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Dynamic Processes of Electric Motors for Operating some Aircraft Equipment

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***Abstract* – In this paper are detailed some results obtained within a European program in the field of avionics. The objectives of the program and the implementation team are briefly presented. A number of technical details are provided regarding the electric motor used to steer an airplane's running gear: advantages, comparative densities between the motor used (HDD) and the competitive motors, cross-section of the used motor, winding scheme of the motor, motor scheme with partial short-circuit. The mathematical model of the motor is presented, Simulink scheme of a simulation program in case of using a voltage inverter and a series of simulations obtained with its help (MSMP supplied by a voltage inverter, transmission ratio 1000, inertia10000 Nm^2 and MSMP supplied by an inverter with prescribed currents, transmission ratio 1000, inertia 10000 Nm^2). The paper concludes with the conclusions obtained by conducting the research. It is mentioned that the following notable results were obtained: decrease with 30% of the production and maintenance costs, decrease with 10% of the airship weight, carrying out a drive with a probability to lose the functionality.**

Cuvinte cheie: *avionica, motor electric, model matematic, program Simulink, simulări.*

Keywords: *airplane, electric motor, mathematic model, Simulink program, simulations.*

I. INTRODUCTION

The problems developed in this paper are of great practical interest. They refer to the electrical operation of various systems in the equipment of aircraft [1], [2], [3], [4], [5].

A team from the University of Craiova, Faculty of Electrical Engineering, was part of the European project team STREP (Specific Target REsearch Project) DRESS - Distributed and Redundant Electro-mechanical nose wheel Steering System, no. 030841, team coordinated by Prof. eng. PhD Sergiu Ivanov [6].

This project was financed by the European Commission by the financing program PC6.

The project had thirteen partners; their surveys are presented in the following table [7].

The objectives of DRESS consisted in:

- study and validation of a redundant electromechanical actuator;

- study and validation of a control system based on a distributed architecture.

A special attention was paid to the shimmy phenomenon (new systems of oscillations damping by using an electromechanical system).

TABLE I.
PROJECT PARTICIPANTS

No.	Participant name	Country	Tasks
1	MESSIER-BUGATTI	FR	Management Specifications & assessments System architecture design Technology education
2	Saab Avionics	S	Actuator design, integration & validation
3	AIRBUS UK	UK	Specification Final tests
4	MESSIER-DOWTY	FR	Landing gear & test rig design Landing gear actuator integration & validation Shimmy damping analysis
5	INSA Toulouse	FR	Research & optimum design of actuator & complex test rig
6	UC Louvaine	B	Research & optimum design of power electronics
7	University of Craiova	RO	Research & optimum design of electric motors
8	Universite Alsace	FR	Research & optimum design of system control
9	Budapest UTE	H	Research & optimum design of distributet architecture Safety analysis
10	TTTech	A	Manufacture of RDC & power electronics prototype
11	Equip Aero	FR	Manufacture of mechanical parts for the prototype
12	Stridsberg PT	S	Manufacture electrical motor prototype
13	Institut of aviation	PL	Manufacture of dummy nose landing gear test rig

The electrical drive was preferred for the front alighting gear of the airships for replacing the classical variants, with a lot of drawbacks, variants consisting in an electro-hydraulic drive with pinion - cremaillere or push-pull system (for large airships).

The implementation of the electromechanical technology for the front alighting gear has a series of advantages [8]:

- the decrease of the total weight of the airships and of the time necessary for standing and maintenance;

- the decrease of the production and maintenance costs;

- the traffic improvement and the safety increase during the ground operation, even in conditions of poor visibility, up to the limit of zero visibility;

- possibility to integrate in a completely automatic future system of ground guidance.

The simulations validation has been made by means of some tests on a prototype.

The test was carried out on a testing stand with a simplified alighting gear, connected to the control system, stand carried out in the project.

The research collective of the University of Craiova was involved in three work packages (WorkPackages):

WP 340 - Shimmy damping control;

WP420 - Electric motor / power card technology study and modelling;

WP430 - Thermal analysis and modelling.

The researches carried out by this collective have been used by the work package WP410 (Power architectures studies/Actuator sizing), which finished the architecture and dimensioned the electromechanical system, as well as by the package WP710 (Modelling evaluation), which integrated the models of all subsystems (automatic control, power electronics, motor, mechanical demultiplier, alighting gear, airplane) for the simulation of the whole system of the airplane.

