Acquisition System for Static Torque Characteristics Measuring

Goran Vuković, Srđan Ajkalo, Srđan Jokić and Petar Matić

***Abstract*—In this paper developement of an acquisition system (AS) for static torque characteristics of electrical machines measuring is described. AS is implemented on the device „Dr.Staiger, Mohilo+CoGmbH" using acquisition card with appropiate software. Performances of the new system are illustrated by few representative measurements.**

***Index Terms*—Static Torque Characteristics, Machine Testing, Measuring and acquisition.**

I. Introduction

MEASUREMENT and acquisition of the torque of electric machines is one of the most difficult machines inspections. Test system must have the capability to drive machine in investigated operating mode (burden state) while a torque transducer, for direct measurements is sophisticated, delicate and expansive device. Regarding that, torque measuremets of machine in burden state are, in most all events, performed in specialized test laboratories, mostly as a standard testing [1-3].

True torque value is required information for electric machine construction in order to determine whether the tested machine reaches its projected performance, to determine operating characteristics, as well as in standardization to identify if tested machine satisfies designated standard. In modern electric motor drive, torque is estimated (calculated) with accessible gauge measurements (current and voltage), but the only way to determinate exact value of torque on motor spindle is direct measurement. Torque measurement domain is covered by the appropriate regulations. [1-4]

Torque characterisitcs are represented with torque conditionality on machine speed, on machine spindle (or indirectly, conditionality of time).

Existing equipment for recording torque characteristics is due to the price and complexity, for many years held in use. Improvement technologies, primarily measurement - acquisition systems, the existing devices are exceeded. In such cases, it is very cost-effective to renovate measurement-acquisition systems, by the retention of burden system. In this way, the existing set of equipment (torque encoders and burden system) are still in use, and allows the direct processing of measured data on the computer.

In this paper, just such a procedure is described, in which the measurement system of outdated technological device for torque measurements is changed with contemporary system. First described is the torque sensor with burden system, and hardware and software of a new measurement - acquisition system. After that, follow the pictures of important torque characteristics that serve to illustrate the performance of projected system. At the end are the guidelines for further work.

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II. Description of the Device and Purpose

Analyzing device "Dr. Steiger, Mohilo+CoGmbH" is intended for inspection and verification torque characteristics of electric machines and other rotation devices [5]. Block scheme of the device "Dr.Steiger,Mohilo+CoGmbH" with measurement-acquisition system is represented on Fig. 1.

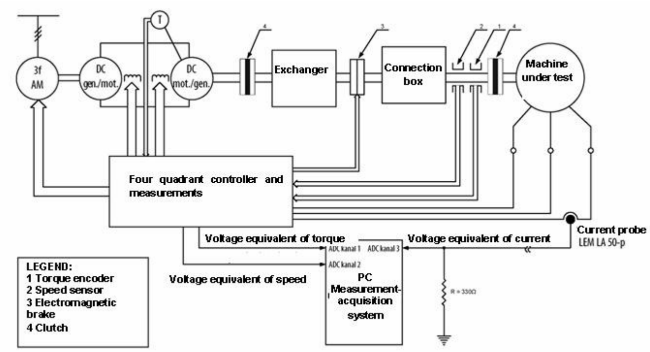

Fig. 1. Block scheme of the device "Dr. Steiger, Mohilo+CoGmbH".

Components of the device are measurement desk, burden system, and command-measurement desk. On the measurement desk is fixed machine under test and connected with one of three measurements spindles, depending on motor speed and power. Coupling between device and tested machine has been accomplished with special claw clutch. For each of the three spindles there are a couple of sensors for speed and torque measurements. Torque encoders are inductive and speed measurement is implemented with optical increment encoders. Spindles are getting out from a specific transmission box that allows various combinations of simultaneous or particular use of spindles with several speed ratios. Ranges of torque and speed values that can be measured with observe equipments have been mentioned in Table I.

TABLE I
TORQUE AND SPEED RANGE

	Rotating speed	Torque
1	by 3600 rpm	by 30 Nm
2	by 10000 rpm	by 10 Nm
3	by 26000 rpm	by 3.5 Nm

The transmission box is connected through the clutch with electromagnetic brake, which blocks spindle by the starting torque measurement. The clutch connects transmission and changing box with four speed ratios: 1:1, 1:1.4, 1:2.2 and 1:4. Changing box is connected with the burden system by the rubber clutch. Burden system is controlled in all of four quadrants and has measurements tacho generator.

