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TRANSDUCERS AND METHODS FOR TORQUE MEASUREMENT DURING TESTING OF STEPPING MOTORS

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Summary: *An equipment based on optoelectronic and piezoelectric techniques used in the stand for determining of dynamic characteristics of stepping motors. Torque measurement of stepping motors has a peculiar character, which makes it difficult or impossible to use many typical methods and measuring devices. The good dynamic propertes of presented torque meters are basis to number of experiments.*

1. INTRODUCTION

The torque measurement carried out during testing of stepping motors included:

- dynamic measurement during determining the pull-in and pull-out characteristics of stepping motors as well as of the power transmission systems including these motors;
- analysis of the transient characteristic – dynamic measurement of single-step response;
- determination of static torque-angle characteristics.

Dynamic torque measurement of small stepping motors has a peculiar character, which makes it difficult or impossible to use many typical methods and measuring devices. The time for testing procedures is relatively short - because of necessary of elimination of temperature influence. Both micromotors and other parts of drives have small dimensions. Small values of moment of inertia of rotors are a reason of interaction between torque transducer and objects under tests.

Torque meters can be divided into three groups: swing torque meters, dynamometric, torsion meters. The most useful kinds of torque transducers are torsion meters. There is the elastic deformation of the mechanical transducer (*MT*) - the so-called *"torsion element"* - under the action of the applied torque used in measuring process. In terms of the ability of the angular torsion element to change its position with relation to the fixed parts of the power transmission system, we can distinguish:

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- torque meters with fixed torsion elements - so-called *stationary torque meters (STM)* - used mostly for measuring the reaction of the stator of electromechanical subassemblies,
- torque meters with rotating torsion elements - the so-called *rotary torque meters (RTM).*

The operation of *dynamometric torque meters (DTM)* is based on direct measuring of the force on one arm.

2. PLACEMENT OF THE TORQUE MEASUREMENT

There are two main methods of direct determining of torque of small motor [6]. The first one – presented in Fig. 1a – based on measurement "on shaft" – with using of *RTM*. During realisation of the second one measurement of the reaction torque of the stator is done (see Fig. 1b). Both *STM* as well as *DTM* can be used in second configuration.

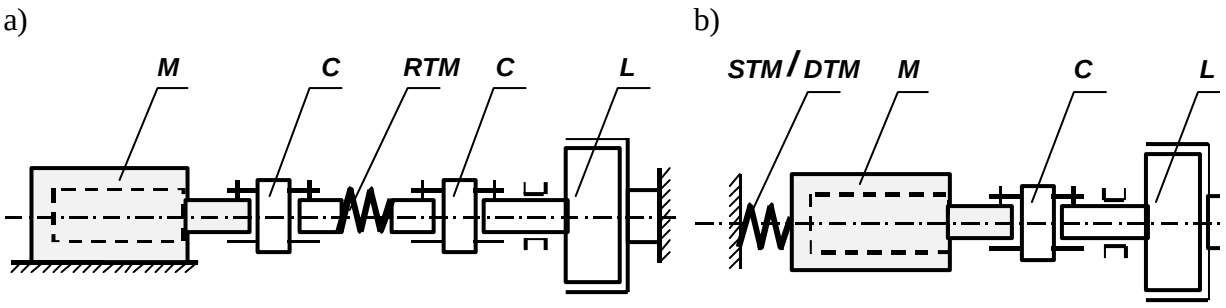

Fig. 1. Two general configuration of measurement of motors torque (description in the text; *RTM* is symbolic presented without bearing system)

M – motor under test, *C* – coupling, *L* – load (brake or inertial rotating mass)

Measurement "on the shaft" gives useful information for designer of drive system with tested motor. The electromagnetic torque of the motor is the result of measurement in configuration from the Fig. 1b.

