World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:8, No:11, 2014

Permanent Magnet Machine Can Be a Vibration Sensor for Itself

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Open Science Index, Electrical and Computer Engineering Vol:8, No:11, 2014 publications.waset.org/9999730.pdf

***Abstract*—**This article presents a new vibration diagnostic method designed to (PM) machines with permanent magnets. Those devices are commonly used in small wind and water systems or vehicles drives. The author's method is very innovative and unique. Specific structural properties of PM machines are used in this method - electromotive force (EMF) generated due to vibrations. There was analysed number of publications which describe vibration diagnostic methods and tests of electrical PM machines and there was no method found to determine the technical condition of such machine basing on their own signals. In this article will be discussed: the method genesis, the similarity of machines with permanent magnet to vibration sensor and simulation and laboratory tests results. The method of determination the technical condition of electrical machine with permanent magnets basing on its own signals is the subject of patent application and it is the main thesis of author's doctoral dissertation.

***Keywords*—**Electrical vehicle, generator, permanent magnet, traction drive, vibrations.

I. INTRODUCTION

PROGRESS in recent years in the production technology and dissemination of magnetic materials field caused that significant part of traction drives (electromobility – e.g. Fig. 1) are PM machines. Their features are the reasons of their popularity: high efficiency, high power density, high torque overload, very good control and relatively simple construction (Table I). A very high torque can be reached in a wide range of machine speed by proper control.

There is many adverse effects appear in machines with permanent magnets, due to their construction. For example, this adverse effect is force reacting on the individual machines parts. An example of these phenomena is magnetic strain, which occur when the machine is supplied or not. That effect does not occur in induction machines or in machines with electromagnetic excitation [1]-[3].

Those phenomena are reflected in vibrations. Vibration emitted by the electric drive depends on construction of bearing and the kind of supply. The author concentrates on the vibrating diagnostic of the machines excited by permanent magnets. Properly executed diagnosis is a very important issue for each drive, especially for traction drives.

Fig. 1 Fiat Panda with Komel's PM motor – research and development project no. NR01-0084-10

TABLE I
COMPARISON OF ELECTRICAL MACHINES

Type of electrical motor	Lift	P[kW]	n [1/min]	η [%]	m [kg]
Asynchronous motor	200	30.0	1472	92.5	265
DC motor	160	34.7	1560	88.5	247
PM motor	160	31.2	1500	91.8	110

Vibrations in electrical machines are undesirable; their high level is considered to be a symptom of failure. Ignoring these symptoms entails a real risk of a catastrophic failure, which costs can often exceed the cost of the drive. Vibrations, which are always accompanied by rotating machines work cause gradual degradation of some components of the unit. 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 analysis of the spectrum of vibration, 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 [4]. Majority of electrical machines vibration diagnostic is based on measurements which are done with external sensors connected to dedicated 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

Scientific work financed by state funds for science in 2013-2015, as a project No. 413/L-4/2012 named "Vibroacoustic diagnostic method of traction permanent magnets motors and generators based on the own signals" realized in Institute of Electrical Drives and Machines "KOMEL".

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circuit from any kind of interference, which could result in incorrect measure [4], [5].

In this work the author focuses on permanent magnets machines vibration diagnostic method – detecting of vibrations caused by unbalance.

The advantage of the described method of detecting vibrations in electrical machines with permanent magnets 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 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 [6]. This diagnostic method of electric machines excited by permanent magnets, 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 f_1 and f_2 defined by (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 – number of pole pairs, f – generator first harmonic frequency of tested generator.

II. The Genesis of Method

The idea of using a PM machine 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. There are 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 (Fig. 2).

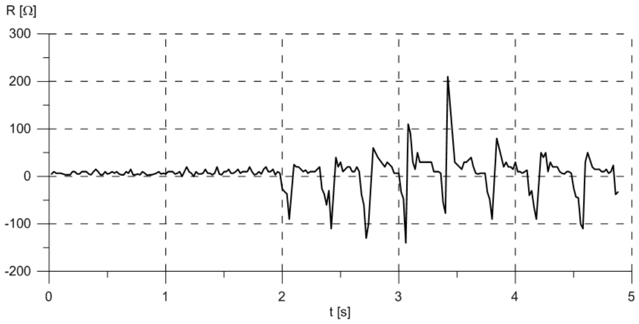

Fig. 2 Distortions during the resistance measurements

III. PM Machine as Vibration Sensor

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

- 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 sensor doesn't require power supply.