Burden system has been realized as the Ward Leonard group. Operating and direct mechanical coupled asynchronous machine are placed in mount of measurement desk. DC machine is electric connected with the burden DC machine. When machine under test is tested in motor mode regime, then burden machine is generator and returns power back to network. In case that machine under test is tested in generator mode regime, the role of other three machines will also be changed. In this way, operating in four quadrants with recuperating is enabled.

Signals from each of torque sensors (each spindle has one sensor) are transmitted in appropriate analog amplifiers with small delays, which on output generate signal of range ±10V. Analog amplifier has potentiometers for gauging, cancel offsets and fine calibration. Each torque sensor has been calibrated in steady state, thus the spindle is blocked with electromechanical brake, and on spindle adjust torque with known weight and length on measurement bar. With known torque value on blocked spindle and voltage measurement on sensor, (assuming that sensor characteristic is linear) it is possible to determine torque constant in Nm/V.

Equipment is electronically (analogue) controlled from the command-measurement desk. Burden system is controlled by speed, manually or automatically. In manual mode, wanted speed of burden machine is directly determined by potenciometer. Manual mode includes also starting torque measurement, when spindle is blocked with eletromagnetic brake. Blocked duration can be adjusted in the range of 1-5s. During blocked period, at the same time machine is started under test and electromagnetic brake, and after that period both of them, machine under test and brake are turned off.

In automatic mode burden machine linearly accelerates or slows down to or from setting speed, at which the accelerate slope reference can be set through periode of acceleration or periode of slow down. It is possible recording torque characteristics of the linear acceleration to the given reference and instantly by linear slow down, as well as by only linear acceleration or slow down. The duration of slow down or acceleration (slope of characteristic) are set in the range of 1-10s. Based on that, recording of group of dynamic torque characterisitcs is possible.

Measurement-acquisition system consists of analog instruments (voltmeters) on wich the read is voltage proportional to measurement's torque registered, respectively voltage proportional to speed of taho generator and digital display with rotating speed of incremental encoder on wich experiment is based. Aquisition system contains grafic plotter with torque or speed signal on vertical axis, and time or speed proportional signal on horisontal axis.

Regarding that torque sensors as well as energetics part of equipment in good functional state, instead of outdated measurement-aquisitions system, new system, based on PC and aquisition card, is projected and adjusted. From electronically parts of old system, only control of burden system is withold.

III. MEASUREMENT-ACQUISITION SYSTEM

For the purposes of innovations in the previous chapter described measurement system is using multifunctional card – Humusoft MF 624. The card is especially adapted to the application of the control systems in real-time and systems for acquisition of measuring data. This PC card in addition to standard personal computer, offers a variety of opportunities. Because of its relatively low price, its application is not limited only to industrial use, but has wide application in research and education institutions [6]. Humusoft MF624 has a digital inputs, digital outputs, timers, counters, Pulse Wide Modulation, encoders inputs, measuring of frequency, as well as 8 analog inputs with 14-bit A/D converter with simultaneous circuits for selection and delay and very short conversion time, which is in case of use one of the channels up to 1.6 μs. Voltage range of analog signal, which card accepts is ± 10 V with the protection of the inputs up to ± 18 V. The important feature of card, except management in real time, is as well the possibility of data acquisition and waves forms analysis with application MATLAB Simulink Real-Time Windows Target and xPC-Target.

Software communication with the card is enabled with a large number of libraries for the programming language C or MATLAB. Card access is possible, from the command windows in MATLAB, as well as using standard blocks of Real-Time Toolbox from Simulink. Part of developed aquisition measurement system, which is realized in the MATLAB Simulink, is shown in Fig. 2. The picture also shows preview for the setting parameters of its card and, in particular, channel selection for A/D conversion.

