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Eddy current loss measurement with a focus on measurement sensors for permanent magnets (PM) in energy-efficient electrical machines

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Summary:

Permanent magnet synchronous machines (PMSMs) fed with frequency converter faces higher order harmonics signals which results higher eddy current losses in permanent magnets (PMs). This eddy current losses in the PMs leads to overheating causing irreversible demagnetization of PMs during the operation of the machines. One of the goals in machine design for the safe operation is to measure the total eddy current loss and minimize overheating of PMs. In this paper, measurement methods with a focus on measurement sensors and a finite element method (FEM) simulation for the eddy current loss (i.e. PM loss) of PMSMs are presented and compared.

Keywords: AC machine, Electrical machine, Eddy currents, loss measurement, permanent magnets, permanent magnet synchronous machines, rare earth metals, Measurement, Permanent magnet motor

Introduction, Motivation and Objective

In the last decades it has become clear that the demand for PM in various modern electrical and electronic applications has increased: the correct characterization of PM with eddy current losses urgently needs to be improved for use of PMSM (Fig. 1) in critical applications such as autonomous electric vehicles and medical applications. The accurate analytical analysis and measurement methods of PM loss with highly sensitive sensors can help PMSM designers to create robust PMSMs with high tolerances and higher energy efficiency at low manufacturing costs. In additions, the sensors should be easily implemented in all types, shapes and form of PM that are used in the PMSM as shown in Fig. 1. Various shape and forms of PM are used in SPMSM (surface permanent magnet synchronous motor), IPMSM (interior permanent magnet synchronous motor) and a SynRM (synchronous reluctance motor).

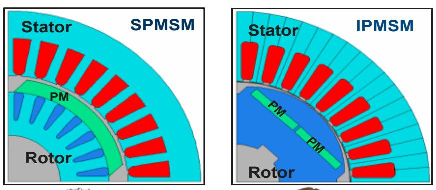

Fig. 1 Cross section (1/4 th view) of permanent magnet synchronous motors with surface mounted magnets (SPMSM - left) and interior magnets (IPMSM - right).

Experimental Measurement Setup Used to Measure Eddy Current Loss

As it can be seen in Fig. 2, the PM sample and the measurement coils available in the printed circuit board (PCB [1]) and matrix array sensors are exposed to the homogenous magnetic flux density (B_{ext}) generated via the PWM inverter signal through the excitation windings. Due to the eddy currents in the PM, the voltage is induced in the measurement coil (sensors). A compact data acquisitions unit (DAQ-FPGA) monitors both the induced voltages in the PCB and matrix sensors. The Matlab tool kit automatically reads the DAQ and the data is used to instantaneously calculate the magnetic field density B, magnetic field intensity H and eddy current loss P_{eddy} using Matlab.

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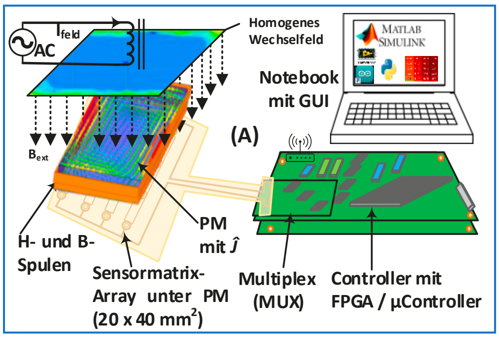

Fig. 2 Experimental measurement setup under inverter excitation current (I_{feld}) for eddy current loss measurement.

To validate the PM loss measurement with FEM simulation, rotor of SPMSM and IPMSM with the PM and the measurement matrix array sensors are created in ANSYS Maxwell software as shown in Fig. 3.

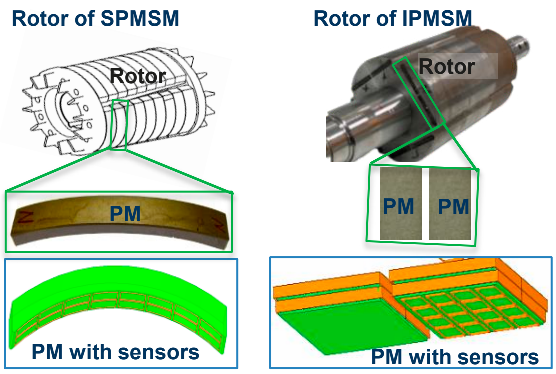

Fig. 3 3D FEM simulation model for PCB sensor and matrix sensor under PM for eddy current loss determination.

The eddy current loss per unit volume of the permanent magnet P_{eddy} is calculated using the integral (1) of the magnetic field strength *H* in the air gap and the magnetic flux density *B* from the permanent magnet.

$$P_{W\_Mess} = \frac{V_M}{T} \int_0^T \sum_{i=0}^{16} H_i \frac{d(\sum_{i=0}^{16} B_i)}{dt} dt \qquad (1)$$

The magnetic flux density of the two matrix sensors must be different due to the additional magnetic field generated and induced because of the eddy current inside the PM.

Results, Summary, Conclusion and Outlook

The eddy current loss with a non-sinusoidal signal such as a pulse width modulation signal generated by variable speed drives is of great interest, which is why it is investigated and presented in this paper. In addition, the analytical (FEM) investigation of the eddy current loss (i.e. PM loss) in PMs under sinusoidal and non-sinusoidal (PWM) external magnetic fields with higher frequency effects is also presented in this paper. The induced voltages (U_{air} and U_{PM}) are measured using the matrix array sensors as shown in Fig. 3. The measured induced voltages can be seen in Fig. 4. An expression of the change of the magnetic field strength *H* and the magnetic field density *B* of the magnet can be evaluated by integrating the induced voltage (U_{air} and U_{PM}) over time respectively.

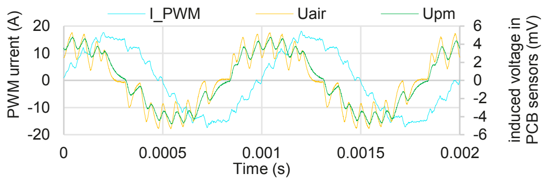

Fig. 4 The induced voltage in the coils under inverter excitation current (PWM) for eddy current loss measurement.

Furthermore, eddy current loss measurement at higher frequencies should be studied in more depth in future research and will be presented in the final paper The further study of the issue related to measurement uncertainty (MU) on induced voltage measurement using matrix sensors is a complex task and still has to be fulfilled. Therefore, the MU calculation of PM loss is not included in this paper although it is of great interest. The next stage of our research will be calibrating measurement matrix array sensors with MU in PM loss measurements. Further research on measurement matrix array sensors with higher external fields is desirable to understand the PM loss phenomena in PWM inverter fields

References

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