SPECIAL ASYNCHRONOUS DYNAMOMETER DESIGNED FOR FAST TRANSIENT PHENOMENA

B. Skala, J. Fořt, L. Sýkorová

Univerzitní 8, Department of Electromechanics and Power Electronics, Faculty of Electrical Engineering
University of West Bohemia in Pilsen, 306 14 Pilsen
tel.: +420 377 634 473, fax: +420 377 634 402, e-mail: skalab@kev.zcu.cz, fort@kev.zcu.cz,sykorovl@kev.zcu.cz

Summary This paper is focused on measurement of output of the rotary electromechanic machines, i.e. torque and speed. Special attention is paid to the torque measurement under transient phenomena. The paper is also concentrated on the optimization and interference of the designed asynchronous dynamometer. Thanks to the dynamometer it is possible to measure very fast transient phenomena with a very high precision. The mathematical model of the asynchronous machine completed with the mathematical description of the mechanical elements has also been added. Part of this work is focused on parameters identification of the modeled mechanical elements. Selected transient states were simulated with the help of MATLAB and SIMULINK language.

1. INTRODUCTION

Some electrical machines have the non-constant torque and speed during one mechanical revolution. Stepping motors, switching reluctance machines or synchronous machine waving on the network may serve as examples.

Also in industry there are many applications where the torque is variable during one mechanical revolution. Typical examples are the starter for combustion engine, compressor powered by electric motor, etc.

In addition, in industry the applications with speed and torque varying simultaneously during one mechanical revolution are quite common. There are various slotted-link mechanisms, etc.

For calculation of the torque stress, the coefficient of irregularity is used very often. However, the unbalance of the rotating parts could be a source of unknown additional stresses. Due to this fact the verification of calculation by measurement is important.

2. THE TYPICAL DYNAMOMETER

A typical rotary dynamometer can be seen in Figure 1. This machine could be a DC machine or an asynchronous machine supplied via frequency converter.

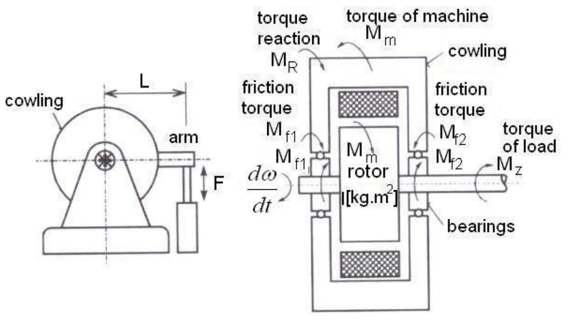

Fig. 1. Typical dynamometer

The force measurement device could be made not only of a spring but also of a piezoelectric sensor or any other press or force sensor, etc.

The dynamometer measures the reaction forces of the rotor. This reaction affects the stator and, in ideal case, this is equal to the action on the rotor. Due to this fact the dynamometer is equipped with very precise bearings. Usually the bearings have a spinning ring of rolling elements even if the dynamometer rotor is at rest. Only in this way the torque is minimized which is needed to put the rotor from the rest state in motion.

The force F on the arm of length L is measured by the force sensor. Reaction torque of the stator is given by the relation

$$T_R = LF_R \tag{1}$$

3. DISADVANTAGES OF THE DYNAMOMETER

The main disadvantage follows from the following analysis.

Let us assume that the rotor of the moment of inertia I *[kg.m^2]* has the angular acceleration $\frac{d\omega}{dt}$.

Then the following relation must be valid:

$$I\frac{d\omega}{dt} = T_i - T_l - T_Z \tag{2}$$

Due to the fact that the stator parts are at rest, the following equation must be valid simultaneously

$$T_R + T_l - T_i = 0 \tag{3}$$

By the combination of both equations (2) and (3) we obtain

$$T_Z = T_R - I\frac{d\omega}{dt} \tag{4}$$

It follows from the last equation (4) that during the acceleration or deceleration we measure the torque with some systematic error. This error can be corrected by the rotor acceleration measurement and by the calculation of the equation element $I\frac{d\omega}{dt}$. On the other hand the advantage is that the bearings friction has no effect.

