

PAPER • OPEN ACCESS

Effect of magnetizing field strength and magnetizing frequency on hysteresis loop shape and its characteristics

To cite this article: M. Vashista and Mohd. Zaheer Khan Yusufzai 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **346** 012003

View the [article online](#) for updates and enhancements.

Related content

- [Hysteresis Loops in Ferroelectrics Undergoing an Isomorphous Phase Transition](#)
Yoshihiro Ishibashi
- [A new type of fluxgate magnetometer for low magnetic fields](#)
Derac Son
- [Multiparameter analysis of the Barkhausen noise signal and its application for the assessment of plastic deformation level in 13HMF grade steel](#)
Leszek Piotrowski, Bolesaw Augustyniak, Marek Chmielewski et al.

Recent citations

- [Hysteresis loop analysis of gas metal arc welded ferritic stainless steel plate](#)
Sanjay Kumar Gupta et al

The 17th International Symposium on Solid Oxide Fuel Cells (SOFC-XVII)
DIGITAL MEETING • July 18-23, 2021

EXTENDED Abstract Submission Deadline: February 19, 2021



Effect of magnetizing field strength and magnetizing frequency on hysteresis loop shape and its characteristics

M. Vashista, Mohd. Zaheer Khan Yusufzai

Department of Mechanical Engineering, Indian Institute of Technology (BHU),
Varanasi, Uttar Pradesh, India 221005

E-mail: mvashista.mec@iitbhu.ac.in

Abstract. Application of external magnetic field over a ferromagnetic material results in change in its global magnetization. Change in global magnetization occurs due to motion of magnetic domain walls to align themselves in the direction of applied magnetic field. The motion of magnetic domain wall generates hysteresis loop consisting of magnetizing curve and de-magnetizing curve. Hysteresis loop is generally characterized by its characteristics such as remnance, coercivity and permeability. In the present study, hysteresis loops were obtained from Ni based sample at different magnetizing field intensity and magnetizing frequency. Hysteresis loops were clubbed together to study the changes in shape owing to variation in magnetizing field strength and magnetizing frequencies. Changes in applied magnetic field strength and magnetizing frequencies affect the process of change in global magnetization process of material. Variation in hysteresis loop shape and its characteristics such as coercivity, remnance and permeability clearly reflects effect of magnetizing field intensity and frequency. A good correlation was obtained between analysis parameters such as magnetizing field intensity and magnetizing frequency with coercivity, permeability and remnance.

Keywords: Hysteresis loop; Coercivity; Permeability; Magnetizing field intensity; Magnetizing frequency; Remnance

1. Introduction

The inherent characteristic of ferromagnetic material is the relation between magnetic flux density B and magnetic field strength H , or the B - H loop or Hysteresis loop. In presence of external magnetic field, the medium exchanges energy with the source of the magnetic field for initiation of magnetization process. If the medium magnetization is a single-valued function of external magnetic field, then the process is reversible and it conserves energy. In this case, the medium stores the supplied energy in it during magnetization process. When the external magnetic field is reduced to zero, the medium returns this energy to the source. But, when the magnetization is a multiple-valued function of the applied field, some amount of energy is dissipated. In presence of slowly variable magnetic field, this loss is caused by hysteresis, which is defined as the lagging of the changes in magnetization behind the changes in magnetic field [1]. Most of the researcher used the rate-independent hysteresis because it is basic and more understandable. Rate-independent hysteresis indicates that the magnetization curves are independent of the field rate, which implies that only the past input extreme leave their marks on the shape of hysteresis curve. The rate of externally applied field, however, plays an important role in changing the energy profiles of the system through the eddy-current losses, which in-turn not only modify the shape of the hysteresis loop and but also enlarges its



area [2]. In the existing non-destructive technique, micro-magnetic methods such as Barkhausen Noise analysis technique and hysteresis (B-H) loop measurement are known to be very efficient for the characterization of ferromagnetic materials. The microstructure and composition of these materials define their mechanical and ferromagnetic properties. Thus, the Hysteresis loop technique and Barkhausen Noise technique can be used for non-destructive evaluation of several material properties of steels [3]. Hysteresis curve wherever crosses the H-axis and B-axis, the obtained intersection points known as coercivity and remnance respectively. The tangent at the steepest point of the curve is known as permeability. These features of hysteresis loop are related with material properties of ferromagnetic materials. Consequently, hysteresis loop characteristics can be employed for material characterization.

