. 6. Relative deviation of calculated torque in respect to full scale (10 Nm).

CONCLUSION

The paper presents the measurement setup for dynamic testing of torque sensor under rotational conditions. This system consists of the induction motor, load emulator, commercial torque meter HBM TW22 (reference torque sensor) and tested magnetomechanical torque sensor. Testing presented in the paper has done with the purpose of calibration of tested sensor.

The calibration characteristic $T(U)$ was obtained in analytical form as a fourth-order polynomial. This characteristic has been used for calculation of torque according to the measured output voltage of the tested sensor. The results obtained were compared with the results obtained by the reference torque sensor and very good agreement between results has been observed.

Furthermore, relative deviations between results were calculated in order to examine the accuracy of the tested sensor. It has been found that in all cases this relative deviation is less than 1 %, which is acceptable for applications in engineering practice.

ACKNOWLEDGEMENTS

This paper has been supported by Scientific Project TR 33016, financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

REFERENCE

[1] Bozic M., V. Vujicic, M. Sucurovic, B. Koprivica, “Simple magnetomechanical torque sensor – design, construction and testing,” International Scientific Conference UNITECH ’17, Gabrovo, Bulgaria, 17-18 Nov. 2017, Vol. 1, pp. I112-I116.

[2] Šućurović M., Vujičić, V., Božić, M., Rosić, M., Koprivica, B., “Testing of magnetomechanical torque sensor using electromagnetic load emulator-temperature correction”, 5th International Conference on Electrical, Electronic and Computing Engineering - IcETRAN 2018, 11-14 June, Palic, Serbia - EEI1.4.

[3] Method for calibration and classification of torque measuring devices, BS 7882:2017, Aug. 2017.

[4] Wegener G., T. Bruns, Traceability of torque transducers under rotating and dynamic operating conditions, Measurement 42 (2009), pp. 1448–1453.

[5] Oliveira R. S., H. A. Lepikson, S. Winter, R. Theska, T. Fröhlich, A. C. P. Bitencourt, R. R. Machado, New proposals for the dynamic tests of torque transducers, 58th Ilmenau Scientific Colloquium, Technische Universität Ilmenau, 08 – 12 September 2014.

[6] https://www.hbm.com/en/2384/t22-torque-transducer-for-simple-torque-applications/.