CHAPTER VI

VOLTAGE CURRENT CHARACTERISTICS OF LOW CURRENT ARCS IN AIR WITH METAL ELECTRODES

6.1. INTRODUCTION

The variation of voltage and current in an arc plasma with Ag-Ag, Cu-Cu, Fe-Fe and Ag-Cu electrode systems have been investigated varying the electrode separation distance from zero upto 0.5 cm in air at atmospheric pressure. The investigation of the properties of low current arcs has been carried out over a wide range of arc currents with different metal electrodes. Considerable amount of information has been collected by different workers on measured arc characteristics (low intensity arcs) (Ayrton, 1902), Nottingham, 1926; Eberhart and Seban, 1966) to establish empirical relations of the form $V_a = f(I)$ where V_a is the voltage across the arc and $f(I)$ is a function of the arc current. An analysis of these empirical relations cannot however, provide the values of the parameters of the arc plasma such as cathode and anode fall, contact potential and other allied properties. High current arcs are increasingly being utilised for the study of scattering of light specially from a CO_2 laser and also for use in laser plasma interaction studies. Pasternak and Offenberger (1975) have carried out probe and spectroscopic measurements in high density d.c. argon arc plasma and have obtained the values of electron density and electron temperature.

The object of the present investigation is to study the voltage current characteristics in arc plasma produced under atmospheric pressure and to calculate some parameters of the plasma after a systematic analysis of the results.

6.2. EXPERIMENTAL SETUP

In this investigation the work has been carried out with arcs using four different types of electrodes, viz. (a) silver-silver, (b) copper-copper, (c) iron-iron and (d) silver-copper (silver being the anode and copper the cathode in the last case). A d.c. source (100V) with an adjustible rheostat and an ammeter (0-5A) is used to excite the arc. The arc current is varied from 2 to 5A and measurements were made for 2, 3, 3.5, 4, 4.5 and 5A. (A detailed experimental arrangement has been discussed in the article 2.9). The experiment consists in measuring the arc current and arc voltage (voltage across the arc) for various electrode separations starting from $x = 0.025$ to $x = 0.5$ cm where x is the electrode separation. The experiment has been repeated with different initial arc currents (I = 2, 3, 3.5, 4, 4.5 and 5A). The tips of the electrodes were photographed and the diameter of the tips was obtained from measurements made with a travelling microscope. The last measurement was necessary to obtain the cross section of the arc plasma so as to calculate its conductivity. All the measurements have been carried out at the atmospheric pressure.

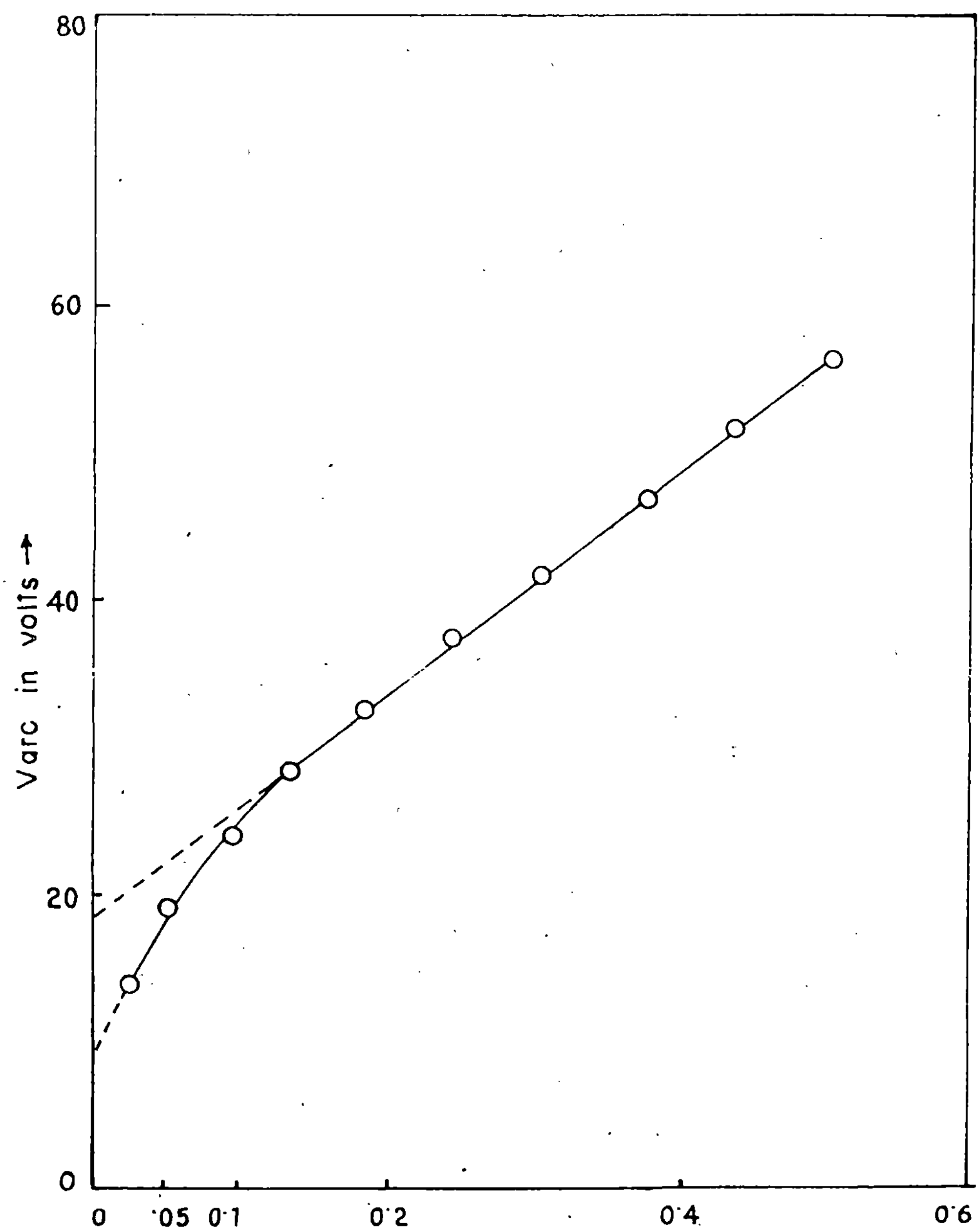

Fig.6·1.

Variation of arc voltage with electrode separation Ag-Ag.

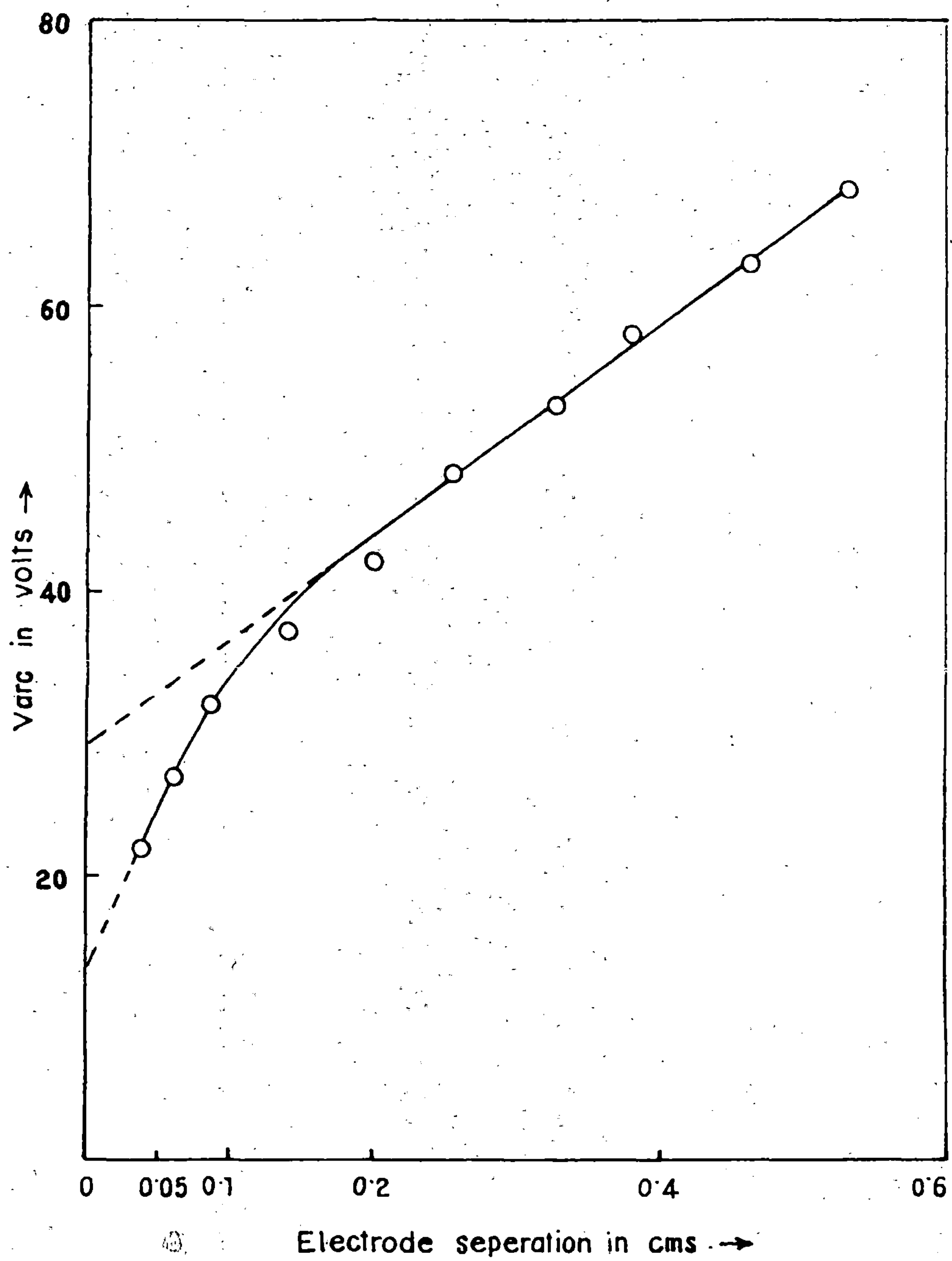

Fig.6.2

Variation of arc voltage with electrode separation Cu-Cu.

