Harmonic Reduction Using Fractional Pitch Winding

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Abstract: The power source and the nonlinear loads on transmission line are major sources of harmonics and if these harmonics are not controlled, they could lead to heat loss, break down of machines and reducing the efficiency of any machine connected to the supply. The non-sinusoidal currents from the power source increase harmonic contents in the air gap of electrical machines with pole pitch winding which will lead to excessive losses, vibration and noise. This paper presents the use of fractional pitch winding technique for the stator of three phase motor for the purpose of suppressing harmonics. This is investigated between two windings of pole pitch and short-pitch and the results simulated using Emetor Electric Motor software.

Keywords: *Harmonics, Fractional pitch winding, Pole pitch winding, Air gap, Coil*

1. Introduction

Harmonics are distortions of voltage or current wave as a result of non-sinusoidal wave form of the field flux (Bakshi and Bakshi 2009). The field produced is known as harmonic field. These fields are produced because of its winding, slotting, saturation and air gap length irregularity (variation in reluctance of the air-gap due to the slotting of the armature coils in salient and non-salient pole machines) which are inherent in the machine. The other minor causes include overhang leakage fields, axial leakage of the main flux, harmonic in the supply system and unbalance supply system. The effects of harmonics on rotating machines are the copper and iron losses which produce heat and thereby reducing the efficiency of the machine. The pulsating torque produced was due to the interaction of the harmonics-generated magnetic fields and the fundamental. These result in a higher audible noise. To eliminate or minimize the harmonics from the voltage waveform, the winding must be properly designed. According to Bhattacharya (2009), the adoption of fractional pitch for the stator winding reduces the low order harmonics. It reduces the 5th and 7th harmonics in the air gap field. The other means of reducing harmonics in stator winding are:

1.1 Winding distribution

The coils are distributed in a number of slots but not concentrated in each phase in order to form polar groups under each pole. The magnitude of the harmonic electromagnetic force depends upon their distribution factors. The distribution factor is small for order of higher harmonics according to Naidu and Kanakshiaiah (1995).

1.2 Skewing

In order to avoid slot harmonics, the slots in the stator and the rotor are skewed. The rotor slots are not parallel to the shaft but skewed to make the motor runs quietly by reducing magnetic hum and to decrease slot harmonics. It also reduces the locking tendency of the rotor especially when the number of the rotor teeth and stator teeth are equal which leads to direct magnetic attraction between the two (Piotrovski 1972).

1.3 Large length of air gap

The use of large air gap length increases its reluctance and therefore reducing the magnitude of the slot harmonics.

1.4 Fractional slot winding

Fractional slot winding is a type of winding in which the number of slots per pole per phase is a fraction or a mixed fraction. It reduces harmonic electromotive force and gives reduction factor for various winding arrangement (Theraja 2008).

2. Methodology

Two winding layouts of three phase double layer winding of full pitch and short pitch coils that are having the same number of slots and poles but different coil span are investigated by Emetor electric motor winding simulation software and the software displays the harmonic spectrum of each winding

2.1 Fractional pitch winding

Fractional pitch winding or a chorded winding is a winding whose coil sides are less than a pole pitch. The electromotive force generated is proportional to (Agarwal 2000), where θ is the angle of chording and n is the order of harmonic. The harmonic spectrum of electromotive force can therefore be considerably reduced by choosing a proper value of θ.

2.2 Analysis of fractional pitch winding

Figure 1 shows a pole pitch coil and coil span (Rajput 2006). The coil pitch can be calculated from relationship shown in evaluation 1.

(1)Where Z is the number of stator slots and P is the number of poles. The coil span falls short of full pitch by an angle θ.

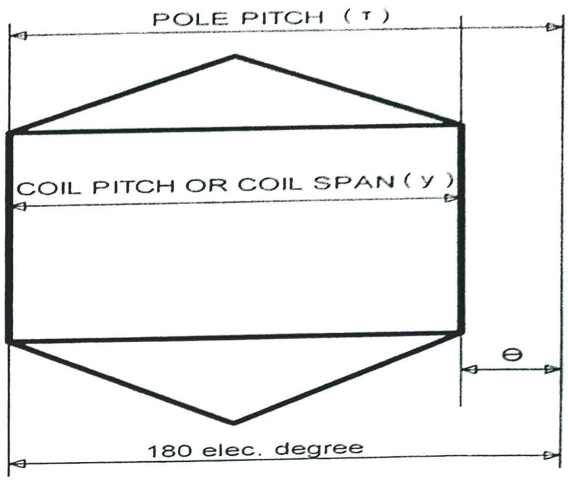

Fig. 1: Coil showing pole pitch and coil pitch

2.3 Chording factor

The winding diagram of a double-layer winding is shown in Figure 2. It has 18 slots and two poles. The pole pitch is $\tau = \frac{Z}{P} = \frac{18}{2} = 9$. The coil span falls short of full-pitch by an angle of θ = $\frac{\tau - \gamma}{\tau} \times 180^0 = \frac{9-8}{9} \times 180^0$ which is equal to $\frac{1}{9} \times$ $180^0 = 20^0$. It is short-pitched by 20^0(elect.). The cording factor for n order of harmonic is;