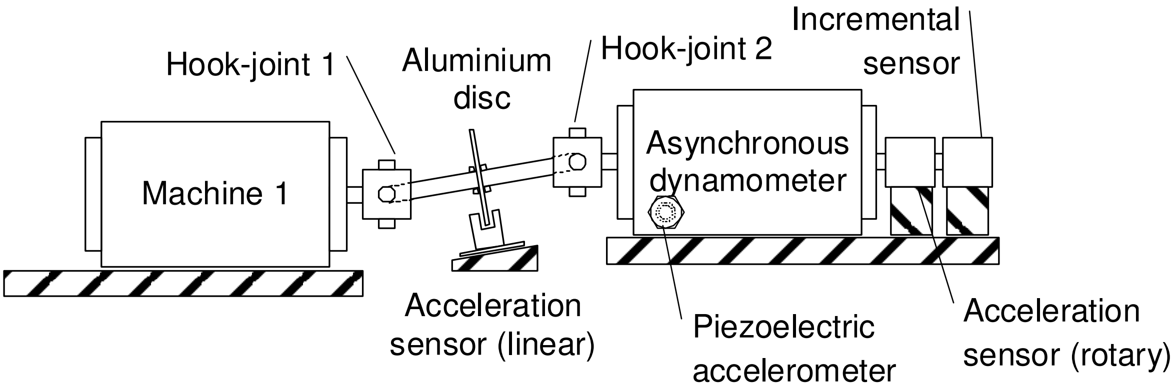

Fig. 2. The sensors placing on the dynamometer (with exception of voltage and current sensors)

4. THE REASONS FOR THE DESIGN OF A NEW DYNAMOMETER

The typical dynamometer is not suitable for transient phenomena measurement even when the force sensor is fast responding and modern digital data acquisition is provided.

If we required the transient phenomena evaluation, another way is possible. We can use for example a torsion torque sensor. This method unfortunately has another disadvantage – we change the torsion stiffness and the behavior during transient phenomena as well.

As a consequence of these reasons we decided to construct a new dynamometer, which would be suitable for fast transient phenomena measurement.

5. SENSORS OF THE NEW DYNAMOMETER

The asynchronous machine was equipped with various sensors:

1. Voltage and current transducers (each phase)
2. Piezoelectric accelerometer (swinging stator)
3. Contactless rotary accelerometer (one end of the rotor shaft, through whole construction)
4. Incremental sensor (the same end of shaft)
5. Contactless linear accelerometer (second and of the rotor shaft)

Thanks to these sensors we can determine every important electrical and mechanical magnitude, especially the systematic error $I\frac{d\omega}{dt}$. Please note that this error consist of rotor component and stator component, if the stator can swing around with a not negligible displacement. The main idea was described in [1].

6. THE DESIGN OF THE NEW DYNAMOMETER

As a machine the standard asynchronous machine of a power 4 kW was used. The stator of this machine can swing around up to 30 deg thanks to two additional bearings.

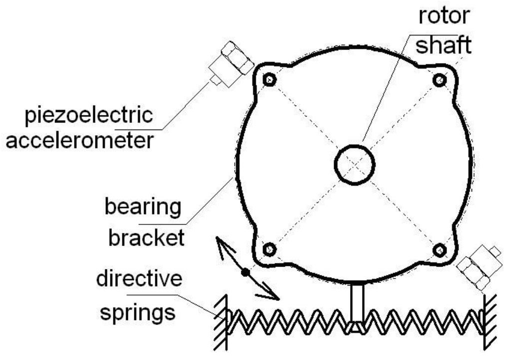

Fig. 3. Piezoelectric accelerometers on the stator and directive springs (principle of mounting)

The reaction is held by two springs. The stator is equipped with a piezoelectric accelerometer. The rotor is equipped with a contactless rotary accelerometer and in addition with an incremental speed sensor.

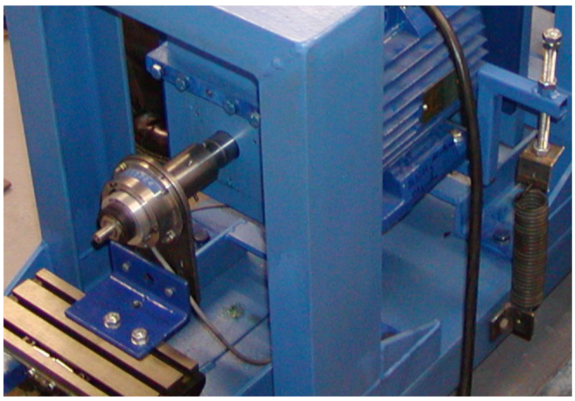

Fig. 4. Rotary accelerometer has the straight-through hole. The incremental speed sensor mounting is possible to the same shaft end

Consequently, we can evaluate the acceleration of the rotor $\frac{d\omega}{dt}$ and stator $\frac{d\omega_S}{dt}$ as well. Moment of inertia of the rotor $I[kg.m^2]$ can be easily found in the machine producer catalogue or determined by measurement [1]. The stator moment of inertia I_S we have to measure before dynamometer mounting.

