Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2019, 6(7):33-37

Research Article ISSN: 2394 - 658X

Hysteresis in Magnetic Recording

Sawsan Ahmed Elhouri Ahmed[1] **and Mohamed Toum Fadel**[2]

[1]University of Bahri - College of Applied & Industrial Sciences
Department of Physics - Khartoum - Sudan
[2]University of Al-Baha (KSA) - College of Applied Arts & Science
In Al-Mandag-Department of Physics

ABSTRACT

In this work we summarized and gathered all information concerning hysteresis properties and Eedy current as well as the application of the phenomena.

Key words: hysteresis properties, Eedy current, Magnetic Recording

---

INTRODUCTION

When a ferromagnetic material is magnetized in one direction, it will not relax back to zero magnetization when the imposed magnetizing field is removed. It must be driven back to zero by a field in the opposite direction. If an alternating magnetic field is applied to the material, its magnetization will trace out a loop called a hysteresis loop. The lack of retrace ability of the magnetization curve is the property called hysteresis and it is related to the existence of magnetic domains in the material. Once the magnetic domains are reoriented, it takes some energy to turn them back again. This property of ferromagnetic materials is useful as a magnetic "memory". Some compositions of ferromagnetic materials will retain an imposed magnetization indefinitely and are useful as "permanent magnets". The magnetic memory aspects of iron and chromium oxides make them useful in audio tape recording and for the magnetic storage of data on computer disks.

Hysteresis Effect

The magnetization of ferromagnetic substances due to a varying magnetic field lags behind the field. This effect is called hysteresis, and the term is used to describe any system in whose response depends not only on its current state, but also upon its past history. The loss of energy per magnetization cycle per volume is given by Steinmetz's equation the magnetization of ferromagnetic substances due to a varying magnetic field lags behind the field. This is called the hysteresis effect. The loss of energy per cycle per volume is given by Steinmetz's equation

$$Q = \eta B^{1.6},$$

Where B is the maximum induction and η is the hysteresis coefficient.

Hysteresis Loop

It is customary to plot the magnetization M of the sample as a function of the magnetic field strength H, since H is a measure of the externally applied field which drives the magnetization.

Hysteresis Loss

Hysteresis losses are the consequence of the fact that on the microscopic scale the magnetization process proceeds through sudden jumps of the magnetic domain walls that are unpinned from defects or other obstacles by the pressure of the external field. The local eddy currents induced by the induction change accompanying the wall jump dissipate a finite amount of energy through the Joule effect. The sum over all jumps gives the hysteresis loss associated with the jump sequence. The jumps are so short (typical times can be of the order of 10^{-8}–10^{-9} s) that the external field has no possibility of altering the internal jump dynamics. The only effect of the field is to compress or expand the time interval between subsequent jumps in inverse proportion to the field rate of change, which yields a number of jumps per unit time and an amount of energy dissipated per unit time proportional to the magnetization frequency. Therefore, one obtains for the hysteresis loss in a loop of peak induction B the typical expression

$$P_h = 4k_{hyst} B^a f \tag{1}$$

The loss per cycle $W_h = P_h / f$ is thus independent of frequency (see Figure 2). The parameter k_{hyst} and the exponent a include the structural aspects affecting domain wall pinning and magnetization reversal. Their value will differ from material to material. The rule a=1.6 has been claimed to have some general validity and is known in the literature as Steinmetz law (Bozorth, 1993). The hysteresis loss is intimately related to the structural disorder in the material. Possible sources of domain wall pinning are interstitials, non magnetic or less-magnetic inclusions, voids, dislocations. At a higher level of complexity, dislocation tangles and grain boundaries play a role. In amorphous alloys, fluctuations of local exchange and anisotropy should be taken into account, but often, in all case where magneto striction is not negligible, magneto elastic coupling to randomly distributed internal stresses dominates. Finally, in thin ribbons, surface roughness may be a substantial source of pinning effects.

Hysteresis in Magnetic Recording

Because of hysteresis, an input signal at the level indicated by the dashed line could give a magnetization anywhere between C and D, depending upon the immediate previous history of the tape (i.e., the signal which preceded it). This clearly unacceptable situation is remedied by the bias signal which cycles the oxide grains around their hysteresis loops so quickly that the magnetization averages to zero when no signal is applied. The result of the bias signal is like a magnetic eddy which settles down to zero if there is no signal superimposed upon it. If there is a signal, it offsets the bias signal so that it leaves a remnant magnetization proportional to the signal offset.

Variations in Hysteresis Curves

There is considerable variation in the hysteresis of different magnetic materials.

