

Magnetic Field Harmonics and its Effect on Vibration in a Bridge Configured Winding Induction Motor

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The magnetic field harmonics of pole pair difference one is the reason behind the lateral force production in an electrical machine. The eccentric motion of the rotor, generates magnetic field of pole pair difference one with respect to the torque producing component of the magnetic field. Due to the interaction of these fields, radial force called unbalanced magnetic pull (UMP) acts on the rotor. The present work is based on a special winding scheme called bridge configured winding (BCW) scheme which has inherent capability of diminishing eccentricity induced magnetic field harmonics when bridge currents are allowed to flow in the winding. The present work investigates the presence of harmonic components in the air gap and its effect on force production. An in-house 2D FE code of BCW induction motor has been used for the investigation.

Index Terms—Eccentric, Harmonics, Induction Motor, Vibration

I. INTRODUCTION

Unbalanced magnetic pull (UMP) in an electrical machine has been studied by various authors since the beginning of 19th century. Eccentric position of the rotor makes magnetic field distribution asymmetric and as a result, a force acts on the rotor in the direction of the shortest air gap. The UMP can be suppressed either passively or actively. Generally parallel winding [1] and damper winding [2] helps in passive suppression of UMP. The dual set of winding scheme can be used for passive [3] as well as active suppression of UMP [4]. Khoo [5] developed single set of winding scheme called bridge configured winding scheme which has the capability to suppress the unbalanced magnetic pull actively as well as passively. Khoo et al. [6] practically implemented BCW scheme on a brushless permanent magnet motor and showed its capability to generate controllable force. Kalita et al. [7] demonstrated partial active vibration control capability of BCW scheme in a 4-pole induction motor. However, the harmonic component of the magnetic field which is responsible for UMP suppression is not clear. The details and the working principle of BCW scheme can be found in [6]-[8]. The present work is an investigation to find out the magnetic field harmonics which is actually responsible for vibration or UMP control in a BCW scheme wound electrical machine.

II. FE MODELLING

An In-house 2D FE code has been used for the analysis of the field present in the air gap of a 36 slot 4-pole BCW induction machine. The present study has been carried out on a BCW Induction Machine which has squirrel cage rotor. Here two types of conductor is being used, (a) Thin conductors (in stator slot), which is grouped in coils and current densities are generally uniform here (b) Thick conductors (in rotor), where currents are induced due to the flux cutting generated due to stator excitation. Hence there exist one source of excitation, two circuit equations and a field equation. A coupled field circuit equation has to be solved for entire domain of the

machine to calculate the magnetic field in the air gap and the forces acting on the rotor. These coupled equations can be represented as,

$$\frac{\partial}{\partial x} \left[\frac{1}{\mu} \frac{\partial A}{\partial x} \right] + \frac{\partial}{\partial y} \left[\frac{1}{\mu} \frac{\partial A}{\partial y} \right] - \sigma \frac{\partial A}{\partial t} + \frac{N_{co}}{S_{sf}} I_f + \frac{\sigma}{l} U_t = 0 \quad (1)$$

$$U_t = R_t I_t + R_t \int_s \sigma \frac{\partial A}{\partial t} ds \quad (2)$$

$$U_f = R_f I_f + N_{co} l \frac{\partial A}{\partial t} + L_{end} \frac{dI_f}{dt} \quad (3)$$

where A is the magnetic vector potential, N_{co} is the number of turns of the coil, s_f is the cross-sectional area of thin conductor, I_f is the current flowing through the thin conductor, U_t is the potential difference across the thick conductor of the rotor, l is the axial length of the rotor, I_t is the current flowing through the thick conductor of the rotor, R_t is the resistance of the thick conductor of the rotor, U_f is the potential difference applied across the stator thin coil, R_f is the resistance of the thin coil, σ is the conductivity of the thick conductor, and L_{end} is the end-winding inductance of the machine.

Once the magnetic vector potential at each node of the machine is known, the magnetic field in the air gap can be calculated as Eq 4,

$$B = \nabla \times A = + \frac{\partial A}{\partial y} \hat{i} - \frac{\partial A}{\partial x} \hat{j} = B_x \hat{i} + B_y \hat{j} \quad (4)$$

Using the components of the magnetic field along x and y directions, the normal (B_n) and the tangential (B_t) components of the magnetic field can be calculated as,

$$B_n = B_x \cos(\theta) + B_y \sin(\theta); B_t = -B_x \sin(\theta) + B_y \cos(\theta) \quad (5)$$

With known normal and tangential component of the field, the forces acting on the rotor can be calculated as shown in Eq. 6 to Eq. 9.

$$\sigma_{nm} = \frac{(B_n^2 - B_t^2)}{2\mu_0}; \tau_n = \frac{2B_n B_t}{2\mu_0} \quad (6)$$

$$F_x = l \int_0^{2\pi} (\sigma_{nm} \cos \theta - \tau_n \sin \theta) r d\theta \quad (7)$$

$$F_y = l \int_0^{2\pi} (\sigma_{nm} \sin \theta + \tau_{tt} \cos \theta) r d\theta \quad (8)$$

where σ_{nm} , τ_{tt} , F_x and F_y are the normal and the tangential component of maxwell stress and forces along x and y direction respectively.

