THE STUDY OF THE SYNCHRONOUS MOTOR

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Abstract: This paper presents the mechanical and electrical characteristics of the synchronous motor. The test setup is presented, used to determine the mechanical and electrical characteristics of the synchronous motor. Modelling the resistive torque allows the loading with different capacities and torsional vibrations. The characteristics of the synchronous motor are presented, as a function of different torques for a constant speed until the fall out of step occurs. The mechanical characteristics, as well as rotational speed and power, as a function of torque, until reaching the loss of synchronism, are plotted. Furthermore, the efficiency of the motor for an operation process that reaches the loss of synchronism is presented.

Key words: synchronous motor, mechanical, electrical characteristics.

1. Introduction

The synchronous machine is an AC machine, whose speed is constant regardless of the (stable) operating regime and the value of the load (within the normal limits) [2].

The operating characteristic of the synchronous machine is defined by the relationship between the rotating magnetic field and the rotating speed of the machine's rotor. In steady state, the rotating speed is a function of the frequency of the supply current, the number of poles of the rotating magnetic field and the winding.

A characteristic element of the synchronous machine is the fact that the excitation winding is supplied with DC current. Due to this, the synchronous machine can operate at unity power factor [4]. The synchronous machine can operate under two regimes: as a generator or as a motor.

As a motor, the machine transforms the electric power from an AC supply into mechanical power, necessary for a mechanical transmission. As a generator, the machine transforms the mechanical power, coming from the shaft of a drive machine, into electrical power, which is discharged in an AC grid [3]. Power plants for alternative rotary current use in the majority of the cases synchronous generators (SG).

The synchronous generators that discharge on their own grid are commonly met in mobile facilities and isolated grids, frequently being used as back-up source of electrical power in the case of system failures. SG is a rotary electric machine with a stator winding connected to the AC electric grid and the rotor winding (part of the inductor) is supplied with DC current. The generation of electric energy can be done my means of turbo-generators, hydro-generators and wind turbines.

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The *turbo-generators* are trained by steam or gas turbines or Diesel engines and operate at high speeds, $n_0 = (1500\text{-}3000)$ rpm. These have a low number of poles, the rotor polys being drowned (the rotor is a block cylinder, with rotor channels), i.e. a constant electrical-gap is ensured and the shaft is horizontal.

The hydro-generators have as a primary machine a hydraulic turbine; the rotational speed in this case is in the order of hundreds of rpms and the number of poles is higher. These generators have obtrusive rotor poles and the electrical gap is no longer constant along the interior circumference of the stator. The shaft is generally vertical [1].

The wind turbine is a machine that converts the kinetic energy of the wind into mechanical energy. If the mechanical energy is then converted into electricity, the machine is called wind generator, wind turbine or wind energy converter [5].

The operating regime of a synchronous machine is characterized by the nominal units of the electric parameters, depending on the operating regime (motor, generator, and compensator): power, voltage, current, efficiency, frequency, rotational speed.

The main disadvantage of the synchronous motor is that it generates electromagnetic torque only at synchronism velocity, and in addition it shows a magnetic characteristic, point at which the motor loses the synchronism.

The excitation voltage and current of the synchronous machine changes the loss of synchronism value. The rated current increases slightly as a consequence of the change in resistive torque until it falls out of step.

This paper presents the experimental determination of the excitation rated current of the synchronous motor: $n = f(Mr)$, $I = f(Mr)$, $P_2 = f(Mr)$, $E_{ff} = f(Mr)$.

2. The Synchronous Motor

The synchronous motor, due to its rigid characteristic, is currently being used more frequently to drive machines and mechatronic systems. The synchronous motor present, compared to the other electrical motors, the following advantages: the rotational speed is independent of the load, the motor is keeping its rotational speed constant, high power factor, high efficiency.

