

THE USE OF MATHEMATICAL COMPUTER MODELS IN THE LABORATORY OF ELECTRICAL MACHINES ON THE EXAMPLE OF AN ASYNCHRONOUS MOTOR

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Abstract: Laboratory stands of electrical machines are based primarily on material models (mock-ups). Together with the development of computer technologies and advanced computational techniques, it is possible to carry out not only experimental research of electrical machines on the material model, but also by means of simulation on the mathematical model. The integration of material models with mathematical computer models significantly increases the possibility of examining electrical machines and consequently improves the quality of engineers' education. The use of mathematical computer models during laboratory exercises on real objects is one of the examples of the so-called augmented reality (AR). The article presents the concept of the material model of a three-phase asynchronous cage motor with the use of a MTLAB-SIMULINK software package.

Keywords: augmented reality, electrical machines laboratory, cage motor, mathematical computer models, simulation model

Introduction

The primary target of laboratory classes of electrical machines is to learn machine construction, principles of their operation and properties. Theoretical information gained on lectures deepens the knowledge of students during laboratory exercises.

Classical electrical machines laboratory consists of appropriately metering machine sets, where laboratory exercises are performed on real objects. Exercises on real objects are often uncomfortable, sometimes dangerous, and in special cases impossible [1]:

- Long time to carry out the experiment, which often exceeds hours of classes,
- Risk of damage or destroy the real object, and thus the limited possibility of its examination,
- High costs,
- Safety of exercisers,
- Large group of students decreases the activity of participation in the exercise.

The mentioned limitations of classical laboratories can be compensated by the use of mathematical models. The main potential of education based on the augmented reality is included in the AR method – applying computer-generated information to real objects [2]. Mathematical model is a mathematical description of a real object. Physical properties of the object are necessary to describe the object. Realization of modeling with the use of mathematical models is a computer simulation [3].

Together with the development of computer technology, we could see the creation of a number applications for conducting simulation studies of static states, and above all dynamic states of objects. The leading application in simulation researches is the MATLAB-SIMULINK software package from the MathWorks Company. The first program of the MATLAB was created in the seventies of the previous century. It is based on the FORTRAN programming language [4]. Over the past 30

years, this program has been constantly developed and improved. Currently, the MATLAB-SIMULINK program allows simulating many fields of science and technology. Object libraries included in this program allow mathematical modeling of devices, configurations and systems. Power System Blockset libraries, which were included in the MATLAB-SIMULINK package from version 5.x/2.x, are primarily used to for application in the electrical machine laboratory. Power System Blockset allows modelling of electric circuits using ready-made models of power sources (Electrical Sources), linear and non-linear elements of electric circuit (Elements), models of power electronic elements (Power Electronics), models of measuring instruments (Measurement) and

most importantly in machine laboratory – models of electrical machines (Machines). The article shows an integrated position using a real object of the asynchronous cage motor and a mathematical model implemented in the MATLAB-SIMULINK environment.

The laboratory stand for the cage motor's examination based on the real object

A modern stand for asynchronous cage motor testing was built in the laboratory of electrical machines placed in the Ship Electrical Engineering and Electronics Institution of the Maritime University in Szczecin. The laboratory stand for asynchronous cage motor testing is shown in Fig. 1.

