

Station for Emulation of Load and Electrical Motors Testing

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Abstract – This paper presents realized station for testing of electrical motors. Station has two main parts: Emulator of load and part for control and monitoring of the whole system. Emulator is a calibrated electromagnetic brake. Emulator can emulate different types of load, like gravitational, linear, fan and compound load, which is combination of first three. Control of emulator and monitoring of motor parameters during testing is realized with Compact RIO controller. Graphical user interface is realized in LabVIEW. Results obtained during motor testing, are shown at the end, and compared with the MATLAB simulated results.

Keywords – Electromagnetic brake, Emulator, Compact RIO, motor, LabVIEW, electrical motor.

I. INTRODUCTION

Testing of electrical induction motors (IM) in laboratory environment requires different types of tests. Crucial tests for testing the IM in laboratory are no load and short circuit load tests in accordance with standard EN 60034-2-1. These tests provide parameters of equivalent circuit of IM, losses and efficiency [1] [2]. No load and full load tests present only two limit points of work regime of IM. It would be very useful if IM could be tested in whole working range, thus we would have real state of IM in its normal work regime. For testing the operation of IM in work environment there are two methods. First one is to test machine on the site, and second one is testing machine in test station. IM drives pumps, fans, cranes and many other working machines, so it is a common case that IM cannot be tested on the site. If we want to test IM like it was in real industrial surrounding we need to connect it to a working machine, which is complicated and expensive process. In order to overcome these problems we can emulate load, so the IM “sees” the load like fan, pump or some other type of work machine. With emulator we have different types of loads in one machine.

In Laboratory for electrical machines and drives on Faculty of Technical Sciences in Čačak, this type of emulator for electrical motors was realised for powers up to 7,5kW [3].

II. MAIN PARTS OF THE EMULATOR SYSTEM

In the next figure (Fig. 1) is shown complete system with all components.

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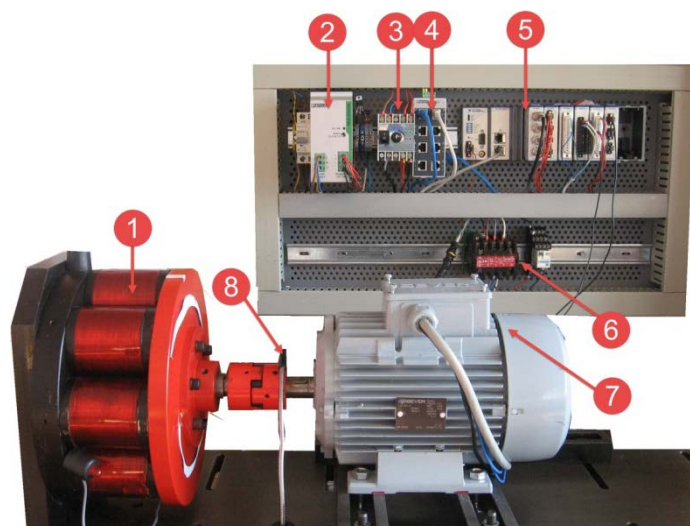


Fig. 1. Emulator system

1. Electromagnetic brake
2. DC power supply
3. Amplifier for Pulse Width Modulated (PWM) signal
4. Ethernet switch, for remote access
5. Compact RIO controller (cRIO)
6. Contactors equipment
7. Motor under the test, induction motor, 1.1kW, 920 rpm
8. Speed sensor

A. Electromagnetic brake

The main parts of the electromagnetic brake are: stator and rotor. There are eight electromagnets on the stator. Each electromagnet has 700 turns of Cu wire for currents up to 10 amperes. Air gap between stator and rotor is about 0.8 mm. There are two types of disk for the rotor, one of iron and one of aluminum. Electromagnetic brake is projected for torque up to 100Nm. In the Fig. 1 on the left side, electromagnetic brake with its main components is shown.

Electromagnetic brake is calibrated with a DC motor whose torque diagram is known [3]. Equations, which are obtained during process of calibration, are implemented in real time controller [4]. Desired torque is achieved by measuring speed of shaft rotation, and with PID controlled current through windings. The required current for actual speed is calculated from implemented equations. Desired torque is achieved with current feedback, and there is no need for using an expensive torque sensor.

B. Compact RIO controller

Control of electromagnetic brake is realized with National Instruments controller cRIO 9074. This integrated system

combines a real-time processor and a reconfigurable field-programmable gate array (FPGA) within the same chassis for embedded machine control and monitoring applications. It integrates a 400 MHz industrial real-time processor with a 2M gate FPGA and has eight slots for I/O modules [5-7].



