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A Review on the Robustness of Induction Motor under Shock Load

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Abstract: *Electric motors play an important role in the industry, and induction motors are the most widely used. Any motor failure interrupts the process, causes loss of productivity, and may damage other machinery. Therefore, to prevent the motor's sudden failure (such as on the large or critical motor), it is essential to have an early fault detection mechanism. In this paper, types and finite element methods of induction motor shock, shock fundamental, and induction motor faults are presented. The finite element method is used to identify artificially induced mechanical faults, and it is also supported with shock. The most common induction motor faults: bearing, rotor, eccentricity, and load, are investigated experimentally. The efficacy of FEM based monitoring for the detection of mechanical faults is demonstrated.*

Keyword: FEM, electric motor, induction motor, shock.

I. Introduction

In electrical machines, it is a shock to one of the device's operating status indicators, specifically in the case of asynchronous motors in the Shock spectrum of manifestations of most construction and machinery power disorders. Monitoring these variables is then possible to detect emerging fault at a stage where there did not cause more damage. The information obtained can also predict the development of various disorders and their impact on the entire set. Therefore, this issue is of great interest. On the other hand, understanding and predicting faults' various manifestations is necessary to make measurements on a wide range of engines with well-defined error [1]. Creating a specific fault but can be expensive and time-consuming. For these reasons, this article deals with Shock's simulation of electrical machines using the finite element method. This is a test of the applicability of this method for this application [2]. The big advantage of this method is the ability to simulate an unlimited number of well-defined faults without the need for special tools. Given that an electrical machine is a large number of Shock sources and many parts, this calculation was greatly simplified.

All induction motors generate noise and Shock, and analysis of these can be used to give information on the motor condition [3]. Noise and Shock in induction motors are caused by forces of magnetic, mechanical, and aerodynamic origin. The largest Shock and noise in induction motors are the radial forces due to the air gap field because the air gap flux density distribution is a resultant mmf wave and the total presence wave. The resultant magnetomotive force, MMF, also contains the effect of possible rotor or stator asymmetries. The presence wave depends on the air gap variation as the resulting magnetic forces also depend on these asymmetries. Thus, by analysing the Shock signal of an induction motor, it is possible to detect various faults and asymmetries. There have been many practical demonstrations of the capability of Shock monitoring to detect a wide range of motor faults; these include shaft eccentricity/misalignment [4] [5], bearing faults, looseness [6], rotor imbalance [7], and broken rotor bar [5–8].

The Shock of either the motor stator core or end caps can be easily monitored by an accelerometer which is usually directly mounted on the motor. Analysing the measured signal using conventional signal processing techniques such as fast Fourier transforms (FFTs) does not always achieve adequate results. When looking at a Fourier transform of a signal, it is impossible to tell when a particular event took place. To determine when and at what frequencies a signal event occurred, Darowicki and Zieliński [9] derived the short-time Fourier transform (STFT) based on applying a time window to localise the spectrum in the time domain.

Jurado and Saenz [10] showed that the discrete STFT is suitable for harmonic analysis, and by selecting a small window length, it was able to detect transients within noisy data. Arabaci and Bilgin [11] showed experimentally that using the STFT for fault diagnosis and classification in induction motors, where the faults were broken rotor bars and broken end rings, increased accuracy rates.

Ying Xie et al. [12] This study considers a Y2-200L2-6 three-phase induction motor. Its starting torque was improved by combining the characteristics and design method of a star-delta hybrid connection winding, which can meet the motor's demand for oil fields. Meanwhile, the electromagnetic Shock and optimisation of Shock reduction were studied based on the improved motor. The Shock's experimental results were compared with the finite element simulation results to verify the calculation method's validity. The optimal design scheme of the stator winding was proposed based on the characteristics of the winding connection. Lang Wang et al. [13] orders of electromagnetic force for different slot combinations are analysed. A modal analysis calculates the natural frequency of the stator. Spatial and temporal variation characteristics of the motor's radial electromagnetic stress wave are calculated using a finite-element method and analysed in space and time domains by the 2-D Fourier analysis. The induction motor is quiet when both the Shock mode and the frequency of the electromagnetic force wave keep away from the resource mode and the stator

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core's natural frequency. The quietest induction motor is found employing the comparison with four different slot combinations. Chunyu Wang et al. [14] proposed a new skewed slot type based on the double skewed slot, which can better reduce Shock and noise. Two dimensional fast Fourier transform and three-dimensional finite element method are adopted to analyse and compare the three type skewed slots' performance—Zechen Li et al. [15] to reduce the noise of the motor. By planning the turn's relationship between the two parts of the winding, the air-gap magnetic field's harmonic component can be decreased. Besides this, by adjusting the turn's ratio in each slot of concentric winding per phase, respectively, the air-gap magnetic field's waveform becomes closer to a sinusoidal type. The theoretical analysis results, 2D-FEM, 2D-FFT, and harmonic response corroborate each other such that the motor applying CSDLSD winding could reduce both the Shock and noise. Jiaqing Li et al. [16] The space distributions of the magnetic flux field and the Maxwell stress tensor on the rotor surfaces are analysed using an analytical method. The time-step finite-element 3-D whole model of a novel skew squirrel-cage induction motor is presented for verification. The results indicate that the radial and the axial forces decrease, but the rotary torque remains unchanged.

