COMPARATIVE STUDY BASED ON FEM ANALYSIS BETWEEN SQUIRREL CAGE AND WOUND ROTOR OF A THREE-PHASE INDUCTION MOTOR

Eng. **Sorin VLĂSCEANU**, Prof. Eng. **Alecsandru SIMION**,
Assist. Prof. Eng. **Leonard LIVADARU**, Eng. **Florin LAZĂR**, Eng. **Nicolae-Daniel IRIMIA**

Faculty of Electrical Engineering
"Gheorghe Asachi" Technical University of Iaşi

REZUMAT. Lucrarea de fata urmareste o analiza comparativa dpdv a performantelor obtinute de la un motor asincron trifazat cu rotorul in scurtcircuit si unul cu infasurare bobinata pe rotor. Studiul efectuat porneste de la un motor a carui rotor in colivie este inlocuita cu o infasurare bobinata in urma reproiectarii infasurarii rotorice. O atentie deosebita se acorda proiectarii infasurarii rotorice pentru a obtine cupluri ridicate la pornire. Caracteristicile pentru cele doua structuri sunt prezentate comparativ si sunt obtinute prin analiza de camp utilizand software special de calcul.

Cuvinte cheie: masina de inductie, rotor in colivie, rotor bobinat, metoda elementului finit (MEF).

ABSTRACT. The presented paper aims a comparative analysis, from the performance point of view, between a squirrel cage tri-phased induction motor and a wound rotor construction. The study uses as starting point an induction motor with squirrel cage rotor, wich has been replaced with a winding after a design algorithm. Particular attention is given to the design of the rotor winding in order to obtain high starting torque. The characteristics for the two motor types are presented in a comparative manner. This characterics are obtained using field analysis in a special computing software.

Keywords: induction machine, squirrel cage rotor, wound rotor, finite element method (FEM).

1. INTRODUCTION

Induction machines are highly used in electric drives and home appliances due to their inherent advantages. This advantages may be the nature of technological nature: easy to construct, robust, performances, stable operation, and also economic reasons. Considering this advantages in this paper a comparison is made between the characteristics and performances of two induction motor types: wound rotor induction motor and squirel cage rotor induction motor.

This study uses as a start point an three phase induction motor with squirell cage rotor from the electrical machines laboratory. Using this motor on a test bench it was possible to plot it's characteristics. The test results are not the object of this paper, they were presented in another paper [3].

Following the electric and geometrycal measurements the motor parameters have been introduced in a field analysis program, FLUX Sqeweed. This program uses as computation algorithm the finite element method (FEM), the obtained characteristics being ploted as time functions.

Another step in this study is represented by the redesign of the rotor winding as a wound type. The design algorithm is according to guidebook [1] and it's main objective was to obtain a easy to build and efficient, in the same time, winding.

After the wonding design process, the rotor electric circuit, from the simulation, was replaced accordingly to the one obtained. The two motor types characteristics are presented in a comparative manner for a more precise approach on results.

The use of one of the two motor type in an electrical drive depends essentially on the application type and the system required performances.

Regarding the starting characteristics the squirell cage rotor is inferior to the wound rotor, because the starting torque has a smaller value for the same feeding current. [2] Another advantage for the wound rotor motor is given by the possibility of obtaining a slightly variable speed under the syncronous speed by introducing of resistances on the rotoric circuit.

2. MOTOR DESCRIPTION

The induction motor used in this study is a three phased type, with a classical construction and a squirrel cage rotor. The motor is feeded directly from the three phased grid with a rated voltage U_N=380 V , developing an shaft torque of P_N=550 W. The motor has a pole pair number of 2p=2, and a feeding frequency of f=50/60 Hz, the rotor speed in this case is n=2850/3460 rot/min.

The stator winding has a star connection with a rated current I_N=1,6 A. The ferromagnetic stator core is made of sheets of electrotechnical steel with a width of 0.5 mm, isolated with lacquer. Figure 1 presents the stator winding, similar to the curly winding from the direct current machine [2], in one layer with y_1 =4 slots per pole and phase. The four coils, which form a stator phase, are in series.The motor phase resistance is in this case R_f =9,8 Ω measured at the rated motor temperature.