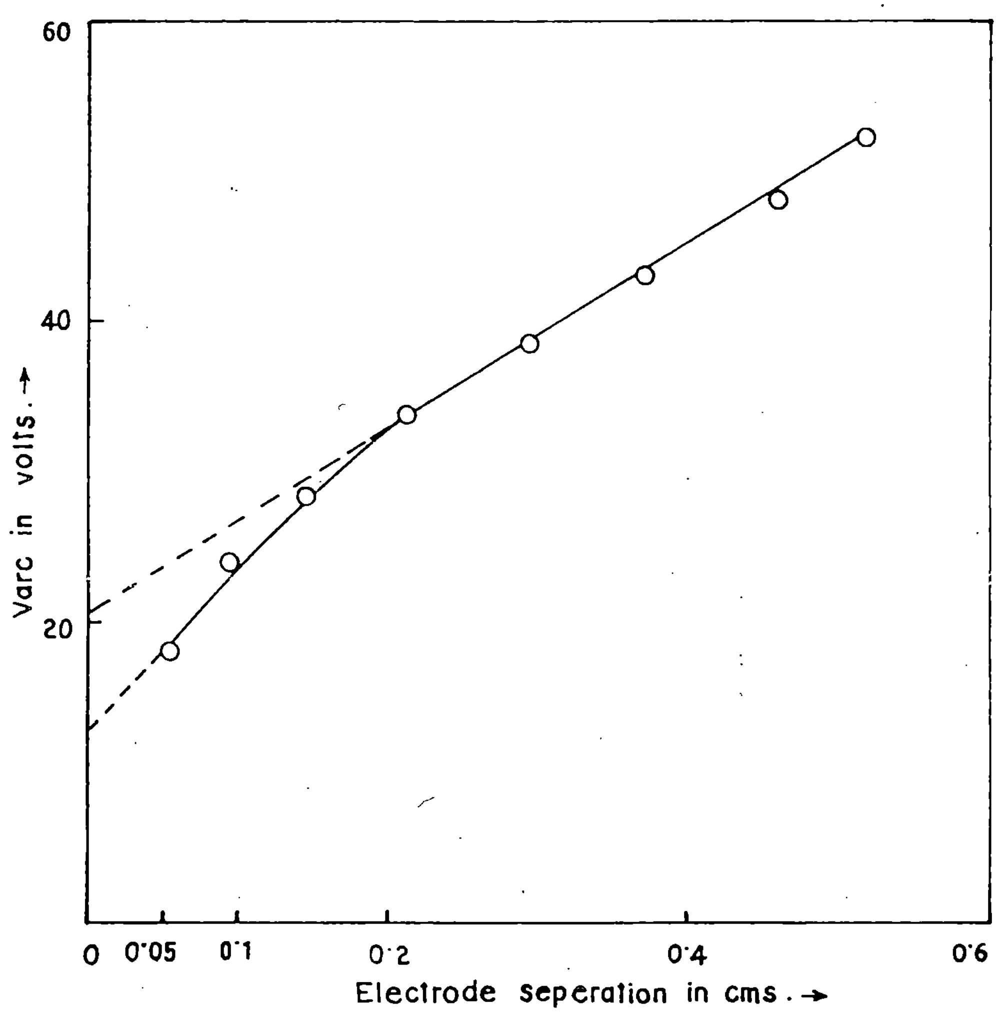

Fig.6·3.

Variation of arc voltage with electrode separation Fe-Fe.

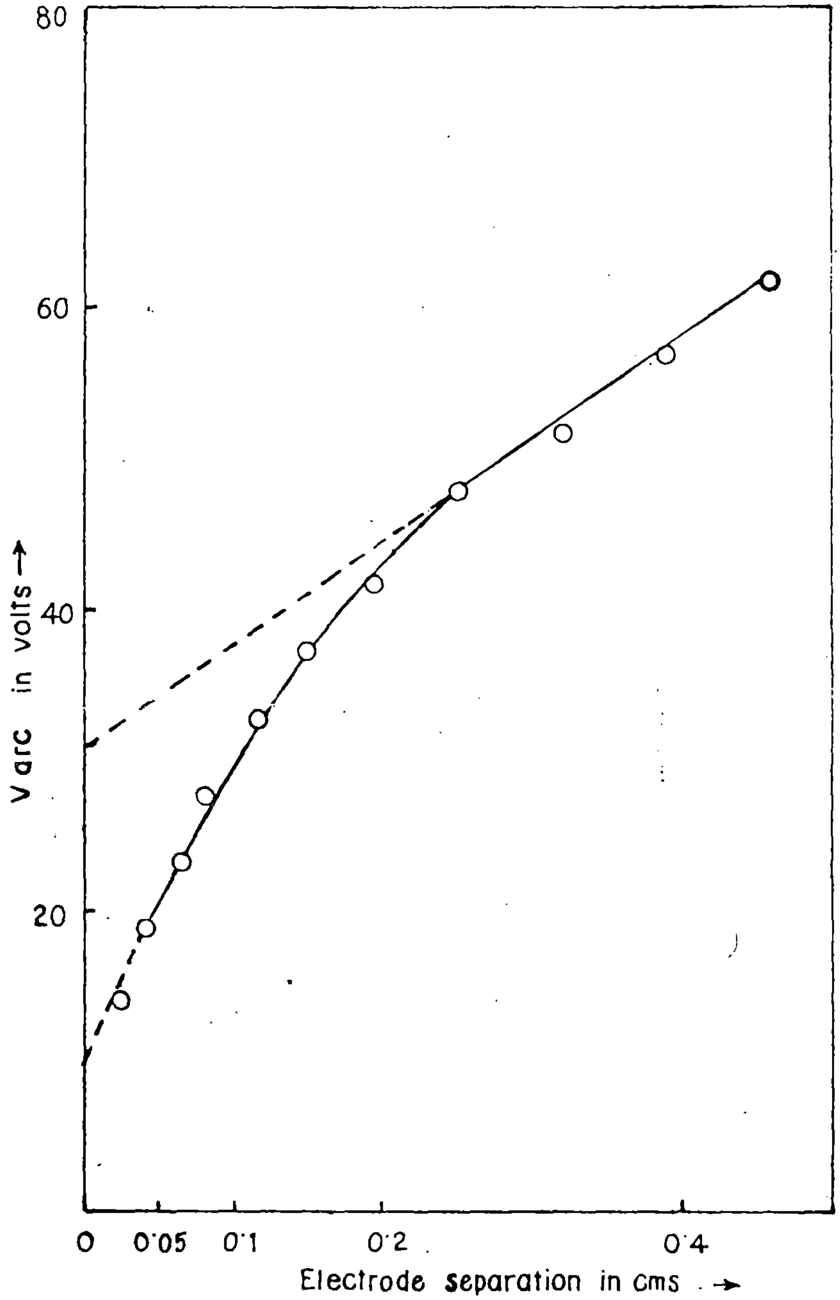

Fig.6·4.

Variation of arc voltage with electrode separation Ag-Cu.

6.3. RESULTS AND DISCUSSION

6.3.1. Calculation of cathode and anode fall:

Variation of arc voltage with electrode separation has been plotted for different electrodes such as Ag-Ag, Cu-Cu, Fe-Fe and Ag-Cu for an initial arc current of 4A (Figs. 6.1 to 6.4). In the last case Ag is the anode and Cu the cathode. It has been observed that for small electrode separation, the curve rises rapidly and then there is the linear increase of arc voltage with electrode separation. The total arc voltage V_A can be represented by an expression

$$V_A = V_C + V_P + V_a \qquad (6.1)$$

where

V_C - cathode fall

V_P - total fall of voltage at the positive column

V_a - anode fall.

The linear rise of the upper portion of the curve reveals that the positive column has become uniform whereas the longitudinal electric field is constant. In the arc plasma analysis, the linear portion of the curve has been extrapolated to $x = 0$ where x is the electrode separation and the intercept for $x = 0$ along the Y axis will give the sum of the cathode and anode falls.

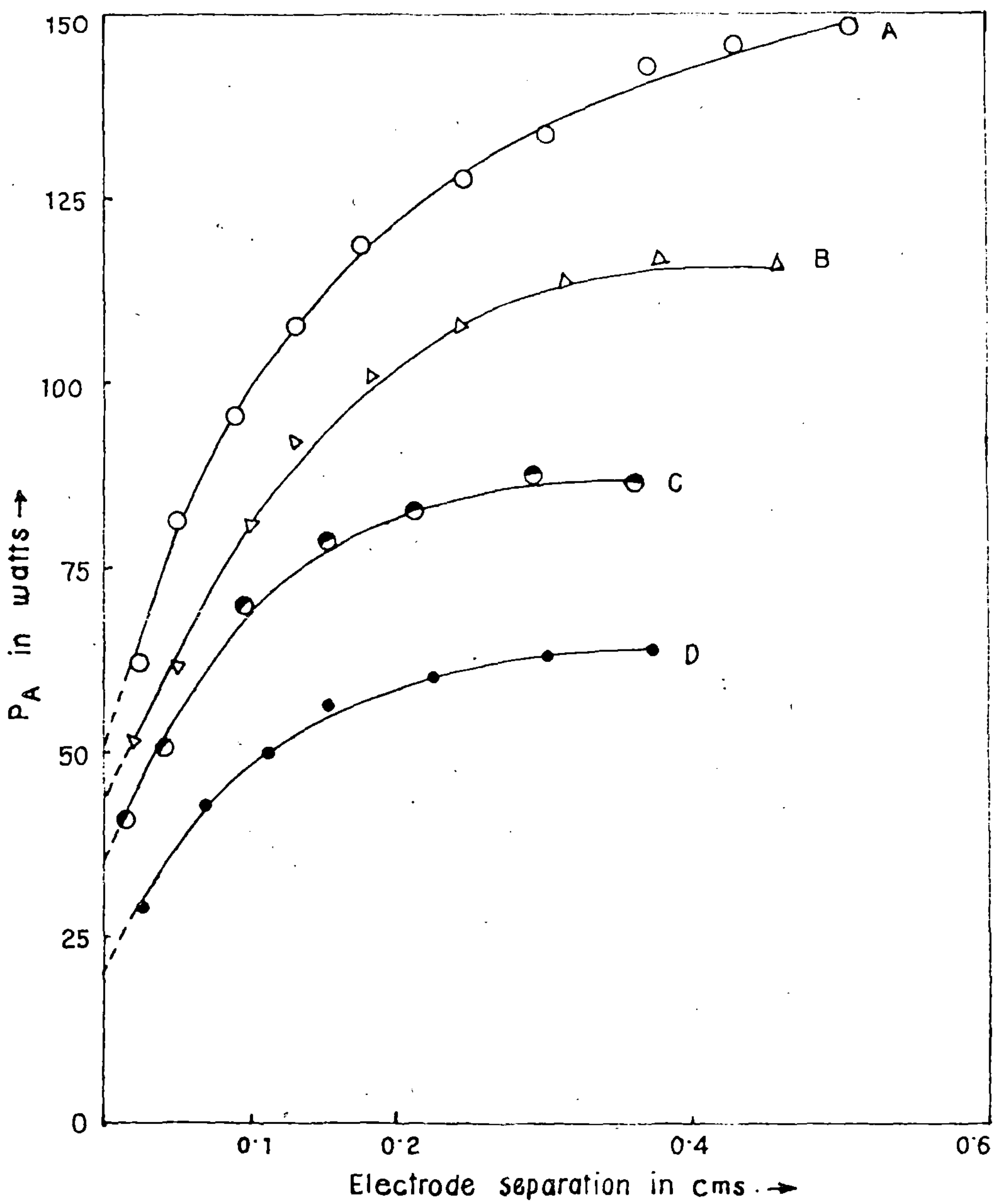

Fig. 6·5.