For driving the electromechanical system we studied, owing to the high density of delivered power, there has been chosen the variant of permanent-magnet synchronous motor.

From the multitude of variants of such motors, taking into account the previous experience of two partners (SAAB AB and Stridsberg Powertrain AB), the option was the motor produced by Stridsberg Powertrain AB type HDDb09N [9].

This motor is a special type of permanent-magnet synchronous motor, with independent phases, characterized, according to its producer, by a four-six times higher power density over the classical synchronous motors (Fig. 1).

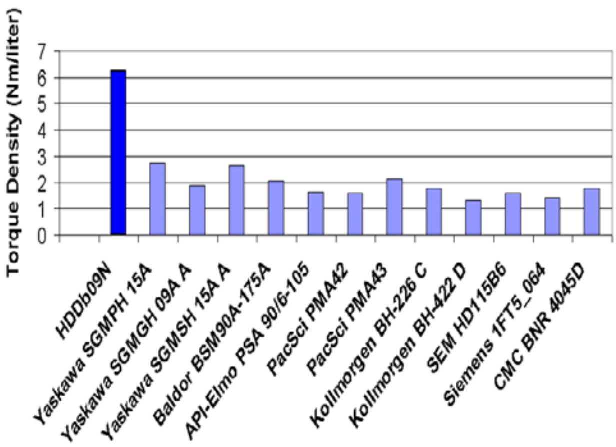


Fig. 1. Comparative densities between the motor used (HDD) and the competitive motors [2].

II. Technical details

From constructive point of view, the phase windings of the used motor does not coexist in the slots, so, on one hand, the phases are magnetically separated and, on the other hand, the solution redundance is improved (Fig. 2).

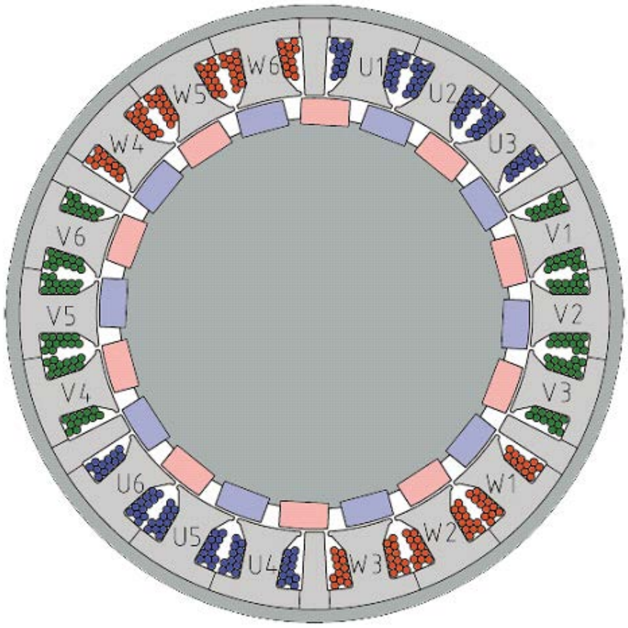


Fig. 2. Cross-section of the used motor [2].

In addition, it is equiped with six half-phases which are physically and magnetically separated and which can be each supplied to a bridge one-phase inverter (Fig. 3).

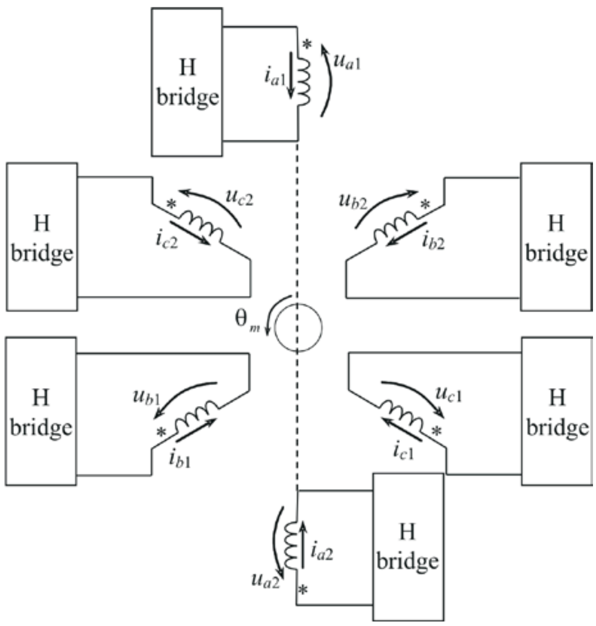


Fig. 3. Winding scheme of the motor [1].