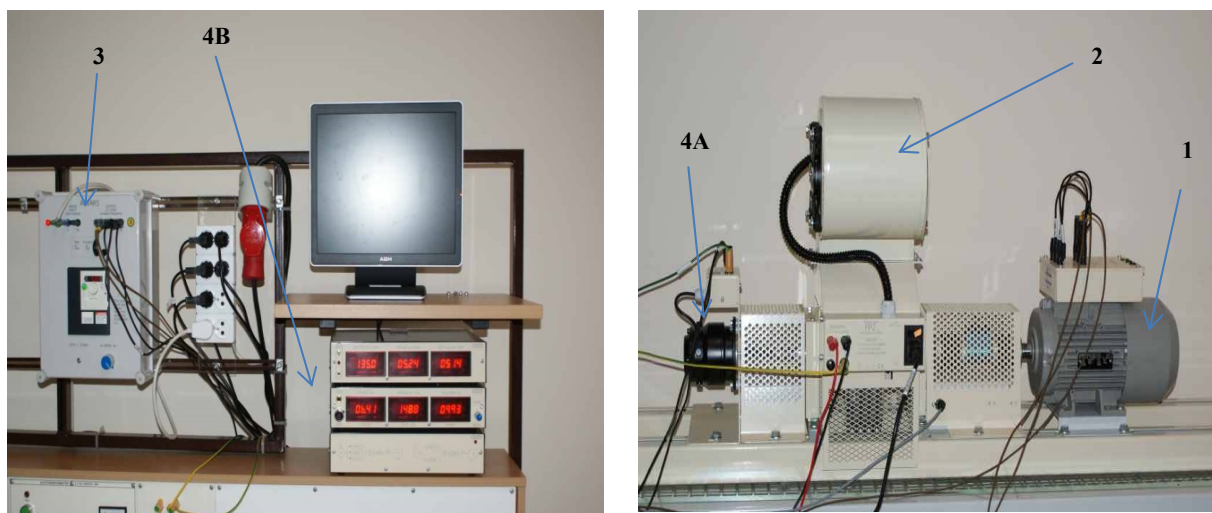


Fig. 1. The laboratory stand for the cage motor's examination based on the real object: 1 - 1500 W 3-phase asynchronous cage motor, 2 - magnetic powder brake, - 3 - frequency variator settings, - 4 - measuring devices: A - size measurement of mechanical, B - size measurements of electrical

Table 1. Main features of the motor

P_N	U	p	f	I_N	$\cos\phi$	n	η
[W]	[V]	-	Hz	[A]	-	RPM	%
1500	400	4	50	5.5	0.85	1423	81

where: P_N - operating power, U - mains voltage, p - number of poles, f - frequency, I_N - nominal current, $\cos\phi$ - power factor, n - rotating speed, η - efficiency

Operational characteristics of the asynchronous cage motor are presented by a mechanical characteristics $n = f(T_e)$ (Fig. 2), i.e. speed ratio

of the rotor to the moment on the shaft. This is the most important characteristics of the motor describing its properties.

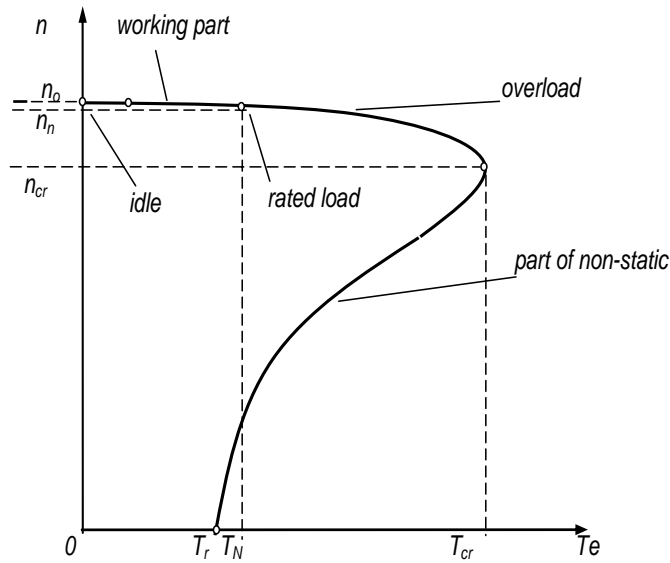


Fig. 2. Mechanical characteristics [5]: n_0 – the idling speed, n_n – the nominal speed, n_{cr} – the critical speed, T_r – the starting torque, T_n – the rated torque, T_{cr} – the critical moment

After exceeding the critical moment T_{cr} (e.g. during the significant overload), the motor has an unstable part of the mechanical characteristics, i.e. it “limps” (speed automatically decreases to zero). In the laboratory, only part of the mechanical characteristics (practically slightly exceeding the rated load) can be determined on the real object. Further overload of the motor can cause its damage. There were tests conducted on the laboratory stand. The mechanical characteristics is obtained by a change of breaking torque. Results of measurements are shown in Table 2.

