UNIVERSITY OF CRAIOVA
FACULTY OF ENGINEERING IN ELECTROMECHANICS,
ENVIRONMENT AND INDUSTRIAL INFORMATICS

ANALYSIS OF SOME BASIC PROCESSES SPECIFIC TO RELUCTANCE SYNCHRONOUS MOTOR OPERATION

SUMMARY OF THE DOCTOR'S THESIS

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CONTENT

The utilization on an ever larger scale of the reluctance synchronous machine as an element in automatic systems has imposed an ample approach, in speciality papers, of the problems regarding both the **steady state process** and the **dynamic process**.

In this context there has to be mentioned **the very important problem of the parameters correct evaluation and of their influence on the machine behaviour**. In fact, this is the main subject of this thesis.

The problems requiring development in this case are immediate.

Thus, in order to carry out an adequate study in this field, it is imposed, first of all, to evaluate the present stage in the analyzed problems.

Then, it is necessary to use an adequate mathematical model.

In addition, it is necessary to know the parameters influences on the machine behavior, both in steady-state and in dynamic conditions, both in the conventional supply case and in the case of the static converter supply, as well as on the static and dynamic stability.

Finally it is obviously necessary to check experimentally the conclusions obtained in theoretical way, with accent on the modern methods for the machine parameters determination.

1. PRESENT STAGE IN RELUCTANCE SYNCHRONOUS MOTORS PROBLEMS

In the first chapter the present stage of the research in the analyzed problems is evaluated. In order to emphasize the RSM advantages, there are presented a series of comparative tables between these machines and the permanent magnet synchronous motors (PMSM) and the asynchronous motors (AM), respectively.

The existing constructive variants of RSM, with continuous rotation, are presented, with the advantages and the drawbacks of each of them. With this occasion, the advantages of the axially-laminated construction are emphasized; this solution leads to the greatest values of the magnetic asymmetry ratio.

The present methods for the speed adjustment of these motors are also emphasized, by presenting the conclusions emerging from a representative bibliography.

2. GENERAL-CASE MATHEMATICAL MODELS OF THE SYCHRONOUS MACHINE

This chapter emphasizes the importance of knowing the RSM mathematical model for the study of the driving systems including such machines.

In this context it can be said that, from the driving point of view, this one is optimal when it generates an as simple as possible structure of the adjustment system. In this situation, because of the great number of equations and parameters occurring in the case of the reluctance synchronous motors speed adjustment, some simplifications have been necessary. However, this fact leads to a model which does not reflect exactly the system dynamic behaviour.

As a consequence, the utilization of some as complete as possible mathematical models is imposed; they are materialized in a great number of differential equations.

Starting from this conclusion, in this chapter, there are presented the equations used for the proposed analyses, with accent on making evident the magnetic fields of the excitation winding, of the damping windings and of the armature winding and on relating the rotor windings to stator, respectively.

There are presented here, in details, the operation equations of the unsaturated and saturated synchronous machine, for the general case.

3. MATLAB-SIMULINK MODELS

The third chapter is dedicated to the presentation of the Matlab-Simulink models used in order to finalize the researches.

Starting from the mathematical models presented in the second chapter, two Matlab-Simulink models of the unsaturated RSM (fig. 3.1) and two models of the saturated RSM have been conceived.

