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Simulation of the Temperature Influence of an Inductive Sensor for the Geometry Detection of Rotating Components

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Summary:
In this work, the influence of temperature on the output signal of an inductive sensor for the detection of geometric changes in rotating magnetically conductive components was investigated. For the study, the measurement system is modeled and simulated in a numerical field computation software. A radial displacement of the sensor and changes in the magnetic properties of the permanent magnet used are examined. A signal change of up to 14.9% could be proved over the required temperature range. The results show the need to suppress radial displacement and to record the temperatures at the magnets.

Keywords: inductive sensor, simulation study, temperature compensation, permanent magnets, geometry detection

I. Motivation

There are many areas of application for monitoring of the air gap in rotating components in industry like turbines or engines. It is often very important that geometric changes can be detected early during operation. An inductive sensor consisting of a permanent magnet and a coil can be used for local geometry detection of rotating magnetic conductive components. The rotating component is magnetized via the permanent magnet and the resulting change in the magnetic flux is detected in the coil via an induced voltage. In field measurements geometric changes could be determined due to the induced voltage signals during operation. After the machine had come to a standstill overnight, the signals showed strong deviations, which indicates a temperature influence of the measuring system. For this reason, the influence of temperature on the sensor signal is analyzed using a simulation study. The aim of this work is to be able to compensate the influence via signal processing.

II. Simulation study

The magnetic field simulation program used for the simulation study is based on the finite element method. Firstly, the model of the rotating system is created on the basis of CAD data. Then the magnetization characteristics are inserted for the used materials. The simulated induced voltage signal of the sensor for a known geometry at a temperature of 20 °C is shown in Fig. 1 and serves as a reference state for further investigations.

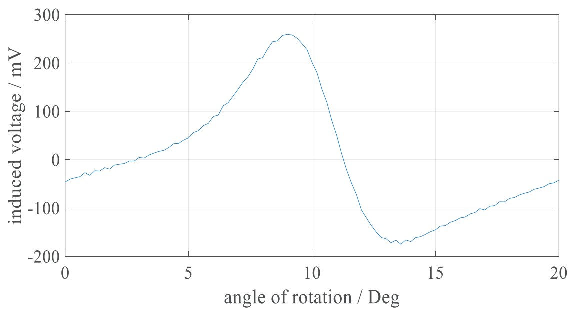

Fig. 1. Simulated induced voltage signal of the sensor via the angle of rotation.

A change in temperature has different overlapping effects on the sensor system. The two most significant changes for the sensor signal are the expansion of the drum cover on which the sensor is mounted, which leads to a radial displacement of the sensor, and the change in the magnetic properties of the permanent magnet. These two approaches are examined and evaluated in the study.

a. Radial displacement

The sensor system is attached to the drum casing. Since the attachment points of the curved cladding are clearly spaced from the sensor, a radial displacement can be assumed. The increased distance between the sensor and the rotating component leads to an increased air gap and thus to a smaller change in the magnetic flux density through the coil. This results in a lower induced voltage in the sensor. Static heating tests on the real component result in a shift of up to one millimeter between the axis of rotation and the sensor due to the temperature expansion of the drum casing. Fig. 2 shows the differential voltage between the induced voltage of the shifted state and that of the initial state.

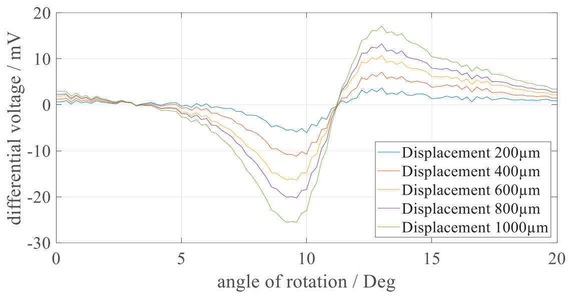

Fig. 2. Differential voltage of the induced voltage between the initial system and the shifted state.

The differential voltages have an almost proportional relationship with the displacement. Furthermore, a slight spread of the extreme points of the induced voltage signals can be seen, which results from the extreme point position of the differential voltage. The changes due to the considered radial shift in the examined value range amount up to 9.2% for the maximum induced voltage. Therefore, it can be concluded from the simulation results that the radial displacement has a significant influence on the sensor signal. If the displacement is known, the influence in signal processing can be compensated on the basis of the deterministic behavior. Since the measurement of the radial displacement of the sensor is problematic in terms of accuracy, the displacement should be structurally restricted in order to be able to optimize the accuracy of the geometry detection.

b. Properties of the permanent magnet

The remanence of permanent magnets is temperature-dependent and can be described in good approximation in the work area using equation (1) [1]. The temperature coefficient α is material-specific and is specified by the manufacturer of the permanent magnet.

$$B_{R,\vartheta}=B_{R,\,20\,°C}\left(1+\alpha(\vartheta-20\text{ °C})\right) \qquad (1)$$

The remanence of the permanent magnet decreases with increasing temperature ϑ. The lower magnetic field leads to less flooding in the rotating magnetically well-conducting component and thus to a smaller change in the magnetic flux density through the coil. As a maximum temperature, 70 °C can be expected from the heating of the bearings. A magnet made of neodymium-iron-boron is installed in the sensor under investigation. The temperature-dependent remanence is implemented in the simulation model. Fig. 3 shows the differential voltage between the induced voltage of the specified temperature and that of the initial state.

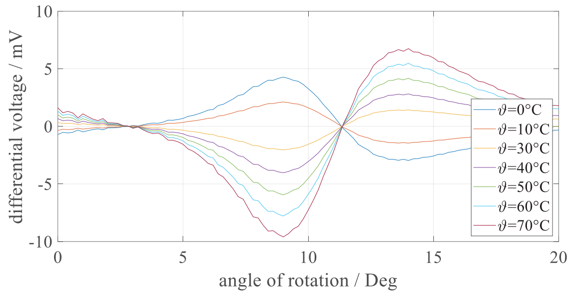

Fig. 3. Differential voltage of the induced voltage between the initial system and the temperature-varied state.

The signal of the differential voltage for the investigated temperatures shows a linear amplification of the induced voltage signal. An almost constant gain factor of -5.7% between 0 °C and 70 °C could be proved in the simulation. This shows that the magnetic properties of the material of the permanent magnet have a significant influence on the sensor signal. Since the relationship can be regarded as almost linear, a temperature change can be compensated in the signal processing. This requires a temperature measurement on the permanent magnet, which must be taken into account when designing the sensor.

III. Results

The results of the simulation study show the significant influence of temperature on the signal induced by the sensor. A maximum change of 14.9% of the maximum induced voltage upon superposition of the radial displacement and the change in the magnetic properties can be determined in the examined value ranges to the initial state. These results show the need for constructive countermeasures to prevent radial displacement of the sensor and to detect the temperature on the permanent magnet. Due to the almost linear relationship between the temperature and the remanence of the permanent magnet, this influence can be compensated in signal processing if the change is measured.

References

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