The following general formulas of torque balance in the test stand for testing of stepping motors' dynamics are valid (without taking into consideration any additional flexible elements):

$$T_e = T_{fmb} + T_m(\omega) + (J_r + J_{ad})\varepsilon + T_v(\omega) + T_{fa} + T_b\,, \tag{1}$$

$$T_{SR} = T_e\,, \tag{2}$$

$$T_{RTM} = T_e + T_{fmb} + T_m(\omega) + T_{f1}\,. \tag{3}$$

One used the following designations in the system of equations (1-3):

$J_{r(ad)}$ - moment of inertia of rotating masses of the motors rotor (additional elements of the stand);

T_{fmb} - torque of dry friction of bearing of the motors rotor;

$T_m(\omega)$ - torque of viscous friction braking the rotor;

$T_v(\omega)$ - torque of viscous friction braking the additional parts of the stand;

T_b - torque of an active-type of breaking load; i.e. having the sense independent on the angular velocity;

T_{f1} - torque of dry friction of “left” bearing of the *RTM* rotor;

T_e - electromagnetic torque;

w, ε - angular elocity and angular acceleration;

T_{SR} -torque measured by stationary/dynamometric torque meter;

T_{RTM} -torque measured by rotary torque meter;

3. TORQUE METERS FOR DIAGNOSTIC OF ELECTRICAL MICROMACHINES

Torque meters of small measuring ranges – up to *1 N×m* – are produced only by few renowned manufacturers of research equipment. The several types of new torque meters were developed in the *Institute of Micromechanics and Photonics of Warsaw University of Technology* [3,5,7,10].

Using of the optoelectronic technique gives the possibility of generating the output signal direct in stationary part of the rotary torque meter. The idea of measuring system used in *OPM* type called meters was presented on Fig 2 (processing channel see on Fig. 3).

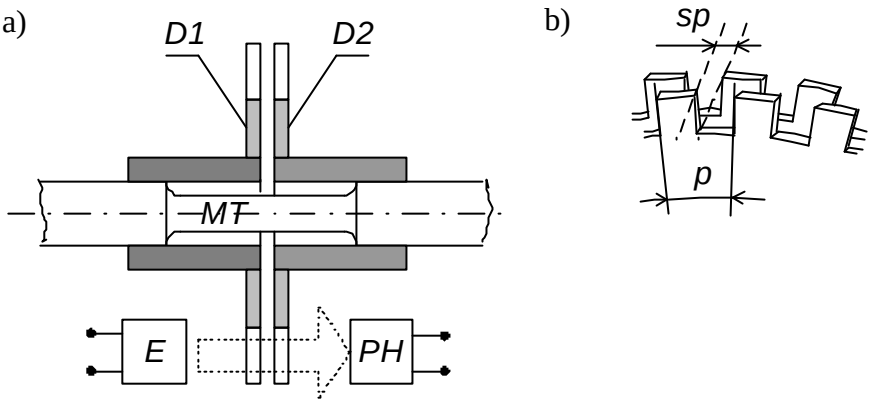

Fig. 2. Schematic of general idea of the *OPM* type measuring system

a) schematic plain view of the system, b) symbolic view of a part of the system,

D1 and *D2* – glass discs being mutually twisted, *p* – angular pitch of one sector (with transparent and non-transparent parts) on the disc (recommended ratio *0,5*), *sp* – resultant width of the clearance within one pitch, *E* – infra red emitter, *Ph* – detector, *w* – angular width of window bounding the infra-red beam, *k* – number of sectors (line marks on the discs).

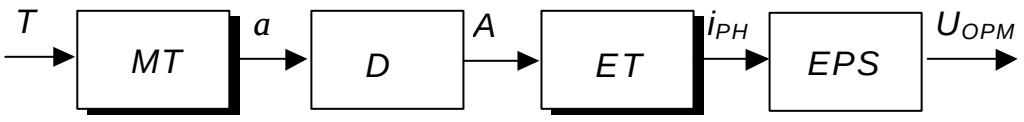

Fig. 3. Processing in the *OPM* type rotary torque meters

T - measured torque, *MT* - mechanical transducer, *a* - angle of twist of *MT*, *D* - mask system (discs and stationary mask), *A* - resultant radiation area, *ET* - electrical transducer (open optoelectronic connection), i_{PH} - resultant current of *p-i-n* photodiodes, *EPS* - electronic processing system, U_{OPM} - output voltage

The performance features of advanced version - called *OPM/Z* - are:

- output signal is generated in stationary part of *RTM* in four optoelectronic couples

- both angular position and angular velocity of the shaft do not impact on the output
- measurements can be taken with the shaft stopped
- output signal (voltage in range *-5V ¸ 5V*) can be easily recorded
- measurement range can be selected (the range of the family is *0,05 N×m ÷ 2,0 N×m*)
- distinguishably small moment of inertia of rotating parts: *12,0 g×cm²*
- in the series of types the internal measuring path has been used; the path is provided with the original transducer, which does not increase the mass *M.I.* of the rotating unit and enables the continuous measuring of speed.

