Journal of Magnetism and Magnetic Materials 355 (2014) 282–288

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

A method of local magnetic loss determination in punched ferromagnetic strips

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ARTICLE INFO

Article history:
Received 1 July 2013
Received in revised form
30 September 2013
Available online 24 December 2013

Keywords:
Punching process
Magnetic loss
Ferromagnetic material

ABSTRACT

The paper deals with results of measurement and numerical modelling of temperature increases at ferromagnetic strip heated by induced currents. The temperature rises are analysed both for transient and steady state. The ferromagnetic material used was subjected to mechanical punching. In the paper it is shown that magnetic losses at ferromagnetic material along the punched edge are several times larger than those in “green” material.

1. Introduction

Scientific research studies concerning changes in magnetic material properties resulting from mechanical or laser cutting have been conducted for many years. Both laser cutting and mechanical punching causes internal stresses in material structure, which are then one of the reasons for changes in the material′s magnetic properties. In the case of mechanical punching deformation occurs in addition to the stresses, which also results in a major change of the material′s magnetic properties. It is possible to indicate two main methods of testing local material properties that are effective in this case. The first of these methods, called the needle-probe method, allows to measure local material properties by registration of the voltage measured on the probe surface [1]. In this way the magnetic flux measurement is executed (over the cross section limited by the measuring needles). The second method involves measuring the material′s microhardness [2]. It is known that internal stresses cause hardening of the material. In both cases the measurements must be carried out repeatedly because we always measure the local material parameters that are subject to a certain distribution. Examples of research using these methods can be found in the available literature. In addition to the two main methods as indicated above, for many years a method using coils placed in holes drilled near the cut edge has been used [3]. We should also mention a new solution, which was described a few years ago, which uses a magnetovision camera to measure the local properties of the magnetic material [4]. Specifically, the paper presents the results of research work which are probably the first described attempts at designating local material properties estimated by an IR camera. Recording the results of measurement of the local transient temperature is necessary in order to implement a mathematical model describing the dynamic process of heating of a ferromagnetic strip subjected to punching. The one-dimensional segmented numerical model used presents a portion of the ferromagnetic strip. This model enables authors to determination of distribution of power loss density vs. distance from the cut edge, which allows them to justify the non-uniform temperature distribution on the surface of the sample. The results of the calculations obtained from this model have been compared with the measurement results.

2. Measurement setup and measurement results

For testing we used the sample in a rectangular shape with dimensions of $300 \times 30 \times 0.35$ mm, made of anisotropic materials M165-35S. The sample was cut out from a larger sheet sized $300 \times 60 \times 0.35$ mm which had been subjected to heat treatment in order to restore the material properties. In this way, just near one cut edge the material properties were quite different (worse) with respect to “green” material properties. Sheet selection was made after reviewing the results of investigation of the sample material subjected to mechanical cutting. On the basis of the available literature it was concluded that plastic deformations occurring near the cut edge (the test results indicate that it is a distance comparable to the thickness of the sheet metal) leads among other to an increase of the dislocation density in mentioned zone. This is the cause of change of material electrical resistivity as well as hysteresis losses

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http://dx.doi.org/10.1016/j.jmmm.2013.12.035