The Hysteresis Loop and Magnetic Properties

A great deal of information can be learned about the magnetic properties of a material by studying its hysteresis loop. A hysteresis loop shows the relationship between the induced magnetic flux density (B) and the magnetizing force (H). It is often referred to as the B-H loop. The loop is generated by measuring the magnetic flux of a ferromagnetic material while the magnetizing force is changed. A ferromagnetic material that has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as H is increased. As the line demonstrates, the greater the amount of current applied (H+), the stronger the magnetic field in the component (B+). At point "a" almost all of the magnetic domains are aligned and an additional increase in the magnetizing force will produce very little increase in magnetic flux. The material has reached the point of magnetic saturation. When H is reduced to zero, the curve will move from point "a" to point "b." At this point, it can be seen that some magnetic flux remains in the material even though the magnetizing force is zero. This is referred to as the point of retentively on the graph and indicates the remanence or level of residual magnetism in the material. (Some of the magnetic domains remain aligned but some have lost their alignment.) As the magnetizing force is reversed, the curve moves to point "c", where the flux has been reduced to zero. This is called the point of coercivity on the curve. (The reversed magnetizing force has flipped enough of the domains so that the net flux within the material is zero.) The force required to remove the residual magnetism from the material is called the coercive force or coercivity of the material. As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in the opposite direction (point "d"). Reducing H to zero brings the curve to point "e." It will have a level of residual magnetism equal to that achieved in the other direction. Increasing H back in the positive direction will return B to zero. Notice that the curve did not return to the origin of the graph because some force is required to remove the residual magnetism. The curve will take a different path from point "f" back to the saturation point where it with complete the loop.

From the hysteresis loop, a number of primary magnetic properties of a material can be determined.

1. Retentively - A measure of the residual flux density corresponding to the saturation induction of a magnetic material. In other words, it is a material's ability to retain a certain amount of residual magnetic field when the magnetizing force is removed after achieving saturation. (The value of B at point b on the hysteresis curve.)
2. Residual Magnetism or Residual Flux - the magnetic flux density that remains in a material when the magnetizing force is zero. Note that residual magnetism and retentively are the same when the material has been magnetized to the saturation point. However, the level of residual magnetism may be lower than the retentively value when the magnetizing force did not reach the saturation level.
3. Coercive Force - The amount of reverse magnetic field which must be applied to a magnetic material to make the magnetic flux return to zero. (The value of H at point c on the hysteresis curve.)
4. Permeability, m - A property of a material that describes the ease with which a magnetic flux is established in the component.
5. Reluctance - Is the opposition that a ferromagnetic material shows to the establishment of a magnetic field. Reluctance is analogous to the resistance in an electrical circuit.

Hysteresis Loops of Hard Iron and Soft Iron

The magnetization curves of Ferromagnetic materials, Paramagnetic Materials and Diamagnetic Materials are given. Para or Diamagnetic materials have linear magnetization curve hence there are no hysteresis loops and Ferromagnetic Materials have non-linear curves hence they have hysteresis loops. Hysteresis loop implies hysteresis loss. This means in magnetizing or demagnetizing a ferromagnetic material, some energy is expended. The energy expended will depend on the ease with which we can magnetize a ferromagnetic material. Soft irons are used in electro-mechanical relay switches. An actuating current easily magnetizes the soft iron core and attracts the spring-loaded switch. In this process the electro-mechanical relay is closed. As the current is turned off the switch is immediately opened by spring action. The hysteresis loop of Soft Iron alongside the hysteresis loop Hard Iron Soft iron gives rise to temporary magnet whereas hard iron gives a permanent magnet. Because of high remnant Magnetization as well as a much higher Coercive Magnetic Field that hard iron becomes a permanent magnet.

Theoretical Basis of Spontaneous Magnetization in Ferromagnets

The theoretical basis of magnetism is the Orbital Angular Momentum of the orbital electrons in an atom and the Spin Angular Momentum of the spinning electron circulating around the nucleus of the atom. Just as our Earth has orbital period of 365.25 days around the Sun but it has a spin period of 24 hours around it spin axis. In similar fashion orbital electrons have orbital angular momentum J_L as well as it has J_S spin angular momentum. Both these angular momentums give rise to dipole moments. Their parallel alignment can give rise to strong spontaneous magnetization as we find in magnetic materials such as ferro-magnetic materials. Their random alignment can give rise to weak spontaneous magnetization as we find in paramagnetic materials. Diamagnetic materials have no magnetization. In 1915, Albert Einstein in team with W.J. de Hass (the son-in-law of the great Dutch physicist H.A. Lorentz) demonstrated that magnetism was a result of the alignments of electron's orbital magnetic moment and spin magnetic moment. They attached a soft iron cylinder from a friction less pivot. The soft iron was surrounded by solenoid. Whenever a impulsive current was passed through the solenoid, the soft iron got magnetized and experienced a rotary motion so as to keep the overall Angular momentum equal to zero.