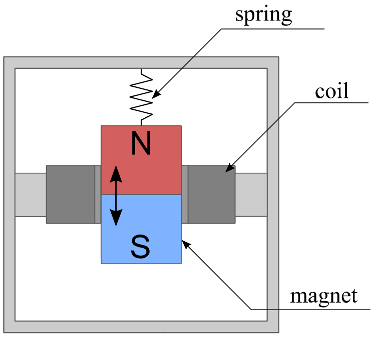

Fig. 3 An electrodynamic sensor

There are some similarities can be noted when the comparison of PM machine with electrodynamic sensor was made (Fig. 4):

- Similar construction – permanent magnet and coil (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.

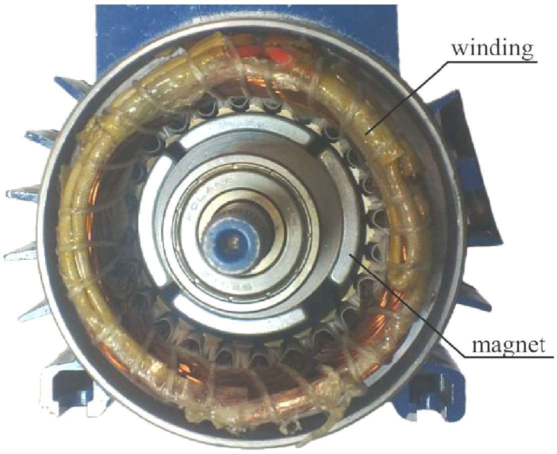

Fig. 4 PM machine

IV. SOURCES OF HARMONICS IN THE MACHINE WITH PERMANENT MAGNETS

The most important sources of harmonics occurring in the induced voltage or current are listed below. Sources of harmonics that can be eliminated or reduced to a large extent at the design stage of the machine:

- Incorrectly chosen winding factor,
- Incorrectly chosen number of slots in the machine, asymmetry of the air gap caused by technology tolerance,
- Nonlinear magnetization characteristics.

Mechanical sources of harmonics that may occur during the operation of the machine:

- Unbalance,
- Radial or axial asymmetry between the stator and the rotor,
- Bearing damage.

V. COMPUTER SIMULATIONS AND LABORATORY TEST RESULTS OF PM GENERATOR WITH UNBALANCE AS A SOURCE OF VIBRATION

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. Those machines are commonly used in small wind and water turbines.

Computer simulations were carried out using an Ansys Maxwell 2D program on field model (Fig. 5). The program uses for calculations the finite element method and Maxwell's equations. The results of the simulations showed the vibration impact on EMF by modeling the changes in rotor motion.

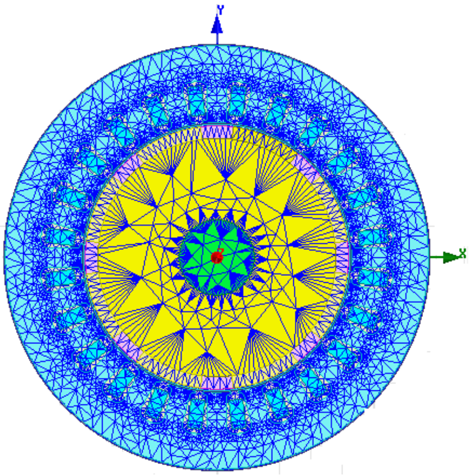

Fig. 5 Field model of generator

The waveform voltage of the generator, which is no supplied but under the influence of the forced oscillations is presented in Fig. 6. Vibrations were forced by placing the test generator on common frame with induction motor, which has had mounted unbalance on the shaft. Machines were not coupled. Both machines have the same number of pairs of poles. Powered motor was a source of vibration for the generator with permanent magnets. The EMF was induced on the generator terminals, which was recorded.

