Supply voltage and resistant torque influence on dynamic characteristics of reluctance synhronous motors

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***Abstract* - The reluctance synchronous motors, as well as the synchronous permanent magnet motors, are the best solution from technical and economic point of view, for low and middle powers. This paper presents a series of simulations of the dynamic regime behaviour for such a motor. The simulations are carried out for cases of stepped modification of the supply voltage and the resistant torque, respectively. There are presented the mathematical model used (the two axes theory mathematical model of the motor written in matrix form) and the Matlab simulation program for the case of the supply voltage modification. There are detailed five sets of characteristics obtained for five concrete situations of torques, voltages and inertia moments. Finally there are presented the conclusions obtained by study: 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 reluctance synchronous motors has 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 applied torque shock; the previous conclusions emphasize the fact that the reluctance synchronous motors 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 reluctance synchronous motors, which is an important work instrument for the designers of such type of motors.**

Keywords - *simulatons, reluctance synchronous motor, mathematical model, Matlab, design*

I. Introduction

The reluctance synchronous motors (RSM), as well as the synchronous permanent magnet motors, are the best solution from technical and economic point of view, for low and middle powers [1], [8], [11].

The larger and larger utilization of voltage and frequency static converters makes them very useful in driving electrical vehicle, tools advance, automatic positioning systems etc. [6], [9], [10].

Owing to the feature of keeping unchanged speed, irrespective of external disturbances (if they do not exceed certain limits) as well as because they are noiseless, these motors have found applications in air conditioning installations and in installations of power electronic equipments ventilation [7].

These are only a few possible applications of the reluctance synchronous motors which justify this research.

Forwards there will be presented a few simulations from a larger study regarding the behaviour in certain dynamic regimes caused by some external disturbances (supply voltage modification and step increase of the resistant torque).

II. Mathematical Model

In order to carry out the simulations, the two axes theory mathematical model of the motor written in the following simplified matrix form has been used [2], [3], [4], [5]:

$$|U| = |A|\frac{d}{dt}|X| + |B||X| \tag{1}$$

where

$$U = \begin{vmatrix} u_d & u_q & u_E & 0 & 0 \end{vmatrix}^T \tag{2}$$

and

$$X = \begin{vmatrix} i_d & i_q & i_E & i_D & i_Q \end{vmatrix} \tag{3}$$

The matrixes A and B are detailed in the frame of the Matlab program presented in III.

III. Matlab Program

Starting from this model, there has been conceived a simulation Matlab program [12], [13].

The integration function used in this program is detailed forwards (the exemplification is made for the case of voltage disturbance).

```
function xdot = valdot(t, x)
  Rs = 3.77;
  RD = 1.5;
  RQ = 4.5;
  Lss = 0.0081;
  LDs = 0.0059;
  LQs = 0.0067;
  Ld=0.281;
  Lq=0.081;
  J = 0.025;
```

```
U = 220;
if t > 1
   U=170;
end
p = 2;
Lmd = Ld-Lss;
Lmq = Lq-Lss;
omega1 = 2 * pi * 50;

A = [ Lss+Lmd  0       Lmd      0
     0       Lss+Lmq  0       Lmq
     Lmd      0       LDs+Lmd  0
     0       Lmq      0       LQs+Lmq ];

 B = [ Rs            -x(5)*(Lss+Lmq)  0        -x(5)*Lmq
       x(5)*(Lss+Lmd)  Rs              x(5)*Lmd  0
       0              0               RD       0
       0              0               0        RQ  ];

  m = 1.5 * p * ( (Lmd - Lmq) * x(1) * x(2) + Lmd *
x(3) * x(2) - Lmq * x(1) * x(4) );

  ud = U * sqrt(2) * cos(omega1 * t - x(6));
  uq = U * sqrt(2) * sin(omega1 * t - x(6));
  udq = [ud uq 0 0]';
  xcr = x(1:4);
  xpcr = inv(A) * (udq - B * xcr);
  xdot(1:4) = xpcr;
  mr = 7.6;
  xdot(5) = p / J * (m - mr);
  xdot(6) = x(5);
  xdot=xdot;
```

