# Analysis Appendix

**Equation List**

$$H = n_1 (LS)^{-1} V_s \text{ (1)}$$
$$B = RC(n_2 A_c)^{-1} V_s \text{ (2)}$$
$$P = AVf \text{ (3)}$$
$$V = L * Area\ of\ sample\ face \text{ (4)}$$
$$B = \mu_0 \mu_r H \text{ (5)}$$
$$\mu_0 = 4\pi * 10^{-7} \text{ (6)}$$
$$\text{flux density} = H\mu_r \text{ (7)}$$

**Apparatus Measurements**

n1 = 160 turns
n2 = 150 turns
S = 0.1 +/- 5% Ohms
R = 1e6 +/- 5% Ohms
C = 0.5e-6 +/- 2% F

**Sample Measurements**

Iron Magnetic Length**:** 333 +/- 5mm
Iron Cross Sectional Area: 759.08 +- 0.5 $mm^2$
Carbon Magnetic Length: 78 mm +/- 0.5 mm
Carbon Cross Sectional Area: 844.32 $mm^2$

*Table 1 –Series Resistor Voltage and Capacitor Voltage for Iron Sample with C = 0.5e-6 +/- 2% F and S = 0.1 +/- 5% Ohms (Small sample of full dataset with 2000 points)*

| Time [s] | Vc [V] | Vc [V] |
|---|---|---|
| -2.50E-02 | 3.42E-01 | -3.40E-01 |
| -2.50E-02 | 3.38E-01 | -3.39E-01 |
| -2.50E-02 | 3.34E-01 | -3.39E-01 |
| -2.49E-02 | 3.31E-01 | -3.39E-01 |
| -2.49E-02 | 3.27E-01 | -3.39E-01 |
| -2.49E-02 | 3.22E-01 | -3.38E-01 |
| -2.49E-02 | 3.18E-01 | -3.38E-01 |
| -2.48E-02 | 3.13E-01 | -3.38E-01 |
| -2.48E-02 | 3.09E-01 | -3.38E-01 |
| -2.48E-02 | 3.06E-01 | -3.37E-01 |
| -2.48E-02 | 3.01E-01 | -3.37E-01 |
| -2.47E-02 | 2.96E-01 | -3.36E-01 |
| -2.47E-02 | 2.91E-01 | -3.36E-01 |

*Table 2 - Series Resistor Voltage and Capacitor Voltage for Carbon Steel Sample with C = 0.5e-6 +/- 2% F and S = 0.1 +/- 5% Ohms (Small sample of full dataset with 2000 points)*

| Time [s] | Vc [V] | Vc [V] |
|---|---|---|
| -2.50E-02 | 3.58E-01 | 1.78E-01 |
| -2.50E-02 | 3.56E-01 | 1.78E-01 |
| -2.50E-02 | 3.55E-01 | 1.77E-01 |
| -2.49E-02 | 3.53E-01 | 1.78E-01 |
| -2.49E-02 | 3.51E-01 | 1.77E-01 |
| -2.49E-02 | 3.49E-01 | 1.77E-01 |
| -2.49E-02 | 3.46E-01 | 1.76E-01 |
| -2.48E-02 | 3.44E-01 | 1.76E-01 |
| -2.48E-02 | 3.40E-01 | 1.75E-01 |
| -2.48E-02 | 3.39E-01 | 1.75E-01 |
| -2.48E-02 | 3.35E-01 | 1.73E-01 |
| -2.47E-02 | 3.34E-01 | 1.75E-01 |
| -2.47E-02 | 3.30E-01 | 1.72E-01 |

*Table 3 - Hysteresis Saturation Point for Iron Sample with*

*C = 0.5e-6 +/- 2% F and S = 0.1 +/- 5% Ohms*

| Variac Voltage [V] | Top-right corner X [mV] | Top-right corner Y [mV] | Error in corner X [mV] | Error in corner Y [mV] |
|---|---|---|---|---|
| 3 | 13.75 | 26.87 | 0.5 | 1 |
| 5 | 18.25 | 43.75 | 0.5 | 2 |
| 7 | 21 | 56.25 | 0.5 | 2 |
| 10 | 25.5 | 72.5 | 0.5 | 2 |
| 13 | 33.5 | 95.3 | 1 | 5 |
| 17 | 42 | 118.8 | 1 | 5 |
| 20 | 50.5 | 139.1 | 1 | 5 |
| 23 | 61.5 | 160.9 | 1 | 5 |
| 25 | 68 | 170.3 | 2 | 5 |
| 30 | 88 | 196.9 | 2 | 10 |
| 35 | 120 | 228.1 | 2 | 10 |
| 40 | 167.5 | 259.4 | 5 | 10 |
| 45 | 227.5 | 284.4 | 5 | 10 |
| 50 | 315 | 303.1 | 10 | 10 |
| 55 | 460 | 318.8 | 10 | 10 |

**Sample Calculations**

H and B Values:

```
Hi = (n1/(Li*S)).*Vsi;
Bi = (R*C/(n2*Aci)).*Vci;
Hs = (n1/(Ls*S)).*Vss;
Bs = (R*C/(n2*Acs)).*Vcs;
```

Remanence and Coercive Forces:

```
remi = [];
coerci = [];
for i=1:length(Hi)-1
    if (Hi(i) >= 0 && Hi(i+1) < 0)
        remi(end + 1) = Bi(i);
        remi(end + 1) = Bi(i + 1);
    end

    if (Bi(i) >= 0 && Bi(i+1) < 0)
        coerci(end + 1) = Hi(i);
        coerci(end + 1) = Hi(i + 1);
    end
end
```

Iron Remanence (mean) = 0.838 +/- 0.003 T
Iron Coercive Force (SEM) = -252 +/- 1 A/m
Steel Remanence (mean) = 0.440 +/- 0.002 T
Steel Coercive Force (SEM) = -3390 +/- 10 A/m

Power Dissipated By Steel Sample:

```
Ps1 = (2.11e-2 - 1.24e-2)*2;
Ps2 = (2.11e-2 - 4.49e-3);
fs = 0.5*((1/Ps1)+(1/Ps2));
Ps_err = Ps * (0.002/Ls + Ac_err/Acs + 2/fs);
```

P = 100 +/- 6 W

Maximum Relative Permeability and Flux Density:

```
Uo = 4*pi*(10^-7); %http://physics.info/constants/
Ur = Bi4./Hi4./Uo;
Ur_err = Ur .* (Bi4_err./Bi4 +  Hi4_err./Hi4)./2;
Flux = Ur_max*Hi4(ind);
Flux_err = Flux .* (Ur_err(ind)./Ur_max  + Hi4_err(ind)./Hi4(ind))
```

Relative permeability= 1900 +/- 200 H/m
Calculated as: 333000 +/- 6000 N/(Am)