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Two-Dimensional Quasi–Static Analysis for Induction Motor with Faulty Rotor

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Abstract: This paper presents the Finite Element Method technique for predicting performance of Induction motor having Electric and Magnetic asymmetry for rotor cage due to some broken rotor bars. The motor parameters like magnetic vector potential, flux density, surface currents have been determined very precisely by carrying out two dimensional quasi static, transient analysis and by using one of the latest FEM tool i,e. COMSOL Multi physics. The required detailed magnetic field distribution analysis can be carried out for further evaluation of motor's operational behavior. The simulation results have been validated experimental results of the model.

Keyword: Rotor bar faults, Induction Motor, Quasi static field analysis, Finite element analysis.

1. Introduction

The induction motor is one of the most reliable, efficient and cost saving electrical machines, representing today a major electric energy consumer in industry. Fault diagnosis systems are used as a tool for maintenance and protection of the costly systems against faults. In this paper the attempt has been made to study and diagnosis of the partially broken rotor bars type failure of induction motor. These flaws may occur due to the small cracks appeared at the welding points, thermal stress due to over load, non-uniform heat distribution, hot Spot and arc, magnetic stresses due to the electromagnetic force, unsymmetrical magnetic force, electromagnetic vibrations, residual stress from manufacturing stage, dynamic stress due to axial torque, environmental stress due to the contamination, materials wearing by chemical materials and humidity mechanical stress due to mechanical fatigue of different parts, faulty ball-bearings and laminations loosing. In order to elaborate an accurate diagnosis methodology, a preliminary step supposes a deep analysis of the consequences of the broken rotor bars on the machine parameters and operation. In this context a lot of interesting and helpful information can be obtained by using modern numerical investigation tools based on **Finite Element Method (FEM)** with COMSOL Multiphysics package in order to comparatively analyze the healthy and damaged motors. [1,2]

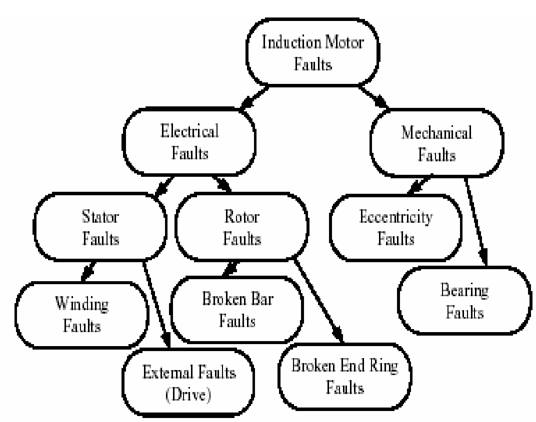

Figure 1. Induction Motor Fault Categories.

2. Finite Element Model of Induction Motor

The finite element field-circuit model of the machine takes into account the non-linearity of the magnetic materials and is suitable for a deep study of induction machine behavior with rotor faults. To evaluate the performance of rotor fault induction motor the magnetic field analysis done in quasi-static and transient states to compare the non-linearity conditions with healthy rotor model. Various specifications for the design of induction motor model are given in Table 1. [4, 6]

Table 1. Specifications of Induction Motor

Number of pole pairs	2
Number of stator slots	8
Number of rotor bars	8
Power	2500W
Current	11.5A
Voltage	180V
Frequency	50Hz
Speed	1198rpm
Length of motor	0.8m
Efficiency	84.6

The use of two dimensional perpendicular induction currents, vector potential tool box of AC/DC module of COMSOL Multiphysics has been employed for the simplicity of model analysis.

The stator and rotor magnetic cores are made up of Samarium Cobalt and soft iron respectively. The remnant flux density, Br = 0.847 T and relative permeability is 1000. The transient analysis with Laplace smoothing method with triangular type element has been applied to the model. The numerical simulations in this paper use the following features of FLUX2D software package: quasi-static and transient magnetic modules, field-circuit coupling, rotating air-gap (field-circuit-mechanic coupling). [9, 10, 11]

The time varying current flowing in the conductor produce time varying field in plane perpendicular to the conductors, which further induces eddy currents in the source conductor and even any other parallel conductor present here. The magnetic field and surface currents can be determined by expressions of Laplace, Poisson , and Helmholtz equations that are generally denoted by: [3,5]

$$\text{curl}\,[(1/\mu)^{\cdot}\,\text{curl}\,\boldsymbol{A}] = \boldsymbol{J} \quad (1)$$

$$\nabla^2 A = -\mu J \quad (2)$$

$$\nabla^2 A = 0 \quad (3)$$

The 2D electromagnetic field computation model in (x, y) Cartesian coordinates is based on the magnetic vector potential formulation characterized by partial differential equation -4 derived from equation- 1 to 3

$$\text{curl}\,[(1/\mu)^{\cdot}\,\text{curl}\,\boldsymbol{A}] = \boldsymbol{J}_s - \sigma\cdot\partial\boldsymbol{A}/\partial t \quad (4)$$

The two unknown quantities $\boldsymbol{A}$ and $\boldsymbol{J}_s$ in equation 4 are determined by a field-circuit coupling model of the machine. Once the magnetic vector potential chart is determined, all the derived quantities associated to the electromagnetic field, such as magnetic flux density, current density etc. are easily computed.