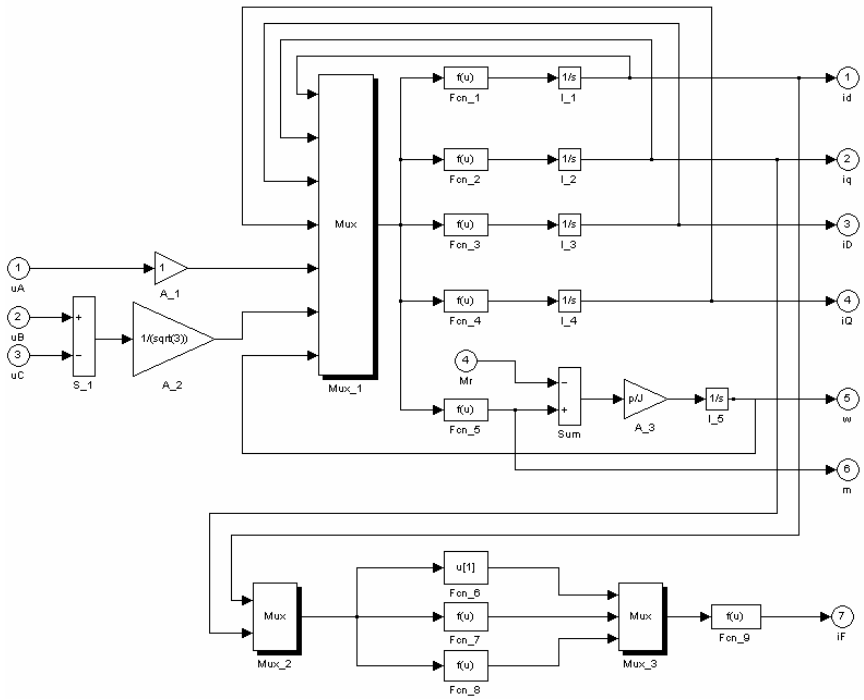


Fig. 3.1. One of the Matlab-Simulink models of the unsaturated RSM.

This relatively great number of models has been necessary because, first of all, there is not an adequate block in the Simulink library of the last versions of program and because it is not possible to process adequately other existing blocks and, secondly, it has been necessary to verify the validity of the simulations which have been performed.

In this chapter there is also presented the model of a voltage and frequency static converter, considered as being representative (voltage source indirect VFSC with PWM command and voltage inverter with pre-computed commutation moments). In order to do this, the accent was laid on a modular construction, which allows possible subsequent adaptations.

4. RSM PARAMETERS INFLUENCES FOR THE STEADY-STATE OPERATION CASE

The parameters influences on the RSM behavior in the case of the steady-state operation are analyzed in the fourth chapter. The starting point is represented by the equations written when the iron losses are considered, which are subsequently used in order to catch the way in which the parameters modification influences the electromagnetic torque.

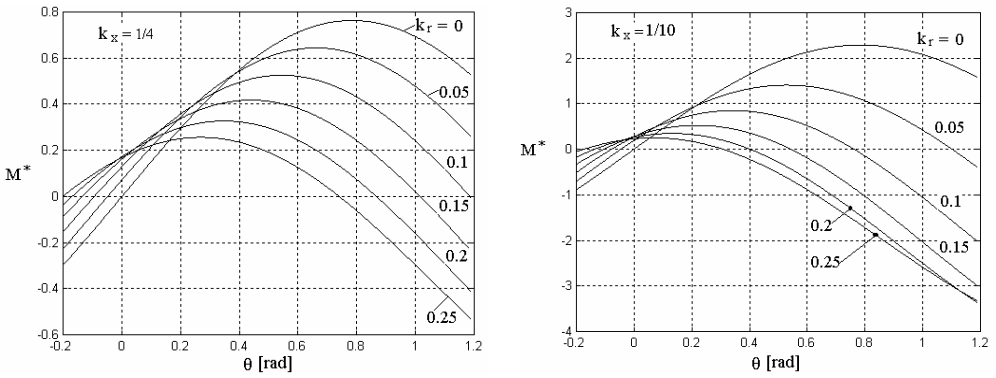
A few simulation programs, conceived in a modern manner, have been run and the emerging conclusions have been emphasized.

A part of these conclusions are:

- the more the asymmetry degree is, the best the technical performances of the RSM (overloading rate and power factor) are; this fact justifies the preoccupation for developing the rotor constructive solutions having a high anisotropy;
- the armature winding resistance has to be considered in the case of the low power RSM; its value cannot be neglected anymore;
- it is noticed that this parameter has a negative influence, materialized in the decrease of the range of stable operation and in the decrease of the maximum torque; it is mentioned that the advantages obtained by increasing the asymmetry degree become minor for relatively increased values of the winding resistance (k_r>0,15);

- it is recommended, in the design stage, to decrease the supply voltage when the rated power decreases; this way, the value of the winding resistance is kept under certain limits; it is also followed to obtain an as great as possible value for X_d, by adopting an as small as possible air-gap, both solutions leading to the decrease of the ratio k_r.

A few graphics are depicted in this summary, for exemplification (fig. 4.1).

