

Constant dB/dt DC Characterisation Through Digital Control of Magnetic Field

Abstract. Control over the rate of change of flux density when plotting DC BH loops is of paramount importance when characterising magnetic materials which exhibit large values of dB/dt for a linear change of applied field. A new method is described which allows constant dB/dt measurements to be made in a user friendly manner through a small number of iterations of a simple waveform control algorithm. The method was demonstrated on a grain oriented silicon steel and shown to provide accurate results after 3 iterations of the test algorithm.

Streszczenie. Przy badaniu materiałów magnetycznych przy prądzie stałym szybkość zmian indukcji ma kluczowe znaczenie. Przedstawiono nową metodę pozwalającą na pomiar i kontrolę wartości dB/dt. Metodę sprawdzono na przykładzie blach zorientowanych i osiągnięto odpowiednią dokładność już po trzech iteracjach. (Cyfrowa kontrola pola magnetycznego jako metoda utrzymania stałej wartości dB/dt)

Keywords: DC measurements, grain oriented steel, waveform control

Słowa kluczowe: kontrola kształtu indukcji, badanie materiałów magnetycznych.

Introduction

The accurate measurement of the DC magnetic properties of soft and hard ferromagnetic materials is vitally important for the design and quality control of many electromagnetic devices. Accurate DC magnetisation, or demagnetisation, curves are vital for designers of actuators whilst designers of AC devices require DC characterisation for their finite element design packages.

Control over the rate of change of flux density when plotting DC BH loops is of paramount importance when characterising advanced magnetic materials which often exhibit large values of dB/dt for a linear change of applied field. These materials include materials such as grain oriented electrical steel, nickel iron and amorphous materials. This can lead to significant errors in both the loops and measured parameters such as the coercivity.

Measurement System

A system designed for characterising the DC properties of a wide range of magnetic materials has been described previously [1]. A schematic of this system is shown in figure 1.

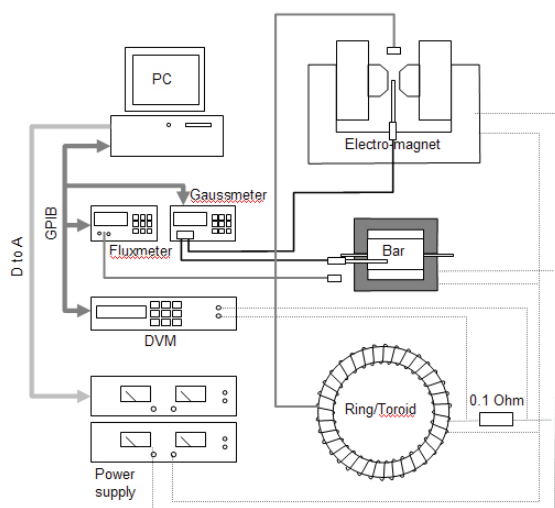


Figure 1: Schematic of measurement system

The fully automatic system was designed for the accurate measurement of the DC magnetic properties of soft and hard ferromagnetic materials utilizing discrete calibrated instruments in order to provide a traceable

calibration route separate from the transfer of standard magnetic test samples. Custom written software is used to operate the system in a number of modes including constant dH/dt, H tracking, and two modes which modulate the rate of change of flux density through complex control of the rate of change of field which was shown to give accurate measurement of coercivity.

All modes use cycle times of between 60 and 300 seconds and may utilize a variety of test configurations including a bar permeameter, electromagnet, ring samples or Epstein frame.

For ultimate accuracy the modulated dB/dt modes should be used but these require a range of preliminary measurements to understand the material characteristics and can only be performed by users with expert knowledge.

Description of new test algorithm

In order to make this process more user friendly a digital waveform control technique was developed. The technique builds on the H tracking mode which magnetises the material following a pre-defined time domain H waveform. A flow chart of the algorithm is shown in figure 2.

The algorithm begins with the demagnetisation cycle. This follows the regime outlined by Jiles et al [2]. An alternating field of a user defined frequency (usually 1 Hz) is set at a peak field sufficient to saturate the material. This then decays by 10% every 1.5 cycles until the peak field reaches a pre-defined value after which it decays at 1% of the predefined value until the field reaches zero.

Next the H waveform generated by the previous iteration is used to plot the BH loop. For the first iteration this is a sawtooth H waveform.