The validity of the improved method is verified through the comparison with the conventional one. Yang et al. [17] In the paper, a method was eliminating the harmonic with the lowest mode number was proposed for suppressing electromagnetic Shock. The 2D finite element method was adopted to analyse electromagnetic force distribution and electromagnetic Shock of two motors with 12-slot 8-pole and 24-slot 8-pole. It was illustrated that the proposed method was suitable to the fractional slot motor while not to the integer slot motor. A rig for the 12-slot 8-pole motor was built for the test. Both simulated and experimental results confirm the validity of the proposed method. Toru Ito et al. [18] this study is the instantaneous electromagnetic force acquisition in the stator side to reduce the Shock. In this paper, the electromagnetic force is acquired from the displacement measured by the strain gauge. Using the switched reluctance motor with salient poles, both the stator and the rotor's displacements are measured. The measured results are compared with the simulation results and experimental results measured by an acceleration sensor. Thus, the effectiveness of the method is examined. Yan Li et al. [19] this paper mainly studies the electromagnetic Shock of a three-phase asynchronous motor under no-load condition. A time-stepping finite element model of the three-phase asynchronous motor was built to calculate the transient electromagnetic field. Maxwell stress tensor method is adopted to capture the radial electromagnetic force under steady-state no-load condition. Experimental results show that the method proposed in this paper can be applied to calculate the electromagnetic Shock at the motor design stage.

II. Shock Fundamentals

Shock is a mechanical phenomenon. It can be said that this is the movement of a flexible body or environment whose individual body vibrates around the equilibrium position.

The forces acting on the vibrating body define the motion equation:

$$m.\frac{d^2x}{dt^2} = F(t) - k.x - b.\frac{dx}{dt}$$

Where

m is body mass, x is a deviation from the steady-state of the body, F(t) is force dependent on time, k is the stiffness of the spring, and bb is the coefficient of damping

The forces acting on any system create the oscillation itself. In a simple case, the oscillation has a harmonic character. This occurs when the system is exposed to a single source with a constant exciting force. For the description of harmonic oscillation, the relationship is used:

$$X(t) = x_{max}.\sin(2.\pi.f.t)$$

where

x(t) is displacement value, x_{max} is maximum displacement value, and f is Shock frequency.

This relationship applies to very simple oscillations. There are several sources and influences in electric machines that affect Shock generation. Therefore, the actual course of shock displacement is the sum of forces that change over time with different frequencies [20].

III. Induction Motor Shock

There are many mechanical and structural shock sources with which we have to contend in the analysis and design of electrical machines. The most common form of mechanical shock is caused by various types, often, but not always, rotating character.

The shock in electrical machines:

- Electromagnetic Shock and noise associated with parasitic effects due to harmonic voltage, phase unbalance, magnetic saturation, and magnet astrictive deformation.
- Mechanical Shock and noise associated with mechanical assemblies, e.g., Bearings.
- Aerodynamic Shock associated with the flow of air produced by the fan through the motor.

A. Shock transmitted to the electric machines:

Shock resulting from the connection of the machine load, for example. Misalignment of the shaft, belt drive teeth of the gears, couplings.

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- Shock transmitted to the machine from the base (or other structure) to which the machine is mounted. For example. Shock transmitted countries (buildings or structures) from passing Lorries, the ongoing construction Shocks caused by natural phenomena (e.g., earthquake, wind power), etc.

B. Types of Induction motor faults

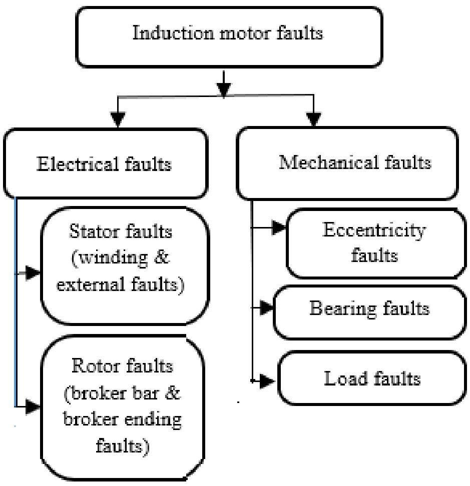

Figure 1. Types of Induction motor faults

IV. Types of Faults

The motor faults can be classified mainly as mechanical and electrical faults. The mechanical faults primarily contain bearing defect, eccentricity and load defect. Electrical faults are classified as stator faults, rotor faults and those related to power supply problems. Each of these faults is discussed below

A. Bearing Faults

Bearing related faults are the prime cause of early motor failure. Nearly 40% of the total machine failures are reportedly due to bearing failure. Most of the motors use bearings having, inner race ring, rolling elements, an outer race ring and a cage to support the rolling elements.