This amply demonstrated that ferromagnetism is a result of the alignment of magnetic dipole moments due to orbital angular momentum and due to spin angular momentum. But as we will see shortly that the spontaneous magnetization is primarily due to the spin angular momentum.

Electron's Orbital Magnetic Moment and Spin Magnetic Moment

By definition, a loop of orbiting electron has a dipole moment:

I = loop current due to circulation electron = $-q\;X\;\frac{v}{2\pi r}$ (2)

L (orbital angular momentum of electron) = Moment of Inertia X Angular Velocity

Therefore

$$L = m_e r^2 X\,\frac{v}{r} = m_e v r \qquad (3)$$

Substituting (2) and (3) into (1)

$$\mu_L = -q\,X\frac{v}{2\pi r}\;X\;\pi r^2 = -\frac{qvr}{2} = -\frac{q}{2m_e}.L \qquad (4)$$

Magnetic Moment (μ) of Orbiting Electron is anti-parallel to Orbital Angular Momentum (L)

Similarly:

$$\mu_S = -\frac{q}{2m_e}.S \qquad (5)$$

Where S = Spin Angular Momentum

In a preferred direction say Z-direction we have the projection of L and S on Z-axis.

We have seen in Quantum Mechanics that:

$$\mu_{LZ} = -\frac{q}{2m_e}.m_l h = -\frac{qh}{4\pi m_e} m_l \qquad (6)$$

Where $m_l = 0, \pm 1, \pm 2, \ldots\ldots \pm l$

Where l = (n -1)

$$\mu_{SZ} = -\frac{q}{2m_e}.\pm\left(\frac{1}{2}\right)h = -\frac{qh}{4\pi m_e}\left(\pm\frac{1}{2}\right) \qquad (7)$$

Here:

$$\mu_B\;(Bohr\;Magneton) = \frac{qh}{4\pi m_e} = 9.274\;X10^{-24}\frac{J}{T} = 5.788X10^{-5}\frac{eV}{T}$$

Both spin and orbital angular momentum have a role to play

After detailed investigation it was found that in Ferro-magnetic materials, spin angular momentum rather than orbital is the main contributor to Ferro-magnetism. The orbital angular momentum have a role to play but when there are uncompensated spins as in the case of transition elements the orbitals have negligible role to play. Ferromagnetism occurs because of coupling of uncompensated spins in parallel direction. This coupling occurs directly and is called direct exchange coupling or through intermediate anions usually Oxygen molecule through super exchange.

In crystals this results in net magnetic moments even at 300K. This is purely a Pauli-Exclusion Phenomena and Columbic Interaction phenomenon. Uncompensated spins of two atoms in an overlapping electron clouds have preference for parallel alignment (which contributes to net magnetic moment) rather than anti-parallel alignment (which is zero magnetic moment). Parallel alignment corresponds to lower energy level E_2 because of less columbic repulsion and anti-parallel alignment corresponds to higher energy level E_1 because of stronger Columbic repulsion due to closer spatial proximity. So obviously the lower energy state is preferred hence there is spontaneous magnetization in elements with uncompensated spin electrons. This is the case for Transition Elements hence Fe, CO and Ni are the strongest ferromagnetic materials.

$$\Delta E = E_1 - E_2 = exchange\ energy$$

At room temperature:

$\Delta E \gg k_B 300K$

Hence spontaneous magnetization is high up to Curie temperature. At Curie temperature exchange coupling is disrupted by thermal fluctuations and material becomes paramagnetic. The Curie Temperatures of important Ferro-magnets are listed below:

Materials	**Curie Temperature (K)**
Fe	1043
CO	1388
Ni	627
Gd	293

Giant Magneto-Resistance Used In Hard Discs of Computers

Giant Magneto-Resistance (GMR) is widely used in hard disc memories of computers. It made its mass market debut when IBM commercialized its record breaking 16.8GB hard disc in computer market. IBM called it spin valve based on electronic spin. In 1980, Peter Gruenberg of KFA Research Institute in Julich, Germany, and Albert Fert of the University of Paris-Sud saw large resistance change of 6% and 50% in Spin Valves. In IBM, using sputtering, scientists built trilayer GMR and demonstrated a large resistance change.

A Current Flow through GMR Experiences a Spin Valve Effect

The tri-layer can have its ferromagnetic layer anti-parallel or parallel.

Anti-parallel FM layers behaves like a open valve offering large resistance and parallel FM layers behave like a close valve offering small resistance. The scattering of electron depends on the spin of the conducting electron. There are two cases:

Case 1: conducting electron spin is the same as the spin of the FM layer. This will undergo very weak scattering. Hence low resistance.

Case 2: conducting electron spin is opposite the spin of the FM layer. This will undergo very strong scattering hence high resistance.

