Frequency Spectrum Analysis of Magnetic Field Strength for Effective Condition Monitoring of Magnetic Cores

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This paper presents a new approach for Inter-laminar Fault (ILF) analysis and condition monitoring of magnetic cores with Grain-Oriented Electrical Steels (GOES). The proposed technique relies on interpreting frequency spectrum of the magnetic field strength over one cycle of magnetisation. Experimental work was undertaken on stacks of four standard Epstein size laminations subjected to artificial ILFs of different severity. Impacts of each fault scenario on the magnetic field strength in time and frequency domains were studied. This approach can effectively increase accuracy of fault diagnosis, and improve detectability of weak fault signatures in magnetic cores.

***Index Terms*— Condition monitoring, core fault, frequency spectrum, magnetic field.**

I. Introduction

MANUFACTURING process of electromagnetic devices usually starts with their magnetic cores, which are constructed from electrical steel laminations. Like other parts of the device, magnetic cores can experience variety of faults which are known as core fault or Inter-laminar Faults (ILFs). Core faults can create fault current loops, which in principle deteriorate the laminated structure of the magnetic cores. Local hot spot and local power loss are the immediate consequences of core faults, that impact on the normal operation and overall efficiency of the device [1-2].

In recent publications, analytical, and experimental techniques were developed for fault diagnosis and condition monitoring of magnetic cores based on the phenomenology of magnetic hysteresis [1-2]. These techniques rely on measuring and interpreting the dynamic hysteresis loops (DHLs) and instantaneous waveform of the magnetic fields. This paper aims to propose a new approach for fault diagnosis and condition monitoring of magnetic cores by looking at the frequency spectrum of the magnetic field strength.

A key feature of this study is to increase accuracy of fault diagnosis to improve detectability of weak fault signature. For this purpose, experimental work was conducted on stacks of standard Epstein size laminations of Grain Oriented Electrical Steels (GOES). Artificial ILFs, with a wide range of severity level, were applied between the laminations. DHLs and instantaneous waveshapes of magnetic field strength of the test samples were acquired. An in-depth analysis on the acquired data in time and frequency domains were performed to understand impacts of ILF on frequency spectrum of magnetic field strength. The proposed technique and associated analysis can provide new prospect in condition monitoring of magnetic cores of practical electromagnetic devices.

II. Theoretical Context:

Thin Sheet Model (TSM), originated from the statistical energy loss separation developed by Bertotti [3], has been identified as a reliable analytical model to analyse the dynamic characteristics of GOESs. In this method, the total energy loss W_{tot} is separated into hysteresis loss W_{hys}, classical eddy-current loss W_{eddy}, and excess loss W_{exc} [4]:

$$W_{tot} = W_{hys} + W_{eddy} + W_{exc} \quad (1)$$

Energy loss separation of (1), can be described through the magnetic field separation:

$$H(t) = H_{hys}(t) + H_{eddy}(t) + H_{exc}(t) \quad (2)$$

where $H(t)$ is the magnetic field at the surface of the lamination.

Two component loss model can be also defined where the magnetic cores are subjected to complex magnetising regime [2, 4]. In such model, total energy loss and total magnetic field are separated into hysteresis and dynamic components:

$$W_{tot} = W_{hys} + W_{dyn} \quad (3)$$

$$H(t) = H_{hys}(t) + H_{dyn}(t) \quad (4)$$

In a recent work the two component models of (3) and (4) were further developed to represent the additional energy loss and the corresponding additional magnetic field caused by ILFs in magnetic cores constructed from GOESs [2]:

$$W_{tot} = W_{hys} + W_{dyn} + W_{add} \quad (5)$$

$$H(t) = H_{hys}(B) + H_{dyn}(t) + H_{add}(t) \quad (6)$$

where W_{add} and $H_{add}(t)$ are additional energy loss and additional magnetic field caused by the ILFs.

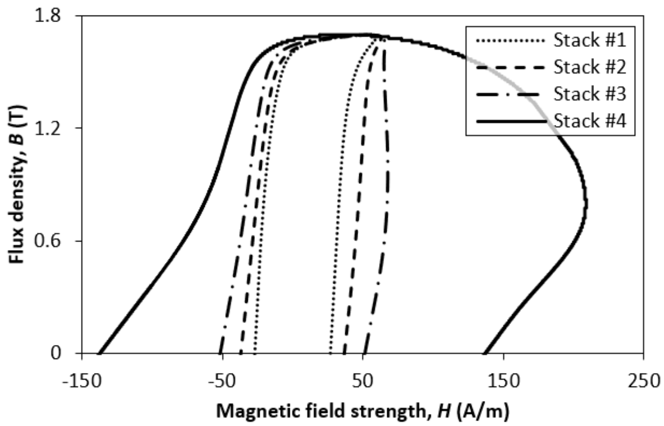
III. Experimental Set-up and Sample Preparation

Experimental works were conducted on 0.3 mm thick standard Epstein size laminations of 3 % SiFe GOES, with standard grades of M105-30P and a measured resistivity of $\rho = 0.461$ μΩm. Four stacks, each contains four strips, were assembled and marked as: Stack # 1 with no ILF, Stack # 2 with ILFs at one position, Stack # 3 with ILFs at three positions, and Stack 4 with ILF throughout the laminations. A low frequency magnetising system comprising a single strip tester was employed to magnetise the test samples [5]. All test samples were magnetised under controlled sinusoidal induction at a magnetising frequency of 50 Hz.