The dynamometric torque meters have been designed in *IMIF WUT* in two versions, both with use of piezoelectric force transducers [6,7]. The configurations are presented on Fig. 4, and processing channel – on Fig. 5.

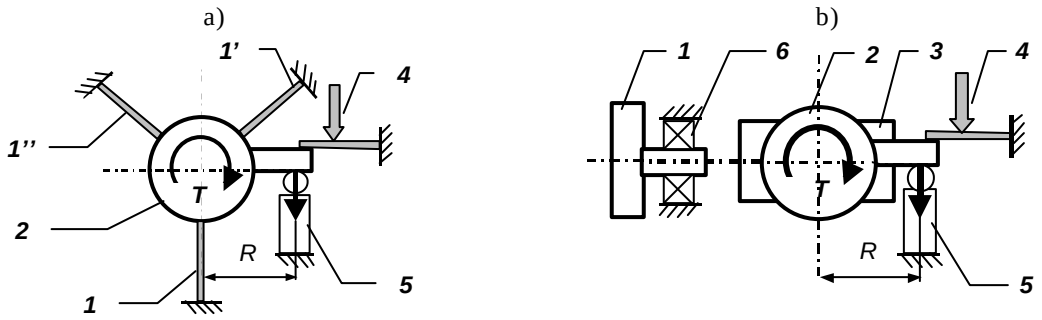

Fig. 4. Two types of dynamometric torque meters with piezoelectric force transducers a) suspension on system of three flat springs, b) suspension on ball-bearing

1, 1', 1'' – flat springs, *2* – mount, *3* – stator, *4* – pre-force load system, *5* – force transducer with ball shape end, *6* – ball-bearing, *R* – arm of measured force

Fig. 5. Processing in the dynamometric torque meters with piezoelectric force transducers

T - measured torque, *R* – arm of force, *F* – force, *A* – charge amplifier, *ET* – elec-trical transducer (piezoelectric), q_{FT} - electrical charge, U_{out} - output voltage

4. TORQUE MEASUREMENT IN A NEW STAND FOR TESTING DYNAMIC OF STEPPING MOTORS

The new measuring system is used in experiments during realisation of the research project "Methods of measuring of torque of stepping motors" (see *Acknowledges*). The stand gives the possibility of measuring simultaneous both torque "on shaft" as well as reaction torque of the stator. The scheme of the stand is presented on Fig. 6.

The set of *OPM/Z* meters consist of devices with ranges *± 0.05 N×m*, *± 0.1 N×m*, *±0.25 N×m*, *±0,5 N×m* and *± 1.0 N×m*. Because of high sensitivity of bath piezoelectric force transducer as well as charge amplifier special designed new dynamometric stationary torque meter *PMD* (see Fig. 7) is characterised by high resolution and accuracy. An example of possibility of measurement of small values of torque is presented on Fig. 8. The testing torque signal with relatively small amplitude (circa *0.015 N×m*) – generated by commutation phenomena in DC micromotor – was without any problems registered by torque meter.