As we can note, the motor model is obtained by concatenating two machines without mutual inductances between phases, with an angular displacement of 180°.

Among possible damages of the motor, there has been analyzed the case of the partial shortcircuit of a few turns.

In this case, the equivalent circuit is presented in the following figure.

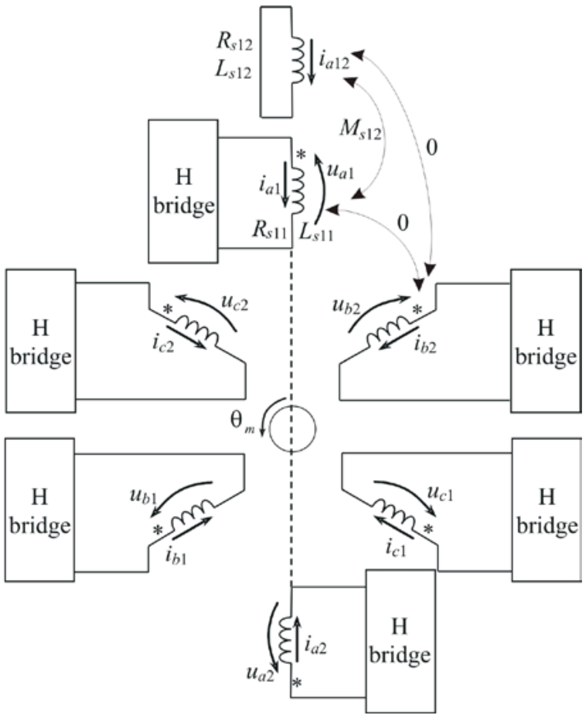


Fig. 4. Motor scheme with partial shortcircuit [6].

III. MOTOR EQUATIONS

The machine equations in this case, according to [9], become:

$$\begin{bmatrix} u_{a1} \\ u_{c2} \\ u_{b1} \\ u_{a2} \\ u_{c1} \\ u_{b2} \\ 0 \end{bmatrix} = [\mathbf{R}] \begin{bmatrix} i_{a1} \\ i_{c2} \\ i_{b1} \\ i_{a2} \\ i_{c1} \\ i_{b2} \\ i_{a12} \end{bmatrix} + [\mathbf{L}] \frac{d}{dt} \begin{bmatrix} i_{a1} \\ i_{c2} \\ i_{b1} \\ i_{a2} \\ i_{c1} \\ i_{b2} \\ i_{a12} \end{bmatrix} + \tag{1}$$

$$+K_T \dot{\theta}_m \begin{bmatrix} 0 \\ -\sin\left(P\theta_m - \frac{\pi}{3}\right) \\ -\sin\left(P\theta_m - \frac{2\pi}{3}\right) \\ -\sin\left(P\theta_m - \pi\right) \\ -\sin\left(P\theta_m - \frac{4\pi}{3}\right) \\ -\sin\left(P\theta_m - \frac{5\pi}{3}\right) \\ 0 \end{bmatrix} + \dot{\theta}_m \begin{bmatrix} K_{T11}\left(-\sin P\theta_m\right) \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ K_{T12}\left(-\sin P\theta_m\right) \end{bmatrix}$$

where:

$$[\mathbf{R}] = \begin{bmatrix} R_{s11} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & R_s & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & R_s & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & R_s & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & R_s & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & R_{s12} \end{bmatrix} \tag{2}$$

$$[\mathbf{L}] = \begin{bmatrix} L_{s11} & 0 & 0 & 0 & 0 & 0 & M_{s12} \\ 0 & L_s & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & L_s & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & L_s & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & L_s & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & L_s & 0 \\ M_{s12} & 0 & 0 & 0 & 0 & 0 & L_{s12} \end{bmatrix} \tag{3}$$

The notations used are the classic ones used for supply voltages, currents through equivalent windings and motor parameters.

The electromagnetic torque expression is:

$$\begin{aligned} T_{em} = &-K_T \left(i_{c2} \sin\left(P\theta_m - \frac{\pi}{3}\right) + i_{b1} \sin\left(P\theta_m - \frac{2\pi}{3}\right) + \right. \\ &+ \left. i_{a2} \sin\left(P\theta_m - \pi\right) + i_{c1} \sin\left(P\theta_m - \frac{4\pi}{3}\right) + i_{b2} \sin\left(P\theta_m - \frac{5\pi}{3}\right) \right) + \\ &+ K_{T11}\left(-i_{a1} \sin P\theta_m\right) + K_{T12}\left(-i_{a12} \sin P\theta_m\right). \end{aligned} \tag{4}$$

As we can note, the motor can also be used as three-phase machines without star connection of the phases, its supply being ensured by three one-phase inverters, bridge or star, supplied to a three-phase inverter.

