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Experimental Investigation of Two-mass Electromechanical System

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***Abstract*—The paper describes the experimental stand construction of two-mass system, special construction of the speed measuring device. The results of experiments are presented. The speed measuring device is tested, substantiate suitability. The load torque range of first mass is analysed. The starting transients of the first mass at different loads are investigated experimentally. The transient responses of the speed and the torque are compared with simulated.**

***Index Terms*—Electromechanical systems, electromagnetic transients, induction motors, electromagnetic coupling.**

I. INTRODUCTION

Electromechanical system as object of investigation comprises electrical and mechanical parts. Electromechanical power converter and its control system depend to on electrical part as well as all moving masses coupled between them form mechanical part. Electromechanical system includes various mechanical chains, with infinite or finite elasticity and clearance. Systems with infinite stiffness and without clearance compose single-mass system and are quite well analysed. Systems with capable to deform chains are more complex. They are described by high order nonlinear differential equations, and without essential simplifying of problem they cannot be solved in analytical way. In these cases computer models for problem solving must be developed, using specialized software, and system responses simulated. Some problems of two-mass system were considered in [1]–[5].

The results of computer simulations must be experimentally confirmed. Afterwards computer models of two-mass system can be used for complex modelling, be adapted for various control systems that reduce the negative influence of component of transient responses.

The paper presents the description of experimental two-mass system stand design, design of speed measuring device. In this paper speed and torque step responses with a different load is considered too.

II. DESIGN OF EXPERIMENTAL TWO-MASS SYSTEM STAND

Two-mass experimental system stand is designed to measure speed and torque responses of the first mass and to change the load.

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In the physical construction, an induction system consists of mechanical and electrical parts. Mechanical part consists of rotating elements. They are interconnected by the special chains which have elasticity and potential clearance. The electrical part consists of supply, brake and measuring devices.

Induction motor with squirrel-cage rotor is the first mass of system. The second induction motor with the same parameters serves as the load of the first mass. Parameters of both induction motors are presented in Table I.

TABLE I. PARAMETERS OF THE MOTOR.

Motor power, *kW*	**Number of pole pairs**	**Phase voltage, *V***	**Power factor**	**Rated torque, *N·m***	**Rated current, *A***	**Inertia, *kg·m²***
1,5	2	230	0,81	2,4	3,45	0.0033

The second mass characterizes rotor inertia of the second motor. Different load should be developed during experiments; therefore the second motor is supplied by frequency converter. Frequency converter supplies the motor for rotation in inverse direction than the main motor rotates. In this way the load of first mass can be changed by changing frequency of the converter.

Torque and speed meter is mounted between induction motor for measuring of torque and rotational speed. Torque meter has analogue output signal proportional to measured torque, also the meter has a pulse output signal with a frequency proportional to the rotational speed. Frequency-voltage converter is designed for measurement of pulse rate change. Measured output voltage of the converter reflects speed transient responses.

High-precision double-circuit couplings are used to connect motors and torque meter. The couplings have low elasticity and clearance can be ruled out.

The designed experimental stand part consists of universal power supply source and measurement devices. Power supply source supplies torque meter and speed measurement device. The transient responses are measured with oscilloscope Fluke 199B.

One of possible two TTL signals is used to measure the speed of torque angle meter. At one shaft turn 360 pulses are formed. The signal converter should be designed, which changes pulses frequency to voltage for measuring the speed. For this, a special chip is used.

The synchronous speed of motor and the amount of pulses per one shaft turn is known. Pulse frequency when motor rotates at synchronous speed is calculated as seen in (1)

$$f_s = \frac{n_s}{60} \cdot n_A = \frac{1500}{60} \cdot 360 = 9000 \quad \text{Hz}, \tag{1}$$

where f_s – synchronous frequency; n_s – synchronous speed; n_A – amount of pulses per one shaft turn.

