Results obtain by the Romanian Partners for the Frame of the FP5 European Project "ELMAS: Hybrid Vehicles"

Răzvan MĂGUREANU, Mihaela SCORȚESCU, Crişan DAVIDESCU*

Abstract

As a partner in ELMAS – "ENK6-CT1999-00017 – New High Efficiency Electric Machines Solutions for Mild Hybrid Applications", Politehnica University of Bucharest and also ICPE and Electrotehnica acting as subcontractors were involved in the research of new technical solutions to be used in development of a hybrid vehicle. The project was coordinated by Centro Ricerche Fiat (Italia) Other partners were: University of Sheffield (UK), Politecnico di Torino (Italia), Volvo Technology (Sweden), Aachen University Of Technology (Germany) Switched Reluctance Drives LTD (UK). The Romanian partners were in charge of: design and manufacture of the permanent magnet synchronous motor, design and manufacture of power inverter, control of the motor and inverter through a CAN bus. In this article will be presented the results obtained by romanian partners.

Keywords: hybrid electric vehicle, brushless synchronous motor, Nd–Fe-Br permanent magnets, IGBT inverter, CAN bus

1. Introduction

The main focus of the ELMAS Project ENK6, CT1999-00017, *New high efficiency electric machines solutions for mild hybrid applications*" was the elaboration of an electric drive for a hybrid electric car.

In the frame of this project, beside the authors of this article, there were participants from University Politehnica of Bucharest (UPB) (PhD Eng. Sergiu AMBROSI, PhD Eng. Valeriu BOSTAN, PhD Eng. Mihai CUIBUS); from ICPE Bucharest (PhD Eng. Paul MINCIUNESCU) and from Electrotehnica (PhD Eng. Doru CREANGĂ).

The UPB, besides coordinating the Romanian partners involved in this project, has realised a software for the inverter control that were implemented on DSP signal processors, and also a software for communication between the vehicle central unit and the inverter that use a CAN interface.

ICPE has made the brushless synchronous motor and the power inverter to operate it was made by Electrotehnica.

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2. Project description

The ELMAS Project, entitled "New high efficiency electric machines for mild hybrid applications solutions", has as aim to generate a feasibility study for various types of electric motors, that could be applied for drive hybrid cars as well as evaluating the benefits of this type of vehicle, related to CO_2 emissions, efficiency and fuel consumption reducing.

On the mechanical part, the solution that was adopted involve two clutches, one between the internal combustion engine and electric motor, and the second one between the electric motor and gearbox. In this way, the vehicle traction can be accomplished in three ways: by internal combustion engine, by electric motor, or by means of both motors (Figure 1).

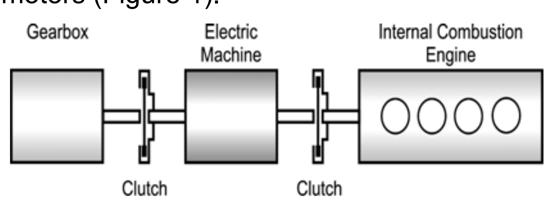


Figure 1. Power train configuration for a hybrid vehicle with two clutches

Regarding the electric car, two solutions were approached:

- brushless synchronous motor: the solution was adopted by Centro

Ricerche Fiat;

- engine type "switch reluctance": the solution was adopted by VOLVO.

The power electric part is shown in Figure 2.

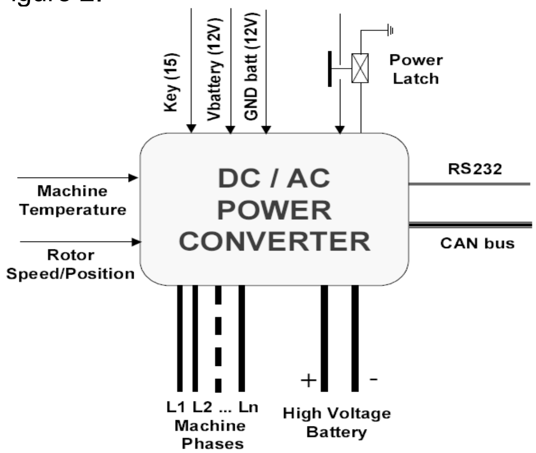


Figure 2. Wiring diagram of power converter

Figure 3 shows the wiring diagram of power converter DC / AC.

