CHAPTER VII

CONDUCTIVITY AND POWER RELATION IN AN ARC PLASMA IN A TRANSVERSE MAGNETIC FIELD

7.1. INTRODUCTION

Conductivity and power relation in an arc plasma with current varying from 2.25 A to 4 A in a transverse magnetic field (zero to 1660 G) have been measured by double probe method at a pressure of 0.075 torr. It is well known when a magnetic field acts on a discharge, various changes such as an increase of equivalent pressure, a change of radial ion and electron density and a marked change in the voltage current characteristics take place. Some amount of work, both theoretical and experimental has been done. Allen (1951) observed in case of an arc plasma placed in a transverse magnetic field that the current voltage characteristics show a slight negative gradient over a wide range of current (25 A to 80 A) without magnetic field but became increasingly negative with increase of magnetic field. Goldman and White (1965) investigated the effect of magnetic field on arc stability and found that the field had no stabilising effect on the discharge but it increases the arc voltage drop. The effect of a variable transverse magnetic field on the voltage current characteristics and power relation in an arc plasma (arc current varying upto 2A) has been investigated by Sen and Das (1973) and a detailed mathematical analysis has been provided to explain the observed results. In order to extend the investigation to higher arc currents than that investigated by Sen and Das (1973) and to study the interaction of strong magnetic field with arc parameters, the present investigation has been undertaken.

7.2. EXPERIMENTAL SET-UP

A schematic diagram of the experimental arrangement has been shown in Fig. 7.1. The measurement has been carried out in a mercury arc plasma produced within a cylindrical glass tube of inner radius 0.9 cm and with two mercury pool electrodes 38.0 cm apart. The arc is run on a d.c. source (250 volts) with regulating rheostats in series. The background air pressure within the system has been maintained at 0.075 torr. Two cylindrical tungsten wires of 0.014 cm radius fitted in glass capsules with a bare tip of 0.1 cm length and 6.6 cm apart from each other have been placed at the axis of the tube. Voltage, current and conductivity between the two probes for four different arc currents namely 2.25, 2.5, 3.0 and 4.0 A in a transverse magnetic field have been measured by high impedance measuring meters. The magnetic field has been provided by an electromagnet energised by a stabilised power supply (type EM 20). The magnetic field which has been varied from 0 to 1660 gauss has been calibrated (Ref. fig. 2.8) with a gauss meter (Model G 14).

