THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI.
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N^0. 4 – 2012, ISSN 1453 – 083X

METHOD OF DETERMINING THE MAIN FEATURES OF MAGNETIC FERROMAGNETIC MATERIALS

Livia GHEORGHIEŞ, Ovidiu DIMA
"Dunarea de Jos" University,
email: lgheorg@ugal.ro

ABSTRACT

The purpose of this paper is to present a method for determining the main magnetic features such as magnetic induction B, magnetization M, the coercive magnetic field Hc, permeability μ, using hysteresis cycle chart.

The method can be used for:

-determining the amounts of phase with the existing magnetic properties of ferrous alloys,

-determination of delta ferrite in austenitic steels and the weld seam weld bonding of these steels,

-pointing to the deformation of martensitic transformation in cold austenitic stainless steels and proper calibration, intensity estimation of martensitic transformation and the amount of martensite in the structure.

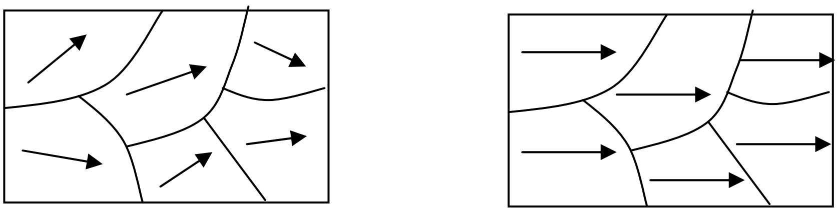
KEYWORDS: magnetic properties, hysteresis cycle, the martensitic transformation

1. Introduction

Knowing the characteristics of magnetic materials is important for achieving their selection and use of equipment and technology in the industry [1].

The purpose of this paper is to present a method for determining the main magnetic features such as magnetic induction B, magnetization M, the coercive magnetic field Hc, permeability μ, the hysteresis cycle obtained using the chart on the screen of an oscilloscope.

A ferromagnetic sample can be considered as consisting of fields of magnetization with magnetic moments oriented randomly, so the total magnetic moment is zero proof figure 1a [3], [4]. If the evidence of such an external magnetic field is applied, the fields tend to be guided by the direction field, which produces a total magnetic moment nonzero figure 1b.



a) H=0, M=0   b) $\vec{H}\neq 0$, $\vec{M}\neq 0$

Fig. 1. *View on orientation magnetic domains*

Magnetic moment of unit volume is called magnetization $\vec{M} = \frac{d\vec{m}}{dV}$, and is measured as the magnetic field H in A/m. Between magnetic induction B, magnetic field H and magnetization M is the following relationship:

$$\vec{B} = \mu_0\left(\vec{H} + \vec{M}\right) = \mu\vec{H}.$$

Dependence of B and H of M is a linear function of ferromagnetic materials that, with increasing field, tending to increase the

THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI.
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N0. 4 – 2012, ISSN 1453 – 083X

magnetization saturation value Ms, OC curve, figure 2 [2].

Decreasing to zero field is found that magnetization decreases only up to the Mr, called remanent magnetization and to cancel the magnetization, demagnetize the sample, should apply a magnetic field of opposite sign first -Hc value. The field is called the coercive field Hc. Growing up in this new field so again reach saturation value -Ms, the magnetizaţiei the point on the curve D and the decrease is obtained, -Mr, with the new sense of the field. Purpose of reversing the field again and raised her son to obtain the saerple demagnetization +Hc saturation value and then to +Hmax. Magnetizaţiei variation curve corresponds to a change in the field from +Hmax. to -Hmax. and again to +Hmax. cycle is called hysteresis, figure 2. Using a magnetic field produced by an AC frequency of 50Hz, the sample will be magnetized and demagnetized with this frequency. If by any means whatsoever is applied to X plates of an oscilloscope with a voltage proportional to the magnetic field applied e_x sample and the Y plates of the oscilloscope e_y apply a voltage proportional to the magnetization, then the oscilloscope screen will appear that the sample characteristic hysteresis cycle.