For development of aplication in Real Time it is necessary to implement a specific procedure in MATLAB Simulink environment. Creation of the models into the Simulink develop environment, represents first step in preparation of simulation in real time and after that folows the input of parameters of models required for simulation and input of parameters for graphic performance of signal. After this step, it is necessary to configure the Real Time Windows Target and the input of

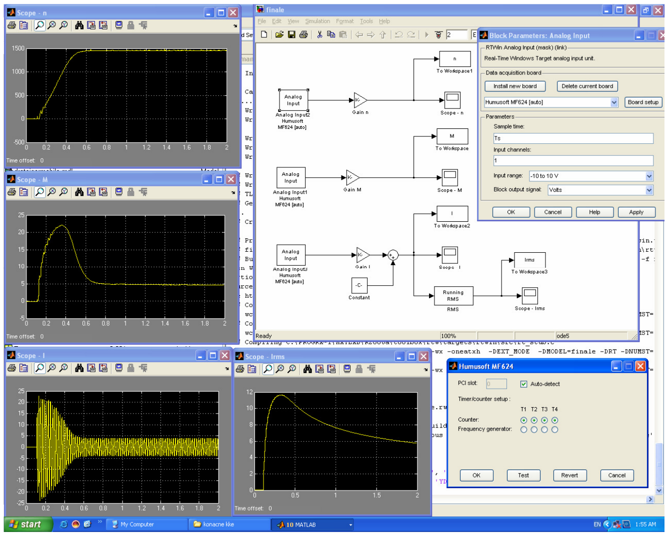

Fig. 2. Real-Time Windows Target blocks and developed measurement-acquisition system.

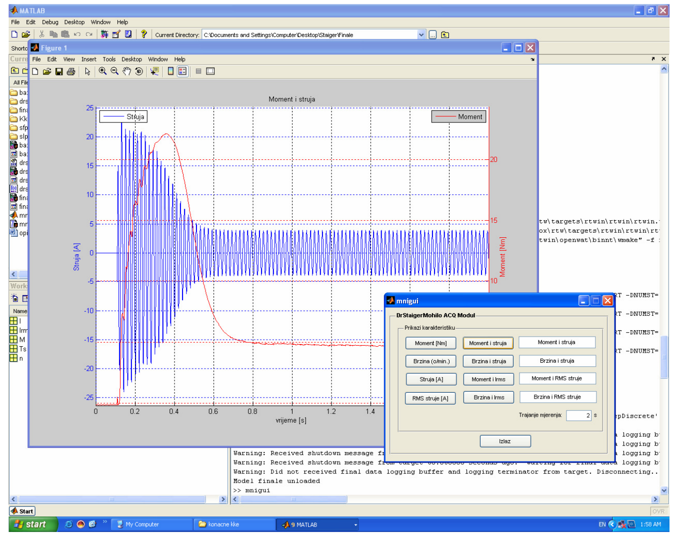

Fig. 3. GUI for the presentation of measuring characteristics.

simulation parameters for the Real Time Workshop. This Parameters are used to generate C code for the purpose of Real Time aplication. Namely, the Real Time Workshop generates C code for Simulink model, then the Open Watcom C/C ++ Compiler compiles and links C code in the Real Time executable application. After these steps folows connection of Simulink with acquisition card, while executable aplication starts from the local computer [7]. This is one of the differences between Humusoft MF624 card and more expensive I/O cards such as dSpace 1104 with DSP and that after connecting Simulink to acquisition card forwards the HEX executive program. In this way it carries out the relief of local computer and allows working of more complex aplication in real-time. Nevertheless, a compromise price and features of MF624 card in the system are completely met.

Voltage signals from a measurement torque and speed converters machine under test from the front panel of the "Steiger" device, as well as the measurement currents signal are accepted on the channels 1, 2 and 3 of A/D converter. Voltage dependence of the value of the appropriate physical size (torque constant) is determined by the calibration. Value mappings are entered in the Simulink model in the form of a gain block and possible DC offset, so that the output data measurements corresponds to values in the appropriate measurement units. Scope component allows the current view thus scaled values of measurement signal in real time. Also, it is possible to record the characteristics in the files, in order to further process, store or present measured data.

Part of the program for the representation of measurement signal characteristics and the development of measurements documentation was made in the form of graphical user panels (GUI). The appearance of the user panel to display measuring characteristics is given in Fig. 3.

It is necessary to note that depending on the complexity of the Simulink models, the Real Time Applications may have time selection of signals between 1 ms and 100 µs, so they are suitable for most laboratory experiments. In this concrete example the chosen time of the selection is 1 ms.