IV. SIMULATIONS

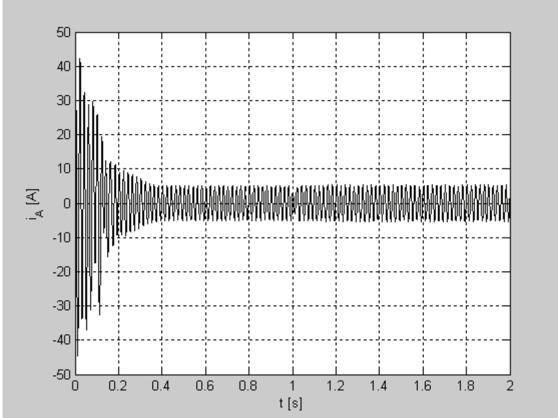
With the help of this program there have been obtained a series of simulations regarding two situations of disturbances which may occur in practice:

a) supply voltage decrease;

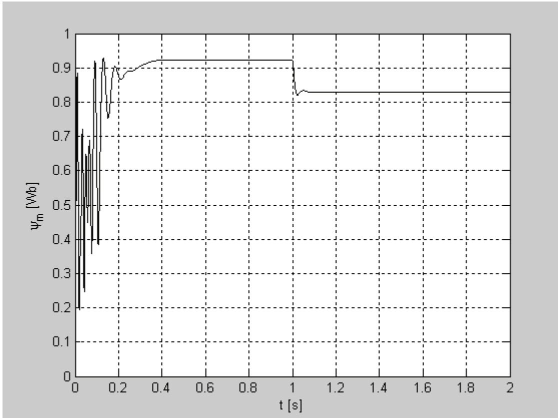
b) step increase of the resistant torque.

In order to carry out these simulations there have been considered the data corresponding to a flux barrier reluctance synchronous motor rated at 1,5 kW. These data are detailed in the program presented in the previous paragraph.

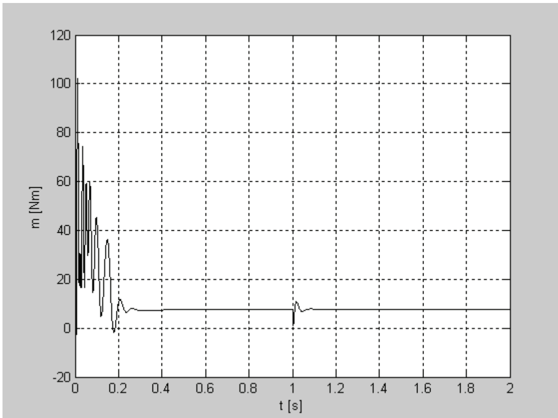
a) The simplest possible disturbance is **the** supply voltage decrease during the operation. For emphasizing the effects of this disturbance on the RSM dynamic stability, it has been considered that the RSM starts with the rated load (Mr=7,6 Nm), with an inertia moment J=0,025 kg m^2. After synchronization, at t=1 s, a voltage decrease occurs, from 220 V to 200 V (fig. 1) and from 220 V to 170 V (fig. 2).



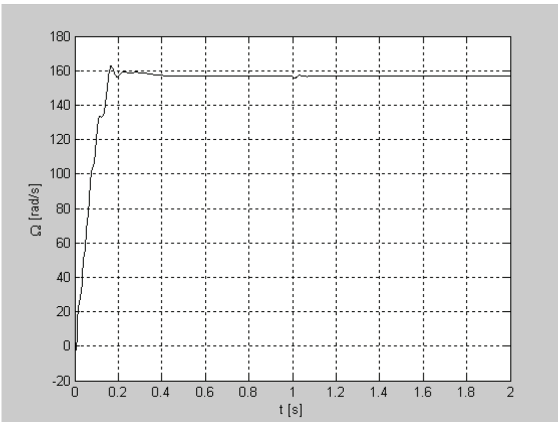
a) i_A=f(t)



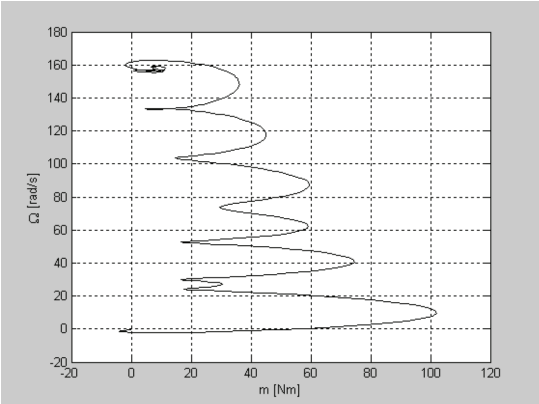
b) Ψ_m=f(t)



c) m(t)

