STUDY ON SQUIRREL CAGE FAULTS OF INDUCTION MACHINES BY MEANS OF ADVANCED FEM BASED SIMULATIONS

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Abstract. Squirrel-cage induction motors play an important role in the world's industry. Hence there is a strong demand on their reliable and safe operation. Their faults and failures can lead to excessive downtimes and generate enormous costs due to reduced output, emergency maintenance and lost revenues. In this paper a FEM model of a three phase squirrel-cage induction machine is presented. It is used to analyse the behaviour of the machine having rotor faults.

Keywords. Modelling, induction motors, flux model, harmonics

1. INTRODUCTION

Nowadays most of the motors used in industry are squirrel-cage induction motors because of their simple design, rugged construction, reliable operation, low initial cost, easy operation and maintenance, relatively high efficiency, etc. Hence numerous studies were presented in recent years in the field of fault detection of these machines. It is becoming a highly important issue to avoid any kind of failure of induction machine. Moreover it is well known that unexpected failures on electrical drive system could result in many unpleasant events. In many applications induction machine's failures can shutdown the entire industrial process. Such unplanned machine shutdowns cost both time and money. The one of the most inconvenient failure of squirrel-cage induction machine are the rotor failures, because these faults practically can not be repaired [1].

In this paper some of the results of the FEM analysis of the squirrel-cage induction machine will be presented, both in the case of healthy condition and when the machine has rotor faults.

Well-developed fault detection of any electrical machine requires a well-grounded theoretical basis. The use of simulation tools helps the researchers to emphasis the effects caused by faults in an electrical machine and to develop efficient fault detection methods. Using FEM analysis the changes in electric, magnetic and mechanic behaviour of the machine due to any fault can be easily observed without the need of opening the machine, or experimenting in laboratories. The main idea is to understand the electric, magnetic and mechanical behaviour of the machine in its healthy state and under fault conditions.

2. FEM MODEL OF THE INDUCTION MACHINE

In recent years the Finite Element Method (FEM) became widely used in the design and analysis of electric machines [2]. Several program packages for magnetic field computations have been developed: MagNet, Flux 2D, AnSys, etc.

Based on the well-known Maxwell's equations the FEM based programs can compute the magnetic field distribution in any electrical machine, and upon this all the parameters and characteristics of the machine can be easily computed. The MagNet software package (by Infolytica Inc.) was used to perform the required simulations. This program is one of the best electromagnetic field computation software, world-wide used by engineers and designers to design and analyze electromagnetic devices. The 2D magnetic field analysis was performed for a transversal cross-section of the machine.

As is mentioned in [3], to reduce computational time usually the electrical machine models are created on the smallest symmetrical part of the machine, in order to reduce the geometrical complexity and the number of finite element mesh nodes. These simplifications cannot be done in the study of asymmetrical magnetic fields caused by machines faults. Hence to obtain the correct magnetic field distribution also in the case of an induction machine having rotor faults the FEM analysis must be performed over the whole cross section of the machine.

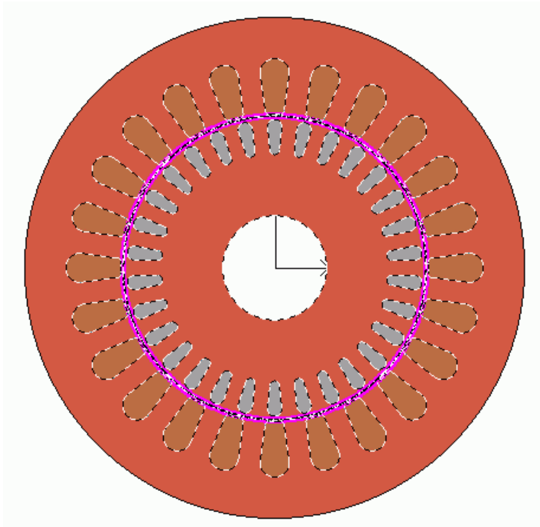
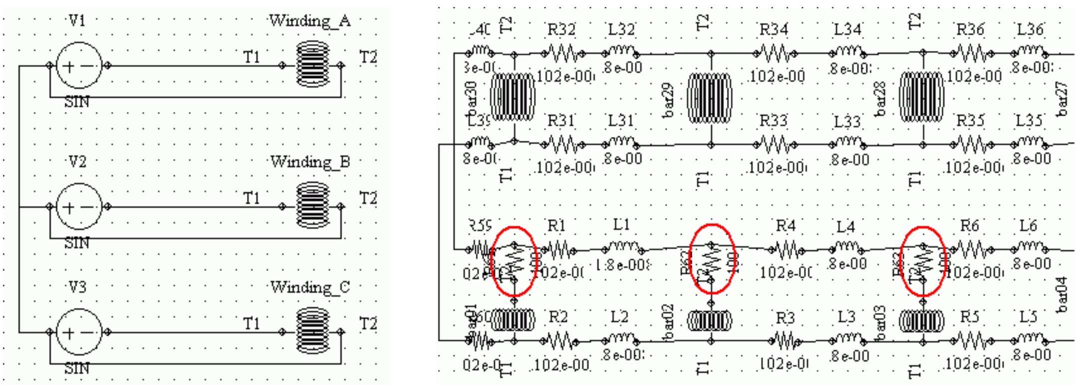


