Determination of the Torque-Speed Characteristic of Induction Motor in Electric Machinery Education

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Abstract - The paper describes the measuring method for determination of the torque-speed characteristic of an induction machine used in electric machinery classes performed at the Polytechnic of Zagreb. The torque-speed characteristic is determined by recording and differentiating speed signal during the starting. Data is gathered using a measuring system based on a simple digital acquisition card, and processed in custom software, built with LabVIEW, on a personal computer. Advantages and shortages of this sort of measurement compared with other measuring methods are given, and measuring equipment deployment and software development are described.

I. INTRODUCTION

The induction motor torque-speed characteristic gives information on the dependence of induced mechanical torque on mechanical speed. Sometimes this characteristic is called torque-slip characteristic, where slip is defined as speed relative to synchronous speed expressed as a fraction of synchronous speed.

Typical torque-speed curve of a squirrel-cage induction motor given in Figure 1 provides information about the operation of induction motor. The induced torque of the motor is zero at synchronous speed. The curve is nearly linear in normal operating conditions which are between pullout speed and synchronous speed [6]. Maximum possible torque the machine can induce is called the *pullout* torque or the *breakdown* torque and it limits the short-time overload capability of the motor [7]. It is usually two or three times the rated full-load torque of the motor. The starting torque of the motor is slightly larger than its full-load torque, so this motor will start carrying any load that it can supply at full power [4].

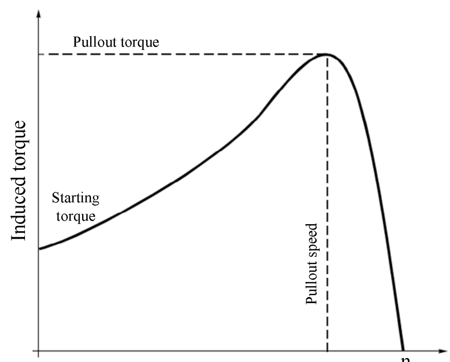

Figure 1. Typical torque-speed characteristic of an induction machine

The torque-speed characteristic is required in order to predict behavior of induction machines in electrical motor drives [1]. It should be measured as accurately as possible, while the selection of which method to apply depends on the characteristics of both the machine and the testing facilities [3].

Main scope of the paper is the implementation of a new measuring method into laboratory exercises and integration of two methods in one exercise. It shortly describes two of the methods outlined in IEEE standard test procedure for polyphase induction motors and generators [3], one of which had been used in the exercises, and the new one, recently included. Main technical aspects of the methods are described in the paper, as well as the deployment of the measuring equipment, development of the software needed for measurements and data processing, and the expected benefits in class.

II. LABORATORY EXCERSISES

Laboratory exercises are performed in the summer semester of the second year of study, after the students have taken the “Electrical machines I” course, and therefore have certain knowledge about electric machinery which enables them to be more self-confident in individual work in the laboratory. The subject is divided in six exercises which follow the classroom lectures, and help students gain better understanding through practical work with electric machinery and measuring equipment. All of the exercises are done in small groups of maximum seven students whose scope is to perform the tasks under the guidance of the teaching assistant. Each individual exercise lasts two academic hours during which students have to take notes which will be the base for reports they have to generate in order to successfully complete the course. Reports are based on the guidelines given in the printed material for all of the exercises. The concept of producing reports documenting work in the laboratory is an old and proven method in engineering disciplines education, especially because of the importance of technical reports in engineering. This was one of the guiding concepts in the integration of the new measuring technique, described later in the article, into existing program of laboratory exercises.

Torque-speed characteristic is the title and the central part of the report produced after the exercise described in this article. Students use measuring equipment under the supervision of the teaching assistant and, following his directions, and guidelines given in the manual, take notes and finally draw the torque-speed characteristic. As mentioned earlier, there are several methods for determination of the torque-speed characteristic of an induction machine. Four of them are described in [3]. The method that has been used so far is based on direct measurement of the torque and speed. Electric generator dynamometer is directly coupled to the tested engine. Dynamometer housing is made free to rotate and connected to the weight transducer by the torque arm. Speed is measured by inductive transducer mounted on the shaft of the dynamometer. The students control the load and the speed of the motor by controlling the field windings voltage of the electric generator dynamometer connected to a large resistor. Measurement is performed at reduced voltage maintained using a variable-voltage transformer. Equipment setup for this exercise can be seen in Figure 2.