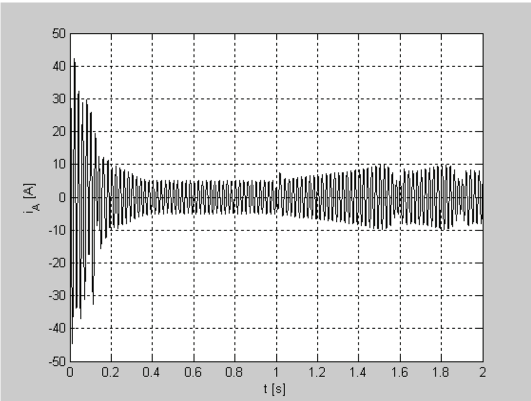


d) Ω=f(t)

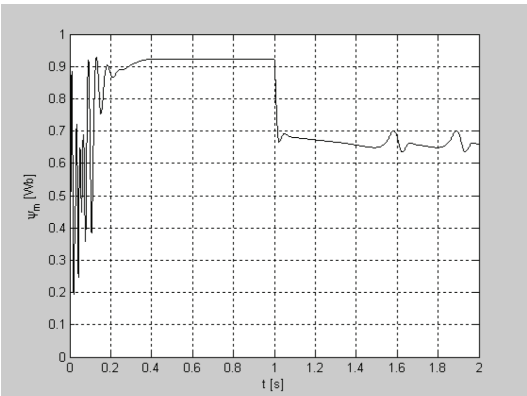


e) Ω=f(m)

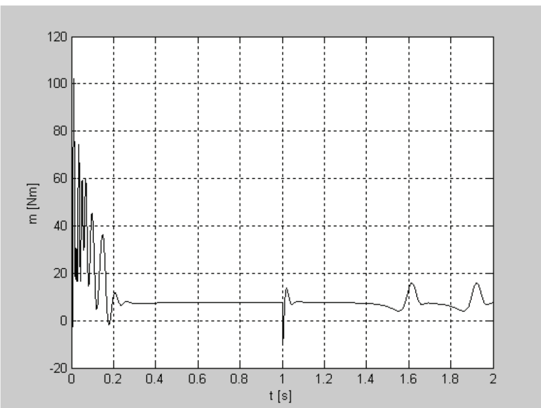
Fig. 1. Characteristics obtained for the case of the voltage decease to the value U=200 V (Mr=7,6 Nm, J=0,025 kg m2).



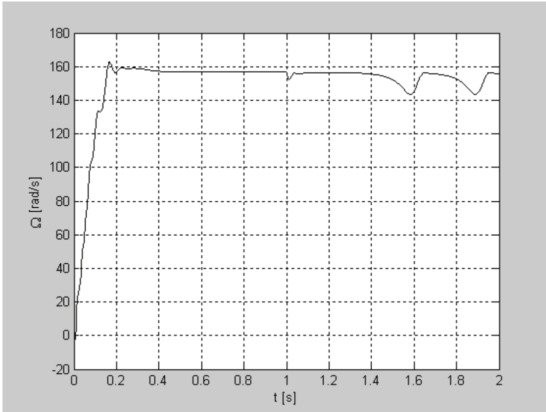
a) i_A=f(t)



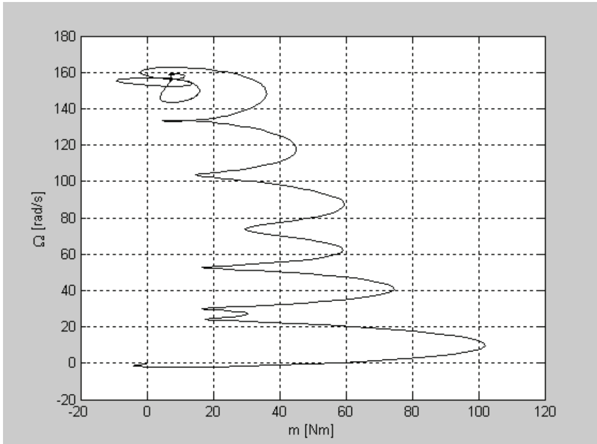
b) Ψ_m=f(t)



c) m(t)



d) Ω=f(t)