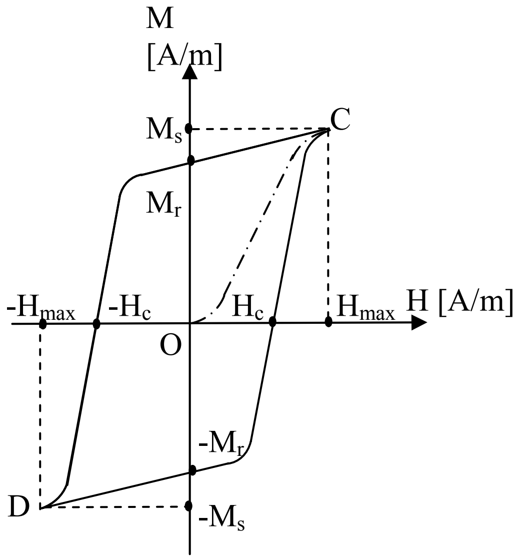


Fig. 2. *Shape of hysteresis cycle*

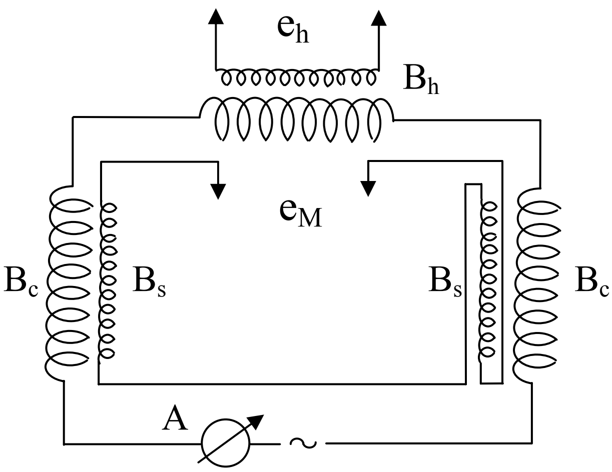


Fig. 3. *Electrical schema of experimental measurements*

2. Layout

Schematic diagram of the facility is shown in figure 3. Supply circuit is made from an AT to have an adjustable voltage. Bc identical coils are solenoids that produce their center on their axis of symmetry, a known magnetic field intensity H.

(H = 1.2 x104 / m, for a current of 1A through their turns). The two coils are connected in opposition probe Bs and Bc are placed inside the solenoids in their center, each having 5200 turns each. Coreless transformer is Bh, the mayor crossed the stream causing the solenoids magnetic field Bc. Thus to obtain a transformer secondary voltage:

$$e_H = -\frac{d\Phi}{dt} = -\mu_0 S\frac{dH}{dt} \quad , \quad \Phi = B.S = \mu_0 H.S$$

where: μ_0 is the magnetic permeability of vacuum, S is the average size of the transformer secondary turns Bh and H is the magnetic field created by electricity transformer primary of the circuit.

This voltage is directly proportional to e_H with current and hence the circuit is proportional to the magnetic field Bc:

$$e_H = C_1\frac{dH}{dt} \quad , \quad C_1 = -\mu_0 S \quad .$$

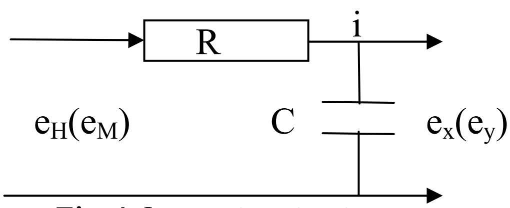


Fig. 4. *Integration circuit*

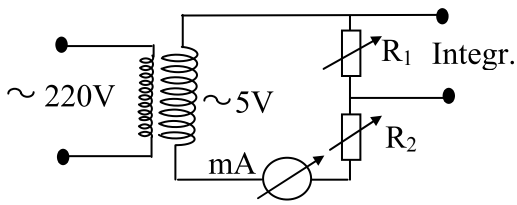


Fig. 5. *Electrical transformer and integrated circuit*

To have the X terminals of the oscilloscope voltage proportional to field strength magnetic e_x, will have to be integrated voltage e_H. Voltage integrated circuit for e_H is composed of an electrical resistor with resistance R and a capacitor with capacitance C, figure 4. Figure 5 is shown coupling an integrated circuit in a transformer.

