Effects of secondary grain size on laser scribing optimization in GOES

Giuseppe Carlo Abbruzzese
SpIReS S.r.l., Terni, Italy

This study investigates the impact of laser scribing on excess dynamic losses, taking into account secondary recrystallized grains. Magnetic domains formed by the grain structure interact with those created by laser scribing. By applying STGG principles [2], an "effective distance" is identified, influenced by physical scratching from the laser and the average rolling direction grain boundary distance. This establishes criteria for optimizing magnetic losses in specific grain structures, utilizing a modified Pry and Bean model [3] for estimating dynamic losses.

Keywords: GO electrical steel; excess losses; laser scribing; secondary grain size effect

1. Introduction

Grain-oriented electrical steel, following final heat treatment for secondary recrystallization, develops a microstructure composed of large "secondary" grains with an almost perfect Goss orientation {110}⟨001⟩. The typical grain size ranges from 1 to 20 mm within the sheet plane, depending on production technology. This microstructure, dominated by highly oriented grains ⟨001⟩//RD, establishes a magnetic equilibrium state characterized by large magnetic domains with relatively wide spacing between parallel 180° domain walls, which define the magnetic regions within the grains.

During magnetization—such as in the practical use of these sheets in power transformers operating at 50 Hz—the movement of magnetic domain walls contributes to excess losses due to localized eddy currents. These losses are in addition to the classic dynamic losses (primarily influenced by sheet thickness and electrical resistivity) and hysteresis losses, which are mainly attributed to defects and closure domains.

As the average grain size increases, the parallel magnetic domains become wider, leading to greater excess losses. Depending on sheet thickness and grain size, these excess losses can constitute up to 40-50% of the total losses. This realization prompted the development of domain refining technologies aimed at increasing the number of domain walls and redistributing the magnetic energy across more walls. This slows domain wall movement and reduces localized eddy current effects.

2. Results and discussion

The most effective and practical domain refining method involves laser scribing on the strip surface. This process introduces perpendicular stress to the domain orientation, accompanied by closure domains, thereby narrowing the width of the parallel magnetic domains. While this technique is generally effective, the laser and scribing machine parameters (e.g., laser power and line spacing) should be continuously adjusted to accommodate the underlying crystallographic microstructure.

In fact, grain boundary misorientation (2-4°) induces closure domains, further contributing to domain refinement. Consequently, smaller grain sizes are typically associated with reduced excess losses.

However, practical applications often overlook these adjustments due to the lack of a comprehensive physical model describing the interactions between laser parameters and microstructural properties. As a result, systematic optimization of laser scribing parameters is seldom pursued.

This paper introduces a comprehensive model for magnetic losses, incorporating the interplay between laser line spacing and grain size effects [1]. The Statistical Theory of Grain Growth (STGG [2]) is employed to establish topological relationships that define the "effective distance" for domain refining. This effective distance captures the interaction between the selected laser line spacing and the spacing of consecutive grain boundaries along the rolling direction (grain size).

By combining this "topological" function with the Pry and Bean approach to dynamic losses [3] and a modified Steinmetz formula for the hysteresis losses, the model enables an estimation of the dependency of magnetic losses on the microstructure. To optimize these losses, the study provides examples demonstrating how laser line spacing should be adjusted according to the secondary grain size. These results are further analyzed and validated through comparisons with industrial experimental data obtained with rotating mirror laser technology.

References

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