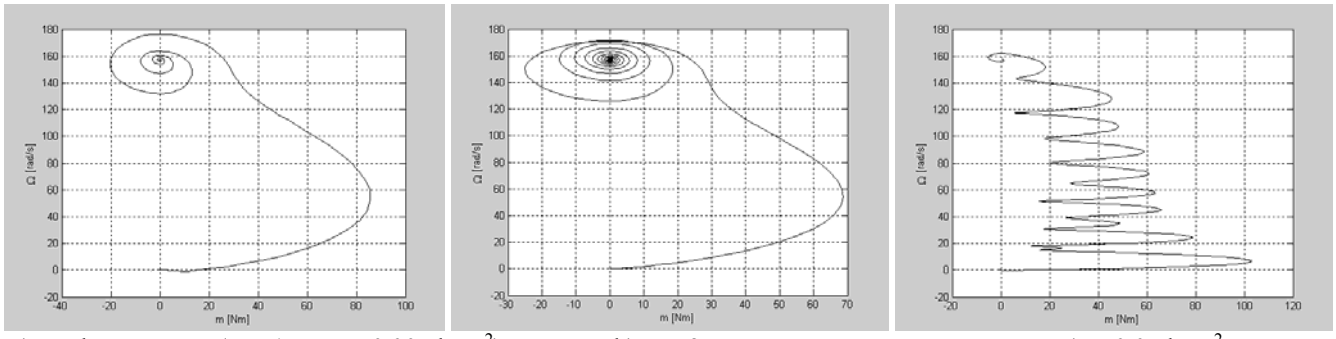


a) b)

Fig. 4.1. Static angular characteristics for: a) k_x=1/4; b) k_x=1/10.

5. RSM PARAMETERS INFLUENCES FOR THE DYNAMIC REGIME OPERATION CASE

The parameters influences for the dynamic regime operation are analyzed in the fifth chapter. For this, the cases of the asynchronous starting (fig. 5.1) and of the VFSC supply have been simulated with the help of the programs detailed in the third chapter.



a) Real parameters (R_D=1,5 Ω, J=0,005 kgm^2) b) R_D=3 Ω c) J=0,05 kgm^2

Fig. 5.1. Characteristics m=f(Ω) for different values of the RSM parameters.

The following significant conclusions have been obtained by finalizing the analysis:

- the increase of the value of the resistance R_D leads to the increase of the transient regime duration;
- a small value of the resistance R_Q, even at null resistant torque and a small inertia moment, can lead to an unstable operation;
- the increase of the stator leakage inductance value has a slight stabilizing effect;
- the increase of the inertia moment value makes the synchronization to occur after a greater number of oscillations of the current;
- the speed is considerably dependent on the values of the chosen parameters, especially on the inertia moment value (for an increased J, the speed oscillations decrease but the starting duration increases);
- in the case of the load starting, the rotor initially has a trend to rotate conversely over the inductor field; in addition, the steady–state current value has a natural trend of increasing;
- the shock current is not strongly conditioned by the parameters variation and the load starting does not cause the significant increase of this current over the no-load starting case;

- in the case of the VFSC supply, it is noticed that for the situations when the resistance RD increases, the resistance RQ decreases and the inertia moment increases significantly, the duration of the analyzed transient regime increases.

6. RSM PARAMETERS INFLUENCE ON STABILITY

The reluctance synchronous motors parameters influences on stability are analyzed in the sixth chapter.

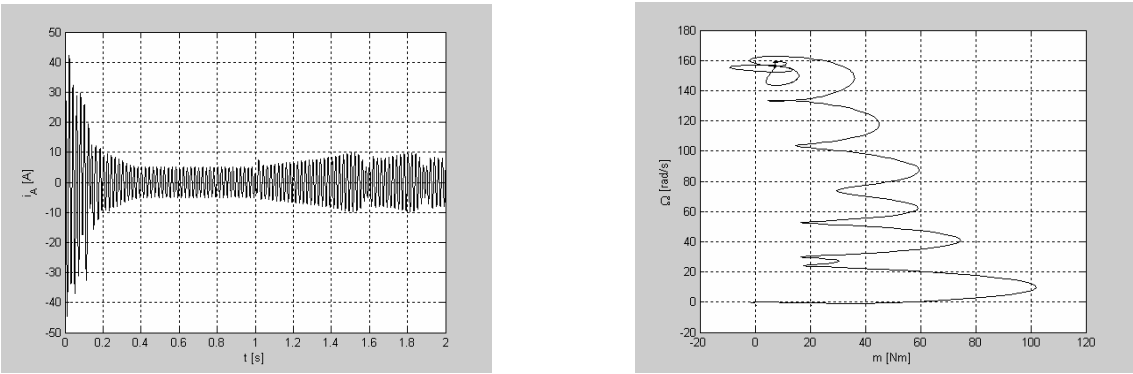
An analytical demonstration emphasizing the parameters effects on the static stability has been developed here:

- the more the ratio L_q/L_d is near to 1 the greatest the stability is;
- in order to obtain an as large as possible stability range, it is necessary for R_s to be as small as possible;
- the stability increases when the value of the inductivity L_{mq} increases.