We should consider the fact, that the motor speed in transient responses may be higher than synchronous speed. Therefore output signal should have the margin. It is assumed, that measured speed range one and a half time higher as synchronous is sufficient. Supply voltage of used microchip is V_{cc}=15 *V*. According to the description of microchip, the maximum output signal can also reach V_{maks}=15 *V*. The maximum measured frequency f_{maks} is calculated according to desired value with a margin as seen in (2)

$$f_{maks} = 1{,}5 \cdot f_s = 1{,}5 \cdot 9000 = 13500 \quad \text{Hz}. \tag{2}$$

Converter plate is constructed under the scheme shown in Fig. 1.

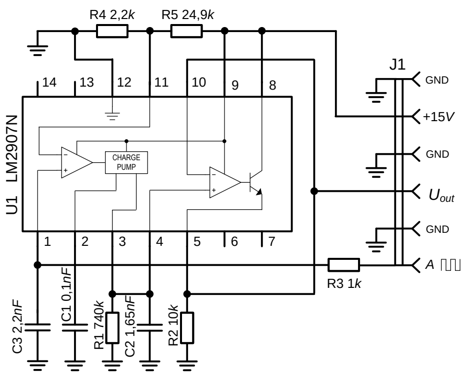

Fig. 1. Wiring diagram of speed measuring device.

The desired measuring frequency is set by chosen capacitor C1 and resistor R1. According to the recommendations for microchip capacitor *C*1=0.1 *mph* is selected. Resistance is calculated according to the formula as seen in (3)

$$R1 = \frac{1}{f_{maks} \cdot C1} = \frac{1}{13500 \cdot 1 \cdot 10^{-10}} = 740 \quad \text{k}\Omega. \tag{3}$$

The elements R3 and C3 are used to filter the input signal disturbances. The elements R4, R5 are required to set the comparator voltage level of microchip, at which the input pulse is identified.

The accuracy of used elements is low therefore it is necessary to test the board experimentally for getting of the output exact characteristics. Measuring card is made and tested. The frequency pulse generator is connected and set the pulses amplitude corresponding to the amplitude of torque angle meter output signal. The board is tested by changing the frequency of the pulse generator. The output signal curve is plotted according to the test results. It is shown in Fig. 2.

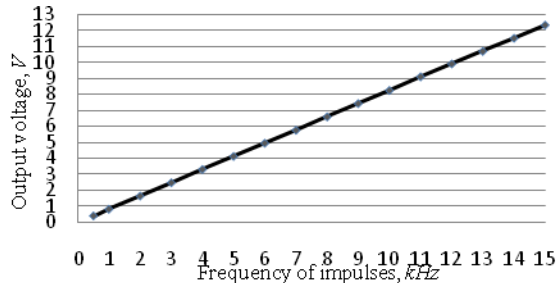

Fig. 2. Characteristic of speed measuring device.

Angular speed ω is calculated by formula as seen in (4)

$$\omega = \frac{f \cdot 1000}{360} \cdot 2 \cdot \pi. \tag{4}$$

According to the characteristic, proposed linear equation can be used for calculated of speed at any point as seen in (5)

$$f = 1{,}2158 \cdot U_{out} - 0{,}0311. \tag{5}$$

The results indicate that the device characteristic in the desired output frequency range is linear; therefore it is suitable for speed measurements of the test stand.

Mounted experimental stand is shown in Fig. 3.

