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SENSORLESS VIBRATION DIAGNOSTICS OF PERMANENT MAGNET GENERATORS – THE UNBALANCE EXAMPLE

BEZCZUJNIKOWA DIAGNOSTYKA DRGANIOWA GENERATORÓW Z MAGNESAMI TRWAŁYMI – PRZYKŁAD NIEWYWAGI

Streszczenie: Praca przedstawia zastosowanie wibracyjnej metody diagnostycznej dla generatorów z magnesami trwałymi pracujących w stanach asymetrii obciążenia. 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. W pracy przedstawiono min. podobieństwo maszyny z magnesami trwałymi do czujnika drgań, zawarto wyniki obliczeń, symulacji oraz badań laboratoryjnych. Metoda ta jest przedmiotem zgłoszenia patentowego.

Abstract: This paper presents a new vibration diagnostic method designed for diagnose of permanent magnets (PM) generators. Those machines are commonly used in small wind, water systems and electrical vehicles. 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. In this article several issues will be discussed: the method genesis, the similarity of permanent magnet machines to vibration sensor, mathematical model, and results of simulation and laboratory tests. The method of determination the technical condition of PM electrical machine basing on its own signals is the subject of patent application.

Słowa kluczowe: *pomiary drgań, generator z magnesami trwałymi, diagnostyka, akwizycja danych, analiza danych, maszyna elektryczna*
Keywords: *vibration measurement, permanent magnet generator, diagnostics, data acquisition, data analysis, electrical machine*

1. Introduction

Vibrations in electrical machines are undesirable, their high level, higher than the acceptable level, is considered to be a failure symptom. Ignoring these symptoms entails a real risk of a catastrophic failure, which costs can often exceed the drive cost [1]-[3]. Vibrations, which are always accompanied by rotating machines work cause gradual degradation of the some unit components. Vibration diagnostics task is to collect the information about degree of components wear. Depending on the aim of test and type of tested machines, it is very essential which waveform (displacements, velocities or accelerations) have to be recorded. The vibration velocity RMS value is dedicated for determination of overall assessment of the rotary machine. It reflects the destructive energy. However, if it is wanted to know the vibration cause it is necessary to conduct a detailed vibration spectrum analysis, which is transformation of the waveform in time domain to the frequency domain. Knowing the basic operating parameters of the machine and its construction, each component of vibration spectrum could be attributed to these elements or states. Majority of electrical machines vibration diagnostic is based on measurements which are done with external sensors connected to dedicated for this purpose complicated and expensive meters or analyzers. In such solutions, mounting of vibration sensor is often problematic, because the machine is rarely designed by the manufacturer for this purpose. Mounting affects the frequency response of the measurement signal. Additionally, it is needed to pay special attention for the separation of the measuring circuit from any kind of interference, which could result in incorrect measure.

The advantage of the described method of detecting vibrations in electrical machines with permanent magnets is that the measurement system does not require to use a sensors for measuring vibration. Excitation circuit and armature winding perform a function of the vibration sensor at the same time. Vibration measuring sensors are used ones, for scaling the measurement. Vibration measurement with this method can be performed on-line during normal operation of the machine [1] -[4]. This diagnostic method of vibration caused by unbalance of PM electric machines, which has a number of poles pairs p and works with the rotational speed n, includes registration a waveform of voltage or current of diagnosed machine, perform frequency analysis and separation the frequencies f1 and f2 defined by equations (1) and (2).

$$f_1 = \frac{(p-1)f}{p} \tag{1}$$

$$f_2 = \frac{(p+1)f}{p} \tag{2}$$

where:
*f*1, *f*2 – searched frequencies,
p – pole pairs number,
f – generator first harmonic frequency of tested generator.

2. The genesis of method

The idea of using a machine with permanent magnet as a vibration sensor appeared during the winding resistance measurements of such machines. When something is vibrating in vicinity of PM machine the measure of winding resistance become impossible because of disruptions (figure 1). There is no such phenomena during the measure of winding resistance of induction machine, in similar environment. The electromotive force is inducted when the machine with permanent magnets is vibrating. That EMF introduce distortions and the measure of winding resistance is impossible. This is a serious problem for example during registration of winding resistance for determination of the winding temperature rise after the heating test [1]-[3].