Fig. 1. The solid model of the induction machine

The three-phase squirrel cage induction machine in study (of B3-90L-1.5×1500 type) has the following main characteristics: 1.5 kW, 220/380 V (Δ/Y), 6.18/3.56 A (Δ/Y) and 1410 rpm. The rotor cage of the motor has 30 bars.

Due to the user-friendly interfaces of MagNet it was simple to build up the 2D model of this induction machine. Firstly the geometrical model was completed and the boundary conditions were set up. Also in this stage the materials of each components were specified. The obtained solid model of the machine is shown in Fig. 1.

Following the circuit model had to be built up by connecting the Y-connected stator coils to the three voltage sources (Fig. 2a).

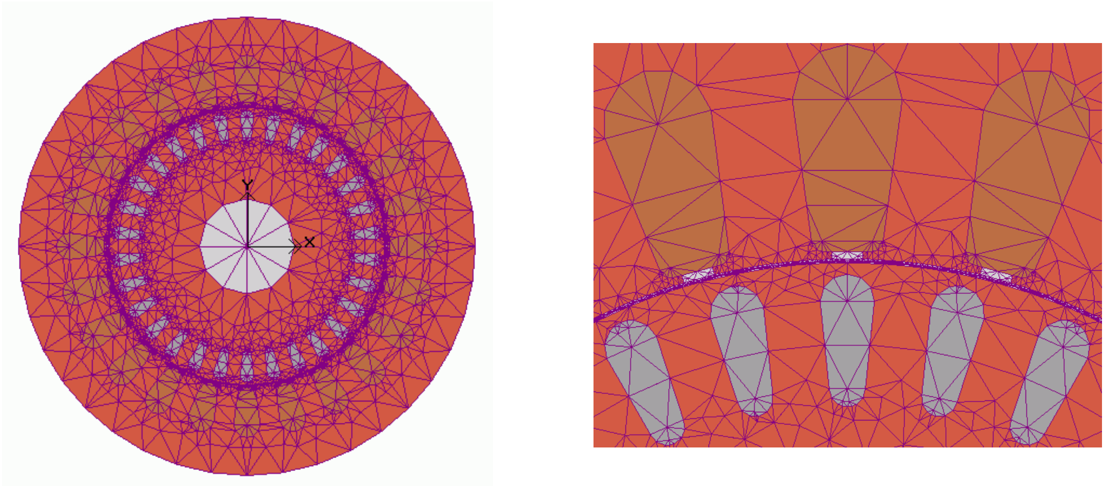


a) the stator circuit b) the rotor circuit

Fig. 2. The circuit model of the induction machine

The circuit model of the squirrel cage is a little bit more complicated: it is built up of 30 solid rotor coils corresponding to the parallel connected rotor bars. Between the ends of two neighboured rotor coils a series resistor-inductor assembly is connected in order to model the end rings, as shown in Fig. 2b. The bar ruptures are simulated in the rotor circuit model by connecting in series with the solid rotor coil a resistance (marked in Fig. 2b). Its resistance is 100 times greater than that of the bar's [4].

After the pre-processing stage the program automatically generated the mesh. This was corrected manually near the air-gap, where the magnetic flux has the highest gradient, in order to get the most accurate results. The final solution mesh was obtained after a few adaption steps (see Fig. 3).



a) the entire mesh   b) a zoom on the mesh

Fig. 3. The solution mesh of the 2D FEM model of the induction machine

In order to be able to analyse the squirrel-cage induction machines dynamic behaviour in both healthy and faulty conditions the *Transient with motion* solver was used. The simulation time was set up to 350 ms, enough to obtain a steady-state regime. The step time was 0.5 ms. Shorter step times could not be used due to the very long simulation times required. The rated load was applied (10 Nm). First the healthy machine was simulated. Next the machine having 3 neighbored broken rotor bars was studied. In the post processing stage of the simulation the advanced visualisation tools of the MagNet package were used (the contour and the shaded plots).