Each stator slot contains 70 round copper wires with a 0.7 mm diameter, and a current density of 3.62 A/mm^2.

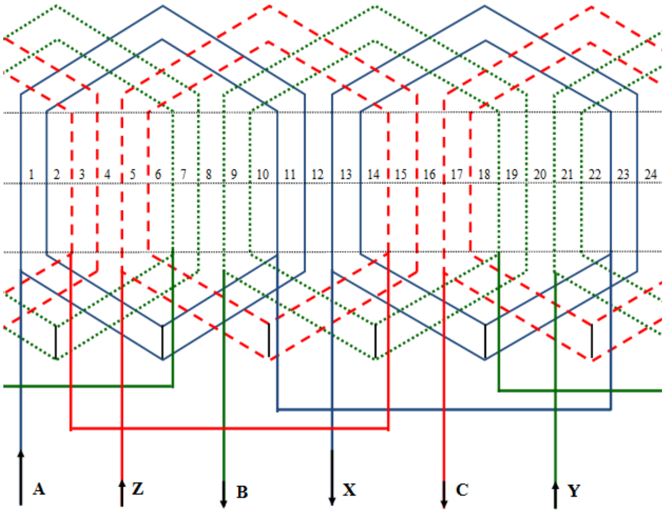


Fig.1. Stator winding

The rotor core is build, like the stator one, from sheets of electrotechnical steel. The rotor core has 18 oval slots with parallel tooth walls. The rotor bars, found in slots, are inclined in respect to the generators with and angle of 20^0 corresponding to the angle between two rotor slots.

Following the study of steady state operation characteristics, the rotor squireel cage was replaced with a winding consisting of copper wires with acces to the coils ends via a brush-ring based system.

The stator winding is maintained so that the results comparison, obtained in the case of the squirrel cage rotor and the case of wound rotor, would be feasible. Consequently, the same electrical parmeters, presented so far, are maintaned for the stator winding.

The redesigned rotor winding is presented in figure 2. This winding has a similar with the stator one. It presents single layer coils, placed in slots and diametral pitch. The slots per pole and phase number is q2=3, such that each rotor phase winding consists of three in series coils. The phases present a star connection type. Each coil is made of 22 wires in series, with a wire diameter of 1.2 mm.

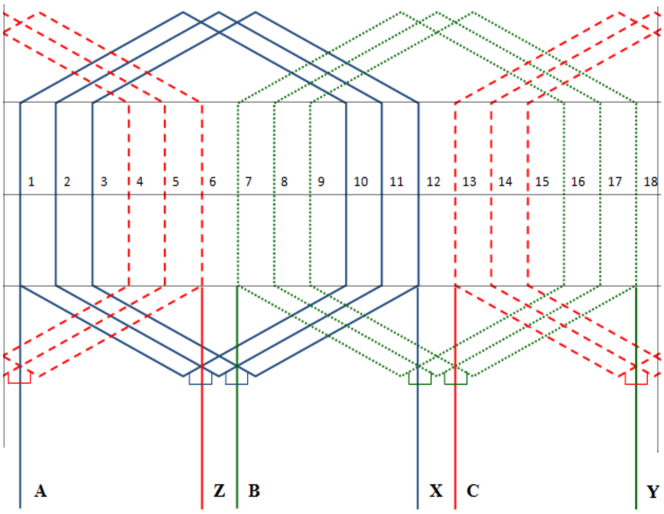


Fig.2. Rotor winding

For a better description of the machine in the next picture the geometrical structure is presented.

