

Modeling the mechanical and electrical characteristics of the synchronous motor for different variations of torque in time

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Abstract. The paper presents the mechanical and electrical characteristics of the synchronous motor at different imposed variations of torque over time. Modelling the resistive torque allows the loading with different capacities vibrations. The experimental setup is designed and presented in such a way as to allow a servomotor to stop the synchronous motor in variable torque values. The resulting characteristics highlight the mechanical characteristics of the synchronous motor as well as the resistance to repeated sudden repeated breaking within a shorter or longer period, observing the evolution of the speed up to the point of de-synchronisation of the motor. It is presented the mechanical characteristics of the mechanical power, electrical current, rotational speed and mechanical torque in function of time observing the behaviour of the synchronous machine when applying sudden varying resistive torques and its de-synchronization. The determination of these characteristics is made at a constant value of the excitation current.

1. Introduction

The synchronous machine is used in most industrial applications as an motor, generator or synchronous compensator [1]. It is an AC machine at which the speed is constant no matter the torque value at the shaft, within normal limits and regardless of the stabilized operating regime. The speed is synchronous and is strongly linked to the frequency ‘ f ’ of the alternating current power grid from which the machine is supplied [2].

Just like the other rotating electric machines the synchronous machine consists of three main parts: the stator, the rotor and the construction parts, but it has a wide constructional variety.

Depending on the role played by the two armatures, there exist:

- synchronous machines in normal construction, with induced stator and inducting rotor;
- synchronous machines in reverse construction, with inducting stator and induced rotor.

In the paper the normal construction is considered, being the most widespread; the reverse construction is encountered in relatively low power machines, and especially in synchronous machines used as excitation sources for brushless excitation systems, consisting of the synchronous generator which outputs power on the rotating rectifier [3].

The basic operating mode of the synchronous machine is the electric generator mode, just as the motor mode is the basic mode for the asynchronous machine. The synchronous machine as a generator is the economic basis for electricity generation in all existing power plants. In this mode the synchronous machines reach the highest rated powers, being the largest man-made electrical machines [4].

In the generator mode, the machine converts the mechanical power received at the shaft from an auxiliary motor into electrical power, fed into an AC network. In the motor mode, the machine converts the electrical power received from an AC network into mechanical power, presented at the shaft and provided to a mechanical installation [2].

Three-phase synchronous generators are used to generate electricity in power plants. They can be driven into rotation by primary motors such as: hydraulic turbines, diesel engines, thermal turbines, etc. Three-phase synchronous motors are built for high power (hundreds of KW) and are used for the driving at constant speed of certain machines: pumps, compressors, fans, etc [4].

In the following, only three-phase synchronous machines will be referred [5].

2. The synchronous motor

The Synchronous motor mode is especially used due to the benefits of asynchronous motors (higher efficiency, the power factor tending towards unity, steady torque at varying speed, bigger air-gap). This was only possible after technology managed to successfully solve two serious deficiencies of the synchronous motor: the absence of the starting torque and the possibility of developing a pendulum-like behavior with the danger of exiting synchronism (loss of stability) [6].

In this operating mode, the synchronous machine is used in all drives requiring constant speed (compressors, turbochargers, irrigation pumps, etc.), replacing asynchronous motors (especially at high power where economic considerations predominate: efficiency, power factor) [2].

Due to their rigid characteristics, the synchronous motor is increasingly used on a large scale, especially in the mechatronic drives.

The main disadvantage of the synchronous motor is that it develops torque only at synchronous speed and additionally has a rigid mechanical characteristic until the resistive torque reaches the maximum value of the electromagnetic torque at which time the motor exist synchronism.

Other drawbacks are related to the oscillations that may occur at sudden load variations at the shaft, the more complicated construction due to the exciter and the higher cost. In case of reduced power drives, startup electrical schematics are more complex in the case of varying the imposed speed dependent on the technological process. Synchronous motors are currently preferred especially to drive work machines that require high power and constant working speed [5].

3. Mechanical and electrical characteristics of the synchronous motor

The synchronous motor has a rigid mechanical characteristic in relation to the load at its shaft [7]. In the following section we study the behavior of this machine at different variations of torque from time and amplitude point of view. The aim is to study the behavior of the synchronous machine to see how far it can work until it exists synchronism [8].

In order to determine the mechanical and electrical characteristics it consists of the following components:

- Universal power supply with thermal protection;
- Digital-analogue measuring device, voltmeter, ammeter;
- Varying transformer drive – to generate the excitation current and voltage;
- Servomotor controller;
- Servomotor with brake and controller;
- Active Servo dedicated software;
- Synchronous machine;
- General tripolar switch with 2 positions.

This was used to simulate an increasing value of the torque.

