LOCAL AND CUT-EDGE-LENGTH IRON LOSS SIMULATION USING A LOCAL MATERIAL MODEL

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Abstract – ***Iron losses of high speed electric machines have a significant influence on the overall system efficiency. The cutting process of the lamination causes residual mechanical stress in the lamination. A local magnetic deterioration can be observed and iron losses increase. A continuous local material model for the consideration of the changing magnetization properties in finite element simulations has been introduced in previous work, as well as an a-priori assessment of realistic iron-losses during the design stage [4]. Thereby, global loss parameters are identified according to the specific machine design. A local iron loss calculation considering both, a local magnetization and local loss parameters misses yet. However, this paper presents an approach for local iron loss simulation and gives a comparison to the global cut edge length dependent loss simulation approach.***

I. INTRODUCTION

In state of the art magnetic simulation of electric machines, a local consideration of material properties can be used to solve the field equation [4]. In the state of the art loss calculation global loss parameters are determined to account for the local magnetic deterioration of the material and hence the increase of local iron losses [1]. Local effects such as different width of stator teeth or local phenomena in the rotor are not considered. Therefore, calculation errors are indispensable. This contribution presents an approach to consider both, the local magnetization and local loss parameters.

II. MAGNETIC MEASURMENTS

The magnetic properties of the iron material are measured using a single sheet tester (SST) [2]. The iron loss model presented in [3] is employed and parameterized the by measured data. The total iron loss P_{Fe} is calculated under consideration of static hysteresis P_{hyst}, eddy current P_{cl}, excess P_{exc}, and saturation losses P_{sat}. (1) - (5).

$$P_{\mathrm{Fe}} = P_{\mathrm{hyst}} + P_{\mathrm{cl}} + P_{\mathrm{exc}} + P_{\mathrm{sat}} \tag{1}$$

$$P_{\mathrm{hyst}} = \sum_{i=1}^{N} a_1(\xi)\left(1 + \frac{B_{\min}(x_i)}{B_{\max}(x_i)}\left(r_{\mathrm{hyst}} - 1\right)\right) B_{\max}^{\alpha(\xi)}(x_i) f_1 \tag{2}$$

$$P_{\mathrm{cl}} = a_2 \sum_{\mathrm{i}=1}^{N} \sum_{n=1}^{\infty} \left(B_n^2\,(nf)^2\right) \tag{3}$$

$$P_{\mathrm{exc}} = \sum_{\mathrm{i}=1}^{N} a_5(\xi) \sum_{n=1}^{\infty} \left(B_n^{1.5}\,(nf)^{1.5}\right) \tag{4}$$

$$P_{\mathrm{sat}} = a_2 \sum_{\mathrm{i}=1}^{N} a_3(\xi) B_{max}^{a_4(\xi)+2}(x_i) f_1^2 \tag{5}$$

With $\xi = S, x$ being two different variable for the two different models used in this paper namely cut-edge length S being used for the global approach and x being used for the local model. In standard SST measurements sheets with a total width and a length $l_{tot} = w_{tot}$ of 120 mm are used. In this study electrical sheets of the material M270-35A are cut in strip width w_{st} from 4 mm to 120 mm in a total of six steps using guillotine shears. The cutting and measuring process is performed as introduced in [1]. Both $B_{\max}$-$H_{\max}$ curves and losses are determined for each strip width. The cutting length S_{SST} is calculated with:

$$S_{SST} = 2\,w_{tot} + 2\frac{w_{tot}}{w_{st}} l_{tot} \tag{6}$$

The specific losses P_s of the sheet in dependency of the cutting-edge length of the SST probe S_{SST} and the polarization J are shown in Fig. 1. The specific losses P_s show a linear dependency of the total cutting-edge length S.

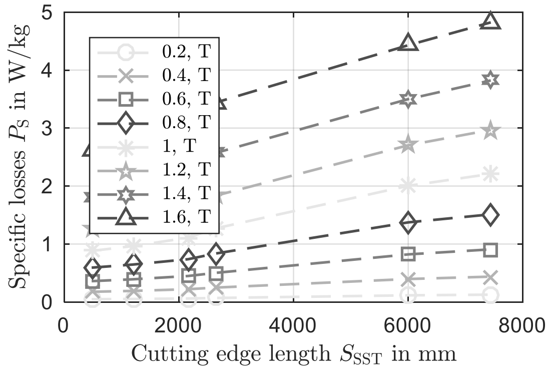

Fig. 1: Specific losses of M270-35A measured in parallel to the rolling direction.

III. FEM SIMULATION MODEL

For this study a permanent magnet synchronous motor (PMSM) for full electric drivetrains is chosen. The data sheet of the motor is shown in TABLE I.

TABLE I
TECHNICAL DATA OF THE STUDIED PMSM.