$$Kc = \sin\left(n \cdot \frac{\pi \ coil \ span}{2 \ pole \ pitch}\right) \qquad (2)$$

All single layer windings are effectively made up of full pitched coils, but double layer windings usually have short pitched or short chorded coils (Laughton and Warne 2003). The n^{th} harmonic coil electromotive force is reduced to zero if the chording angle, is such that $\cos\frac{n\theta}{2} = 0$, or $\frac{n\theta}{2} = 90^0$. The harmonic is completely suppressed. With n=2, and $\theta = 90^0$, *then* $\cos\frac{2\times 90^0}{2} = 0$. Therefore, in the second harmonics and its multiples, no harmonics are present in the harmonic spectrum of the winding factor. With $\cos\frac{n\theta}{2} = 0$, Agarwal (2000) enables windings to be designed which will not permit specified harmonics to be generated.

The fifth harmonic 300Hz system in electric motor produces torque which opposes the direction of the rotation and consequently results in retardation of its speed, heat generation within the winding, increasing losses and decreasing its efficiency. If the applied voltage to the motor is distorted, then the motor will not operated to its full rating capacity. The resultant waveform of the fundamental and the present of the third harmonic is shown in Figure 2

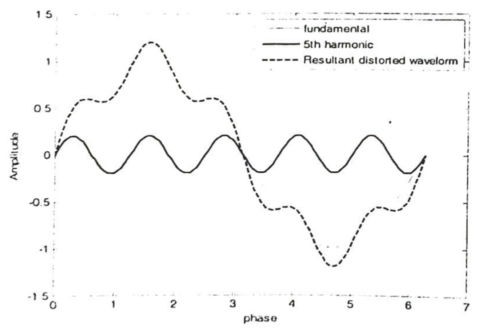

Fig. 2: Fundamental waveform with fifth harmonic distortion

The winding diagram of a full pitched coil of a double layer winding having eighteen slots and two poles is shown in Figure 3.

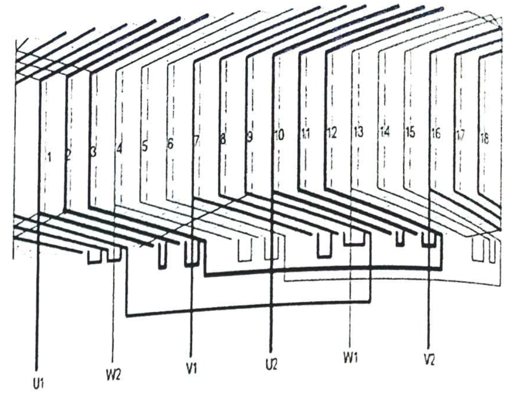

Fig. 3: Double layer winding with Z=18, P=2 and y=9

The winding diagram of a short pitched coil of a double layer winding having eighteen slots and two poles is shown in Figure 4.

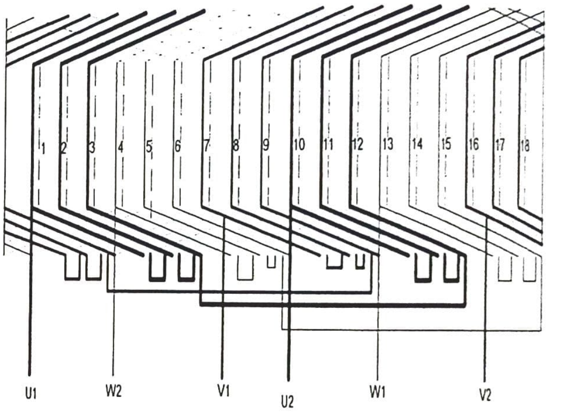

Fig. 4: Double layer winding with Z=18, P=2 and y=8

Harmonics are energy levels existing at multiples of the fundamental wave frequency. The combined harmonic spectrum of the three phase winding magnetomotive force (mmf) of the full pitch and short pitch coil is shown in Figure 5. The air gap flux is not purely sinusoidal as it contains odd harmonics (5^{th}, 7^{th} , 11^{th} etc).The third harmonic flux waves produced by each of the three phases neutralize each other as it differs in time phase by 120^0. Thus air gap does not contain third harmonics and its multiples.

