POSSIBILITY FOR STUDY OF THE RELUCTANCE SYNCHRONOUS MOTORS DYNAMIC REGIMES

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***Abstract* – This paper presents a possibility for studying the dynamic regimes of the reluctance synchronous motors.**
There are detailed the mathematical model and the graphics obtained by simulation in certain dynamic regimes.
The reluctance synchronous motors are permanently subdued to certain electrical and mechanical disturbances. These disturbances cause dynamic regimes which can finish by a new steady state, by a continuous regime of oscillations around the synchronism speed or by an unstable regime in which the synchronism is lost.
As a consequence, the paper analyzes the influences of certain disturbances on the operation motor.
The experimental stand used and the results obtained are also presented.
Finally the main conclusions are emphasized:
- the RSM is very sensitive to the parameters variation; it results, therefore, that the simulations are very important in the machine design. A design conceived without performing preliminary simulations, regarding the machine behaviour for different values of the parameters, is a mistake.
- the RSM has got a different behaviour over different values of the torque shock, at the same inertia moment;
- the synchronism loss is conditioned by the value of the torque shock applied to it;
- the dynamic stability decreases at the same time with the supply voltage decrease (when the decrease is under a certain limit, the synchronism is lost);
- the previous conclusions emphasize the fact that the RSM static stability is dependent both on the disturbance magnitude and character and on the initial conditions;
- with the help of some simulations like the ones presented before it is possible to establish the dynamic stability limit for each RSM, which is an important work instrument for the designers of such type of motors.

Keywords: *reluctance synchronous motors, dynamic regimes, disturbances, simulations, experimental determinations.*

1. INTRODUCTION

The reluctance synchronous motors have many undoubted advantages [4], [5], [6], [7]:

- they do not have sliding contacts (no brushes and rings);
- the sparks are not allowed to occur;
- their construction is very simple;
- they are noiseless;
- they have got a high reliability etc.

In this paper there are presented aspects regarding the dynamic regimes.

2. MATHEMATICAL MODEL

The equations detailed in [1] are the starting point, but the fact that the RSM has not got excitation winding is taken into account. The mathematical model written in the reference frame which is fixed relatively to the rotor is such obtained:

$$\begin{aligned} u_d - R_s i_d &= \frac{d\psi_d}{dt} - \omega\psi_q \\ u_q - R_s i_q &= \omega\psi_d + \frac{d}{dt}\psi_q \\ -R_D i_D &= \frac{d\psi_D}{dt} \\ -R_Q i_Q &= \frac{d\psi_Q}{dt} \end{aligned} \tag{1}$$

where

$$\begin{aligned} \psi_d &= L_d i_d + L_{dh} i_D \\ \psi_q &= L_q i_q + L_{qh} i_Q \\ \psi_D &= L_{dh} i_d + L_D i_D \\ \psi_Q &= L_{qh} i_q + L_Q i_Q \end{aligned} \tag{2}$$

The following equations are obtained by replacing (2) in (1):

$$\begin{aligned} u_d - R_s i_d + \omega L_q i_q + \omega L_{qh} i_Q &= L_d \frac{di_d}{dt} + L_{dh}\frac{di_D}{dt} \\ u_q - R_s i_q - \omega L_d i_d - \omega L_{dh} i_D &= L_q \frac{di_q}{dt} + L_{qh}\frac{di_Q}{dt} \\ -R_D i_D &= L_{dh}\frac{di_d}{dt} + L_D\frac{di_D}{dt} \\ -R_Q i_Q &= L_{qh}\frac{di_q}{dt} + L_Q\frac{di_Q}{dt} \end{aligned} \tag{3}$$

The motion equation is atached to these relations:

$$\frac{3}{2}p\left(\psi_d i_q - \psi_q i_d\right) - m_r = \frac{J}{p}\frac{d\omega}{dt}, \qquad (4)$$

respectively

$$\frac{3}{2}p\left(L_d i_d i_q + L_{dh} i_D i_q - L_q i_q i_d - L_{qh} i_Q i_d\right) - m_r = \frac{J}{p}\frac{d\omega}{dt} \qquad (5)$$