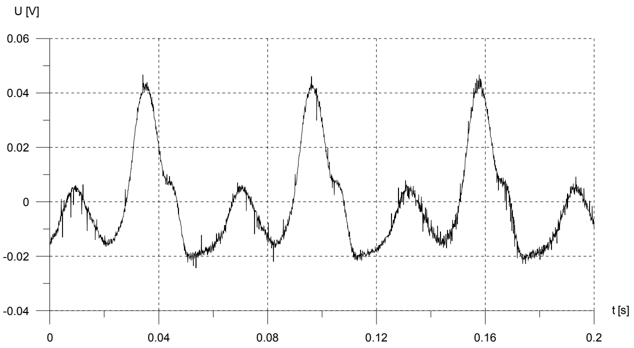

Fig. 6 The waveform of the induced emf - the real measure

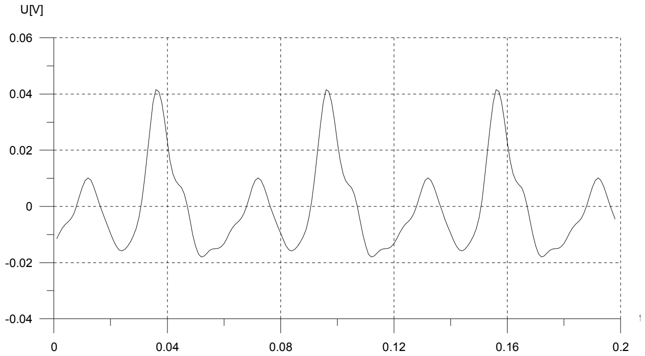

Fig. 7 The waveform of the induced emf - the result of simulation

The voltage waveform of the computer simulations of the generator, which is no supplied but under the influence of the forced oscillations is presented in Fig. 7. Comparing Figs. 6 and 7 it can be seen that the real voltage induced in the winding of the generator coincides largely with the result of the simulation. The method of function selection that describes the motion of the rotor due to the occurrence of vibration was created correctly.

The frequencies f_1 and f_2 for tested generator were calculated using (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 Fig. 8, and for measures are presented in Fig. 9. The FFT analysis for the machine without additional mass (balanced) on shaft are presented in Fig. 8 (a) for simulation and Fig. 9 (a) for measures. The FFT analysis for the machine with additional mass on shaft (unbalance) are presented in Fig. 8 (b) for simulation and Fig. 9 (b) 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.