Choose R so R>> Xc, where Xc = 1/ω.C is capacitive reactance of the capacitor . In these circumstances, the electric current in the circuit can be approximated by i = e_H / R. How voltage across the capacitor is collected e_x = Q / C where Q is the way electric charge accumulated on any plates of the capacitor is related to the intensity of electric current in the circuit through the relation $Q = \int idt$.

Follows:

$$e_x = \frac{Q}{C} = \frac{\int idt}{C} = \frac{\int \frac{e_H}{R} dt}{C} = \frac{1}{R.C}\int e_H dt$$

$$e_x = \frac{1}{R.C}\int C_1 \frac{dH}{dt} dt = K_1.H \text{, where : } K_1 = \frac{C_1}{R.C}$$

Since R>> Xc, electric voltage e_x (that is integrating well e_H), is much lower than the voltage e_H, choose R / Xc = 100-1000, and sometimes provides an amplification of the tensions at the entrance to the oscilloscope.

X terminals connected to the oscilloscope, e_x voltage will cause a horizontal line with length proportional to the amount of magnetic field intensity H. In the absence of a ferromagnetic sample probe within any of the coils, the voltage across pick Y is zero. The two voltages obtained from the two probe coils are equal in magnitude and opposite in phase, the probe coils are identical but connected in opposition. The two coils are crossed by flows Bs magnetic $\Phi_1 = \mu_0$.NHS, $\Phi_2=\mu_0$.NHS respectively, where N is the number of turns and S turns average surface coil probe. $B_0=\mu_0H$. Since these flows can be written as: Φ_1=NSB_0 Φ_2 = NSB_0 respectively. Total flow becomes $\Phi_t = \Phi_1 - \Phi_2 = 0$.

When the coils in a probe, eg a coil probe, place a ferromagnetic sample with relative magnetic permeability μ_r and section and flows through is **s** the two coil magnetic probe are: Φ_1'=N.B_0 (S-s) + NBS, respectively Φ_2'= NSB_0, B= μ.H = μ_0.μr.H. Given the link between magnetic field intensity H, the sample relative magnetic permeability μ_r its magnetization is M = H (μ_r-1).

Total magnetic flux becomes: $\Phi'_t = \Phi_1' - \Phi_2$ Φ'_t = N.B_0 (S-s) + NBS-NSB_0 = Ns (B-B_0), or:

Φ't = NsH μ_0 (μr-1) = Ns μ_0. M.

Because the magnetic field varies in time, be produced by an alternating current, and that the sample magnetization M varies over time and consequently in the total magnetic flux Φ'_t. The two coil circuit a voltage probe appears induced e_M.

$$e_M = -\frac{d\Phi_t^1}{dt} = -N.s.\mu_0\frac{dM}{dt} = C_2\frac{dM}{dt} \quad .$$

$$where \;:\; C_2 = N.s.\mu_0 \quad .$$

Integrating and this voltage can be applied to Y plates of an oscilloscope e_Y voltage directly proportional to the sample magnetization M. e_Y=K_2.M, where K_2 is a constant. Applied e_Y voltage oscilloscope entry Y, will cause a vertical line on the screen, whose length is proportional to the magnetization M. The composition of the two voltages e_X and e_Y is obtained on the oscilloscope of the sample studied hysteresis cycle M = f (H) .

2.1. Calibration facility

Calibration facility can be done using a sample whose magnetic characteristics were determined following previously on other plants or process described below.

a) Calibration of horizontal. Since the coercive field of the sample is measured horizontally, the magnetization is zero, it must be known accurately represent the magnetic field in units of a division on the oscilloscope. If the screen has 50 divisions, knowing the value of the field of reading an ammeter electric current intensity, determine the division.