The relations (3) and (5) can also be written in matrix form:

$$\begin{bmatrix} L_d & 0 & L_{dh} & 0 & 0 \\ 0 & L_q & 0 & L_{qh} & 0 \\ L_{dh} & 0 & L_D & 0 & 0 \\ 0 & L_{qh} & 0 & L_Q & 0 \\ 0 & 0 & 0 & 0 & \frac{J}{p} \end{bmatrix} \cdot \frac{d}{dt}\begin{bmatrix} i_d \\ i_q \\ i_D \\ i_Q \\ \omega \end{bmatrix} = $$

$$= \begin{bmatrix} u_d - R_s i_d + \omega L_q i_Q + \omega L_{qh} i_Q \\ u_q - R_s i_q - \omega L_d i_d - \omega L_{dh} i_D \\ -R_D i_D \\ -R_Q i_Q \\ \frac{3}{2}p\left(L_d i_d i_q + L_{dh} i_D i_q - L_q i_q i_d - L_{qh} i_Q i_d\right) - m_r \end{bmatrix} \qquad (6)$$

3. SIMULATION OF SOME DISTURBANCES

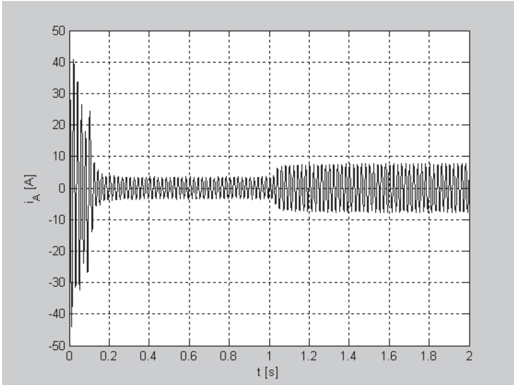
The reluctance synchronous motors are permanently subdued to some electrical and mechanical disturbances. These disturbances cause dynamic regimes which can finish by a new steady state, by a continuous regime of oscillations around the synchronism speed or by an unstable regime in which the synchronism is lost.

There are two types of disturbances and, in relation with them, the stability study have different denominations:
- low value disturbances, defining the so-called static stability;
- finite value disturbances, defining the dynamic stability.

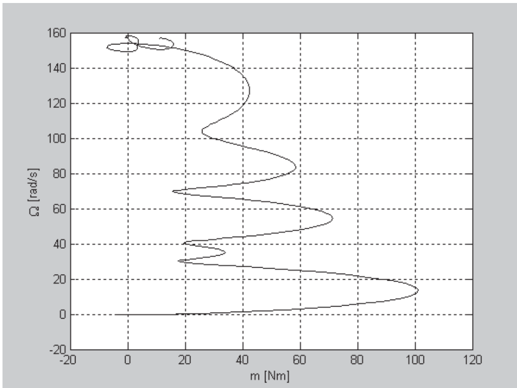
In those which follow the second case is referred to.
In order to analyze this problem from mathematical point of view, the mathematical model presented before will be used. It is necessary to make the numerical integration of these equations and the study of the system answer to different disturbing quantities. The study depends not only on the initial conditions, but also on the disturbance magnitude and character.

The simplest disturbance which can be considered is **a sudden saltus of the resistant torque**.
At the beginning, it is considered that the RSM is started without load, with an inertia moment J=0,025 kg m^2 and, after one second, a resistant torque M_r=11,4 Nm (1,5M_N) is applied to the motor shaft.

