CACLULATION OF INDUCTANCE COEFFICIENTS OF HNDUCTION MACHINES UNDER DYNAMIC ROTOR MISALHGNMENT FAULT

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Abstract- In this study, for calculation of induction machine inductances under dynamic axial non-uniformity condition, modified winding function method has been used. This method is able to calculate the inductances of induction machine with no restrictions about the axial and radial non-uniformities. The inductances of a three-phase squirrel cage induction machine under dynamic rotor misalignment conditions are calculated. Effects of several rotor axial asymmetries on inductances in these conditions are shown.

Keywords- Induction machine, Rotor misalignment, Analytical model, Inductance calculation.

I. INTRODUCTION

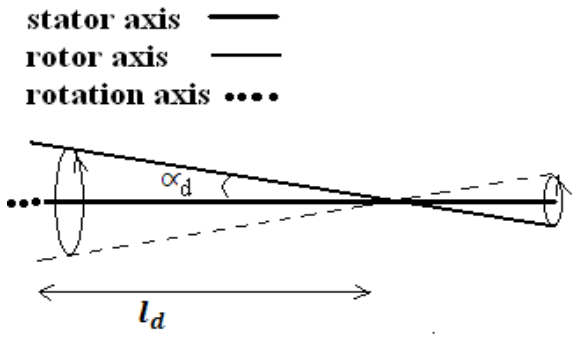
Winding Function Approach (WFA) presented in [1], has been shown to be accurate for the analysis of AC motor performance based on the basic geometry and winding layout of machine. The information used in WFA is the machine geometry and winding layout [2]. The computation quickness of this approach constitutes its main advantage when several machine non-uniformities are to be studied. An essential part of this approach is the calculation of machine inductances. Contrary to the classical d-q model, this method can implicitly take into account all space harmonics. Moreover, by this approach, stator and rotor asymmetries as well as a non-uniform air gap can be taken into account. Hence, this method has been widely used for the analysis of asymmetrical and fault conditions in electrical machines, such as broken rotor bars [2, 3] and fault condition in stator windings [4].

A new method to calculate inductances under nonsymmetrical air-gap, called the modified winding function approach (MWFA) was presented in [5]. MWFA is indeed very well suited to analyze induction machines with air gaps of arbitrary shape. Although, modern methods based on FEM [6, 7] give accurate results, however these methods are time consuming especially for the analysis of electrical machines with asymmetry in the motor body such as air gap eccentricity. In eccentricity condition, the rotor axis is separated from the stator axis, while the rotor axis reminds parallel to that of the stator. Inclined air gap eccentricity or rotor misalignment (RM) occurs when the rotor axis is not parallel to the stator axis. Then, the air gap changes in both axial and radial directions. In reality, the most probable case is the RM fault. Different eccentricities in induction machines are documented previously [8-14]. These models are not able to analyze the effects produced by the axial air-gap non-uniformity in induction machines.
In [15], an extension of the MWFA for the inductance calculation considering axial non-uniformity was proposed. This method was used to calculate the mutual inductance of a three phase induction machine under axial non-uniformity condition. In recent years, different RM faults in induction machines have been studied [16-20]. This paper uses precise method, based on MWFA, for induction machine inductances under RM condition. This will ensure that all space harmonics ignored by the Fourier series expansions of the inverse air gap function are included in the model. Effects of several rotor axial asymmetries on inductances in these conditions are shown.

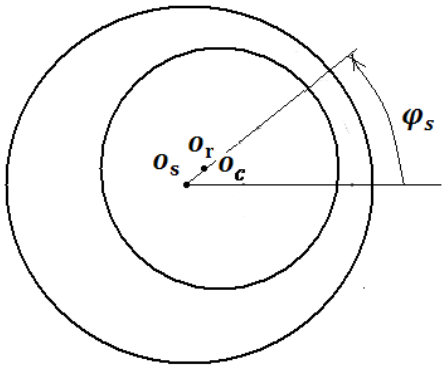
II. MODELING DYNAMIC ROTOR MISALIGNMENT FAULT IN INDUCTION MACHINES

Rotor misalignment (RM) is caused by improper alignment of right and left bearing centers. Consequently, along the axial direction, the degree of eccentricity is not constant. To model the RM, this fault can be treated as a variable circumferential eccentricity.