Measuring points are taken depending on speed, ranged from locked-rotor to synchronous speed. Experience has proven a dozen points are enough, with preference of choosing more points in higher speeds range. Alongside speed, at each point the operator, i.e. the students, measure the torque, phase voltage, current, and real power. During the production of the report, in order to establish values of current, voltage and torque at rated values, the students need to calculate them from the values measured at reduced voltage. As the final goal of the report, the torque-speed characteristic, and the current as function of speed characteristic need to be drawn.

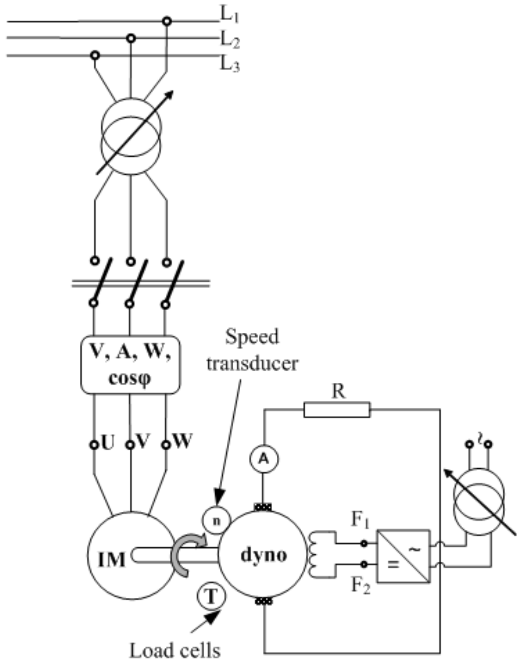

Figure 2. Equipment setup in laboratory exercises for direct measurement of the torque and speed

III. Implementation of the New Method

Another method for obtaining data for a torque-speed curve of an induction machine outlined in the IEEE Standard 112-1996 [3] is the Acceleration method. In this method the value of acceleration is determined at various speeds, and the torque at each speed is determined from the acceleration of the mass of the rotating parts. Torque is calculated as follows:

$$T = J \cdot \frac{2\pi}{60} \cdot \frac{dn}{dt} \tag{1}$$

where T is the torque in Nm

J is the moment of inertia of rotating parts in $kg \cdot m^2$

n is the speed in min^{-1}.

The accelerating time should be long enough so that electrical transient effects in the instruments and in the motor do not distort the torque-speed curve [3], and long enough to ensure successful measurement of the necessary number of data points. Detailed explanation can be found in the literature [1] and [2]. The benefits of acceleration method are short starting period and small heating of the motor, which allow repeating of the experiment, and the ability to perform the tests at rated voltage.

The measuring technique in laboratory exercises is based on the acceleration method, but it is not performed under no load conditions. There are two reasons for such modification of the method. Primary reason for adding the load is increasing the duration of accelerating time to the value ten times larger than electromagnetic time constant which represents the duration of electrical transient effects. To avoid the influence of the transient effect on the torque-speed characteristic, motor should be reversed, meaning it should be rotated manually in the reverse direction to that expected when the motor is energized [2]. This can be performed using the electric generator dynamometer working as a motor. Using the dynamometer as additional load obviates the time-consuming activity of uncoupling the motors after the first part of the exercise, allowing students to be more individual in the laboratory work. Accurate measurements of speed and acceleration are essential requirements [3] for this method, so the data acquisition system should be fast enough, in terms of sampling rate, to record speed, voltage and current, which also may be of interest. Speed transducer used in acceleration method should be a tachometer. It is necessary to have information about the rotation direction because of the reversing before energizing the machine. The measuring system should be able to record the speed, perform mathematical operations including differentiating to determine acceleration and display the results during the measurement and after the processing.

