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Laminated iron core losses evaluation and measurements

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Abstract

The paper presents a methodology for determination of harmonic iron losses in laminated iron cores under sinusoidal and non-sinusoidal excitation. The measurements are performed by using a convenient Epstein device supplied by a signal amplifier and are registered in a PC by using an appropriate data acquisition system. Eddy currents in iron laminations are modeled by finite element techniques while leakage field, respective inductances and losses are compared to measured ones.

Keywords: Iron losses; Epstein device; Harmonics

1. Introduction

The purpose of specific total loss measurements is to classify electrical steels and to assist electric machine design. Under standard measurement conditions, specific total loss is measured only at sinusoidal magnetic induction. However the actual magnetic induction waveform of an electric machine is usually non-sinusoidal and the specific power loss values are not directly applicable because of the included harmonic components which can cause a large additional increment of the specific total loss [1–8].

The Epstein device is used for measurement of iron losses in laminated iron cores under sinusoidal and non-sinusoidal excitation that are used in magnetic circuits of electrical machines and transformers.

2. Measurement system description

The main components of the device (Epstein type) are four pairs of coils ensuring excitation of iron laminations stack of the magnetic material to be measured. The four pairs of coils are connected in series, creating a primary and a secondary winding. The leakage between these two windings is very small. The specimens are placed similarly in the internal space of the coils in cross wise order creating an elementary one-pole transformer. Magnetic flux in the air produces part of output voltage corrected by M winding (see Fig. 1). The magnetizing waveforms are generated by a Waveform Generator, which can generate a wide variety of waveforms with high accuracy.

This arbitrary waveform generator enables the design of any repetitive function on a personal computer (PC), either mathematically or graphically. The waveforms created in this way are downloaded via an interface and stored in a file with a controlled number of samples. In addition a number of standard voltage waveforms are available including sine, square, triangle, ramp and pulse. The arrangement used to obtain measurements in order to be acquired by a convenient card, includes a current transducer (LA-25NP) and a voltage transducer (LV-25P). The audio power amplifier, which was used with the system, can be operated in stereo or bridged (mono) mode.

When a sinusoidal flux density is developed in the specimen in order to obtain measurements – which may be conveniently reproduced – the source voltage is adjusted so that the average rectified value of the secondary voltage U_2 is given by

$$\bar{U}_2 = 4fN_2S\bar{B} \quad (1)$$

where f is the frequency (Hz), N_2 the number of turns of the secondary winding, S the cross-section area of the test specimen (m^2), and B is the peak value of the magnetic flux density (T). Even if the ac flux density does not vary sinusoidally with time, it can be demonstrated that the peak flux density B can be calculated from Eq. (1), provided that no even harmonics are present. A schematic diagram of the system is shown in Fig. 2.

In order to guarantee a well-matched load, the test frame and windings are carefully chosen to ensure that waveform distortion due to mismatched loads is kept to a minimum. Control over the secondary voltage magnitude and wave shape is achieved by

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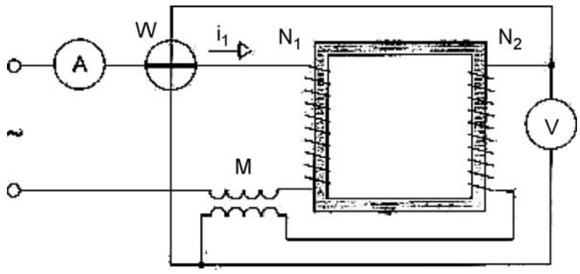

Fig. 1. Measurement set-up for ferromagnetic sheet losses (Epstein device).

using a standard analogue proportional feedback circuit, shown in Fig. 3.

The electronic arrangement of analog feedback is used for improvement of sine waveform in order to comply with the standard IEC-404-2. The arrangement inputs are the signal of the waveform generator and the output signal of the Epstein device, which are compared and the power amplifier ensures a sine waveform signal. Appropriate potentiometers are used in order to perform coarse and fine adjustments as well as the feedback control. Fig. 3 shows the preamplifier and analogue proportional feedback circuit adopted.

Sixteen strips have been used in the Epstein device and all measurements have been performed under sinusoidal voltage variation. Measurements have been processed for three different frequencies (50, 500 and 1000 Hz). The sinusoidal voltage was supplied by an appropriate card, supplying the amplifier.

