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The Static Eccentricity Fault Diagnosis in Time Domain at Line Start Permanent Magnet Synchronous Motor

Zafer DOGAN[1] (zafer.dogan@gop.edu.tr)
Burak KARA[2] (burak.kara@gop.edu.tr)
Cem EMEKSIZ[3] (cem.emeksiz@gop.edu.tr)
Levent GOKREM[4] (levent.gokrem@gop.edu.tr)

[1,2,3]*Department of Electrical&Electronics Engineering, Faculty of Engineering and Natural Sciences, Gaziosmanpasa University,60240 Tokat*
[4]*Department of Mechatronic Engineering, Faculty of Engineering and Natural Sciences, Gaziosmanpasa University,60240 Tokat*

Abstract – Recently, Line Start Permanent Magnet Synchronous Motor have been commonly utilized in industrial areas because of their high efficiency. Motor faults during operation cause losses of production and high maintenance and repair expenditures. In this study, the effect of static eccentricity fault on line start permanent magnet synchronous motor was investigated. The simulation models of motor belonging to healthy and fault status were formed via Finite Elements Method. The analyses in time domain of motor currents under different load conditions were carried out by using these models. When the results of the analyses were investigated, the motor fault was successfully diagnosed via the recommended method.

Keywords *- Writing paper, journal, abstract, table design.*

1. Introduction

Electricity motors are commonly used in many areas of life from domestic areas to industrial areas [1,2]. %40 of total electricity consumption in Turkey is consumed by electricity motors [3]. Asynchronous motor (ASM) is at the top of the motors commonly used in industrial areas [4]. However, that efficiency of ASM is not high is the biggest disadvantage. The need of producing motor with high output directs the researchers to the

[1]***Corresponding Author***

motors with permanent magnet line start permanent magnet synchronous motor (LSPMSM), which have been started to be used lately, were developed at the end of these studies.

Both the cage structure of ASM and magnet are available in the rotor structure of LSPMSM [1,5]. In the rotor of LSPMSM, the cage structure provides a start-up as ASM. This feature, not available in other motors with magnet, is the biggest advantage of LSPMSM against these motors. The magnets in rotor increase the performance of the motor during steady state over ASM [6,7]. This rotor structure of LSPMSM brings motor the ability of being supplied directly from the line and high efficiency. Thanks to these superior features, LSPMSM has been started to be preferred instead of ASM in industrial areas.

Moisture, dust, and heat affect the electricity motors in industrial environments, and they are operated under such heavy operating conditions as different load conditions. These negative conditions cause motor faults.

Faults emerging in LSPMSM are classified in three groups as magnetic, electrical, and mechanical. The magnetic faults are demagnetization fault and magnet breakage occurring in magnets upon mechanical strains and thermal changes [8]. Electrical faults are stator winding faults, broken rotor bar fault, and the fault of rotor end ring breaking. These faults emerge as a result of electrical, mechanical, and magnetic strains [9]. Mechanical faults are the disorders happening in motor load alignment, immediate load changes, and eccentricity caused by such external environment effects as dust, moisture, and etc., and bearing faults [3,10].

As seen in all the other motors, eccentricity fault is at the top of the faults frequently encountered in LSPMSM. Eccentricity fault causes unequal air gap between stator and rotor. %5-10 eccentricity is an acceptable situation during the process of motor production.

The negative effects of eccentricity fault in motors are rise of magnetic current density harmonic components in air gap, occurrence of cogging torques, decrease in average torque, overheating, and rise of noise level. The main reasons of eccentricity are motor shaft bending, positioning errors in load anchorage, bearing abrasions, and ellipse stator structure [6,11].

Eccentricity fault occurring in motors are seen in three different types like static, dynamic, and mixed. Types of this fault are seen in Figure 1.