The chapter also includes a series of simulations of the dynamic regime behaviour, for several particular cases, which emphasize the influences of different disturbances on the dynamic stability.

The following conclusions have been obtained, by finalizing the analysis:

- the RSM has a different behaviour at different values of the shock torque, at the same inertia moment (the going out of synchronism depends on the applied shock value);
- the dynamic stability decreases when the supply voltage decreases (the voltage decrease under a certain value makes the machine to go out of synchronism) (fig. 6.1);
- the same shock of torque has different influences, this fact depending on the existing total inertia moment;
- the RSM dynamic stability depends both on the disturbance magnitude and character and on the initial conditions;
- the stability limit can be established for every RSM with the help of the performed simulations; this is an important instrument for the designers of such motors.



a) $i_A=f(t)$ b) $\Omega=f(m)$

Fig. 6.1. Characteristics obtained when the supply voltage decreases to the value U=170V (M_r=7,6 Nm, J=0,025 kgm^2).

It is emphasized that the RSM is very sensitive to the parameters variation. As a consequence, the importance of these simulations in the machine design emerges immediately. A design conceived without carrying out, beforehand, simulations regarding the behaviour depending on different values of the parameters, is an error. These simulations mean an useful pre-determination of the parameters. This way, useful information, absolutely necessary, is available for the designer. Thus, he knows the parameters which must be avoided.

7. EXPERIMENTAL DETERMINATIONS

The test bench which has been conceived and carried out by the author in the frame of the Faculty of Engineering in Electromechanics, Environment and Industrial informatics from Craiova, is presented here (fig. 7.1).

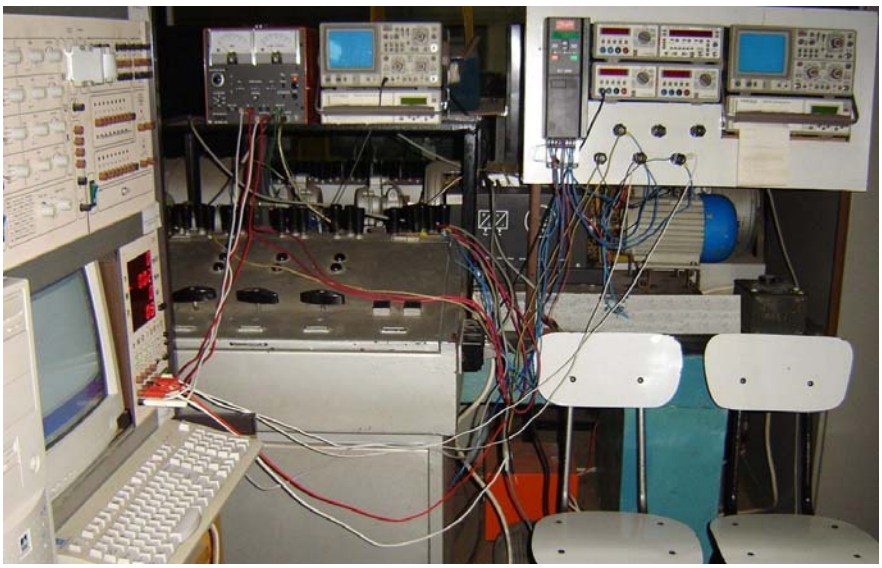


Fig. 7.1. Photo of the experimenatal scheme.

It is emphasized that this bench can be used for monitoring both the steady-state processes, owing to the numerical multi-meter ELWE M13 and of the interface ELWE Comenius, and the dynamic processes, owing to the utilization of the data acquisition board Keithley KPCI 3102.

A few concrete cases of performed determinations are then exemplified:

- the determination of the RSM parameters (the stator resistance, the longitudinal synchronous inductivity, the transversal synchronous inductivity, the leakage reactance, the magnetization inductivity, the over-transient reactances and the inertia moment);
- experimental determinations in steady state conditions (which validate the conclusions obtained in the fourth chapter);
- experimental determinations in dynamic regime (confirming the conclusions detailed in the fifth and in the sixth chapters).

A special mention must be emphasized for the method of the decreasing current, allowing the determination of the synchronous reactances, method which has, in the frame of this chapter, an original materialization. This method has many significant advantages: it is no need to couple the RSM with another driving machine, the scheme is easily to be carried out, the test duration is very short, the energy consumption is negligible.