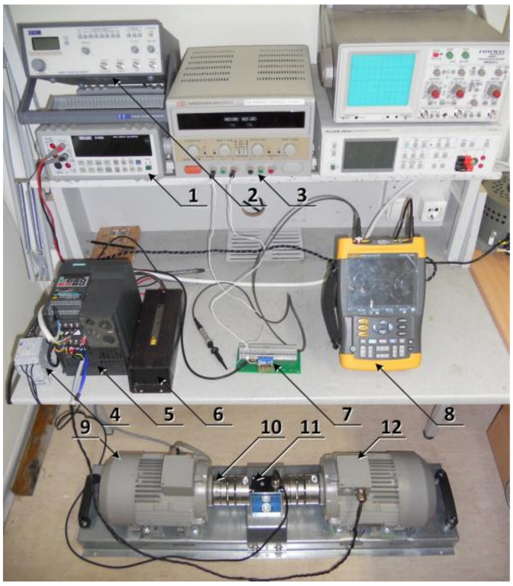

Fig. 3. View of two-mass system experimental stand: 1 – multimeter; 2 – frequency generator; 3 – power supply unit; 4 – contactor; 5 – frequency converter; 6 – braking resistance; 7 – speed measuring device; 8 – oscilloscope „Fluke“; 9 – main motor corresponding to the first mass; 10 – double-circuit coupling; 11 – torque meter; 12 – load motor as the second mass.

III. SIMULATION RESULTS

In this study an experimental stand was investigated. The first (main) motor is connected directly to the network; contactor for fast switch on is used. The second motor rotating in the opposite direction than the first motor is connected to the converter with braking resistor. The frequency converter, supplying the second motor by determinate frequency of voltage, changes its speed and in this way the load of the first motor is produced.

Tests were performed to investigate the main motor starting transient response. In the experiment, the second motor rotates at a constant speed set by frequency converter and then the main motor is switched on. Several tests with different second motor speeds were performed, which were set by the frequency 0 *Hz*, 10 *Hz*, 20 *Hz*, 30 *Hz*, corresponding to developed load of 0 *N·m*, 2,2 *N·m*, 5,3 *N·m*, 7 *N·m*. The test, when the second motor load is 0 *N·m*, corresponds to no-load two mass system. Transient response is influenced only by the inertia of the second mass. The test provides the speed meter output voltage dynamic characteristics. The test graph is stored in a digital form using the oscilloscope computer software package. The test data of voltage is proportional to motor speed, so using (4) and (5), the data is converted into radians per second. Graphs are plotted using software package *Microsoft Excel* and their comparison is presented in Fig. 4.

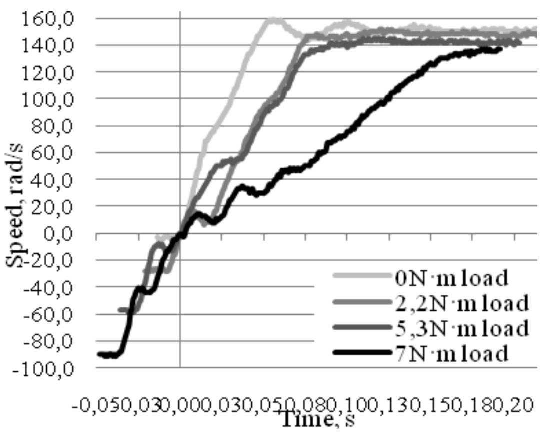

Fig. 4. Comparison of speed values of induction motor in experimental two-mass system with different load.

Analysis of the curves shows that during the starting the initial steady state speed of the second mass (second motor) presents. Initial part of the curves show second mass breaking mode until it reaches zero speed then direction of rotation changes and first motor begins dominate. Curve obtained at 0 *N·m* load is very similar to that obtained by modelling the single mass system [2], [5], especially at steady state speed. However, oscillations are visible during acceleration, which are similar to obtained transient response by modelling of the two-mass system with elasticity [5]–[8]. This happens because the coupling of masses elasticity. As precision couplings with low elasticity were used, therefore oscillations are small.

Comparison of curves indicate that with increasing load, transient response settling time rises as were observed in simulation experiments [7], [9] and starting oscillations increase, however, after reaching the rated speed, the oscillations begin to decrease. It can be supposed, as is observed in [5] that happens because coupling of masses. The second mass is the load of the main motor; therefore rotation of the second mass determines change in the load and in this way can be obtained the operation mode in which the elasticity of the system reduces the oscillations.

Comparison of transient responses of torque with the same load is shown in Fig. 5.

