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The Analysis of Own Signals of PM Electrical Machines – Example of Eccentricity

M. Barański

Abstract**—**This article presents a vibration diagnostic method designed for Permanent Magnets (PM) electrical machines–traction motors and generators. Those machines are commonly used in traction drives of electrical vehicles and 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.

Keywords**—**Electrical vehicle, permanent magnet, traction drive, vibrations, electrical machine, eccentricity, diagnostics, data acquisition, data analysis.

I. 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 (Fig. 1). These fluctuations increase the level of vibration and accompanying noise.

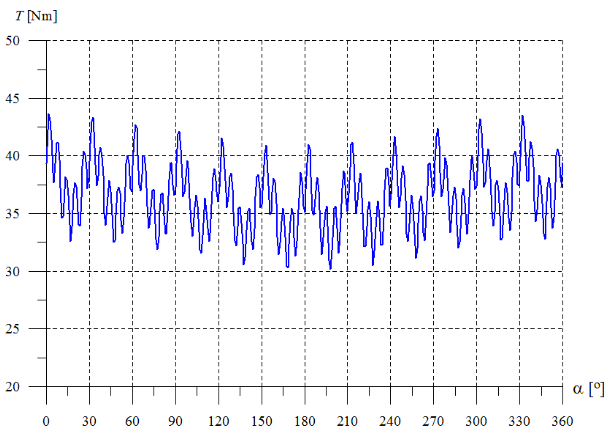

Fig. 1 Torque fluctuations

The high level of vibration in electrical machine is undesirable phenomenon and it is considered a failure symptom. Ignoring these symptoms entails a failure risk, which costs often exceed the device cost [4], [5], [7], [12], [16], [17].

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.

Main advantage of the method 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 on-line during normal machine operation [6], [18], [22], [23].

When the phenomenon was analysed, a similarity between PM machine and electrodynamics sensor, which is used to measure vibrations has been observed [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 electrodynamics sensor.

II. 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 [11].

III. PM Machine as a Vibration Sensor

Fig. 2 presents static test results of PM machine. The graph shows comparison a frequency analysis of vibration sensor signal and own signals of machine. The machine was tested

Marcin Baranski is with the Institute of Electrical Drives and Machines Komel, Laboratory of Electrical Machines, Research and Technical Expert, Katowice, 188 Rozdzienskiego Ave., Poland (e-mail: m.baranski@komel.katowice.pl).

using the vibration table (Fig. 3). Frequency analysis of own signals largely coincides with sensor frequency analysis. It is proof that the PM machine can be used as a vibration sensor for itself.

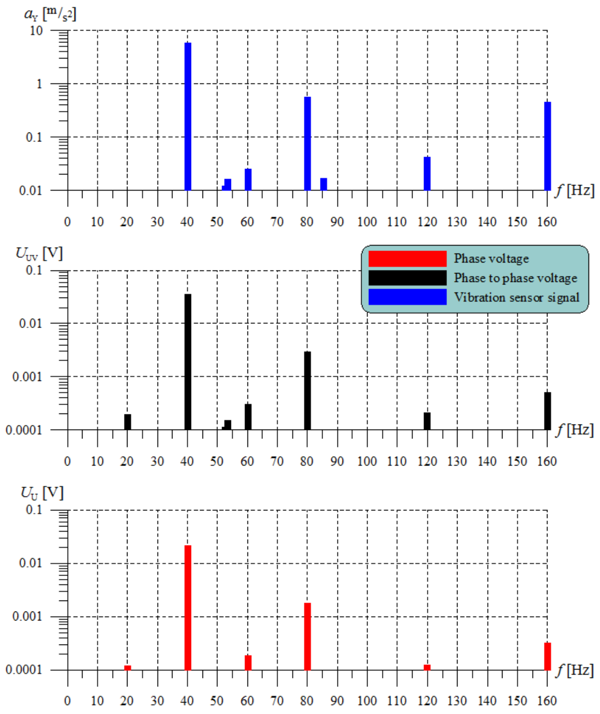

Fig. 2 The results of static tests

Fig. 3 The static test

IV. The Field-Circuit Model

The field–circuit model and the finite element mesh is presented in Figs. 4 and 5.

The analysis was done using Ansys Maxwell 2D software [13], [21]. 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.