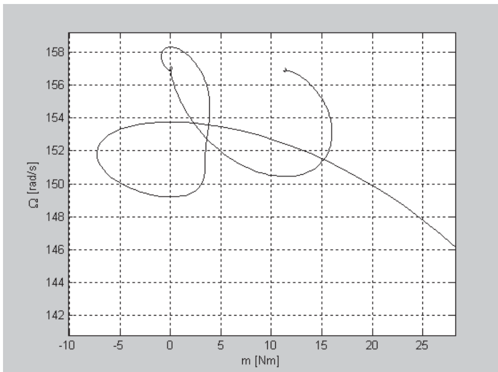
For comparison, in the following figure there are depicted the characteristics of the current, of the torque and of the speed for a similar case, but for a torque shock equal to 15,2 Nm (2M_N).



a) i_A=f(t)

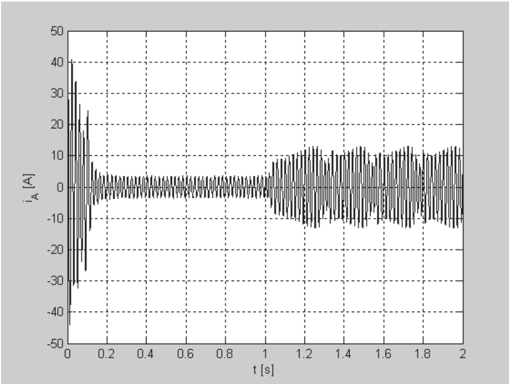


b) Ω=f(m)

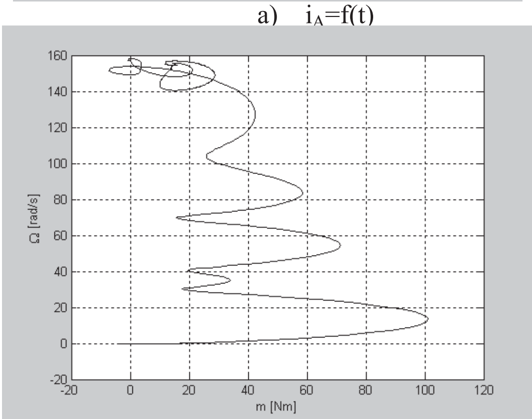


c) Zoom Ω=f(m)

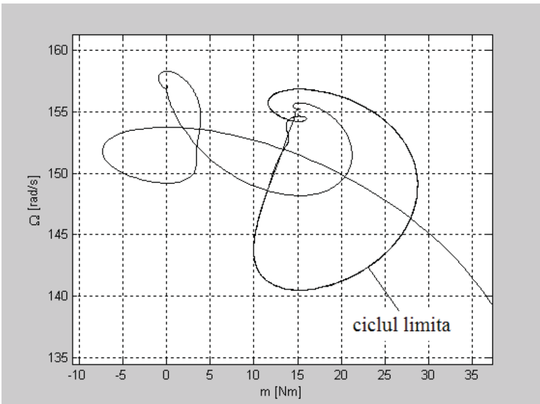
Figure 1: Characteristics obtained for a torque shock M_r=11,4 Nm (J=0,025 kg m^2).



a) i_A=f(t)



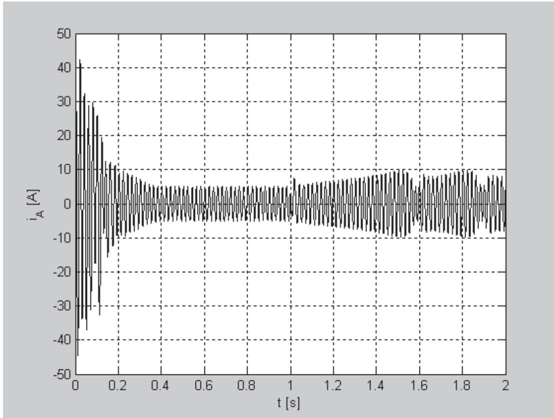
b) Ω=f(m)