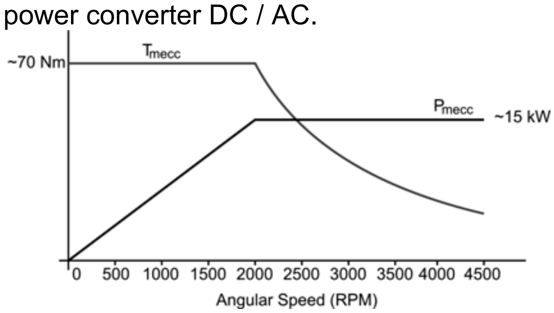


Figure 3. Performance requirements of the electric car, torque and mechanical power

The operating specifications were detailed established by Centro Ricerche Fiat. For example, in Figure 3 there are presented the performance requirements for system operating, in the case of lowest battery voltage - 190V, rated voltage being 220V.

Specifications for transient regimmes are shown in Figure. 4 and 5.

In Figure 4, the system response requirements for a ramp command signal are presented, where:

$\Delta t_{start} \to 0$

$\Delta t_{OK} < 0{,}1s$

suprareglaj <5 %

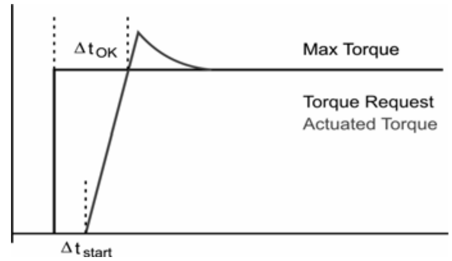


Figure 4. System response request for a ramp command signal

In Figure 5, the requirements for a command signal ramp type are presented, where:

$\Delta t_{up}, \Delta t_{down} < 0{,}1s$

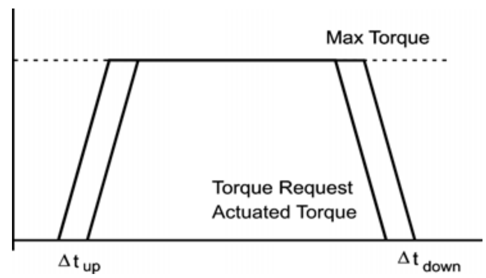


Figure. 5. System response request for a ramp type command signal

The expanded structure of these two motors is shown in Figure 6.

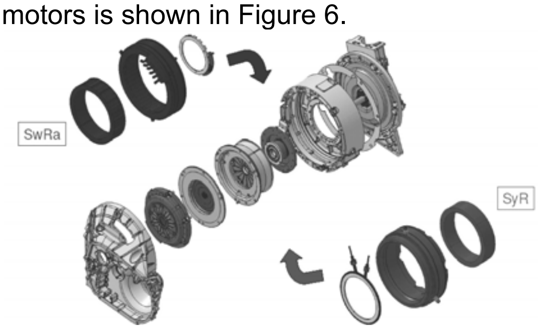


Figure 6. Overview of a XXXX

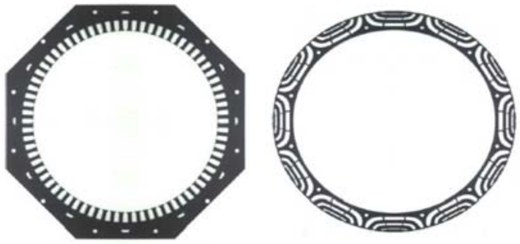
In this figure, the following notations are used:

- SYR: brushless synchronous motor; SwRa: engine type "switch reluctance".