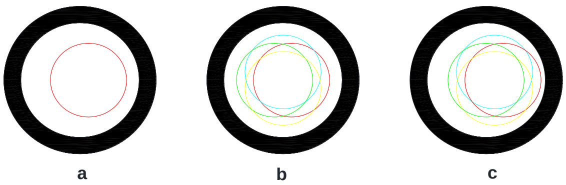

Figure 1: Eccentricity faults: a) Static eccentricity b) Dynamic eccentricity c) Mixed eccentricity

In case of Static Eccentricity fault (SE), the centers of rotor and stator axes are fixed points different from each other. The most important reasons of SE are the ellipticity of stator, bearing defects, and false positioning of rotor [10]. In case of Dynamic eccentricity, the center of stator axis is a fixed point. The center of rotor axis constantly turns around the stator axis. Such factors as rotor shaft bending, bearing abrasion, and mechanic resonance are the occurrence reasons of this fault [10]. In case of mixed eccentricity, both the static and dynamic eccentricity states emerge at the same time.

In diagnosing motor faults, such motor data as current, flux, voltage, speed, torque, and etc. are used. The most used one among these is motor current data. The preferability reason is easy collection and inclusion of many electrical, mechanical, magnetic, and thermal data.
Current data obtained from motor are analyzed by using signal processing method. As a result of these analyses, feature vectors of signals are acquired. The accuracy and reliability of feature vectors is very significant for fault diagnosis. As signal processing methods, analysis methods in terms of frequency domain, time domain, or time and frequency domain are used [12].
In this study, under the environment of ANSOFT Maxwell, the healthy and SE fault simulation models of LSPMSM were formed by using Finite Elements Method (FEM). Current signals were obtained from these simulation models under different load conditions. These signals diagnosed the SE fault in LSPMSM via analysis in terms of time.

2. Modelling LSPMSM

FEM is a reliable method frequently used in modelling electric machines. It enables motor fault status to be modelled as real-like as possible. Therefore, it is at the top of the methods commonly used for motor fault diagnosis. Maxwell equivalences are used in magnetic analyses of electric machines [2].
The relation between electric field intensity E and current intensity J can be calculated via the equivalence below.

$$J = \sigma E \tag{1}$$

The statement of induced area under these conditions;

$$\nabla x E = -\nabla x A \tag{2}$$

is defined as above. A is equal to the rotational of magnetic vector potential. In a two-dimensional problem, the electric field,

$$E = -(A x \nabla V) \tag{3}$$

Can be defined with a statement above. Using this statement, the current intensity,

$$J = -\sigma A - \sigma \nabla V \tag{4}$$

can be written as above. According to the gradient of magnetic vector potential and voltage value, current intensity statement,

$$\nabla x \left(\frac{1}{\mu(B)} \nabla x A \right) = -\sigma A - \sigma \nabla V + J_{\text{source}} \tag{5}$$

can be calculated as above. μ is magnetic permeability of the environment; ∇V is the gradient of voltage value of the area out of conductive material in two dimension solutions.
SE fault of LSPMSM was done through the full model, whose cross-sectional shape is seen in Figure 2.

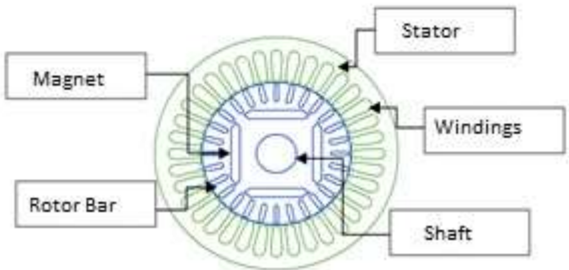

Figure 2: LSPMSM simulation model

The successful results producibility of the analysis of LSPMSM through FEM is depended on accurate modeling and suitable operating. Motor parameters of modelled LSPMSM are stated in Chart 1.

Chart 1: Electrical and physical parameters of LSPMSM

LSPMSM	
Terminal number : 4	Rated Speed :1500d/d
Stator external diameter :160mm	Rotor external diameter :97.9 mm
Stator length :121 mm	Stator slot number :36
Rotor slot number : 28	Frequency :50 Hz

Magnetic flux intensity distribution belonging to the healthy status model of LSPMSM is seen in Figure 3. In this model, air gap span between rotor and stator is 1 mm. As can be seen in this figure, because the span in air gap of the motor does not change, magnetic flux distribution in air gap is regular.