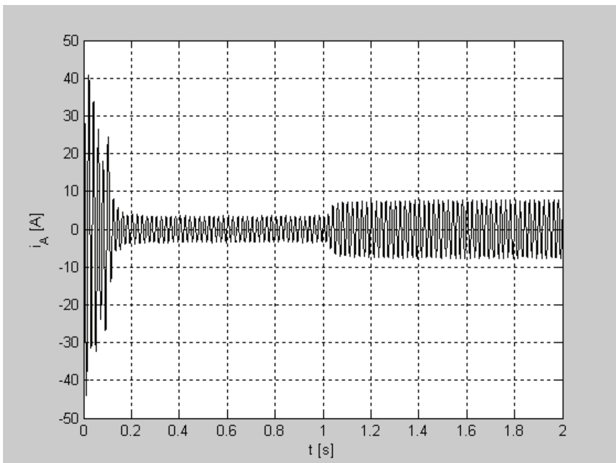
e) Ω=f(m)

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

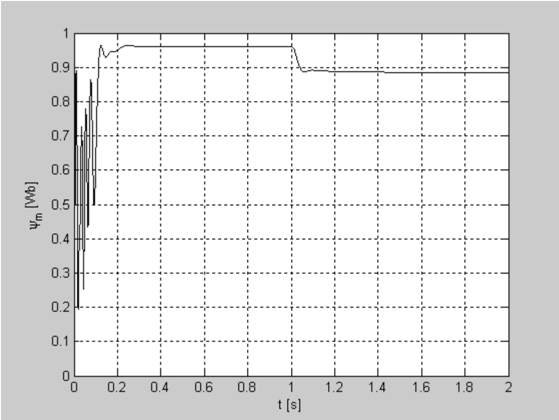
b) Another possible disturbance is a sudden shock of the resistant torque.

Resistant torque of different values has been applied in the case of different inertia moments.

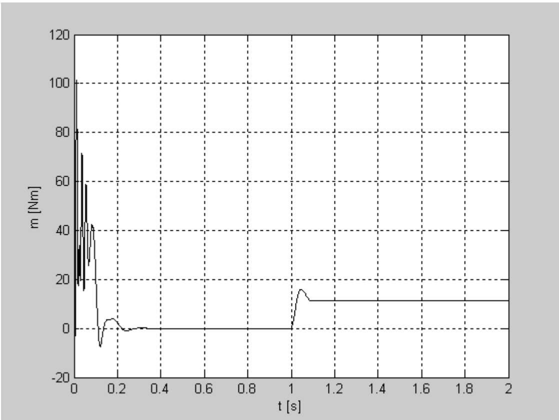
Figures 3, 4 and 5 show the characteristics obtained with the help of the program detailed in the previous paragraph for tree concrete situations.



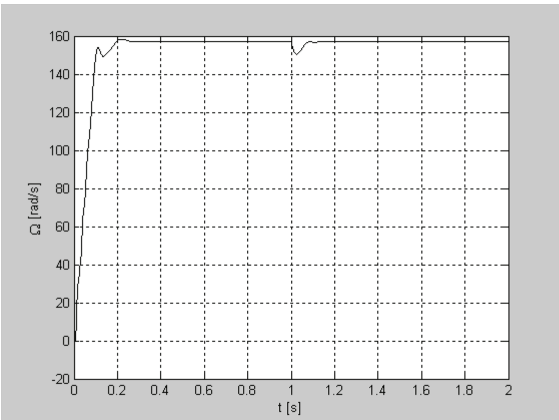
a) i_A=f(t)



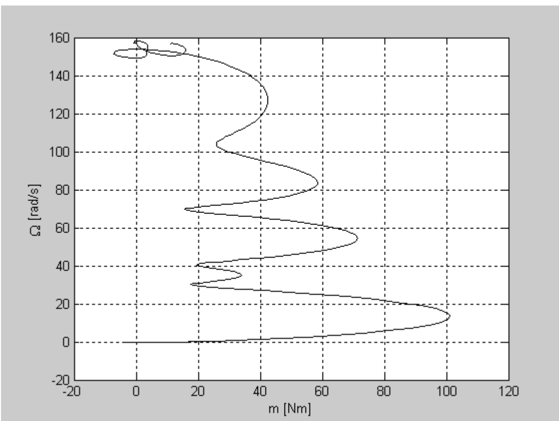
b) Ψ_m=f(t)



c) m(t)