The SYR engine design was carried out by Politecnico of Turin and realised by ICPE.

There were studied many solutions about rotor lamination method manufacturing, both by electro erosion using a laser for cutting and a dye use covering a pole.

As a result of this study, there were choosen the punching method for a 1/12 of the circumference. The made laminations are shown in Figure 7.



a) Stator lamination b) Rotor lamination

Figure 7. Laminations manufactured for brushless motor

In order to verify the rotor and stator magnetic structure load, the University Politehnica of Bucharest and ICPE have studied this problem on the basis of a two-dimensional model, using a FEM computer program which allowed the calculation of the magnetic field and the electromagnetic torque machine for both magnetic and non-magnetic flange rotor for different rotor positions.

Figure 8 presents the results of these calculations for iddle operation.

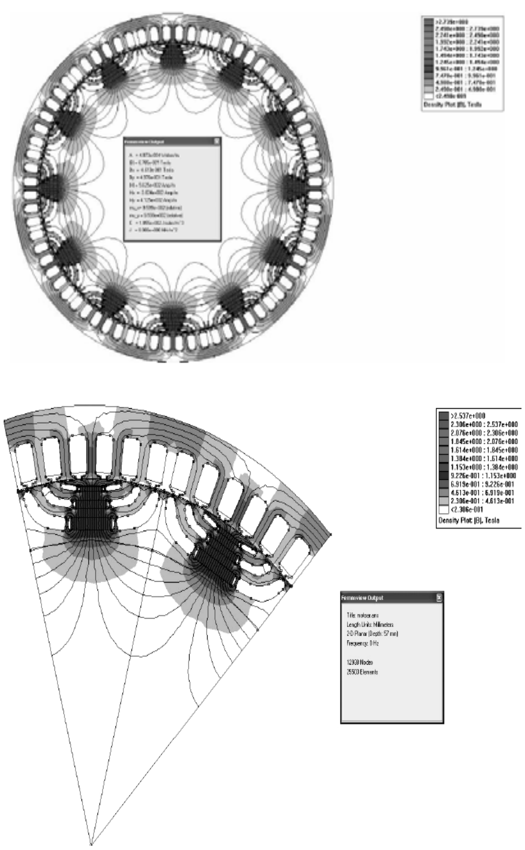


Figure 8. Magnetic field distribution in the machine for iddle operation

Figure 9 presents the results for rated load operation of the machine.

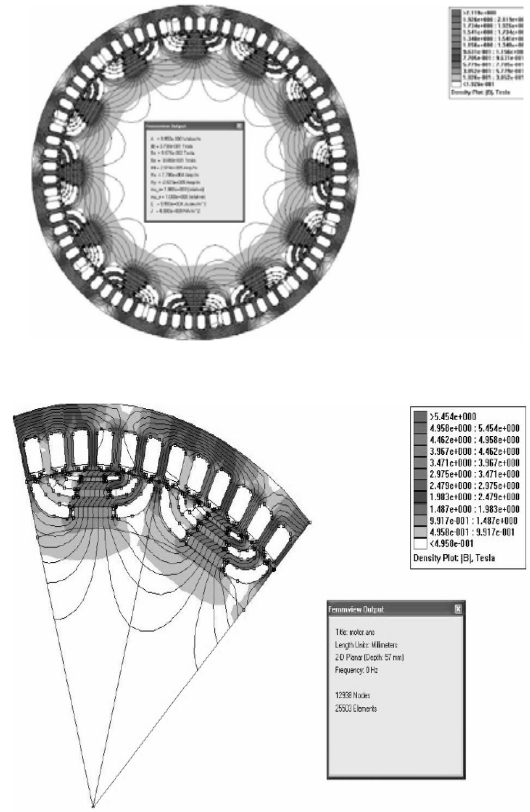


Figure 9. Magnetic field distribution in the machine for rated load operation

Figure 10 presents the distribution of air-gap flux density in the middle of a pair of poles, underlining a wide variation because of stator teeth and slots.