The mechanical characteristics, shown in Figure 3, was prepared on the basis of the obtained measurements.

The broken line marks the part of characteristics, which can only be determined analytically. In order to test the motor in the whole rpm range and determination of the entire mechanical characteristics, we should use the computer mathematical model of the motor and carry out simulation researches.

Table 2. Results of the measurements of real research

T_e [Nm]	n [RPM]
0	1493
3	1468
5	1457
6	1447
7	1440
8.5	1430
9.5	1424
10.2	1418

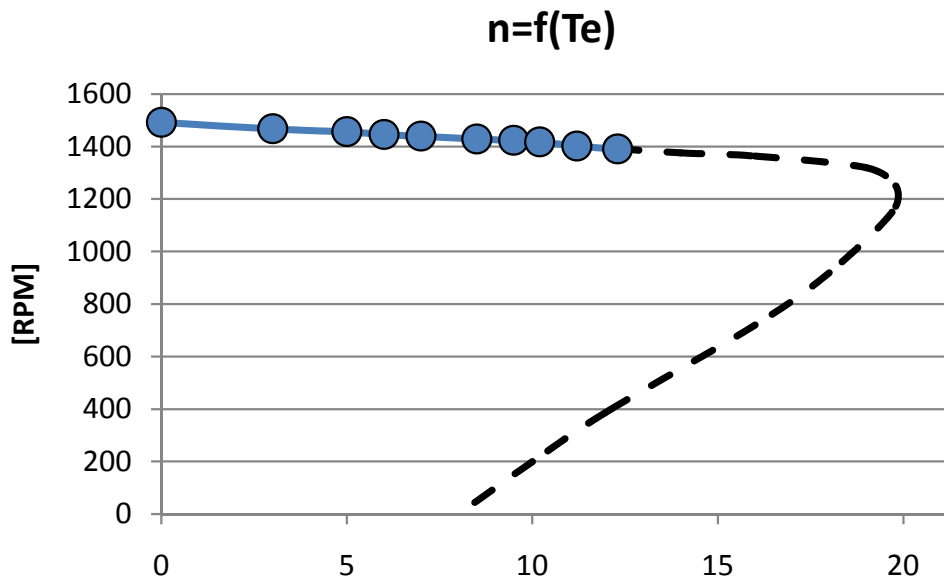


Fig. 3. Mechanical characteristics of the cage motor as a result of researches on the real object

Integrated simulation studies of the asynchronous cage motor used in the real model

The Speed Set block enables the adjustment of any motor speed and read values of the moment and speeds of the testing motor's rotor in the measuring block (T_e , ω measurement).

The MATLAB-SIMULINK program includes system for asynchronous motor testing (Fig. 4).