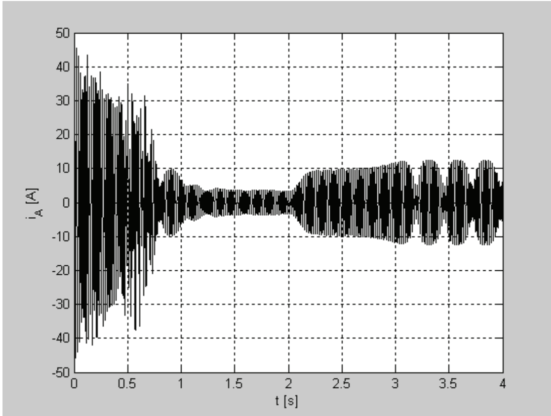


d) Ω=f(t)

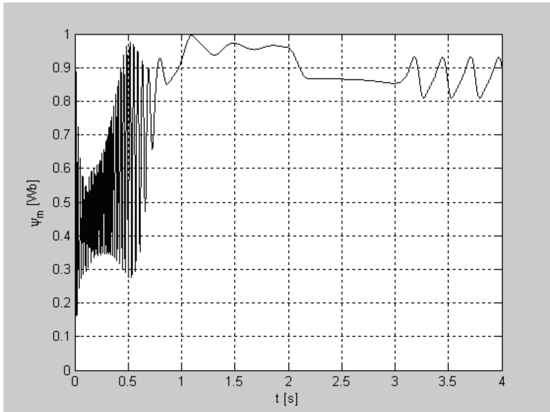


e) Ω=f(m)

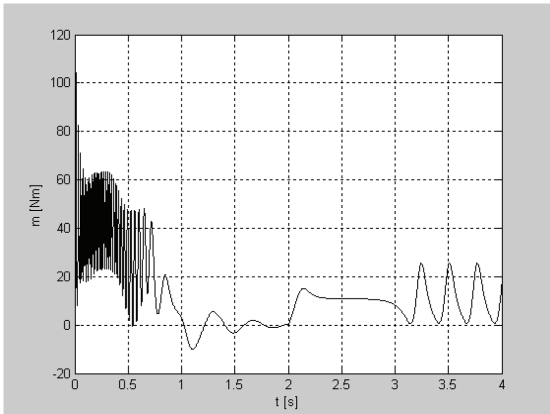
Fig. 3. Characteristics M_r=11,4 Nm (J=0,025 kg m^2).



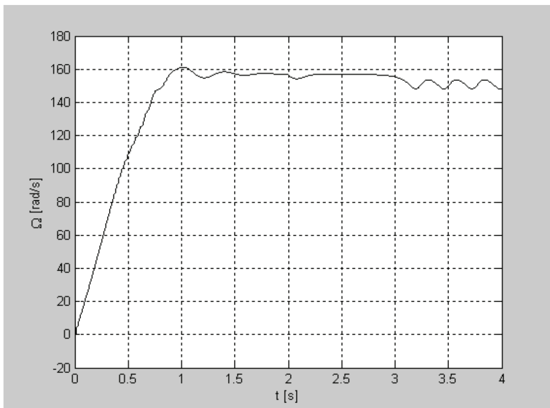
a) i_A=f(t)



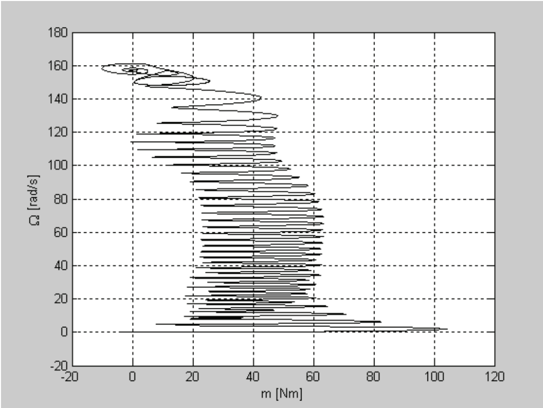
b) Ψ_m=f(t)



c) m(t)