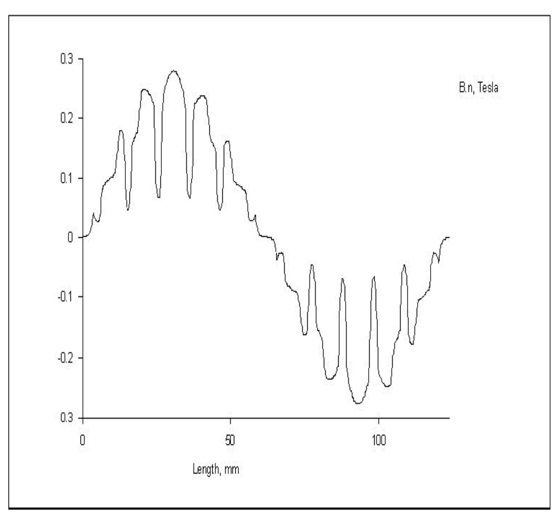


Figure 10. Calculated distribution of magnetic induction in the air gap

The electromagnetic torque characteristic of the motor, for a couple of poles, at different angles of the rotor position, is shown in Figure 11.

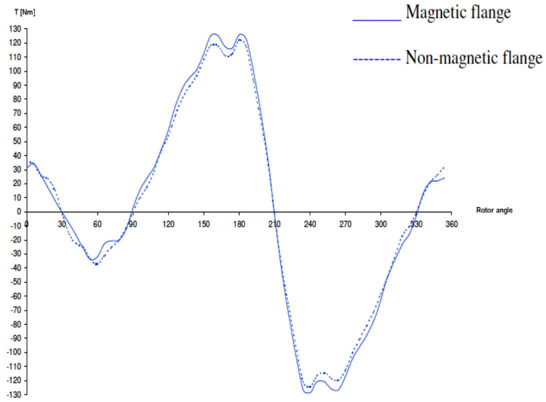


Figure 11. Electromagnetic torque variation depending on the rotor position

In Figure 12, is presented the torque ripple.

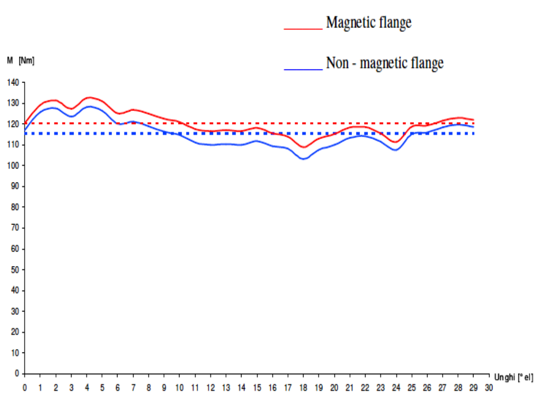


Figure 12. Electromagnetic torque ripple

It is obvious that for the torque oscillation compensation there was required the rotor lamination tilt. In Figure 12, there are shown with full line the electric machine total electromagnetic torque variation curves for lamination untilt and with dash line the torque variation in the case of their tilt. In this case, can be observed a total compensation of torque oscillations depending on the rotor position.

Before the motor manufacturing, it was necessary to determine the mechanical stress and deformation for different rotor speeds up to 9000 rpm. These calculations were made by our partners from the University of Aachen.

In Figure 13a), there are presented different parts of the rotor, and, in Figure 13b), there are presented the deformations.