Fig. 1 shows an elementary induction machine with RM fault. In this condition, the symmetrical axis of rotor, which is superimposed to the rotor rotating axis, is inclined relative to the symmetrical axis of stator. The air-gap function changes in non-uniformity conditions compared to the symmetrical case. In this condition, the air gap length variation can be described by air gap function as follows:



(a)



(b)

Figure 1. Dynamic RM fault in an induction machine. (a) axes position and (b) a cross section of machine [20]. o_s is stator center, o_r is rotor center and o_c is rotor rotating center.

$$g(\varphi,\varphi_S,z)=g_0(1-\delta(z)cos(\varphi-\varphi_s)) \quad (1)$$

where g_0 is effective air gap length in healthy condition, g is air gap function in case of RM, φ_s is angle at which rotor rotation and stator centers are separated and δ is eccentricity level. The stator and rotor slots effect is included by Carter's coefficient referred to the slots [21]. δ is obtained from the ratio between the distance of stator and rotation centers ($o_s o_c$ in Fig. 1-b) and the air gap length of healthy machine. Through geometric analysis on Fig. 1-a, it is straight forward to show that the eccentricity level at any point along the axial direction as follows [20].

$$\delta(z)=-tan(\alpha_d)(z-l_d)/g_0 \quad (2)$$

α_d is the inclined angle of the rotor and l_d is the rotor shaft misalignment level. α_d and l_d are clearly shown in Fig. 1-a.

III. WINDING FUNCTION APPROACH FOR INDUCTANCE CALCULATION

Inductances of electrical machines can be calculated by the winding function theory. The general expression for mutual inductance between any two windings *a* and *b* in any electrical machine, considering axial nonuniformity, is given by the following equation [15].

$$L_{ab}=\mu_\circ r\int_0^l\int_0^{2\pi} n_a.M_b.g^{-1}d\phi dz \quad (3)$$

where

$$M_b=n_b-\frac{\int_0^l\int_0^{2\pi} g^{-1}.n_b d\varphi dz}{2\pi l\int_0^l\int_0^{2\pi} g^{-1}d\varphi dz} \quad (4)$$

$\mu_\circ$ is free space permeability, *l* is axial stack length of the machine, g^{-1} is inverse air gap function, *r* is mean radius of the air gap, n_a is turn function of winding *a* and M_b is modified winding function of winding *b*. The winding functions of the stator phases and rotor loops of the machine do not change under the air gap non-uniformity conditions compared to the symmetrical condition.

The inductances of induction machines can therefore be calculated by means of (3). This technique has capability to simulate the mechanical asymmetry and fault of stator and rotor with no restrictions about the axial and radial non-uniformity.

IV. CALCULATION OF INDUCTANCES

In this section, inductances of a 2200 W, three phase induction machine are calculated under different RM conditions. Specifications of the simulated motor have been summarized in Table 1. Fig. 2 shows the turn function of stator phase A. Phase A winding is distributed in 12 slots. All the inductances are computed at several rotor angular positions and stored within a computer file. It should be noted that the magnetic saturation and leakage flux have not been considered.

TABLE 1. SPECIFICATIONS OF SIMULATED MOTOR

Number of poles	4
Inner diameter of stator (mm)	90
Air gap length (mm)	0.3
Core length (mm)	90
Number of stator slots	36
Number of rotor slots	28
Rated voltage, V	380
Rated frequency, Hz	50
Rated power, hp	3