The stator is supplied with three-phase alternating current and the rotor is powered by a DC voltage called excitation voltage. Both voltages as well as the excitation current are monitored. A servomotor applies a resistive torque to a synchronous motor coupled to the shaft with it. A controller monitors the results and displays them as graphs [8].

4. Torque modelling for characteristics determination

The execution and monitoring system consists of a servomotor, a controller and dedicated software called ActiveServo.

Through ActiveServo we generate torque diagrams that will brake the motor. Torque charts can be built to act on the synchronous motor shaft for a longer or shorter time.

ActiveServo monitors the electrical and mechanical parameters of the motor via the brake servomotor, displaying the results.

5. The mechanical and electrical characteristics at different variations of the motor torque with time

In the experimental determinations performed to study the characteristics, a synchronous motor with the following characteristics was used: $P_n = 0.27\text{kW}$, $I_n = 1.5\text{A}$, $f = 50\text{Hz}$, $n = 1500\text{rpm}$, $U_{\text{err}} = 20\text{Vcc}$; $I_{\text{err}} = 4\text{A}$. The excitation source generated a fixed voltage at the excitation current value of 3A .

For the studied synchronous motor we will observe the time dependence of the following quantities: The current of the rotor circuit I [A], the mechanical power on the shaft P_2 [W], the motor torque M [Nm], the speed n [rpm]

By imposing torque variations at the synchronous machine's shaft, we observed its behavior in terms of speed because any variation of torque at the shaft leads to variations of speed, current and torque. Four different torque characteristics were set-up to observe and determine these aspects.

In the first part of this study, we considered that variations are short-lived, and they occur for 10s, a leap of linear increasing or decreasing variation occurs for one second. The resulting torque characteristic is shown in figure 1.

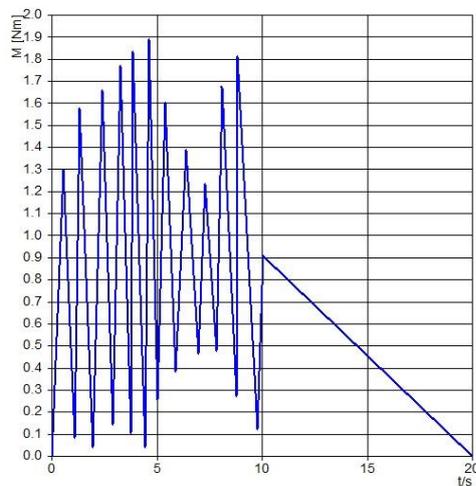


Figure 1. Variable imposed torque characteristic for $I_{\text{err}}=3\text{ A}$, in 10s

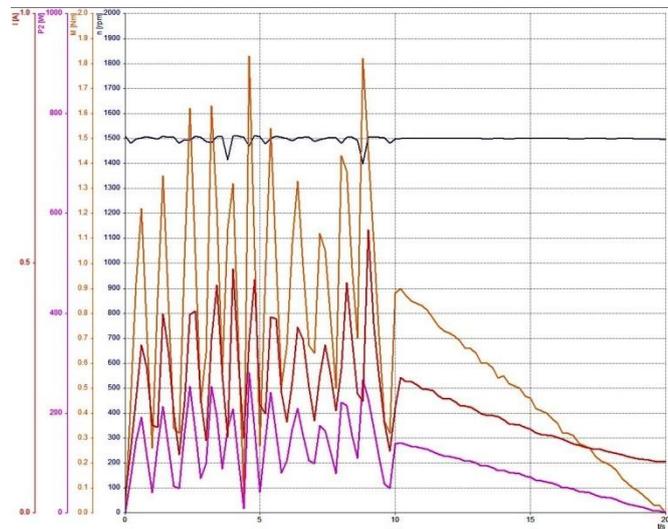


Figure 2. Mechanical and electrical characteristics for varying torque with time, at an excitation current of $I_{\text{err}}=3\text{ A}$, in 10s

From the analysis of the studied graph, in figure 2 it is observed that the speed has small variations at linear increasing and decreasing torque up to the value of 1.63Nm . From this value, the motor tends to become out of sync, especially when the motor torque drops. Speed is variable and drops to 1400rpm . At variations that return to smaller torques, it returns to the synchronism speed, but then, the speed variation returns at a sudden increase of torque to 1.8Nm .

For this reason it was found appropriate to see what happens to the synchronous machine if it has the same torque variations, but over a 50s time period, shown in Figure 3.

