Harmonics reduction with Pulse Width Modulation Method for Flux Concentration Interior PM Motors

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***Abstract*—This paper presents an optimum design technique for harmonics reduction in the air-gap of flux concentration Interior PM Motors with Pulse Width Modulation (PWM) method. A 2-D Finite Element Analysis (FEA) is used for a nonlinear magnetic problem. The computation can be solved by using Newton-Raphson algorithm combine with Matlab optimization toolbox for a constrained optimization problem. Owing to an arrangement of the magnet, the flux density is higher concentrate. The simple of PWM method is performed to reduce the significantly selected harmonic contents of the air-gap flux density. The analytical results are in very good agreement comparing with classical flux concentration interior PM motor that obtain by the FEA. Then an obtained back electromagnetic force (EMF) is closed to sinusoidal waveform.**

***Index Terms*—Harmonic analysis, optimization, magnetic flux density, permanent magnet motor, pulse width modulation.**

I. INTRODUCTION

Nowadays, Permanent Magnet Synchronous Motors (PMSMs) are widely used in various industrial applications due to their inherent advantages of high power density, compactness, high efficiency and high performance drive system [1]. Numerous investigations are attempted to improve the output performance of the PM motors such as winding inductances, stator losses or by acting on magnet configuration [2]-[5]. Indeed, the back-EMF harmonic is depended on any parameter such as magnetization, magnet, air-gap or winding type if the back-EMF waveforms contain important harmonics, poor performances are obtained.

In this paper, a topology of flux concentration interior PM motor is considered. The design process is emphasized for eliminating a selected set of undesired harmonics by technique of PWM that well known in power electronics.

II. PRINCIPLE OF THE PWM-DESIGN METHOD

The main idea is to use PWM technique in the design process of flux concentration interior PM motor. A preliminary design has focused on the harmonics of the source field (magnet) that it is important for reducing the low-order harmonics of the back-EMF. Assuming that the shape of the air-gap flux density function is similar to the PWM waveform which is applied on the iron pole is illustrated in Fig. 1. The obtained angles are gathered in the form of vector *x* by solving a constrained optimization problem. In order to solve the problem it should be defined the conditions as follow:

$$x = [\theta_1, \theta_2, \theta_3, \cdots, \theta_n]^T \tag{1}$$

$$F(x_\infty) = [f_1, f_2, f_3, \cdots, f_n]^T (x_\infty) = 0 \tag{2}$$

where :
$$f_1(x) = \int_0^\pi M(\theta)\sin(\theta)\,d\theta \quad - \frac{\pi}{2} M_1 \tag{3}$$

$$f_i(x) = \int_0^\pi M(\theta)\sin(h_i\theta)\,d\theta \qquad h_i = 3,5,7,... \tag{4}$$

and

- $M(\theta)$ is the amplitude of the magnetization function produced by the PMs.
- M_1 is the required first harmonic of the magnetization
- $h_i = 3,5,7,...$ is a set harmonic orders to be eliminated

The angles θ_i are defined between 0 and ¶. Therefore, the constraint should be added to the optimization problem as following below:

$$0 < \theta_1 < \theta_2 < \theta_3 < \cdots \theta_{n-1} < \theta_n < \pi \tag{5}$$

To achieve the required objective then the function of the position θ should be had a radial flux density of the form

$$B_g(\theta) \approx B_m \sin(p\theta) \tag{6}$$

where *p* is the pole number and B_m is the desired amplitude of the flux density.

TABLE I
MOTOR SPECIFICATIONS

Parameters	Unit	Value
Number of pole	-	8
Number of slot	-	24
Maximum stack length	mm	51.4
Internal diameter	mm	40
External diameter	mm	146
Magnet Type	-	NdFeB
Iron core type	-	XC10

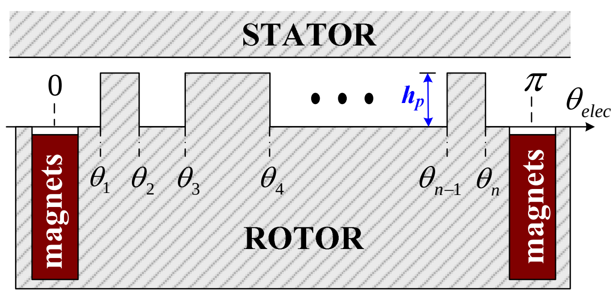
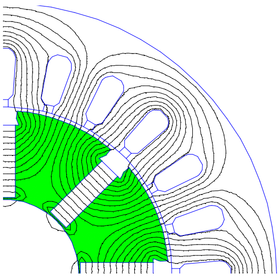


