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DYNAMIC CHARAKTERISTICS OF ASYNCHRONOUS MOTOR IN STEADY-STATE REGIME

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Abstract: *The paper presents experimental results and mathematical modeling aimed to describe complex machine aggregates working under dynamic conditions.*
From parameters obtained experimentally the generalized Kloss characteristics is derived for nominal operational speeds of 1,450 min^{-1}, 1,000 min^{-1} and 750 min^{-1} under sinusoidal excitation. The steady-state motion is conveniently reinterpreted as an ellipse centered at the working point. Working point is given as the intersection of moment characteristics of the asynchronous motor with the loading characteristics of DC motor with separate excitation. The results of measurements show, that it is necessary to consider the linear dynamic characteristics especially for dynamic response computations near to the resonance.
Key words: dynamic characteristics, dynamic testing, asynchronous motor, critical moment

1. INTRODUCTION

Experimental stand with the possibility of dynamic loading of machine aggregates and mechanisms (Fig. 1) enables to simulate various cases of dynamic loading regimes with prescribed static and dynamic characteristics corresponding to production technological processes such as are the rolling, cutting, shearing, pressing, etc. The stand can be used for laboratory testing, production testing and examination, life testing and general tests of arbitrary mechatronic system or of mechanical subsystems as are the gears, couplings, clutches, shafts, motors, etc.[1].

Another application is the investigation of energy and information flow through the electrical, pneumatic, hydraulic or mechanical subsystems of mechatronic system. Under mechatronic system we mean the integration of the electromechanical power subsystem with the electronic control subsystem to provide optimal regulation of the technological process or to provide optimal dynamic regime of the aggregate.

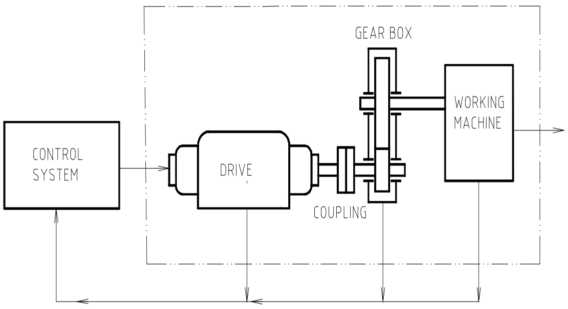

Fig. 1. Outline of the dynamic stand

2. EXPERIMENTAL STAND

Experimental stand for dynamic loading of machine aggregates enables to investigate the influence of parameters of the aggregate on unevenness of the angular velocity $\omega(t)$ or of the driving torque $M(t)$ (Fig. 2). Also it is possible to obtain the dynamic characteristics of the machine aggregate in steady-state or in transient regime in the form of relationship $M(\omega)$. The stand can be helpful in assessment of capability of tested machine with respect to operational reliability, working accuracy and overall efficiency [2].

