Magnetic loss behaviour of non-grain-oriented material due to cyclic mechanical stress

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From its key role in the magnetic core of electrical machines, non-oriented electrical steel is subjected to a variety of mechanical effects which affect its magnetic properties. Commonly studied effects include the magneto-mechanical effect, where static mechanical stress from the cutting and packaging processes can heavily affect magnetic behaviour. Another related effect is due to cyclic mechanical stress, which can be caused by repeated variations in the operating point of the electric machine. This effect can accumulate after an increasing number of cycles and therefore decrease the total efficiency and power of an electrical machine. In this paper, samples of a non-oriented FeSi alloy are subjected to different fatigue conditions in order to observe and quantify the changes in magnetic properties due to cyclic mechanical stress. A discussion on the possible relationships between the measured values and its physical origins is briefly presented.

Keywords: mechanical fatigue; non-grain-oriented; Wohler curve

1. Introduction

Electric machines are used widely in diverse applications with varying pre-requisites. The last few decades have seen a rise in the demand for these machines as well as in the need to constantly improve their efficiency and durability. Iron losses which originate from the constant remagnetisation of the non-oriented electrical steel in the magnetic core of electrical machines impact the total machine efficiency significantly. Machines are usually designed with material data of magnetic properties (loss and magnetizability) and mechanical properties (yield and tensile strength). These values are obtained by standardized measurements according to international standards. This however, neglects operational characteristics of electrical machines as well as simplifies known effects.

Iron losses as well as the magnetizability of electrical steels are affected by magneto-mechanical effects, i.e., static and dynamic stresses. Due to the magneto-mechanical coupling, stress results in micromagnetic property changes. Static residual stress can come from various sources, such as packaging and processing of the electrical steel. In addition to the effect of static mechanical stress, the magnetic material in electrical machines is also subjected to cyclic loading, which can lead to material fatigue during operation time. This is caused by centrifugal forces in frequent start and stop cycles of the machine, which lead to microstructural changes, such as cyclic softening or hardening of the material, that can affect magnetic behaviour. In contrast to static mechanical stress, the mechanical fatigue does not depend only on the amplitude and direction of the current applied stress, but also from the number of stress cycles that the material has been subjected to. Some material properties such as the alloy and grain size can also affect the changes in magnetic properties due to cyclic loading. In order to study the influence of cyclic loading on magnetic properties of non-oriented electrical steel, in this paper, magnetic characterization measurements are performed and results are compared from samples which were subjected to cyclic loading.

2. Results and discussion

In order to study the intensity and area of effect that cyclic loading can have on magnetic properties, samples of a non-oriented FeSi material with 0.3 mm thickness were subjected to cyclic loading. Measurements were conducted for two groups of samples with different grain sizes. The samples were subjected to different stresses and number of cycles, all within the material elastic region up to its yield strength. A number of different stress-cycles configurations were considered for the measurements.

The magnetic characterization measurements were conducted before and after the application of stress in each sample in order to compare its influence. The measurements were made with a Single Sheet Tester (SST) in the standard sinusoidal conditions. Figure 1 presents the measured loss and relative permeability against the number of fatigue cycles and the stress amplitude σ_a for the samples grain size of 80 µm at 1.4 T and 100 Hz.

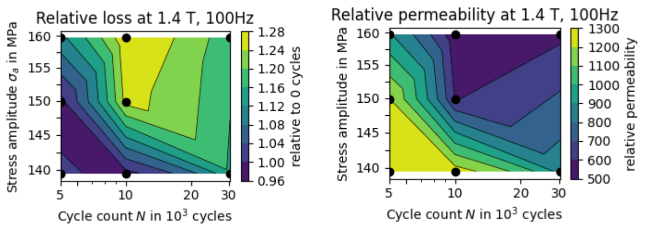

Figure 1: Left: relative total loss comparing before and after fatigue application. Right: relative permeability μ_r after fatigue application.

The observed results show a significant relationship between the measured properties and the applied mechanical fatigue, both in regards to the stress amplitude as well with the number of fatigue cycles, with a behaviour similar to the Wohler curves utilized in determining the fracture point due to the applied cyclic loading.

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