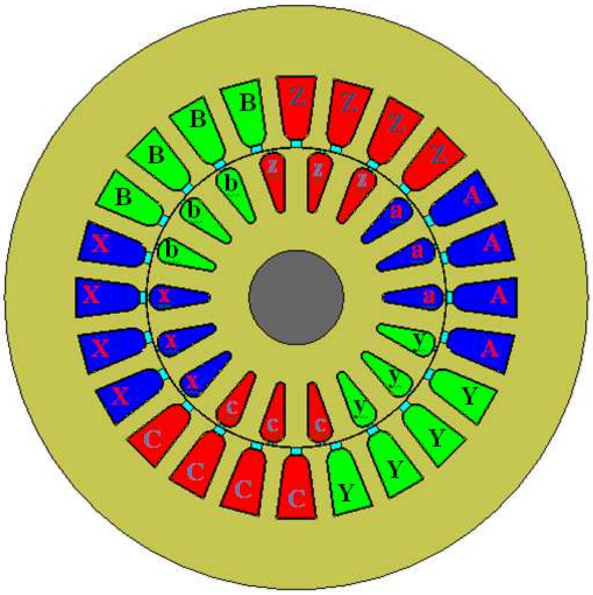


Fig.3. Machine geometry

Figure 3 also presents the arrangement of stator windings in slots. The conductors enter through the slots of the first phase denoted by A, and get out through the ones denoted by X. The second and the third stage similar to the first are arranged symmetrically in the time slots and with the same frequency range, except that the early phases labeled "B" and "C" are out of phase by 2π / 3 of electrical degrees. The wires of return for the second phase are denoted by the letter "Y" and for the third phase is denoted by Z.

3. SIMULATION STUDY OF THE INDUCTION MOTOR

The FEM approach is based on an transitory analysis and uses a commercial software package. Figure 4 shows a detail of the mesh area made into the program to enable the calculation problem.

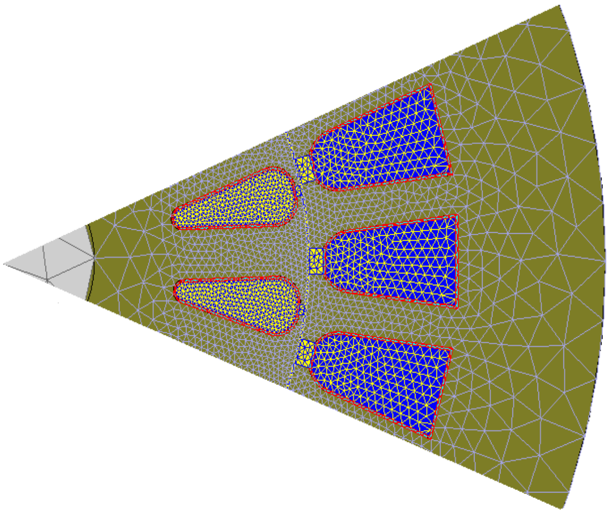
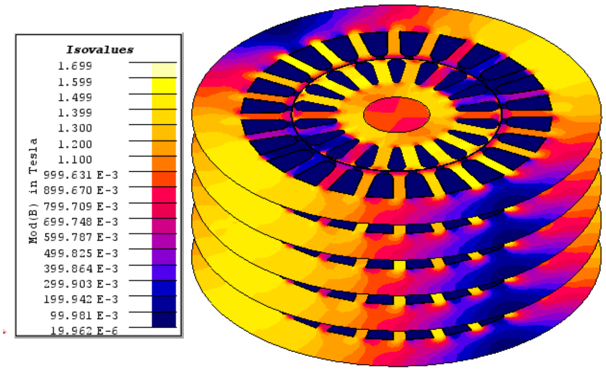


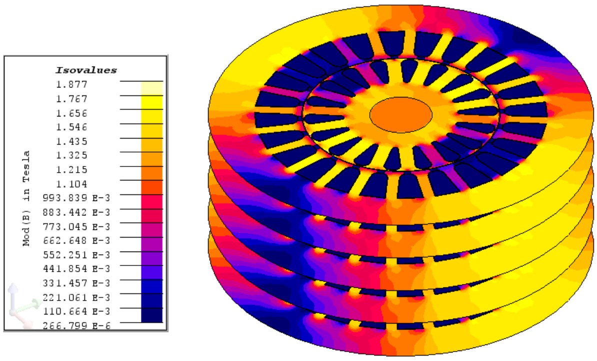
Fig.4. The mesh domain

Regarding the load of the magnetic circuit, the simulation program offers essential information concerning the magnetic field distribution in different constructive parts of the machine, establishing the levels of magnetic saturation for the magnetic circuit.