III. INVESTIGATION

The magnetic field behaviour of the BCW induction machine is quite complex. To study the behaviour of the field the Induction machine has been simulated in different conditions. (a) Normal condition - the rotor is centric with respect to the stator. (b) Eccentric condition - the rotor is 20 percent eccentric with respect to the stator. (c) Eccentric condition - the rotor is 20 percent eccentric with respect to the stator with magnified and reduced bridge current. Air gap magnetic field component of an electrical machine can be represented as,

$$B_p = A \cos(p\theta + \omega t) \quad (9)$$

where p , θ and ω are pole pair number, spatial distribution and rotational frequency respectively. Considering this representation of the field, spatial fast frequency transform (FFT) has been carried out to separate the field of a particular orientation (2-pole, 4-pole and 6-pole) from the simulated magnetic field data. The code has been simulated for 5 sec. and last one sec. data has been used for the analysis. Fig. 1 shows the comparison in the behaviour of 2-pole, 4-pole and 6-pole field amplitude when bridges of the winding is in OPEN and CLOSED conditions. Fig. 2 and Fig.3 represent the variations in 2-pole and 6-pole fields when bridge currents are amplified and reduced respectively. Fig. 4 represents the force orbit when bridges are in OPEN and CLOSED conditions. A modulated 6-pole field is observed when the bridge is in CLOSED condition as shown in Fig. 1. It can be observed from Fig. 3 and Fig. 4 that the amplification and reduction in bridge current leads to amplification and reduction of 6-pole field amplitudes respectively, whereas 2-pole field behaves in the opposite sense.

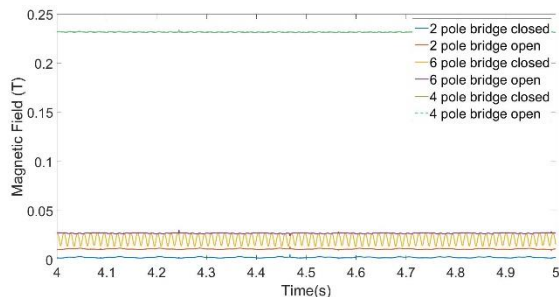


Fig. 1 Comparison of four pole, two pole and six pole field components with eccentric rotor when bridges are open and closed

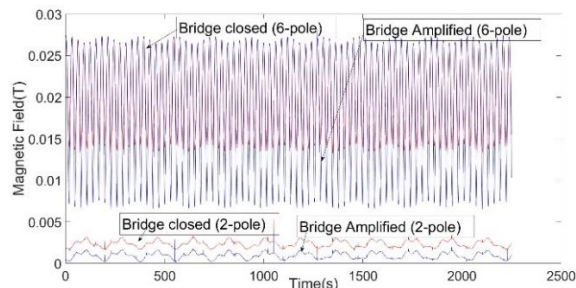


Fig. 2 Comparison of amplitude of two and six pole field when bridge current is amplified with eccentric rotor

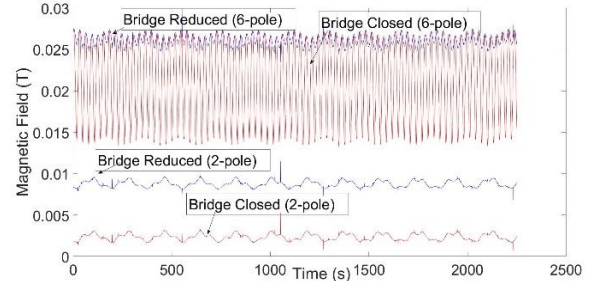


Fig. 3 Comparison of amplitude of two and six pole field when bridge current is reduced with eccentric rotor

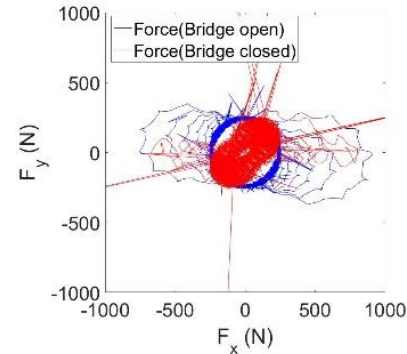


Fig. 4 Comparison of the forces generated in the air gap in different conditions

IV. CONCLUSION

The eccentricity generated asymmetry in a 4-pole machine creates 2-pole and 6-pole magnetic fields. It can be inferred from the behavior of the field that it is the 6-pole field which is responsible for force reduction as shown in Fig.4. In CLOSED condition of a BCW machine, the eccentricity induced bridge currents are able to amplify and modulate the 6-pole field to mitigate the developed UMP in the machine. Further reduction of UMP can be achieved by amplifying the bridge currents.

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