

# AUTOMATED MEASUREMENT OF MAGNETIC PROPERTIES OF FERROMAGNETIC MATERIALS USING PYTHON

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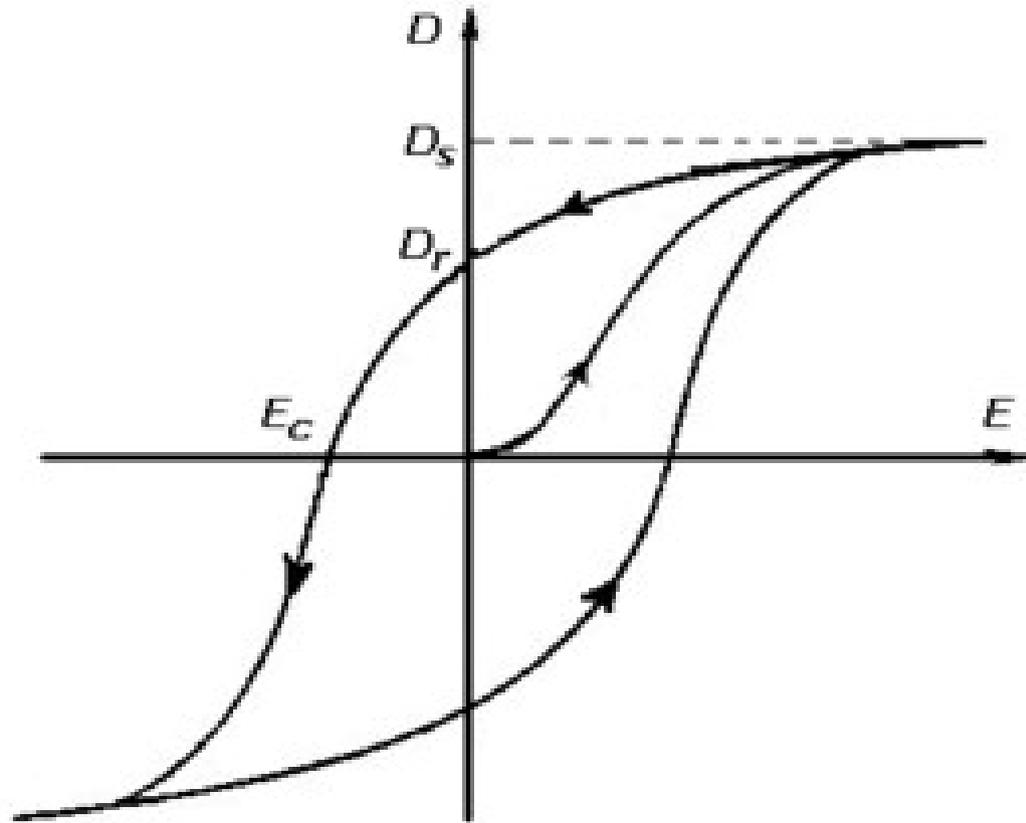
Magnetism is a phenomenon by which materials exerts an attractive or repulsive force on other materials. Magnetic dipoles are found to exist in magnetic material and may be thought of as small bar magnets composed of north and south poles. The externally applied magnetic field is called magnetizing field whose strength is  $H$ . It is measured in ampere per meter (A/m). The magnetic induction or magnetic flux density  $B$  represents the magnitude of internal field strength within a substance or material and is measured in Tesla (T) or Weber per square meter ( $\text{wb}/\text{m}^2$ )

Hysteresis is basically a phenomenon where the behaviour of the system depends on the way the system moves. On increasing the magnetizing field  $H$  applied to a magnetic material, the corresponding induction  $B$  traces a different path when it increases from that when the field decreases tracing a loop. It is often referred to as the B-H loop. The Retentivity, Coercivity and the Susceptibility of the specimen are calculated. The result agrees with reported values.

Dr Retentivity

Ec Coercivity

<http://en.wikipedia.org/wiki/File:EHysteresis.PNG>



The magnetic field strength and magnetic flux density are related according to the relation  $B = \mu_0 H$  in free space and  $B = \mu H$  with medium where  $\mu_0$  is the permeability of vacuum, a universal constant which is  $4\pi \cdot 10^{-7} \text{ H/m}$  and  $\mu$  is the permeability of medium. The relative permeability,  $\mu_r = \mu / \mu_0$  is used to describe the magnetic properties of materials. It is a measure of the degree to which the material can be magnetized, or the case with a magnetic induction  $B$  produced in the material in the presence of an uniform external applied field  $H$ . Hence ,  $B = \mu H$  which is

$$B = \mu_0 (H + M) \quad \text{and} \quad \mu_r = \mu / \mu_0 = (1 + \chi)$$

where,  $M$  is the magnetization or induced dipole moment per unit volume of the material which is proportional to applied field as

$$M = \chi H$$

$\chi$  is called magnetic susceptibility of the material .