Fig. 2. cRIO controller with modules

The system is commonly programmed by using LabVIEW software and can be used in a wide variety of applications for monitoring and control in real-time [8]. Controller with modules is shown in Fig. 2.

C. I/O modules

cRIO provides direct hardware access to the input/output circuitry of each I/O module using LabVIEW FPGA elemental I/O functions. Each I/O module contains built-in signal conditioning which are ready for direct connection to industrial sensors and actuators. Following modules are used for emulator:

- NI 9402 – fast 100ns, 8 channel bidirectional module for generation of PWM 5V/TTL level signal.
- NI 9403 – fast 55ns, 4 channel bidirectional module is used for acquisition of 5V digital signals from speed sensor.
- NI 9225 – 3 channel analog input module, measurement range of 300V RMS, 24 bit resolution, 50kS/s is used for measuring motor voltage
- NI 9227 – 4 channel analog input module, measurement range of 5A RMS, 24 bit resolution, 50kS/s in combination with current transformers is used for measuring motor current.
- NI 9211 – 4-Channel, 14 S/s, 24-Bit, ± 80 mV thermocouple input module is used for measuring of motor and brake temperature.
- NI 9476 – 32 channel, 500 μ s digital output, 6 to 36 V output range (based on supplied voltage), sourcing 250 mA/ch is used to turn on/off motor and brake power supply.

D. Sensor for speed measuring

Digital unipolar HALL sensor is used for measuring the speed of motor – emulator shaft. The magnet ring is placed on the motor shaft. In this way, problems with encoder - motor shaft coupling were overcome. HALL sensor TLE 4905L [9] is a cheap solution.

E. PWM amplifier

Control of brake current is realized with pulse width modulation. Connection between module 9402 and brake is made with PWM amplifier. PWM amplifier is a simple module with a FET transistor which works in a switching regime. Signal from module 9402 directly turns on and off current throw windings. Frequency of PWM is set to 1 kHz but it can be changed easily.

F. Emulator software

Complete software part of Emulator is realized in LabVIEW. Graphical user interface consists of four tabs. These tabs are shown in Fig. 3. Name of the first tab is *PID current* and in this tab user can tune PID parameters of brake current and watch response in time chart diagram Fig. 3.a. In second tab *PID speed*, the user can tune speed loop. Third tab *Load Emulator* is the main part of application and the user can choose between different types of load here. Forth tab is a monitoring tab in which user can watch and record motor and emulator parameters, like voltage, current, temperature etc.

III. LOAD EMULATOR

After the user sets up PID parameters for current control, the user can access the tab called Load Emulator which is presented in the Fig. 3. C. This tab consist of two parts, block with parameters for emulation of load on the left side and torque speed diagram on the right side. Emulation of load is realized with equation (1) [3]:

$$M_k = k_1 n^2 + k_2 n + k_3 \quad (1)$$

Between four options, of types of loads, from dropdown menu: the user has to choose one: gravitational, linear, fan or compound. When the user chooses gravitational type of load coefficients k_1 and k_2 are automatically set to zero so the torque is equivalent to coefficient k_3 . If user chooses fan type of load than torque changes with square of the speed with coefficients k_2 and k_3 set to zero. Compound type of load is combination of gravity, linear and fan type.

IV. INDUCTION MACHINE IN “UNSTABLE” PART OF TORQUE-SPEED DIAGRAM

System, induction motor – load, usually defines operating point on linear, stable, part of the torque-speed characteristic. Due to load variations, which may occur during operation with induction machine, it is very important to know maximum available torque (breakdown torque) and overload coefficient. For loads greater than maximum available torque motor enters the unstable, nonlinear part of torque-speed characteristic. In this part of the characteristic it is usually impossible to achieve a stable operating point and motor slows down.