Fault in any of these components in the bearing will produce a unique Shock frequency component. These fault frequency components are dependent on bearing geometry and running speed. Bearing faults are generally caused by contamination, inadequate lubrication, corrosion, improper installation and brandling. Temperature is also one of the prominent causes of bearing failure. An increase in temperature above the normally permissible range will affect the lubricant and cause pitting and wear and tear. The bearing problems listed above usually causes an increase in Shock, noise levels that may progress further to complete bearing failure.

B. Eccentricity

Eccentricity fault is a common type of fault in the induction motor due to an uneven air gap between the stator and the rotor. The prime results of eccentricity fault are Shocks and noise. For a healthy motor, the centre of the rotor is associated with the stator bore, and thus, the centre of rotation is the same as the stator's geometric centre. However, when the rotor's alignment is not in the centre, eccentricity could cause unbalanced magnetic pull and stator to rotor rub, causing motor damage [21]-[22].

C. Load Faults

Load faults are considered external faults, usually mechanical such as gearbox failure, load imbalance and misalignment. Aircraft gears can be considered a critical application requiring high reliability to sage human lives [23]. Thus, it is an important research area to consider for condition monitoring for the past few decades. Other applications involving mechanical loads and gears connected to electrical motors have been a hot favourite for condition monitoring researchers. In [24], an example of gear-related failures and coupling miss alignment faults connected to motors are considered. The load fault primarily causes a non-constant load torque, i.e., the torque is not constant with time. Faults such as mechanical imbalance, shaft misalignment, broken tooth and misalignment in the gearbox, bearing related faults etc., can cause torque oscillations [25].

D. Rotor Faults

One of the probable electrical faults in induction motors is the rotor faults which constitute about 10% of the total failures. These faults mainly occur in the rotor windings, in the case of wound rotor machines in the rotor bars and squirrel cage induction motors in end rings. Cage rotors can be categorised as cast and fabricated, where casted rotors were initially used only for a small motor. However, most of the used type of induction motor (up to 3000kW) is the squirrel cage type with cast rotors due to recent casting development. Rotor faults can be caused due to a combination of factors such as thermal, electromagnetic and mechanical stresses that affects the rotor during its operation. Also, pulsating loads, frequent direct on-line starting and manufacturing defects can cause broken rotor bars. Rotor faults include cracked rotor bars, broken rotor bars (BRB), end-rings and rotor laminations short circuit.

Usually, the die-cast rotor is of Aluminium or Copper in the case of high-efficiency motors. Although there are various causes of rotor faults, asymmetries present in the rotor due to technological limitation, or melting of rotor bars and end-rings may cause rotor failures. Several other reasons related to technical problems, such as the unequal metallurgical stresses developed in cage assembly during the brazing process of manufacturing, may lead to failure during operation. Another reason may be due to the restricted longitudinal moment of rotor bars, which may cause thermal stresses during starting. Large centrifugal forces arising due to heavy end-rings may cause undue stresses to rotor bars causing damage.

The rotor fault existence can be detected by observing spectrum magnitudes' abnormality at particular frequencies in the motor current spectrum [26]. The use of motor current spectrum analysis is done by [27-28] to detect a broken rotor bar. In [29], the residual current analysis using wavelets is performed to extract and remove the current's fundamental frequency. The results of both cases, i.e., motor and generator actions of induction machines, were presented and shown to detect BRB effectively. In [30], the stator's current and voltage are used to compute the input power on the induction motor's stator phase to diagnose BRB.

E. Stator Faults

The most frequent induction motor faults after bearing faults are stator faults. An induction motor under operation may be subjected to a combination of mechanical, thermal, electrical and environmental stresses. As a result of these stresses, continuously acting on the motor may cause stator-related faults. Stator defects can be broadly categorised as (i) laminations and frame faults and (ii) stator winding faults. However, the most common types of stator faults are the ground faults and the inter-turn short circuit. Stator insulation failure reasons are given below:

- High temperatures of the stator core.
- Slacking of core lamination.
- Loose-fitting of end winding.
- Contamination such as moisture and dust.
- Star-up stresses.
- Electrical discharges.
- Escape in cooling assembly.