Comparison the torque curves indicates that at no-load mode, after settling time, torque is close to zero, while at other load values the torque reaches load torque value. With greater load appear repetitive oscillations of longer duration, although their maximum value is not very different. Comparing these results with the simulation results [2], significant similarity with transient response curve of two - mass system with elasticity is seen.

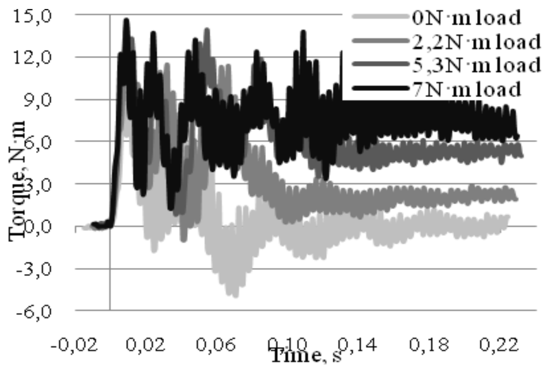

Fig. 5. Comparison of torque values of induction motor in experimental two-mass system with different load.

Obtained torque curves have component of high frequency noises, which is not observed during simulation and that happen due to frequency inverter. For detailed analysis the curves with periodic oscillations is convenient to approximate. Because the curves are constructed from the points of values in time domain, value of each point is approximated by adding to these values of two adjacent points and dividing by their sum. Approximated transient responses of torque are shown in Fig. 6.

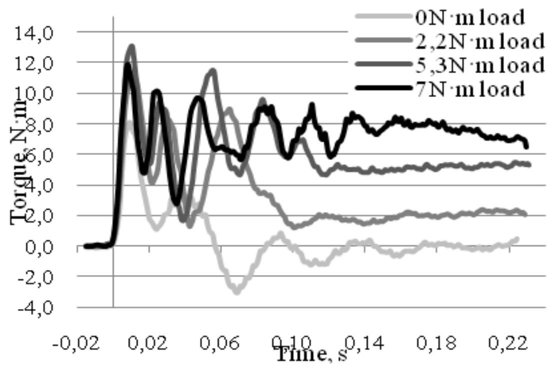

Fig. 6. Comparison of torque extrapolated values of induction motor in experimental two-mass system with different load.

Fig. 6 indicates more significant oscillations either during transients, or also at the steady state mode. The test at load of 7 *N·m* shows the steady state torque value close to maximum value of the oscillations, indicating, that was approached the maximum possible load. Comparison with the simulation results [2], [6], gives that the first maximum value of torque is different and that can be explained in this way: simulation results show produced electromagnetic torque, while the experimental results present the shaft torque. Besides that, the simulation model is developed under the estimated real motor parameters errors. However, comparing simulation and experimental results gives important possibility to understand and clarify the nature of the torque variation and its influence on different operating modes.

Therefore, application of various control system tending to improve the transient response during simulations, can be applied for real two-mass system and the same applied control principles will make the same impact on real system.

IV. CONCLUSIONS

The elaborated experimental stand allows investigation of dynamic processes of the two-mass system; perform experiments at different operation modes, changing the load or the type of second mass.

Designed the speed measuring device allows accurate measuring of the motor shaft rotating speed. Large amount of pulses per one turn allows accurate measuring of dynamic processes.

Experiments have been confirmed the simulations results of transient responses at different load; they are confirmed influence of elastic coupling of mass. With increasing of load, settling time becomes longer and decreases the steady state value of speed. For higher loads because elasticity of coupling higher frequency oscillations appear during transients but they reduce with speed approaching to steady state.

Experimental results of torque in dynamics mode are similar to that obtained during the simulations. The amplitude of torque transient response is different because simulation produces electromagnetic torque, and the experimental investigation results gives shaft torque, also the simulation model is underestimating the real motor parameter errors. However, the experiments and simulation show oscillations at the dynamic mode.

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