IV. MEASURING SYSTEM

Measuring system is a product of Veski Inc. from Zagreb, consisting of measurement/acquisition device and a personal computer equipped with corresponding software. The system is designed for measurement, preparation, acquisition, storage, processing, and data presentation of voltages, currents and speeds for rotating machinery under 5 kW of power. It is adjusted for measuring the currents up to 10 A, voltages up to 500 V and speeds up to 60000 min^{-1}. Sampling rate is 48 kHz which is high enough to enable obtaining the speed by differentiation, i.e. to avoid the coarseness of quantization. The acquisition device is connected to the PC via a USB port. This data acquisition device is used to measure different physical quantities, some of which are mechanical, and some electrical. Using appropriate measuring transducers this device may be used for measuring any type of quantity, whether mechanical, chemical, etc. The software determines its functionality and the way it emulates traditional electronic instrumentation. This concept is called virtual instrumentation, and it is one of the main advantages of a system such as this. The block scheme of the measuring system including the software is given in Figure 3.

Acquisition device is modular, and composed of modules for signal adaptation (voltage and current transducers, resistors), data acquisition card, and power supply. Device has three inputs, for voltages and currents of each phase, additional input sockets for tachometer signal, measuring signal control sockets, and a USB socket. The deployment of measuring system is simple and intuitive for people with small experience in electrical measurements, so it can be done by the students themselves during the exercises. During the equipment deployment, leads should be connected from the voltage source to the acquisition device. In this method, motor is connected directly to the power grid, so the (3-phase) variable voltage transformer should be disconnected and motor should be started directly on line (DOL).

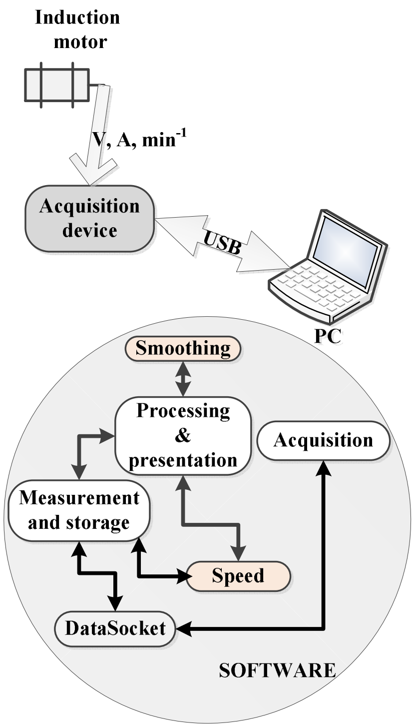

Figure 4. Block scheme of the measuring system

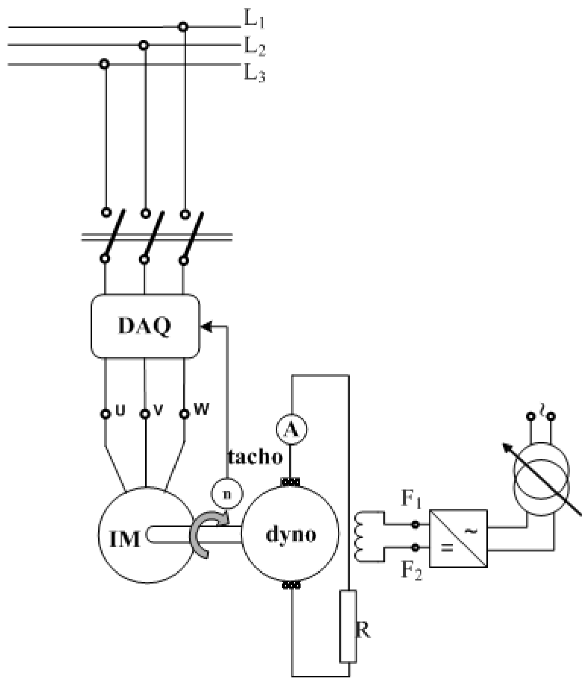

Figure 3. Equipment setup in laboratory exercises for acceleration method

Tachometer should be connected to the sockets provided for speed measurement. Equipment setup should follow the one given in Figure 4. Software deployment, on the other hand, provided some challenges and it should be carefully monitored when performed by the students.