Specification	Value
Number of pole pairs p	6
Stator inner diameter d_{stat}	180 mm
Peak torque T_{peak}	250 Nm
Peak Power P_{peak}	125 kW
Maximum electrical fundamental frequency f	12 kHz

IV. LOSS CALCULATION MODELS

In the cut edge length dependent loss estimation the cut length of the stator S_{Stat} and the rotor S_{Rot} is determined seperatly. In order to identify loss parameters used for the simulation, the equivalent cut edge length of the stator S'_{Stat} and the rotor S'_{Rot} needs to be calculated using the formula:

$$S'_{Stat} = S_{Stat} \frac{w_{tot} l_{tot}}{A_{Stat}}, \tag{7}$$

where A_{Stat} is the area of the stator lamination and the rotor respectively. First, the measured data (see Fig. 1) is linear interpolated by the equivalent cut edge length of the stator S'_{Stat} and the rotor S'_{Rot} to get equivalent losses. For the identification of the loss parameters, the methodology introduced in [1] is used. All geometrical and loss parameters of the studied PMSM and the material M270-35A can be found in TABLE II.

TABLE II
GEOMETRICAL PARAMETERS OF PMSM AND LOSS PARAMETERS.

Parameter	Stator	Rotor
Cut edge length S	4497,6 mm	3880,2 mm
Equivalent cut edge length S'.	4880,1 mm	6834,4 mm
Area of lamination A	13271,4 mm^2	8157,6 mm^2
Hysteresis loss parameter a_1	0,0291	0,0379
Hysteresis loss exponent α	1,8	1,8
Eddy current loss parameter a_2	$5{,}07 \times 10^{-5}$	$5{,}07 \times 10^{-5}$
Saturation loss parameter a_3	0,549	0,565
Saturation loss exponent a_4	0,45	$5{,}27 \times 10^{-9}$
Excess loss parameter a_5	$3{,}72 \times 10^{-4}$	$2{,}1 \times 10^{-4}$

For the consideration of the local loss distribution, the local parameters of the different iron loss mechanism have to be identified. This is done by using the SST measurements of different specimen width. Thereby, the loss coefficients $a_i(x)$ of the iron loss model in (1) - (5) receive a local dependency. Depicted in Fig. 2 are the resulting local loss parameters normalized to the corresponding undamaged parameter $a_{i,\mathrm{und}}$ and the influence depth of the cut edge δ. The penetration depth perpendicular to the cutting edge is a model parameter of the continuous local material model and depends on the used cutting technique and material [4]. A mayor share of the increase in iron losses is within the first millimeters of the degradation.

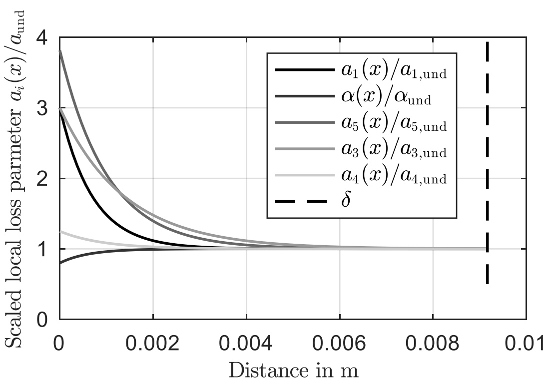

Fig. 2: Local loss parameters, scaled to the corresponding undamaged parameter and penetration depth $\boldsymbol{\delta}$.

V. RESULTS

The eddy current loss distribution as an example for one share of the iron losses referenced to the maximum occuring loss based on cut edge length loss model is shown in.Fig. 3

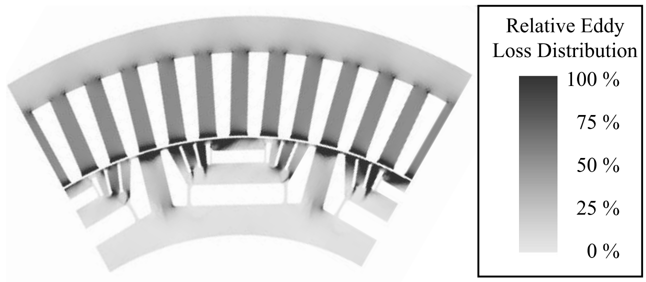

Fig. 3: Relative eddy current loss distribution in lamination for a cut edge length dependend loss model.

The losses occure in localy small areas and therefore model errors using the global loss paramter approach are indispensable. In the full paper, the authors will discribe a detailed comparison of local loss effects in the motor and the results of the two models.

A simulation of an entire torque speed map with and without consideration of cut edge effects is performed, based on the material M270-35A. In specific points of the torque speed map iron loss increases up to 40 % in case the cut edge length approach is used in comparison to the neglection of cut edge losses. The authors will give a detailed description and comparison of the entire simulation tool chain in the full paper.

VI. CONCLUSIONS

Two different approaches for the simulation of losses have been presented and discussed. The cut edge length dependent loss model can be used as an a-priori estimation for the influence of the cut edge on overall performance. The local loss model represents the real physical situation.

REFERENCES

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