Variation of power developed at arc with electrode separation Ag-Ag.
(A: 5A, B: 4A, C: 3A ε D: 2A)

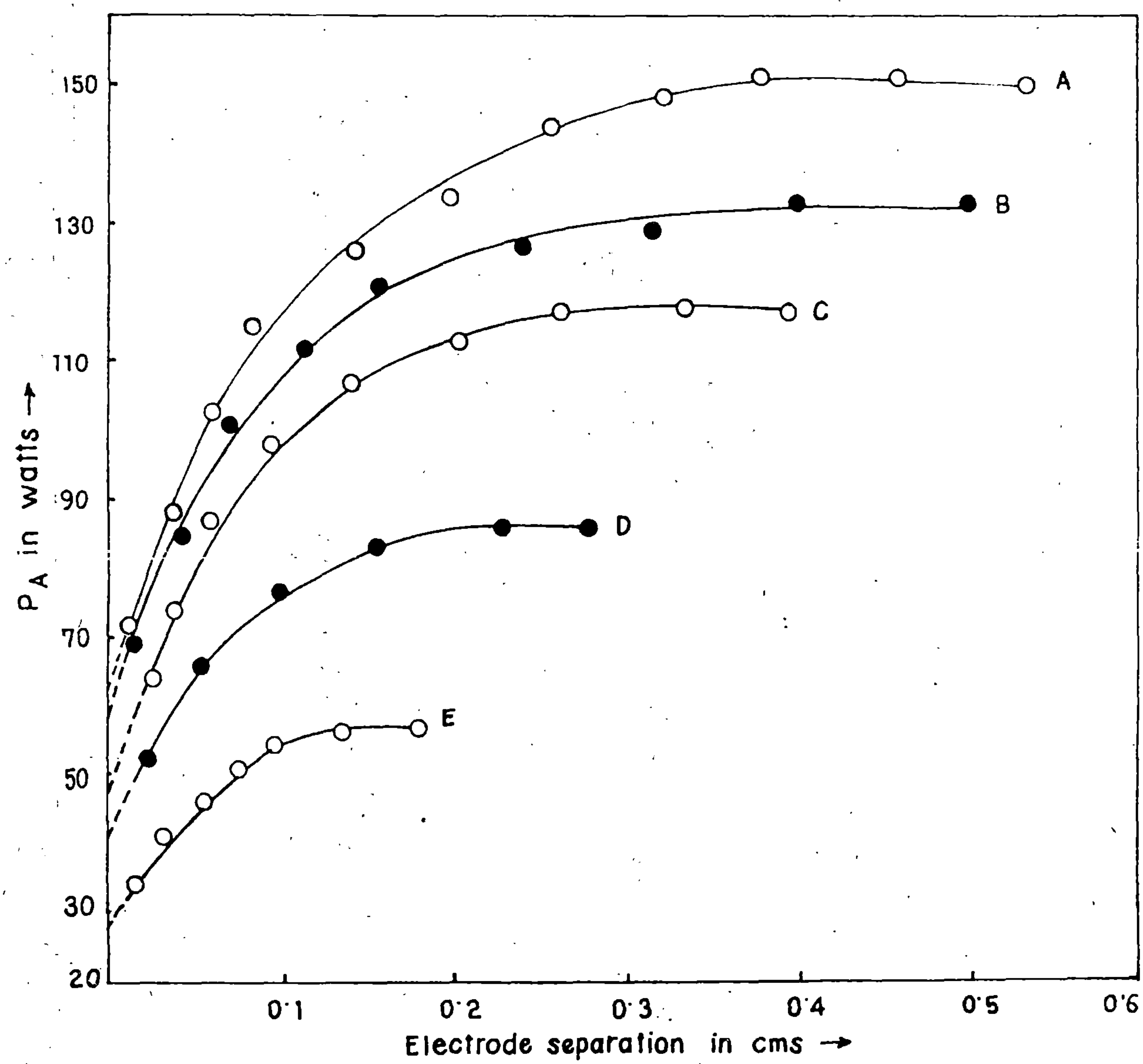

Fig. 6·6.

Variation of power developed at arc with electrode separation Cu-Cu.

(A : 5A, B: 4A, C: 4A, D: 3A & E: 2A)

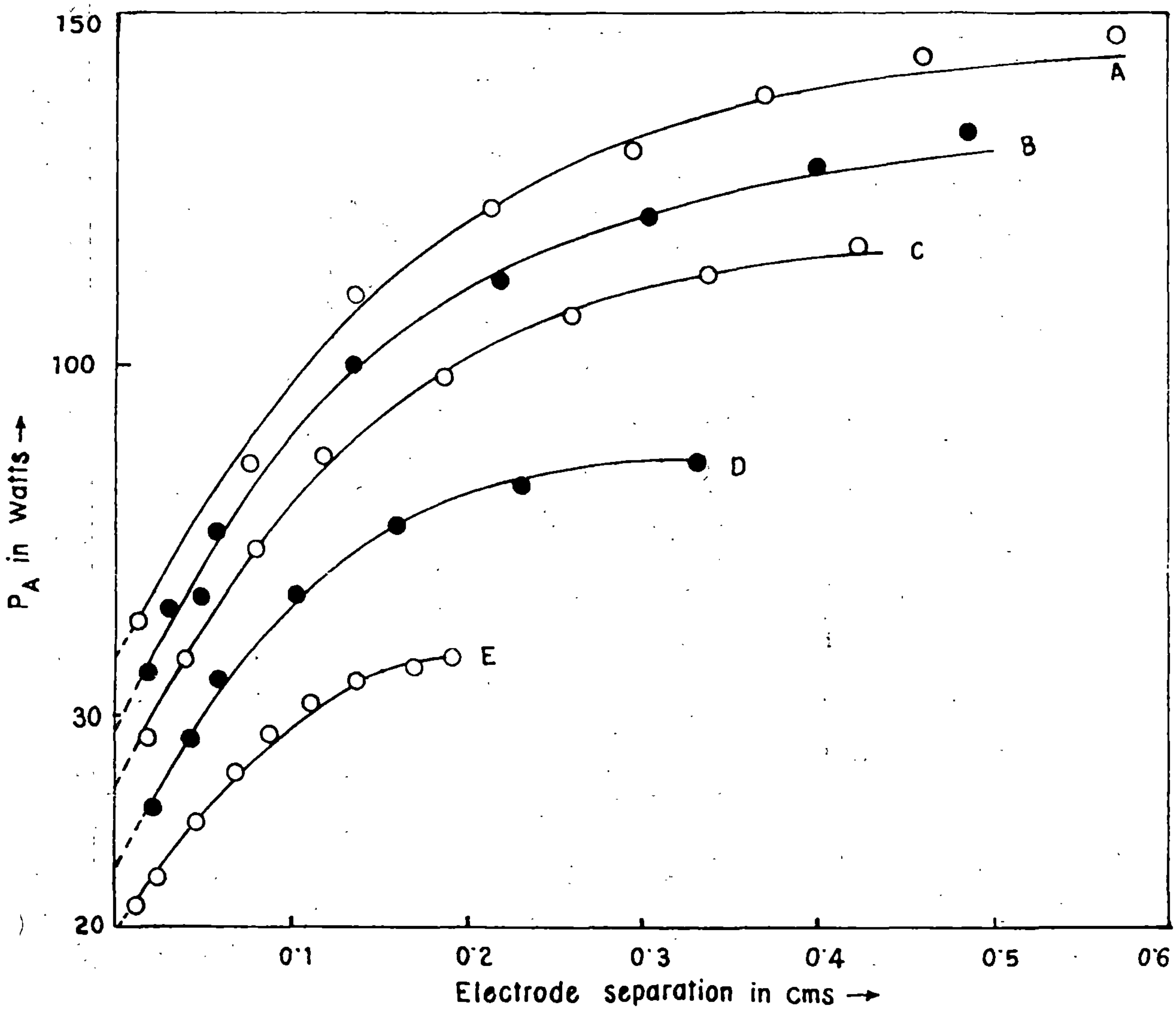

Fig.6·7.

Variation of power developed at arc with electrode separation Fe-Fe.

(A: 5A, B: 4.5A, C: 4A, D: 3A & E: 2A)

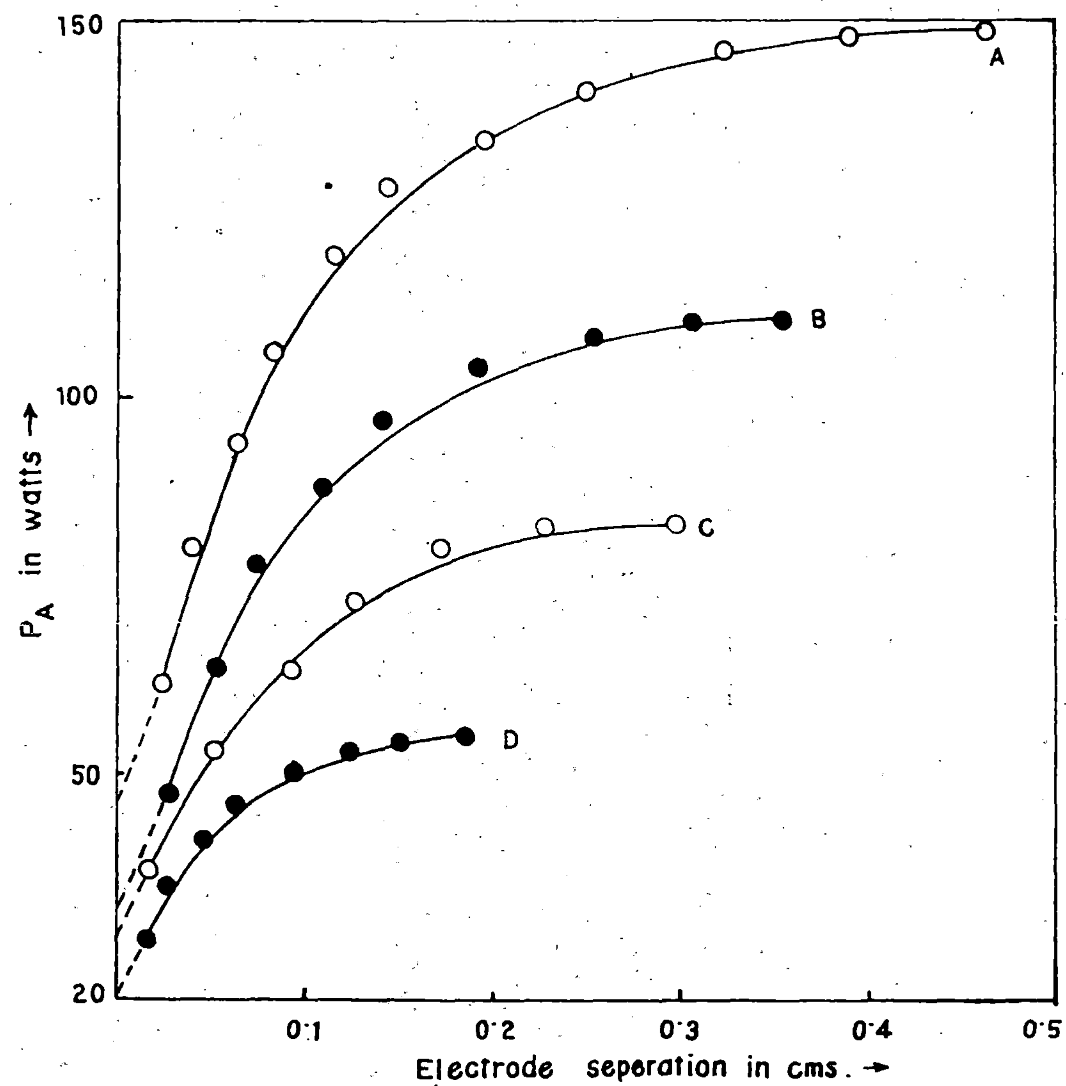

Fig.6.8.

