

Measurement of the hysteresis loop (HYS)

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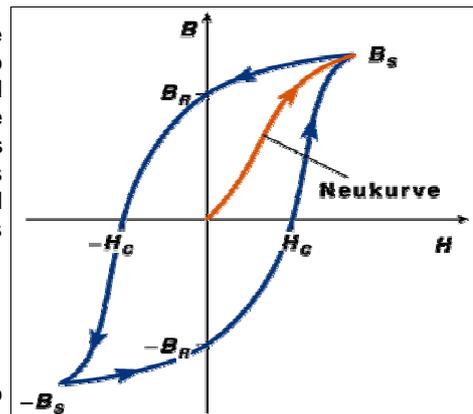
1 Basics

The characteristics of magnetism are usually only known from bar magnets or other similar permanent magnets. Differences between magnets or dia-, para- or ferromagnetism can hardly be determined without electronic equipment. When plotting the hysteresis graph, one can clearly see differences between „hard“ or „soft“ magnetic substances. The form of the hysteresis graph can be explained with the model of the „weißchen Bezirke“.

2 Implementation

Through a coil (called primary) flows a current which can be adjusted. This coil creates a magnetic field which intersperses the test material. Because of the length of the coil, the field inbetween the coil can be assumed as homogenous. The magnetisation of the core influences the magnetic field through it. Inside the primary coil, there is a secondary coil which is suited completely in the homogenous part of the primary field. Through a change of the magnetic flux, „voltage kicks“ are induced in this secondary coil. These „voltage kicks“ are transformed into a proportional voltage with the help of the integrator.

The primary magnetic field strength is proportional to the current flowing through the coil which again is proportional to the voltage drop over a resistor. The voltage drop is recorded on the x-axis of the plotter. The y-axis of the plotter is the output voltage of the integrator. The characteristic hysteresis graph and the „Neukurve“ can be seen when the current is driven from 0A to the maximum current (saturation current) and back to 0A where the polarisation is inverted and the previous step is repeated.



2.1 Calibration of the integrator

To determine the constant of proportion, the integrator has to be calibrated. Therefore, we connect the x-coordinate of the plotter directly with the power source. The integrator is supplied with 1/1000 of this voltage for a certain time, in our case for exactly 60 seconds. Because the output voltage U_a of the integrator is proportional to the „voltage kick“ which is supplied on the input of the integrator, the constant of proportion can be calculated:

$$U_a = K \cdot \int_0^t U_i dt$$

With our measured values (see appendix „1“) we get:

$$U_i = 0,015 \text{ V}$$

$$U_{a(+)} = 12,9 \text{ V}; U_{a(-)} = 12,3 \text{ V}; \Rightarrow U_a = 12,6 \text{ V}$$

$U_{a(+)}$ is the output value for positive polarity of the integrator and $U_{a(-)}$ for negative polarity.

$$K = \frac{U_a}{U_i \cdot t} = \frac{12,6 \text{ V}}{0,015 \text{ V} \cdot 60 \text{ s}} = 14 \text{ s}^{-1}$$

Errors we get from the calibration of the integrator (poor integrator, inaccuracy in time measurement or errors reading the instruments) spread in the following calculations and create further inaccuracies.

2.2 Measurement: „Neukurve“ of the hysteresis loop (materials: iron core and ferrit core)

First of all, we determined the optimum scaling settings of the plotter. Then we demagnetized the iron core

with an alternating current and a declining amplitude. After that, we recorded the „Neukurve“ and the hysteresis loop. This is done likewise for the iron and the ferrit. The graph numbered „2“ shows our recording for iron and graph „3“ for ferrit.

Graph „4“ is an expansion of the relevant area of graph „3“. The magnetisation of the core was not influenced, because we used the same currents on it as in „3“, we just lifted the plotter-pen where it reached the limit.

