Modification of Gyration Radius for Accurate Eccentricity Fault Detection in Induction Motors

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Abstract — In this paper, radius of Gyration as a proposed index for eccentricity fault detection in induction motors (IMs) is modified for accurate fault detection in IMs. The modified index can precisely detect static eccentricity (SE) and dynamic eccentricity (DE) in different degrees. Furthermore, competency of this index for accurate eccentricity fault recognition in IMs while load varies is analyzed. In addition, the presented techniques can precisely and economically identify and characterize SE and DE in induction motors without the need to have actual fault data from field experience. It is performed by developing dual-track studies of eccentricity simulations and, hence, simulated eccentricity signatures data. These studies are made using two-dimensional (2D) and 3D time stepping finite element method (TSFEM) modeling. Times series data mining (TSDM) method is utilized for feature extraction and pattern recognition from developed torque processing. TSDM addresses the problem of discriminating various types and degrees of motor faults. Simulation results are verified by the experimental results.

I. INTRODUCTION

Eccentricity fault detection methods in induction motors (IMs) have been studied in many papers. Modeling of the faulty IM, selecting an appropriate signal processing tools and proposing competent indices are vital stages of these methods [1]. Among these stages, the first and the third stage determine the method efficiency. Because, the veracity of the simulated signals utilized for feature extraction and pattern recognition closely depends on the modeling precision. In order to model faulty IM precisely, considering effects of spatial distribution of the stator windings, non-linear characteristics of the core materials, stator and rotor slots is necessary. In [2], all general modeling approaches used to calculate faulty IMs signals have been criticized. It has been concluded that finite element method (FEM) is the best modeling approach to simulate faulty IM performance. This fact has been proved in [3] by comparison of the obtained results using winding function method (WFM) as a very common and applicable simulator and FEM. In [4], static eccentricity (SE) has been modeled using time stepping finite element method (TSFEM). Amplitude of the side-band components (ASBC) at frequencies $f_s \pm f_r$ has been used as a proper index for SE fault identification. It has been revealed that fault extension increases this index which can be utilized for fault severity estimation. In [5], time stepping finite element coupled state space method has been employed to calculate the developed torque of the IM with eccentricity fault. Time series data mining (TSDM) has been used for feature extraction via torque processing. Then, radius of Gyration (RG) as an applicable index has been utilized for fault recognition. However, the calculated torque in this method has been obtained from the two-dimensional (2D) TSFEM and skewing of the rotor bars has not been taken into account. Since RG varies based on the variation rate of the developed torque in this method, considering skewing is necessary for achieving accurate results. Furthermore, the proposed index (RG) has not been normalized. So, this index closely depends on the IMs parameters and therefore it should be calculated for every motor.

II. TWO AND THREE-DIMENSIONAL TSFEM MODELING

Magnetic field distribution within the motor can be determined by FEM. The stator currents, torque and speed of the motor can be then calculated using other specifications of the motor. Modeling a faulty IM consists of the three following parts:

A. Motor Elements Modeling

Accuracy of the fault diagnosis approaches depends on considering the physical characteristics of the materials [2, 4]. The reason is the noticeable impacts of the materials characteristics on the motor performance. A 3D scheme of the simulated IM has been depicted in Fig. 1. In this modeling, all magnetic, geometrical, electrical and mechanical characteristics of the motors even end effects of the windings and skin effects are taken in to account. The non-linear characteristics of the stator and rotor cores and spatial harmonics due to the stator and rotor slots have been taken into account. The stator and rotor consists of laminated M-19 sheets. The stator and rotor laminations include 36 and 44 slots, respectively. The rotor slots have been filled by the melted Aluminum. The stator slots have been filled by the copper. Furthermore, stator windings and their spatial distribution is reckoned and a three-phase voltage supply is used in the simulations (see Fig. 1). It is noted that in the 3D-FEM, inductances due to the end effects of the stator coils can be calculated accurately. However, in the 2D-FEM, inductances due to the end effects are ignored.

B. Fault Modeling

Eccentricity fault is due to bearings fatigue, manufacturing and assembling process and other mechanical reasons. In this fault, conformity of the stator axis, rotor axis, and rotor rotating axis are disturbed. There are three types of eccentricities: SE, dynamic eccentricity (DE) and ME.