V. SOFTWARE

Software for the measuring system was developed using LabVIEW, programming tool designed for developing applications in test and measurement, automation, instrumentation control, data acquisition and processing [10]. This tool was chosen because applications for measurement are developed much faster in LabVIEW than with *traditional* programming languages. Rich user interfaces imitating parts of *conventional* measuring instrumentation and equipment are included in the program. This is important for electrical engineering students who have some experience in working with electronic instrumentation. User interfaces reminding the students of an oscilloscope, ammeter, 7-segment numeric display, knobs, button, dials, etc. provide the students with familiar surroundings, and hopefully giving them an insight to another possible application of the personal computer, not just the Internet and fun they are used to [8]. Although LabVIEW is declared to be compatible with different operating systems, software installation on unsupported Linux distributions was not simple, and some issues had to be resolved without the official support from the manufacturer, National Instruments. Installation and following software development under MS Windows went smoothly. One of the dominating distinctions between

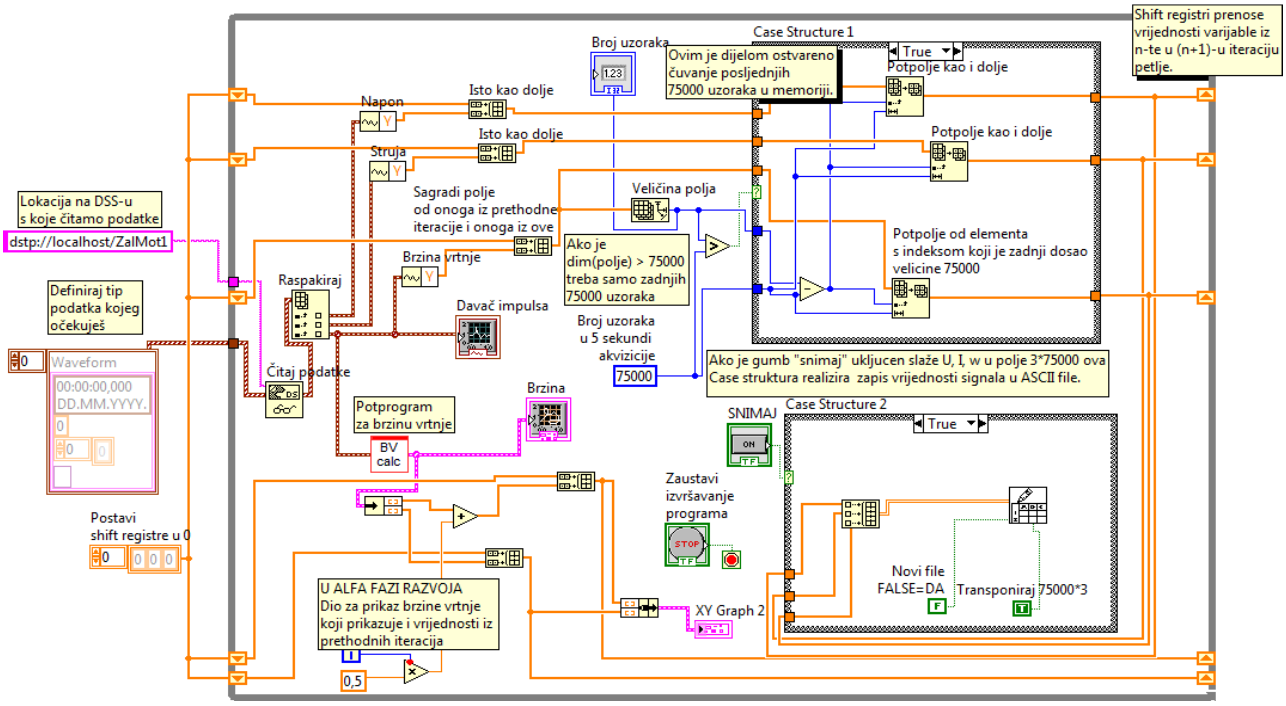

Figure 6. Block diagram of the *Measurement and storage* VI

LabVIEW and other programming languages is the *dataflow* paradigm, a programming paradigm in which functions are not executed in a determined order, but following the arrival of data to a certain function. Thus, the order of execution of functions does not have to be the same every time we start the program. Source code in LabVIEW is written, or better, drawn as a block diagram. Functions are represented by *blocks* and *nodes* interconnected with *wires*. An example of a block diagram is given in Figure 5. Objects in LabVIEW are called *virtual instruments* (VIs) and the structure of an application is often built up of several or more VIs. SubVI is a object large enough to be a VI, but used by VIs of higher rank to perform a specific function. Software developed for the torque-speed characteristic determination purposes has three main VIs and four subVIs, two of which are custom made, and two are integral part of the LabVIEW package. Figure 3 shows the structure of the VIs, with main VIs colored white, and subVIs colored pale red.