IV. SIMULINK PROGRAMS

The Matlab-Simulink [10] programs carried out in the frame of this project enable the simulation of several combinations motor-controller.

For each combination, there can be simulated different damages which could occur in different operation conditions.

For example, there is presented the Matlab-Simulink block scheme of a program for simulating the operation of such a motor (Fig. 5).

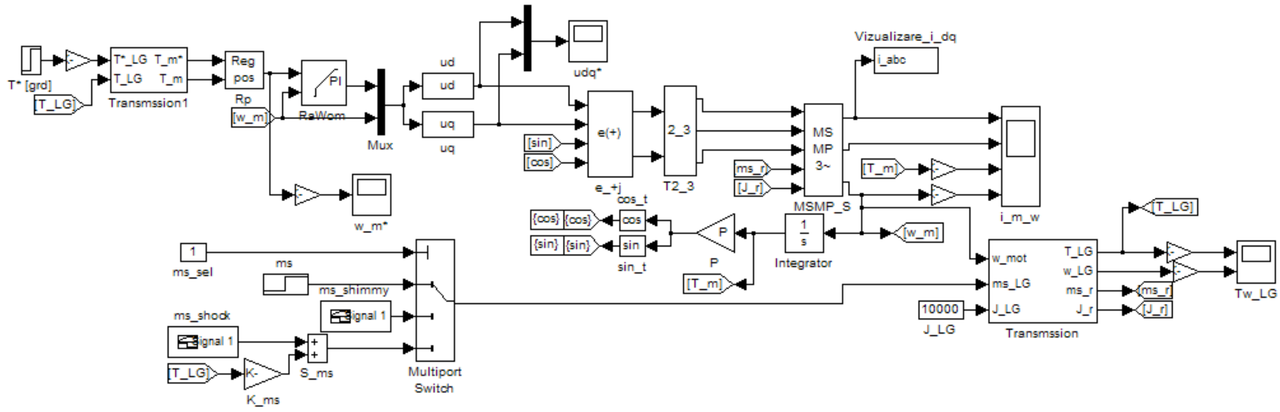
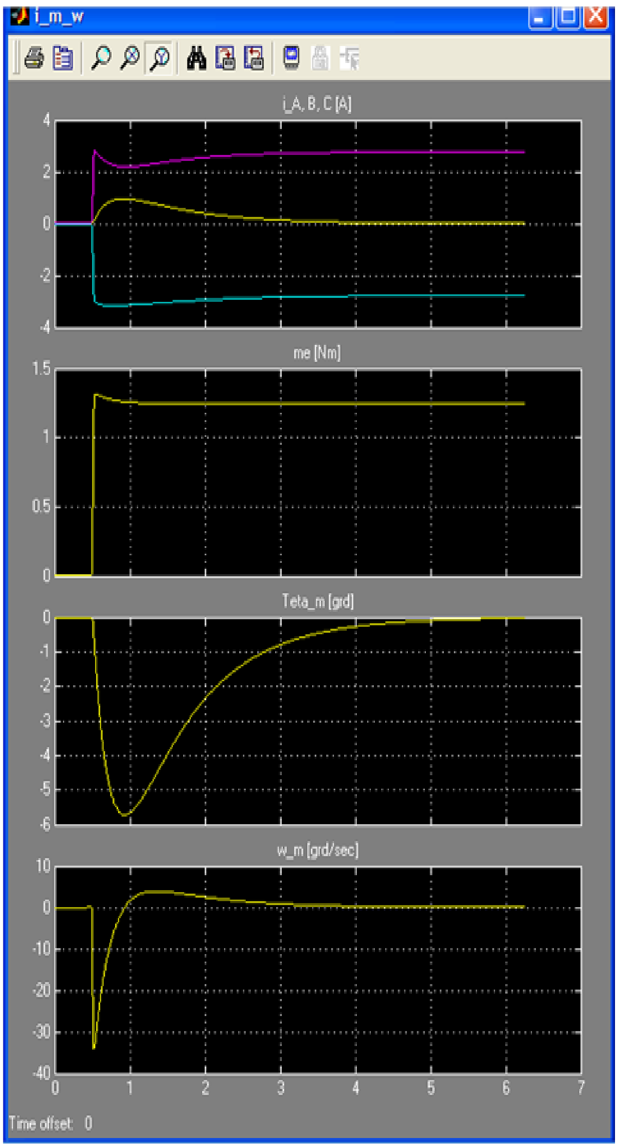