Variation of power developed at arc with electrode separation Ag-Cu.

(A: 5A, B: 4A, C: 3A and D: 2A)

Table 6.1

Electrode	Medium	V_c(V)	V_a(V)
Ag-Ag	Air	9 - 9.5	9.5 - 10
Cu-Cu	Air	10 - 10.5	17.5 - 18
Fe-Fe	Air	9 - 11	10 - 10.5
Ag -Cu	Air	12 - 12.5	11 - 11.5

The non-linear portion of the curve can be similarly extrapolated to $x = 0$ and the intercept will give the value of cathode fall. Hence anode fall can also be calculated. In this way, the values of cathode and anode fall for different types of electrodes have been calculated and results have been presented in Table 6.1. The results indicate that the values of cathode and anode fall as calculated, are consistent (von-Engel, 1965).

6.3.2. Calculation of contact potential difference at the electrode:

As the arc voltage and arc currents for different electrode separations have been measured, it is possible to calculate the power developed across the arc. The variation of power developed at the arc with separation of electrodes has been plotted for Ag - Ag, Cu-Cu, Fe-Fe and Ag-Cu electrodes. These curves have been shown in figures 6.5, 6.6, 6.7 and 6.8, for different arc currents, (2 to 5A).

It is evident that for $x = 0$, (where x is the distance between the two electrodes) the extrapolation of the curves will give the value of power loss at the electrodes when they are in contact. As the total power drawn from the d.c. source (100V) and power loss at the electrodes are known when they are in contact, from extrapolation of the curves the loss of power at the external resistance R_r can be obtained and hence the value of R_r for different currents can be calculated. Similarly dividing the power loss at the electrodes by the corresponding current, contact potential difference for different electrodes can be calculated. The value of R_r has been calculated as it is necessary to find x_{max} (the value of x at which the power developed at the arc becomes a maximum). The results are presented in Table 6.2 for different electrode systems and are currents.

Table 6.2

Arc current A	P_i W	P_0 W	$P_R = (P_0 - P_i)$ W	R_r Ω	$V_{contact}$ V
Ag-Ag electrode system					
5	50	500	450	18.00	10.0
4	42	400	338	22.37	10.2
3	34	300	266	29.55	11.3
2	21	200	179	44.75	10.5
Cu-Cu electrode system					
5	63	500	437	17.48	12.6
4.5	58	450	392	19.36	12.8
4	48	400	352	22.00	12.2
3	38	300	262	29.80	12.66
2	24	200	176	44.00	12.0
Fe-Fe electrode system					
5	52	500	448	17.93	10.40
4.5	47	450	403	19.90	10.44
4	42	400	358	22.38	10.50
3	30	300	270	30.00	10.00
2	20	200	180	45.00	10.50
Ag-Cu electrode system					
5	45	500	455	18.20	9.0
4	34	400	364	22.68	8.5
3	28	300	272	30.22	9.3
2	18	200	182	45.50	9.0

where P_i = power loss at the electrodes when they are in constant,

P_O = power drawn from the source,

P_R = power loss at the external resistance,

$V_{contact}$ = the contact potential at the electrodes.

It is thus observed that for different values of arc current, the contact potential difference is almost a constant for a pair of electrodes though it varies with the nature of electrodes which is generally expected. The values of R_r as calculated from the extrapolation of the curve showing the variation of power developed across the arc with distance is also found to be consistent with the value obtained by direct measurement. This indirect method for the computation of R_r and its consistency with the direct measurement justifies the procedure adopted here for the calculation of $V_{contact}$, the contact potential.

6.3.3. Variation of P_A (power generated at arc) with electrode separation:

From the nature of the variation of P_A with electrode separation as depicted in figs. 6.5, 6.6, 6.7 and 6.8, it is evident that the curves show a tendency of saturation at a certain electrode separation depending upon the nature of electrodes and the value of arc current. To find out the variation quantitatively the following analysis has been made.

At any arc voltage V_A and arc current, I_A,

$$P_A = V_A I_A = V_A^2 / R_a \tag{6.2}$$

$$V_A = V_S - I_A R_r \tag{6.3}$$

where V_S is the source voltage, R_r the external resistance, and R_a is the arc resistance. The eqn. (6.3) can be simplified as

$$V_A = V_S - \frac{V_A}{R_a} R_r$$

$$V_A \left(1 + \frac{R_r}{R_a} \right) = V_S$$

$$V_A = \frac{V_S}{\left(1+ \frac{R_r}{R_a}\right)} \tag{6.4}$$

So,

$$P_A = \frac{V_S}{\left(1 + \frac{R_r}{R_a}\right)^2 R_a}$$

$$= \frac{V_S^2 R_a}{(R_a + R_r)^2}$$

$$= \frac{V_S^2 \rho x/S}{(\rho x/S + R_r)^2} \tag{6.5}$$

as $R_a = \rho x / S$ where ρ is the specific resistance, x the exlectrode separation and S the area of cross section.

Differentiating P_A with respect to x we get

$$\frac{dP_A}{dx} = \frac{(\rho x/S + R_a)^2 V_s^2 \rho/S - 2V_s^2 \rho x/S\,(\rho x/S + R_a)\rho/S}{(\rho x/S + R_a)^4}$$

Maximising we get

$$\rho x/S + R_r = 2x\rho/S$$

$$x_{max} = R_r S/\rho = R_r S \sigma \qquad (6.6)$$

where S is the area of cross section, σ is the conductivity of the arc plasma, R_r the value of the external resistance and x_{max} is the value of x for which the power developed at the arc shows a tendency of maximisation.

6.3.4. Calculation of conductivity:

It is evident from the nature of the curves showing variation of arc voltage with electrode separation that in the linear portion of the curve, the electric field is almost a constant and actual calculation shows that R_a/x, is constant. It however, depends upon the nature of the electrodes and also upon the strength of the arc current. The diameter of the cross section of the tips of electrodes before exciting the arc was measured by a travelling microscope. Then the arc was excited for a minute for taking the usual measurements. The diameter was again measured after cooling the electrodes. The average value of cross section of the electrodes come out to be $S = 0.1617$ cm^2. The cross -

section of the tips of the electrodes has been assumed to be equal to arc plasma cross section. The values for x_{max} shown in the last column in Table 6.3 have been calculated from the relation $x_{max} = R_r S \sigma$.

Table 6.3

Current A	$R_a/x\Omega cm^{-1}$	S cm^2	σ mhos Cm^{-1}	x_{max} cm
		Ag - Ag		
2	280.90	0.1617	0.02202	0.1592
3	125.33	0.1617	0.04938	0.2359
4	62.47	0.1617	0.09902	0.3437
5	36.90	0.1617	0.16770	0.4879
		Cu - Cu		
2	360.00	0.1617	0.01718	0.1201
3	169.44	0.1617	0.03652	0.1694
4	101.80	0.1617	0.06080	0.2162
5	64.54	0.1617	0.09583	0.2708
		Fe-Fe		
2	281.50	0.1617	0.02198	0.1599
3	122.14	0.1617	0.05066	0.2475
4	64.74	0.1617	0.09576	0.3483
5	38.55	0.1617	0.1604	0.4649
		Ag - Cu		
2	277.43	0.1617	0.02228	0.1621
3	134.93	0.1617	0.04585	0.2241
4	81.90	0.1617	0.07553	0.2808
5	55.98	0.1617	0.11050	0.3250

Values of R_r calculated for different electrodes for different arc currents have been shown in Table 6.2. Though the experimental results (Figs. 6.5, 6.6, 6.7 and 6.8) do not show any maximum, still the tendency of saturation is evident in each curve and the electrode separation at which the process of saturation sets in is in satisfactory agreement with the value of x_{max} calculated.

6.3.5. Arc voltage arc current characteristics:

The variation of arc voltage with arc current for different electrode separations is shown in the Figs. 6.9, 6.10, 6.11 and 6.12 for Ag-Ag, Cu-Cu, Fe-Fe and Ag-Cu electrodes respectively. It is observed that the average arc voltage decreases with the increase of the arc current at constant electrode gap. The slope of each curve is negative for the range of current investigated. It is also observed that curve moves upwards with the increase in electrode gap. Now the relationship between arc voltage and arc can be written as

$$V_a = C_g I_a^m \tag{6.7}$$

where C_g is a function of electrode gap. The value of the exponent m can be obtained by log plot of arc voltage against arc current. The variation has been plotted for different electrode system in Figs. 6.13, 6.14, 6.15 and 6.16. The results are shown in Table 6.4.