2.3 Determination of the inductivity B, the saturation field strength H_s , the remanence B_R and the coercitive field strength H_c out of the measurement protocol

primary winding: $N_1 = 100$, $l_1 = 34\text{mm}$, $a_1 = 34\text{mm}$
 secondary winding: $N_2 = 2000$, $l_2 = 10\text{mm}$, $a_2 = 26\text{mm}$
 coil opening: $a_0 = 20\text{mm}$
 diameter of the iron core: $18,5\text{mm} \times 19\text{mm}$
 diameter of the ferrit core: $14\text{mm} \times 14\text{mm}$
 diameter of the AlNiCo probe: $18\text{mm} \times 10\text{mm}$
 $I_{\max} = 2\text{A}$ (value given by ampèremeter of the power source)

Saturation field strength H_s

$$H = \frac{N_1 I}{l_1} \frac{1}{\sqrt{1 + \left(\frac{(1 + \sqrt{2}) \cdot a_1}{2 \cdot l}\right)^2}} = \frac{100 \cdot 2\text{A}}{0,034 \text{ m}} \frac{1}{\sqrt{1 + \left(\frac{(1 + \sqrt{2})}{2}\right)^2}} = 3,8 \cdot 10^3 \frac{\text{A}}{\text{m}}$$

(formula to calculate the field inside a short coil with quadratic cross-section, edge length a)

Inductivity B_s at saturation field strength H_s with $B(t=0) = 0$

$$B(t) = \frac{1}{N_2 \cdot F_m} \int_0^t U_i dt = \frac{1}{N_2 \cdot F_m} \frac{U_a(t)}{K} \quad (*)$$

Iron

$F_m = 0,0185 \text{ m} \cdot 0,0190 \text{ m} = 3,5 \cdot 10^{-4} \text{ m}^2$
 $U_{a,s} = (7,8 \text{ V} + 10,4 \text{ V}) / 2 = 9,1 \text{ V}$
 $B_s = 0,92 \text{ T}$ (with formula *)

Ferrit

$F_m = 0,014 \text{ m} \cdot 0,014 \text{ m} = 1,96 \cdot 10^{-4} \text{ m}^2$
 $U_{a,s} = (1,82 \text{ V} + 1,92 \text{ V}) / 2 = 1,87 \text{ V}$
 $B_s = 0,34 \text{ T}$

Remanence B_R

Iron

$F_m = 0,0185 \text{ m} \cdot 0,0190 \text{ m} = 3,5 \cdot 10^{-4} \text{ m}^2$
 $U_{a,s} = (1,6 \text{ V} + 4,2 \text{ V}) / 2 = 2,9 \text{ V}$
 $B_R = 0,29 \text{ T}$ (with formula *)

Ferrit

$F_m = 0,014 \text{ m} \cdot 0,014 \text{ m} = 1,96 \cdot 10^{-4} \text{ m}^2$
 $U_{a,s} = (0,34 \text{ V} + 0,1 \text{ V}) / 2 = 0,22 \text{ V}$
 $B_R = 0,04 \text{ T}$

Coercitive field strength H_c

$$H_c = \frac{N_1 I_c}{l_1} \frac{1}{\sqrt{1 + \left(\frac{(1 + \sqrt{2})}{2}\right)^2}} \quad (**)$$

Iron

$U_c = (0,2 \text{ V} + 0,5 \text{ V}) / 2 = 0,35 \text{ V}$
 $I_c = (0,23 \text{ A} + 0,1 \text{ A}) / 2 = 0,16 \text{ A}$
 $H_c = 0,30 \cdot 10^3 \text{ A/m}$ (with formula **)

Ferrit

$U_c = (0,09 + 0,03) / 2 = 0,06 \text{ V}$
 $I_c = (0,014 \text{ A} + 0,043 \text{ A}) / 2 = 0,0285 \text{ A}$
 $H_c = 0,053 \cdot 10^3 \text{ A/m}$

2.4 Measurement of the remanence of the AlNiCo bar magnet

To determine the remanence of the AlNiCo bar magnet, we measured the output voltage (see graph on appendix „1“) on of the integrator while putting the bar magnet into the coil and closing the magnetic circle with the iron U–core. With final voltage $U_{a,R}$, we get:

AlNiCo

$$F_m = 0,018 \text{ m} \cdot 0,010 \text{ m} = 1,8 \cdot 10^{-4} \text{ m}^2$$

$$U_{a,R} = 0,96 \text{ V}$$

$$B_R = 0,19 \text{ T (with formula *)}$$

3 Questions

3.1 What are the pre–conditions for the occurrence of ferromagnetism?

Material which should be ferromagnetic has to consist of molecules with permanent magnetic dipoles. These also have to interact very much so that even a small external magnetic field is sufficient to bring many dipoles into line.