3. Meshing of FE Model

Before applying for post-processing of the model the meshing of the geometry has to be carried out. The 2D- linear Lagrange, Triangular element type used. The complete view of the meshing of the geometry is shown in figure 2. The statistical data of the Adaptive Refinement mesh is given in the Table 2. The Comsol Multiphysics software provides very versatile options for the mesh generations even the minimum element quality and element area ratio adjustments play very significant role to get very accurate and reliable solutions of the model for complicated geometries. Due to multi-material, multi-physics and complex geometry involves in the electrical machines, the analysis becomes quite difficult. The latest powerful FEM tools made it convenient for 2D/3D computations.

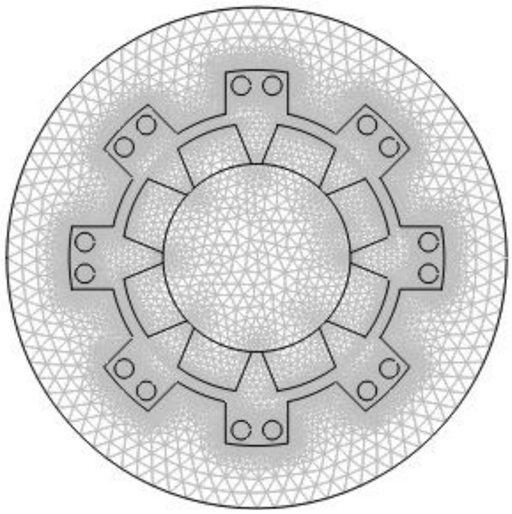

Figure 2. Meshing of the I.M.Model

Table 2. Adaptive Meshing Refinement Statistics of Induction Motor

Items	Adaptive Meshing Statistics
Number of degrees of freedom	126081
Number of mesh points	31221
Number of triangular elements	61536
Number of boundary elements	3282
Number of vertex elements	144
Minimum element quality	0.7949
Element area ratio	0.0066

3. Simulation Results

The simulation of the induction motor operation with broken bars are based on the 2D finite element numerical model of the machine, the only a single modification has been made for developing the unhealthy motor model the resistivity of the broken bars have been considered 10^5 times higher than the resistivity of healthy bar [7]. The two diagonally opposite Rotor bars have been made here with highly resistive to represent as broken bars. The electromagnetic field surface plot of the symmetrical and unsymmetrical rotor conditions are shown in figure 3. The symmetrical rotor for healthy motor model in running conditions having uniformly distributed field as shown in figure 3(a). The magnetic stresses on the intermediate rotors for unhealthy motor model are depicted in figure 3(b).

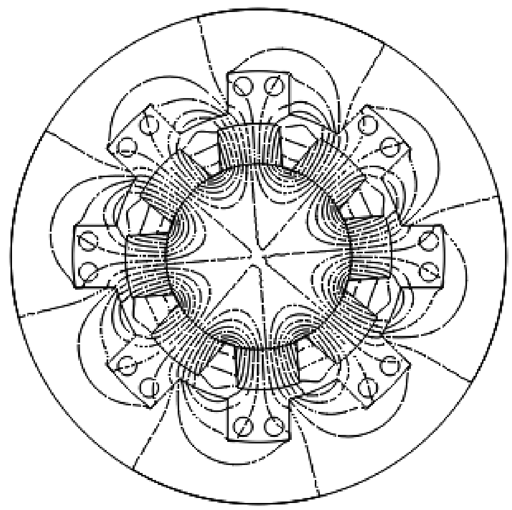

Figure 3(a). Magnetic Flux Analysis of Induction Motor Symmetrical Rotor (healthy rotor)

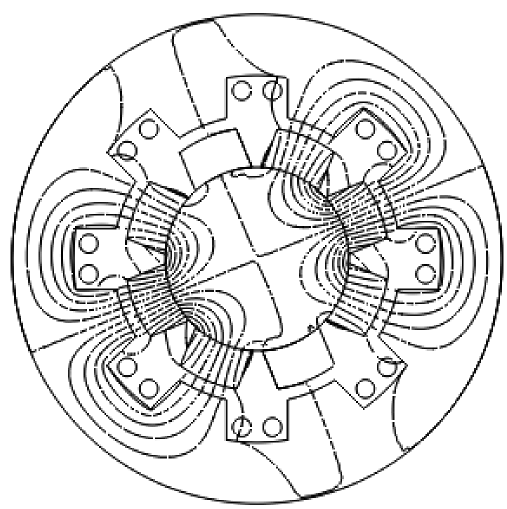

Figure 3(b). Magnetic Flux Analysis of Induction Motor Unsymmetrical Rotor (with two diagonally rotor bars broken)

The Magnetic Field analysis for the Healthy Rotor Motor is shown in figure 4(a). And for the Unhealthy Rotor is shown in figure 4(b). The magnetic stress due unsymmetrical field can easily be seen in figure 4(b) represented with red lines.