The *Acquisition* VI starts communication with the hardware and opens a link to the DataSocket server – a protocol used by LabVIEW for sharing data between programs and computers. This VI uses two standard subVIs for communication establishment and data acquisition. The *Measurement and storage* VI converts signals received, maintaining the last five seconds of the signal during live recording in the buffer [9] and, at the user's command, stores data to the hard drive. Processing and (graphical) presentation is performed in a VI bearing that name. The result of the software analysis, the torque-speed curve can be seen on Figure 6. The result given is smoothed and polynomial interpolated using least square method, so the students are left to discuss precision and accuracy with the teaching assistant. This seems to be a good "trick" to interest the students more for electrical measurements problems.

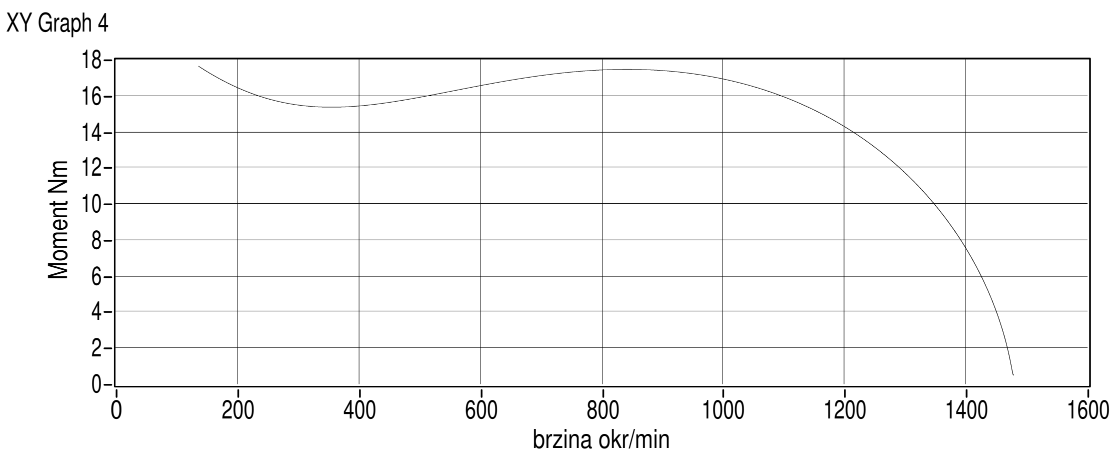

Figure 5. The torque-speed characteristic drawn by the software

VI. CONLUSION

Implementation of the new method in the exercises has several benefits. Students will notice that it is possible to measure the same physical quantity in several ways, get familiar with some of the computer tools used in contemporary electrical engineering, and be able to run the software and make simple modifications themselves. This would be encouraged in order to help better understanding of the electric machinery and the measuring techniques. Teamwork would be important as a desirable quality during the performance of this exercise, preparing the future engineers, at least a bit, for their future work in a team. Students' reactions to the new method are to be tested through a questionnaire and through laboratory reports comparison between several generations in order to qualitatively evaluate improvements in students' knowledge and skills. Without careful investigation, however, it can be stated that their competence in electrical measurements and their skills in computer usage are improved through work with the newly deployed equipment.

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