3.2 Are there no more „Weißsche Bezirke“ in a demagnetized material?

There are still the “Weißsche Bezirke”, but they are so small and their directions so different that their effects equalise referred to the whole material. The material seems to be nonmagnetic.

3.3 Why is there a saturation–value for inductivity for ferromagnetic substances?

In every material there is only a certain amount of magnetic dipoles. When all dipoles point in one direction no more magnetic field can be produced with this material.

3.4 What are the reasons for the appearance of the hysteresis graph?

The hysteresis graph shows the magnetic field e.g. for a iron bar as function of the external magnetic field power H . While the current is increasing B is getting bigger and in the graph you see the “Neukurve”. This part shows at first nonmagnetic material.

When the graph flattens out you see that the magnetisation M is nearly saturated. When H declines, the magnetisation of the material decreases not with the same speed because the direction of the “Weißschen Bezirke” partly remains. Even when the field H is zero a field B_r is left over which is based on the remaining magnetisation. This effect is called hysteresis (Greek: hysteros = later, afterwards). Therefore this graph is called hysteresis graph and the remaining magnetic field B_r is the remanence field.

When you change the direction of the current in the coil now and produce an external magnetic field H in the opposite direction you can bring the magnetic field B to zero again. The needed external field for this is called “Koerzitivfeld” H_c . If H increases more you will reach the point where all magnetic momentum show in the opposite direction. When you let H decrease again there also will resist a magnetisation opposed to the first. By changing the current of the coil again you can close the hysteresis graph.

3.5 How does the hysteresis graph look for „soft“ magnetic material, which is reverse–magnetized easily and for „hard“ magnetic material which is reverse–magnetized hardly.

The area included by the hysteresis graph is proportional to the energy which gets lost in the process of magnetisation and demagnetisation. When this area is small, so when there is a small loss of energy, the material is called magnetic soft. The remanence field B_r is very small compared with a magnetic hard material. The area for a magnetic hard material is big because much energy is needed to magnetise the material.

3.6 Discuss the differences of the hysteresis graphs of iron and Ferrite. In what way are those magnetic materials suitable for technical applications (e.g. transformer, speakers, permanent magnets, high frequency technology)?

The hysteresis graph of iron is wider and saturation value and remanence value are bigger than the ones of Ferrite. This means that for the magnetisation of Ferrite not so much energy is needed as for iron and so Ferrite is magnetic softer. When you need a magnet with a strong duration (e.g. loudspeakers or permanent magnets) so iron is the more suitable material. Where there shall be little loss of energy, you will prefer Ferrite.

3.7 Which sources of error are possible for the recording of the hysteresis graph because of a poor integrator?

The temperature drift pushes the graph in positive or negative direction of the induction voltage so that you won't reach the earlier saturation value when magnetising again. Also the remanence will slide more and more in the drift direction. A loss of linearity can stretch or shrivel the graph.

3.8 Why is it important for this experiment to avoid air gaps in the magnetic circle? What are the consequences of a small air gap in the magnetic circle for the recorded hysteresis graph and the characteristic values B_s , B_R , H_C and μ_{diff} ?

Air gaps should be avoided for not to interrupt the closed magnetic flow. For H_C the gap means that the current has to be stronger to reach an appropriate magnetic induction which extinguishes the remanence. For B_s and B_r nothing will change because air is diamagnetic and therefore also has no remanence. Only B_r will be reached later. The area of the graph has to be bigger because in this arrangement causes more loss in the air. That means for the geographic course of the hysteresis graph that it will be widened.