$$\chi = (1/\mu_0) (dB/dH) - 1.$$

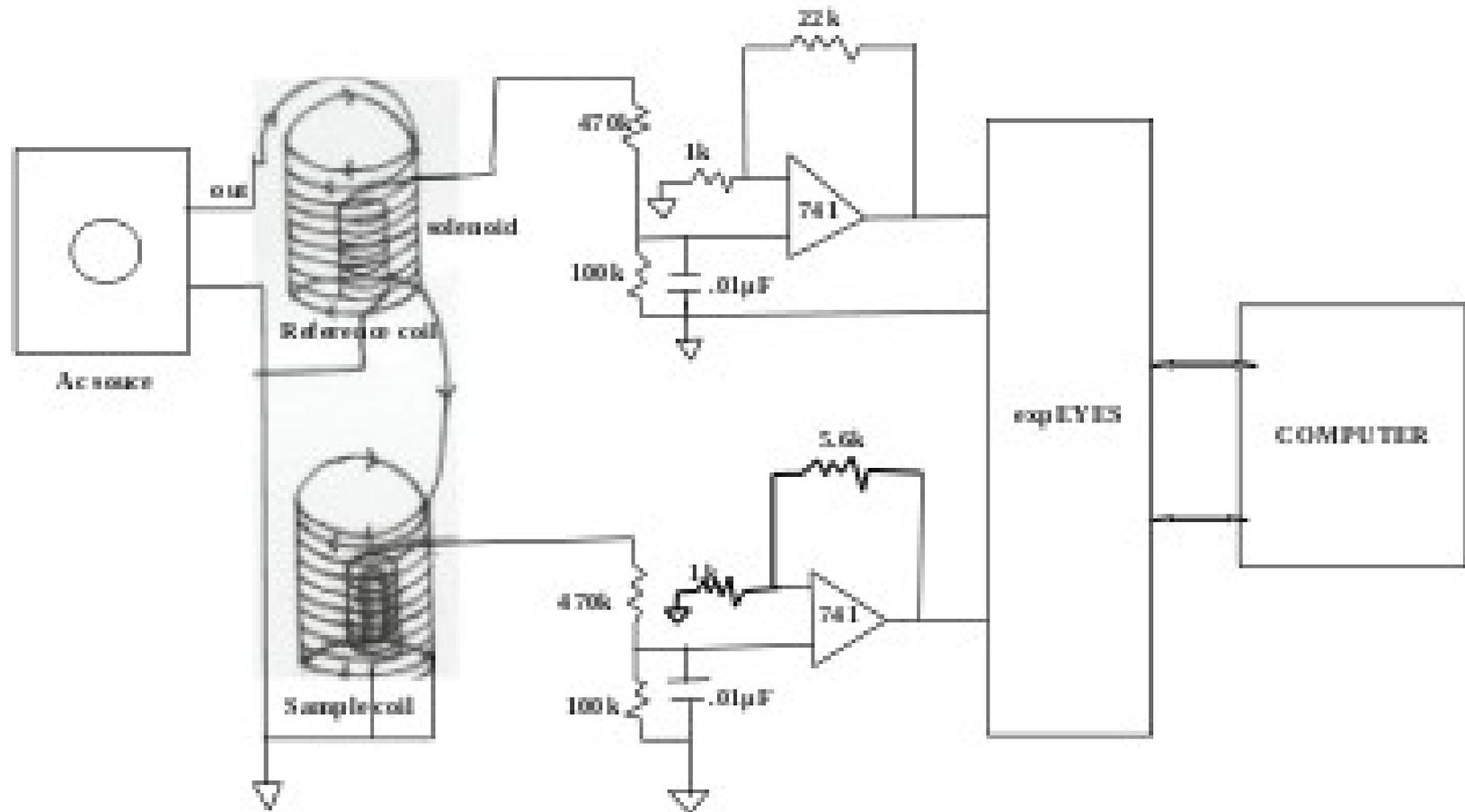
# Susceptibility tables

Material	Relative Permiability		Coercivity	Retentivity
	Init	Max	Oer	Gauss
Pure Iron	150	5000	1	13000
Cobalt	70	250	10	5000
Nickel	110	610	.7	4000
Alnico 5	4	575		12500
Steel	50	100	70	10300