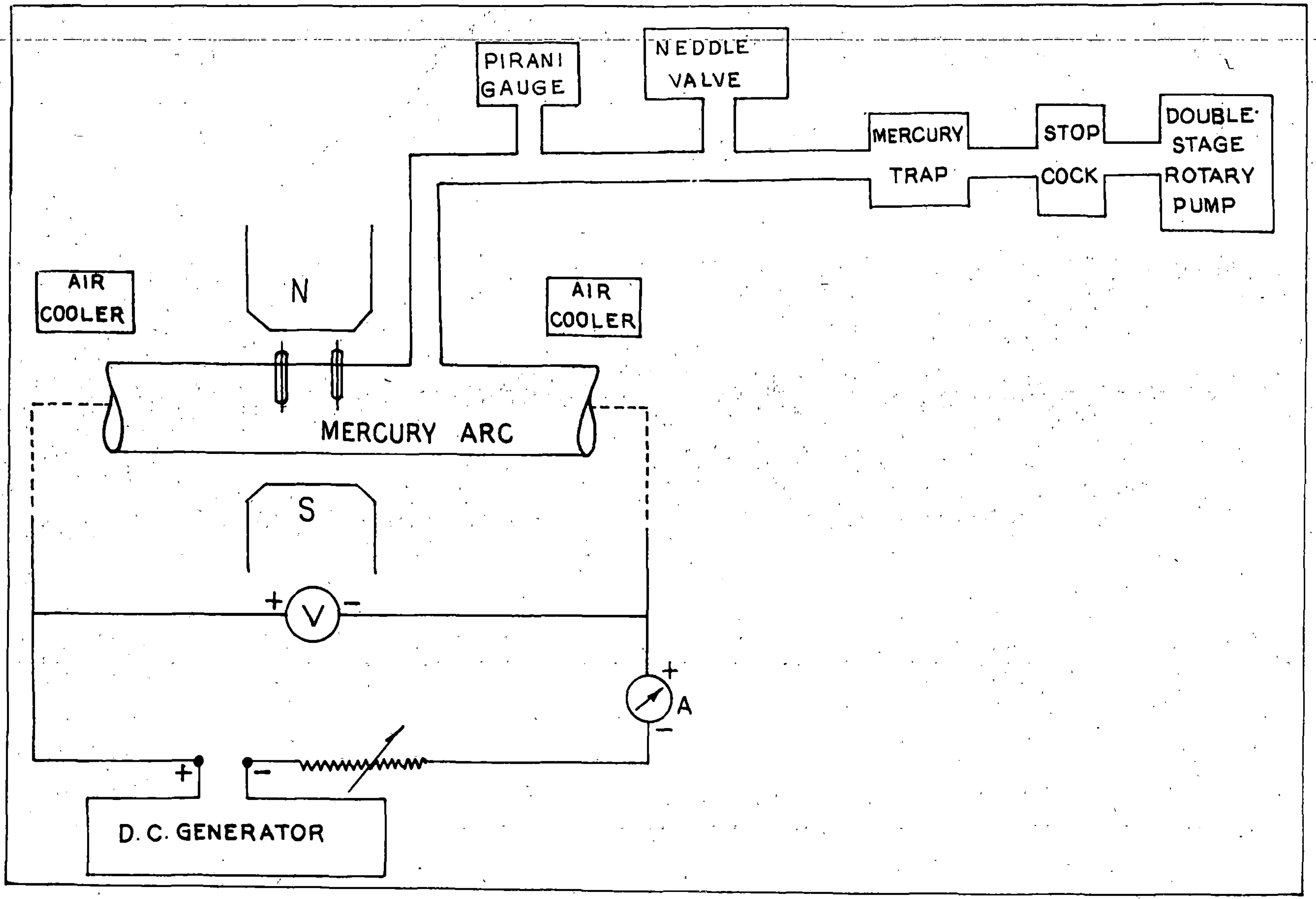

Fig. 7·1. Schematic diagram of experimental set-up in a transverse magnetic field.

7.3. RESULTS AND DISCUSSION

The variation of current and voltage in mercury arc plasma in a variable transverse magnetic field (0 to 1660 G) for arc currents (2.25 A, 2.5 A, 3A and 4 A) have been investigated. The voltage for all values of arc current increases and the arc current itself decreases with the increase of the magnetic field. The power consumed in the arc (central region) which is the product of voltage drop across the arc and the corresponding arc current shows a maximum for values of magnetic field which depends on the arc currents. The variation of power across the arc with magnetic field for different arc currents is shown in Fig. 7.2.

Besides the above set of experiments the conductivity of the arc plasma has been measured utilising a double probe placed in the central region of the positive column for the same values of magnetic field variation and for the same variation of arc current. The values of log σ/σ_H where σ and σ_H are conductivities without and with magnetic field have been plotted against the corresponding values of magnetic field for different initial arc currents in Fig. 7.3. It is evident from the nature of curves (Fig. 7.3) which are straight lines that the variation of σ/σ_H with magnetic field can be represented by an expression of the type