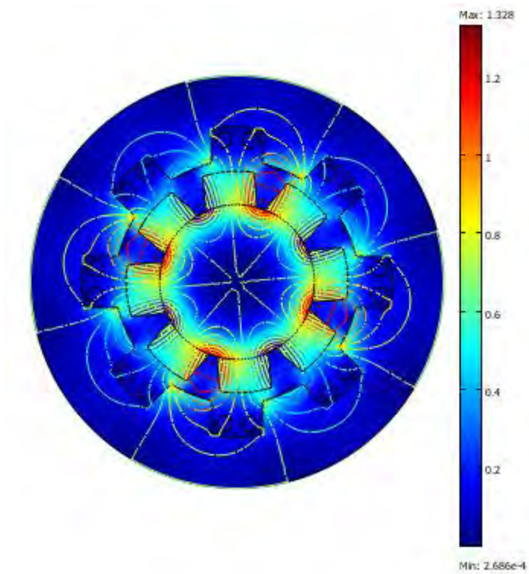

Figure 4(a). Magnetic Field Distribution Surface Plot for the Healthy Rotor

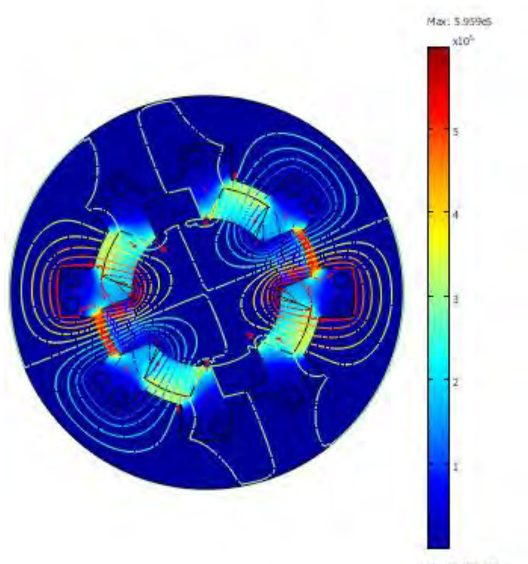

Figure 4(b). Magnetic Field Distribution Surface Plot for the Unhealthy Rotor

The magnetic energy 3D surface plot is shown in figure 5. The adjacent rotors to the broken bars face sever Electromagnetic stresses, which creates unsymmetrical characteristics in mechanical, electrical and magnetic domain. The finally motor develops number of abnormalities during transient and running conditions. The pre-diagnostic computational results may save the big loss and time. [12]

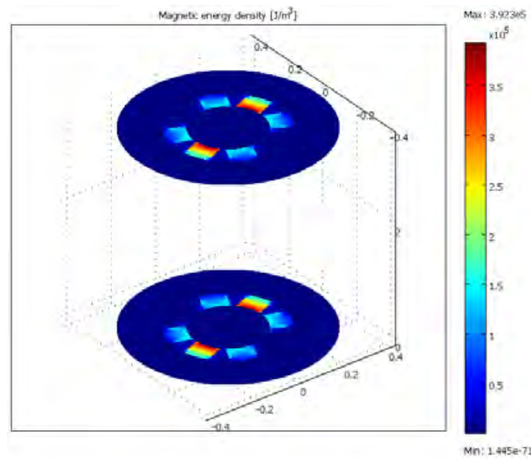

Figure 5. 3D Magnetic Energy Density Plot of Induction Motor with Two Broken Rotor Bars

4. Conclusions

The present finite element approach is very significant to predict the faults of Induction motor with the influence of stator/rotor asymmetry on operating characteristics. The computational simulation provides accurate and inexpensive technique for evaluating the performance of Induction motor in unhealthy operational conditions without damaging the actual geometrical structure of motor. The Finite element method used to compute magnetic and electric characteristics like magnetic field, Magnetic potential and surface current density etc. with symmetrical (healthy) and asymmetrical (unhealthy) rotor in 2D quasi-static and transient conditions. The analysis can further be extended by increasing/decreasing the number for broken rotor bars to predict the non-linearity in the operational period [13].

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