Among the main disadvantages of the synchronous motor are: complicated design due to the exciter, higher cost. For the low power control, the starting-up connections are more complex, in the case of changing the speed imposed by the technological process.
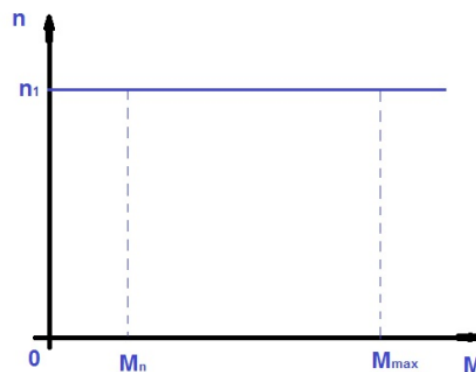

Fig. 1. *The mechanical characteristic of the synchronous machine*

The synchronous motors are favored nowadays for the control of the machines that require high power and constant working speeds.

Due to the fact that the speed of the synchronous motor does not vary with the load of its shaft, its mechanical characteristic is linear, and the slope of the characteristic, defined by the ratio between the angular velocity derivative and the derivative of the torque, is zero, Figure 1.

If a certain load torque value is exceeded, the motor falls out of step and stops, although theoretically the value of the torque can be as high as possible.

2.1. Mechanical and Electrical Characteristics of the Synchronous Motor

Choosing the type and the power of the electric motor, its rational use, the possibility of speed adjustment etc., require the study of the mechanical and electric characteristics of the motor. Each type of motor has a multitude of characteristics.

In order to draw the mechanical and electrical characteristics the setup in Figure 2 is used. The setup has the following components:

1 - Universal power supply with thermal protection for direct and three-phase alternating current;

2 - Digital-analogue measuring device, voltmeter, ammeter - to measure the excitation current and voltage;

3 - Varying transformer drive - to generate the excitation current and voltage;

4 - Digital-analogue measuring device, voltmeter, ammeter - to measure the current and voltage in the stator winding;

5 - Servomotor controller;

6 - Servomotor with brake;

7 - Active Servo software;

8 - Synchronous machine;
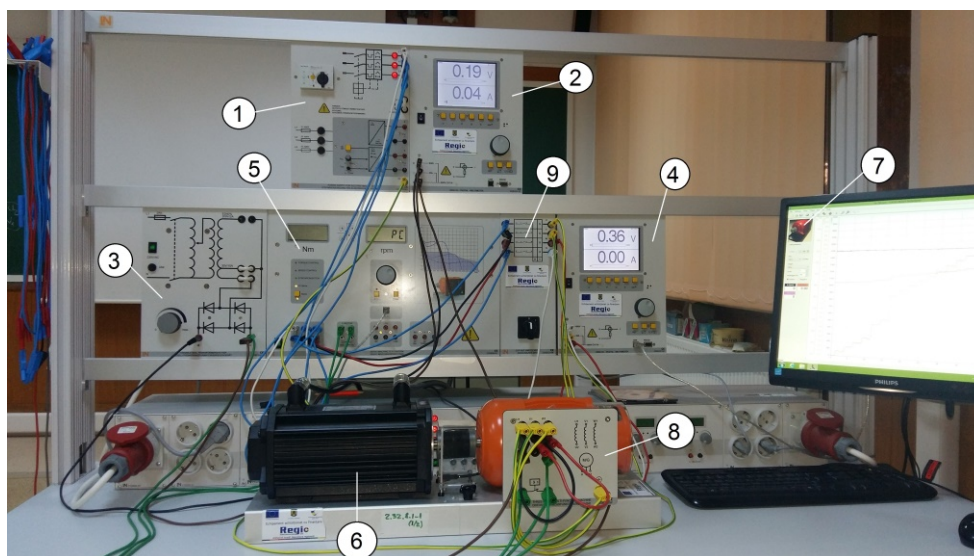
9 - General three-electrode switch with 2 positions.