As shown in the induction spectral maps in figure 5, and also the color scale atached to it, the mean values for the magnetic load fall in the limit of allowable values 1,4÷1,8T, for both motor types. Magnetic induction with a value of 1.8 T can be seen in the regions where the magnetic field lines close and in the rotor theeth with copper winding, due to larger values of the current density, as against the aluminium bars.



a) rotor bar



b) wound rotor

Fig. 5. Flux density color maps

Another important characteristic is given by the time required for the machine to start. At no load operation the wound rotor motor has a starting time that is 60% higher than the time required for the squirrel cage rotor motor to start (figure 6). The overcoming of synchronous speed is due to the rotor inertia wich has the tendency to maintain the rotation movement of the rotor. [3]

The starting times are strongly influenced by the electromagnetic torque produced by the motor during the starting process (figure 7).

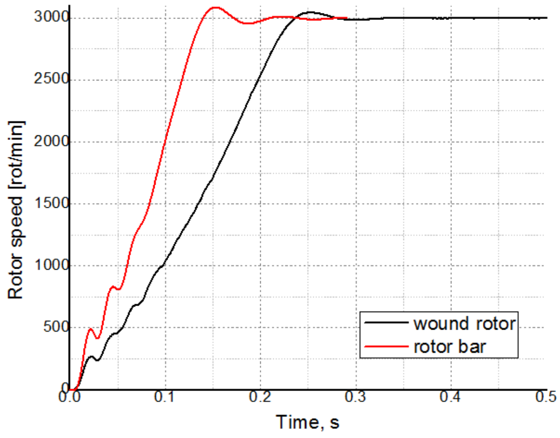


Fig. 6. Rotor speed

In the first moments from the start, in the case of squirrel cage rotor, the electromagnetic torque varies around the value of 4 Nm (between the limits of approximately 10 Nm to approximately -2.5 Nm), whereupon it self-regulates to the value of the resistant torque (given by friction losses). This resistant torque is imposed in the program with a value of 0,1 Nm according to the measurements made on the real motor. The critical torque has a value of around 6,5 Nm. In the case of wound rotor motor the starting torque and the critical torque have smaller values, which justifies the longer time needed for the motor to start.

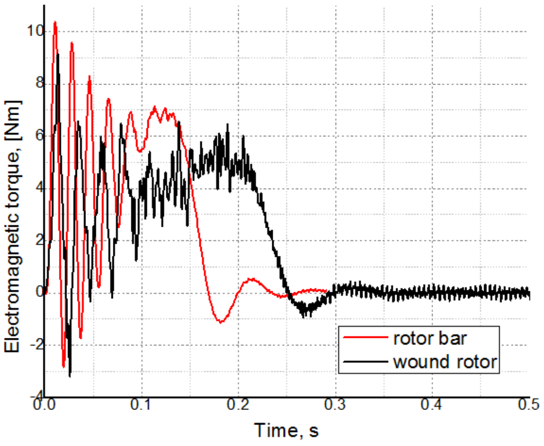


Fig. 7. Electromagnetic torque

Although the stator winding is the same in both cases, the current values are not the same. In the case of squirrel rotor the stator phase current has a frequency f_1 = 50 Hz and a starting amplitude of approximately 9,5 A. This value decreases as the rotor accelerates to a value of about 1 A, at no load operation. The wound rotor motor has a starting value of the phase current of about 2/3 of the squirrel cage starting current, but at steady state this value is about 1.3 times higher.

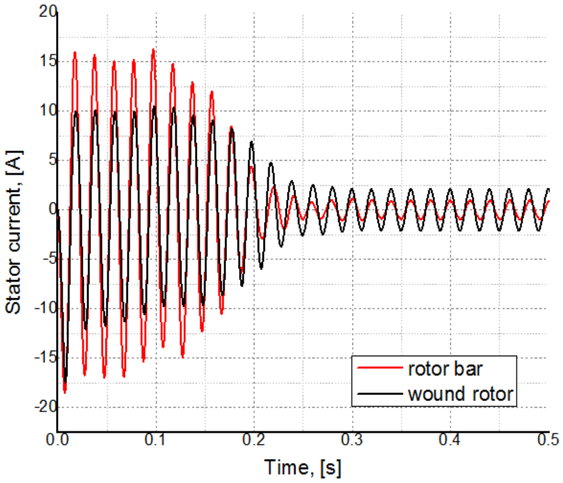


Fig. 8. Stator current

Due to the fact that the rotor windings are completely different (rotor bars have a greater section than the wires in the wound rotor case) the currents from the bars and the ones in the windings cannot be compared. For this reason the current density through the bars (figure 9) and the windings will be scrutinized. Taking into account that the copper conductor section is S_{Cu2}=1.13 mm^2 (d_{Cu2}=1.2mm), the mean value of the current density doesn't exceeds the value of 19 A/mm^2 at start, with approximately the same value for the aluminium bars.