Fig. 4. gives an appearance of measurement apparatus. On the left side of Fig. 4. can be seen electro-mechanical part of the equipment, in the middle are adaption circuits and on the right side is a personal computer with acquisition card.

Fig. 4. Measurement apparatus.

IV. Experimental Results

Below are a few clips and analysis of important torque characteristics, that were recorded in the developed equipment. The modes of interest are regime states from the point of view as with the exploitation, as well as projected (nominal) size. Device under test is standard low voltage three-phase asynchronous motor with nominal power 1.1 kW, the nominal speed of 1400 rpm and 2.85 A nominal current. Nominal torque value of the machine is 7.5 Nm. The first measured value is from starting torque of machine Motor is at the same time blocked with the electromagnetic brake and connected to the nominal voltage value. Recording of the starting motor torque, in the duration of 5 seconds, is shown in Fig. 5.

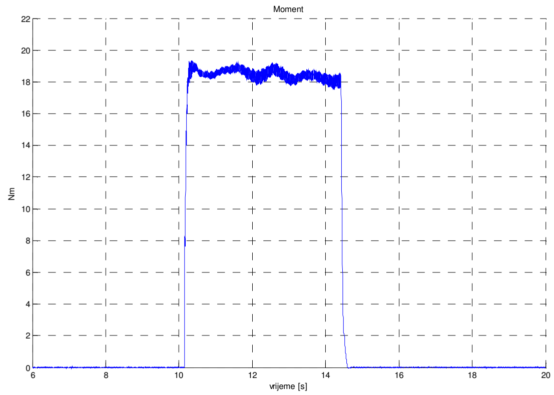

Fig. 5. Initial torque of the nominal power.

Measured value of starting torque is 18.5 Nm, and starting current 14.2A, so the ratio of starting and nominal torque is 2.5 and ratio of starting and nominal current is 5. Noise in measuring torque on Fig. 5 is the consequence of vibrating of claw clutch between machine and burden system.

Second measurement is a verification of nominal working point. Asynchronous motor is bound to burden system and connected to nominal voltage. Speed rotation of machine spindle is set to nominal value which is confirmed by reading from the encoder. Measured values are current (effective value) and machine torque, and they're displayed on Fig. 6. Fig. 6. shows that when machine has nominal torque, it conducts nominal current (in tolerance interval [1-3]), so that measured machine has real values like on name plate. If this experiment would have additional temperature measurement, and extended length, it would provide verification of nominal power in heating experiment.

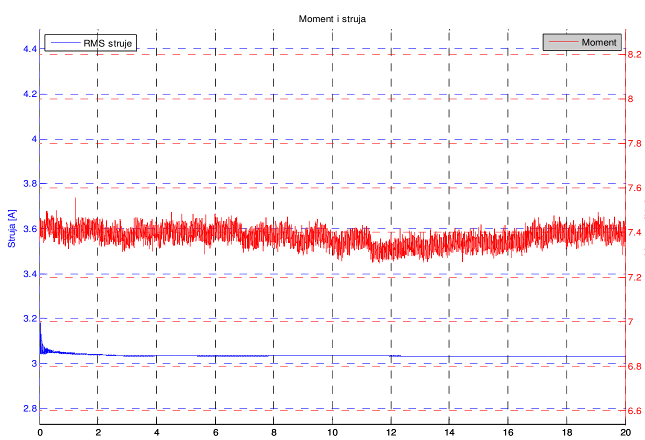

Fig. 6. Torque and the effective value of current when the motor has nominal speed and nominal power.

To illustrate possibility of recording dynamic torque characteristics, machine was linearly accelerated from idle to nominal speed, and then turned off. Acceleration time was 5s. Oscillations of torque are again the result of clutch vibrations in idle state and in starting. Fig. 7.a shows recorded torque characteristics, and Fig. 7.b rotation speed. This measurement confirms the value of starting torque recorded in experiment from Fig. 5.