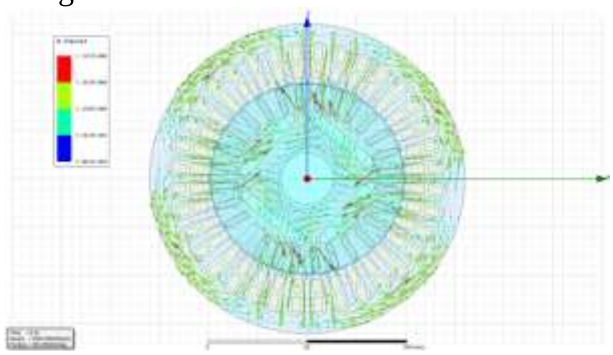

Figure 3: Healthy status

SE faults of LSPMSM were formed under two different levels by sliding rotor and stator from their center on a steady plane. Eccentricity span is 1; fault level is 0,4 mm for Static eccentricity 1(SE1); 2. fault level is 0,8 mm for Static eccentricity 2(SE2).

In Figure 4, magnetic flux intensity distribution of LSPMSM belonging to SE2 status is seen. As can be seen in this figure, SE fault caused locally variable reluctance occurrence in air gap. As a result of this, irregular flux distribution occurred in air gap.

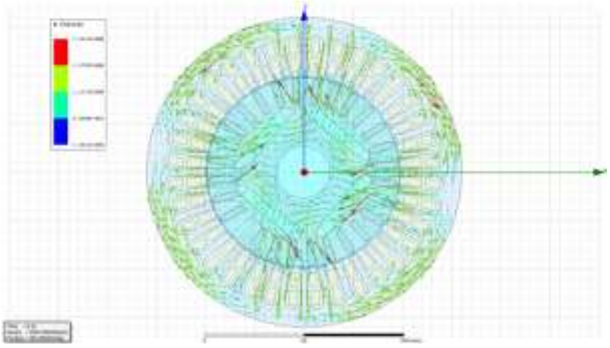

Figure 4. SE fault status

3. Time Domain Analysis

Analysis in time domain is a strong agent for the fault diagnosis of motors. The signals obtained from motors generate a diagram against time. Therefore, each kind of analyses to be operated on rough signals in time domain is the basic and cheapest method.

In the analysis in time domain, specific parameters from signal are acquired by implementing statistical processes proper to characteristics of the signals to be analyzed. Later, signal analysis is done by evaluating these parameters.

The mostly used parameters in the fault diagnosis of electric motors are frame energy, minimum and maximum skewness, kurtosis, effective value, variance, entropy, and mean and standard deviation. In this study, standard deviation, mean, kurtosis, and variance parameters were used in the analysis of current signals of LSPMSM.

Standard deviation is related to the distribution of the numbers in a serial around the mean of that serial [13]. As parameter, standard deviation (*σ)* is given in equation 6.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{6}$$

In a signal, mean (μ) is calculated through the equation below.

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{7}$$

Kurtosis is a criterion of a random variable indicating the kurtosis of probability distribution or kurtosis. This parameter can be calculated through equation 8.

$$B = \frac{\sum_{i=1}^{N}(x_i - m_x)^4}{(N-1)\sigma_x^4} - 3 \tag{8}$$

In this relation, x_i refers to *i*. data; *N* refers to total data number; m_x refers to mean of data; $\sigma_x$refers to standard deviation of data.

Variance explains the change of the values in a serial according to mean. Variance equals to square of standard deviation.

4. Simulation Results

SE fault of LSPMSM was diagnosed through the analysis of motor current signals. Current signals of LSPMSM operated under free and on load operation conditions were obtained for 2.5 seconds through 10 kHz sampling frequency. Time diagrams of current signals obtained from LSPMSM in healthy and fault status are seen in Figure 5.

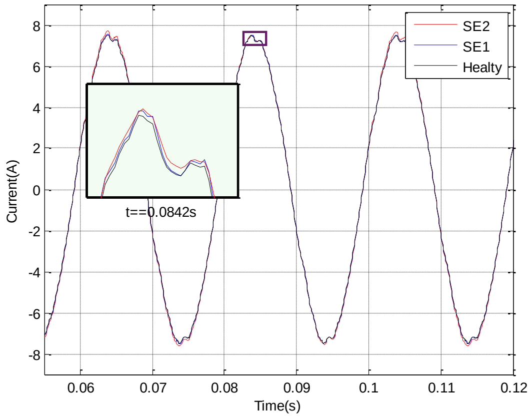

Figure 5: Current signals of LSPMSM for healthy and fault status

On observing the signals given in the figure above, deteriorations are seen on the top points of the signal according to healthy status. SE2 7.707A and SE1 7.54A are at healthy 7.512A values.