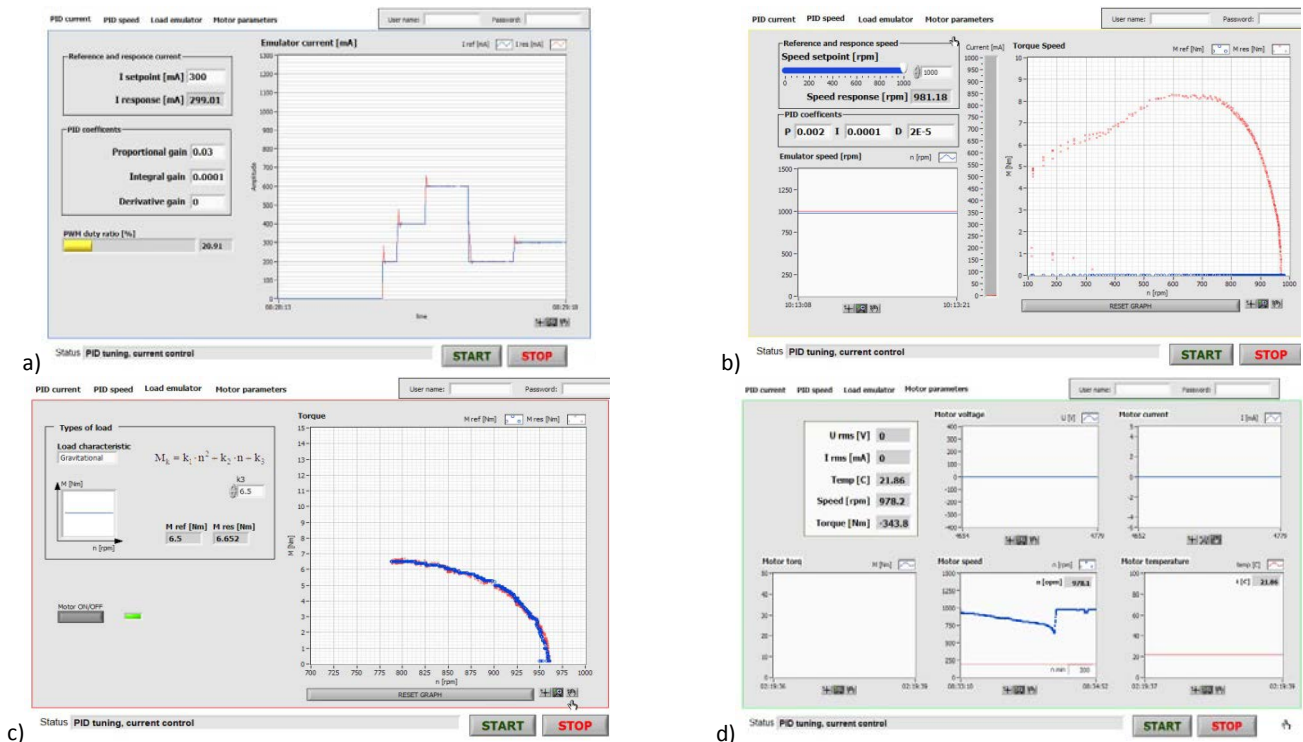


Fig. 3. Graphical User Interface tabs: a) PID current, b) PID speed, c) Load Emulator, d) Monitoring

The analysis and examination of this unstable part of the characteristic (where the slip is greater than the breakdown slip) is usually based on mathematical simulations. However, with this testing platform (with load emulator) testing induction motor in the “unstable” part of torque-speed characteristic can be achieved. The software’s speed loop allows us to define the motor speed and the load required to meet the required speed. In this way it is possible to define the motor speed corresponding to the unstable part of the characteristic, which will define operating point of the machine. In this case, load emulator acts as an adaptive load that allows stable operating point on unstable part of the characteristic. This enables analysis of the induction motor at speed range from zero to breakdown speed and validation of mathematical simulation models of the motor. Results of testing induction motor of 1.1kW as well as simulation results are shown in following.

Induction motor parameters obtained from short circuit and no load test are shown in TABLE I [10].

TABLE I – 3 phase AC 1.1 kW Motor ATB SEVER parameters obtained from short circuit and no-load test

U_{01} (V)	R_1 (Ω)	R_m (Ω)	$X_1=X_{2(L)}$ (Ω)	X_m (Ω)	$R_{2k(L)}$ (Ω)
100	7.1	11.76	5.9723	94.64	5.7001
200	7.1	8.209	5.9723	93.88	5.7001
300	7.1	5.97	5.9723	84.1	5.7001
400	7.1	3.833	5.9723	60.96	5.7001
380	7.1	4.455	5.9723	63.76	5.7001

Software for plotting torque-speed curves of induction machines [11] is used to simulate characteristics of the motor (Fig. 4)