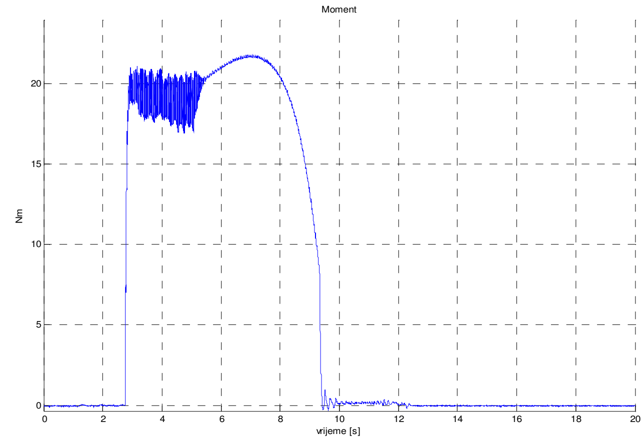

Fig. 7.a. Moment of the linear motor accelerating.

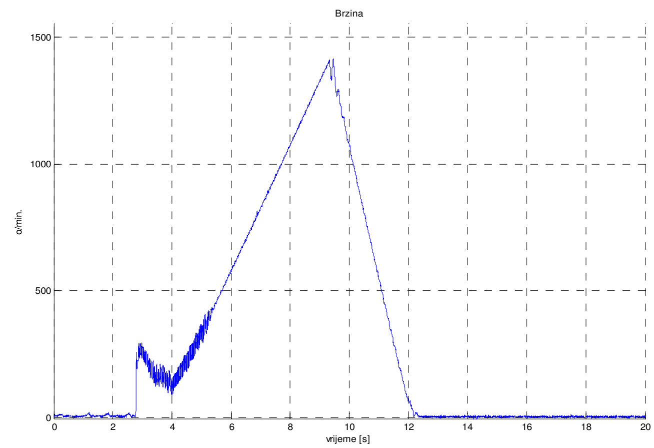

Fig. 7.b. Motor speed by determining the pull-out torque.

To illustrate performance of measuring equipment in different operating regime states, experiments are done with burdening the measured machine in motor and in generator regime state. Fig. 8.a shows machine torque and Fig. 8.b matching speed when machine is burdened from ideal idle state in motor regime state. Experiment is done by having speed of burdened machine equal to synchronous (ideal idle state), and after that speed of rotation was manually changed, so the torque also changed. Machine was burdened in four points in total.

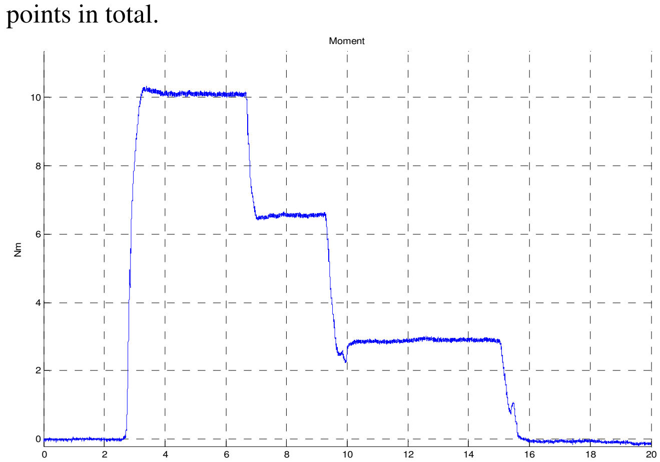

Fig. 8.a. Burdened machine in motor mode - torque.

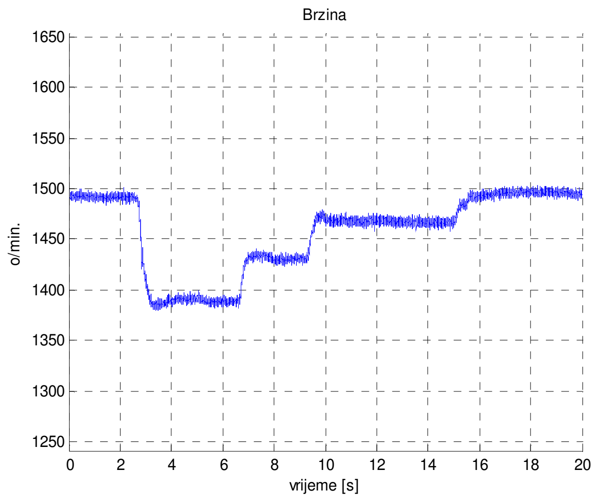

Fig. 8.b. Burdened machine in motor mode - speed.