(dislocations in the material due to plastic strain increase the energy required for Bloch wall motion) [5]. In addition, mechanical cutting causes grain fracture, which also contributes to an increase of hysteresis losses. According to knowledge presented in available literature, at the area near the punched edge, hysteresis losses are the main reason for the magnetic loss increase. The phenomenon is very complicated because there may be both an increase and decrease in losses depending on the direction of internal stress (compressive or tensile) with respect to direction of magnetization. So, the authors selected material in which the hysteresis losses constitute a major portion of the total losses. Measurements were performed using a magnetic circuit like the one that is used in the Single Sheet Testers—a magnetic U-shaped core with a large core cross section in relation to the strip's cross section, along with a single strip forming a magnetic circuit. Fig. 1a and b presents the components of the Single Sheet Tester and details of measuring system. The exciting coils were wound on the U-shaped magnetic core, whereas the measurement coil was wound on the single strip (this coil registered the induced voltage). The U-shaped core was made of ferrite, thus ensuring the smallest air gap between it and the strip sample as well as relatively small core losses in relation to losses in the strip sample. Such an arrangement is a compromise in relation to the classical SST, in which there are two U-shaped cores with exciting and measuring coils wound on the investigated strip. By selecting a magnetic circuit as described above we followed the results of research and guidelines described in the literature [6,7]. During the investigation, due to the need to apply an IR camera and due to predicted increases in the strip's temperature, it was not possible to wind the exciting coil directly on the strip because of the incomparable increase in temperature of the strip's ferromagnetic material and coil. The exciting circuit was supplied by a feeder with an adjustable frequency and voltage, thus keeping the sine-induced voltage (the feeder had a feedback loop). The supply voltage for which recorded waveforms are shown had a frequency of 120 Hz. The frequency used was a kind of compromise between the obtained temperature increases and acceptable hysteresis and the eddy current loss ratio occurring in the investigated ferromagnetic strip. The greater the frequency of the supply voltage, the greater the temperature increases and, at the same time, eddy current loss began to play a dominant role in both temperature distribution during the steady and transient state. In addition, the enforced magnetic flux had such a value as to reach an average flux density over 1.7 T. Then, due to saturation of the non-destructed part ("green" part) of the material, the magnetic flux was pushed into the area near the punched edge too, thus generating greater total iron loss than that in the material without cut edge (with the same total dimension). As a result of the study, the temperature increases were registered in several points on the surface of the ferromagnetic strip. The points were placed at different distances from the cut edge and along the section perpendicular to the cut edge. Detailed distances were as follows: $P_1 = 1.5$ mm, $P_2 = 5.7$ mm, $P_3 = 14.3$ mm and $P_4 = 29.3$ mm. So, the measurement points are not evenly distributed along X axis. During the measurements an IR camera with a sensitivity of 15 mK was used. Some measured sample pictures with marked P_1–P_4 points are presented in Fig. 2. The measurement was executed at an ambient temperature $T_a = 21$ °C by placing the test strip horizontally

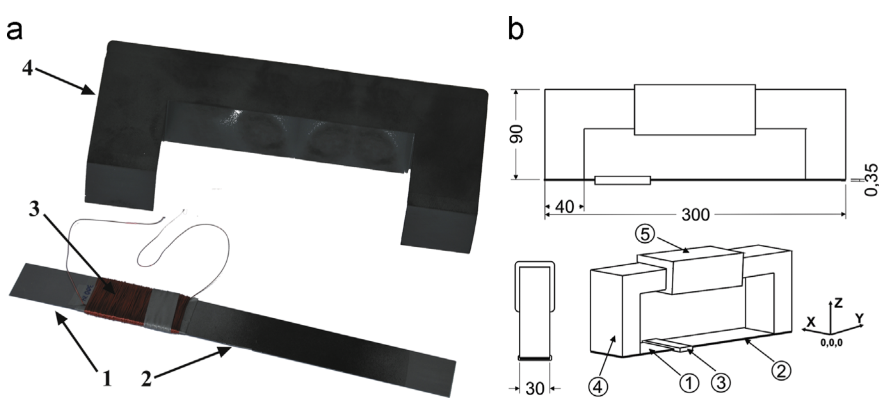

Fig. 1. The measurement setup. (a) The components of the SST, (b) details of the measurement system, 1—single ferromagnetic strip, 2—cut edge, 3—measurement coil, 4—U-shaped ferrite core without exciting coil, 5—exciting coil.

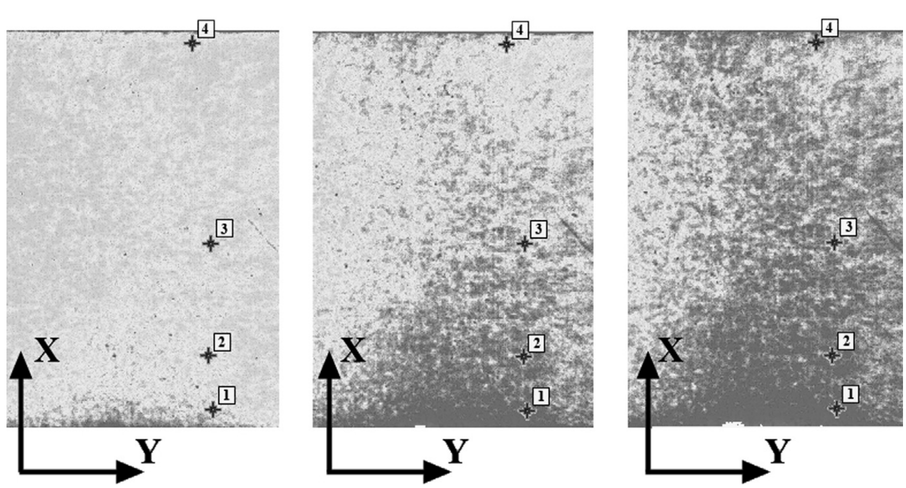

Fig. 2. The measured thermographic pictures representing the three selected film frames. The measuring points are marked.