We have two cases: Left Hand is parallel FM and right is anti-parallel FM. Its equivalent electrical circuit, considering all permutation of spins,

It is evident that Parallel FM has a much lower resistance and antiparallel FM offers a very high resistance path. We study GMR in the case when the current flows in the direction perpendicular to the layers. The GMR effect is exploited in magnetic field sensors and its applications range from automotive to information storage technology.

REFERENCES

[1]. Mayergoyz, Isaak D. (2003). Mathematical Models of Hysteresis and their Applications: Second Edition (Electromagnetism). Academic Press. ISBN 978-0-12-480873-7.

[2]. Bertotti, Giorgio (1998). "Ch. 2". Hysteresis in magnetism: For physicists, materials scientists, and engineers. Academic Press. ISBN 978-0-12-093270-2.

[3]. The term is attributed to Truesdell & Noll 1965 by Visintin 1994, page 13.

[4]. Visintin 1994, page 13

[5]. Mohammad Al Janaideh, Subhash Rakheja, Chun-Yi Su An analytical generalized Prandtl–Ishlinskii model inversion for hysteresis compensation in micropositioning control, IEEE/ASME Transactions on Mechatronics, Volume:16 Issue:4, PP 734 - 744, 15 July 2010

[6]. Johnson, R. Colin. "'Missing link' memristor created: Rewrite the textbooks?". EE Times April 30, 2008. Retrieved September 2011. Check date values in: |access-date= (help)

[7]. Zifeng Yang; Hirofumi Igarashi; Mathew Martin; Hui Hu (Jan 7–10, 2008). An Experimental Investigation on Aerodynamic Hysteresis of a Low-Reynolds Number Airfoil (pdf). 46th AIAA Aerospace Sciences Meeting and Exhibit. Reno, Nevada: American Institute of Aeronautics and Astronautics. AIAA-2008-0315.

[8]. Love, Augustus E. (1927). Treatise on the Mathematical Theory of Elasticity (Dover Books on Physics & Chemistry). New York: Dover Publications. ISBN 0-486-60174-9.

[9]. Ewing, J. A. (1889). "On hysteresis in the relation of strain to stress". British Association Reports: 502.

[10]. Hopkinson, B.; Williams, G. T. (1912). "The Elastic Hysteresis of Steel". Proceedings of the Royal Society. 87 (598): 502. Bibcode:1912RSPSA..87..502H. doi:10.1098/rspa.1912.0104.

[11]. Chandran Suja, V.; Frostad, J. M.; Fuller, G. G. (2016-10-31). "Impact of Compressibility on the Control of Bubble-Pressure Tensiometers". Langmuir. 32: 12031–12038. doi:10.1021/acs.langmuir.6b03258. ISSN 0743-7463.

[12]. Alvarez, Nicolas J.; Walker, Lynn M.; Anna, Shelley L. (2010-08-17). "A Microtensiometer To Probe the Effect of Radius of Curvature on Surfactant Transport to a Spherical Interface". Langmuir. 26 (16): 13310–13319. doi:10.1021/la101870m. ISSN 0743-7463.

[13]. Gregg, S. J.; Sing, Kenneth S. W. (1982). Adsorption, Surface Area, and Porosity (Second ed.). London: Academic Press. ISBN 978-0-12-300956-2.

[14]. Sing, K. S. W.; Everett, D. H.; Haul, R. A. W.; Moscou, L.; Pierotti, R. A.; J. Roquérol, J.; Siemieniewska, T. (1985). "Reporting physisorption data for gas/solid systems with special reference to the determination of surface area and porosity (Recommendations 1984)". Pure and Applied Chemistry. 57 (4): 603–619. doi:10.1351/pac198557040603.

[15]. Tompsett, G. A.; Krogh, L.; Griffin, D. W.; Conner, W. C. (2005). "Hysteresis and Scanning Behavior of Mesoporous Molecular Sieves". Langmuir. 21 (8): 8214–8225. doi:10.1021/la050068y. PMID 16114924.

[16]. Parkes, Martin (8 April 1999). "Subject: Accuracy of capacitance soil moisture ..." SOWACS (Mailing list). Archived from the original on 28 September 2011. Retrieved 28 September 2011.

[17]. Scanlon, B. R.; Andraski, B. J.; Bilskie, J. (2002). "Methods of soil analysis: Physical Methods: Miscellaneous methods for measuring matric or water potential" (PDF). Soil Science Society of America. 4: 643–670. ISBN 0-89118-810-X. Archived from the original (PDF) on 2006-03-13. Retrieved 2006-05-26.

[18]. Bozorth, R.M. (1993) Ferromagnetism. IEEE Magnetics Society, Piscataway. http://dx.doi.org/10.1109/9780470544624.