It is then necessary to isolate only the descending half of the BH loop beginning at positive H_{pk} and ending at negative H_{pk}. This is then shifted along the H axis so that zero magnetic field strength corresponds with zero magnetic flux density.

The characteristic generated in the previous stage is then fitted to a simple 30th order polynomial of the form given in equation 1.

$$(1) \quad H(B) = a_1 B + a_2 B^2 + a_3 B^3 + \dots + a_{30} B^{30}$$

This is performed using a least squares linear fit utilising the Householder algorithm.

Next, a phase shift must be introduced between B and H to allow the formation of hysteretic curve. The phase shift is duplicated from the phase shift measured on the previous

iteration. The coercivity error is then minimised through the modification of the phase angle with simple proportional control until it is within predefined limits.

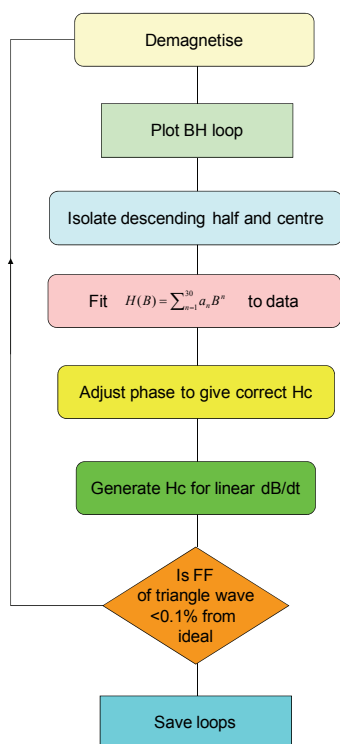


Figure 2: Flow chart of constant dB/dt measurement algorithm

The function generated may now be used to generate the H waveform for a sawtooth B waveform (constant dB/dt) by feeding it back to the beginning of the process (a demagnetisation stage precedes this).

This process continues until the measured B waveform describes a sawtooth wave within pre-defined limits. These limits are usually 0.1% of the ideal form factor and THD of a perfect sawtooth wave.

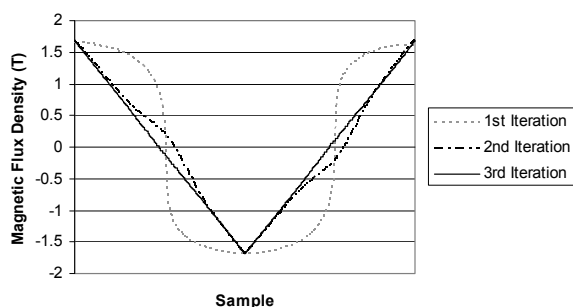


Figure 3: B waveforms for 3 iterations of the control algorithm

Results

Figure 3 shows three iterations measured from a conventional grain oriented silicon steel, 0.30 mm thick. This was measured as 24 strips within a 700 turn Epstein frame. The test parameters are shown in table 1.

Table 1: Test parameters

Test Parameter	Value
Loop time	120 s
Demag time	60 s
Demag frequency	1 Hz
Peak field	2 kA/m
Peak demag field	10 kA/m

It is clear from the plots in figure 3 that after three iterations the B waveform describes a sawtooth wave. This is confirmed by the form factor errors shown in table 2 with the third iteration having an error of less than 0.1%.

Table 2: Form factor errors

Iteration	Form factor error
1	15.1%
2	0.96%
3	0.05%

BH loops for the 3 iterations are not shown here since the loop shapes are barely discernible, however it is clear from table 3 that the coercivity measured from the loop by linear interpolation about the H axis – average of the descending and ascending halves of the loop – is significantly changed.

Table 3: Measured coercivity for the 3 iterations

Iteration	Coercivity (A/m)
1	10.2
2	6.8
3	6.7

The significant difference in measured coercivity between iteration 1 and iteration 2 is due to the large dB/dt exhibited in the iteration 1 waveform.

Conclusions

A new method was described which allows constant dB/dt measurements to be made in a user friendly manner through a small number of iterations of a simple waveform control algorithm based on H waveform prediction from a curve fitting approach.

The method was demonstrated on a grain oriented silicon steel and shown to provide accurate results after 3 iterations of the test algorithm.

REFERENCES

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Author: Dr Philip Anderson, Wolfson Centre for Magnetism, School of Engineering, Cardiff University, Newport Road, Cardiff, UK CF24 3AA, E-mail: andersonpi1@cf.ac.uk