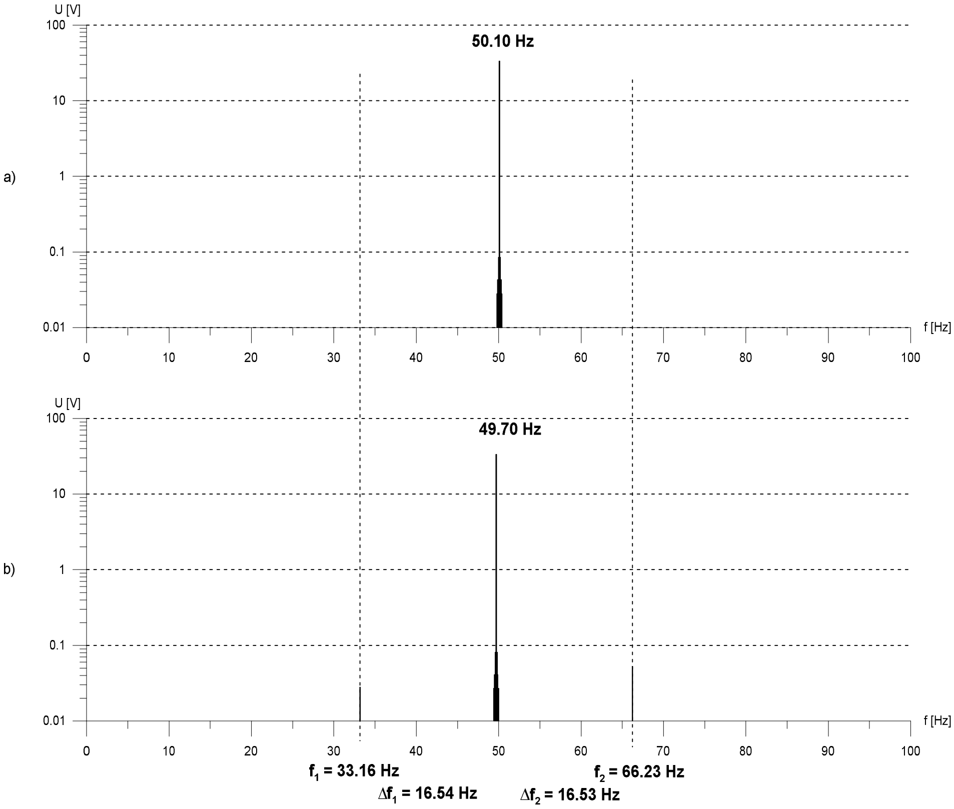

Fig. 8 Frequency spectrums induced voltage of the generator - the results of the simulations

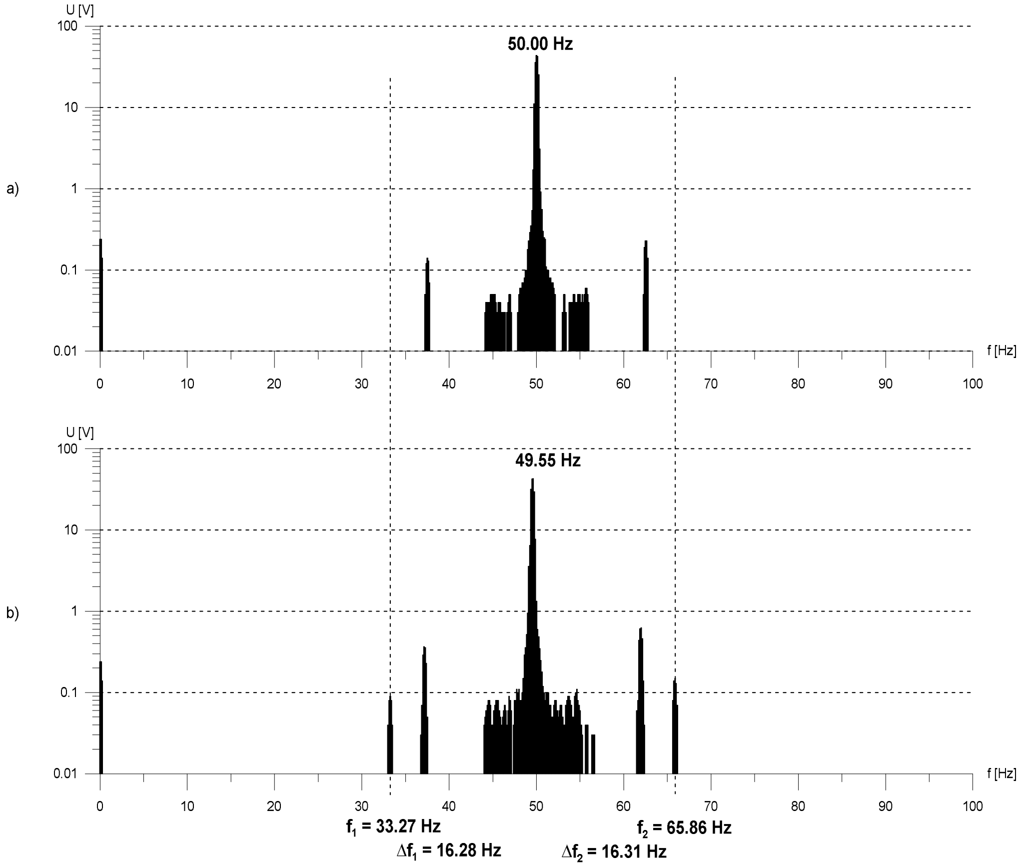

Fig. 9 Frequency spectrums induced voltage of the generator - the results of the real measure