7. CALIBRATION OF THE DYNAMOMETER

The dynamometer was calibrated in three levels. First level was static calibration.

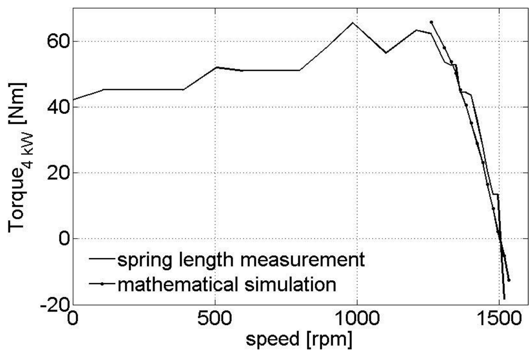

Fig. 5.The comparison of various principles of the torque determination. Due to the overloading of the machine the comparison was performed only in the working part of the torque characteristic

With the help of a force sensor the spring forces on the well known length of the arm were measured.

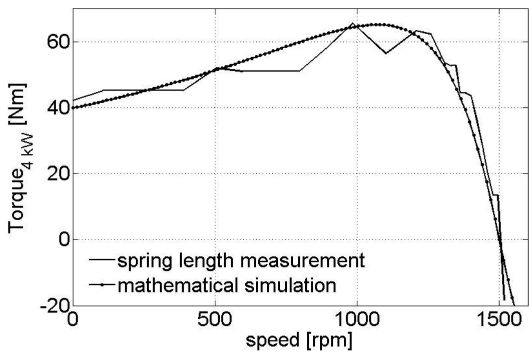

Fig. 6. The comparison of the measurement and simulation of the static torque characteristic

In the second level we applied the unit step function and evaluated the magnitudes obtained from force sensor and piezoelectric accelerometer as well.

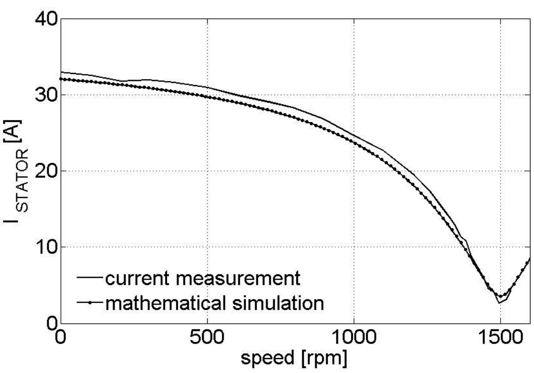

Fig. 7. The comparation of the measurement and simulation of the stator current characteristic

At the third stage we compared the transient response with the simulation results.

8. DETERMINATION OF ELECTRICAL PARAMETERS

The determination of the equivalent circuit parameters was based on no-load test and short circuit test. The precision of this determination was verified with the help of resistivity measurement by the Ohms method.

9. NAME PLATE OF THE DYNAMOMETER

power	4 kW
nominal speed	1435 rpm
nominal current	14,4 / 8,3 A
nominal voltage	230 / 400V D/Y

10. DETERMINATION OF MECHANICAL PARAMETERS

The moment of inertia was also determined by special measurement. The trifilar torsion pendulum method was used.

When we want to improve the classical dynamometer, the precision must be very high. Due to this fact we provide measurement several times with various angles displacement and length of hanging as well. All experiments were measured and evaluated by the computer.

We measure not only the rotor but even the stator moment of inertia. The moment of inertia of the stator included the terminal box, foots and all other accessories (lifting eye).

As was already mentioned earlier, the displacement of the stator cannot be neglected. To determine the mechanical parameters of the swinging stator we measure the free oscillations. With the help of following equation we can calculate the value of damping and stiffness of spring.

Logarithmic decrement is given by the relation

$$\ln\frac{x(t)}{x(t+T)} = NT = 2\pi\frac{\delta}{\sqrt{1-\delta^2}}\,\vartheta = konst \qquad (5)$$

From the ratio of the vicinal amplitudes we can determine character, amplitude and other dumping parameters.

A general vibration is described by the differential equation

$$m\ddot{x} = -cx - k\dot{x} \qquad (6)$$

Which can be written as

$$\ddot{x} + 2N\dot{x} + \Omega^2 x = 0, \qquad (7)$$

where is

$$\frac{k}{m} = 2N \text{ a } \frac{c}{m} = \Omega^2 \qquad (8)$$

Then the

$$\delta = \frac{N}{\Omega} \qquad (9)$$

is relative dumping. For

$$\delta > 1 \qquad (10)$$

the dumping is above critical and vice-versa, for

$$\delta < 1 \tag{11}$$

the dumping is subcritical.