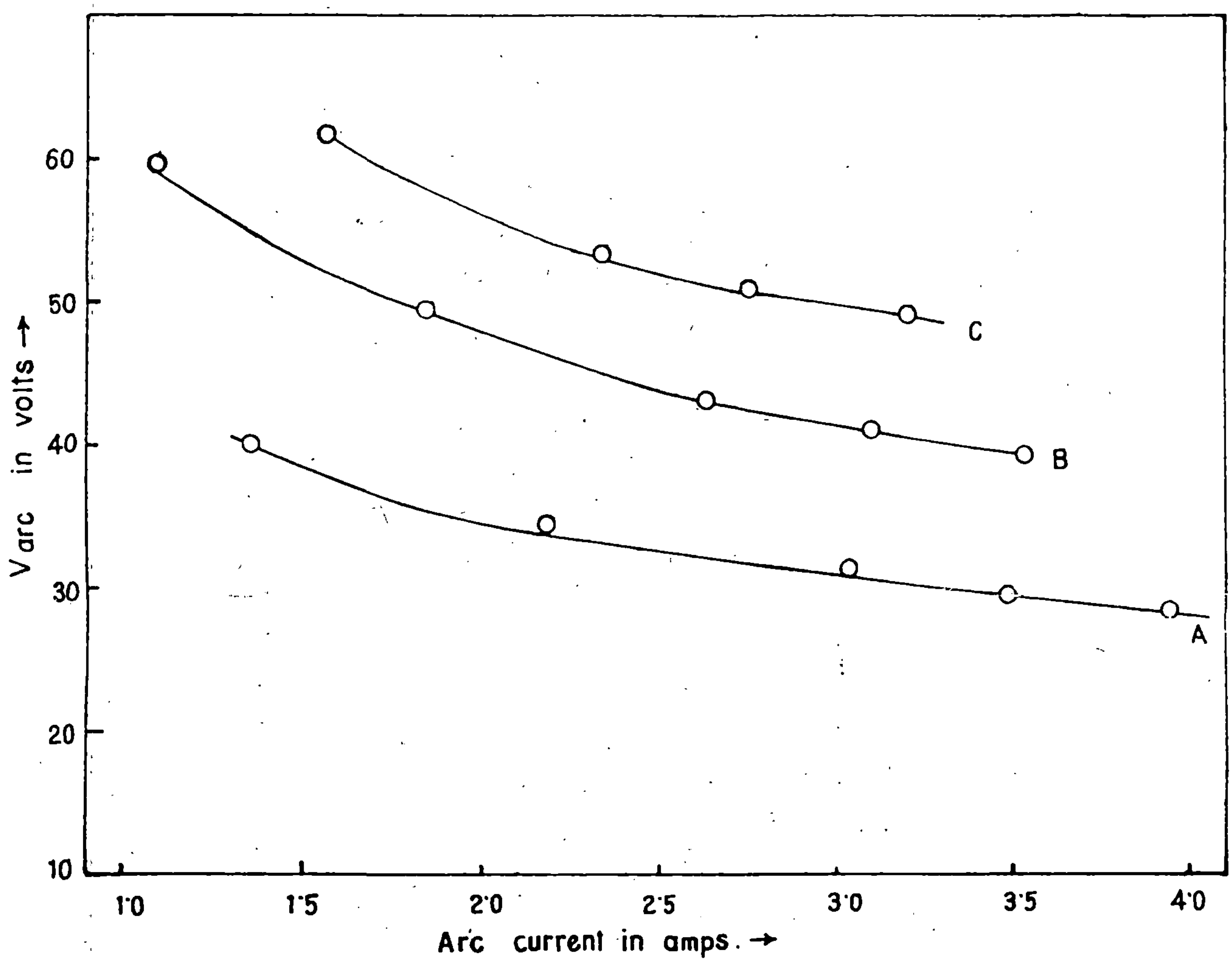

Fig. 6·9.

Variation of arc voltage with arc current Ag-Ag

(A: 0.1 cm, B: 0.2 cm, & C: 0.3 cm).

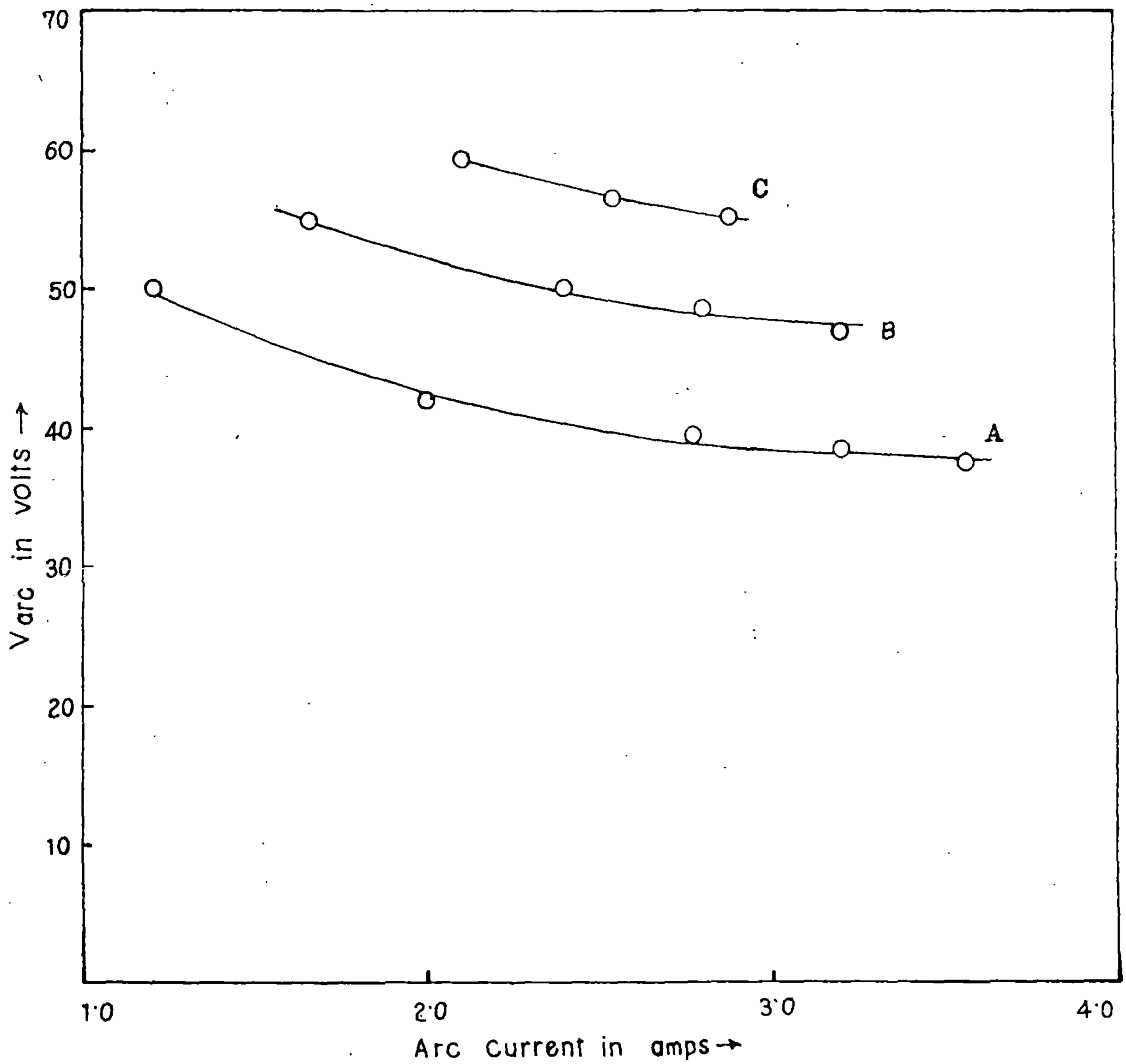

Fig. 6·10.

Variation of arc voltage with arc current Cu-Cu

(A: 0.1 cm, B: 0.2 cm & C: 0.3 cm)

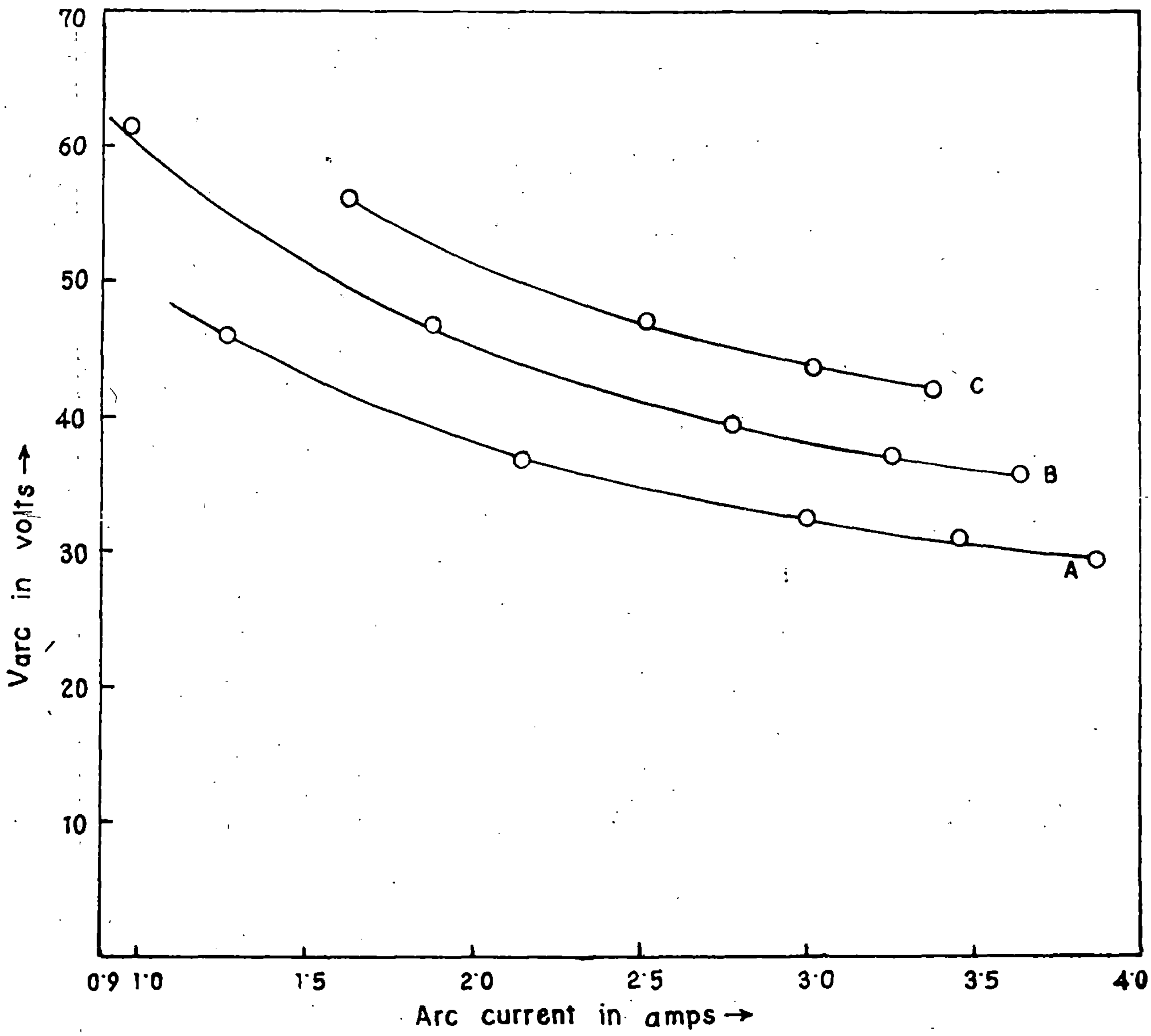

Fig. 6·11 .