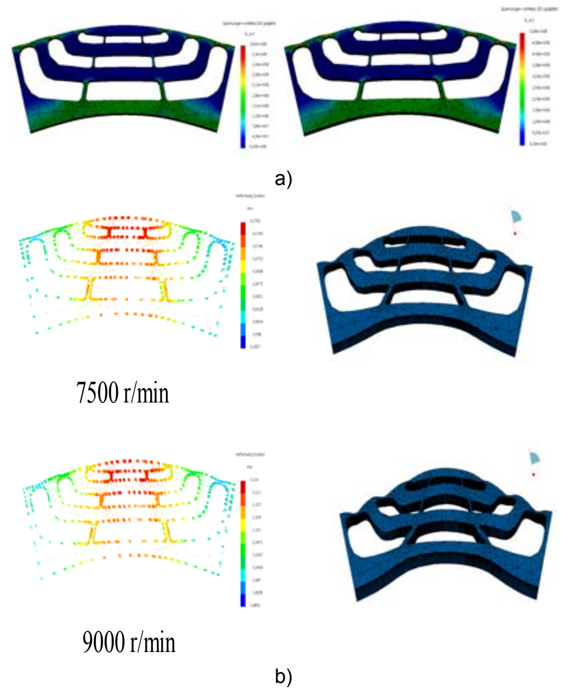


Figure 13 Calculation of the efforts and deformations occurring in rotor laminations

To highlight these distortions, on the right side of each the picture, the effect was magnified ten times.

It was observed that, due to the small thickness bridges between different levels of rotor winding, it was necessary to modify the original design and to strengthen these bridges until deformations were allowable.

The final form of the motor is shown in Figure 14, where on may observe the bottom water cooling channels of the motor, the stator winding coil ends, the top one of the two clutches and, on the left side, the power cables for current up to 370 A.

Figure 14 Permanent magnets motor

In Figure 15, the inverter with IGBTs made by Electrotehnica SA is presented.

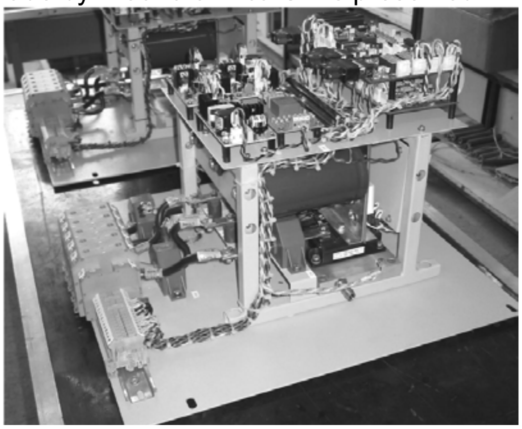
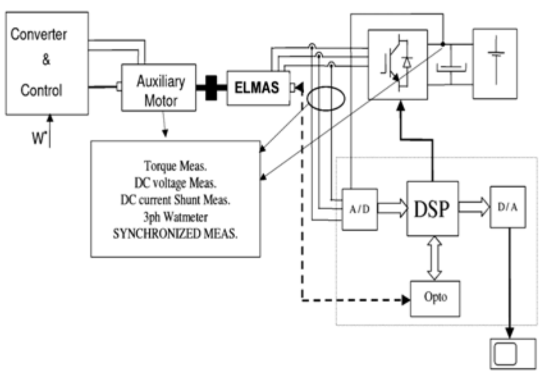
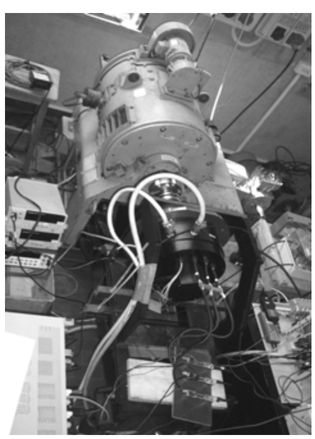


Figure 15 Inverter with IGBTs

The complete drive was initially tested at the Polytechnic of Turin according to the diagram shown in Figure 16a). A view of the completed test facility is shown in Figure 16b).