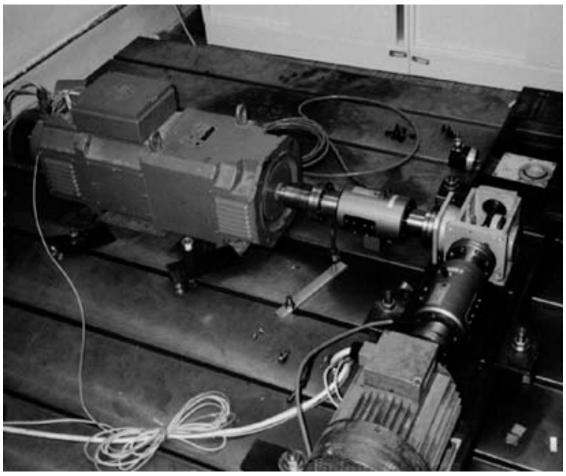

Fig. 2. Dynamic testing stand detail

2.1 The structure of the experimental device

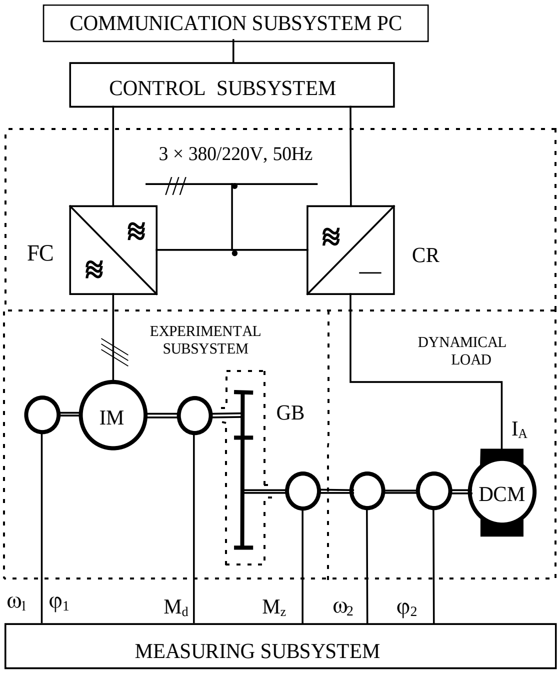

Fig. 3. The configuration of the dynamic load simulator

Following subsystems (Fig. 3) build up the experimental stand [3]:
- power subsystem on input (e.g. tested drive)
- transmission subsystem (e.g. tested gear, clutch, shaft)
- loading subsystem with options for active or passive loads
- control subsystem with it`s own sub-systems, like the measuring subsystem including relevant sensors of velocity, posi-tion, torque or of electrical quantities, the regulating subsystem with software gover-ning the control computer system
- communication subsystem working on line or off line.

2.2 Dynamic loading subsystem

The dynamic loading subsystem consists of rectifier and motor, working in both directions of energy flow between the DC motor and the supply mains.

Dynamic properties of the load are achieved by dynamic change of the armature current, for example by constraining the current in the regulating loop of the rectifier [3]. Block diagram of dynamic load simulator (Fig. 4.) includes the model of DC motor with position or velocity regulation of the load. When compared against the conventional solution, the innovation applied here is the software-controlled cur-rent restriction to achieve the desired time profile of the load. DC motor is operating in braking regime and the software-control incorporated provides the loading of the experimental subsystem by a torque with pre-selected time evolution.

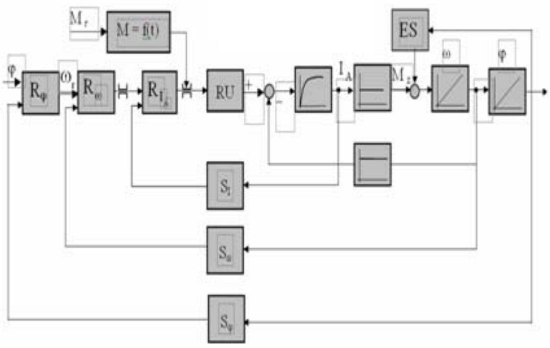

Fig. 4. Block diagram of the dynamic load simulator

The interface between the simulator and subsystems is provided by PLC-unit, which is communicating with the control PC via control unit RSKI and at the same time provides analog signals to converter feeding the motor. The nature of the regulation of the converter is thus indirect digital-analog.

2.3 Options of experimental stand

The technological process is simulated by software-controlled load provided by DC motor DCM (Fig. 5). Tested mechatronic system is, for example, a gear G. Driving equipment is simulated by asynchronous motor IM, which can be used to test the capability of the equipment or of the operating cycle of the technological process. In Fig. 5 FC stands for frequency converter, IM for asynchronous motor, G for gear, T_1, T_2 for torque transducers, φ for position sensor, ω for velocity sensor, DCM for loading equipment (for example, DC motor), A/D for AD converter, CC for control computer, CR for controlled rectifier and PC for the communicating computer.

The input of the gear under test is driven by frequency controlled asynchronous motor. The output of gear is connected to DC motor with controlled rectifier in inverter regime.