Variation of arc voltage with arc current Fe-Fe

(A: 0.12, B: 0.2 cm & C: 0.3 cm)

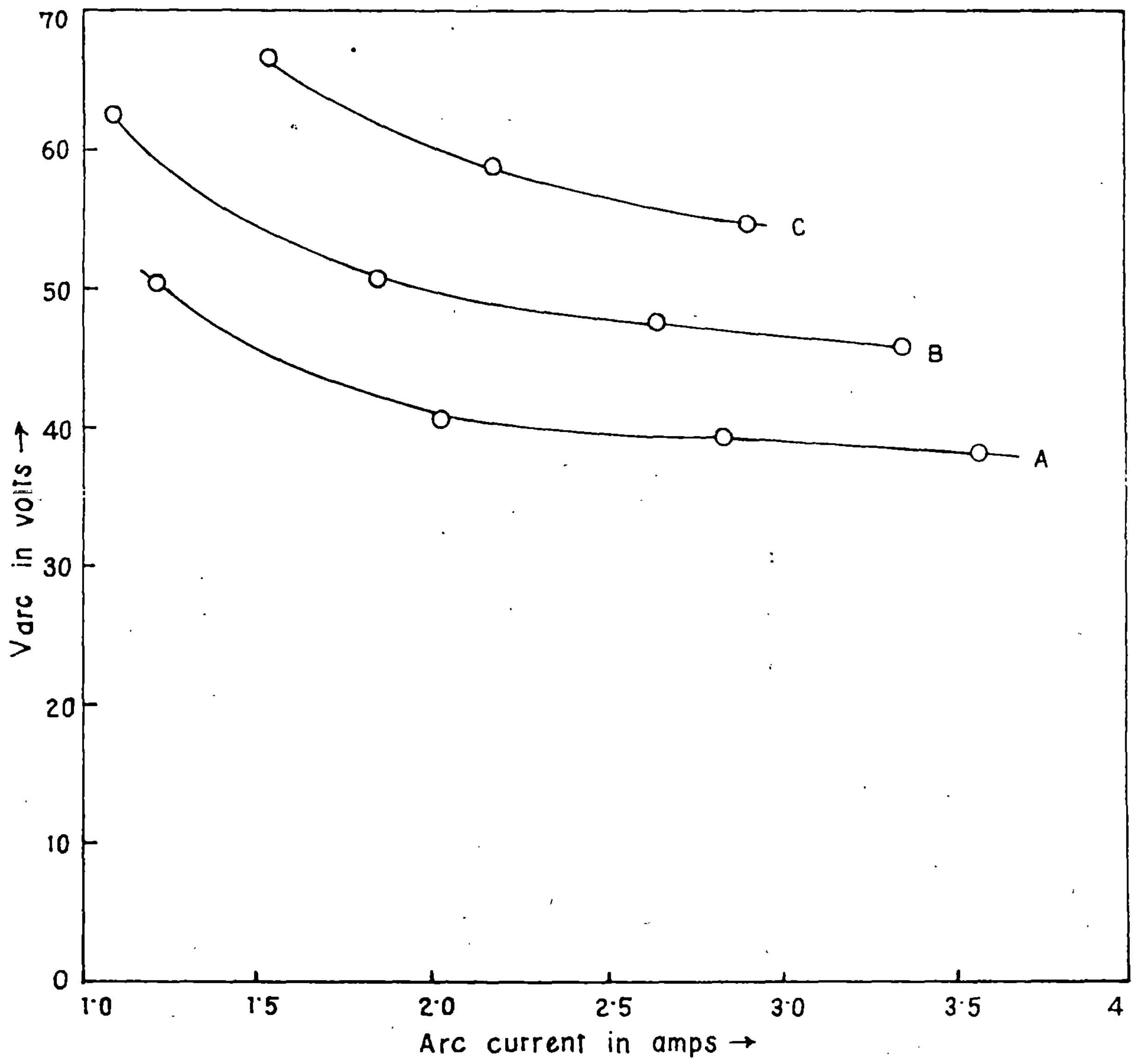

Fig. 6·12.

Variation of arc voltage with arc current Ag-Cu

(A: 0.12 cm, B: 0.18 cm & C: 0.28 cm).

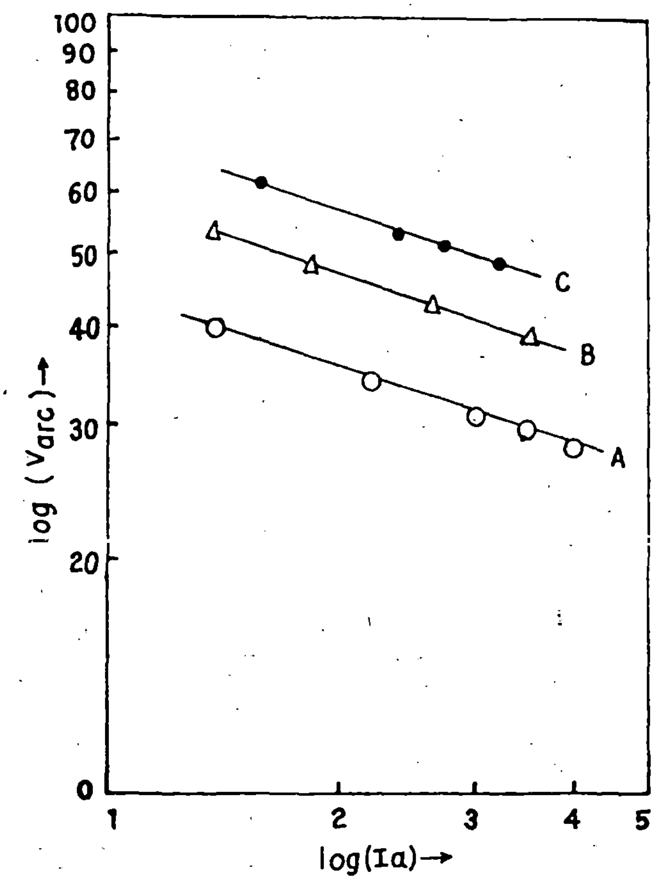

Fig. 6·13.

Variation of log arc voltage against log arc current Ag-Ag (A: 0.1 cm, B: 0.2 cm ε C: 0.3 cm).

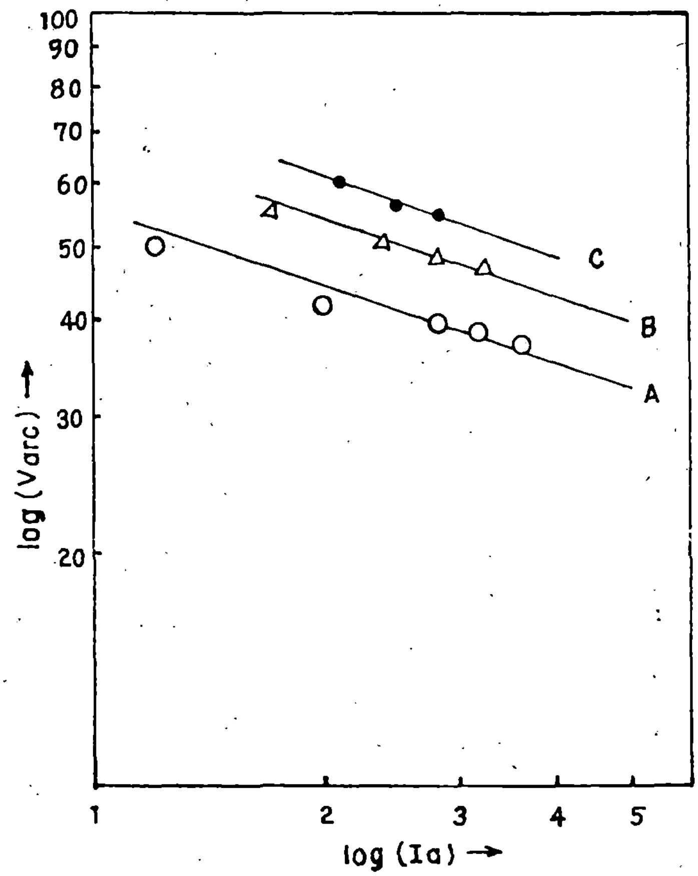

Fig. 6·14.

Variation of log arc voltage against log arc current Cu-Cu

(A: 0.1 cm, B: 0.2 cm ε C: 0.3 cm)

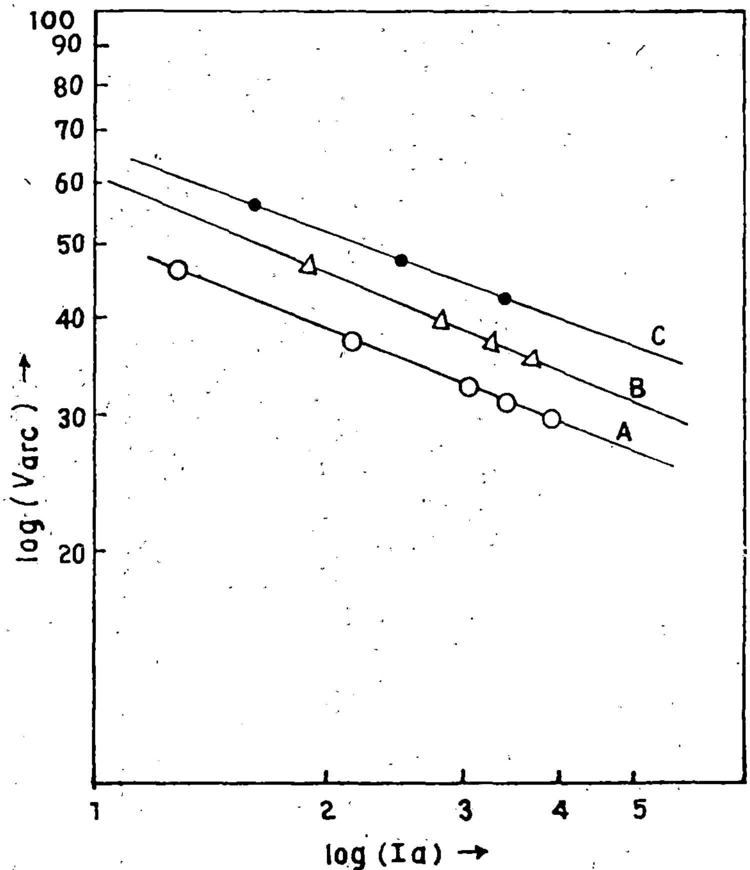

Fig. 6·15.

