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AT-16 An application-oriented methodology to consider material degradation effects due to cutting and punching on iron losses and magnetizability

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Non-oriented electrical steel used in traction drives is mainly characterized by its magnetic properties, i.e., the specific iron loss, magnetic saturation polarization and permeability. Additionally mechanical properties, e.g. manufacturability and yield strength, become important since they strongly influence power density and cost of the resulting electric machine.
A negative side effect of material processing is the decrease in magnetic permeability [1] and increase of local hysteresis loss [1] in the vicinity of lamination edges. The reason for this is related to local detrimental changes in the microstructure, such as dislocations, internal stresses, and grain morphology. These adverse influences need to be considered during the design process of electrical machines.
Commonly these effects are to a great extent studied qualitatively and specified by using building factors. However just a few attempts were made to include the occurring material degradation effects in the simulation process, see e.g. [2, 3].
In addition knowledge on the connection of material processing steps and magnetic material properties is indispensable to fine-tune the material processing, as for instance the cold-rolling or cutting process parameters [1], itself, but also the material composition.

This paper presents a pragmatic material model allowing for consideration of material degradation effects on magnetizability and iron losses as a function of the distance to the cut-edge.
On that account, material characteristics are measured for samples with different ratios of cut-edge length vs. overall lamination volume. A number of single sheet tester samples of 120mm x 120mm are cut in smaller stripes by guillotine cutting others by CO_2 laser, resulting in sample sets with additional guillotine/laser cut edges.

In order to study the impact on the magnetization behavior, quasi-static measurements with negligible amount of eddy-current disturbance are conducted.
Due to the cutting, a spatial distribution of magnetic polarization $J(x)$ as function of the distance x from the cut-edge is present. Micro-magnetic measurements reported in [4] show that the spatial distribution is parabolic and can have a depth, depending on its definition, of up to 10mm [1, 4, 5].
The homogeneity of the magnetic field strength H over the sample allows a consideration of the material degradation as a local inhomogeneous decrease of the magnetic permeability μ, noted as $\Delta\mu(H,x)$ [6].
Following [6] the increase of the dislocation density at the cut-edge, and $\Delta\mu_{cut}(\mathrm{H})=\Delta\mu(H,x=0)$ are assumed to be material constants. Hence, the spatial distribution of $\Delta\mu$ can be expressed in terms of a field-independent distribution function $\eta(\mathrm{x})$[6], which relates to the spatial distribution of the magnetic polarization [6]. Therewith it is possible to reconstruct the magnetic polarization distribution as a function of the distance to the cut-edge,

$$J(x)=\mu_0(\mu(H,N=0)-\Delta\mu_{cut}(H)\eta(x))H. \quad (1)$$

Fig. 1 (top) shows the obtained results for lamination cut by a guillotine and Fig. 1 (bottom) a laser cut lamination. In addition to the adaptation of magnetic polarization curves, i.e., magnetic permeability, in the degraded region, an important aspect is the consideration of the increased iron loss. Therefore the impact of cutting is implemented into the coefficients of the *IEM-formula* [6, 7], which was developed to allow for a more accurate iron loss estimation.

Based on measurement results it is assumed that the quasi-static hysteresis losses are most prone to be affected by cutting, corroborated by the behavior of the coercive field $H_c(H)$ and quasi-static hysteresis loops $J(H)$. Hence, parameter a_1 from eq. (2) related to the pure hysteresis loss is adapted to account for the increasing dislocation density with decreasing sample width. Ref. [8] shows that the magnetic property deterioration depends on the cutting strains, defined as $S = A/V$, the cutting surface A (m^2) referenced to the volume V (m^3). A nearly linear dependency of parameter $a_1$on the cutting strains is obtained. Together with the mathematical description for the magnetic polarization, the *IEM-formula* is rewritten as

$$P_{fe}=a_1(S)\cdot f\cdot B(H,x)^{\alpha}+a_2\cdot B(H,x)^2\cdot f^2\cdot (1+a_3\cdot B(H,x)^{a_4})+a_5\cdot B(H,x)^{1.5}\cdot f^{1.5}. \quad (2)$$

This model is subsequently applied to calculate iron losses in sample sets of different sample sizes. Fig. 2 presents the obtained loss predictions at 50Hz (top) and 400Hz (bottom). The accuracy is sufficient for various sample sizes using just two measured sample sets for parameterization.

Details on the model together with a parameterization as well as further comparisons with measured data will be given in the full paper.

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