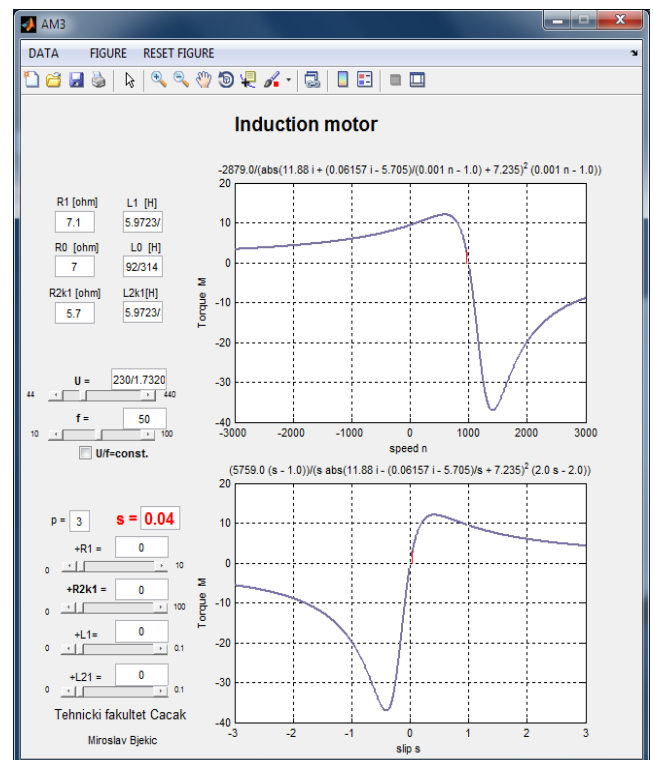


Fig. 4. Software for plotting static torque-speed curves $M=f(n)$

Simulated torque-speed characteristics of three phase induction motor (with nominal values given in TABLE II in the Appendix) are given in Fig. 5 with respect to the values given in TABLE I.

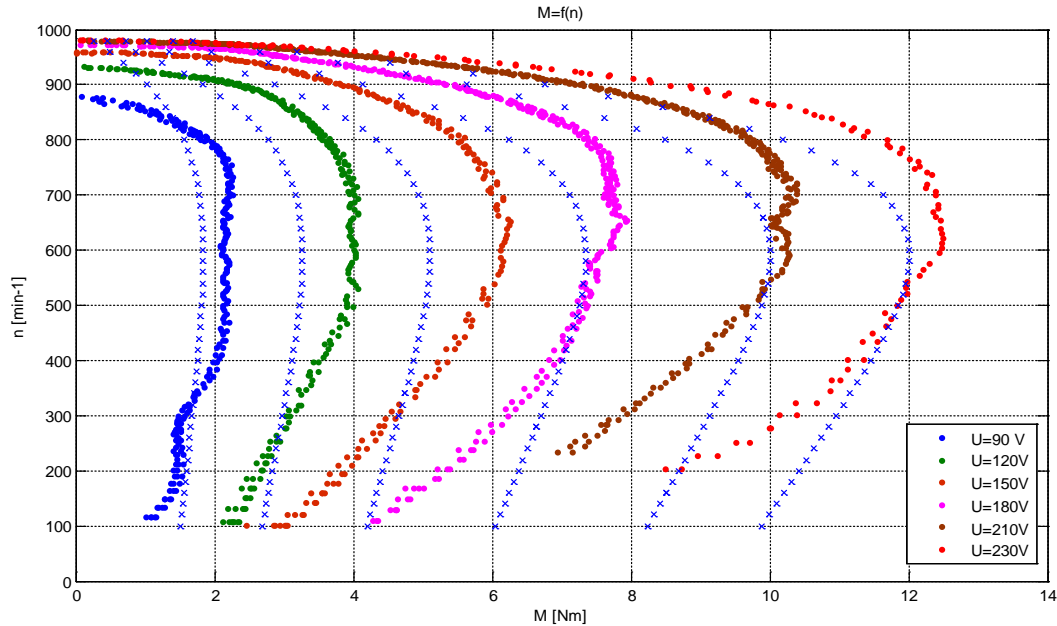


Fig. 5 – Simulated and measured results of static torque-speed characteristic.

Fig. 5 shows simulated and measured results of static torque-speed characteristic. It can be noted that measured values are not completely match with simulated values. Differences are the result of idealized conditions and omissions in the mathematical simulation model on one side, and calibration accuracy of electromagnetic emulator on the other side. Accurate results for torque-speed characteristics can be expected with electromagnetic brake calibrated with torque sensor

V. CONCLUSION

This paper presents a platform for load emulation of electric motors up to 7.5kW. Main part of the platform is electromagnetic emulator of load that can ensure application of the continuous load to the motor. Graphical user interface is realized in LabVIEW and allows easier control and setting the load reference and visualization of measured motor quantities. Motor can be tested and examined in unstable part of torque-speed characteristic due to implemented speed loop. The simulation results and measured results are close, which makes basis for further work and development on the platform for testing electric motors.

VI. APENDIX

TABLE II – 3 phase AC Motor ATB SEVER nominal values

U_n (V)	I_n (A)	f_n (Hz)	n_n (rpm)	P_n (kW)	n_s (rpm)	$\cos\varphi$
380	3.5	50	920	1.1	1000	0.7

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