SOROS GERJESZTÉSŰ EGYENÁRAMÚ MOTOR DINAMIKUS TESZTMÉRÉSEI ÉS SZIMULÁCIÓJA

DYNAMIC TEST MEASUREMENTS AND SIMULATION ON A SERIES WOUND DC MOTOR

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ABSTRACT

This paper presents the experimental study and simulation of the series wound DC motor of a prototype racing car designed and constructed at the Faculty of Engineering, University of Debrecen. During the measurements, different loads were applied on the motor shaft, and the motor was spun up from rest. During spinning up the intensity of current flowing through the motor and the angular speed of the rotor were measured. After that simulation was performed with the same parameters applied. This allowed us comparing the measured and simulated values.

1. INTRODUCTION

The Faculty of Engineering, University of Debrecen has had more than a decade of tradition in the development and construction of various alternative (electric, pneumatic) powered vehicles [1, 2, 3, 4, 5, 6], with which student teams take part in various national and international competitions. These include the MVM Energy Race, the Shell ECO Marathon, and the Pneumobil races [7, 8].

In order to achieve more effective racing, we have been developing a vehicle dynamics model and a simulation program based on it for several years [9, 10]. This program calculates the vehicle dynamic functions of a vehicle from its technical data and also calculates the loads on each vehicle component (e.g. axle loads) during vehicle movement. Using the program and supplementing it with an optimization procedure, the optimal vehicle parameters (e.g. optimum gear ratio in the drive train) can be calculated for a given driving dynamics aim (racing task). The application of these technical parameters to the vehicle significantly increases the chances of successful racing.

2. SIMULATION PROGRAM

The vehicle dynamics model and the simulation program based on it are capable of generating, the dynamic functions of a vehicle moving on a linear track. Complemented by an optimization process, the program can be used indirectly to determine the optimal vehicle parameters for a given driving dynamics aim.

In addition to the usual driving dynamics functions (acceleration, velocity and position-time functions), the program is able to calculate the time dependence of the tangential and normal forces on the wheels and the loads on the front and back axles. It also calculates the intensity of current flowing through the motor, the voltage on the motor, and the angular speed and torque of the motor versus time.

The program takes into account almost all the factors that influence the vehicle's motion. These include electromagnetic and dynamic motor characteristics (electric resistance and self- and mutual inductance of windings, bearing and brush resistance torque on the motor shaft), rolling and air resistance, moment of inertia of the rotating machine parts, vehicle's centre of gravity and the coefficient of friction between the wheels and the ground as a function of tyre slip [11, 12, 13, 14].

The program can be used to determine the optimal technical parameters (e.g. the gear ratio in the chain drive) for a given vehicle dynamics aim (e.g. completing the race in the shortest possible time). As the program is based on a general vehicle dynamics model, it can be used to design, simulate the motion and optimize the technical data any of our racing cars [15, 16].

For modular development and greater clarity, the main vehicle components are organized into separate blocks, which are:

- front wheels;
- rear wheels;
- vehicle body;
- motor;
- powertrain.

The block diagram of the vehicle dynamics simulation program is shown in Figure 1.

The forces between the “vehicle body” and “front and back wheels” (vertical and horizontal axle loads) are calculated in the “vehicle body” and the “front and rear wheel” blocks. In addition, the “rear wheel” block is used to calculate vehicle velocity, acceleration, and motor load (M_{terh}). Since the motor load is provided by the vehicle itself, the motor simulation block also uses the output data computed by the "vehicle body" block. The calculated loading torque is finally read by the "motor block" which calculates the motor angular speed and then, from the angular speed, loading torque, $L_a(I)$, $L_g(I)$, $L_{ga}(I)$, $M_{ell}(\omega)$ characteristics, R_a, R_g resistances and supply voltage ($U_{TÁP}$) it calculates the motor torque applied on the vehicle (M_{motor}). From the motor angular speed (knowing the gear ratio), the "powertrain block" calculates the angular speed of the rear wheels. The cycle ends by feedback, the rear wheel angular speed is connected back to the "rear wheel block" and the torque of the motor (M_{motor}) back to the "vehicle body" block. By running the cycle several times, the program generates the vehicle dynamics functions specific to the motor and vehicle. To perform the calculations, the motor and vehicle technical data (input parameters) described above are required. A detailed list of input parameters required to run the program can be found in reference [9].

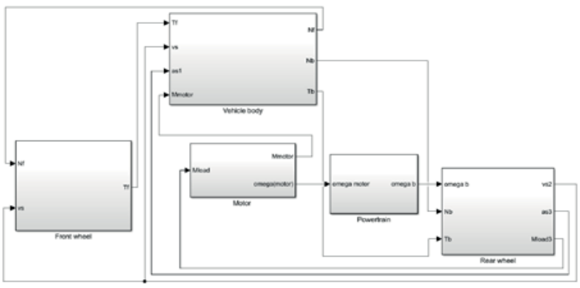

Figure 1. Block diagram of the vehicle dynamic simulation program

From the input parameters, the simulation program generates the following vehicle dynamic functions as a function of time [17]:

- the intensity of current flowing through the motor;
- motor torque on the vehicle;
- acceleration, velocity and distance travelled by the vehicle;
- tangential and normal forces exerted by the road on the vehicle wheels;
- tangential and normal axle loads;
- rolling and bearing resistance torques;
- air resistance force;
- tyre slip.

