Success Story
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New technique for iron loss modeling increases accuracy of computation by an order of magnitude

Summary. Accurate estimation of losses in soft magnetic materials is crucial for precise efficiency computation of electrical machines. Today's applied models feature a frequency domain based approach following a significant drawback. They are imprecise if the material is operated at high saturation level or if it is exposed to non-sinusoidal flux density waveforms. This renders such models unusable if it comes to highly-utilized electric machines. A new way of iron loss modelling was investigated at the Linz Centre of Mechatronics (LCM). The proposed technique features a time-domain based approach. While measurement effort and complexity is comparable with existing approaches, the degree of accuracy was significantly increased.

Accurate iron loss modeling as decisive factor for electric machine design

Recent advances in Mathematics and Computer Science upgraded Electric Machine Design to the next level. Applying dedicated optimization algorithms and numerical modelling and evaluation techniques, a typical design scenario features the nonlinear evaluation of several thousand machine designs to find the best possible solution. To achieve suitable run times, computationally intensive tasks are forwarded to computer clusters.

Besides optimizing the technical performance, minimizing the production cost is always a major objective of optimization problems. This follows highly-utilized compact machine designs and the applied soft magnetic materials are driven at very high flux densities. The time course of the flux density in the bigger part of the designs further features periodical characteristics far off being sinusoidal.

Due to the change of the flux density in the soft magnetic materials, hysteresis and eddy current losses occur. These losses impact the machine design's efficiency and thus their accurate computation is of significant importance.

The basis for currently applied iron loss models was developed long time ago, while the focus was on sinusoidal flux density characteristics and lower saturation levels. Even though the original models were extended and adapted by corrective factors in the past, their performance is unsatisfying for today's engineers.

New loss modelling technique featuring higher accuracy and similar complexity

Facing the drawbacks associated with existing iron loss models, researchers from LCM came up with a new technique. This novel approach features a time-domain based approach. This allows for more properly taking into account nonlinear material characteristics and non-sinusoidal flux density waveforms. Well known time domain based models already exist, but they usually show very high complexity and they require a considerably higher measurement effort. Thus, they are not applicable for electric machine design. The approach developed at LCM overcomes this drawback. The measurement effort is comparable with thus available in the field. Figure 1 gives the preferred flux density characteristics used for modelling. Instead of sinusoidal characteristics used for classical models, triangular signals are considered here. The number of required measurement series is comparable and also existing measurement devices can be reused. While saving the nonlinear models necessitates just little disk space, their evaluation during machine design analyses comes along with low computational expense.

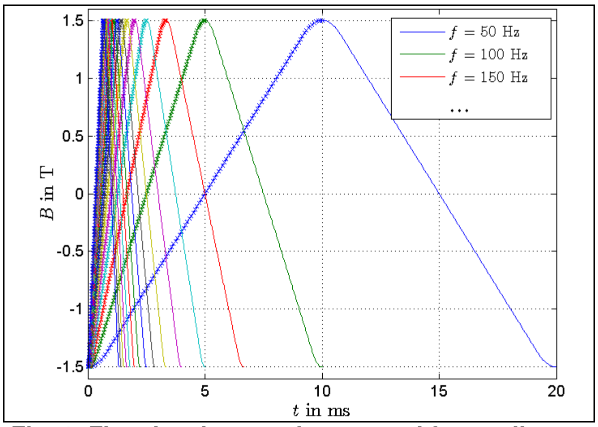

Fig. 1: Flux density waveforms used for nonlinear modelling

Impact and effects

The proposed approach for iron loss computation aroused a great deal of interest in the scientific community when it was published in the prestigious journal IEEE Transactions on Industrial Electronics, first.

In addition, practising engineers from industry took notice and are interested in applying this model to their everyday machine design modelling and optimization.

Both, experts from science and industry are especially surprised by a unique feature of the proposed modelling technique. While common models fail at very high flux density levels and high frequent flux density characteristics, the proposed technique even gets more and more accurate with increasing flux density magnitude and frequency. This is a key advantage, as iron losses show an over proportionate increase with regard to these parameters. Moreover, it enables accurate iron loss computation up to very high rotor speeds and utilization of the soft magnetic materials.

In Figure 2, the verification of the model for multi-harmonic flux density characteristics is presented. The analyses comprise investigations for different fundamental frequencies and good matching of measurement results and modelling output can be observed. This follows an accurate computation of the iron losses, while the modelling error of currently applied models is around 30% for such flux density characteristics.

A lot of research was conducted in the past to increase the accuracy of iron loss estimation. In this particular case, the attention of electric engineers was attracted by a further benefit. The now introduced technique constitutes a consistent approach that takes into account all the requirements that apply for electric machine design. The essential measurements can be done using common measurement setups and within comparable measurement time. The modelling technique obtains increased acceptance due to its physical background. Finally, by contrast to many recently derived approaches, the model can be easily applied within finite element software.

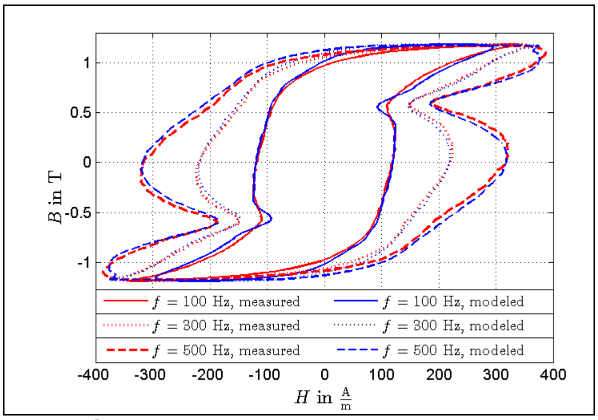

Fig. 2: Comparison of modelling and measurement results for complex magnetization patterns

Researchers of LCM were very excited at the large interest and are looking forward to frequent practical tests of the model in the near future.

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