The converter is controlled by current regulator with generator of pre-selected wave form of the control voltage. The actual wave form corresponds to the desired time profile of the dynamic loading torque, applied to the gear.

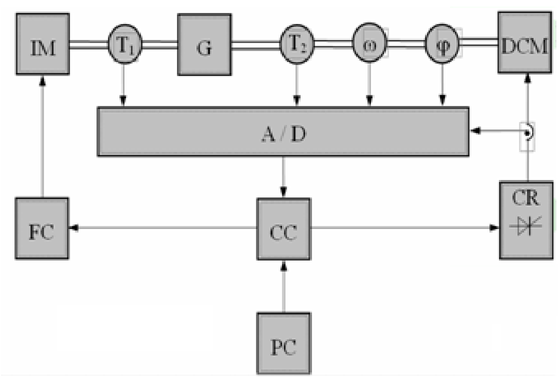

Fig. 5. Block diagram of computer controlled stand

Dynamic loading moment can be defined as function of time or as function of the shaft position. As the technological loads are in most cases periodic in time, in the measurement of spiroid gear the time dependence was used.

The time evolution of the moment can be given as discrete sequence of values defined by user or it is possible to select one of predefined forms with user adjusted parameters. Standard wave forms are rectangular (Fig. 6), triangular (Fig. 7), saw-form (Fig. 8), sinusoidal (Fig. 9) or static and can be described [4] as follows:

a) rectangular form – generated for example in metallurgical processes, vibrating equipment, in semi-automats for cold forming, etc.

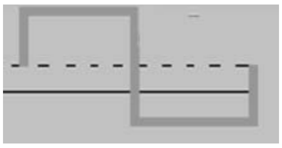

Fig.6. Rectangular wave form of aggregate load

b) triangular form – characteristic for milling machine, planning machine, shaper, etc.

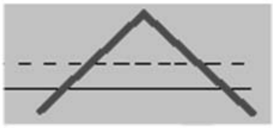

Fig.7. Triangular wave form of aggregate load

c) saw-form – appears with rotating excavators, various cutting machines, etc.

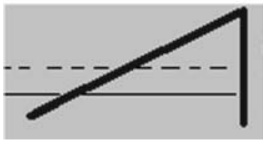

Fig.8. Saw wave form of aggregate load

d) sinusoidal form – steady harmonic load

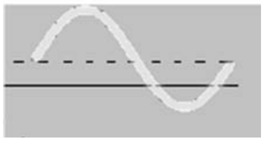

Fig.9. Sinusoidal load of aggregate

e) static load – the user can define the loading profile as combination of hyperbolic, constant, linear and quadratic terms, so that $M_z(\omega)$ is function of the angular velocity ω in the form

$$M_z = K_{-1}\omega^{-1} + K_0\omega^0 + K_1\omega^1 + K_2\omega^2, \quad (1)$$

with user defined constants K_{-1}, K_0, K_1 and K_2.

3. STEADY-STATE UNDER PERIODIC LOAD

Variation of parameters of aggregate (the inertia moment, fluctuating loads) gives rise to overall vibration, for which the unevenness of both the angular velocity and the driving torque is typical [5]. As a result, the steady state appears in the form of the steady state motion (Fig. 10).