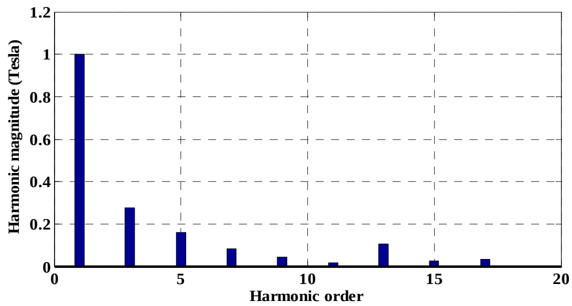
Fig. 1. A set of PWM waveform is applied over one pole

III. APPLICATION TO A FLUX CONCENTRATION PM MOTOR

In this section, the previous presented method is applied which is called PWM-Flux concentration interior PM motor (Fig. 3) by acting on the iron surface of rotor whose parameters are given in Table I. The objective is to reduce the required harmonics of the air-gap flux density. The calculation results of flux line and spectral analysis of air-gap flux density with the design technique of PWM are illustrated in Fig. 2-3 that compared with the topology is called classical flux concentration interior PM motor (Fig. 2). It can be seen that the desirable harmonics : 7th, 11st and 13rd have been strongly reduced.

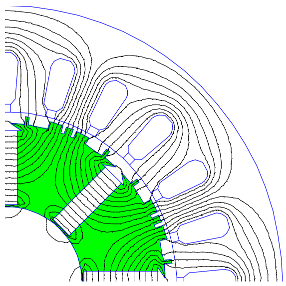


(a) Circular representation

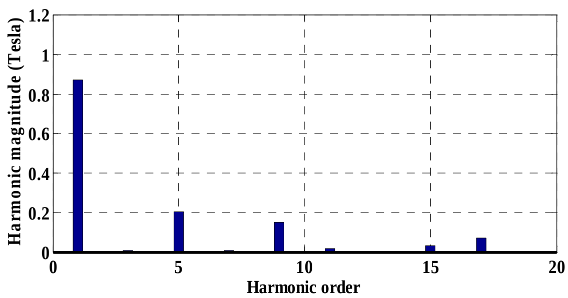


(b) Spectral analysis

Fig. 2. Classical Flux Concentration Interior PM Motor



(a) Circular representation

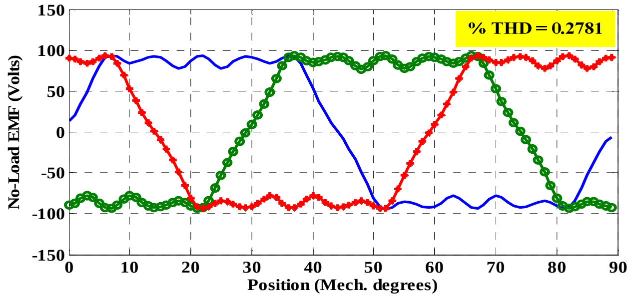


(b) Spectral analysis

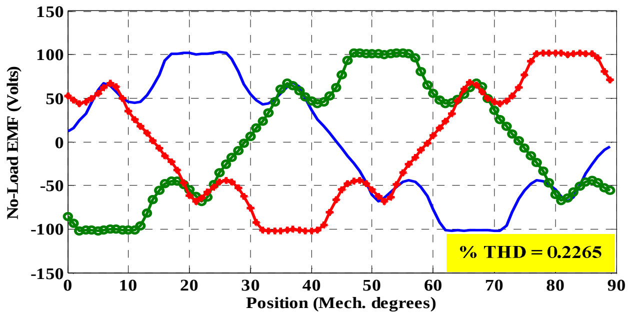
Fig. 3. PWM-Flux Concentration Interior PM Motor

IV. PERFORMANCE OF THE FLUX CONCENTRATION PM MOTOR

This section is shown the behavior of the PWM-Flux concentration PM motor. In order to highlight the effect of the proposed method, the back-EMF waveform is illustrated (see Fig. 4) that closed to sinusoidal waveform. The harmonics distortion percentage of classical topology is 0.2781 while PWM-Flux concentration interior PM motor is 0.2265. Therefore, it can be confirmed that PWM-Flux concentration interior PM motor is more efficient than the classical topology.



(a) Classical Flux Concentration Interior PM Motor



(b) PWM-Flux Concentration Interior PM Motor

Fig. 4. Comparison of the back-EMF waveform

V. CONCLUSION

The use of specific technique which reduce the harmonics content of the flux density in the air-gap allows achieving almost sinusoidal waveform of the back-EMF that are satisfied. It manifests that the THD percentage of PWM-Flux is decreased about 18.56 %. The results are further analyzed using FE as an optimization problem is defined and solved.

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