The present study describes the measurement of magnetic properties of ferromagnetic material such as Steel and Ferrite in response to the alternating magnetic field inside a driven solenoid. Magnetic Susceptibility, Retentivity and Coercivity are measured and the hysteresis loss per cycle of the sample materials is calculated. Data acquisition is done using expEYES- a microcontroller based data acquisition system along with the firmware developed by the IUAC New Delhi . The hardware consists of an AT mega32 microcontroller, 12 bit  $ADC_S$  and  $DAC_S$ , several oscillators and amplifiers. It can run on any computer system having PYTHON interpreter and a library for communicating to the Serial /USB ports. The data acquisition has been done in PYTHON

# Experimental Details

Two solenoids of same cross section and number of turns are electrically connected in series and driven by an ac source which is a 1KVA variac. The voltage swing observed is a maximum of 90v and a minimum of 20v. The solenoids produce a near-uniform ac magnetic field along the axis  $B = \mu_0 NI/2a$ , where  $I = I_0 \sin \omega t$  is the current through the solenoid,  $N$  the number of turns per unit length and the average radius  $a$ . The magnetizing field is  $H = NI/2a$ . The solenoids are kept apart to avoid mutual coupling between them. At the centre of the coils and placed coaxially inside the energising coils are two identical pick-up coils which act as sample coil and a reference coil respectively. The fig 1 illustrates the equivalent circuit for the experiment.



**Fig 1. Equivalent circuit for the experiment**

With no sample material in the sample coil, the solenoid is excited by the ac source. The induced ac voltage on both the coils is

$$V = -d\phi/dt$$

where  $\phi$  is the magnetic flux due to the applied field.

The sample material is introduced in the sample coil coaxially in this field and the reference coil is left empty. The total magnetic flux associated now includes contributions from both the applied field and the field due to sample magnetization which is

$$\phi = BAN$$

where  $B = B_0 \sin \omega t$  due to the applied field.  $A$  is the area of cross section and  $n$ , the total number of turns of the sample coil.

The ac voltages induced across the sample coil and reference coil are proportional to  $dB/dt$  and  $dH/dt$  respectively. The signals obtained are amplified conveniently using op-amp 741 based non inverting amplifiers and acquired by the data acquisition system - expEYES. It converts analog wave forms into digital values for processing.

A PYTHON program is developed for data processing. The program reads the signals  $dH/dt$  and  $dB/dt$  alternately and are written in separate arrays. The total number of samples is 100 split over 5 cycles with period 20 mS corresponding to the 50 Hz

```
t,vv,tt,v = p.capture01(NP+1,delay)
```

Noise reduction is done by adding corresponding data from all the acquired cycles of the picked up signal. for i in range (1,21,1):

for j in range (1,5,1):

vv[i] += vv[i+j\*20]

v[i] += v[i+j\*20]

for i in range (1,21,1):

vv[i] /=5.

v[i] /=5.

The derivatives obtained are corrected for any base line shifts coming from the electronics.

```
sumb = 0
```

```
sumh = 0
```

```
for i in range (1,21,1):
```

```
    sumb += vv[i]
```

```
    sumh += v[i]
```

```
for i in range (1,21,1):
```

```
    vv[i] -= sumb/20.
```

```
    v[i] -= sumh/20.
```

These signals are integrated to get B and H.

```
sumb =0
```

```
sumh =0
```

```
for i in range (1,21,1):
```

```
    sumb += vv[i]
```

```
    vv[i] = sumb
```