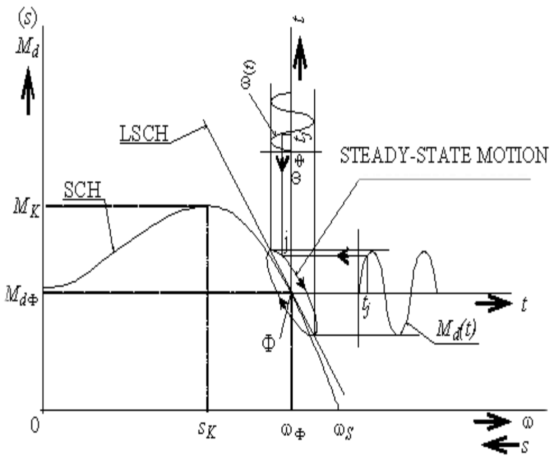

Fig. 10. Steady-state motion of the machine aggregate

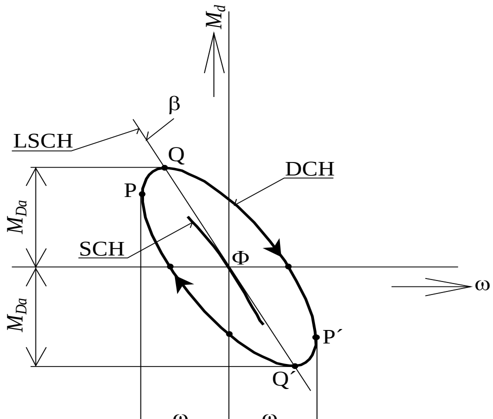

Fig.11. Dynamic characteristics

The steady-state motion is characterised by closed trajectory of the form of an ellipse, depicted in detail on Fig. 11 together with it`s characteristic points and with the corresponding linear static characteristics LSCH. Linear static characteristics is defined as tangent line at the working point Φ.

4. EXPERIMENTAL MEASUREMENT

For analysis of dynamic properties of drives those properties are of importance, which influence the relations between input and output parameters of the motor.

No.	n_d = 750 [min^{-1}]		
	M_d [Nm]	n_d [min^{-1}]	s
1	11.40	0	1
2	12.10	75	0.90
3	12.80	150	0.80
4	13.70	225	0.70
5	14.40	300	0.60
6	15.10	375	0.50
7	15.40	450	0.40
8	15.50	465	0.38
9	15.30	525	0.30
10	13.90	600	0.20
11	9.80	675	0.10
12	6.80	712.5	0.05
13	5.03	720	0.04

Table 1. Measurement of static moment characteristics of asynchronous motor at speed *750 min^{-1}*

From measurement of the driving torque and of the slip (Table 1) the static moment characteristics of asynchronous motor was derived.

In general the static moment characteristics of asynchronous motor is described by the refined Kloss formula:

$$M_d^s = \frac{2M_{dk}(1-as_k)}{\frac{s_k}{s}+\frac{s}{s_k}+2as_k}, \qquad (2)$$

where s is the slip at the asynchronous speed, s_k is the critical slip corresponding to the critical moment M_{dk} and a is the ratio of working resistances of stator and rotor.

No.	n_d = 1 450 [min^{-1}]		
	M_d [N m]	n_d [min^{-1}]	s
1	11.18	0	1
2	11.85	75	0.95
3	12.22	150	0.90
4	12.64	225	0.85
5	12.95	300	0.80
6	13.58	375	0.75
7	13.94	450	0.70
8	14.25	525	0.65
9	14.73	600	0.60
10	15.15	675	0.55
11	15.67	750	0.50
12	16.13	825	0.45
13	16.32	900	0.40
14	16.51	975	0.35
15	16.61	1050	0.30
16	16.51	1125	0.25
17	15.46	1200	0.20
18	14.00	1275	0.15
19	11.39	1350	0.10
20	7.1	1425	0.05

Table 2. Measurement of static moment characteristics of asynchronous motor at speed *1450 min*$^{-1}$

The relation (2) was used to compute the characteristics for experimental results under sinusoidal loading with following detailed properties: n_d=*1000 min*$^{-1}$ (speed of asynchronous motor), M_{dk} = *16.1 Nm* (maximum moment), s_k = *0,23* (critical slip) and a = *0* (ratio of working resistances of stator and rotor).

Using the above measured parameters allowed to find analytical as well graphical presentation of the moment characteristics of asynchronous motor from Table 1 for rated revolutions n_d = *750 min*$^{-1}$ (Fig. 12) and from Table 2 for measurement at speed n_d = *1 450 min*$^{-1}$ (Fig 13).