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TABLE II
COMPARISON OF SIMULATION RESULTS AND LABORATORY TESTS

	f [Hz]	f_1 [Hz]	f_2 [Hz]
	50.00	33.33	66.67
Formulas (1) and (2)	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

VI. CONCLUSION

The calculations, simulations and tests confirm the effectiveness of new vibration diagnostic method for machines excited by permanent magnets, where vibrations were created as a result of unbalance (Figs. 8, 9, Table II). 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 specific properties of the machine are used [7]-[17]. 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. It is quite essential for the wind power plant where admittance is difficult for various reasons. Other mechanical sources of harmonics in electrical machines, which may occur during the operation of the machine with permanent magnets, will be analyzed by the author in future works [11]-[17].

REFERENCES

[1] M.Barański and A.Polak and A.Decner, Bearings vibration diagnosis based on hodograph X, Poland, Przegląd Elektrotechniczny, 1/2014, pp. 10-12.
[2] M. Barański, Multiaxial vibration analyzer with SV06A module, data acquisition system (Personal Daq 300*)* and LabView as a graphical programming environment, Master disseration, Gliwice, Poland,2010, pp. 1-4.
[3] M. Barański and A. Decner, The vibration acceleration $a_y = f(a_x)$ function as a tool to determining the bearing technical condition, Zeszyty Problemowe – Maszyny Elektryczne, Katowice, Poland, 2012, pp. 171-175.
[4] A. Decner, Remote monitoring of electric machines, Zeszyty Problemowe – Maszyny Elektryczne, Katowice, Poland, 2011.
[5] M. Barański and A.Decner, Telemetry in diagnosis of electrical machines, Zeszyty Problemowe – Maszyny Elektryczne, Katowice, Poland, 2012, pp. 29-31.
[6] M. Barański and T. Glinka, “Vibration diagnostic method of permanent magnets generators – detecting of vibrations caused by unbalance”, PL Patent application P.405669.
[7] D. Torregrossa, “Multiphysics Finite-Element Modeling for Vibration and Acoustic Analysis of Permanent Magnet Synchronous Machine”, IEEE Transactions On Energy Conversion, 2011, pp 490-500.
[8] R. Islam, “Analytical Model for Predicting Noise and Vibration in Permanent-Magnet Synchronous Motors”, IEEE Transactions On Industry Applications, 2010, pp. 2346-2354.
[9] S. Lakshmikanth and K.R. Natraj and K.R. Rekha, “Noise and Vibration Reduction in Permanent Magnet Synchronous Motors –A Review”, International Journal of Electrical and Computer Engineering, 2012, p.405.
[10] S. Nandi and H.A. Toliyat, “Condition monitoring and fault diagnosis of electrical machines-a review”, Industry Applications Conference, 1999, pp.197-204.
[11] M.Barański, Vibration diagnostic method of permanent magnets generators – detecting of vibrations caused by unbalance, Przegląd Elektrotechniczny, 6/2014, pp. 236-239, Poland,.
[12] M.Barański, New vibration diagnostic method of PM generators and traction motors – detecting of vibrations caused by unbalance, Energycon Conference materials, IEEEXplore, 2014, pp. 28-32,Croatia.
[13] M.Barański, Vibration diagnostic method of permanent magnets generators – detecting of vibrations caused by unbalance, EVER Conference materials, IEEEXplore, 2014, pp. 1-6, Monako.
[14] M.Barański, New vibration diagnostic method of PM generators and traction motors – detecting of vibrations caused by unbalance, Zeszyty Problemowe – Maszyny Elektryczne, 2014, Poland.
[15] M.Barański, PM Electrical Machines Diagnostic - Methods Selected, ICEMDS Conference materials, 2014, Spain.
[16] M.Barański and Tomasz Jarek, Analysis of PMSM Vibrations Based on Back-EMF Measurements, ICEM Conference materials, 2014,Germany.
[17] M.Barański and Bedkowski Bartlomiej, Electrical machine with permanent magnets as a vibration sensor - a test stand model, ICEM Conference materials, 2014,Germany.

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