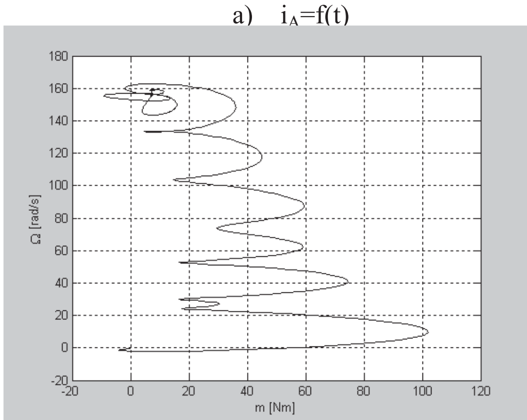
c) Zoom Ω=f(m)

Figure 2: Characteristics obtained for a torque shock M_r=11,4 Nm (J=0,025 kg m^2).

Another perturbation can be **the supply voltage decrease** during the operation. In order to emphasize the effects of this disturbance on the RSM dynamic stability, it has been considered that the RSM starts with rated load (M_r=7,6 Nm) with an inertia moment J=0,025 kg m^2. After synchronization, at t=1 s, a voltage decrease occurs, from 220 V to 170 V (fig. 3).



a) i_A=f(t)



b) Ω=f(m)

Figure 3: Characteristics obtained for the case of the voltage decrease to the value U=170 V (M_r=7,6 Nm, J=0,025 kg m^2).

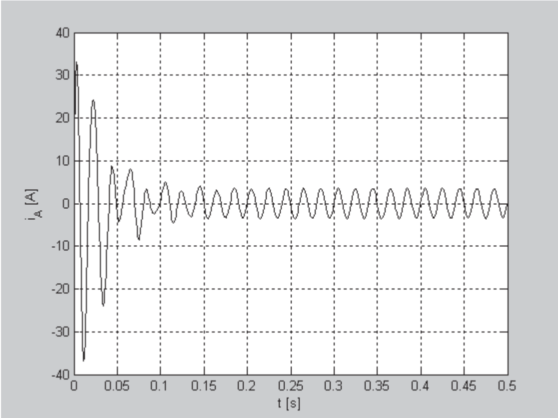
4. ASYNCHRONOUS STARTING SIMULATION

The reluctance synchronous motors develop electromagnetic torque only when the rotor speed is equal to the stator rotating field speed. From this reason, both the starting and the synchronization and the operation stability keeping in different exploitation conditions, are essential problems which must be analyzed and solved in the design stage.

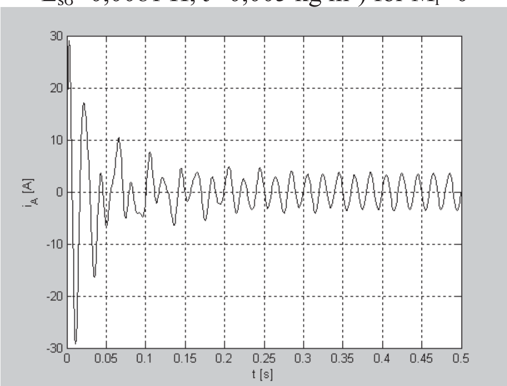
As it is known, in order to make asynchronous starting, the reluctance synchronous motors are fitted out with a starting cage. This is also the case of the motor which will be analyzed further on (also used in the experiments detailed in the final part of the paper).

In those which follow it is assumed that the machine parameters are modified in turn and these modifications effects are analyzed in the case of the dynamic regime we mentioned before, considered as being representative. For doing this, the program detailed before has been used for a RSM having the following parameters:

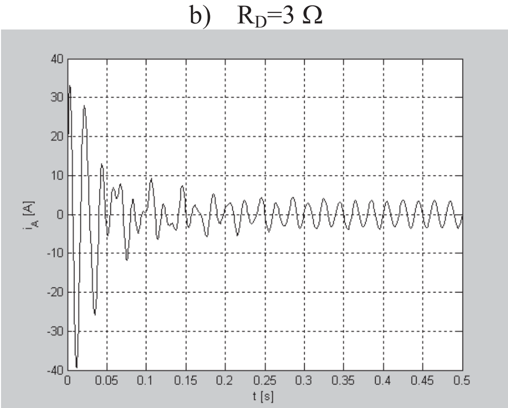
R_s=3,77 Ω; R_D=1,5 Ω; R_Q=4,5 Ω; L_d=0,281 H; L_q=0,081 H; $L_{s\sigma}$=0,0081 H; $L_{D\sigma}$=0,0059 H; $L_{Q\sigma}$=0,0067 H; p=2; J=0,005 kg m^2.



