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VALIDATION AND CALIBRATION OF A MEASUREMENT SYSTEM FOR TESTING ELECTRIC MOTORS

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Abstract

The authors have been dealing with the modelling and simulation of electric vehicles and motors for many years. Knowing their electromagnetic and dynamic characteristics is essential for the simulation of electric motors. These data have to be determined experimentally because the manufacturers usually do not provide them. In the last two years, we have designed and realised a measurement system for testing electric motors at the Faculty of Engineering of the University of Debrecen. In this publication, we present the validation and calibration of the individual components of the above system, the applied methods and procedures, and the obtained results.

Keywords: *measurement system, electric motor, validation, motor test bench, sensors.*

1. Introduction

At the Faculty of Engineering of the University of Debrecen, we have been dealing with the simulation of electric vehicles and motors for many years [1, 2]. For the simulation of electric motors, it is essential to know the electromagnetic and dynamic characteristics of the motor. Manufacturers usually do not provide most of these, so it has to be determined experimentally. We have published several papers on this topic [3, 4]. In the last three years, we have designed and built a motor testing measurement system (MS) (Figure 1). A detailed description of the system can be found in [5]. Now, we present the validation and calibration processes and methods regarding individual elements of the system and the results obtained during the research.

Figure 1. *The self-developed measurement system* [5]

Firstly, the optical LED sensor was validated (Figure 2). We measured the RPM of a 2.2 kW

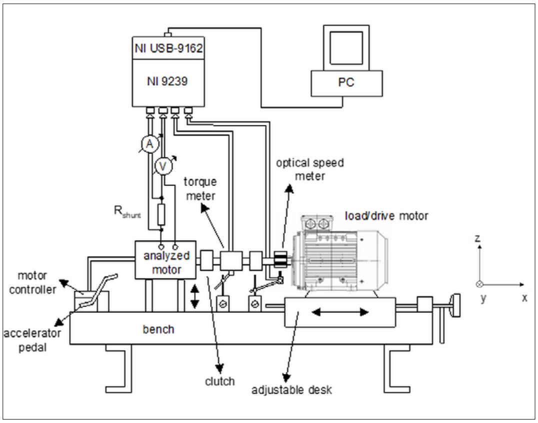

Figure 2. *The schematic drawing of the measurement system* [5]

three-phase asynchronous motor, which was part of the MS at that time as a drive motor. It should be noted that a motor can operate as a drive motor when fed with three-phase alternating current using a frequency converter or as a load motor when fed with regulated direct current. For the actual validation, on the one hand, we used the inbuilt frequency converter of the MS; on the other hand, a self-made device based on the principle of magnetic induction; additionally, a manual tachometer operating on the optical principle was used. The process is presented in Section 2.

Secondly, we determined the relationship between the intensity of the direct current flowing through a three-phase asynchronous motor – operated as a load motor – and the load torque exerted by it. Results are given in Section 3.

Lastly, we measured the total electrical resistance of the high-performance starting resistor used as the load resistor in the MS. Section 4 provides the details of the last test.

2. Validation of the optical LED sensor

In the MS, the angular speed is measured with an optical LED sensor (ROS-P, Monarch Instrument) which operates from 6 V direct current and outputs a voltage signal of 6V or 0V, depending on whether the light beam is reflected from the film strip placed on the rotating surface (the shaft of the motor) to the sensor or not. The maximum angular speed which the sensor can measure is 250000 RPM. Applying more than one strip this maximum value is reduced. The optical LED sensor and its typical output voltage signals can be seen in **Figure 3**. **[5]**

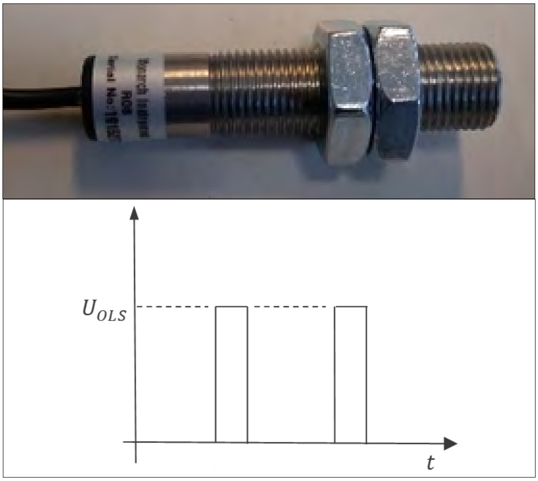

Figure 3. *The optical LED sensor and its typical output voltage signals.* **[5]**

The output voltage signals are counted by the software component of the MS **[6]** implemented by our research group in NI LabVIEW. Simultaneously, the angular velocity is calculated from the number of strips (N_{strip}) – placed on the circumference of the shaft – and the voltage signals (N_{signal}), detected during a short Δt time with the formula given below **[5]**:

$$\omega = \frac{2\pi}{\Delta t} \cdot \frac{N_{signal}}{N_{strip}} \qquad (1)$$

The device was validated using several independent methods:

- Compare the measured values to the ones that are set and displayed on the frequency converter.
- Compare the measured values to those provided by a homemade device that works on the principle of magnetic induction. We attached a permanent magnet to the shaft of the motor, which then passes in front of a coil and induces a voltage at every turn. The terminals of the coil were connected to the NI 9239 analog-digital voltage module, which measures the induced voltage as a function of time. The RPM can be determined from the number of voltage signals generated during a given period.
- Compare the measured values to those measured by a manual optical angular speed meter (type: DT2234C+, measurement range: 2.5-99999 RPM, accuracy: ±0.05% + 1 digit).