Previous researchers successfully correlated the hysteresis loop characteristics such as permeability, coercivity, remanance, core loss, saturation magnetization etc. with the metallurgical and mechanical properties of ferromagnetic material. Grain size, hardness and stress have considerable effect on magnetic hysteresis loop [4-5]. Fourier descriptor analysis of hysteresis loop was successfully attempted to distinguish the quenched specimen from quenched aged and also to distinguish specimen with different aging conditions of precipitation hardened steel [6]. In a similar way, effect of isothermal-annealing treatments on coercivity and remanance were studied on industrially cold rolled low carbon steel and observed that coercivity and remanance decreases with increase in annealing time and recovery process [7]. Coercive field, remanant induction, hysteresis loss Core loss, remnance and coercivity were attempted to monitor the changes in microstructure during cold rolling on account of recovery and recrystallization [8]. Coercivity was observed to decreases with increase in magnetic softness while studying the aging behaviour of steel at different length of time [9]. During thermal aging process of steel the recovery of dislocation and precipitation of Cr- rich phase affected the coercivity [10].

The shape of hysteresis loop not only depends on the strength of applied magnetic field but also varies with magnetizing frequency, which in turn may affect the coercivity, permeability and remnance. Hence, the aim of present contribution is to study the effect of magnetic field strength and magnetizing frequency on hysteresis loop characteristics.

2. Experimental details:

In the present work, pure nickel in form thin sheet was used as a workpiece material because of its good ferromagnetic properties. Magnetic Barkhausen Noise analyzer (Magstar) was employed for hysteresis loop measurements, the analyzer (refer fig.1) is capable to apply the magnetic field upto 1500 Oe as well frequency of applied magnetic field can be vary from 0.1 Hz to 200 Hz. Typically, low frequency applied magnetic field penetrates more deeply into the material owing to attenuation effect. Hence in study the effect of magnetizing frequency and magnetic field strength on hysteresis loop and its characteristics parameter, the magnetizing frequency was varied from 0.05 Hz to 1 Hz and external magnetic field was varied in wide range from 100 Oe to 1000 Oe.

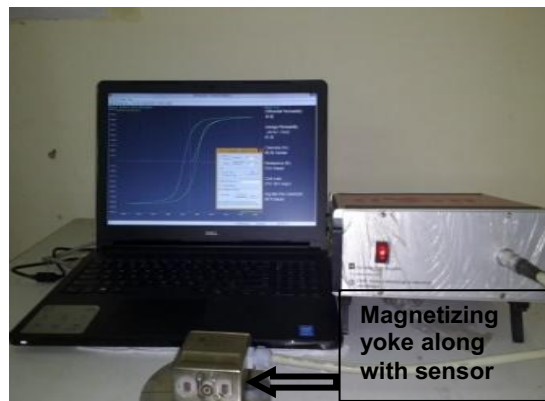


Fig. 1 Magnetic Barkhausen Noise analyzer

Figure 2 shows the typical hysteresis loop obtained from pure nickel sheet along with the various associated parameters. All the measurement were carried out using sinusoidal waveform, and after each and every measurement samples were demagnetize to eliminate the effect of previous magnetization process.