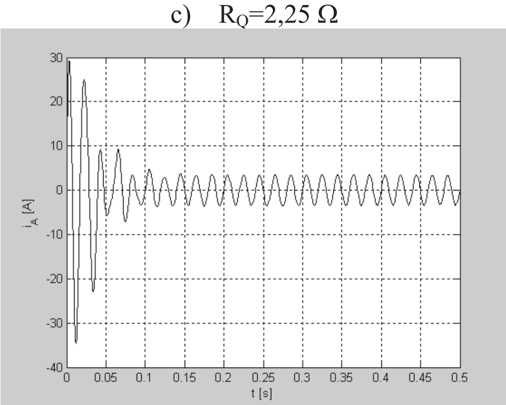
a) Real parameters (R_D=1,5 Ω; R_Q=4,5 Ω; $L_{s\sigma}$=0,0081 H; J=0,005 kg m^2) for M_r=0



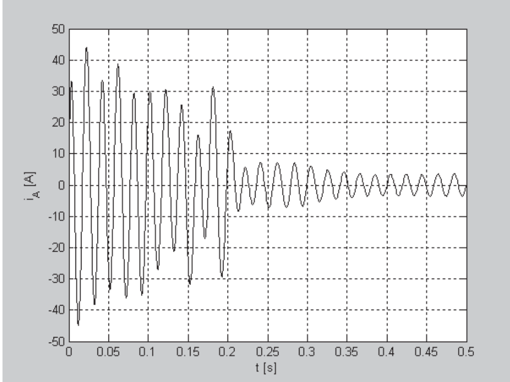
b) R_D=3 Ω



c) R_Q=2,25 Ω

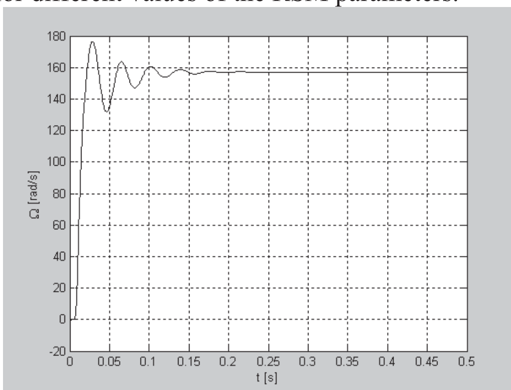


d) $L_{s\sigma}$=0,012 H

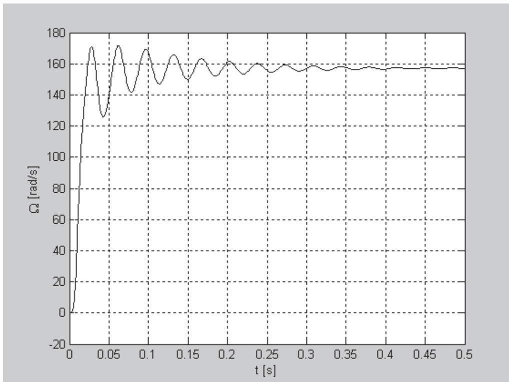


e) J=0,05 kg m^2

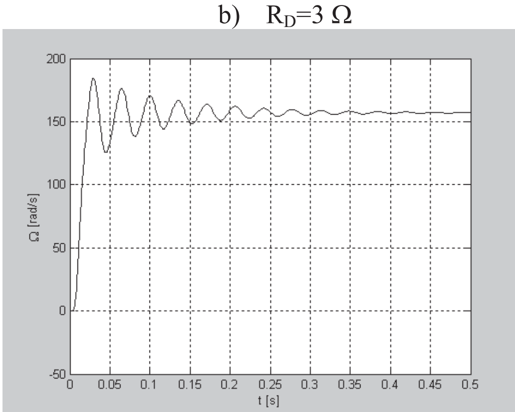
Figure 4. Characteristics i_A=f(t) for different values of the RSM parameters.