Fig. 2. *The setup for the determination of the electric machine's characteristic*

The power supply 1 ensures a tree-phase alternative voltage of 400 V at the stator winding of the synchronous machine, with Y-configuration. The digital-analogue measuring device 2 measures the DC current values of the excitation voltage and current, which are variably drained by the varying transformer drive 3 on the rotor winding of the synchronous machine 8. Controller 5 communicates with the servomotor 6 through the software Active Servo 7. The synchronous machine is connected to the grid through the switch 9, and then the excitation voltage and current are generated on the rotor winding. The voltage and current of the whole system is monitored by the digital-analogue measuring device 4.

2.2. Torque Modelling for Characteristics Determination

The servomotor used for the experimental determinations is part of a complete testing systems composed of: digital controller, a servomotor with brake, and a software: Active Servo. The systems allows the braking of the electric motors at predefined values of the torque, the display of the rated value on the time diagram, as well as the manual and auto phasing of the generators.

The setup's servomotor allows the generation of different resistive torques for the synchronous motor through the controller. The controller sends the control input to the synchronous motor, after comparing the reference input to those sent by the torque sensor, within the mechanical transmission of the servomotor - synchronous motor. The reference inputs are set by the experiments program, taking into account the purpose of the experiments in terms of the determination of the different operation characteristics of the synchronous motor.

The servomotor, by means of the mechanism, mechanically connected to the shaft, runs the experiments program defined by the set control input. From a design and operational point of view, the servomotor has the following characteristics [5]:

- Wide range speed control;
- Generated mechanical characteristics are linear;
- High start-up torque;
- High overload capacity;
- Lowe electromechanical time constant;
- Protection against self-starting
- Small dimensions and specific weight;
- The absence of self-starting.

The servomotor with brake is an induction motor with resolver type self-cooling. This has thermal monitoring and together with the controller, it forms a monitoring and braking system that does not need any calibration. Its technical parameters are:

- Maximum speed: 4000 rpm;
- Maximum torque: 10 Nm;
- Temperature monitoring: continuous temperature sensor (KTY);
- Resolver resolution: 65536 impulses/rotation;

The system's controller has as main task to generate the resistive torques imposed on the studied characteristic. It has the following technical characteristics:

- Static and dynamic operation within the four quadrants;
- 10 selectable operation modes/machine models;

- Amplifier with galvanic insulation for voltage and current measurement;
- Displays the values of torque and couple;
- Four quadrant display;
- USB interface;
- Thermal monitoring of the electric machine;
- Testing the presence of a protective cap at the shaft;
- Input voltage: 320…528 V; 45…65 Hz;
- Maximum output power: 3 kVA.

The Active Servo software is a tool for monitoring and registering the machine's characteristic in order to determine the static and dynamic operating points. It simulates seven different loads (flywheel, pump, calender, lifting engagement, compressor, rotational speed, configurable time dependent load) for which the parameters can be configured individually.

The monitoring software allows the execution of the following operations:

- Measurement, determination and display of the mechanical and electrical variables: speed, output mechanical torque, current, voltage, real, apparent and reactive power, efficiency, power factor;
- Simultaneous display of the measured and determined values (for example, the instantaneous display of the efficiency);
- Current and voltage measurements (including RMS values even for non-sinusoidal wave forms);
- Speed and torque control;
- Registration of time dependent variables;
- Programming the margin values for speed and torque, in order to prevent inadequate loading of the test machine;
- Operation in all four quadrants (display of generated torque);
- Plotting the characteristics from various experiments to better illustrate the effect of changing parameters;
- Exporting graphs and measurements.

3. Mechanical and Electrical Characteristics of the Synchronous Machine

For the experimental determinations, in order to study the characteristics, a synchronous motor with the following properties was used: $P_n = 0.27$ kW, $I_n = 1.5$ A, $f = 50$ Hz, $n = 1500$ rpm, $U_{err} = 20$ Vcc, $I_{err} = 4$ A. the excitation source generated a voltage of 20 VDC at a operating current of 3 A. The motor was braked in 15 steps of the torque's value.