3. SIMULATION RESULTS

In order to validate the results obtained by means of FEM simulations these were compared with those measured previously on an advanced test bench built up especially for the purpose of studying the electrical machines having different kind of faults [1]. As it was observed the results obtained via measurements and simulation are quite similar, and both are in accordance with the theoretical expectations.

To illustrate these statements in Fig. 4 the phase current measured [1] and simulated using the FEM model described above are plotted in the case of the induction machine having 3 neighboured rotor bars broken.

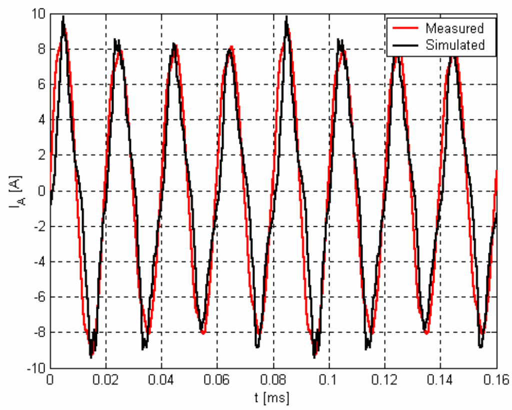
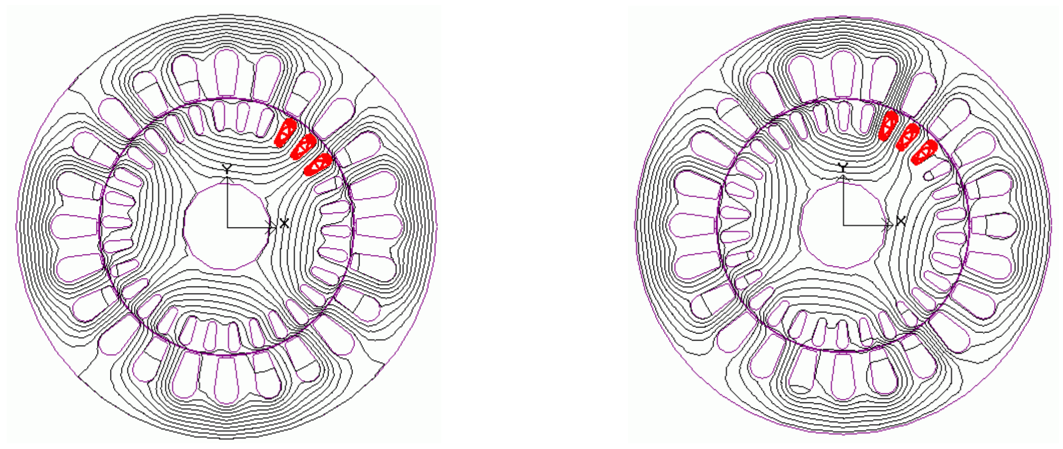


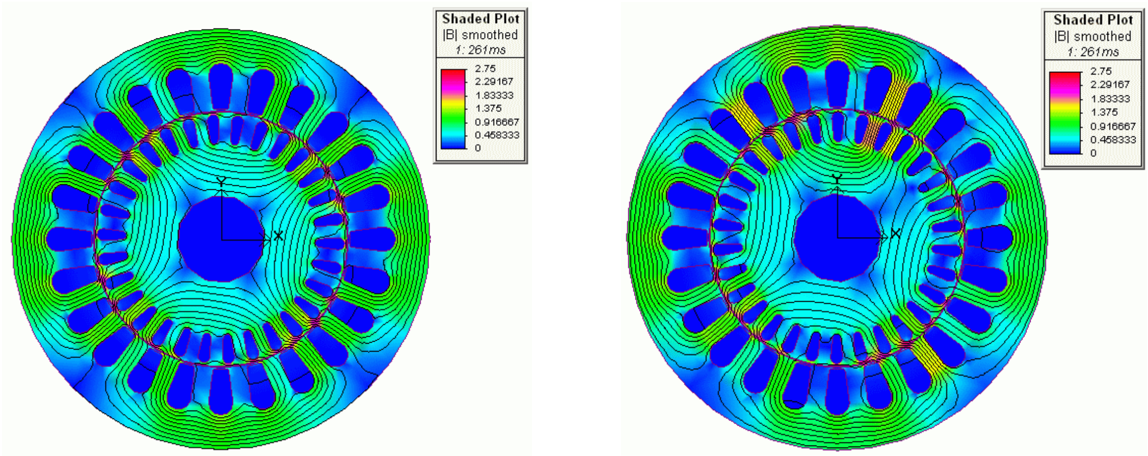
Fig. 4. The measured and simulated phase current

From the numerous results obtained using the FEM model for the healthy and for the machine having 3 broken bars only the most significant ones will be presented in Fig. 5.