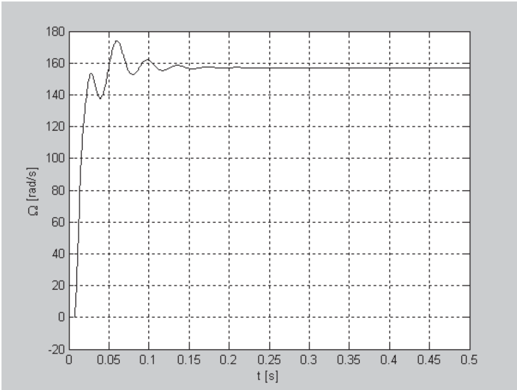
a) Real parameters (R_D=1,5 Ω; R_Q=4,5 Ω; $L_{s\sigma}$=0,0081 H; J=0,005 kg m^2) for M_r=0



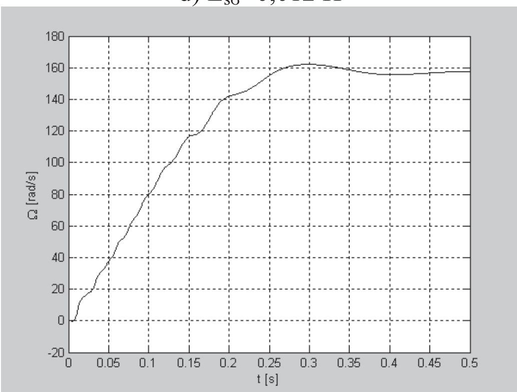
b) R_D=3 Ω



c) R_Q=2,25 Ω



d) $L_{s\sigma}$=0,012 H



e) J=0,05 kg m^2

Figure 5: Characteristics Ω=f(t) for different values of the RSM parameters.

5. EXPERIMENTAL DETERMINATIONS

In order to perform the experimental tests afferent to this paper, a test stand has been developed; its structure can be adapted to the steady state and dynamic regime tests.

The used test scheme is detailed in the following figure [3].

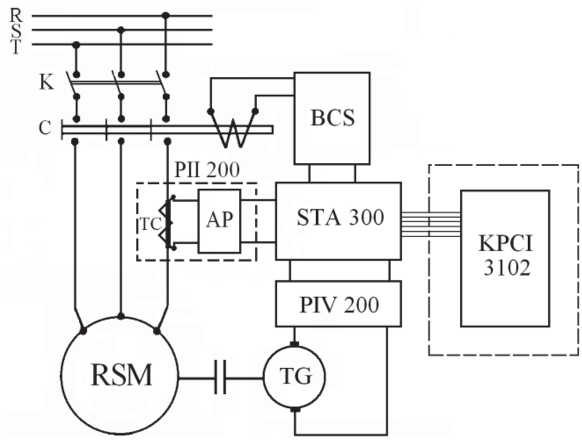


Figure 6: Experimental scheme.

The meaning of the notations from the previous figure are:

- KPCI 3102 – data acquisition board;
- RSM – variable reluctance synchronous motor;
- BCS – command and synchronization block;
- PII 200 – Hall probe current transformer;
- PIV 200 – adaptation and protection block;
- STA 300 – connection block;
- TG – speed-indicating generator.

The phase current and the speed have been acquired during a transient regime of no-load asynchronous starting, with the help of the previous scheme (figures 7 and 8).