- **Characteristic $n = f(M)$**

The obtained values of speed depending on the torque   Table 1

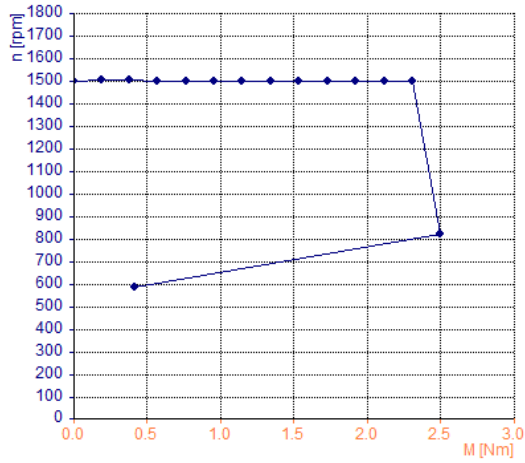| n [rpm]	1500	1507	1507	1502	1501	1500	1501	1502	1502	1500	1501	1501	1500	821	587
M [Nm]	0	0.19	0.38	0.57	0.77	0.96	1.15	1.35	1.54	1.73	1.92	2.12	2.31	2.50	0.42

Fig. 3. *Characteristic n = f(M)*

● **Characteristic *I = f(M)***

The obtained values of current depending on the torque   Table 2

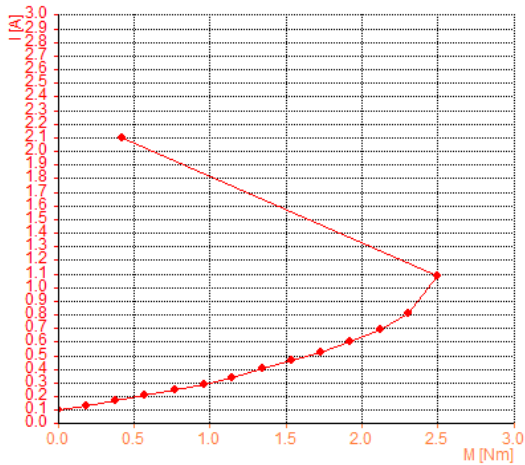| I [A]	0.10	0.13	0.17	0.21	0.25	0.29	0.34	0.41	0.47	0.53	0.60	0.69	0.81	1.09	2.10
M [Nm]	0	0.19	0.38	0.57	0.77	0.96	1.15	1.35	1.54	1.73	1.92	2.12	2.31	2.50	0.42

Fig. 4. *Characteristic I = f(M)*

● **Characteristic *P_2 = f(M)***

The obtained values of power depending on the torque   Table 3

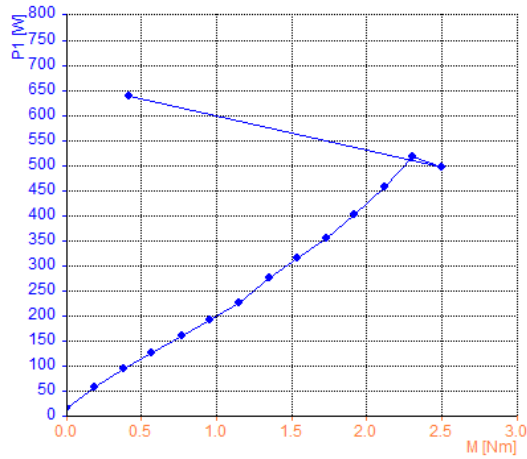| P_2 [W]	0	29.98	59.97	89.65	121.03	150.80	180.76	212.34	242.23	271.75	301.79	333.23	362.85	214.94	25.82
M [Nm]	0	0.19	0.38	0.57	0.77	0.96	1.15	1.35	1.54	1.73	1.92	2.12	2.31	2.50	0.42