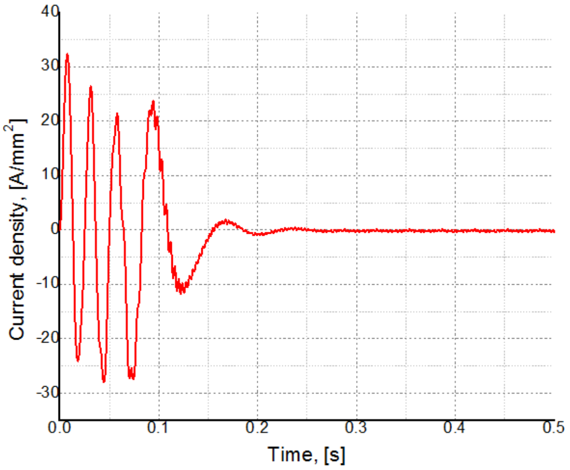


Fig. 9. Current density for a rotor bar

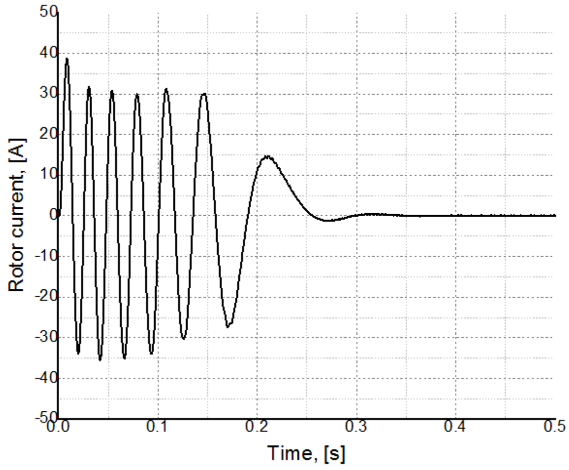


Fig. 10. Current density for rotor winding

A more thorough analys of the obtained results can me made from the exhibition of the waveform for the airgap flux densitiy for the two motor poles (figure 11). The airgap flux density waveform has distortions caused by the presence of stator slots, in respect of which the flux density has smaller values. The increased number of stator slots (24) forming a pole pair causes the flux density waveform to be close to that of a synousidal waveform. The maximum values if the flux density have a value of approximately 1 Tesla and can be observed in the middle of the poles, for the wound rotor type. In the case of a squirrel cage rotor the maximum values for the flux denstity reach a value of 0,9 Tesla.

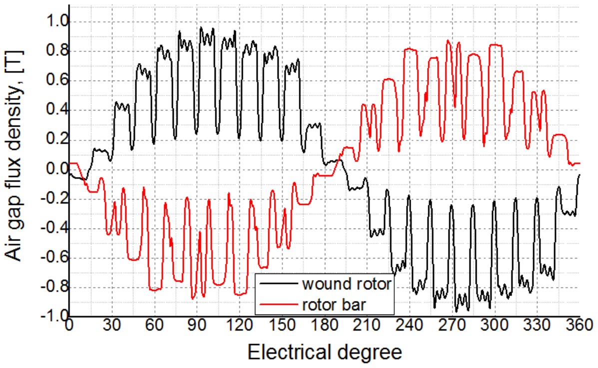


Fig.11. Airgap flux density

Generally the high order time harmonics produce additional heating in electrical machine windings. The windings resistance increases when frequency increases, so that energy loses caused by high order harmonics can be important. High order time harmonics also produce parasitic torques in induction motors, and lower the power factor.

The rotor winding modification leads to an increase of the fundamental with approximately 15%, but also an increase of harmonics of order 3, 7, 9. This harmonics can influence the motor performances by creating inverse fields, therefore the appearance of parasitic torques.

