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THE ANALYSIS OF OWN SIGNALS OF PM ELECTRICAL MACHINES – EXAMPLE OF ECCENTRICITY

ANALIZA SYGNAŁÓW WŁASNYCH MASZYN ELEKTRYCZNYCH Z MAGNESAMI TRWAŁYMI – PRZYKŁAD EKSCENTRYCZNOŚCI

Streszczenie: Praca przedstawia zastosowanie wibracyjnej metody diagnostycznej dla maszyn z magnesami trwałymi. Maszyny te są wykorzystywane w małych elektrowniach wiatrowych oraz wodnych. Opisywana metoda jest innowacyjna i unikalna. Wykorzystuje ona specyficzne właściwości konstrukcyjne maszyn z magnesami trwałymi, tj. indukowanie się SEM pod wpływem wibracji. Przeanalizowano liczne publikacje opisujące diagnostykę maszyn elektrycznych i nie napotkano na metody bazujące na wykorzystaniu własnych sygnałów maszyny do określenia ich kondycji układu wibroakustycznego. W pracy przedstawiono m.in. model polowy, wyniki obliczeń oraz symulacji komputerowych.

Abstract: This article presents a vibration diagnostic method designed for permanent magnets (PM) electrical machines. Those machines are commonly used in small wind or water systems. The described method is very innovative and unique. Specific structural properties of machines excited by permanent magnets are used in this method - electromotive force (EMF) generated due to vibrations. There was analyzed number of publications which describe vibration diagnostic methods and tests of electrical machines and there was no method found to determine the technical condition of such machine basing on their own signals. This work presents: field-circuit model, results of static tests, results of calculations and simulations.

Słowa kluczowe: *magnesy trwałe, drgania, maszyna elektryczna, ekscentryczność, diagnostyka, akwizycja danych, analiza danych*
Keywords: *permanent magnet, vibrations, electrical machine, eccentricity, diagnostics, data acquisition, data analysis*

1. Introduction

The radial asymmetry of geometry between stator and rotor can lead to damage of the drive. Otherwise, the eccentricity will increase. Asymmetry between stator and rotor can be made during the manufacturing process. This phenomenon does not exclude further work of the machine, but will be the fluctuations of electromagnetic field (Figure 1).
These fluctuations increase the level of vibration and accompanying noise.
The high level of vibration in electrical machine is undesirable phenomenon and it is considered to be a failure symptom. Ignoring these symptoms entails a failure risk, which costs often exceed the device cost [1]
Electrical machines vibration diagnostic majority is based on measurements which are done with external sensors connected to dedicated complicated and expensive meters or analyzers. In such solutions, vibration sensor mounting is often problematic, because the machine is rarely designed for this purpose. Additionally, it is needed to pay special attention for the measuring circuit separation from any kind of interference, which could result in incorrect measure.

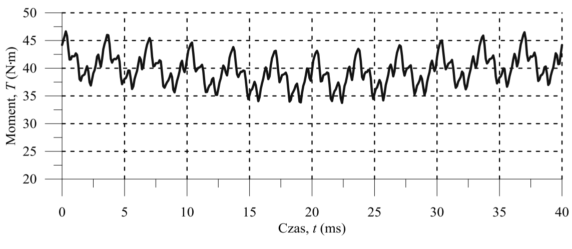

Fig. 1. Torque fluctuations

The method main advantage is that the measurement system does not require sensors for measuring vibration. Excitation circuit and armature winding perform a function of the vibration sensor at the same time. Vibration measurement with this method can be performed online during normal machine operation [2 - 4].
When the phenomenon was analysed a similarity between PM machine and electrodynamic sensor

which is used to measure vibrations has been observed:

- a similar structure – permanent magnets and coils (winding). While the sensor is exposed to the vibrations an emf is generated. That EMF signal can be used for vibration analysis,
- greater number of turns and pole pairs makes the signal greater. That means the sensitivity is dependent on the number of turns in the coil – in analogy to the electrodynamic sensor.

2. The eccentricity

The radial asymmetry of geometry between stator and rotor called eccentricity causes irregular distribution of the air gap. There are three types of asymmetry:

- static,
- dynamic,
- mixed.

The static asymmetry is characterized by the permanent location of air gap maximum. This eccentricity can be result of core ovality or incorrect installation. In the case of dynamic asymmetry, the air gap maximum location changes with the rotor position. This eccentricity can be result of the bad bearing condition, bent of shaft, etc. The mixed asymmetry is connection of the both.

3. The field – circuit model.

The field – circuit model and the finite element mesh is presented in Fig. 2 and Fig. 3.

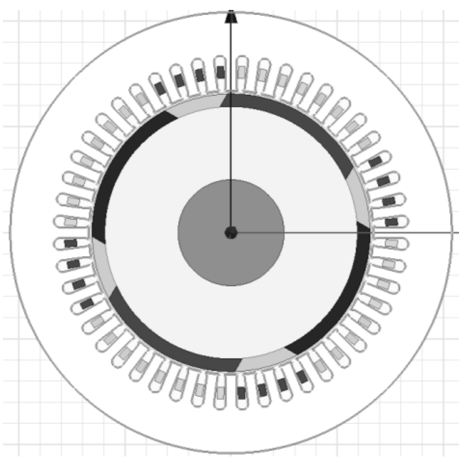

Fig. 2. The PM machine 2D model

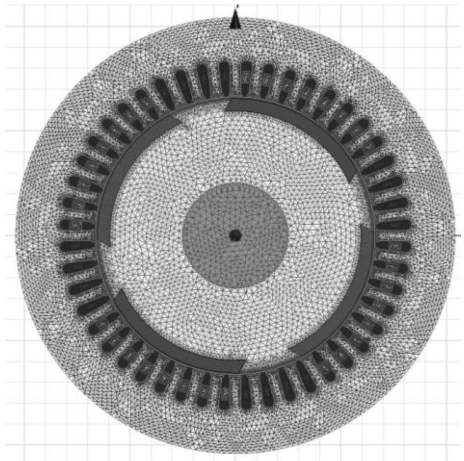

Fig. 3. The finite element mesh

The analysis was done using Ansys Maxwell 2D software [5]. Steps of model analysis:

- creation of a model,
- definition of boundary conditions,
- definition of material properties of model elements,
- definition of excitation circuit,
- modeling of finite element mesh,
- simulation parameters,
- simulation of model,
- results analysis.