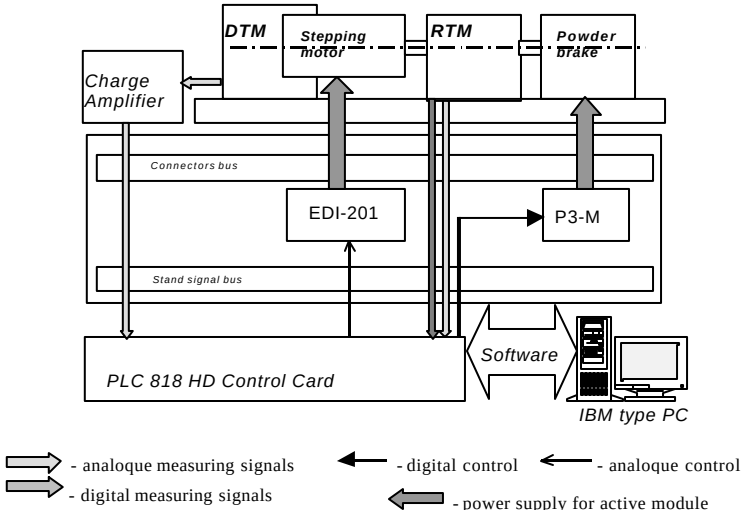

Fig. 6. Structure of the test stand

DTM – new dynamometric torque meter with piezoelectric force transducer, *RTM* – rotary torque meter *OPM/Z* type (with integrated angular position and velocity speed transducers), *EDI-201* – stepper motor drive circuit, *P3-M* – specialised powder brake supply unit

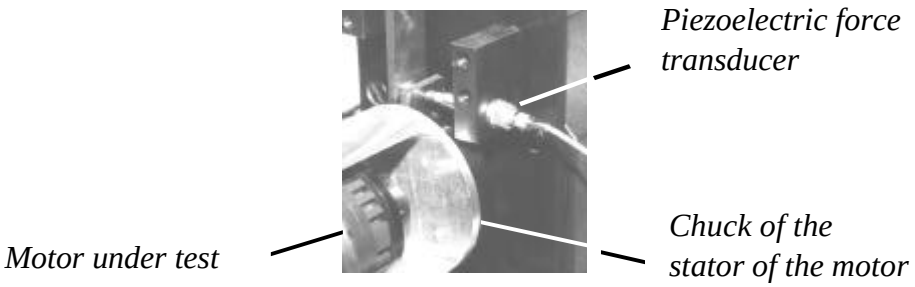

Fig 7. View of dynamometric torque transducers made for stand for testing of characteristics of stepping motors

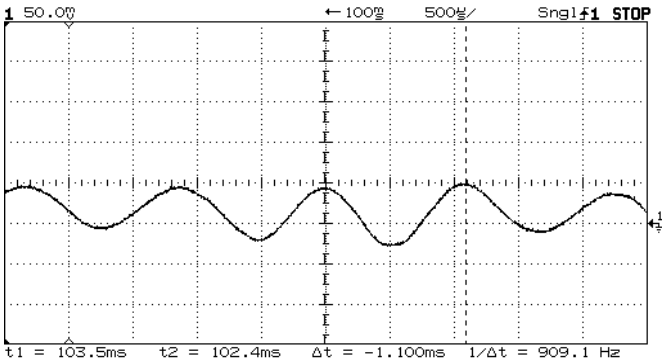

Fig 8. Testing of the new torque meter with piezoelectric force transducer (description in the text) - *Y axis - 50 mV/Div ≡ 0.01 N·m/Div*; *X axis- 0.,5 ms/Div*

An exemplary course of the frequency characteristic of the *PM* type (permanent magnet in rotor) stepping motor (*Escap*) – registered by new dynamometric torque meter is presented on Fig. 9.

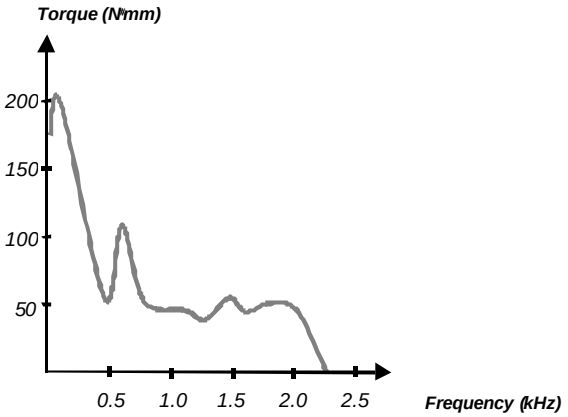

Fig. 9. Exemplary *PM* stepping motor pull-in characteristic obtained with use of new *DTM*

5. CLOSING REMARKS, ACKNOWLEDGEMENT

Analysis of properties of new transducers and methods makes it possible to carry out an extensive using of measured systems for testing of stepping motors' dynamics. Development of verified simulation models of new rotational torque meters allows customising the institute's hardware offer to specific needs of various measuring situations. Systematisation of assessment criteria will allow using the adopted research method to analyse the influence of torque measurement position on the load curves of electric small-power motors.

ACKNOWLEDGEMENTS

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