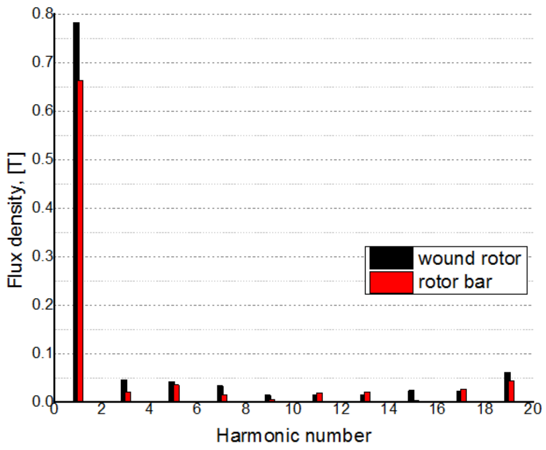


Fig.12. Time harmonic content

4. CONCLUSIONS

Induction machines with squirrel cage rotors are ones of the most used rotating electrical machines, due to relatively easy to manufacture and robust rotor considerations. Regarding the starting capabilities, the squirrel cage motor is slighlty inferior to the wound rotor type, because it produces a lower torque for a given feeding current.

Taking intro account that the induction machines designed for special electric drives require high torque output at low feeding currents and frequent starts, replacing the squirrel cage with a copper winding can be taken into consideration.

A comparison between the squirrel cage rotor and a wound rotor proves the fact that the second type requires lower feeding current during start-up process.

The basic problems with the starting process of an induction motor, due to high values of feeding current, can be solved using resistances in series with the rotor winding. Thus, the usage of one of the two motor type, in an electric drive, depends essentially on the required performances and the application type.

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About the authors

Eng. **Sorin VLĂSCEANU**,
„Gheorghe Asachi" Technical University of Iaşi, Department of Electrical Machines, Romania.
email:soryn_85@yahoo.com

Received the B.Sc. and M.Sc. degrees in electrical engineering from the Technical University of Iasi, Romania, in 2009 and 2010, respectively. He is currently a Ph.D. student in the domain of Electrical Engineering, at the same university. He has published 8 papers in conference proceedings. His research interests are in the area of double fed induction motors.

Prof. Eng. **Alecsandru SIMION**, PhD.,
„Gheorghe Asachi" Technical University of Iaşi, Department of Electrical Machines, Romania.
email: asimion@iota.ee.tuiasi.ro

Received the B.Sc. and Ph.D. degrees in electrical engineering from the Technical University of Iaşi, Romania, in 1968 and 1976, respectively. He is currently a Professor with the Department of Electrical Machines at Electrical Engineering Faculty from the Technical University of Iaşi, Romania. He has published over 230 papers in conference proceedings and 10 books. His technical interests are electric machines and drives, simulation and design. He is the holder of 12 patents.

Assoc. Prof. Eng. **Leonard LIVADARU**, PhD.
„Gheorghe Asachi" Technical University of Iaşi, Department of Electrical Machines, Romania.
email: livadaru@ee.tuiasi.ro

Received the B.Sc. and Ph.D. degrees in electrical engineering from the Technical University of Iasi, Romania, in 1985 and 2003, respectively. He has published over 150 papers in conference proceedings and 5 books. His technical interests are electric machines, simulation, design and optimization based on finite element method.

Eng. **Florin LAZĂR**,
„Gheorghe Asachi" Technical University of Iaşi, Department of Electrical Machines, Romania.
email: lazar_florin1@yahoo.com

Received the B.Sc. and M.Sc. degrees in electrical engineering from the Technical University of Iaşi, Romania, in 2009 and 2011, respectively. He is currently a Ph.D. student in the Electrical Engineering domain, at the same university. He has published 5 papers in conference proceedings. His research area is related to the permanent magnet synchronous machines.

Eng. **Nicolae-Daniel IRIMIA**,
„Gheorghe Asachi" Technical University of Iaşi, Department of Electrical Machines, Romania.
email: sckummi@yahoo.com

Received the B.Sc. and M.Sc. degrees in electrical engineering from the Technical University of Iaşi, Romania, in 2009 and 2010, respectively. He is currently a Ph.D. student in the Electrical Engineering domain, at the same university. He has published 10 papers in conference proceedings. His research area is related to the advanced control strategies of variable reluctance machines.