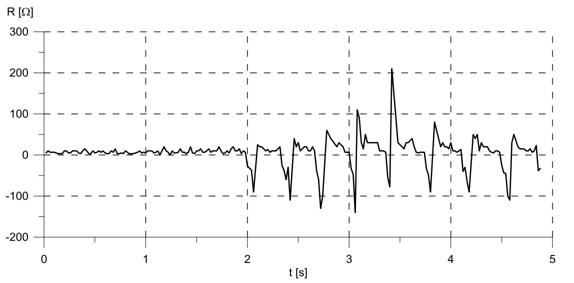

Fig. 1. Distortions during the resistance measurements

3. Generator PM as a vibration sensor

When the problem was analysed a similarity between PM machine and electrodynamic sensor which is used to measure vibrations has been observed. Electrodynamic sensor (figure 2) is characterized by [1]-[3]:

- simple construction – a permanent magnet hanged on a spring inside a coil. The permanent magnet moves inside the coil and generates a voltage on terminals of the coil. The voltage signal is proportional to vibrations. There are also constructions where a coil moves and the permanent magnet is fixed rigidly to the chassis,
- sensitivity depends on the number of turns in the coil,
- the supply is no required for the sensor.

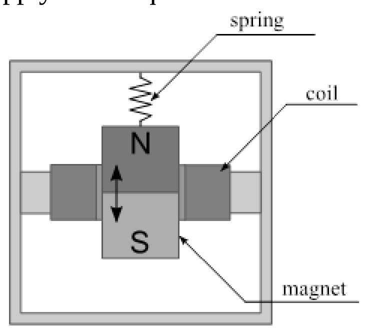

Fig. 2. An electrodynamic sensor

There are some similarities can be noted when the comparison of PM machine (figure 3) with electrodynamic sensor was made [1]-[3]:

- 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.

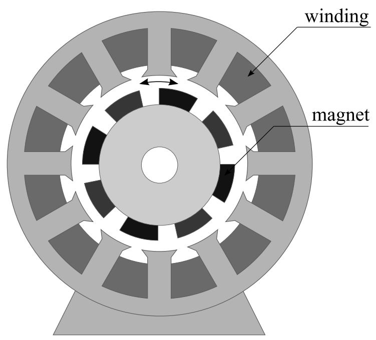

Fig.3. PM machine

4. Computer simulations and laboratory test results

The physical model to analysis of vibrations was developed using the equivalent circuit shown in All the parameters were determined using the circuit method, base formulas and machine design data.
Simulations and laboratory tests described in the article were made for PM generator of type: PMGhR90X – 6M, and parameters: U_N = 40 V, I_N = 17,2 A, P_N = 1,2 kW, n_N = 1000 rpm. This machine are commonly used in small wind turbines.
Computer simulations were carried out using an Ansys Maxwell 2D program on field model (figure 4). The program uses for calculations the finite element method and Maxwell's equations[5].

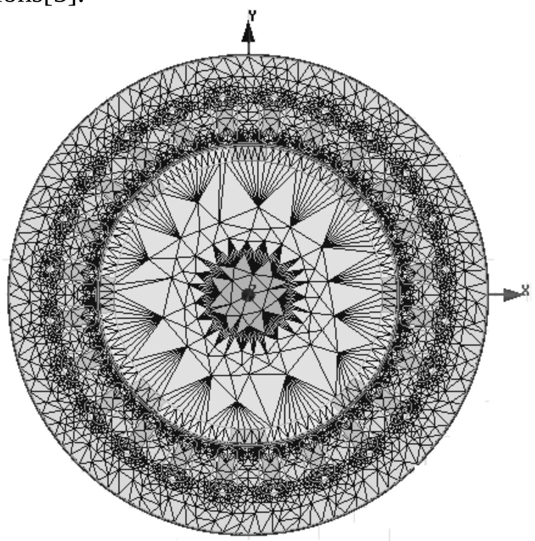

Fig. 4. Field model of generator

The frequencies f_1 and f_2 for tested generator were calculated using formulas (1) and (2). These frequencies are detectable when the rotating parts of machine are unbalanced. The vibrations were generated by making the shaft unbalanced. The generator was rotating with nominal speed. The FFT analysis was made for EMF obtained as a result of simulations and measures. The results of FFT analysis for simulation are presented in figures 5 and 6. Measures are presented in figures 7 and 8. The FFT analysis for the machine without additional mass (balanced) on shaft are presented in figure 5 for simulation and figure 7 for measures. The FFT analysis for the machine with additional mass on shaft (unbalance) are presented in figure 6 for simulation and figure 8 for measures. Fundamental frequency f and the frequencies f_1 and f_2 are marked. The frequency spectrum of the real object is different from the simulation. The reason of the difference is that the simulation model assumes an ideal machine, a fully symmetrical. The real machine is not perfect, unfortunately [1] – [3].