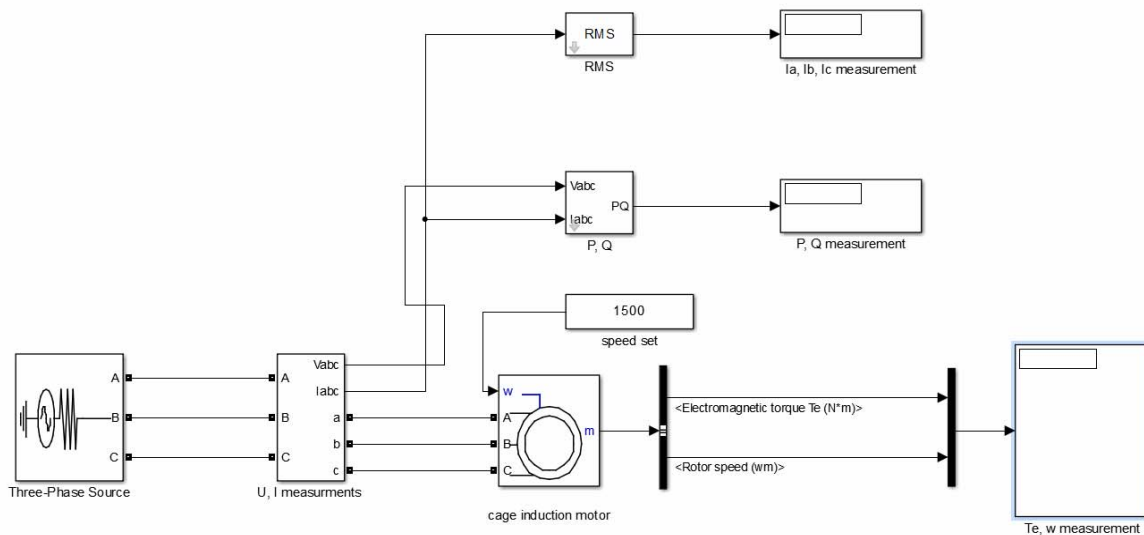


Fig. 4 Simulation model of a synchronous machine implemented in the MATLAB-SIMULINK program

Parameters of the motor should be entered in accordance with the motor data from a real model (Table 1) and calculations based on these data [1]:

Stator resistance:

$$R_s = \frac{U \cdot \cos \varphi \cdot (1 - \eta)}{I_N} - C^2 \cdot R_2' - \frac{P_w}{3 \cdot I_N^2} \quad (1)$$

where:

- U - nominal phase voltage,
- C - bringing coefficient (1.01-1.05),
- R_2' - rotor resistance reduced to the stator.

Rotor resistance:

$$R_r = \frac{1}{3} \frac{(P_N + \Delta P)}{I_N^2 \cdot \frac{1 - s_N}{s_N}} \quad (2)$$

where:

- ΔP - losses,
- s_N - slip.

Stator inductance:

$$L_s = \frac{U}{4 \cdot \pi \cdot f \cdot I_N \sqrt{1 - \cos^2 \varphi}} \quad (3)$$

Rotor inductance:

$$L_r = \frac{U}{4 \cdot \pi \cdot f \cdot (1 + C^2 \cos^2 \varphi) I_R} \quad (4)$$

where:

- I_R - starting current.

Motor parameters calculated on the basis of presented formulas and obtained from motor nameplate data (Table 1) are inscribed in the parameter settings window (Fig. 5).

Simulation tests were conducted. Results of obtained measurements are presented in Table 3.

Mechanical characteristics presented in Figure 6 was prepared on the basis of obtained measurements.