These current signals recorded in Matlab environment were made independent from load by being normalized in the range of 0-1. Finally, standard deviation, mean, kurtosis, and variance parameters were calculated for these normalized signals. In figure 6, histograms belonging to means calculated from current signals of healthy and fault status of LSPMSM are seen.

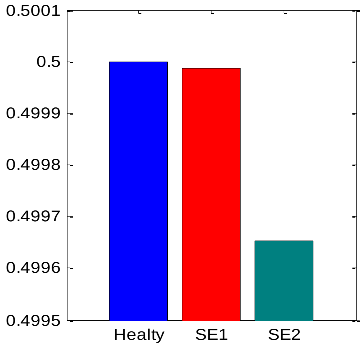

Figure 6: Means in Healthy and Fault Status

On investigating mean histograms, healthy 0.5 is SE1 0.4999, SE2 0.49965 values. It is seen that the means of fault status have lower values than the means of healthy status. Also, as the fault level increases, the means decrease.

In figure 7, histograms belonging to variances of current signals of LSPMSM are seen.

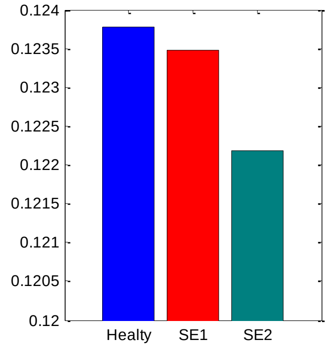

Figure 7: Variances in Healthy and Fault status

The calculated variance values are healthy 0.1238, SE1 0.1235, and SE2 0.1223. Variances decrease from healthy status to SE1 and SE2 fault levels, and fault can easily be diagnosed. In figure 8, standard deviations of LSPMSM current signals are seen.

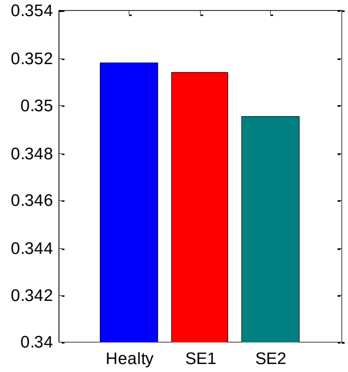

Figure 8: Standard Deviations in Healthy and Fault status

Standard deviation values are healthy 0.3519, SE1 0.3516, and SE2 0.349. As can be seen in Figure 8, SE fault can be easily defined according to standard deviation values.
In Figure 9, kurtosis values of LSPMSM current signals are seen.

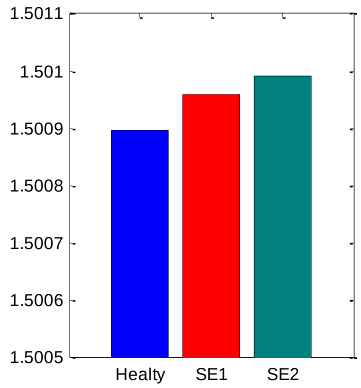

Figure 9: Kurtosis in Healthy and Fault status

Kurtosis values are Healthy 1.5009, SE1 1.5096, and SE2 1.501. As the fault level of motor increases, kurtosis values expand.

5. Conclusions

In this study, motor currents were observed to diagnose SE fault of LSPMSM modelled through FEM. The obtained current signals were analyzed in time domain. As a result of this analysis, standard deviation, mean, kurtosis, and variance parameters were calculated in current signals of LSPMSM. It is seen that the calculated standard deviation, mean, and variance values of fault status are lower than the values of healthy status, and that kurtosis values of fault status are bigger than the values of healthy status. The recommended method by taking these changes into consideration distinctively supplied successful results in the diagnosis of Static eccentricity fault of LSPMSM.

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