Table 1 contains the rotational RPMs measured by the methods mentioned earlier:

Table 1. *The measured RPM values*

The values set on the frequency converter:	5 Hz (300 min^{-1})	10 Hz (600 min^{-1})	20 Hz (1200 min^{-1})	30 Hz (1800 min^{-1})	40 Hz (2400 min^{-1})	50 Hz (3000 min^{-1})
The value measured with the optical LED sensor (1/min):	291	585	1187	1789	2390	2983
The value measured using the magnetic induction principle (1/min):	291	587	1188	1788	2390	2992
The value measured with a manual optical tachometer (1/min):	292	587	1187	1789	2390	2991

Based on the measurement results, it can be stated that the RPM values set by the frequency converter – where the accuracy is 0.01 Hz – are slightly higher than the RPM values measured by the other three methods. However, the values measured by the last three methods are consistent. It should be noted that measurements based on the optical principle only result in accurate outcomes if the reflective strip(s) placed to the circumference of the motor's shaft is wholly separated from its surface. A surface that is too bright or uneven can easily distract the sensor. The most significant relative deviation is within 0.5%; thus, it can be concluded that all three methods are suitable for measuring the RPM with sufficient accuracy. The advantage of optical angular speed measurement is that it does not affect the motion of the rotating object being examined in the slightest way.

3. Determination of the value of the load resistor

In the MS, the load resistor is a high-power starting resistor used in trams (**Figure 4**). The coiled resistance wires are mounted on eight separate boards, which are attached to the base of the MS with the help of four threaded rods. Our goal was to determine the electrical resistance of the entire system, that is, the maximum applicable load resistance, which can be later reduced to the desired magnitude.

Measuring the resultant resistance of the entire system (**Figure 5**), which is a relatively high value, can be accomplished using a digital multimeter. However, when the individual smaller partial resistances within the system are measured, the following measurement setup is recommended. The voltage across the partial resistance is measured, and the current flowing through it is determined from the voltage measured on a shunt resistor. The measured voltage and current ratio gives the value of the sought electrical resistance.

Based on the measurement, the load resistance of the entire system is 7.2 Ω. The advantage of using a high-power load resistor is that it only heats up to a negligible degree, even at high current levels.

4. Determination of the relationship between the torque exerted by the load motor and the intensity of the current flowing through it

Using the asynchronous motor as a load motor, it is fed with a regulated direct current. The intensity of the direct current can be regulated by the control panel of the MS. As the intensity of the current increases, the loading torque of the motor increases proportionally. However, it is essential to ensure that the current intensity does not exceed the rated current intensity of the motor for an extended period, as this can cause damage to the motor.

Our goal was to determine the loading torque associated with different current values. During the experiments, the load motor was connected to a torque sensor via a rotating shaft and was driven by another motor (**Figure 2.**). Afterwards, we increased the current flowing through the load motor in small steps, and for each current value,

Figure 4. *The load resistor.* **[5]**

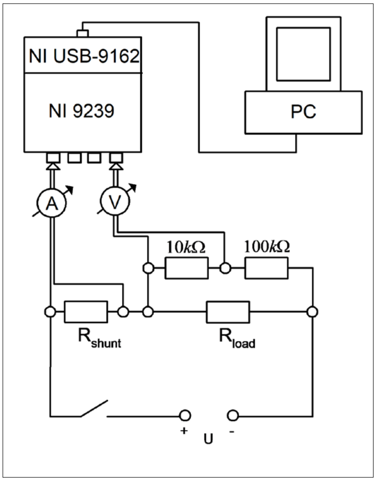

Figure 5. *Measurement setup for measuring low partial load resistances.*

we read the value indicated by the torque sensor attached to the rotating shaft. In this way, we determined the torque-current characteristic of the load motor.

Unfortunately, due to the failure of the torque meter, we could not perform the measurements yet.

5. Conclusions

We validated the MS's built-in optical angular speed meter using two independent methods during the above-described experiments. The relative deviation of the RPMs measured by different devices was less than 0.5%. Thus, the device we installed can be used with appropriate accuracy to measure the angular speed of electric motors in the tested range of 0-3000 RPM.

We determined the total electrical resistance of the starting resistor used as a load resistor and provided a procedure for precisely measuring its partial resistances.

We provided a procedure for measuring the current-load torque characteristic of the load motor. However, unfortunately, due to the failure of the torque meter, the measurements cannot be finished.

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