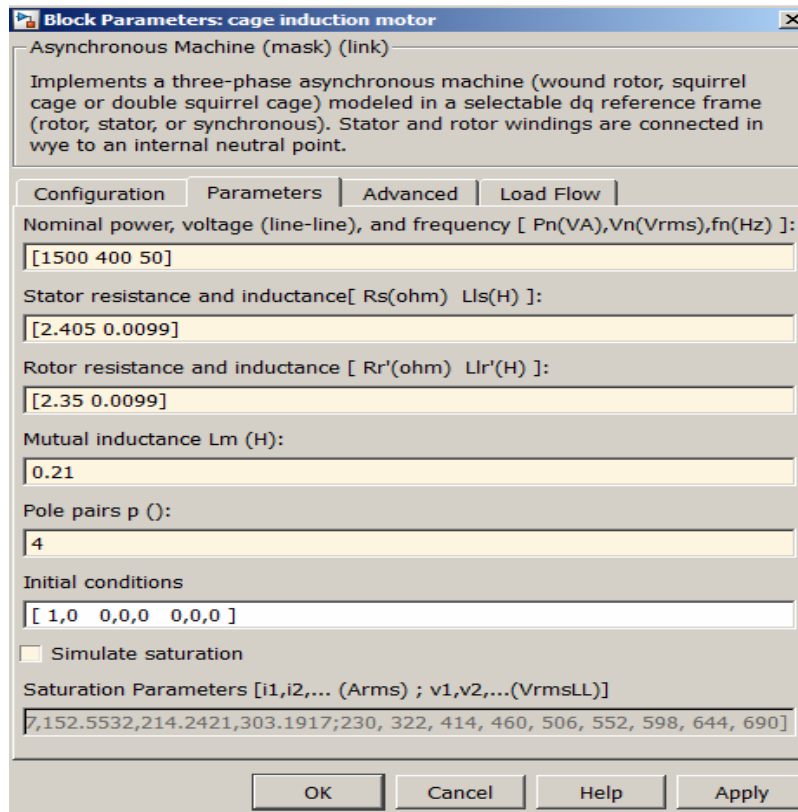


Fig. 5. Motor parameter settings window

Table 3. Results of the measurements of simulation research

T_e [Nm]	n [RPM]
0	1495
3	1480
5	1470
7	1450
9	1440
11	1420
14	1390
16	1370
19	1320
20.3	1250
20	1150
18	920
16	720
12	400
10	200
8.2	0

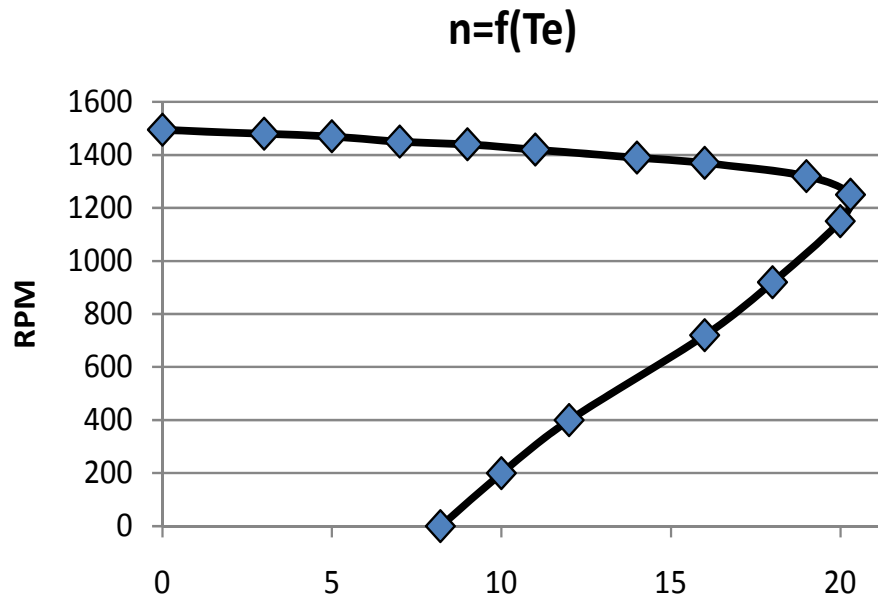


Fig. 6. Mechanical characteristics of the cage motor as a result of simulation researches

Mechanical characteristics of the cage motor obtained by a simulation method (Fig. 6) allows determining the rest of characteristics part, which cannot be determined on the real model (Fig. 3).

Conclusions

Classical laboratory of electrical machines supported by the computer engineering significantly allows expanding the cognitive

value of laboratory exercises, and at the same time improve the efficiency of education. An example of the integrated laboratory stand for cage motor testing, based on the real model with a computer simulation presented in this article, is an instance of the use so-called Internal AR. Problems presented during the cage motor testing on the real model are also visible in the study of other machines. Application of the AR method allows overcoming these disadvantages.

References

1. German-Gałkin S., i inni, *Badania symulacyjne układów mechatronicznych*, Wydawnictwo Naukowe Akademii Morskiej, Szczecin 2011.
3. Dejnaka A., *Rzeczywistość rozszerzona i jej zastosowanie w edukacji*, Dwumiesięcznik Szkoły Głównej w Warszawie, E-mentor nr 2 (44)/2012 e-edukacja w kraju.
4. Szczęsny R., *Komputerowa symulacja układów energoelektronicznych*, Wydawnictwo Politechniki Gdańskiej, Gdańsk 1999.
5. Mrożek B., Mrożek Z., *Matlab 5.x. Simulink 2.x –Poradnik Użytkownika*, Wydawnictwo PLJ, Warszawa 1998.
6. Tarnapowicz D. i inni, *Laboratorium Elektrotechniki dla studentów Wydziału Nawigacyjnego*, Wydawnictwo WSM, Szczecin 2000.