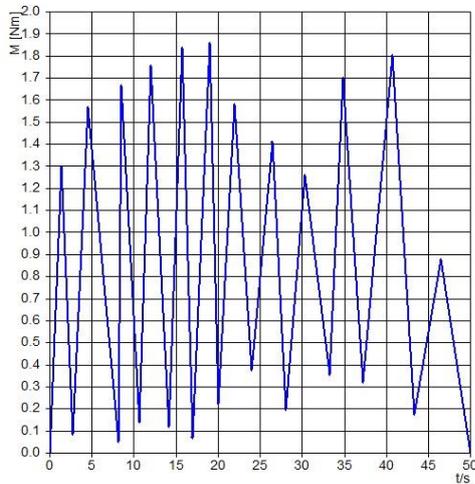


Figure 3. Variable imposed torque characteristic for $I_{err}=3$ A, in 50s

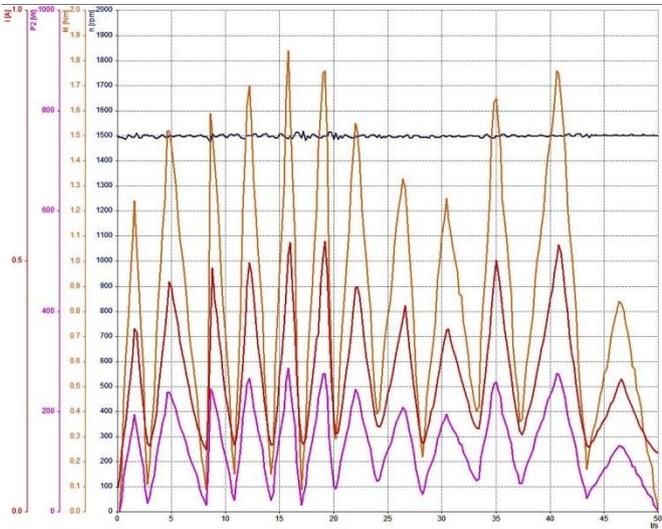


Figure 4. Mechanical and electrical characteristics for varying torque with time, at an excitation current of $I_{err}=3$ A, in 50s

Analyzing the figure 4, in which the torque curve was kept at the same motor torque values but with a run time of 50s, the following is observed:

The speed is kept relatively constant at linear increasing and decreasing variations such that it fits within a 10% variability. We need to study how the synchronous generator supports these variations.

Next, it was studied how the synchronous motor behaves at sudden torque variations because nature can be unpredictable and can accelerate or brake the motor's shaft.

We have imposed the following torque characteristic, which looks like in figure 5.

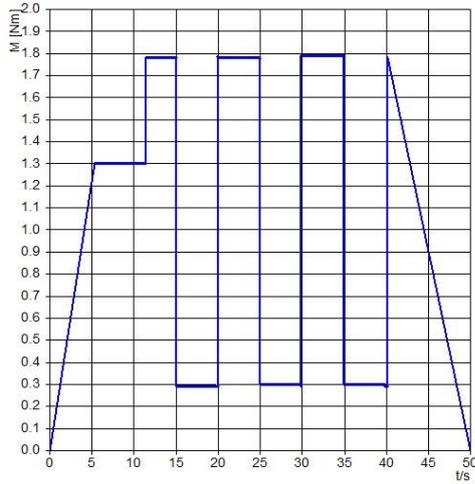


Figure 5. Variable imposed torque characteristic for $I_{err}=3$ A, in 50s

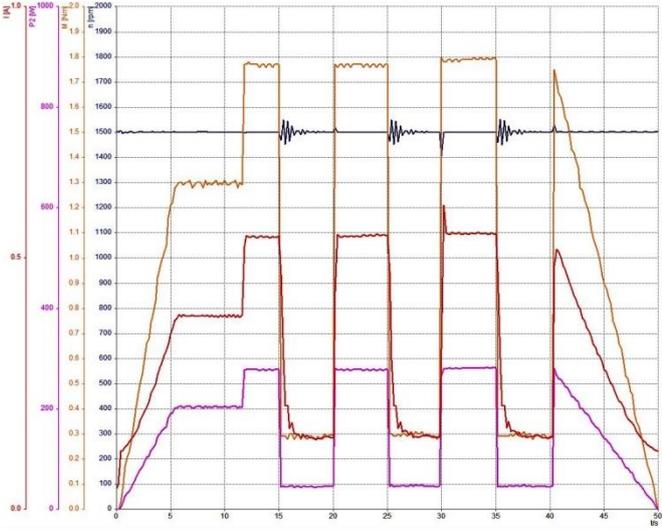


Figure 6. Mechanical and electrical characteristics for sudden varying torque with time, at an excitation current of $I_{err}=3$ A, in 50s

I considered the motor is starting and has a linear torque increase from 0 to 1.3Nm. It is kept at this value and after 7 seconds, the torque increases sharply to 1.8Nm.

After 4s it suddenly increases to 1.8Nm and after another 5 seconds it drops to 0.3Nm. After this value, the sudden increase and decrease of torque is maintained until 40s, after which it decreases linearly from 1.8Nm to 0Nm. The results in figure 6 were obtained.