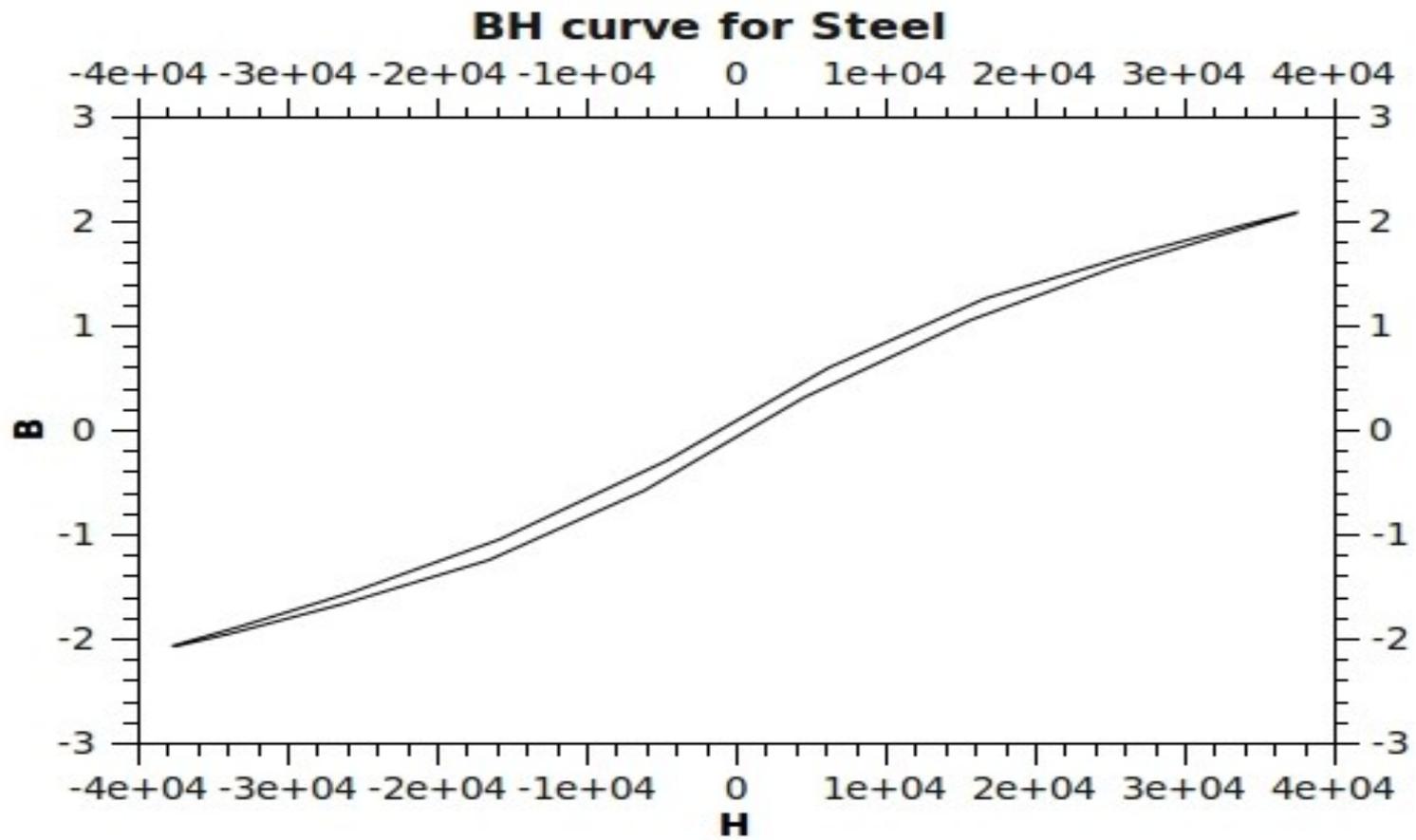
```
    sumh += v[i]
```

```
    v[i] = sumh
```