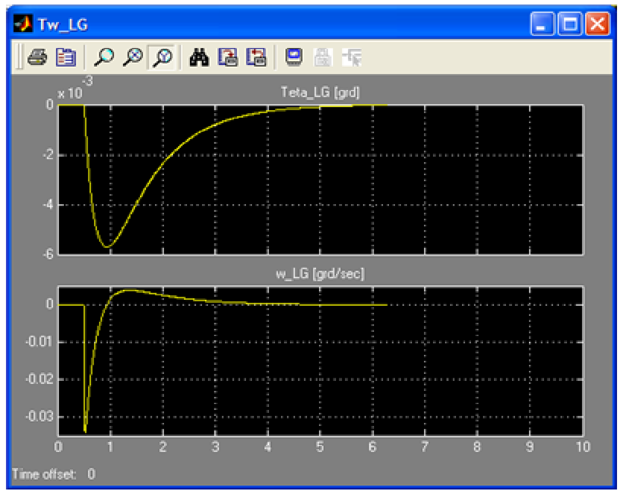
Fig. 5. Simulink scheme of a simulation program in case of using a voltage inverter [8].

V. SIMULATIONS

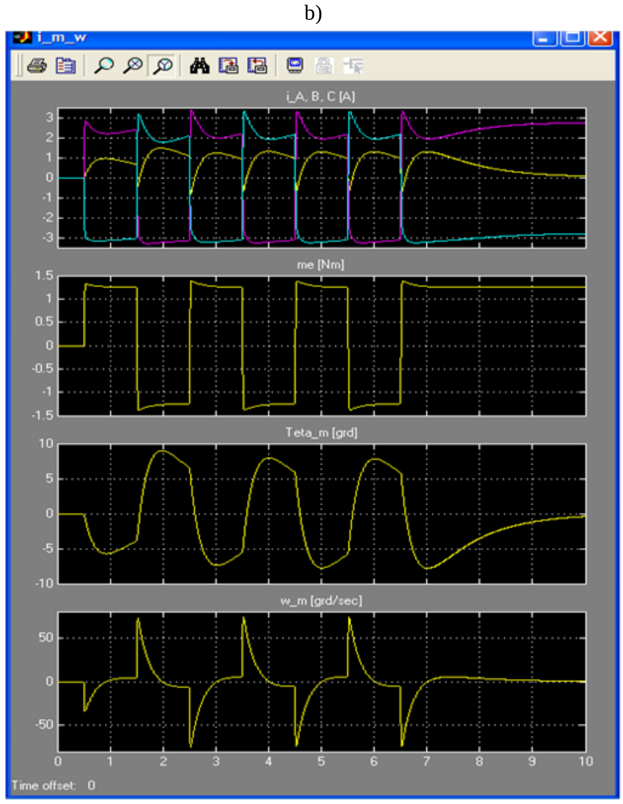
By means of such a progam, there have been obtained a series of simulations; a few of them are presented below, figures 6 and 7.



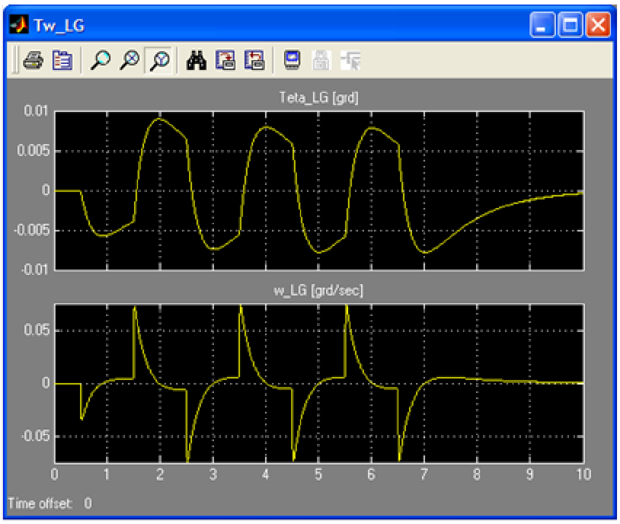
a)



b)