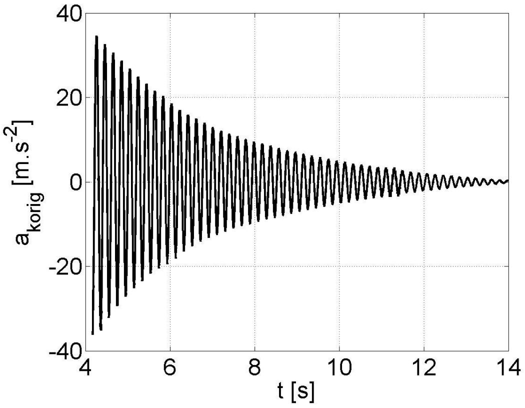

Fig. 8. The measurement of the free stator swinging (acceleration)

Before the integration we have to carefully remove the DC component from the signal.

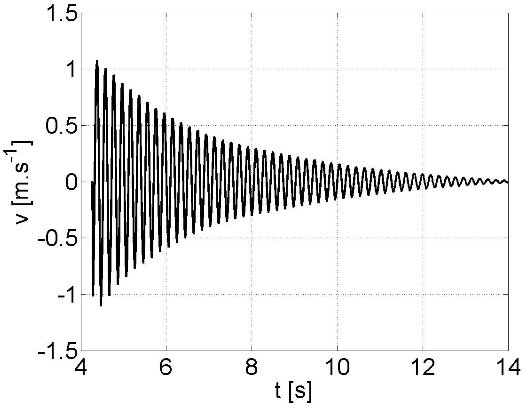

Fig. 9. The measurement of the free stator swinging (speed – first integration)

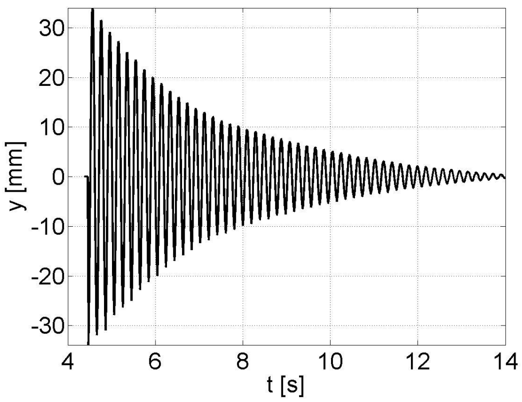

Fig. 10. The measurement of the free stator swinging (displacement – second integration)

11. VERIFICATION EXPERIMENTS

The dynamometer parameters have been determined and typical transient states were simulated. These results have been verified experimentally. The repeatability of experiments was also tested.

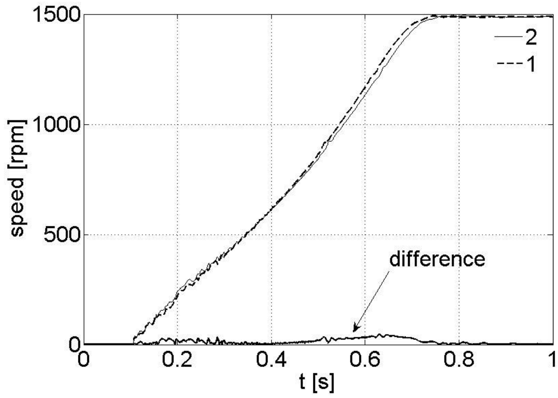

Fig. 11 Comparison of the integration of acceleration signal - rotor speed error. Detent stator (1) versus stator swinging neglected (2).

12. CONCLUSION

The asynchronous dynamometer is supplied with a frequency converter. In this way it should work in the motor as well as the generator mode. The mechanical load will be connected through the cardan shaft. Thanks to this special shaft the torque can be periodically changed during one revolution. In this way we can replace the mechanical load of the piston-engine-type by the electrical rotary machine and tested the dynamometer in fast transient states.

13. NOTIFICATION

c	… stiffness of spring
I_S	… moment of inertia of the stator
I	… moment of inertia of the rotor
k	… damping
m	… mass
T_i	… internal torque
T_l	… torque of bearings
T_Z	… torque of load
T_R	… torque of reaction
T	… time of period of oscillation
t	… time
x, y	… displacement
ω	… angular speed of the rotor
ω_S	… angular speed of the stator
Ω	… natural angular frequency

Acknowledgement

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