$$\sigma_H = \sigma \exp(-\alpha H) \tag{7.1}$$

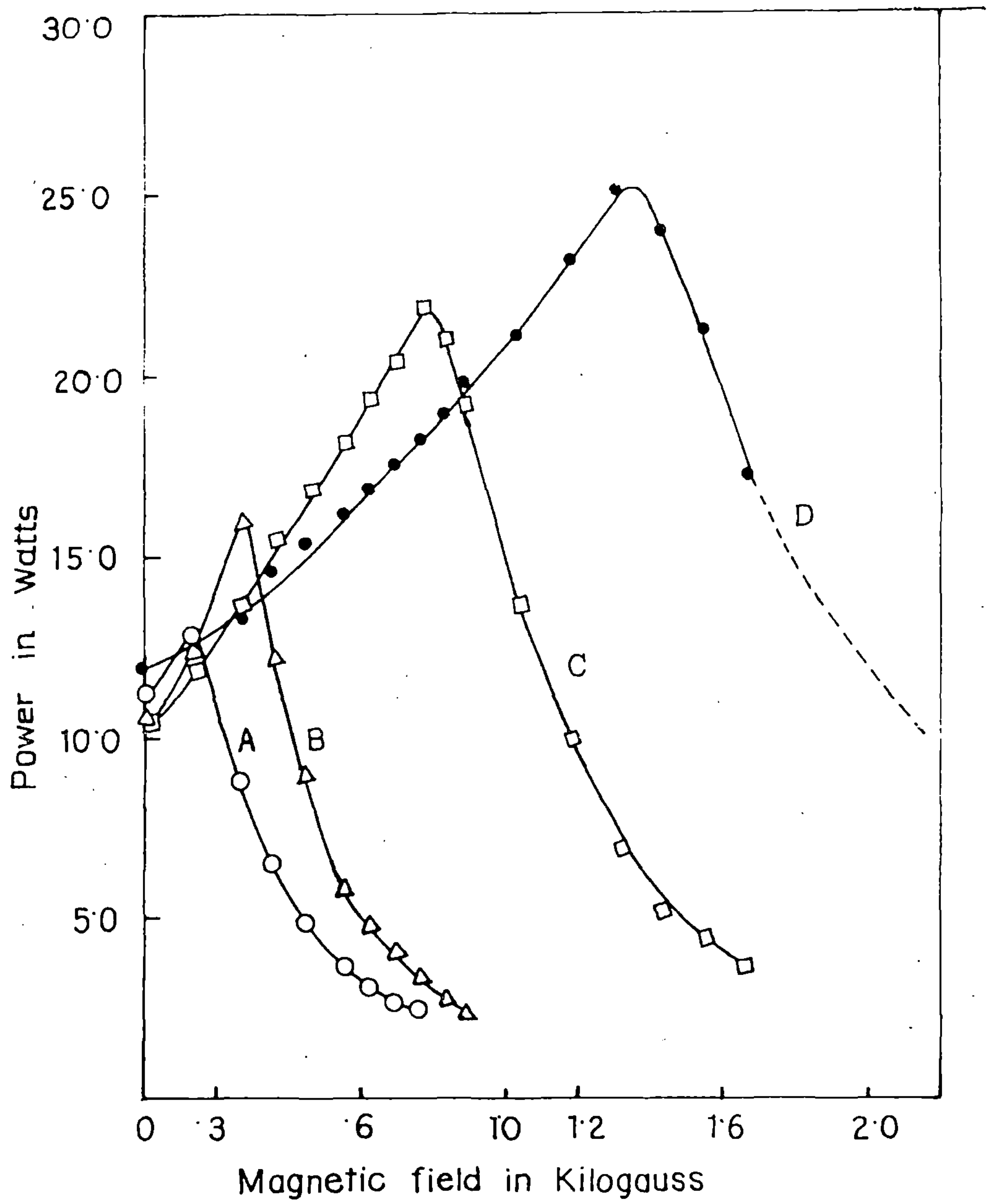

Fig. 7·2. Variation of output power with magnetic field for different values of arc current. A= 2·25A, B= 2·5A, C= 3·0A & D=4·0A.