1) Static eccentricity

In this case the rotational axis of the rotor is identical to its symmetrical axis but has been displayed with respect to the stator symmetrical axis. Although, the air gap distribution around the rotor is not uniform, it is time-independent. The

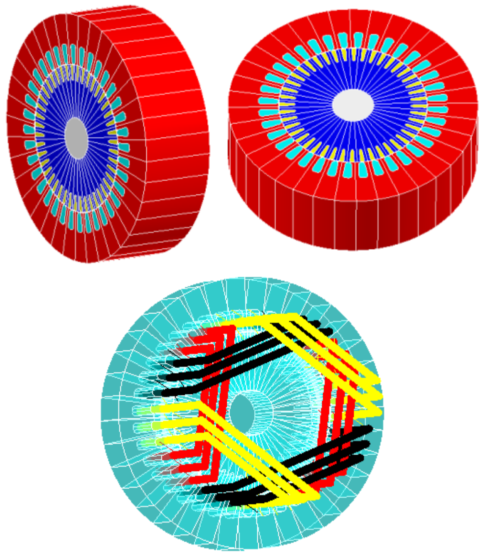

Fig. 1. Geometric configurations of the modeled motor using 3D TSFEM

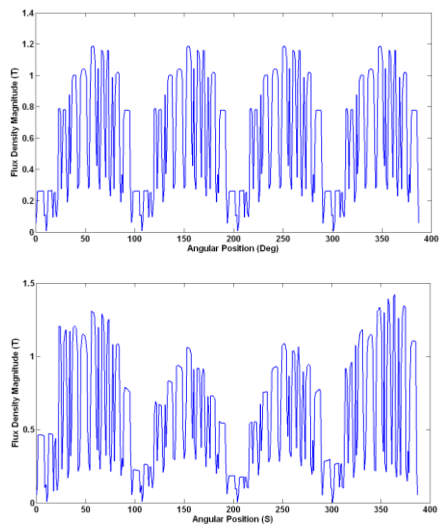

Fig. 2. Distribution of magnetic flux density in IM calculated by 3D TSFEM, (top) healthy and (bottom) 50% SE

reasons for increasing the eccentricity are bad position of the stator core due to the mounting of the motor and non-orientation of the stator and rotor centers during the primary maintenance.

2) Dynamic eccentricity

In this case, the minimum air gap length depends on the rotor angular position, and it rotates around the rotor. This may be due to misalignment or curvature of the rotor axis. Meanwhile, the static eccentricity generates and asymmetrical magnetic pull, which results in the dynamic eccentricity. In this eccentricity, the symmetry axis of the stator and rotation axis of the rotor is identical, but the rotor symmetry axis has been displayed. In such a case, the air gap around rotor is non-uniform and time varying.

C. Solution Method

In this simulation, transient analysis of rotating machines (RM) is employed for modeling and analyzing the IM with mechanical coupling.

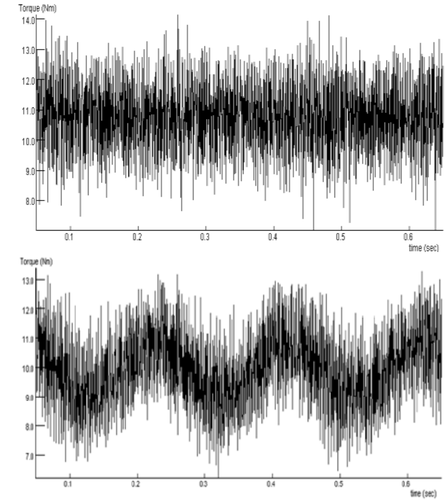

Fig. 3. Torque profile of healthy and faulty IM with 50% DE calculated by 2D TSFEM, (top) healthy and (bottom) 50% DE

The RM program is a transient eddy current solver, extended to include the effects of rigid body (rotating) motion [8]. The solver also provides for the use of the external circuits and coupling to the mechanical equations. In the modeling of the IM, three-phase sinusoidal voltages are applied to the motor terminals as inputs, magnetic flux density and torque are predicted as the selected signals for processing and feature extraction. In this modeling, electrical equations due to the external circuits which exhibit supply and electrical circuits are combined with magnetic field equation in FEM and motion equations of the mechanical coupling.

Fig. 2 demonstrates the distortion of the flux density distribution in the faulty IM. In addition, the local saturation is seen due to eccentricity in the regions which include the smallest air gap. Since motor torque closely depends on the flux density, distortion of the flux density distribution increases the torque ripples which is seen in Fig. 3. Thus, in order to extract proper indices, increase of variation rate of the motor torque may be utilized for processing.

III. References

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