Estimation of Iron Losses in a SynRM with Segmented Rotor

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***Abstract*—Besides the copper losses and mechanical losses, iron losses are inevitably reducing the efficiency of an ac machine. Despite being generally agreed to be much smaller in proportion in comparison to copper losses at lower speed, it is nonetheless necessary to be estimated before concluding that it could eventually be neglected for further studies like thermal analysis. In this study, the iron losses in a 180W SynRM machine with segmented rotor was estimated using Bertotti iron losses model across its operating area. The peak flux density across the laminated core was determined using FE analysis where the harmonics are neglected in this preliminary study. The hysteresis and excess losses' coefficient was determined by curve-fitting the Epstein data of the material which is a M330-50A lamination. The results show a maximum iron losses of only 4.9W across the operating area of the machine, occurring at the operating point of (torque; speed) = (0.21N.m; 6800rpm). The Eddy current losses makes the biggest part of it at 2.8W.**

***Index Terms*—SynRM machine, Iron losses, Bertotti model, Hysteresis losses, Eddy current losses**

I. INTRODUCTION

As in other electromagnetic devices, iron losses occurs in a (Synchronous Reluctance) SynRM machine when its ferromagnetic components are subjected to changing magnetic field. The components in the SynRM machine that is related to these losses are the stator structure and the rotor magnetic segments. The power that ideally transformed into torque production is lost in the material,
dissipated as heat and mechanical micro-vibration. It is therefore important to evaluate these losses so that potential improvements could be considered [1], [2] .

A. Iron losses model

There are 2 types of iron losses models: local and global. Local model calculates precisely the iron losses using fundamental equation of dissipated power density in the material locally, provided that the relation between the magnetic field, the flux density and its derivative are known. It can be presented as in Equation 1.

$$P_{iron} = \int \int_{\tau} \int \left(\frac{1}{T} \times \int_0^T (\oint H.dB)dt \right) d\tau \qquad (1)$$

$d\tau$ represents the elementary volume. Therefore, it is necessary to take into account the hysteresis cycle of the machine precisely. This method is proven to be precise but relatively heavy, complex and time-consuming to be integrated into a multi physical model and optimization tool. It is suitable to be implanted into a finite elements tool as shown by the work of [3] , who have developed the LS (Loss Surface) model that was implanted into FLUX software by Cedrat.

The global model in the other hand uses a frequency approach and usually with hypothesis that the evolution of the flux density in the material is purely sinusoidal. The first formulation on iron losses has been done by Steinmetz [4] who proposed a formulation of iron losses which depends on the frequency of the magnetization cycle f and the maximum flux density $\widehat{B}$. This can be expressed as in Equation 2.

$$P_{iron} = C_{stein}.f^{\alpha}.\widehat{B}^{\beta} \qquad (2)$$

with C_{Stein}, α, β are coefficients determined from experiments. This model regroups numerous physical phenomena of different natures. Further development on the model lead to an improved formula as in Equation 3, separating the losses into the two primarily losses contributors phenomenons: hysteresis and Eddy current.

$$P_{iron} = C_{hys}.f.\widehat{B}^2 + C_{Eddy}.f^2.\widehat{B}^2 \qquad (3)$$

However, Equation 3 still neglects a certain number of losses that are minimal compared to hysteresis losses and Eddy current losses. They are added by Bertotti [5] in his equation (Equation 4) as excess losses.

$$P_{iron} = K_{hys}.f.\widehat{B}^2 + \frac{(\pi d)^2}{6\rho_t m_v}.(f.\widehat{B})^2 + K_{exc}.(f.\widehat{B})^{\frac{3}{2}} \qquad (4)$$

with d the lamination thickness, ρ_t the electrical resistivity of the material and m_v the material density.

Other works such as [6], [7] have lead to further improvements of estimation of hysteresis losses in order to take into account other small phenomena such as the deformation and enlargement of the hysteresis cycle area due to increase in magnetization frequency and hysteresis losses due to minor cycles.

The utilization of all the models cited are finally limited by the fact that they were formulated considering that the evolution of the flux density is purely sinusoidal whereas
the ux density in a magnetic parts of a motor is not always perfectly sinusoidal, or even in some cases completely distorted when field-weakening is involved such as in [8], [9] .

A more general formulation (Equation 5) which is applicable for every form of flux density developed by [10] is the