Variation of log arc voltage against log arc current Fe-Fe

(A: 0.12 cm, B: 2 cm & C: 0.3 cm)

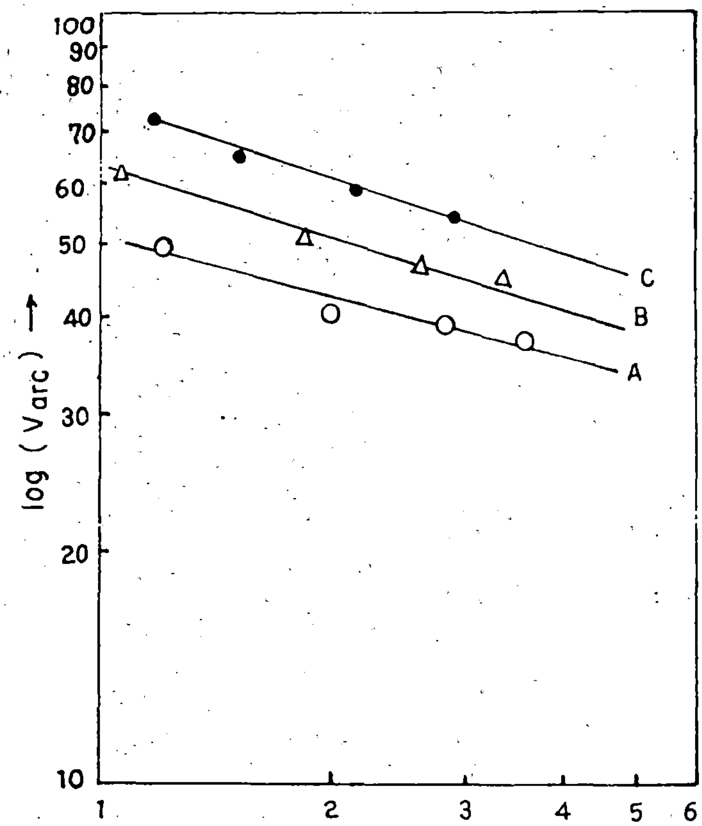

Fig.6·16.

Variation of log arc voltage against log arc current Ag-Cu

(A: 0.12 cm, B: 18 cm & C: 0.28 cm)

Table 6.4

Electrode system	Medium	Current range A	Electrode gap cm	Exponent a
Ag-Ag	Air	1 to 4	0.10	- 0.0330
			0.20	- 0.343
			0.30	- 0.338
Cu-Cu	Air	1 to 4	0.10	- 0.3454
			0.20	- 0.3760
			0.30	- 0.3578
Fe-Fe	Air	1 to 4	0.12	- 0.3614
			0.20	- 0.03536
			0.30	- 0.3558
Ag-Cu	Air	1 to 4	0.120	- 0.2604
			0.180	- 0.2824
			0.280	- 0.2955

It is thus observed that the value of m is nearly a constant and independent of the gap separation. It is to be noted that the proposed equation is similar in form with that introduced by Nottingham (1926). It is thus evident that from an analysis of the data relating the variation of arc voltage and arc current with the electrode separation, it is possible to calculate the cathode and anode fall in arcs.

The method is straightforward and the results are consistent with literature values. Further, analysis of the results also provide the values of contact potential for these elements. This potential difference arises due to the fact that though the two metals are in contact still due to passage of the current, there is erosion of the electrodes and micro-irregularities occur due to improper machining and unequal matching of the electrode surfaces. This causes a finite gap and a sizeable fraction of the voltage develops even when the electrodes are in contact. Further the variation of power developed at the arc with electrode separation has been quantitatively treated and theretical deductions are in agreement with experimental results. An empirical relation between arc current and arc voltage has been established.

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Voltage current characteristics of low current arcs in air with metal electrodes

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Abstract : The variation of voltage and current in an arc plasma with Ag−Ag, Cu−Cu, Fe−Fe and Ag−Cu electrode systems have been investigated allowing a variation of the electrode separation distance from zero upto 0.5 cm in air at atmospheric pressure. The analysis of the results provides the values of cathode and anode fall and also the contact potential difference between the electrodes. The variation of power loss in the arc plasma with electrode separation has been explained quantitatively. An empirical relation has been established between voltage and current in an arc plasma.

Keywords : Metallic arc, cathode and anode fall, power relation.

1. Introduction

The investigation of the properties of low current arcs has been carried out over a wide range of arc currents with different metal electrodes. Considerable amount of information has been collected by different workers on measured arc characteristics (low intensity arcs) (Ayrton 1902, Nottingham 1926, Eberhart and Seban 1966) to establish empirical relations of the form $V_a=f(I)$, where V_a is the voltage across the arc and $f(I)$ is a function of the arc current. An analysis of these empirical relations can not however, provide the values of the parameters of the arc plasma such as cathode and anode fall, contact potential and other allied properties. High current arcs are increasingly being utilized for the study of scattering of light specially from a CO_2 laser and also for use in laser plasma interaction studies. Pasternak and Offenberger (1975) have carried out probe and spectroscopic measurements in a high density dc argon arc plasma and have obtained the values of electron density and electron temperature. The object of the present investigation is to study the voltage current characteristics in arc plasma produced under atmospheric pressure and to calculate some parameters of the plasma after a systematic analysis of the results.

2. Experimental setup

In this investigation the work has been carried out with arcs using four different types of electrodes, viz. (a) silver – silver, (b) copper – copper, (c) iron – iron and (d) silver – copper (silver being the anode and copper the cathode in the last case). A dc source (100 V) with an adjustible rheostat and an ammeter (0 – 5 A) is used to excite the arc. The arc current is varied from 2 to 5 A and measurements were made for 2, 3, 3.5, 4.5 and 5 A. The experiment consists in measuring the arc current and arc voltage (voltage across the arc) for various electrode separations starting from $x=0.025$ to $x=0.5$ cm where x is the electrode separation. The experiment has been repeated with different initial arc currents ($I=2$, 3, 3.5, 4, 4.5 and 5 A). The tips of the electrodes were photographed and the diameter of the tips was obtained from measurements made with a travelling microscope. The last measurement was necessary to obtain the cross section of the arc plasma so as to calculate its conductivity. All the measurements have been carried out at the atmospheric pressure.

3. Results and Discussion

(a) Calculation of cathode and anode fall :

Variation of arc voltage with electrode separation has been plotted for different

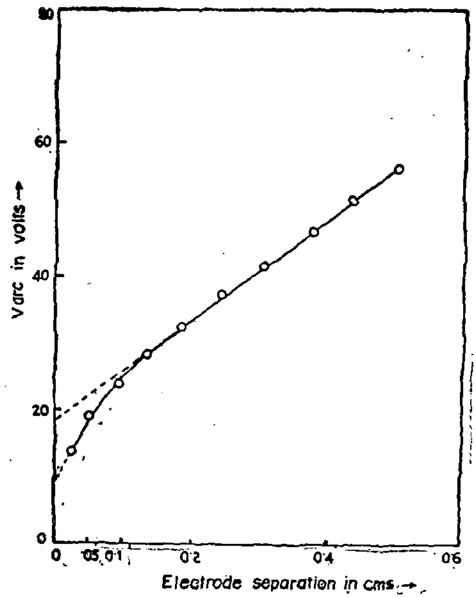

Figure 1. Variation of arc voltage with electrode separation Ag – Ag.

electrodes such as Ag – Ag, Cu – Cu, Fe – Fe and Ag – Cu for an initial arc current of 4 A. A representative curve for Ag – Ag electrode is shown in Figure 1. It has been observed that for small electrode separation, the curve rises rapidly and then there is the linear increase of arc voltage with electrode separation. The total arc voltage V_A can be represented by an expression

$$V_A = V_C + V_P + V_a$$

where

V_C – cathode fall,

V_P – total fall of voltage at the positive column,

V_a – anode fall.

The linear rise of the upper portion of the curve reveals that the positive column has become uniform where as the longitudinal electric field is constant. In the arc plasma data analysis, the linear portion of the curve has been extrapolated to $x=0$ where x is the electrode separation and the intercept for $x=0$ along the Y axis will give the sum of the cathode and anode falls. The non-linear portion of

Table 1

Electrode	Medium	V_c (V)	V_a (V)
Ag–Ag	Air	9–9.5	9.5–10
Cu–Cu	Air	10–10.5	17.5–18
Fe–Fe	Air	9–11	10–10.5
Ag–Cu	Air	12–12.5	11–11.5

the curve can be similarly extrapolated to $x=0$ and the intercept will give the value of cathode fall. Hence anode fall can also be calculated. In this way, the values of cathode and anode fall for different types of electrodes have been calculated and results have been presented in Table 1. The results indicate that the values of cathode and anode fall as calculated, are consistent (von-Engel 1965).

(b) Calculation of contact potential difference at the electrode :

As the arc voltage and arc currents for different electrode separations have been measured, it is possible to calculate the power developed across the arc. The variation of power developed at the arc with separation of electrodes has been plotted for Ag–Ag, Cu–Cu, Fe–Fe and Ag–Cu electrodes and two representative curves for Ag–Ag and Cu–Cu have been shown in Figures 2 and 3 for different arc currents. It is evident that for $x=0$, the extrapolation of the curves will give the value of power-loss at the electrodes when they are in contact. As the total power drawn from the dc source (100 V) and power-loss at the electrodes are known when they are in contact, from extrapolation of the curves the loss of power at the external resistance R_r can be obtained and hence the value of R_r for different currents can be calculated. Similarly dividing the power-loss at the electrodes by the corresponding current, contact potential difference for different electrodes can be calculated. The value of R_r has been

Table 2

Arc current A	P_1 W	P_0 W	$P_R=(P_0-P_1)$ W	R_r Ω	$V_{contact}$ V
		Ag-Ag electrode system			
5	50	500	450	18	10
4	42	400	358	22.37	10.2
3	34	300	266	29.55	11.3
2	21	200	279	44.75	10.5
		Cu – Cu electrode system			
5	63	500	437	17.48	12.6
4.5	58	450	392	19.36	12.8
4	48	400	352	22	12.2
3	38	300	262	29.8	12.66
2	24	200	176	44.0	12
		Fe – Fe electrode system			
5	52	500	448	17.93	10.4
4.5	47	450	403	19.90	10.44
4	42	400	358	22.38	10.5
3	30	300	270	30.00	10.0
2	20	200	180	45	10.5
		Ag – Cu electrode system			
5	45	500	455	18.2	9
4	34	400	364	22.68	8.5
3	28	300	272	30.22	9.3
2	18	200	182	45.5	9.0

calculated as it is necessary to find x_{max} (the value of x at which the power developed at the arc becomes a maximum). The results are presented in Table 2 for different electrode systems and arc currents.

where,

P_1 = power-loss at the electrodes when they are in contact,

P_0 = power drawn from the source,

P_R = power-loss at the external resistance,

R_r = calculated value of external resistance,

$V_{contact}$ = the contact potential at the electrodes.

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It is thus observed that for different values of arc current, the contact potential difference is almost a constant for a pair of electrodes though it varies with the nature of electrodes which is generally expected. The values of R_r as calculated from the extrapolation of the curve showing the variation of power developed across the arc with distance is also found to be consistent with the value obtained by direct measurement. This indirect method for the computation of R_r and its consistancy with the direct measurement justify the procedure adopted here for the calculation of $V_{contact}$, the contact potential.