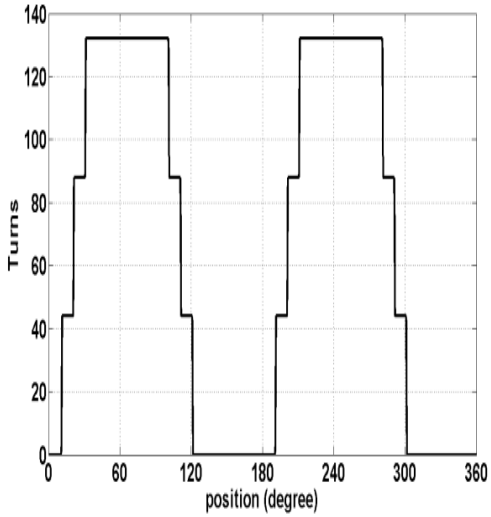


Figure 2. Turn function of the stator phase A.

Comparison of plots in Fig. 3 shows how RM affect the profile of the inductances. Eccentricity level at two ends of machine is specified on these figures. For example, In RM (0.2 , 0.5), eccentricity level at two ends of machine is 0.2 and 0.5 .As shown in Fig. 3, RM causes an asymmetrical mutual inductance between stator phase A and rotor loop 1, a symmetrical magnetizing inductance of stator phase A and a symmetrical mutual inductance between stator phase A and phase B. The magnetizing inductance of stator phase A and mutual inductance between stator phase A and phase B are independent of rotor position. Its reason is that the air gap reluctance is rotor position independent. By increasing the average eccentricity level, the magnitude of inductances increases. For example, the value of magnetizing inductance of the healthy machine, 0.29 H increases to 0.312 H in the case of DM (0.2 , 0.5.

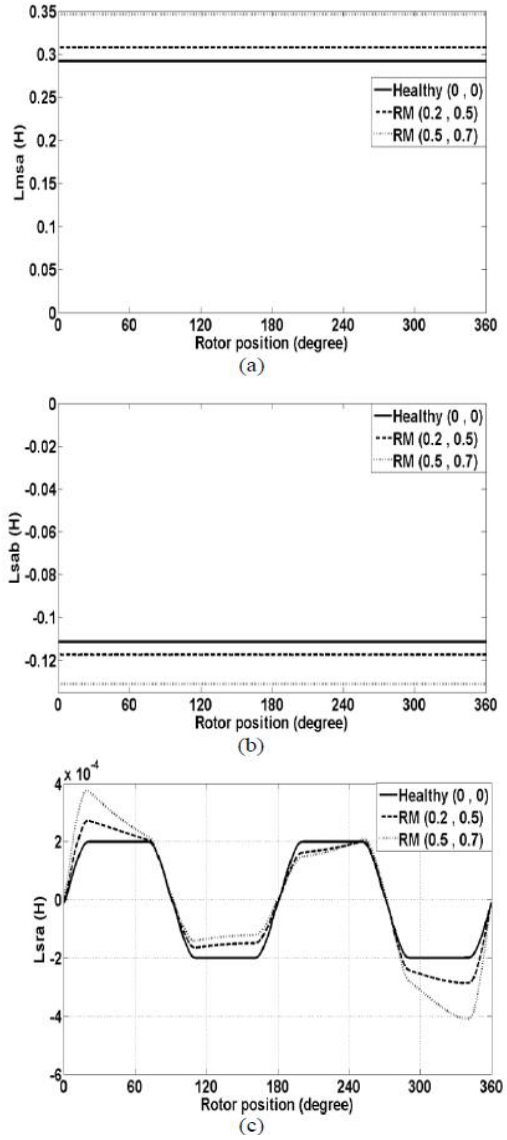


Figure 3. Magnetizing inductance of stator phase A (a), mutual inductance between phase A and phase B (b) and mutual inductance between phase A and rotor loop1 (c), as a function of rotor position under healthy and RM conditions.

CONCLUSIONS

A great deal of research has so far been conducted on the computation of induction machine inductances under different eccentricity conditions. However, they consider the static non-uniformity. In this paper, the time varying inductances versus rotor angle for induction machines under dynamic RM conditions has been calculated using MWFA. This method has capability to calculate inductances under dynamic RM with no restrictions about the axial and radial non-uniformities.

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