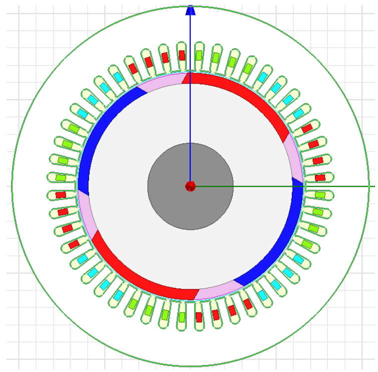

Fig. 4 The PM machine 2D model

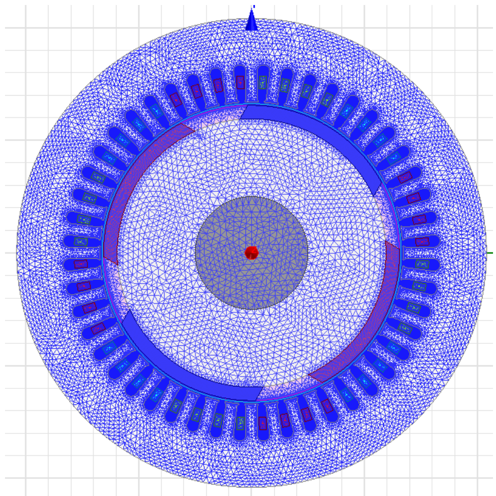

Fig. 5 The finite element mesh

V. The Calculation and Simulation Results

There are presented the results of simulation and calculations of PM machine in Figs. 6 and 7, and Tables I–III. 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, $U = 82$V, $I = 55{,}9$ 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), (3) for all k-th harmonic:

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

$$f_{k2} = \mathrm{k} \cdot f + \frac{(p-1)f}{p} \quad (2)$$

$$f_{k3} = 2\mathrm{k} \cdot f \quad (3)$$

where: f_{k1}, f_{k2}, f_{k3} – searched frequencies; p – number of pole pairs; f–first harmonic frequency; k–natural number.

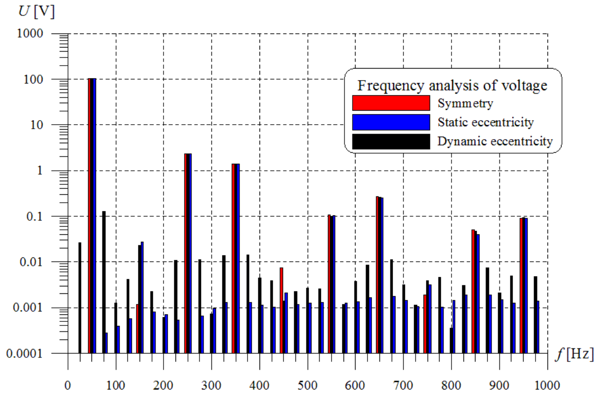

Fig. 6 Frequency analysis of voltage

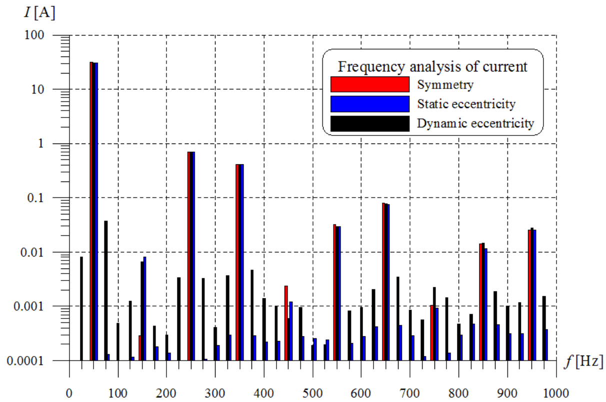

Fig. 7 Frequency analysis of current

TABLE I
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
(1), (2), (3)	50,10	25,05	75,15	100,20
Simulations	50,10	25,10	75,10	100,10

TABLE II
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
(1), (2), (3)	50,10	74,95	125,05	200,40
Simulations	50,10	75,10	125,10	200,10

TABLE III
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
(1), (2), (3)	50,10	124,95	175,05	300,60
Simulations	50,10	125,10	175,10	300,10

VI. 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 [19], [20], [24]. It is quite essential for the wind or water power plant (Fig. 8) and electrical vehicles (Fig. 9) where admittance is difficult for various reasons.

Fig. 8 VAWT wind plant with Komel's generator

Fig. 9 Fiat Panda with Komel's traction motor – research and development project no. NR01-0084-10

The calculations and simulations (Figs. 6 and 7, Tables I-III) 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 [14], [15]. 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 [8]–[10].

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M. Barański (M’13) This author became a Member (M) of **IEEE** in 2013. He was born in Czeladź, Poland, on January 2, 1981. He graduated from the Silesian University of Technology in Gliwice, Faculty of Electrical Engineering.

He has worked in the Institute of Electrical Drives and Machines KOMEL, Katowice, Poland from 2006. Author of patent applications and technical papers: “Thermographic diagnostic of electrical machines”(Roma, Italy, ICEM, 2010), “Noninvasive and invasive methods of squirrel cage’s bars diagnostic” (Ponta Delgada, Portugal, XIICLEEE, 2011), “*New vibration diagnostic method of PM generators and traction motors – detecting of vibrations caused by unbalance*” (Croatia, IEEEXplore, 2014), “*Selected Diagnostic Methods of Electrical Machines Operating in Industrial Conditions*” (IEEE Transactions on Dielectrics and Electrical Insulation, 5(21), 2047-2054, 2014).Now, he is a manager of project: “Vibroacoustic diagnostic method of traction permanent magnets motors and generators based on the own signals”.