Based on the dynamics functions that can be generated by the program, we can determine the optimal vehicle parameters.

A key part of the simulation program is the "motor simulation block", which performs the simulation of the electric motor [18, 19, 20, 21, 22]. This requires an accurate knowledge of the technical characteristics of the motor (electric resistance and dynamic inductances of windings, brush voltage, bearing and brush resistance torques). To determine these characteristics and data experimentally, we have developed (and are still developing) a measuring system for testing electric motors.

3. APPLIED MEASURING SYSTEM AND EXPERIMENTAL METHOD

A schematic drawing of the measuring system used is shown in Figure 2.

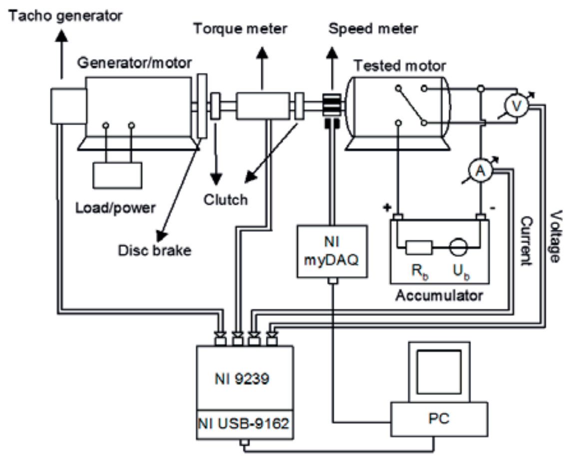

Figure 2. Schematic drawing of the measuring system

In Figure 2 the motor under test is connected to a generator (which is used to change the load on the motor) through a torque meter (rotary shaft torque meter type 7934, marketed by Kaliber Instrumentation and Measurement Ltd.). The motor rpm, torque, and intensity of current flowing through it are converted into voltage signals and measured using a NI 9239 data acquisition card that is connected to a computer using an NI USB-9162 USB adapter. The rpm can be measured either by a tachogenerator or by an optical tachometer.

Test measurements were also performed to test the accuracy of the simulation program and measured motor characteristics. Previously, test measurements were performed on a fixed rotor motor (locked rotor tests [17, 22]). In these measurements the measured values were in good agreement with the simulated ones. In the current dynamic test measurements, the motor is spun up from rest. Power is provided by a 12 [V], 60 [Ah] car battery. During spinning up the intensity of current flowing through the motor and the angular speed of the rotor are measured versus time. First, the unloaded motor was tested, and then, the measurement was repeated, applying discs (Figure 3) of different moments of inertia on the shaft of the motor.

Figure 3. Steel discs used for measurements

The moment of inertia of the discs in Figure 3 and the ribbed sleeve mounted on the motor shaft are shown in Table 1.

Table 1. Moments of inertia of the discs and ribbed sleeve used for the measurements

Disc	Moment of inertia [kg·m^2]
Small disc	0.00151
Big disc	0.0688
Ribbed sleeve	0.000157

Then, in the simulation program, the input parameter values (battery voltage, moment of inertia of the discs, etc.) used for measurement were set and the simulation was run. The measured and simulated values were then compared.

4. MEASUREMENT RESULTS

Figures 4 and 5 show the rpm and current intensity versus time measured during the motor was spinning up from rest. First, the motor was spun up without load, and then the measurement was repeated, with discs of various moments of inertia mounted on the motor shaft (1 small disc, 2 small discs, and finally 1 large disc).

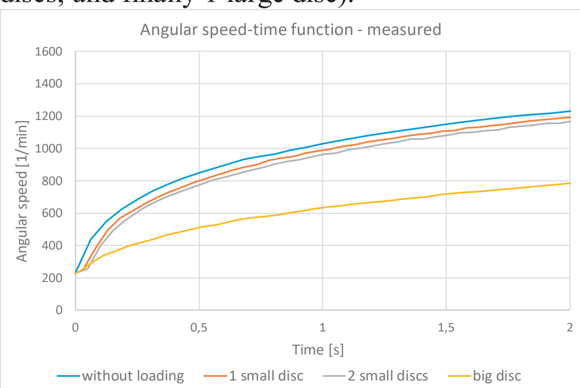

Figure 4. Measured rpm-time functions

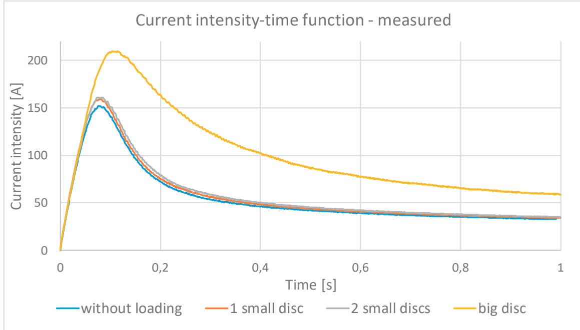

Figure 5. Measured current intensity-time functions

It can be seen from the diagrams that as the load increases, the motor spins up to a lower rpm during the same period of time, whereas the reverse is true for the current: increasing the load results in a higher current at the same time.