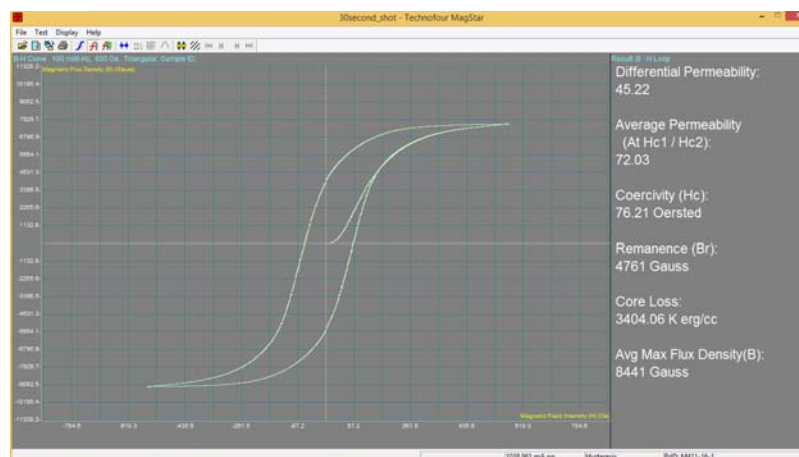


Fig. 2 Screen shot of hysteresis loop obtained from Magstar

3. Results and discussion:

In presence of external magnetic field, global magnetization of material changes as the magnetic domain walls move to align them in the direction of applied magnetic field. The complete motion of domain walls generates a path/curve known as magnetization part of hysteresis loop. When magnetic domain gets aligned, an increase in magnetic field strength does not make any changes in the magnetization curve, but reduction in magnetic field again disturb the alignment of magnetic domain and forces them again to align them in the direction of reducing reverse magnetic field. This motion of domain wall is not reversible, as it follows a different curve (other than magnetization curve) while aligning them in the direction of magnetic field. Magnetization and demagnetization curve forms hysteresis loop. Figure 3 represents the hysteresis loops obtained at various applied magnetic field strength.

Dependency of hysteresis loop on magnetizing parameters is clearly visible in Fig. 3. Increase in magnetic field strength from 100 Oe to 1000 Oe changes the hysteresis loop shape i.e. loops become wider with increasing field strength. Effect of increase in applied magnetic field strength on widening of hysteresis loop is more during the increase in field strength from 100 Oe to 500 Oe, then the widening of loop become less at higher range of applied field strength. Similarly changes in excitation frequency also results into variation in shape of hysteresis loop.

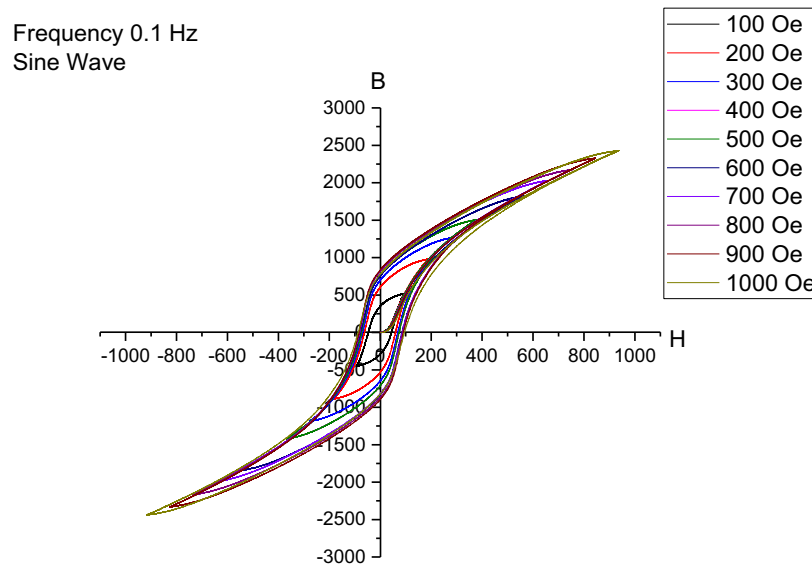


Fig. 3 Variation in shape of hysteresis loop with applied field strength

Variation in shape of B-H loop causes variation in its characteristics i.e. permeability, coercivity and remanance. Figure 4 (a) and 4(b) show the variation in coercivity with excitation frequency and applied magnetic field strength respectively.

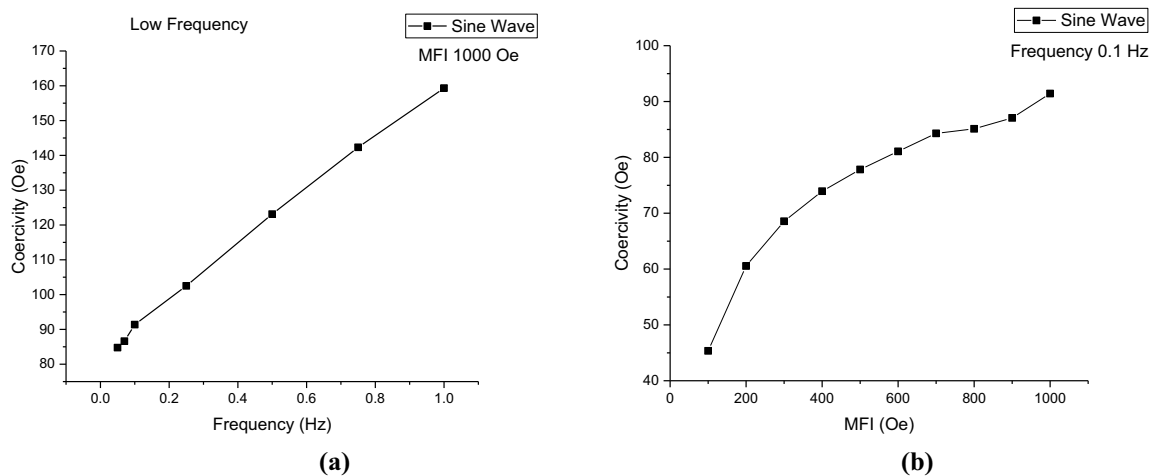


Fig. 4 Variation of coercivity with excitation frequency (a) and applied magnetic field (b)

