Fast estimation of the influence of a tensile plastic strain on the magnetic behaviour of electrical steels

Jeanne Le Soudéer[a,b,c], Olivier de la Barrière[b], Yoann Guilhem[c], Adrien Gilson[a], Olivier Hubert[c], Frédéric Mazaleyrat[b]

[a] IFP Energies nouvelles, Institut Carnot IFPEN Transports Energie, 1 et 4 avenue de Bois-Préau, 92852 Rueil-Malmaison, France.
[b] Université Paris-Saclay, ENS Paris-Saclay, CNRS, SATIE, 91190 Gif-sur-Yvette, France.
[c] Université Paris-Saclay, Centrale Supélec, ENS Paris-Saclay, CNRS, LMPS laboratoire de mécanique Paris-Saclay, 91190 Gif-sur-Yvette, France

Residual stress, hardening, and defects introduced during the cutting process lead to a global degradation of the magnetic properties of electrical steels. Modelling these phenomena requires preliminary measurements beginning by characterizing the influence of plastic strain on the magnetic behaviour. It is proposed in this study to use a hourglass-shaped sample to create a plastic strain gradient and assess magnetic behaviour using a single specimen.

Keywords: magneto-mechanical coupling; magnetic behaviour; magnetic measurements and instrumentation

1. Introduction

Electrical machines are constituted of laminated steel sheets that are cut into the desired design. This process introduces residual stress and defects in the material which impacts its magnetic properties and increases the losses [1]. To properly model these effects it is necessary to proceed to preliminary measurements of the influence of plastic strain on the magnetic behaviour. Such a characterisation is usually achieved by tensile test of several strips at different (homogeneous) plastic strain levels [2], making this procedure long and matter consuming. In this work a fast procedure is proposed allowing to evaluate the influence of plastic strain on magnetic losses using a single sample.

2. Results and discussion

The plastic behaviour of a metallic material generally results in a monotonic and increasing nonlinear relationship between stress and strain. The stress is calculated by relating the applied force to the useful cross-section of the specimen. The use of a correctly dimensioned hourglass specimen (minimum cross-section, maximum cross-section, radius of curvature) makes it possible to obtain a wide range of stress and therefore plastic deformation in a single specimen. This procedure has been applied to a 0.35 mm thickness Fe-3.2wt%Si sheet. An appropriate hourglass sample is wire-cut and a tensile test is carried out up to 12% strain. The strain field is assessed using digital image correlation (DIC) [3]. Then the sample is placed in an Epstein frame closed by three regular Epstein strips of the same material. Local magnetic measurements are conducted on 1cm long areas using a calibrated Bcoil to measure the flux density and a calibrated Hcoil to measure the magnetic field. Assessments are made for induction levels from 0.1 T to 1.5 T under controlled sine waveform. Figure 1 shows the strain field and areas where the sensors are placed. Average plastic strain over the length of the magnetic sensors reaches a maximum of 11.8% at the centre and minimum of 0.80% at the edge of the hourglass. Losses and relative variation of losses are plotted in figure 2 along with reference losses in black (figure 2 left). Relative losses show a consistent trend highlighting a strongly non-linear influence of plastic strain. As permeability decreases with increasing plastic strain, losses variation is lower at high magnetic induction. Results are also compared to magnetic measurements conducted on plastically deformed Epstein strips (full lines in figure 2 left). They are consistent with results from hourglass sample despite strain gradient. The strain is on the other hand more homogenous in the hourglass sample compared to strip samples due to forced strain localization, thus yielding to more reliable results.

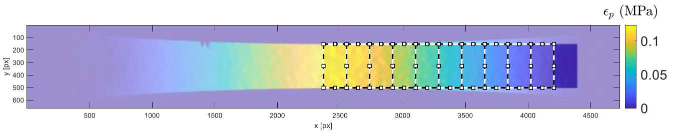

Figure 1: Hourglass sample (speckled for DIC) along with the obtained plastic strain field, Hcoil (below) and Bcoil (above).

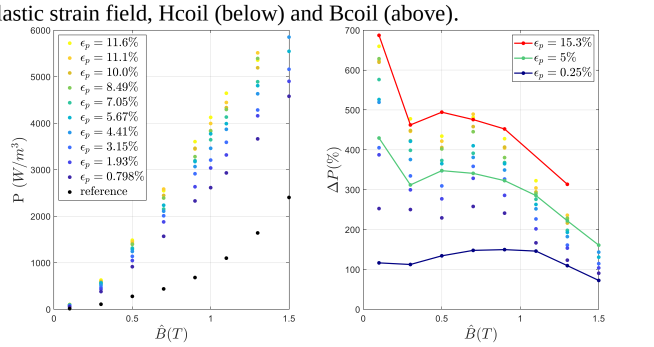

Figure 2: Losses (left) and relative variation of losses (right) as function of peak induction at different plastic strain levels from hourglass sample. Full lines (right) correspond to plastic strained Epstein strips.

References

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