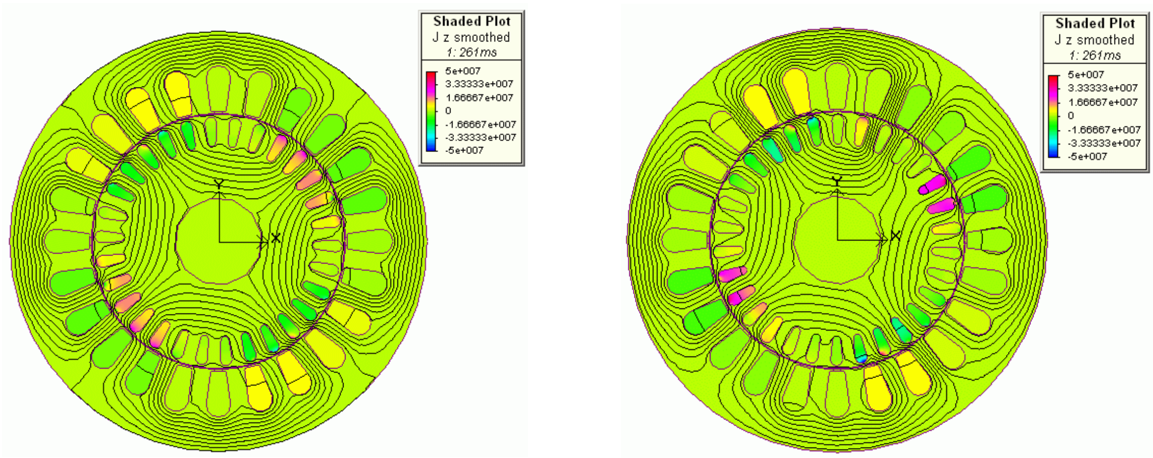
Healthy machine **Machine having 3 broken rotor bars**



a) magnetic flux plots (the bars which were simulated as broken are marked in the figures)



b) shaded plot of the absolute value of the flux density (|B|) at t= 261 ms

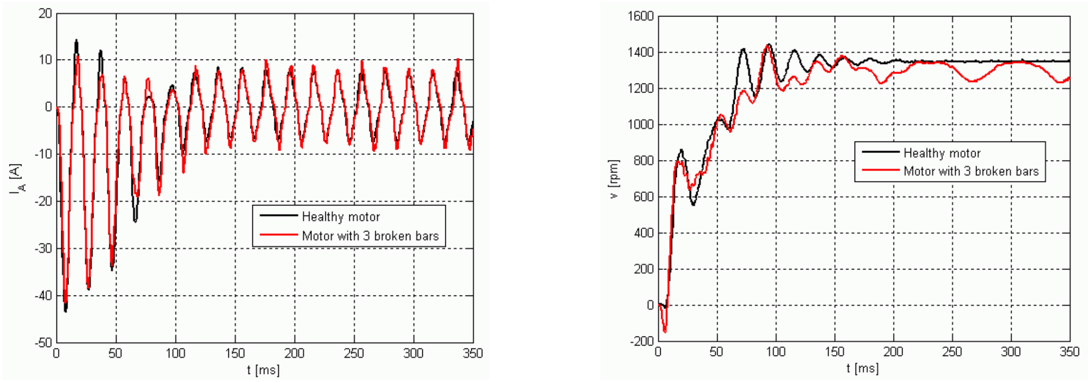


c) shaded plot of the z-axis component of the electric current density (J_z) at t= 261 ms

Fig. 5. Results obtained by the FEM based model of the induction machine

As it can be seen from Fig. 5 the broken bars has affects on the magnetic flux distribution in the machine, generating visible asymmetries. Due to the broken bars some neighboured rotor and stator teeth became saturated. The current densities in the neighboured rotor bars to those broken are significantly increased.