Coercivity of material is defined as resistance offered by material against demagnetization. Generally eddy current is generated in presence of external magnetic field, which opposes the magnetic field. Increase in excitation frequency increases the eddy current which in turn enables the magnetic domains to oppose the demagnetization more effectively in presence of constant magnetic field strength. Thus, the coercivity increases with increase in excitation frequency. The magnitude of eddy current also depends on the strength of applied magnetic field, which increases with increase in magnetic field intensity. In this way, increase in applied magnetic field intensity increases the coercivity as can be seen in Fig. 4 (b). Permeability is known as ‘the ease’ with which a ferromagnetic material can be magnetized in presence of external magnetic field. This is measured by calculating the slope of tangent at the steepest portion (i.e. knee) of hysteresis loop. Figure 5 represents the variation of average permeability (AP) with excitation frequency.

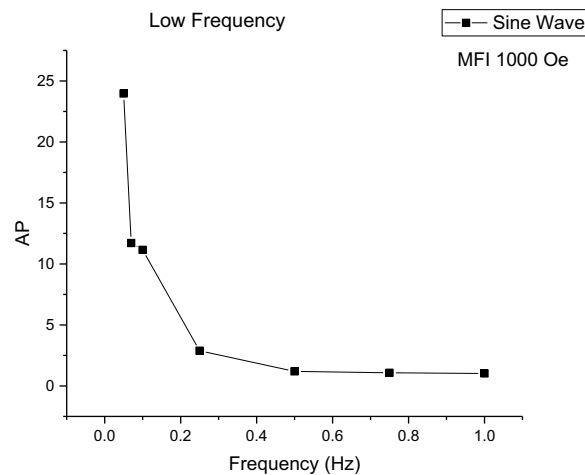


Fig. 5 Variation of permeability with excitation frequency

Figure 5 clearly depicts the reduction in permeability with increase in excitation frequency. Widening of hysteresis loop with increase in excitation frequency occurs in such a way that reduces the slope of tangent, which leads to decrease in permeability. Further, it is quite interesting to note that permeability reduces sharply when the excitation frequency increase from 0.05 Hz to 0.25 Hz then it remains constant with increase excitation frequency. Low magnetizing frequency indicates more penetration of magnetic field into the material. Decrease in frequency from 0.25 Hz to 0.05 Hz (while keeping magnetic field intensity constant i.e. 1000 Oe) enables the magnetic field to cover more depth into the material, that may facilitates material towards magnetization with more ease.

Another importance characteristic of hysteresis loop is 'Remnance', which is defined as the residual magnetism present inside the material when the reducing magnetic field becomes zero. Figure 6 (a) and (b) shows the variation of remnance with excitation frequency and applied magnetic field intensity.