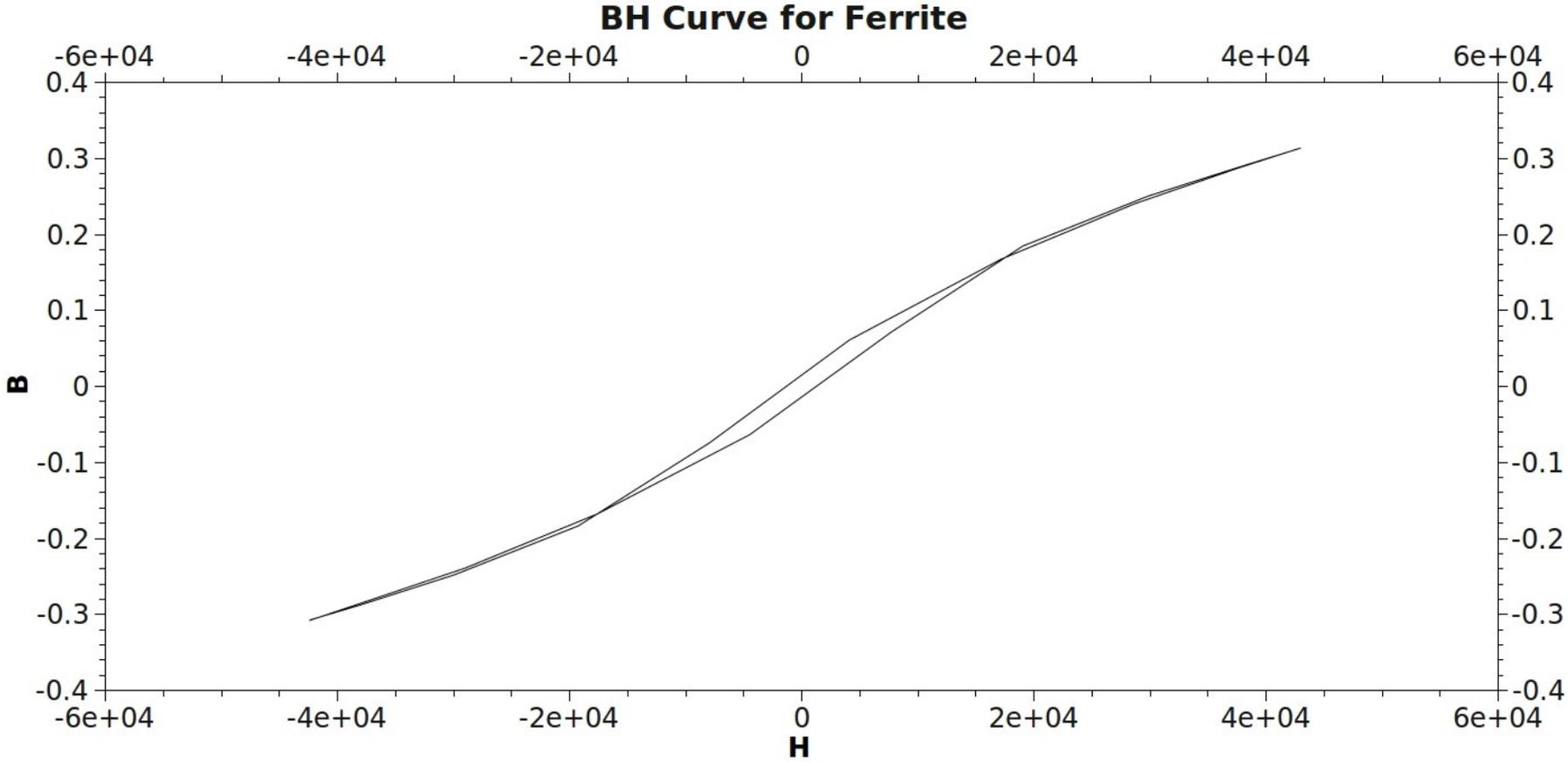
The signals are then time averaged over a full cycle and shifted to have equal voltage swings on either side of the time axis. This follows from the fact that the induced output of a coil can give only a pure alternating signal. Integration is performed to get the respective values of H and B. Once again the constant of integration is fixed by using the fact that the coil produces a pure alternating signal which gives the time integral over one cycle as 0. This is how the constant of integration is removed.

The integrated wave is standardized by measuring the B for standard DC with a Gauss meter and then measuring the alternating current. In the case studied a direct current of 3 A through the coil produces an induction of .04 T. If the coil having a sinusoidal signal of peak value 3A then there is a sinusoidal induction of peak value .04 T . The peak of this induction, got by integrating dB/dt picked by the pick-up coil corresponds to .04 T. The H value is got by dividing B with  $\mu_0 \cdot \phi$  for a sample which does not fill the whole of the pick-up coil is evaluated by scaling with cross section area ratio of the coil to sample.

# Steel



# Ferrite



Retentivity  $B_r$ (T) and coercivity  $H_c$ (A/m) of the specimen are determined. Retentivity is the residual magnetism that exists in the specimen during the zero crossing of the H field when driven by ac field. This is evaluated by checking for zero crossing. When the H field crosses zero the product of the sampled signal before and after crossing is negative or zero. The retentivity value is taken by assuming the BH curve to be a straight line at the crossing and by evaluating the crossing point from the equation to a straight line. The coercivity is the opposing magnetizing force necessary to reduce the residual magnetism to zero value. This is also calculated similarly. The susceptibility is calculated from the slope of the hysteresis loop using the relation,  $\chi = (1/\mu_0)(dB/dH) - 1$ .

# Results

Material	Retentivity	Coercivity T	Susceptibility A/m
Steel	0.12	1512	63.8
Ferrite	0.014	1295	7.87

The Steel sample used has a coercive force of 1512 A/m, retentivity of 0.12 T and susceptibility of 63.8. Ferrite from a Ferrite rod has a coercive field of 1295 A/m, a retentivity of 0.014 T and susceptibility of 7.87.

**Thank You**