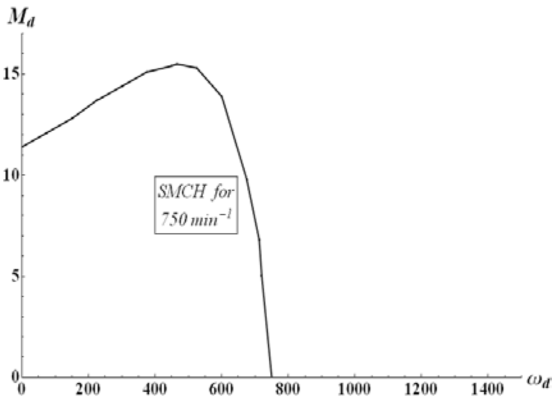

Fig.12 Static moment characteristics at rated revolutions n_d = *750 min*$^{-1}$

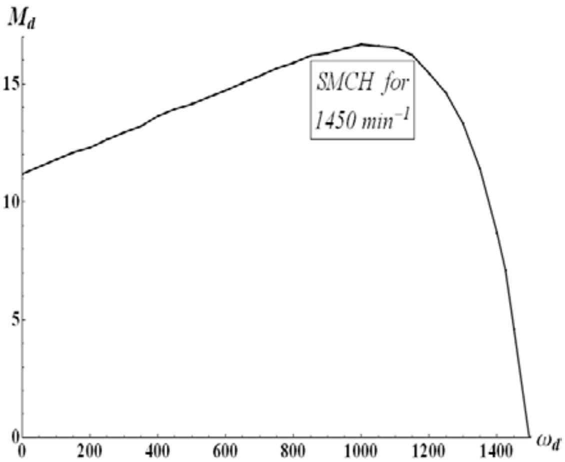

Fig.13 Static moment characteristics at the speed n_d = *1 450 min*$^{-1}$

The characteristics for the speed nd = 1,000 min-1 was computed using the Kloss relation. In Fig.14 all the three characterristics are compared.

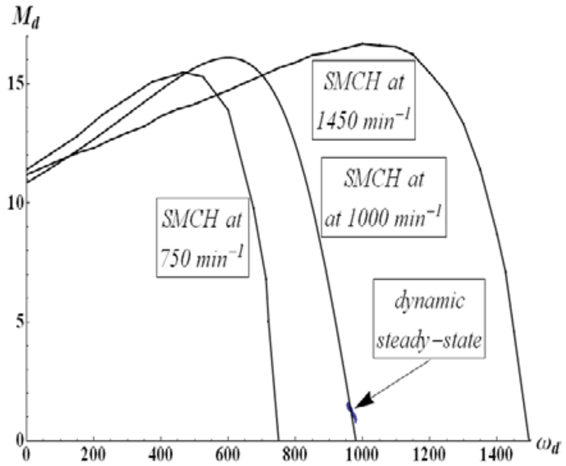

Fig. 14. Comparison of static moment characteristics of asynchronous motor

The working point $P(\omega_\phi, M_\phi)$ is the centre of the ellipse, corresponding to steady state motion. The working point is given as intersection of the moment characteristics of asynchronous motor $M_d(\omega_d)$ with the characteristics $M_z\ (\varphi_z,\ \omega_z)$ of the loading torque of the DC motor.

5. CONCLUSION

The inertia moment and fluctuating loads give rise to vibration of aggregates. Resulting from unevenness of both the angular velocity and the driving torque the steady state appears in the form of the steady state motion (Figs. 12 and 13). Electromechanical moment and the corresponding slip are of periodic nature and the asynchronous motor operates at the so called "dynamic steady state".

As no resonance is developed increasing the inertia moment, the static moment characteristics can be used for computations in case of aggregates with constant transmission ratio.

When the static characteristics is used in computations, than for low rotational speeds the computed amplitude of driving moment underestimates the real value and for high rotational speeds the computed amplitude overestimates the real value. Therefore at least for frequencies in the vicinity of possible resonance the linear dynamic characteristics should be used instead of the static characteristics.

6. ACKNOWLEDGEMENTS

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