From the graph analysis, figure 6, it is observed that the speed is kept constant at the increasing value up to 1.8Nm. However, there is a variation of the speed at the sudden decrease of the torque, which is repeated at each decrease. The electrical current and mechanical power keep the torque characteristic. In conclusion, the motor is slightly offset from synchronism by sudden torque drops, but it does not go out of synchronism.

For this reason it was considered necessary to observe what happens to the speed at variable values of increasing and decreasing values of the motor torque (figure 7).

From the graph analysis in figure 8, it is observed that the speed is kept constant at the increase value up to 1.8Nm. However, there is a variation of the speed at the sudden decrease of the torque, which is repeated at each decrease, but the variations are smaller, with the decrease of the torque value.

The electrical current and mechanical power keep the torque characteristic. In conclusion, the motor is slightly offset from synchronism at sudden torque drops, but it does not go out of synchronism.

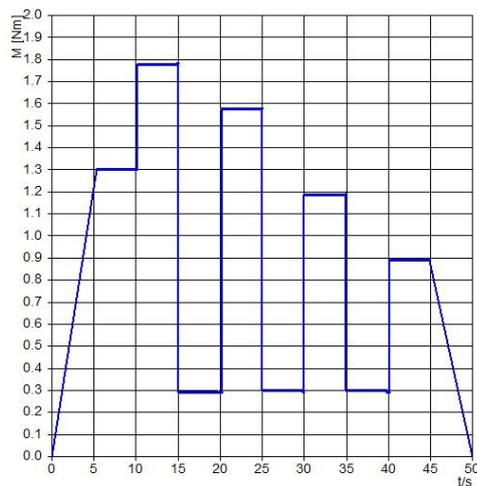


Figure 7. Imposed torque characteristic for $I_{err}=3$ A, in 50s

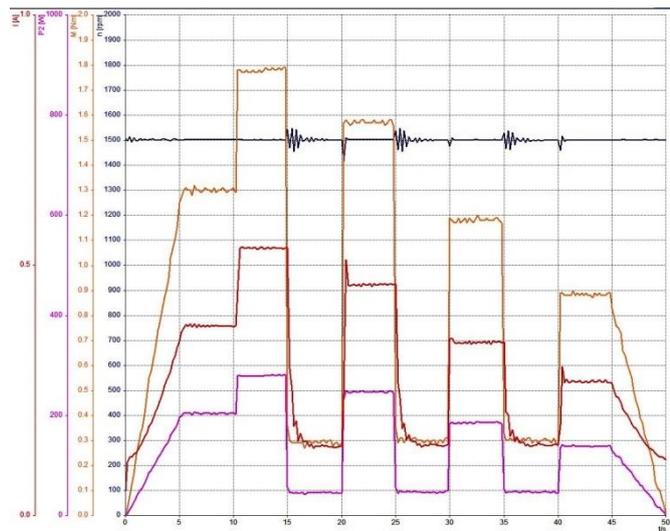


Figure 8. Mechanical and electrical characteristics for sudden varying torque with time, at an excitation current of $I_{err}=3$ A, in 50s

6. Conclusions

In the experimental determinations performed to study the characteristics, a synchronous motor with the following characteristics was used: $P_n = 0.27\text{kW}$, $I_n = 1.5\text{A}$, $f = 50\text{Hz}$, $n = 1500\text{rpm}$, $U_{err} = 20\text{Vcc}$; $I_{err} = 4\text{A}$. The excitation source generated a fixed voltage at the excitation current value of 3A.

For the studied synchronous motor we will observe the time dependence of the following parameters: The current of the rotor circuit I [A], the mechanical power on the shaft P_2 [W], the motor torque M [Nm], the speed n [rpm].

Torque variations at the synchronous machine's shaft were imposed, and it was observed its behavior in terms of speed because any variation of torque at the shaft leads to variations of speed,

current and torque. Four different torque characteristics were set-up to observe and determine these aspects.

In the first part of this study, we considered that the variations are short-lived, and they occur for 10s, a leap of linear increasing or decreasing variation occurs for one second.

In the second part, it was considered appropriate to see what happens to the synchronous machine if it has the same torque variations, but over a 50s time period.

In the third part, it was studied how the synchronous motor behaves at sudden torque variations because nature can be unpredictable and can accelerate or brake the motor's shaft.

For this reason it was considered necessary to observe what happens with the speed at varying increasing and decreasing values of torque.

Analyzing the first two graphs, we can conclude that at linear increasing and decreasing variations, the synchronous motor keeps constant speed around the nominal synchronism value if the variations are over a period of time greater than 2s.

However, if the same variations occur in a shorter time, the motor has a fluctuating speed, but it does not exit synchronism.

From the last graphs, it is noticeable that at torque variations, the motor is slightly offset, the speed variability being higher at decreasing torque, which diminishes if the torque value on the motor shaft is lower.

7. References

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