The hysteresis cycle of the test chart is read corresponds to the number of divisions that Hc, multiplying it with the value in A / m, of a division in determining the value of Hc in A / m

b) vertical calibration. This can be done using an adjustable AC and u_C = Um.sin(ω.t) known type which can be regarded as being generated by a time-varying magnetic flux form:

$$\Phi_C = -\int u_C dt = -\int U_m.\sin(\varpi.t)dt$$

$$\Phi_C = \frac{U_m}{\varpi}.\cos(\varpi.t) = \Phi_{Cm}.\cos(\varpi.t)$$

where: Φ_{Cm} maximum flow calibration.

If the maximum length Φ_{Cm} corresponds lm=50mm, then the flow corresponds to a certain length Φ_Y, l_Y spot oscilloscope vertical deviation.

But Φ_Y=Φ_t=μ_0N.s.M=$\Phi_{C.m}l_Y/l_m$., Follows:

$$M = \frac{\Phi_{C.m}}{\mu_0.N.s}.\frac{l_Y}{l_m} = \frac{U_m}{\varpi.\mu_0.N.s}.\frac{l_Y}{l_m}$$

Maximum voltage is related to the actual value

$$U_m = \sqrt{2}.U_{ef}\text{ , } M = \frac{\sqrt{2}.U_{ef}}{\varpi.\mu_0.N.s}.\frac{l_Y}{l_m}.$$

For our installation we: U_{ef}=16V, ω=314 s^{-1} for ν=50Hz, μ_0=4π 10^{-7}H/m, N=5200 turns, l_m=50mm.

We can write M=$K_2.l_y/l_m$, where

$$K_2 = \frac{\sqrt{2}.U_{ef}}{\varpi.\mu_0.N.s}.\frac{l_Y}{l_m} = 0{,}22\ A.m\ /\ mm$$

Measuring l_Y in millimeters vertically Mr. and Ms, and knowing. section sample **s** can be determined and the residual saturation magnetization of the sample studied. Knob vertical amplifier must remain in the same position during the measurement and calibration. The equipment allows the determination of the coercive field H_C magnetizaţiei residual saturation of the M_r and M_S with an error of about 8% satisfaction measurements for samples with the same series and cross section of the same material. You can also determine the maximum magnetic permeability $\mu_{max} = B / H = \mu_0\ \Delta M/\Delta H$,

M> H in the coercive field because at this value of the displacement field occurs irreversibly block wall that delimits the areas of evidence leading to a marked rise in ferromagnetic magnetizaţiei it. Energy losses in the magnetization are proportional to the area enclosed by the hysteresis cycle.

Thus the density of energy loss will be:

$$w = \mu_0 \oint \vec{M}\ .d\ \vec{H}$$

Energy losses per unit volume, a hysteresis cycle is calculated as the product of magnetic permeability of vacuum μ_0 and area of hysteresis cycle M= f (H) expressed in units of physical quantities M and H.

3. Working mode

Carry istalation in figure 3. It connects to an adjustable voltage source, an autotransformer. Adjust autotransformer with a suitable amount of electric current through the coils B_C, 1A or 2A is recommended. Connect the voltage output from integrated circuit boards deviation X, Y of the oscilloscope respectively.

Hysteresis cycle falls on the oscilloscope for parts handling it centered vertically and buttons that amplifications potentiometers on the oscilloscope's horizontal. Plot to scale on graph paper on screen hysteresis cycle. Read the Graphic Divisions for X_C, Xmax, Yr, Y_S appropriate physical quantities H_C, Hmax, M_r, and M_S respectively.

Hysteresis cycle area is evaluated by counting the squares of graph paper. Hmax is determined by applying three simple rule worth knowing that a 1A current intensity magnetic field strength value is $1.2x10^4$ A/m.

