UK Magnetics Society

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Magnetic Measurements for Innovation

One day UK Magnetics Society seminar at BEMC

Thursday, 17 November 2005

at

National Physical Laboratory, Teddington,Middlesex

Measurement of Magnetic Properties for Operational Conditions

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Abstract

A traceable method of measuring the magnetic properties of soft magnetic materials for operational conditions has been developed. These conditions include the non-sinusoidal waveforms often found for both B and H in electrical machines, at elevated temperatures and at magnetic field strengths that are higher than for conventional copper conductor designs due to the use of permanent magnets.

Introduction

Motor cores, in general do not operate under ideal conditions, indeed they operate in an electrically messy environment; such as variable, non-sinusoidal, frequencies of current, varying elevated temperatures and differing magnetic field strengths. This work aims to simulate these ‘real world’ conditions and characterise soft magnetic materials and laminations to enable better computer modeling of their behaviour, thus resulting in more efficient and novel designs with a significantly reduced time to market.

Methods for measuring the magnetic properties of ring and Epstein strip specimens, such as the peak magnetic field, peak magnetic polarisation, magnetising curve, AC permeability, specific total loss and specific apparent power for arbitrary magnetic flux density waveforms will be presented at the conference. To comply with the requirements of IEC standard 60404 Part 2 [1], it is necessary to be able to control the secondary voltage waveform to be sinusoidal with a form factor (ratio of rms to average rectified voltages) of 1.1107 ± 1%. Under such conditions the rms secondary voltage is related to the peak magnetic polarization, $J_{peak,}$ by;

$$V_{rms} = \frac{2\pi}{\sqrt{2}} f N_2 A_s J_{peak} \quad (1)$$

where f is the frequency in Hz, N_2 is the number of turns on the secondary, and A_s is the cross sectional area in m^2. Control of the waveform shapes is achieved using a suitable feedback technique. When secondary distortions are present the average value of the rectified voltage is used to set the peak magnetic polarisation, J, or the peak magnetic flux density, B, since this does not depend on the shape if only one zero crossing occurs between peaks.

Secondary waveform control

Conventional power loss measurements at power transmission frequencies have relied on analogue feedback methods to control the secondary waveform shape [2]. This approach is limited to relatively low frequencies, and sinusoidal waveforms. The principle of a digital feedback approach is that adding an opposing distortion to the voltage input of the amplifier supplying the primary current can compensate secondary voltage distortions. This procedure can be repeated in an iterative fashion until the required form factor or THD (Total Harmonic Distortion) is obtained. The feedback characteristics (damping factors, phase offsets, etc) can be more easily optimized when compared with purely analogue means of waveform control. In this way the limitations of analogue methods, such as self-oscillations and poor performance at very low and high frequencies are overcome.

Non-sinusoidal waveform shape

Due to the saturation behaviour exhibited by magnetic materials, the relationship between magnetic flux density and magnetic field strength is non-linear. As a result of this, the effect of keeping one quantity varying sinusoidally with time will be to distort the other waveform. The level of distortion depends on the magnetic polarisation generated in the material. If this is close to the saturation value the distortion will be large, reducing to practically no distortion when operating in the linear Raleigh region. Shown in Figure 1 is the primary current (magnetic field strength) waveform for a grade of non-oriented electrical steel at a peak magnetic polarisation of 1.7 T. The secondary voltage (J or B) waveform was sinusoidal.

It can be seen from Figure 1 that the feedback control will need to cope with a transfer function that introduces a considerable degree of non-linearity. It is important that the required waveform shapes are obtained in a time that limits the amount of heating of the material. This heating is caused by the energy loss in the core and for grades of soft magnetic composite (SMC) the related parameter specific total loss can be much higher than an equivalent grade of laminated steel. Work on managing this energy loss will be discussed. It would appear that SMC materials would not be the preferred choice due to their higher specific total loss at 50 Hz. However, these materials offer two considerable advantages. Firstly, since the magnetic flux is not limited to 2D planes like for laminates, 3D flux designs are possible. Secondly, although the specific total loss is much higher at 50 Hz, the low electrical conductivity of the material means that at higher frequencies SMCs can have the edge. This low electrical conductivity originates from an insulating organic layer that is on the surface of the particles before consolidation to a solid form occurs.

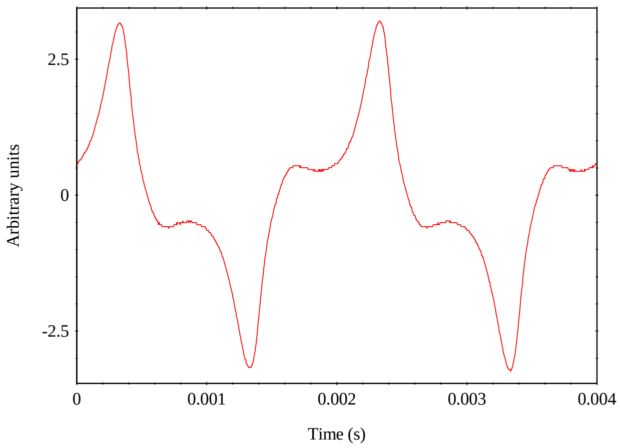

Figure 1. Primary current (magnetic field strength) waveform showing considerable distortions due to the non-linear material behaviour.

In order to better understand the properties of materials measurements under realistic operating conditions are required. Digital feedback is a necessity for producing the required harmonic content in the secondary voltage (J or B) waveform. The same iterative adjustment procedure can be followed, with an arbitrary harmonic content as a target for the secondary waveform.

In this paper results will be presented that show the effect of introducing controlled levels of harmonics into the secondary voltage waveform. A discussion on the differences observed between specific total loss values measured with the peak polarization set using the rms secondary voltage and the average rectified value of the secondary voltage will be given. The influence of the magnetic circuit on the measured properties will be discussed along with the sensitivity of the measurements to the amplifier output impedance.

Operational conditions

As well as the need to measure the properties of soft magnetic materials for non-sinusoidal conditions that has arisen due to advances in power electronics (e.g. PWM control), these materials are being used in hostile environments that require updated and possibly new measurement methods to determine the resulting operational properties. It is essential that these properties are measured since the effective computer modeling of a prototype device depends critically on the input data. Advances in magnetic materials and to a lesser extent modeling techniques have resulted in novel motor topologies that allow applications in previously unavailable situations. This is demonstrated by the considerable worldwide research effort on using electrical machines to replace convention propulsion systems in aircraft and automobiles. Particularly for the case of aircraft, the electrical machines will be operated at elevated temperatures. Knowledge of the temperature coefficient of the quantity of interest is therefore needed. In this paper the temperature coefficient of the specific total loss of soft magnetic materials will be reported. During operation in the presence of permanent magnets and for modeling purposes it may be necessary to know the magnetic properties at magnetic field strengths as high as 25 kA/m. Achieving these field strengths using only a copper winding is not trivial and possible approaches will be presented along with results for the method selected.

Acknowledgement

This work is supported by the Electrical Programme of the National Measurement Science Policy Unit, Department of Trade and Industry, UK. The author would like to thank Dr Dimitrios Georgakopoulos for his assistance with establishing the sampling system used.

References

[1] IEC Standard 60404 Part 2, 1996, Methods of measurement of the magnetic properties of electrical steel and sheet by means of an Epstein Frame.

[2] P. Sankaran and V. J. Kumar, “Use of a Voltage Follower to Ensure Sinsunoidal Flux in a Core” *IEEE Transactions on Magnetics*, Vol. MAG-19, No. 4, 1983.