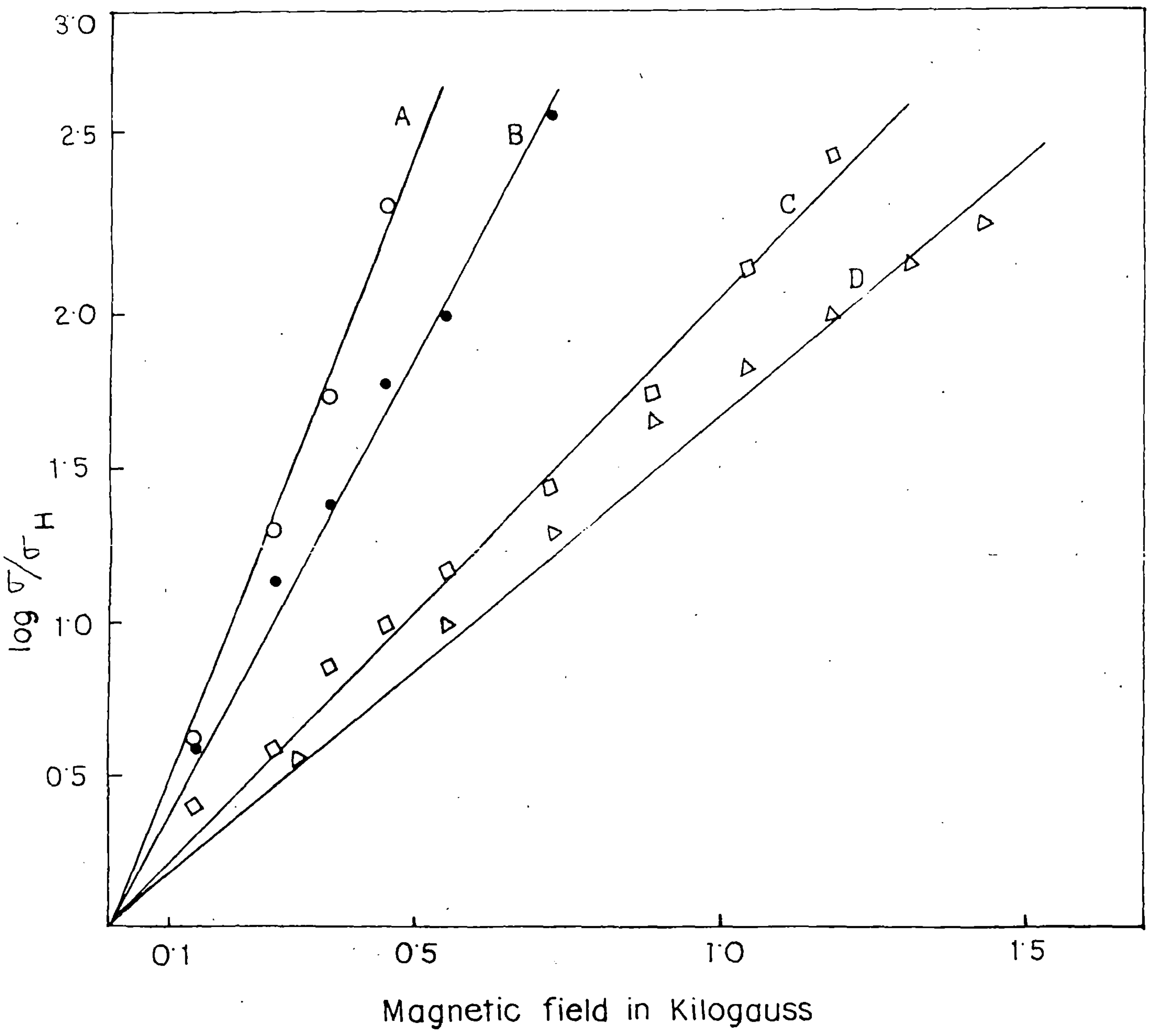

Fig. 7·3. Variation of log σ/σ_H with magnetic field.
A = 2·25A , B = 2·5A , C = 3·0A & D = 4·0A .

where 'a' is constant. Comparing with Beckman's (1948) expression as modified by Sen and Gupta (1971) it is evident that

$$a = \frac{e E C_1^{1/2} r}{2 K T_e P} \qquad (7.2)$$

where E is the voltage drop per unit length of the arc, $C_1 = (e/m \cdot L/v_r)^2$ where L is the mean free path of the electron in the gas at a pressure of 1.0 torr, v_r is the random velocity, T_e is the electron temperature, K is the Boltzmann constant and r is the radius for unit cross section around the axis of the arc. Taking E = 1.5V/cm as measured, $T_e = 25000^{\circ}K$ (Kerelina, 1942) and $p = 0.075$ torr, it is possible to calculate C_1 for different discharge currents as the value of "a" can be obtained from Fig.7.3. The results are presented in Table 7.1.

Table 7.1

Arc current A	$a \times 10^3$	$C_1 \times 10^6$
2.25	5.117	3.767
2.50	3.735	2.004
3.00	2.033	0.5946
4.00	1.659	0.3961

The values of C_1 are consistent with the values obtained earlier by Sen and Das (1973).