Due to the possibility of simulating also the transient regime in both cases (healthy and faulty machine) a comparative study of the main characteristics of the machine in study was performed. In Fig. 6 the plots versus time of some of the main characteristics of the induction machine in study are given (of the phase *A* stator current and of the speed).

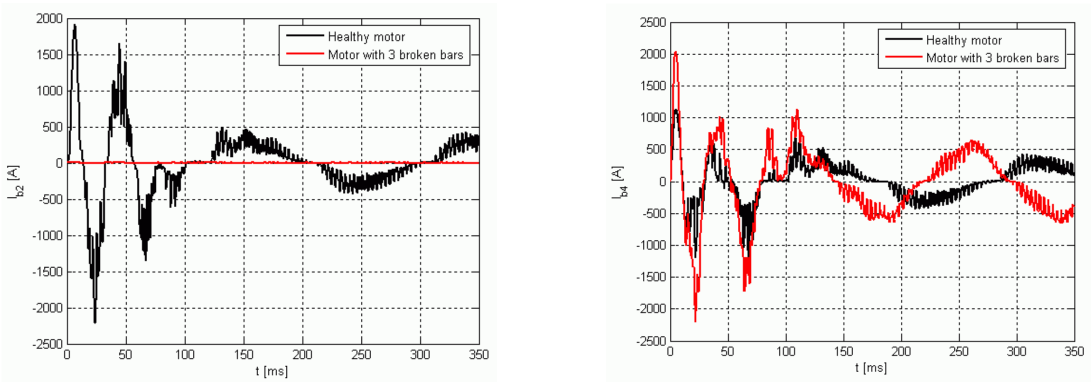


a) stator phase current b) speed

Fig. 6. Results of dynamic simulation for the healthy, respectively the faulty machine

As it can be seen in the figures the currents are increased due to faults. The RMS value of the current during the steady-state regime was 4.8 A in the case of the healthy machine, respectively 5,24 A when it had 3 broken bars. The speed is less at the same load in the case of faulty rotor and it is visibly oscillating.

It is of real interest to see what is happening in the rotor of the machine when broken bars appear. In Fig. 7 the currents through the rotor bar 2 and 4 (the first being the middle one of the 3 broken bars, and the second the next bar to those broken) are given. As it can be seen, the current in the neighboured bar of those broken is increased significantly (its RMS value computed for the steady-state regime changed from 235.6 A to 371.9 A, which means a 58% growing!).



a) current in rotor bar 1 b) current in rotor bar 4

Fig. 7. Results of dynamic simulation for the healthy, respectively the faulty machine

In the study of the fault detection of electrical machines it is very important to determine the harmonic content of the stator currents, because several diagnosis methods are based upon these [5]. Hence the Fourier analysis was performed for the simulated values of the line currents. The harmonic content of the currents in the two studied cases are given in Fig. 8. As it can be seen almost all the harmonics have much greater values in the case of the faulty machine due to the unsymmetries introduced by braking the three rotor bars. It must be mentioned, that also in the case of the healthy machine the line current has more intense harmonic content as it should be expected. This is due to the impossibility to more reduce the time step of the simulation, because it should take extremely long time to perform a simulation of the transient regime of the machine.

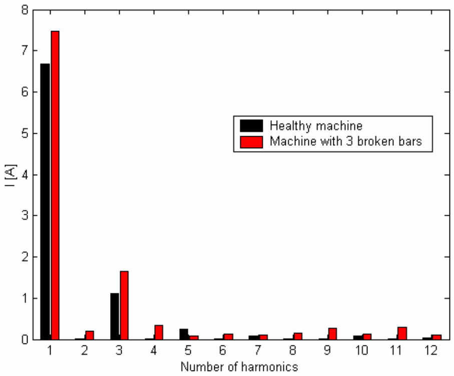


Fig. 8. The harmonic content of the line currents

4. CONCLUSUSION

Finite element method was used to perform dynamical simulation of a three-phase squirrel-cage induction machine. Using this model the most of the typical faults of the machine can be studied. Hence it was proved that the FEM based analysis is an effective and inexpensive method for studying the influence of the faults on the behaviour of any type of electrical machine. Using this method the effects of rotor faults on the performance of the induction machine were studied. Once again it has been proved that the rotor bars next to broken ones are the most exposed to future damage, due to their very high currents, and it can be expected that the fault will soon propagate to these overloaded bars.

The obtained results will be applied in developing new fault diagnostic tools. In the future the model will be also used for studying stator winding faults of the induction machine.

5. ACKNOWLEDGEMENTS

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