NEW METHOD OF A MEASUREMENT OF DYNAMIC MECHANICAL CHARACTERISTIC OF ELECTRICAL MACHINES

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Abstract: In the given article the problem of reduction of Electrical Machines measurement error of the Mechanical Characteristics is considered. The new method of the Mechanical Characteristic measurement, enabling to determine such its making as an inertia moment and moment of mechanical losses in the function of angular velocity of a rotor is offered. Experimental results of researches are indicated.
Keywords: Electrical Machines, Moment of Inertia, Mechanical Characteristic

1 INTRODUCTION

The Electrical Machines are widely used in various spheres of economy and industry, where rigid technical requirements are put forward rather for them. The consequence is the increase of the requirements to the means of technical diagnostics of Electrical Machines condition.

One of the most labour-consuming operations of Electrical Machines control is the measurement of the *Dynamical Mechanical Characteristic* (*MC*), which represents torque on a shaft of a Electrical Machine M_d from angular velocity ω

$$M_d(\omega) = J \cdot \frac{d\omega}{dt} + M_0(\omega). \tag{1}$$

Main makings of MC are the rotor inertia moment J and moment of mechanical losses M_0. The MC measurement is extremely important for the Electrical Machines control with given dynamic properties and all kinds of Electrical Machines (EM).

The MC is a very informative characteristic, according to which it is probable to determine such parameters of the EM as starting, minimum, maximum, nominal and critical moments. On synchronous hollows of the MC it is possible to analyze a condition of EM isolation. However the lack of necessary means of MC measurements it is not frequently supervised.

The fact that they do not provide sufficient accuracy of MC measurements can be refused to defects of existing means of MC measurements.

Existing means of MC measurement admit, that the *moment of mechanical losses* M_0 is constant, when actually it is the function from EM angular velocity $M_0 = f(\omega)$. The *inertia moment* J is determined by separate means of measurement, and on its determination it is necessary a lot of time. It is the reason of additional errors at MC determination.

Thus, there is necessity of more exact and automated measurement of the inertia moment J and moment of mechanical losses $M_0(\omega)$ for MC determining and Computer-Measuring System of the Mechanical Characteristics with improved metrological parameters.

2 A WAY OF MECHANICAL CHARACTERISTIC MEASUREMENT

The authors offers the way of MC measurement, based on [1]. Proposed method consists in the following. Necessary condition of its realization is the availability of *a reference inertia moment* J_m, executed in kind of rotation simple body, for example, disk or cylinder. The reference inertia moment size calculate on its geometrical and weight parameters.

The EM result in movement. In a time run of transient mode measure of angular velocity ω_s, at achievement of synchronous velocity the EM disconnect and during its self-braking measure angular velocity ω_{b1}. When the EM will stay, on the target end of a shaft the EM establish a reference inertia moment J_m and the EM result in movement. After achievement of synchronous velocity the EM disconnect and during its self-braking measure angular velocity ω_{b2}.

The EM movement equations accordingly without a reference inertia moment and with a reference inertia moment J_m is following:

$$\begin{cases} M_{el}(\omega) = J \cdot \varepsilon_s(\omega) + M_0(\omega); \\ 0 = J \cdot \varepsilon_{b1}(\omega) + M_0(\omega); \\ 0 = \left(J + J_m\right) \cdot \varepsilon_{b2}(\omega) + M_0(\omega). \end{cases} \tag{2}$$

The realization of given experiments is the methodical basis of offered way and permits with use (2) to combine and to decide a system from three equations with three unknown $M_{el}(\omega)$, $M_0(\omega)$ and J. We shall record of equations system (2), move unknown in left-hand parts of equations:

$$\begin{cases} M_{el}(\omega) - M_0(\omega) - J \cdot \varepsilon_s(\omega) = 0; \\ -M_0(\omega) - J \cdot \varepsilon_{b1}(\omega) = 0; \\ -M_0(\omega) - J \cdot \varepsilon_{b2}(\omega) = J_m \cdot \varepsilon_{b2}(\omega). \end{cases} \tag{3}$$

Having decided in common second and third equation of a system (3), we shall receive:

$$J = \frac{\varepsilon_{b2}(\omega)}{\varepsilon_{b1}(\omega) - \varepsilon_{b2}(\omega)} \cdot J_m \;, \tag{4}$$

$$M_0(\omega) = \frac{\varepsilon_{b1}(\omega) \cdot \varepsilon_{b2}(\omega)}{\varepsilon_{b2}(\omega) - \varepsilon_{b1}(\omega)} \cdot J_m \;. \tag{5}$$