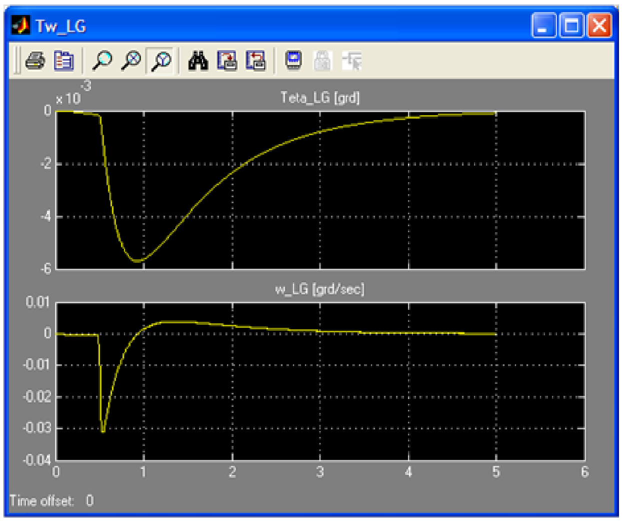


c)



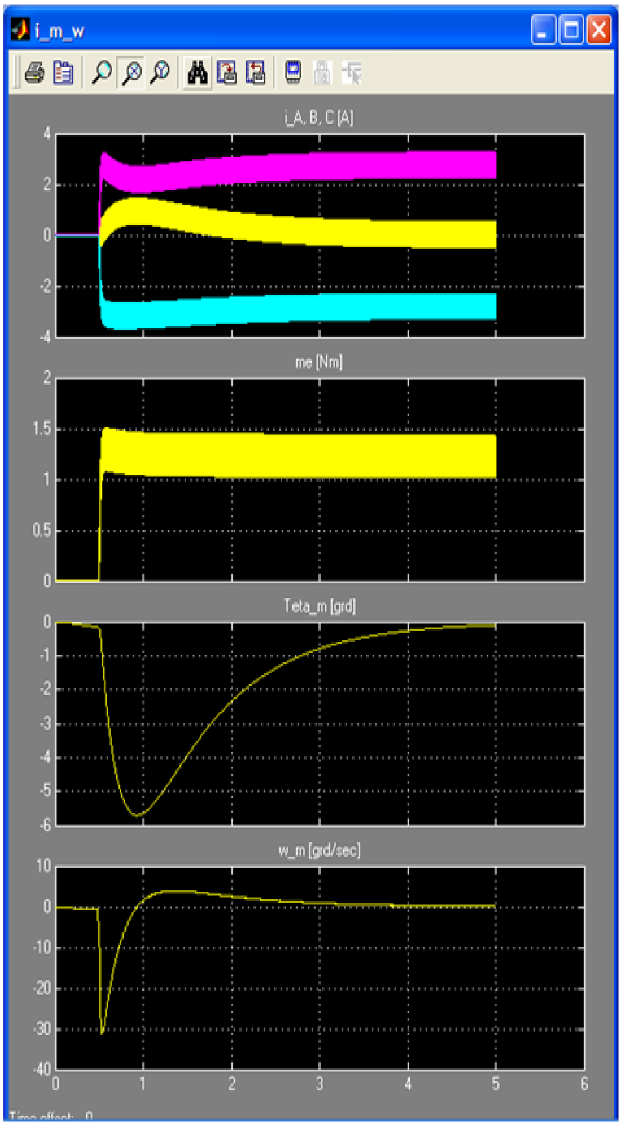
d)

Fig. 6. MSMP supplied by a voltage inverter, transmission ratio 1000, inertia10000 Nm^2.



b)

Fig. 7. MSMP supplied by an inverter with prescribed currents, transmission ratio 1000, inertia 10000 Nm^2.



a)

These simulations were very useful finishing off the final variant, being obtained comparative results for a large variety of dimensions of motor, the optimum variant being chosen among them.

The project finality was a protype which was tested on the test stands of the project coordinator Messier-Bugatti [9].

VI. Conclusions

This paper presents some results obtained within a European project in which a team from the University of Craiova also took part.

Among the achievements of this program can be listed:

- decrease with 30% of the production and maintenance costs;

- decrease with 10% of the airship weight;

- carrying out a drive with a probability to lose the functionality.

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Contribution of authors:
First author – 60%
First coauthor – 20%
Second coauthor – 20%.

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