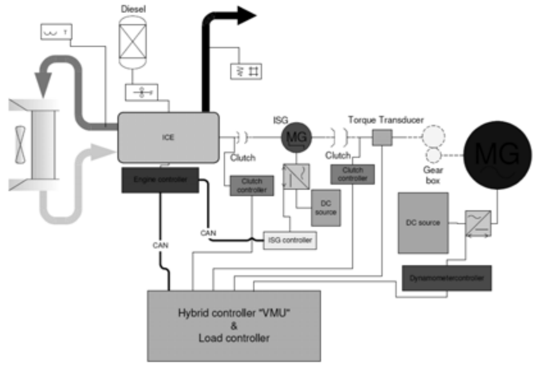
a)



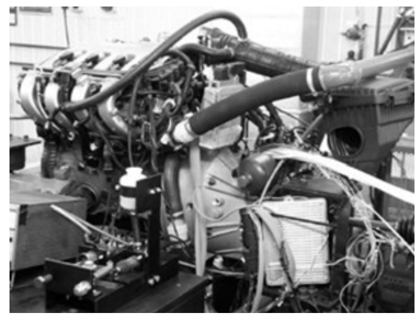
b)

Figure 16 Test facility from Politecnico di Torino

Final tests were made by FIAT Research Centre, according to the test scheme shown in Figure 17a). In Figure 17b), is shown a detail of installation completed.



a)



b)

Figure 17 Electric motor test facility achieved by Centro Ricerche Fiat

Conclusions

The presented operating equipment was used as a basis for the first European hybrid car realised by FIAT. Unfortunately, the ready-to-market version was not made by FIAT because of economic reasons.

To be present and to resist on the global car market of the "compact" class, the manufacturing companies must exceed the critical mass of 1,800,000 units per year. In this case, only the groups Fiat, Chrysler and Reanult-Nissan are able to satisfy this requirement, but the price much higher than the conventional models.

The Japanese groups (Toyota and Honda) succeed to be present on the market for this class.

4. Acknowledgment

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Also, we would like to thank the management of Fiat Group Automobiles SPA and Volvo Group, and, especially, to Francesco Profumo as Head of Electric Machines and Drives Group at Politecnico di Torino, partner in this project, who, later, became Chancellor there, then President of the National Research Council of Italy and, at present, Minister of Education, Universities and Research in the Mario Monti's Government, and, since 2007, Doctor Honoris Causa at Politehnica University of Bucharest.

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5. Biography

Răzvan MĂGUREANU was born in Iaşi (România), on November 30, 1939.
He graduated Technical University of Iaşi in 1961.
He received the PhD degree in electric engineering from the Politehnica University of Bucharest in 1970.
Between 1970 and 1971, he worked as research assistant (postDOC) at University of Manchester, Institute of Science and Technology (UMIST). He is Professor Emeritus at POLITEHNICA University of Bucharest.
Professor Magureanu from 1990 was president or member of the board of different Romanian companies and, at present, he is member of the board of directors of ISPH of Bucureşti.
He was also visiting Professor for several terms or shorts periods in UK, USA, Japan, China, South Korea, Italy, Greece, Denmark.
He is the author of over one hundred scientific papers published in Romania and abroad, ten technical books author and coauthor published in Romania, UK, and Western Germany.
Between 1987 and 1990, he was the coordinator of ICPE research laboratory at Politehnica University of Bucharest.
His research interests concern electric machines, electric drives, power electronics and control of power systems.

Mihaela SCORȚESCU was born in Pufeşti (România), on March 1,1954.
She graduated the University "Politehnica" Bucuresti. She has PhD in electrical engineering since 2004.
She is senior research engineer in the field of electrical engineering at Icpe.
She is Director of ICPE Research department and Icpe Servomotor Department.
She has more than 30 years experience in research and national and international projects management.
Personal area of expertise is in the field of special electric machines.