Fig. 5. *Characteristic $P_2 = f(M)$*

● **Characteristic $E_{ff} = f(M)$**

The obtained values of efficiency depending on the torque   Table 4

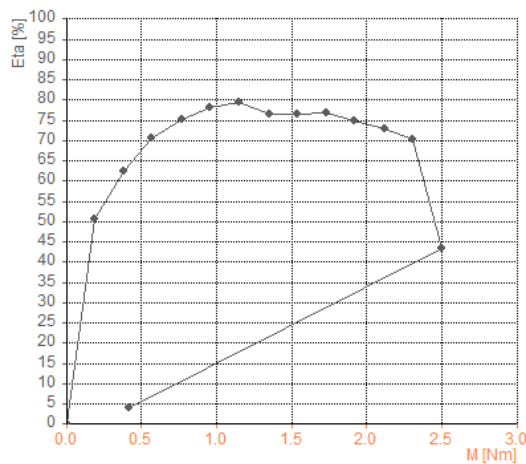| *Eta* [%]	0	50.60	62.46	70.66	75.27	78.19	79.36	76.68	76.40	76.73	74.97	72.97	70.20	43.29	4.05
M [Nm]	0	0.19	0.38	0.57	0.77	0.96	1.15	1.35	1.54	1.73	1.92	2.12	2.31	2.50	0.42

Fig. 6. *Characteristic $E_{ff} = f(M)$*

4. Conclusions

According to the theory, it can be practically observed that the synchronous machine maintains its synchronism torque at a sequential loading of the couple, up to 2.31 Nm, when it is destabilized and it falls out of step. It destabilizes up to a rotational speed of 821 rpm, after which it stops.

The value of the rated current increases incremental up to 2.5 Nm, after which it decreases suddenly, reaching 2.10 A. the rated power, on the other hand, increases

linearly, proportional to the increase in torque, until it reaches the fall-out value, after which it increases together with the increase in rated current. The efficiency is influenced by the torque's values, the curve is non-linear, having a maximum value of 79.36% at a torque of 1.15 Nm, after which it slowly decreases relative to the increase in torque.
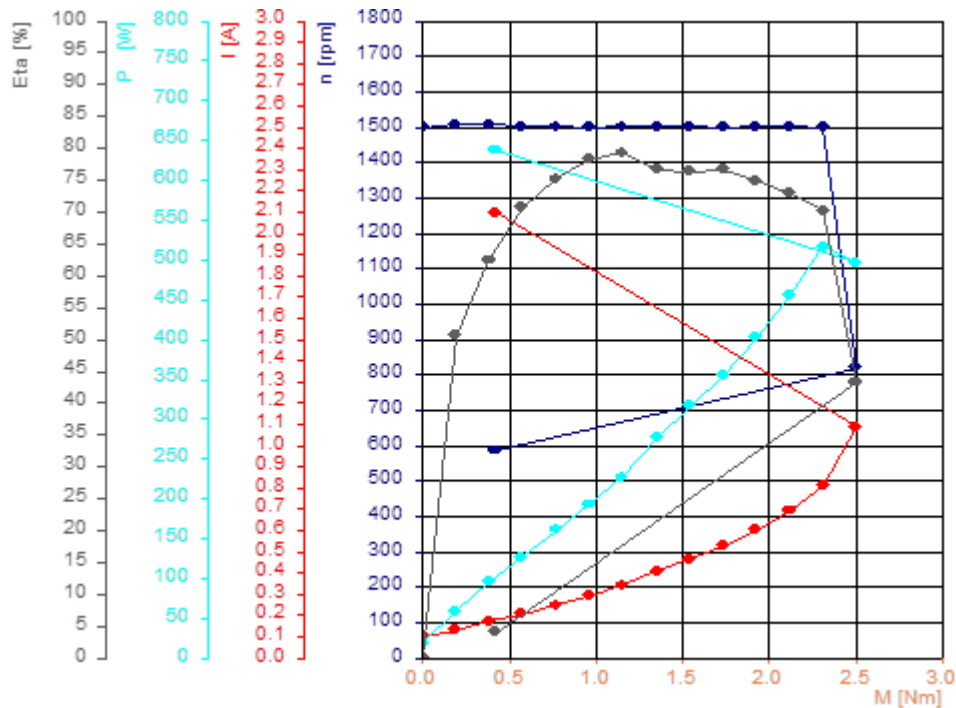

Fig. 7. *Characteristic n, I, P₂, Eff = f(M)*

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