(c) Variation of P_A (power generated at arc) with electrode separation :

From the nature of the variation of P_A with electrode separation as depicted in Figures 2 and 3, it is evident that the curves show a tendency of saturation at a

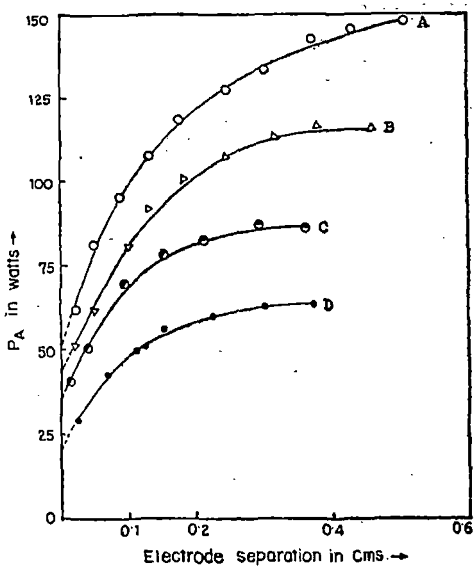

Figure 2. Variation of power developed at arc with electrode separation Ag–Ag [A : 5A, B : 4A, C : 3A, D : 2A].

certain electrode separation depending upon the nature of electrodes and the value of arc current. To find out the variation, quantitatively the following analysis has been made.

At any arc voltage V_A and arc current I_A,

$$P_A = V_A I_A = V_A^2 / R_a$$

$$V_A = V_S - I_A R_r = \frac{V_S}{\left(1+\frac{R_r}{R_a}\right)}$$

where V_S is the source voltage, R_r the external resistance, and R_a is the arc resistance.

$$P_a = \frac{V_S^2}{\left[1+\frac{R_r}{R_a}\right]^2 R_a}$$

$$= \frac{V_S^2 \rho \cdot \frac{x}{S}}{\left[\rho \cdot \frac{x}{S} + R_r\right]^2}$$

as $R_a = \rho.\frac{x}{S}$ where ρ is the spectific resistance, x the electrode separation and S the area of cross section. Maximising P_A with respect to x,

$$x_{\max} = \frac{R_T S}{\rho} = R_T S \sigma.$$

where S is the area of cross section, σ is the conductivity of the arc plasma, R_r the value of the external resistance and $x_{\max}$ is the value of x for which the power developed at the arc shows a tendency of maximisation.

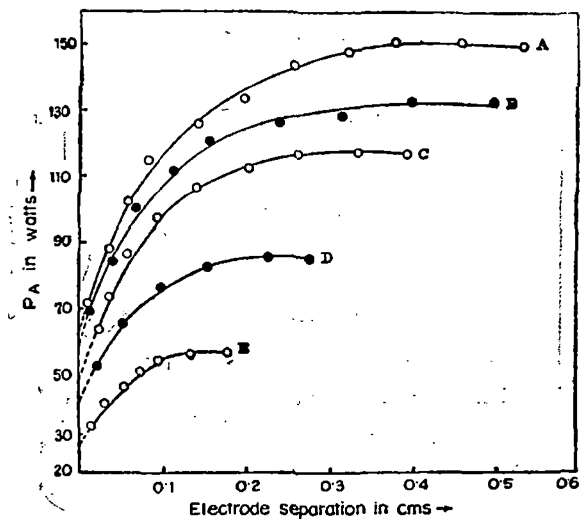

Figure 3. Variation of power developed at arc with electrode separation Cu–Cu [A : 5A, B : 4.5A, C : 4A, D : 3A, E : 2A].

(d) Calculation of conductivity :

It is evident from the nature of the curves showing variation of arc voltage with electrode separation that in the linear portion of the curve, the electric field is almost a constant and actual calculation shows that R_a/x, is constant. It however, depends upon the nature of the electrodes and also upon the strength of the arc current. The diameter of the cross section of the tips of electrodes before exciting the arc was measured by a travelling microscope. Then the arc was excited for a minute for taking the usual measurements. The diameter was again measured after cooling the electrodes. The average value of cross section of the electrodes comes out to be $S=0.1617$ cm^2. The cross section of the tips of the electrodes has been assumed to be equal to arc plasma cross section. The values for x_{max} shown in the last column in Table 3 have been calculated from the relation

$$x_{max}=R_r S\sigma.$$

Values of R_r calculated for different electrodes for different arc currents have been shown in Table 2. Though the experimental results (Figures 2 and 3) do not

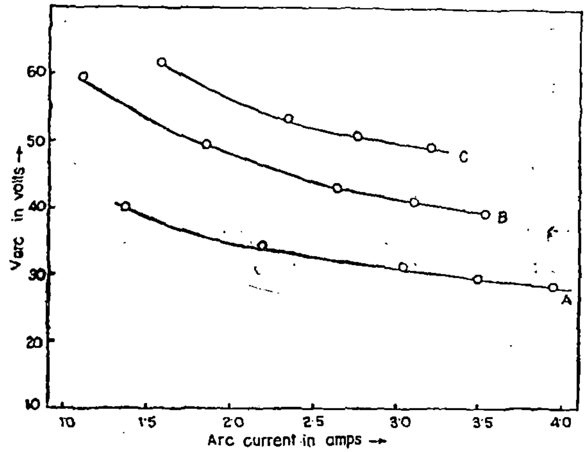

Figure 4. Variation of arc voltage with arc current Ag–Ag [A : 0.1 cm, B : 0.2 cm, C : 0.3 cm].

show any maximum, still the tendency of saturation is evident in each curve and the electrode separation at which the process of saturation sets in is in satisfactory agreement with the value of x_{max} calculated.

(e) Arc voltage arc current characteristics :

The variation of arc voltage with arc current for different electrode separations is shown in the Figures 4 and 5, for Ag–Ag, Cu–Cu electrodes respectively. It is observed that the average arc voltage decreases with the increase of the arc current at constant electrode gap. The slope of each curve is negative for the range of current investigated. It is also observed that curve moves upwards with the increase in electrode gap. Now the relationship between arc voltage and arc can be written as

$$V_a = C_g I_a^m$$

where C_g is a function of electrode gap. The value of the exponent m can be

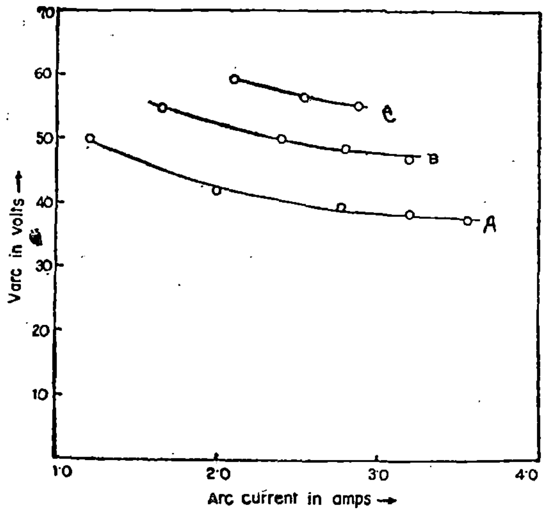

Figure 5. Variation of arc voltage with arc current Cu−Cu [A : 0.1 cm, B : 0.2 cm, C : 0.3 cm].

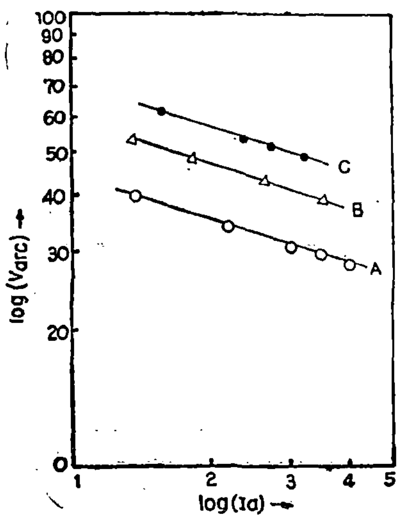

Figure 6. Variation of log arc voltage against log arc current Ag−Ag[A : 0.1 cm, B : 0.2 cm, C : 0.3 cm].

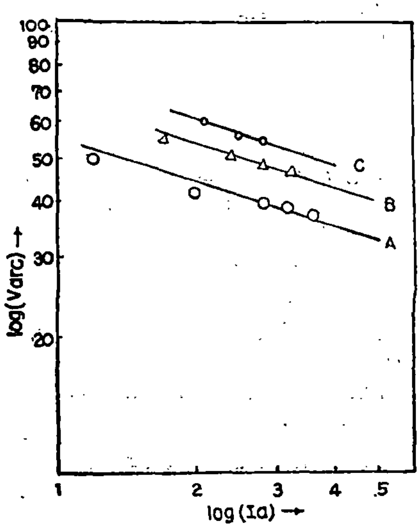

Figure 7. Variation of log arc voltage against log arc current [A : 0.1 cm, B : 0.2 cm, C : 0.3 cm].

obtained by log plot of arc voltage against arc current. The variation has been plotted for different electrode systems in Figures 6 and 7. The results are shown in Table 4.

It is thus observed that the value of m is nearly a constant and independent of the gap separation. It is to be noted that the proposed equation is similar in

Table 3

Current A	R_a/x Ω cm^{-1}	S cm^2	σ mhos cm^{-1}	x_{max} cm
		Ag−Ag		
2	280.9	.1617	.02202	.1592
3	125.33	.1617	.04938	.2359
4	62.47	.1617	.09902	.3437
5	36.9	.1617	.1677	.4879
		Ag−Cu		
2	360	.1617	.01718	.1201
3	169.44	.1617	.03652	.1694
4	101.8	.1617	.06080	.2162
5	64.54	.1617	.09583	.2708
		Fe−Fe		
2	281.5	.1617	.02198	.1599
3	122.14	.1617	.05066	.2475
4	64.74	.1617	.09576	.3483
5	38.55	.1617	.1604	.4649
		Ag−Cu		
2	277.43	.1617	.02228	.1621
3	134.93	.1617	.04585	.2241
4	81.90	.1617	.07553	.2808
5	55.98	.1617	.1105	.3250

form with that introduced by Nottingham (1926). It is thus evident that from an analysis of the data relating the variation of arc voltage and arc current with the electrode separation, it is possible to calculate the cathode and anode fall in arcs. The method is straightforward and the results are consistent with literature values. Further, analysis of the results also provide the values of contact potential for these elements. This potential difference arises due to the fact that though the two metals are in contact still due to passage of the current, there is erosion of the electrodes and micro-irregularities occur due to improper machining and unequal matching of the electrode surfaces. This causes a finite gap and a sizeable fraction of the voltage developes even when the electrodes are in contact. Further the variation of power developed at the arc with electrode separation has

Table 4

Electrode system	Medium	Current range A	Electrode gap cm	Exponent m
Ag–Ag	Air	1 to 4	0.10	−0.3301
			0.20	−0.343
			0.30	−0.338
Cu–Cu	Air	1 to 4	0.10	−0.3454
			0.20	−0.3760
			0.30	−0.3578
Fe–Fe	Air	1 to 4	0.12	−0.3614
			0.20	−0.3536
			0.30	−0.3558
Ag–Cu	Air	1 to 4	0.120	−0.2604
			0.180	−0.2824
			0.280	−0.2955

been quantitatively treated and theoretical deductions are in agreement with experimental results. An empirical relation between arc current and arc voltage has been established.

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