H_C is determined by applying three simple rule given that the corresponding graph is linear horizontal scale:

H_{max}…………X_{max}(mm)
H_C… ………X_C(mm) $\quad H_C=H_{max}.X_C/X_{max}$

The sectional area of the sample **s** were calculated in m^2. Magnetizations remanent and saturation is calculated with:$M_{r(S)}=K_2Y_{r(S)}$ /s where: K_2=0,22 A.m/mm.

Magnetization M_0, mm corresponding to a vertical axis of the graph is determined using the formula: $M_0 = K_2./s$.

H_0 of the magnetic field intensity corresponding to mm on the horizontal axis of the graph is finished by applying three simple rule:

H_{max}………………X_{max}(mm)
H_0…………………1(mm) $\quad H_0=H_{max}./X_{max}$

Calculate: $s_0=H_0.M_0$ (în A^2/m^2) for 1mm^2 cycle area and then the hysteresis cycle area: $A_{ciclu}=p.s_0$ where p- number mm^2 in the cycle graph area.

The density of energy losses in the magnetization arising from the relationship: $w=\mu_0.A_{ciclu}$ and is expressed as: w/m^2.

Plot the tangent to the graph figure 6, in the vicinity of the coercive field, $-H_C$ and calculate its slope tg $\alpha=\Delta M/\Delta H$, so:

$\Delta M=M_0$ x number of squares in which the vertical tangent.

$\Delta H=H_0$ x number of squares in which the horizontal tangent

Maximum magnetic permeability of the sample is determined by the relationship:

$\mu_{max}=\mu_0.\ \Delta M/\Delta H$ (H/m).

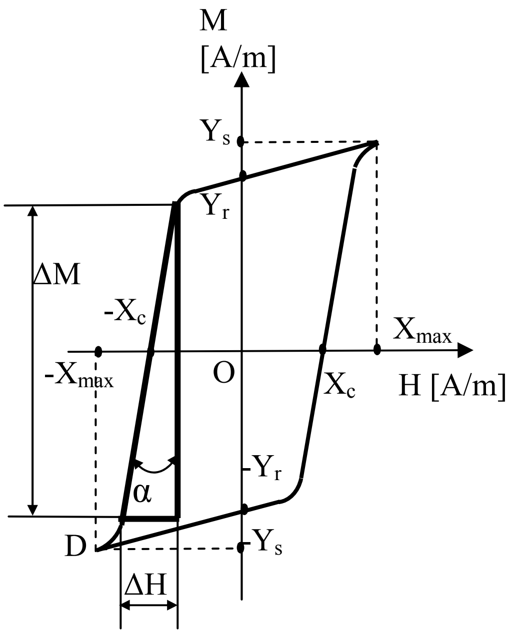


Fig. 6. *Hysteresis cycle and determination of magnetic permeability*

4. Conclusions

The method can be used for:

-determining the quantities of phase with the existing magnetic properties of ferrous alloys,

-determining the amount of delta ferrite in austenitic steels and the weld seam weld bonding of these steels,

-martensitic transformation highlighting the cold deformation austenitic stainless steels and proper calibration, intensity estimation of martensitic transformation and the amount of martensite in the structure.

References

[1]. N. Tiagu, C. Gheorghies - *Fizica corpului solid. Aplicatii practice,* Ed. Ars Docendi, Bucuresti, (2003).

[2]. S. Condurache-Bota - *Carte de lucrari practice de Fizica generala,* Ed. CERMI, Iasi, (2011).

[3]. O. Dima - *Cercetari privind comportarea la coroziune a unor oteluri inoxidabile si a imbinarilor lor sudate in medii industriale agresive.* Universitatea Dunarea de Jos Galati, (2007).

[4]. O. Dima O. Mitoşeriu C. Gheorghieş - *Influenţa deformării plastice la rece asupra proprietăţilor magnetice şi de rezistenţă la coroziune şi abraziune a unor oţeluri inoxidabile austenitice.*. Conferinţa ştiinţifică UGALMAT 2005, Tehnologii şi materiale avansate, Universitatea Dunărea de Jos Galaţi.