Size of inertia moment J averaged in all range of EM angular velocity. The electromagnetic moment M_{el} is determined from the first the system equation (3):

$$M_{el}(\omega) = \frac{\left(\varepsilon_s(\omega) - \varepsilon_{b1}(\omega)\right) \cdot \varepsilon_{b2}(\omega)}{\varepsilon_{b1}(\omega) - \varepsilon_{b2}(\omega)} \cdot J_m. \tag{6}$$

We shall note that $M_{el}(\omega)$ is a dynamic electromagnetic moment without of a moment of mechanical losses $M_0(\omega)$. The complete dynamic moment $M_{el}(\omega)$ is determined as $M_d(\omega) = M_{el}(\omega) + M_0(\omega)$:

$$M_d(\omega) = \frac{\varepsilon_s(\omega) \cdot \varepsilon_{b2}(\omega)}{\varepsilon_{b1}(\omega) - \varepsilon_{b2}(\omega)} \cdot J_m. \tag{7}$$

We shall note, that the offered way can be applied to separate determination of inertia moment J and moment of mechanical losses $M_0(\omega)$. It is for this purpose necessary to conduct two experience of self-braking and to determine required parameters under the formulas (4)-(5).

Offered way enables to determine not only the MC and its making, and other characteristics of the EM in a dynamic mode of its work: the electromagnetic dynamic mechanical characteristic $M_{el}(\omega)$; the electromagnetic moment $M_{el}(t)$; the dynamic mechanical characteristic $M_d(\omega)$; the dynamic moment $M_d(t)$; the rotor EM inertia moment J; the electromagnetic dynamic capacity $P_{el} = M_{el} \cdot \omega$; the mechanical dynamic capacity $P_m = P_{el} \cdot (1-s)$; the dynamic loss in rotor winds $P_l = P_{el} \cdot s$. It enables essentially to expand the area of a given way use.

The block diagram of the *Computer-Measuring System*, realizing a given way, is identity as in [1]. The Computer-Measuring System executes measurement of angular velocity in modes of start-up and self-braking the EM and subsequent processing of measurements results, which consists in following. Numerical smoothing of measurements results, numerical differentiation, calculation J, $M_0(\omega)$ and MC, representation of results in the graphic and tabulated forms, etc.

3 THE EXPERIMENTAL RESULTS

On Figures 1-5 some experimental results, received for asynchronous EM and submitted which evidently wide functional opportunities of offered Computer-Measuring System represent.

The experimental researches have shown, that the moment of mechanical losses $M_0(\omega)$ can be described by following dependences:

1. In a restricted range of angular velocities it is possible to consider, that the torque $M_0(\omega)$ is linearly connected to an angular velocity

$$M_0(\omega) = a \cdot \omega, \tag{8}$$

where a - tangent of lean angle of averaged resistance characteristic.

2. At linear approximating of a region of characteristic $M_0(\omega)$ near to a working angular velocity ω_{work} in linear model the constant component of torque M_{const} is taken into account also:

$$M_0(\omega) = M_{const} + a \cdot (\omega - \omega_{work}). \tag{9}$$

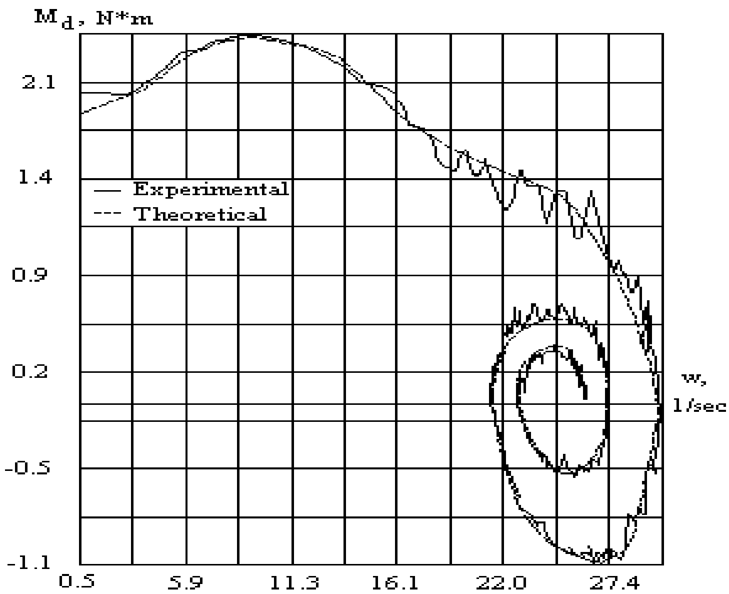

Figure 1. The Mechanical Characteristic

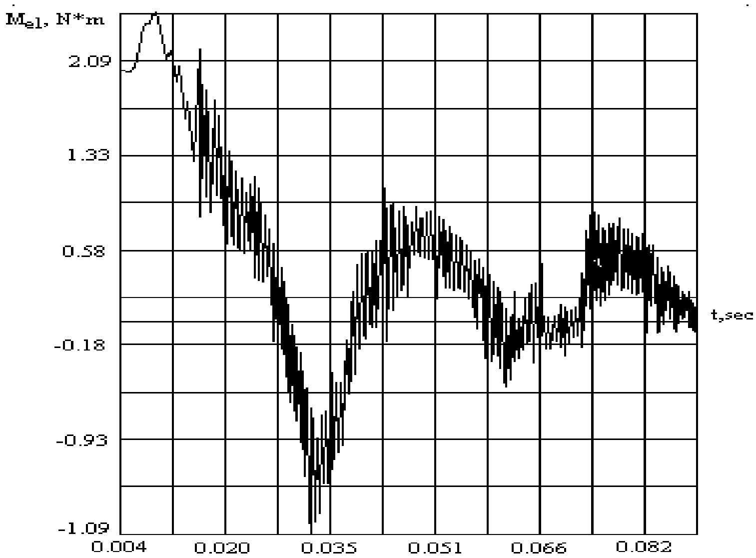

Figure 2. The electromagnetic dynamic moment

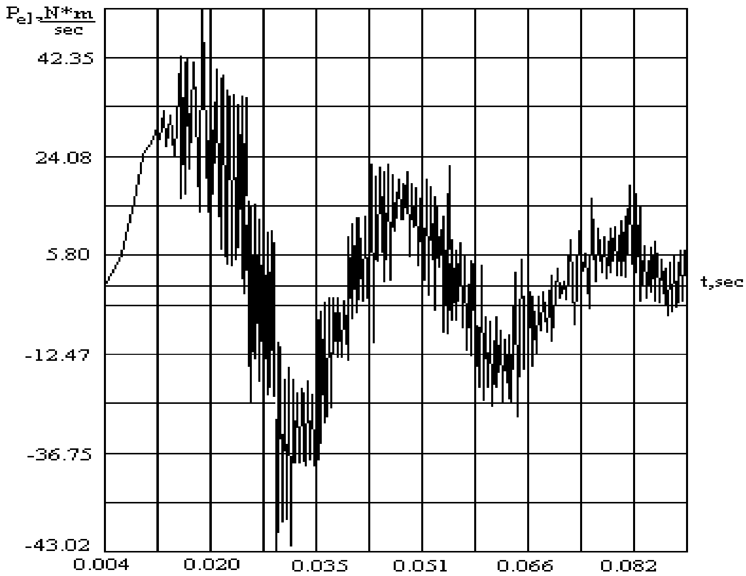

Figure 3. The electromagnetic dynamic capacity

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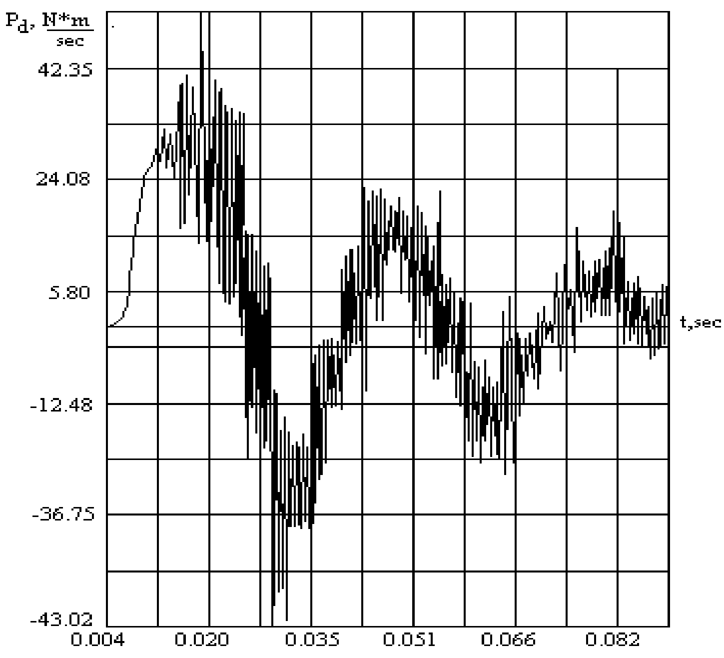