In the early stages, flux leakage monitoring, zero-sequence and negative sequence current components and MCSA were used for fault diagnosis [31]-[32]. Negative and zero sequence components can be used to detect the presence of stator faults [30]. Additional air gap flux harmonics may be introduced due to the occurrence of stator faults, which can be detected at very high resolution [33]. The presence of faults may be accounted for by the asymmetries existing in the magnetic or electric circuit or motor caused by an imbalance in the currents flowing in winding.

In the instantaneous power, signatures are analysed for the recognition of stator faults. A random forest classifier and Park's vector approach are proposed as a medium for recognising stator winding short circuit faults. The proposed method computes the unbalance in voltage and current waveforms and Park's transform for both voltage and current. Principle component analysis is applied to d-q waveforms to compute unbalance in the Park's vector. A novel methodology is introduced in [33] to detect early-stage stator short circuit fault using autoregressive (AR) modelling. The method is based on the instantaneous space phasor (ISP) module of stator currents.

V. FINITE ELEMENT METHOD

The finite element method (FEM) enables estimating the magnetic field distribution within the motor using the motor's dimensions, and magnetic parameters contain the field distribution, other quantities of the motor such as induced voltage waveform, air gap magnetic flux density, and inductances of different windings can be obtained [34]-[13]. The following differences exist between this method and the MEC method:

1. Number of elements used in this method is considerably lower than that of FEM.

2. Before applying the MEC method, the magnetic flux direction must be known, while in FEM, the flux direction is one of the equations' solutions.

The major advantage of the MEC method compared to the FEM is its short computation time. Therefore, the required time for the MEC method's transient analysis is considerably shorter than that of the FEM. However, its accuracy is lower than that of the FEM. In the comparison of FEM and FDM, the following may be noted:

a. The accuracy of the FEM is considerably higher than that of the FDM.
b. Computer implementation of the FDM is easier than that of the FEM.
c. Programming of the FDM is easier than that of the FEM.
d. The FDM needs lower computer memory compared to that of the FEM.

There is an upper limit for FDM solutions' accuracy, while in FEM, finer meshes increase the solution accuracy exponentially. Also, algebraic equations of this method, similar to the FEM, need current density as input. Therefore, other equations are needed to computation inductances and calculate the current density besides these equations. If Am shows the magnetic vector potential, r_m the specific presence and J the z-axes current density at any point in the space, the following differential equation is held:

$$\frac{\partial}{\partial x}\left(rm\frac{\partial \bar{A}m}{\partial y}\right)+\frac{\partial}{\partial y}\left(rm\frac{\partial \bar{A}m}{\partial y}\right) = -j \qquad \text{(i)}$$

Z is the machine's axial direction, x and y are two perpendicular axes in the machine's cross-section. Equation (1) is the basic magnetic vector potential equation in electrical machines; to solve this differential equation, the following functional expression is defined as the difference between the total stored energy in the magnetic field and input energy of the machine:

$$\mathrm{Fu}(A_m) = \overline{\iint_s}\ (0.\overline{5B}.\overline{H} - J.Am)dxdy$$

Wheres is the cross-section of the machine. Minimisation of (2) leads to a set of equations, the solution of which gives magnetic vector potential distribution. Magnetic field distribution in this region is calculated by magnetic vector potential as follows:

$$B = \nabla \times \bar{A}$$

Other quantities such as induced voltage waveform in the rotor, air gap magnetic flux density, and different windings inductances can be evaluated using the motor's magnetic field distribution[15].

A. Using Of Finite Element Method for Calculation of shock

Modelling shock induction motor is a very complex matter in which the wide calculation variety of physical phenomena influences each other. This article deals with the Shock simulation of electromagnetic origin. It is a simplified calculation of one component of Shock to verify the applicability of use and the method's time demands. Overall, the work can be divided into two main parts. The first part is the modelling of radial forces in the air gap based on changes in the electromagnetic field. This task's program was chosen, Ansoff Maxwell, which can calculate the magnetic field distribution based on the user-defined parameters and the machine's physical dimensions. Also, it can read to calculate the force of the magnetic field on the selected geometry (body), torque characteristics, motor current, etc. This program but itself to the necessary analysis is not enough as an additional program chosen for this analysis was selected AnsysWorkbench. This program is, among other things, able using the finite element method to solve tasks in mechanics. One of its features is that it can read simulate the force on a certain part of the model and then record the effects of this action on the selected part. It may not be the action of a constant force, but it is possible to define the changes and direction of action.

VI. Conclusion

Electrical machinery is the powerhouse of modern industry. The shock of induction motors cause production downtime and may generate large losses in maintenance and revenue. Timely detection of incipient motor faults is hence of great importance. This review presents the types and methods of finite elements for induction motor shocks, shock mass, and induction motor errors. The finite element method is used to identify artificially induced mechanical errors and is also tolerated on impact. The induction motor's most common errors: bearing, rotor, eccentricity, and load, are studied. The fem can be used to detect the shock and its effects on the induction motor.

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