4. The calculations and simulations results

There are presented the results of simulation and calculations of PM machine in Fig.4, Fig.5, and Tables 1 – 3. In these figures and tables are compared: healthy machine, machine with static eccentricity and machine with dynamic eccentricity. Nominal parameters of simulated machine are: P = 6,5 kW, U = 82V, I = 55,9 A, n = 1500 1/min, T = 41,4 Nm. The simulation was done for 80% radial asymmetry. It can be observed increase of the amplitude level (1), (2) for all k-th harmonic:

$$f_{k1} = \mathrm{k} \cdot f - \frac{(p-1) f}{p} \tag{1}$$

$$f_{k2} = 2\mathrm{k} \cdot f \tag{2}$$

where:
f_{k1}, f_{k2},– searched frequencies,
p – number of pole pairs,
f – first harmonic frequency,
k – natural number.

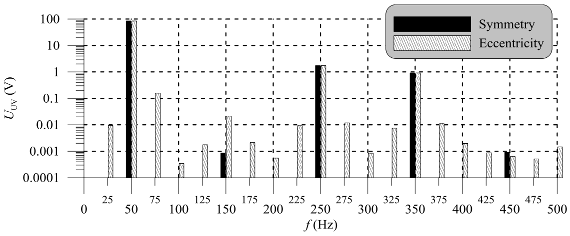

Fig. 4. The frequency analysis of voltage

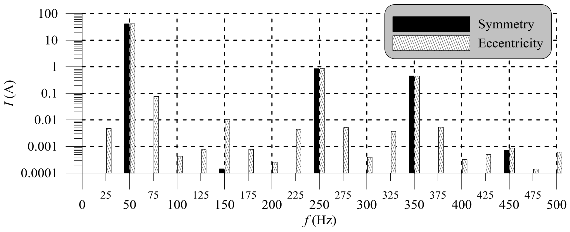

Fig. 5. The frequency analysis of current

Table. 1. Results of calculation and simulation, k=1

Frequencies	f [Hz]	f_{11}[Hz]	f_{12}[Hz]	f_{13}[Hz]
Calculations	50,00	25,00	75,00	100,00
	50,10	25,05	75,15	100,20
Simulations	50,10	25,10	75,10	100,10

Table. 2. Results of calculation and simulation, k=2

Frequencies	f[Hz]	f_{21}[Hz]	f_{22}[Hz]	f_{23}[Hz]
Calculations	50,00	75,00	125,00	200,00
	50,10	74,95	125,05	200,40
Simulations	50,10	75,10	125,10	200,10

Table. 3. Results of calculation and simulation, k=3

Frequencies	f[Hz]	f_{31}[Hz]	f_{32}[Hz]	f_{33}[Hz]
Calculations	50,00	125,00	175,00	300,00
	50,10	124,95	175,05	300,60
Simulations	50,10	125,10	175,10	300,10

5. Summary

In this article author presents vibration diagnostic method. This method does not require to use the expensive sensors and diagnostician does not care about their assembly, which in some cases is an important issue. Using additional equipment for FFT analysis of the voltage or current signal the method allows on-line diagnostics also. It is quite essential for the wind or water power plant (Fig. 6) where admittance is difficult for various reasons.

The calculations and simulations (Fig.4, Fig.5, Table 1 – 3) confirm the effectiveness of diagnostic method for machines excited by permanent magnets, where vibrations were created as a result of eccentricity. Differences between calculation and simulation results aren't large (<0,2%). The analysis shows the possibility to use the machine with permanent magnets as a vibration sensor for itself. This approach is innovative and custom. The author never encountered such an application for PM machines, where the assessment of the intensity of the vibration a specific properties of the machine are used. However, the majority of permanent magnet motors work with inverters and before the frequency analysis, signal should be filtered.

Fig. 6. VAWT wind plant with Komel's generator

6. References

[1]. Barański M., Decner A., Polak A., Jarek T., Selected Diagnostic Methods of Electrical Machines Operating in Industrial Conditions, IEEE Transactions on Dielectrics and Electrical Insulation, 5(21), 2014.

[2]. Barański M., Jarek T., Electrical machine with permanent magnets as a vibration sensor - a test stand model, Electrical Machines (ICEM), International Conference on, IEEEXplore, 2014.

[3]. Barański M., Będkowski B., Analysis of PMSM Vibrations Based on Back-EMF Measurements, Electrical Machines (ICEM), International Conference on, IEEEXplore, 2014.

[4]. Decner A., Zdalne monitorowanie maszyn elektrycznych, Maszyny Elektryczne - Zeszyty Problemowe, 2011.

[5]. Pistelok P., Kądziołka T., Nowa seria wysokosprawnych dwubiegunowych generatorów synchronicznych wzbudzanych magnesami trwałymi, Maszyny Elektryczne - Zeszyty Problemowe, 100, 3/2013.