Figure 4. The mechanical dynamic capacity

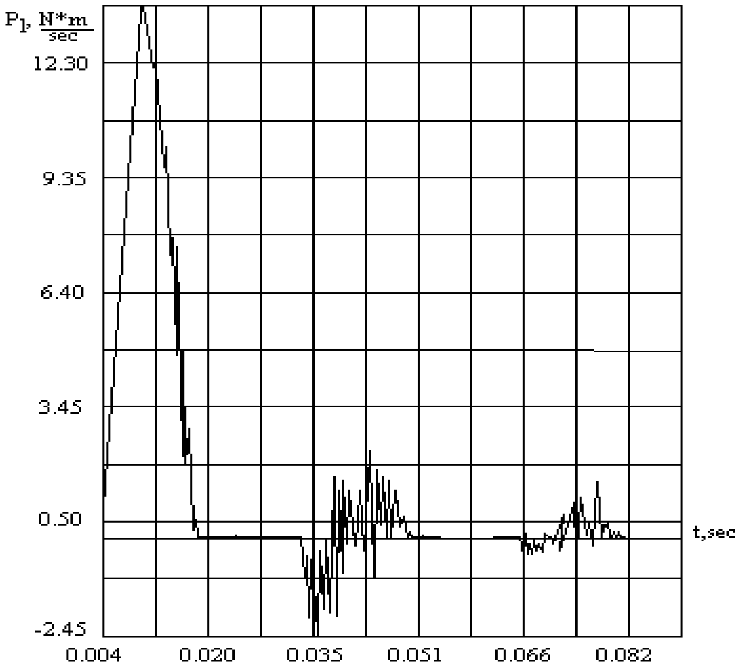

Figure 5. The dynamic loss in rotor winds

$$M_0(\omega) = M_{const} + a \cdot (\omega - \omega_{work}) \,. \tag{9}$$

6. In a broad range of angular velocities the torque is connected with an angular velocity by dependence, near to quadratic.

$$M_0(\omega) = b \cdot \omega^2 \,. \tag{10}$$

7. For generalization of models of self-braking (8), (9), (10) can be uses model based on

$$M_0(\omega) = M_s + (M_{nom} - M_s) \cdot \left(\frac{\omega}{\omega_{nom}} \right)^n , \tag{11}$$

where n - parameter, which one depends on a construction of the mechanism or EM; n=1…2.

5 CONCLUSIONS

1. The new way of the mechanical characteristic of Electrical Drives and Electrical Machines determination is developed.
2. The basis of an offered way is the determination of the rotor inertia moment and moment of mechanical losses in function of angular velocity in *dynamic mode* of the Electrical Drives and Electrical Machines.
3. The application of an offered way permits to divide and to determine such characteristics: a Dynamic Moment and a Electromagnetic Moment, Mechanical Characteristic and the Electromagnetic Mechanical Characteristic, Mechanical Capacity and Electromagnetic Capacity, loss in rotor winds.
4. The block diagram of a Computer-Measuring System of the Mechanical Characteristics is offered.
5. Examples of experimental researches are shown.
6. The functional opportunities of the Computer-Measuring System need to be expanded for determination the MC, inertia moment J and moment of mechanical losses of various gears rotated parts.
7. On the basis of offered method the device was realized, which one has following characteristics

Table 1. Main technical characteristics

Name of characteristic	*Lower measurement limit*	*Upper measurement limit*	*Error, %*
Angular velocity	3 rad/s	314 rad/s	$\leq$ 1.5
Moment of inertia	$2.75 \cdot 10^{-4}$ kg·m^2	$4.43 \cdot 10^{-4}$ kg·m^2	$\leq$ 1.5
Dynamical moment	0.1 N·m	30 N·m	$\leq$ 2.0

NOMENCLATURES

M_d - moment on a shaft
M_0 - moment of mechanical losses
M_{el} - dynamic electromagnetic moment on a shaft
M_s - start moment
P_{el} - electromagnetic dynamic capacity
P_m - mechanical dynamic capacity
P_l - loss in rotor winds
J - rotor inertia moment
J_m - reference inertia moment
ω - rotor angular velocity
ω_s - rotor angular velocity in start-up mode
ω_{b1} - rotor angular velocity in self-braking mode without a reference inertia moment
ω_{b2} - rotor angular velocity in self-braking mode with a reference inertia moment
ε_s - rotor angular acceleration in start-up mode
ε_{b1} - rotor angular acceleration in self-braking mode without a reference inertia moment
ε_{b2} - rotor angular acceleration in self-braking mode with a reference inertia moment
s - sliding
t - time

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