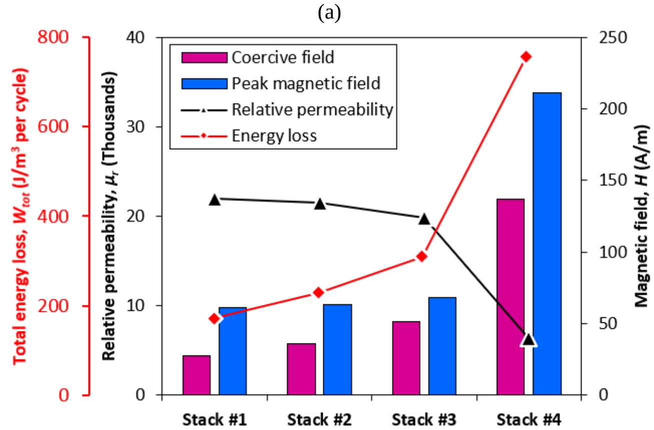
A. *Magnetic hysteresis interpretation:*

During the initial stage of this analysis, it was recognised that frequency spectrum of the magnetic field strength of the test samples, depends highly on the flux density $B(t)$ which is mainly due to the nonlinear behaviour of the material. The initial results revealed that frequency spectrum analysis at 1.7 T provides a more accurate figure of quality of the test samples. Therefore, this analysis was focused on peak induction of 1.7 T.

DHLs of the test samples were initially measured. Accordingly, coercive field, peak magnetic field, relative permeability, and total energy loss of the test samples were calculated, the results are shown in Fig 1-a and 1-b, respectively.



(a)



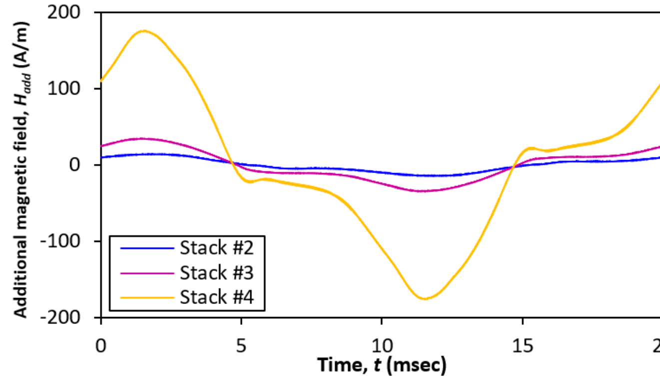
(b)

Fig 1 (a) DHLs and (b) Coercive field, peak magnetic field, relative permeability, and total energy loss at $f = 50\ Hz$ and $B_{pk} = 1.7\ T$

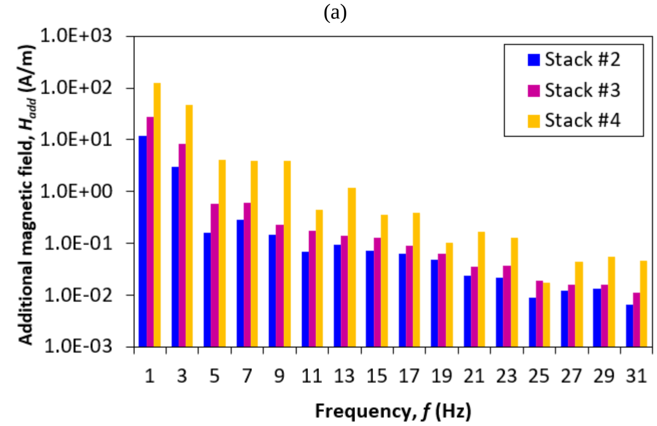
These results indicate that, at each particular flux density, ILFs make a major impact on the coercive field H_c and peak magnetic field H_m. These facts solidly impact on the total energy loss of the test samples, which is shown in Fig 1-b. Furthermore, this experiment reveals that relative permeability of the test samples is notably fell off by severity of the ILFs, which is due to the increase in the peak magnetic field strength H_m at a given peak flux density B_m. Certainly, this phenomenon is adverse for the overall quality of electromagnetic devices.

B. *FFT analysis of magnetic field strength:*

In the next stage of this work, an in-depth analysis on frequency spectrum of the magnetic field strength of the test samples was conducted. The results showed that, except for the fundamental component, frequency spectrum of the overall magnetic field does not show a rational indication of impacts of core faults. As stated earlier, the first and immediate impact of ILFs is to create additional eddy current loops, which result in additional localised power loss at the defected zone. In the final stage of this work, instantaneous waveshapes of $H_{add}(t)$ of Stack #2 to Stack #4 were separately extracted and their frequency spectrum were calculated; the results are shown in Figs 2-a and 2-b, respectively.



(a)



(b)

Fig 2 (a) Instantaneous wave shapes $H_{add}(t)$ and (b) their frequency spectrum at $B_{pk} = 1.7$ T

These results revealed that impacts of ILFs can be distinctly observed in the frequency spectrum of the additional magnetic field. Therefore, with specific emphasis on fault diagnosis in magnetic cores, an accurate signal processing and FFT analysis on the magnetic field strength can provide information on quality of the magnetic cores. This can be used as a diagnostic tool for effective condition monitoring of magnetic cores of practical electromagnetic devices.

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