5. SIMULATED RESULTS

The previously measured characteristics [22] and other parameter values used for the recent measurements were set in the simulation program as input parameters and the simulation was run. Figures 6 and 7 show the simulated rpm- and current intensity-time functions applying different loads on the motor shaft.

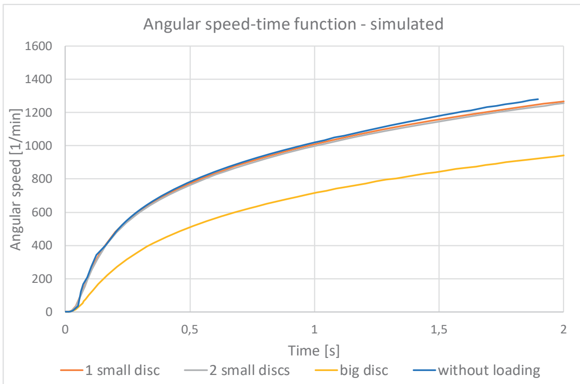

Figure 6. Simulated rpm-time functions

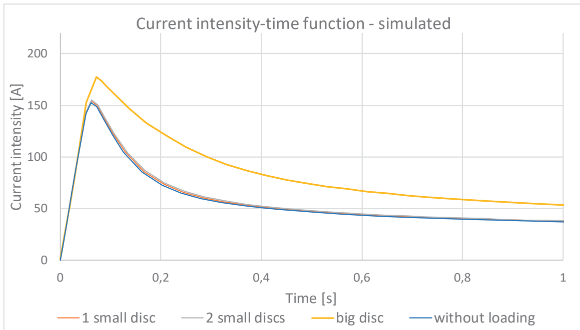

Figure 7. Simulated current intensity-time functions

6. COMPARISON OF MEASURED AND SIMULATED VALUES CONCLUSIONS

Figures 8 and 9 show the relationship between the measured and simulated current intensity- and rpm-time functions in case of an unloaded motor.

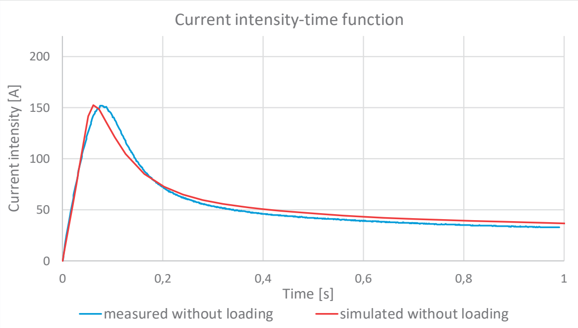

Figure 8. Measured and simulated current intensity-time functions

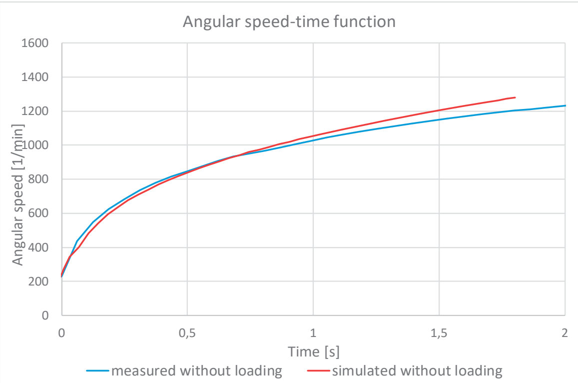

Figure 9. Measured and simulated rpm-time functions

When the loading moment of inertia on the rotor has a low value (unloaded motor or 1 or 2 small discs applied on the motor shaft), the measured and simulated values show good agreement. However, at higher loading moments of inertia the difference is already significant. The reason for this is unknown, and we are planning new test measurements using the new, more advanced torque meter to clarify it.

7. SUMMARY

During the presented research work we performed dynamic test measurements on a series wound DC motor, then simulated it applying the same input parameter values. We used our own simulation program that was developed in Matlab/Simulink environment previously.

On the basis of the results it can be concluded that the measured and simulated values are in a good agreement under unloaded conditions and also, when the loading moment of inertia is small. However, at higher loadings on the motor shaft the difference is already significant. The reason for this is not known yet, and we are planning new test measurements using a new, more advanced torque meter to clarify the difference. Furthermore, we plan to use other types of motor models in the simulation program in the near future, and to compare the simulation results obtained with different models.

8. ACKNOWLEDGEMENT

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