To explain the variation of power with magnetic field we have utilised the equation deduced by Sen and Das (1973). There it was assumed that the application of the magnetic field changes the electron temperature, axial field and radial electron density. They deduced that

$$\sqrt{\frac{T_{eH}}{T_e}}\exp\left(\frac{eV_i}{K}\,\frac{T_{eH}-T_e}{T_e T_{eH}}\right) = \frac{1}{\sqrt{\left(1+C_1 H^2/p^2\right)}} \tag{7.3}$$

where T_{eH} — electron temperature in presence of transverse magnetic field

V_i — the ionisation potential of the gas

P — the pressure

H — magnetic field.

From experimental evidence it is known that $T_{eH}/T_e < 1$ and for values of T_{eH} not much different from T_e

$$T_{eH} = T_e + \frac{2T_e^2 \log\left[\frac{1}{\sqrt{\left[1+C_1(H^2/p^2)\right]}}\right]}{T_e + \frac{2eV_i}{k}}$$

or

$$\frac{T_{eH}}{T_e} = 1 + \gamma \log\left[\frac{1}{(1+C_1 H^2/p^2)^{1/2}}\right] \tag{7.4}$$

where $\gamma = \dfrac{2T_e}{T_e + \frac{2eV_i}{k}}$

With the help of eqn. (7.4) Sen and Das (1973) deduced expressions in magnetic field for arc current as well as arc voltage as follows:

$$\frac{I_H}{I} = \frac{\exp(-aH)}{\left[1 + \gamma \log\left(\frac{1}{\sqrt{[1 + C_1 (H^2/p^2)]}}\right)\right]^{1/2}} \tag{7.5}$$

and

$$\frac{E_H}{E} = \left(1 + C_1\, H^2/p^2\right)^{1/2} \tag{7.6}$$

If W_H and W represent the power with and without the magnetic field, we have

$$\frac{W_H}{W} = \exp(-aH)\, \frac{\left[1 + C_1 H^2/p^2\right]^{1/2}}{\left[1 + \gamma \log\left(\frac{1}{\sqrt{[1 + C_1 (H^2/p^2)]}}\right)\right]^{1/2}}$$

Maximising W_H with respect to H

$$\frac{1}{W}\,\frac{dW_H}{dH} = -a\left[1 + C_1 H^2/p^2\right] + C_1 \frac{H}{p^2} + \frac{(\gamma/2)\, C_1 (H/p^2)}{1 - \gamma \log\sqrt{[1 + C_1 (H^2/p^2)]}}$$

$$= 0$$

The term $\gamma \log\sqrt{[1 + C_1 (H^2/p^2)]}$ can be neglected in comparison to unity. Hence

$$a H^2 - (1 + \nu/2) H + \frac{a p^2}{C_1} = 0$$

$$\text{or} \quad H_{max} = \frac{(1+\nu/2) \pm \sqrt{[(1+\nu/2)^2 - (4a^2/C_1)p^2]}}{2a} \qquad (7.7)$$

where H_{max} is the magnetic field at which the power consumed becomes a maximum. Taking the values of "a" and C_1 from Table 7.1 the values of H_{max} have been calculated and results entered in Table 7.2.

Table 7.2

Arc current A	γ	a x 10^3	C_1x10^3	H_{max}	H_{max} (expt)
2.25	0.1887	5.117	3.767	196.5	146
2.50	0.1887	3.733	2.004	283.1	275
3.00	0.1887	2.033	0.5946	520.2	760
4.00	0.1887	1.659	0.3961	637.5	1310

The results therefore indicate that the agreement is quite satisfactory for smaller values of magnetic field, but discrepancy arises for higher magnetic field values. Similar results were also obtained in the earlier work by Sen and Das (1973). The disagreement observed for higher values of current and magnetic field may be attributed to the fact that the effect of magnetic field on the motion of the electron is linear for smaller values of magnetic field but involves squares and higher powers of magnetic field when it is high (Sen and Gupta, 1971) and equation (7.7) has been deduced on the assumption that the magnetic field is small and terms involving higher powers of magnetic field have not been taken into consideration. It is expected that when higher power terms are also considered better agreement will result.

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CAPTION FOR FIGURES

Fig. 7.1 - Schematic diagram of experimental setup

Fig. 7.2.- Variation of output power with magnetic field for different values of arc current

A = 2.25 A

B = 2.5 A

C = 3.0 A

D = 4.0 A

Fig. 7.3 - Variation of Log σ/σ_H with magnetic field

A = 2.25 A

B = 2.5 A

C = 3.0 A

D = 4.0 A