Experiment similar to measurement in Fig. 8. has been done in generator regime state and displayed on Fig. 9. Results of the torque measuring are shown in Fig. 9.a, and the appropriate speed in Fig. 9.b.

On the basis of burden tested machines can be set slope (gradient) of torque characteristics of the linear part of static characteristics.

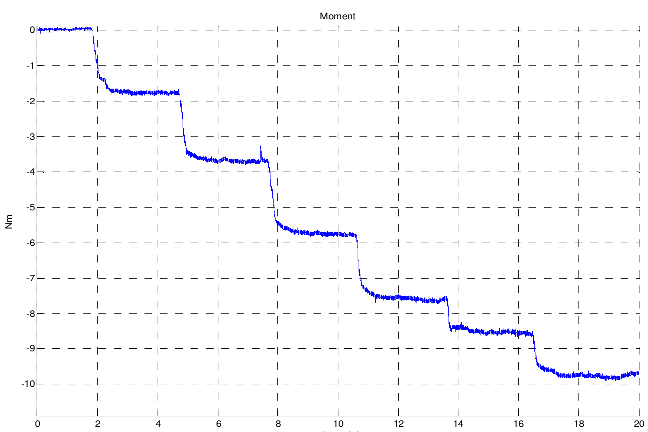

Fig. 9.a. Burdened machine in generator mode - torque.

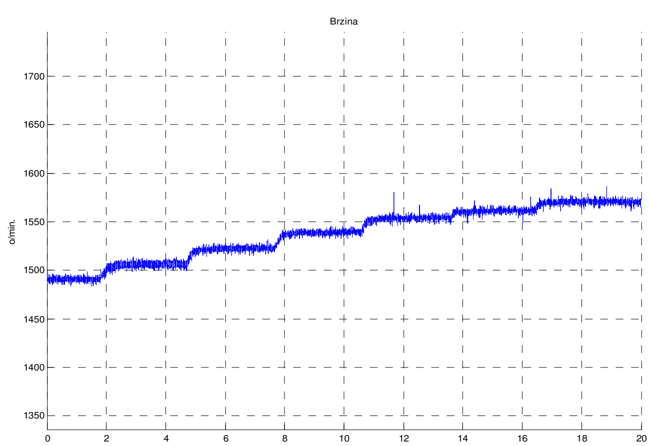

Fig. 9.b. Burdened machine in generator mode - speed.

V. Conclusion

Installation of measurement – acquisition system is obtained a new quality in the accuracy and speed of processing of the measuring data. When to use the existing analog and digital outputs of the acquisition card for the control of the experiment, then the complete recording procedures of torque characteristics could be automate with increasing accuracy of infliction references. Preferably, the modified control system, so that testing can be managed by the moment, and not just by speed.

By details calibration system, with compliance of applicable standards, measurement equipment could be certified to become a legal measurement means (gauge). For the purposes of calibration, it is necessary to determine the exact characteristics of sensor, the linearity, and possible delays in the adaptation instances, according to legal regulations. In this case, the equipment, except in the scientific and teaching purposes, coulde be used as a gauge of the issuing of third person attests.

Small variations of speed are a consequence of speed being regulated by feedback coupled with the encoder, and graphics shows speed recorded with taho generator. To avoid these deviations, it is necessary to input signal from encoder in the acquisition card.

Electromechanical Ward Leonard groups do not have the possibility of faster regulation time or speed. Therefore, this test equipment is used to record relatively slow dynamic processes which, in reality appropriate operation in practice, while recording a fast process (acceleration in idle state or reverse) depends not only on the limit load, but the speed of processing torque signal to the acquisition system. Specific robust, simple four-quadrant work, as well as the need for recording static torque characteristics justify further exploitation.

Measurement equipment can be used for the purposes of examination of modern electromotor drives, by the verification techniques of torque estimation. Comparing estimated and measured values of the torque in stationary state, shortcomings of mathematical models or used estimation techniques can be noticed.

Developed measurement - acquisition system has showed very good in the implementation, and it was free to build to the other seven measuring system for recording of torque characteristics, such as Faculty of Electrical Engineering in East Sarajevo has. In this way it will also improve testing of different machines , ie. larger forces.

Acknowledgment

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