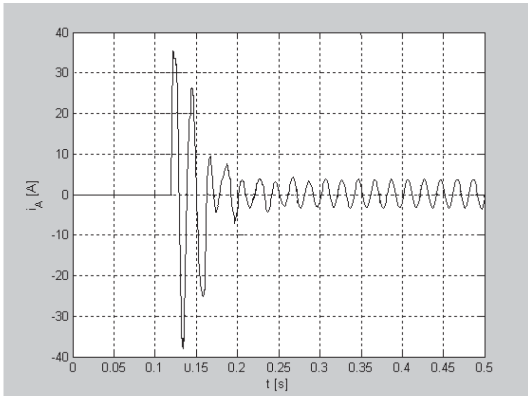


Figure 7: Current variation during the asynchronous starting.

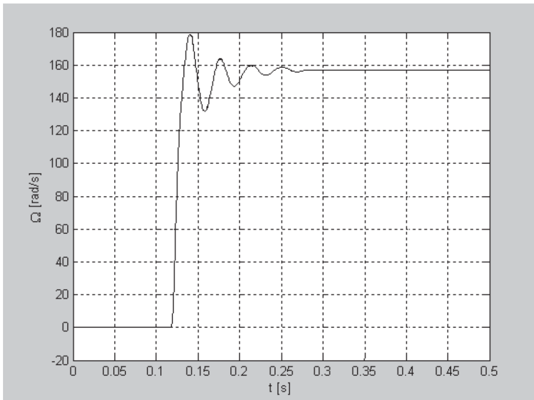


Figure 8: Speed variation during the asynchronous starting.

As it can be noticed, in order to catch better the first moment of the starting, the acquisition process has been initiated before the motor supply, with the help of BCS.

By comparing these graphic results to the results obtained by simulation (fig. 7 to 4.a, fig. 8 to fig. 5.a, respectively), it can be concluded that the experimental determinations confirm the validity of the simulations performed in dynamic regime.

5. CONCLUSIONS

The following conclusions emerge from the analysis of the graphics obtained in the **case of the disturbances**:
- as it can be noticed from the comparison of the figures 1 and 2, the RSM has a different behaviour over the different values of the torque shock, at the same inertia moment; thus, in the first case (M_r=1,5M_N) the motor enters a new steady state, without losing the synchronism, while in the second case (M_r=2M_N) the motor enters an unstable regime; the synchronism loss is conditioned by the value of the applied torque shock;
- in the figure 2 it is noticed that the torque oscillations are not very great and that the speed oscillates around an under-synchronous speed; moreover, the operation point, in coordinates Ω=f(m), finally displaces on a limit cycle;
- the dynamic stability decreases at the same time with the supply voltage decrease (the decrease under a certain limit leads to the synchronism loss);
- the previous conclusions emphasize the fact that the RSM static stability is dependent both on the disturbance magnitude and character and on the initial conditions;
- with the help of some simulations like the ones presented before it is possible to establish the dynamic stability limit for each RSM, which is an important work instrument for the designers of such type of motors.

The following conclusions have emerged from the analysis of the previous graphics obtained in the **case of the asynchronous starting**:
- the increase of the resistance R_D has a non-stabilizing effect, materialized, in the case of its increase, in an increase of the transient regime duration;
- a low value of the resistance R_Q, even in the case of a null resistant torque and a low inertia moment, can lead to an unstable operation; in the analyzed case, its decrease leads to the increase of the transient regime duration (fact which is visible especially on the speed curve);
- the increase of the stator leakage inductivity has a weak stabilizing effect;
- the inertia moment increase makes the synchronization to be reached after a great number of oscillations of the current;
- the speed is considerably dependent on the chosen parameters values, especially on the inertia moment value, (for an increased J, the speed oscillations decrease, but the starting time increases);
- the shock current is not strongly influenced by the parameters variation and the load starting does not cause the significant increase of this current over the case of the no-load starting.

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