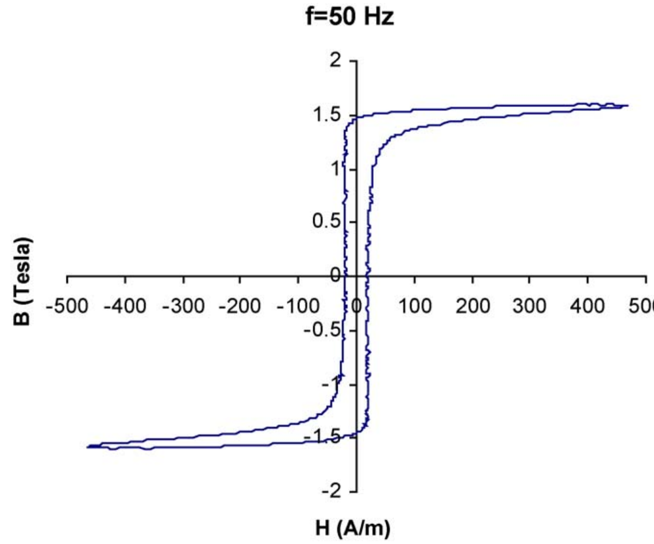

Fig. 4. Measured hysteresis loop at the frequency of 50 Hz.

The measured B–H curve at 50 Hz is shown in Fig. 4. The sampling frequency adopted was 25.000 Hz.

The B–H loop measured at a frequency of 500 Hz is shown in Fig. 5. It may be noticed that as the frequency increases the loop angles are rounded.

Fig. 6 shows the measured loop at the frequency of 1 kHz. The hysteresis loop is almost circular in this case.

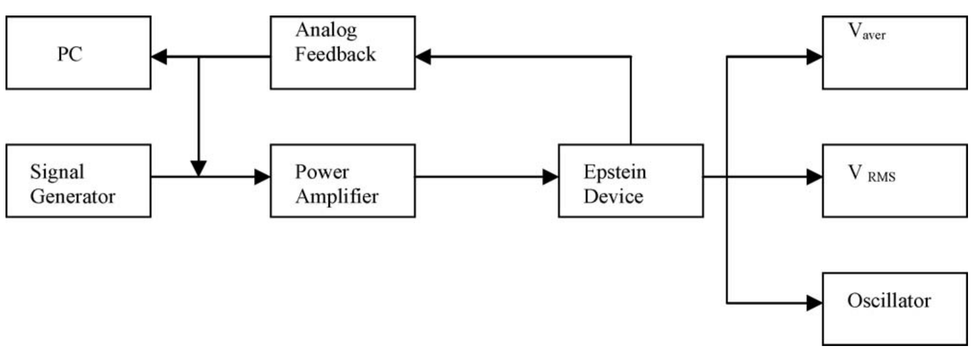

Fig. 2. Block diagram of the Epstein device with the supply and measurements.

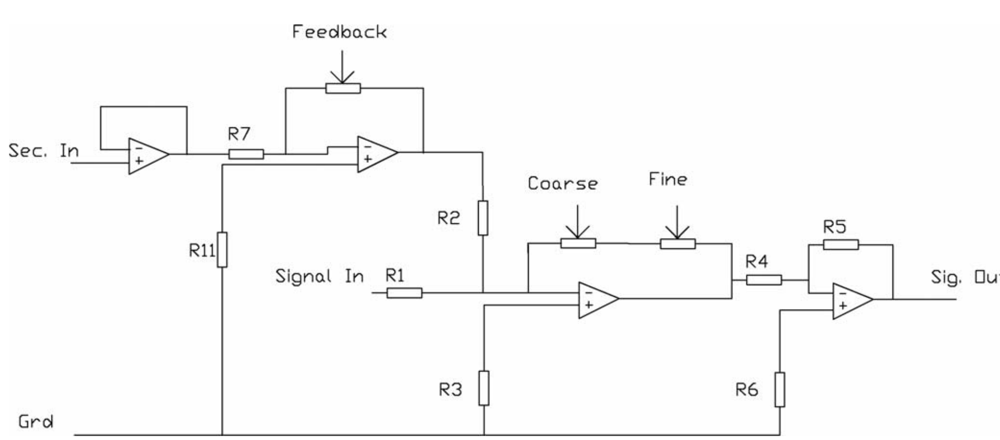

Fig. 3. Analog feedback circuit implemented.