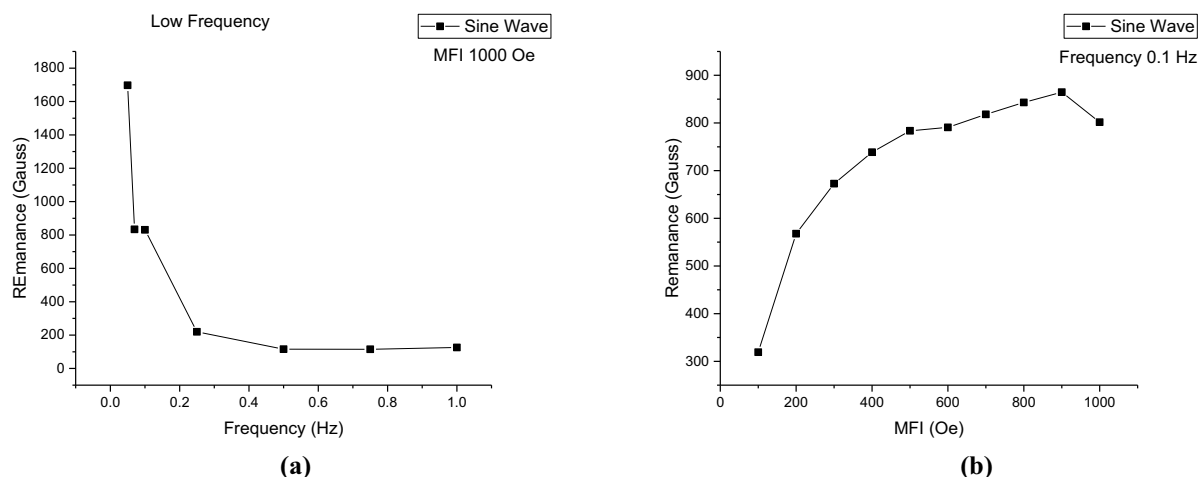


Fig. 6 Variation of remnance with excitation frequency (a) and magnetic field intensity (b)

Remnance is increasing with decrease in excitation frequency. As already indicated that lower magnetizing frequency enables the magnetic field to penetrate more deep into the material, this increases amount of magnetic domains to participate for change in global magnetization of material in presence of constant magnetic field. Thus, remnance increase with reduction in excitation frequency as seen in Fig. 6 (b). Increase in magnetic field intensity at constant excitation frequency causes the widening of hysteresis loop in such a way that increases the remnance.

4. Conclusions:

Following conclusions may be drawn from this experimental study:

- (i) Hysteresis loop shape depends upon the magnetizing parameters, in this way hysteresis loop characteristic such as permeability, coercivity and remnance changes magnetizing parameters.
- (ii) Coercivity increases with increases linearly with increase in excitation frequency and magnetizing field intensity owing to opposition generated by eddy current. Permeability decreases with increase in excitation frequency.
- (iii) Participation of more magnetic domains at lower excitation frequency causes increase in remnance while it increases with increase in magnetic field intensity.

5. Acknowledgments

The authors gratefully acknowledge the funding support they received from IIT (BHU) under Institute Research Project (IIT (BHU)/R&D/IRP/2015-16/2832/L dated 31.12.2015).

6. References:

- [1] Zhu J G 1994 Numerical modelling of magnetic materials for computer aided design of electromagnetic devices, PhD Thesis July 1994, University of Technology, Sydney
- [2] Bertotti G 1998 Hysteresis in Magnetism. Academic Press, Inc., California, USA.
- [3] Martínez-de-guerenu A , Gurruchaga K, Arizti F 2006 Use of Magnetic Techniques for Characterisation of the Microstructure Evolution during the Annealing of Low Carbon Steels, *ECNDT 2006 - Mo.2.2.2*
- [4] Kwun H, Burkhardt GL 1987 Effect of grain size, hardness and stress on the magnetic hysteresis loops of ferromagnetic steels. *J. appl. Phy.* 61 1576-1579.
- [5] Anglada-Rivera J, Padovese L R, Capo-Sanchez J 2001 Magnetic Barkhausen noise and hysteresis loop in commercial carbon steel: influence of applied tensile stress and grain size. *J. of Magn. and Magn. Mater* 231 299-306.
- [6] Shakshin NI, Deordiev GI, Scherbinin VE, Moorthy V, Jayakumar T, Bhattacharya DK, Kalyanasundaram P, Raj B 1997 Evaluation of thermal aging conditions in 17-4PH stainless steel by fourier descriptor analysis of magnetic hysteresis loops. *NDT &E Inter.* 29 379-385.
- [7] Ansari-pour A, Monazatizadeh H, Amighian J 2014 Effect of isothermal annealing on the mechanical properties of cold-rolled low-carbon steel with magnetic hysteresis loop measurements. *MTAEC* 948(3) 367-371.
- [8] Martinez –de-Guerenu A, Gurruchaga K, Arizti F 2007 Nondestructive characterization of recovery and recrystallization in cold rolled low carbon steel by magnetic hysteresis loops. *J. of Magn. and Magn. Mater* 316 842-845.

- [9] Mohapatra JN, Panda AK, Gunjan MK, Bandopadhyaya NR, Mitra A, Ghosh RN 2007 Ageing behaviour study of 5Cr-0.5Mo steel by magnetic Barkhausen emission and magnetic hysteresis loop techniques. *NDT & E Inter.* 40: 173-178.
- [10] Mohapatra JN, Kamada Y, Kikuchi H, Kobayashi S, Echigoya J, Park DG, Cheong YM 2011 Study of thermal aging behaviour of Fe-Cr model alloys by magnetic hysteresis loop technique. *J. of Phy.* Conference series 266-012041.