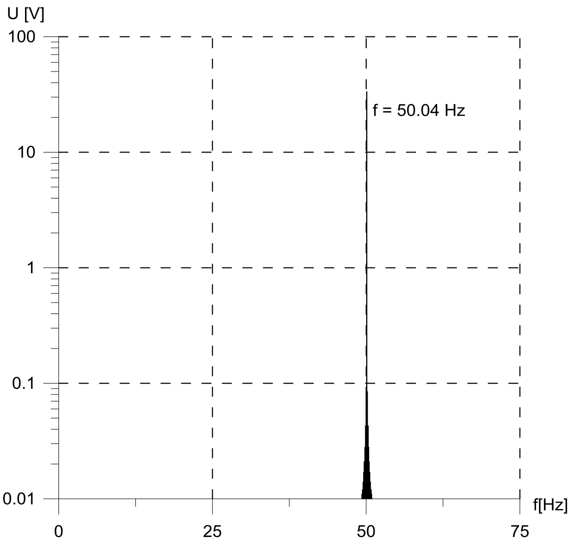

Fig. 5. Frequency spectrums induced voltage of the balanced generator- the results of the simulations

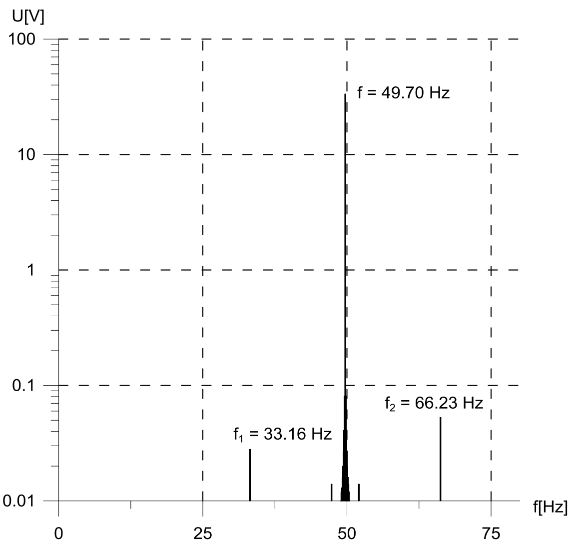

Fig. 6. Frequency spectrums induced voltage of the unbalanced generator- the results of the simulations

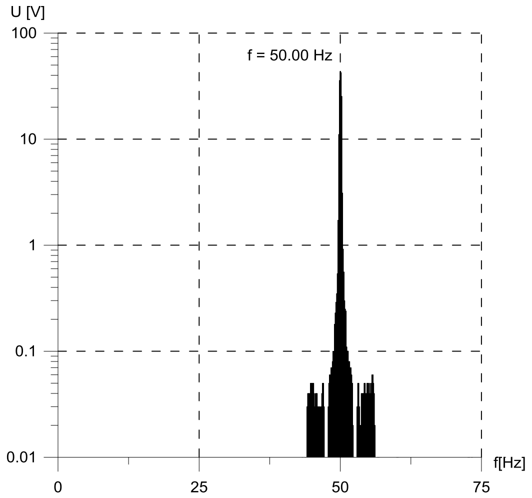

Fig. 7. Frequency spectrums induced voltage of the balanced generator- the results of the real measure

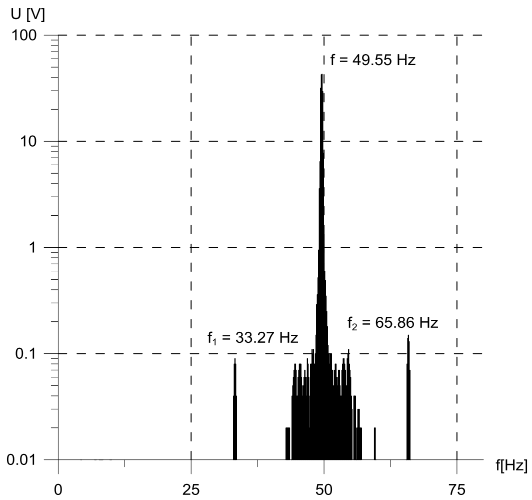

Fig. 8. Frequency spectrums induced voltage of the unbalanced generator- the results of the real measure

Table.1. Comparison of simulation results and laboratory tests

	f [Hz]	f_1 [Hz]	f_2 [Hz]
Calculations (1) and (2)	50.00	33.33	66.67
	49.70	33.13	66.27
	49.55	33.03	66.07
Simulations	49.70	33.16	66.23
Laboratory tests	49.55	33.27	65.86

5. Summary

The calculations, simulations and tests (figures 5-8 and table 1) confirm the effectiveness of new vibration diagnostic method for generators excited by permanent magnets, where vibrations were created as a result of unbalance. 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 generators, where the assessment of the intensity of the vibration a specific properties of the machine are used. Presented diagnostic method greatly simplifies measure of vibration in PM machines, according to the author who makes researches of machines in the laboratory, as well as diagnostics of electrical machines operating in the industry. The 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 [4]. It is quite essential for the wind power plant where admittance is difficult for various reasons. To signals selection author use frequency analysis, however, keep in mind that a lot of PM machine operates with the inverters and is needed filtration of signals.

6. References

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