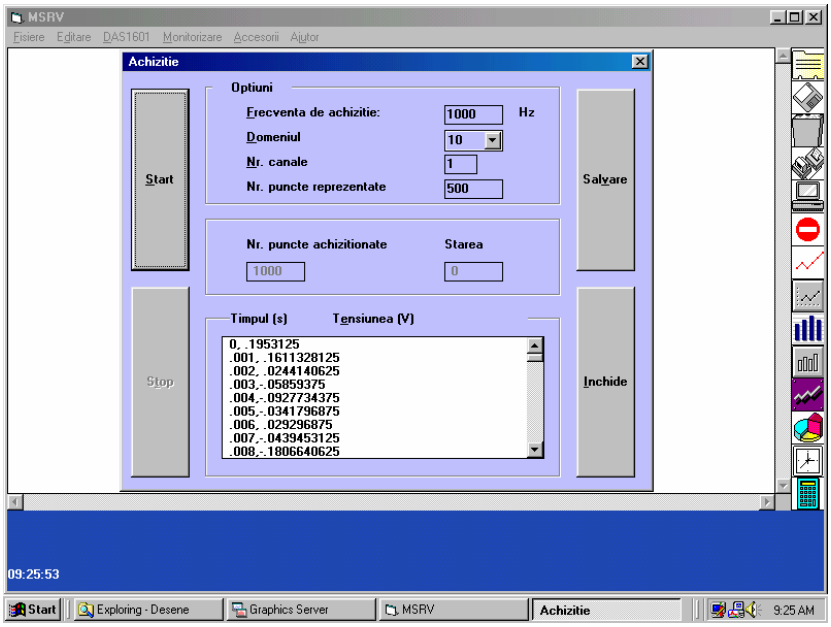


Fig. A.1. Window “Achizitie” of the program conceived in Visual-Basic.

In the final part of the paper there are presented two annexes emphasizing the complexity and the level of the conceived programs. A special mention is imposed to be done for the program for monitoring the RSM dynamic regimes, conceived in Visual Basic, program having many facilities: it allows the data acquisition board configuration, ensures the adequate acquisition of the dynamic signal we want (fig. A.1), it allows the visualization of the acquired signal in different forms, the obtained ascii files can be edited, the data can be saved and printed, it ensures the access to a series of useful accessories, the work interface can be configured adequately etc.

8. CONCLUSIONS AND PERSONAL CONTRIBUTIONS

This paper is a synthesis of the fundamental and applicative research activity developed by the author in the field of the special electrical machines.

The main object of the thesis is the analysis of some steady-state and dynamic processes of the reluctance synchronous motors.

Starting from this objective, there has been developed a computerized system for data acquisition, together with the afferent programs of analysis and simulations.

A few **contributions** brought by the author in the frame of this paper can be emphasized:

- there has been carried out an unitary analysis of the main mathematical models with concentrated parameters of the synchronous machine, with and without saturation, used in the study of its dynamic regimes;
- there has been finalized a study, in steady-state conditions, regarding the RSM parameters influences on the torque, the overloading rate and the power factor;
- there has been performed a study aiming to the parameters influences on the RSM dynamic regime operation, especially for the case of the asynchronous starting and of the supply by a voltage source indirect VFSC with PWM command and voltage inverter with pre-computed commutations moments;
- a detailed analysis of the RSM parameters effects on the static stability has been finalized;
- a study aiming to the dynamic stability when different external disturbances accidentally occur has been performed;
- a Matlab programs package for the study of the parameters influences on the RSM torque has been conceived;
- some variants of Matlab-Simulink models of the reluctance synchronous machine, with and without saturation, have been performed;
- a Matlab-Simulink programs package for the simulation of the RSM dynamic regime operation has been conceived;
- there has been carried out a Matlab-Simulink model of an indirect VFSC voltage source with PWM command and voltage inverter with pre-computed commutation moments (conceived as modular construction for allowing possible subsequent adaptations);
- the experimental tests for the determination of the RSM synchronous reactances have been performed by the method of a d.c. current decreasing in the stator winding;
- some experimental determinations aiming to the parameters influence on the RSM torque have been performed; they confirm the simulations mentioned before;
- some experimental determinations in the case of a RSM asynchronous starting has been performed; they validate the simulations;
- an assembly of support-files for the visual programming of the data acquisition board KPCI 3102 has been conceived;
- an original VISUAL BASIC program for monitoring the RSM dynamic regimes has been performed;
- a monitoring bench for the RSM dynamic regime operation has been conceived and performed (by using a data acquisition board Keithley KPCI 3102).

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