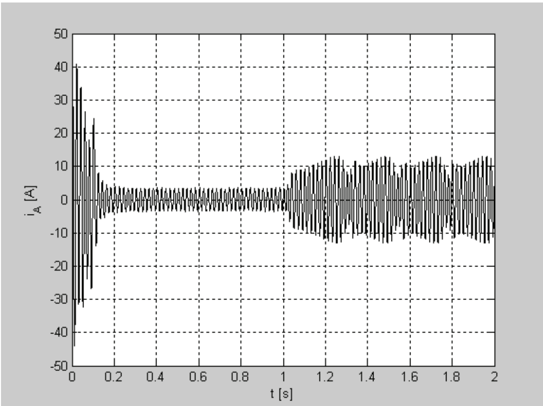


d) Ω=f(t)

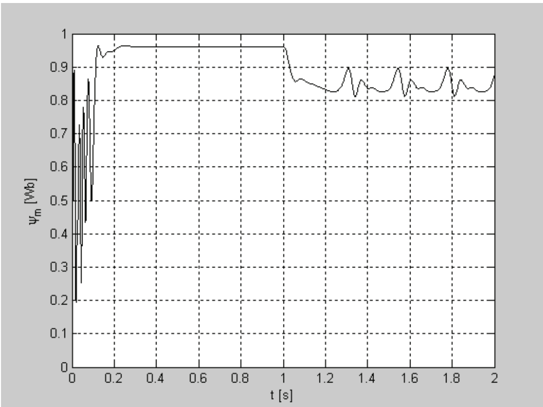


e) Ω=f(m)

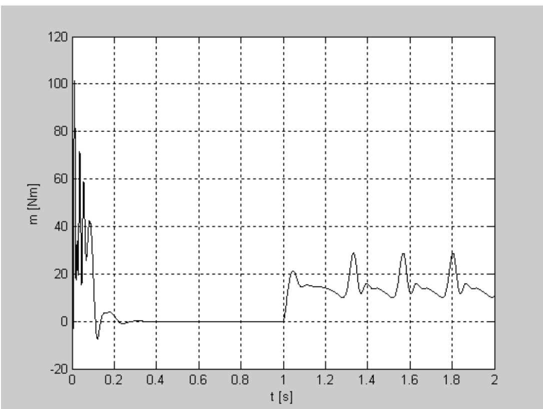
Fig. 4. Characteristics for a torque shock M_r=11,4 Nm (J=0,18 kg m^2).



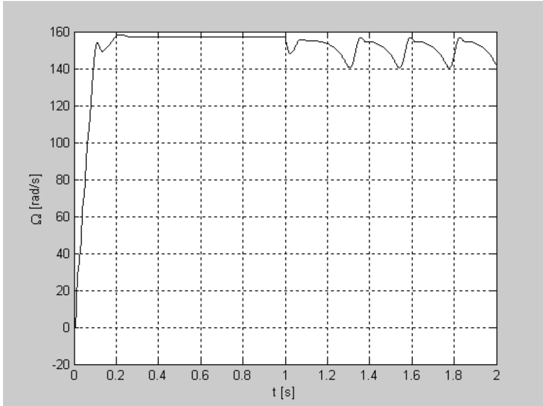
a) i_A=f(t)



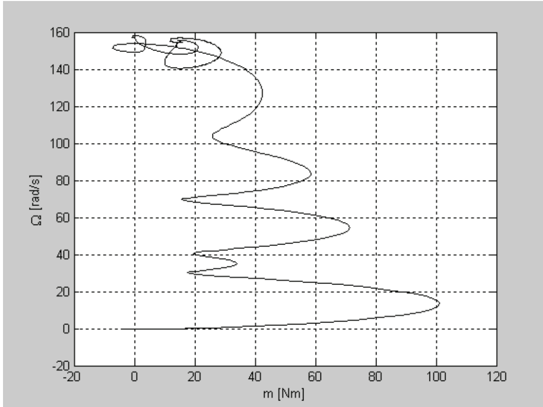
b) Ψ_m=f(t)



c) m(t)



a) Ω=f(t)



e) Ω=f(m)

Fig. 5. Characteristics obtained for a torque shock M_r=15,2 Nm (J=0,025 kg m^2).