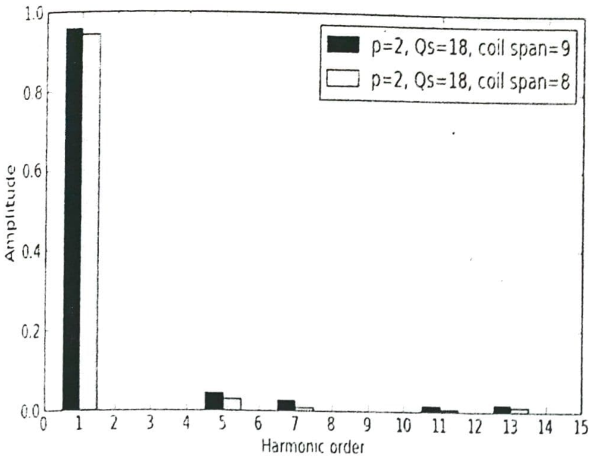

Fig. 5: Harmonic spectrum of three phase winding MMF

The harmonic spectrum of both winding factors of two different spans of the same winding is shown in Figure 6. The magnitude of 5th and 7th harmonics decreases because of the shortening of the coil span of the second winding with y=8. Generators are symmetrical machines since they have even number of north and south poles which results in the cancellation of all even number of harmonics and only odd harmonics remain.

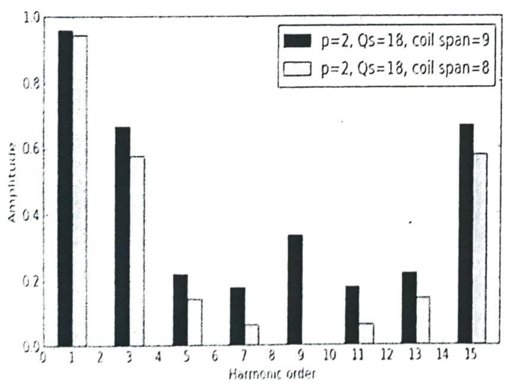

Fig. 6: Harmonic spectrum of the winding factor

Figure 7 is the illustration of the reduction in harmonic amplitude with the corresponding reduction in coil span of the same stator winding having the same number of slot and pole. The second harmonics and its multiples are not present because the winding factors are zero.

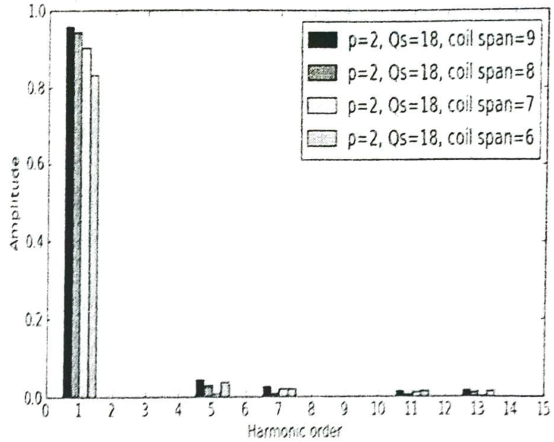

Fig. 7: Harmonic spectrum of three phases winding MMF.

3. Result and discussion

The results obtained in Figures 6 and 7 through simulation of the number of slots and their corresponding number of poles show that the magnitude of the fundamental harmonic decreases as the coil span decreases of stator winding having the same number of slot and pole. The 5th and 7th harmonics in the air gap field are reduced. The fractional pitch winding improves voltage waveform which resembles a sinusoidal to a better degree than would be full pitch winding due to reduction in harmonic content. It is therefore advisable for rewinding personnel to always use fractional pitch winding for three phase induction motor as it reduces harmonic content and gives a motor more efficiency and longer life span.

4. Conclusion

The use of fractional pitch winding technique will reduce harmonic content and improve waveform of induced emf due to reduction in distorting harmonics. It reduces the length of the winding in the winding overhangs which helps to increase the structural integrity necessary to resist short circuit forces. Since the winding is shortened, it reduces copper loss. Heat loss is minimized thereby increasing the efficiency of machine. The wiring arrangements are simpler than fractional slot winding. Using chorded windings with integral number of slots per pole per phase weakens the stator winding mmf harmonics thus minimizing the effect of harmonic torque.

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