V. Conclusions

The following conclusions result from the analysis of the previous graphs:

- comparing the characteristics plotted in figures 6.1 and 6.2 it is noticed that the dynamic stability decreases at the same time with the supply voltage decrease (the synchronism gets lost for a decrease under a certain limit);

- as it is noticed by comparing figure 6.3 with 6.5, the reluctance synchronous motor behaves differently to different values of the torque shocks, for 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, whereas in the second case (M_r=2M_N) the motor enters an unstable state; so, the synchronism is dependent on the value of the torque shock applied to the motor;

- comparing the results obtained in figure 6.4 with the results from figure 6.3 it is noticed that the same torque shock has different influences depending on the total inertia moment; so, if in the first case (J=0,025 kg m^2) the dynamic state is followed by a steady state of synchronism, in the second one (J=0,15 kg m^2) the synchronism gets lost; as a consequence, the dynamic stability decreases when the inertia moment increases;

- figure 6.4 shows that if the rotor enters the oscillations, it does not reach the synchronism anymore; moreover, as in the case of figure 6.5, the operation point, in coordinates Ω=f(m), finally moves on a limit cycle, too;

- figure 6.5 shows that the torque oscillations are not very large and the speed oscillates round a sub-synchronous speed; in addition, the operation point, in coordinates Ω=f(m), finally moves on a limit cycle.

REFERENCES

[1] M. Chomat, M.D. Cullow, “Simulation and Control of Saturated Synchronous Reluctance Machine”, EPE, Trondheim, 1997, pp. 134-139.

[2] M.A. Enache, S. Enache, “Theoretical aspects regarding static stability of reluctance synchronous motors”, The 9-th International Conference on Electromechanical and Power Systems, Chişinau, SIELMEN 2013, CD Proceedings - ISBN 978-606-13-1560-4, 2013.

[3] M.A. Enache, S. Enache, M. Dobriceanu, “Considerations regarding dynamic regimes of reluctance synchronous motors”, 19-th International Symposium on Power Electronics, Electrical Drives, Automation and Motion SPEEDAM 2008, Ischia, Italy, June 11-13, ISBN: 978-1-4244-1664-6, 2008, pp. 284-289.

[4] S. Enache, A. Campeanu, I. Vlad, M.A. Enache, “Simulation of Some Disturbances Influence on Dynamic Behaviour of Reluctance Synchronous Motors”, The 9-th International Conference on Electromechanical and Power Systems, Chişinau, SIELMEN 2013, CD Proceedings - ISBN 978-606-13-1560-4, 2013, pp. 245-249.

[5] S. Enache, A. Campeanu I. Vlad, M.A. Enache, “Possibility for analysis of the reluctance synchronous motors dynamic stability”, Advanced Topics in Electrical Engineering (ATEE), 2011 7th International Symposium, 2011 , pp. 1-6.

[6] J.R. Hendershot, T.J.E. Miller, D.A. Staton, , R. Lagerquist, “The Synchronous Reluctance Motor for Motion Control Applications”, 21st Annual Symposium on Incremental Motion Control Systems and Devices, San Jose, California, June 15-19, 1992.

[7] L. Hertel, W. Hofmann, “Theory and Test Results of a High Speed Bearingless Reluctance Machine”, Proceedings of PCIM 1999, Nurenberg, 1999, pp. 143-147.

[8] H. Hofmann, S. R. Sanders, “Hygh-speed Synchronous Reluctance Machine with Minimized Rotor Losses”, Conference Proceedings of the 1998 IAS Annual Meeting.

[9] V.B. Honsinger, “Steady-State Performance of Reluctance Machines”, IEEE Transaction on Power Apparatus and Systems, vol. PAS-90, no. 1, 1991, pp. 305-317.

[10] T.J.E. Miller, C. Cossar, A.J. Hutton, D.A. Staton, “Design of a Synchronous Reluctance Motor Drive”, IEEE Trans. IAS, Vol. 27, No. 4, July/August, 1991.

[11] E. Spunei, L. Padeanu, F. Piroi, I. Piroi, G. Liuba, “Research on decreasing the cost price for the synchronousHG”, Buletin AGIR, No. 3, 2013, pp. 163-168.

[12] ***, Matlab User's Guide, The MathWorks, Inc., Natick, Massachusetts, 2006.

[13] ***, Matlab Reference Guide, The Math Works, Inc., Natick, Massachusetts, 2006.