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By

E. D. Blix and A. E. Guile

Department of Electrical Engineering,

University of Leeds

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The Magnetic Deflection of Short Arcs Rotating Between Annular Electrodes Above and Below Atmospheric Pressure

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E. D. Blix and A. E. Guile

Department of Electrical Engineering, University of Leeds

SUMMARY

An apparatus has been designed and constructed in which arcs of up to 5 kA, at inter-electrode spacings up to 2·5 cm, can rotate around ring-shaped electrodes in radial magnetic fields up to 0·2 Wb/m^2, in different gases between vacuum and 20 atmospheres.

Preliminary results are described for arcs in air, nitrogen, hydrogen and sulphur hexafluoride, at a spacing of 2 mm, at pressures between 1·5 torr and 14 atmospheres and at currents up to 350 A, on brass and aluminium electrodes.

In contrast to earlier experiments under similar conditions, except that the arc then ran once along rail electrodes and the cathode site transfer conditions were critical, these experiments have shown that the interaction of the arc column with the gas has been predominant at pressures above one to one and a half atmospheres.

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1. Introduction

It was thought at one time that forward movement of an arc in a transverse magnetic field could always be represented simply in terms of a balance between the electromagnetic force on the arc column and an aerodynamic drag as it moved through the gas. In recent years, however, much evidence has been found which shows that the forward, as well as the retrograde, movement of cold-cathode arcs is frequently controlled and mainly influenced by processes at the cathode surface and in the cathode-fall region(1,2).

It has been found(3) that arc velocity varies widely with oxidation time on initially etched brass electrodes, and that the velocity varies approximately inversely with the minimum spark breakdown voltage between the electrodes. Davies and Fitch(4) have shown that the minimum breakdown voltage is a measure of the effective work function of the cathode surface when subjected to positive ion bombardment. Thus the observed behaviour of arc velocity with oxidation time is to be expected if the movement is a function of the time required for new sites to become conditioned by positive ion bombardment, so that they take over the arc current.

It has been suggested(5) that cold-cathode emission is due to a high electric field ($\sim 10^7$ V/cm) across thin semi-conducting or insulating layers on the cathode, and that electrons are deflected by the magnetic field in a relatively low electric field ($\sim 2 \times 10^3$ V/cm) in the gas cathode fall region. The proposed model gives a possible explanation of the change from retrograde motion to forward motion which occurs when pressure, magnetic field or arc current are varied. It is suggested that electrons are emitted parallel with the cathode surface with an average energy of 0.6 eV and with negligible energy normal to the cathode. Those with an initial velocity in the retrograde direction gain energy in the electric field more readily than those emitted in the forward direction, due to the curvature of the electron trajectories, and if the pressure is sufficiently low, their first collision causes excitation which is followed by a further ionising collision. The ions created on the retrograde side of the present emitting site fall on the cathode surface on that side and give rise to new emission. As the pressure is raised, the electrons with initial retrograde velocity suffer elastic collisions before gaining excitation energy, and following isotropic scattering are deflected by the magnetic field towards the forward side.

There are a number of isolated experimental results for retrograde motion at reduced pressures[6,7,8,9]; and virtually none at pressures above atmospheric[10]. There has not therefore been a systematic investigation exploring the interaction of a transverse magnetic field with an arc discharge from very low pressures, where a vacuum or gas arc moves in the retrograde direction, through atmospheric pressure, to a pressure of several atmospheres where the arc moves in a forward direction. This paper describes an apparatus constructed for this purpose and gives some preliminary results which show important new features in the behaviour of a short arc.

2. Experimental Procedure

If it is wished to eliminate, as far as possible, changes in arc velocity due to changes in oxide layers on the cathode surface, then a linear electrode system with a single run over a consistently prepared surface is to be preferred[11]. For work in a number of gases up to several atmospheres with reasonable economy of gas, linear electrodes would need to be short which would limit the arc running time, and the presence of downstream end walls can give an arc velocity below that in unrestricted space[12].

It has been shown[3] that interaction of the gas and the cathode surface layers can affect the arc velocity by varying the oxide thickness and therefore the time taken to establish new emission sites. It is also likely that the efficiency of the emission process will vary from one gas ion to another with a given surface condition. Thus an apparatus with an arc rotating in a circular path avoids the difficulties of linear electrodes, and also enables the effect of the nature and pressure of the gas interacting with different cathode materials to be studied as it varies both in time and over a range of magnetic field, arc current and inter-electrode spacing.

Concentric cylindrical electrodes with an axial magnetic field offer a simple arrangement, but the distance travelled by any element of the arc is proportional to its radial position. Thus if the electrode effects are of secondary importance, an arc with uniform column of sufficient length takes up an involute shape[13]. This can be unsteady at the outer electrode so that the arc length varies. Parts of the arc experience driving forces having radial as well as circumferential components and a unique arc velocity cannot be specified.

The arrangement adopted was therefore one using parallel ring-shaped electrodes with a radial magnetic field produced in the gap by two opposed electromagnets. For strength and as a return path for the magnetic flux, steel was used for the vessel, a vertical section through which is shown in Fig. 1.

The vessel was required to allow tests to be made at gas pressures up to 20 atmospheres. It was designed to B.S.1500 for Class III pressure vessels and allowance was made for forces due to (1) transient pressures generated by arc currents up to 10,000 A, (2) forces due to those currents, (3) force due to vacuum and (4) force due to a magnetic field of up to 0.2 Wb/m^2. The vessel was therefore designed to 400 lb/in^2 and was fitted with a 320 lb/in^2 bursting disc when testing at high currents and pressures to allow for dynamic conditions.

The field coils, designed to produce a circumferentially and axially uniform magnetic field of up to 0.2 Wb/m^2 at the mean electrode radius for a maximum electrode spacing of 2.5 cm, were sealed off with gasketed brass covers to minimise gas contamination when the coils were hot and to keep the internal active volume to a minimum for economy in gas consumption.

The ring-shaped electrodes, which were of brass except for a few tests with aluminium, were 16.2 cm. mean diameter, and of 1 cm. square section, which was machined to give a 6 mm. wide flat surface for the opposing faces of the electrodes. The radial magnetic field at the inner and outer edges of the electrodes varied from that at the mean radius by only $\pm$ 4%. There were circumferential variations due to windows and bushings but these were not significant as average velocity over a revolution was measured. Two connections from the external circuit in which a d.c. generator was the source of power were made to both anode and cathode. The connections were made to opposite ends of a ring diameter and the two currents to the cathode were equalised by resistors so as to eliminate almost entirely the magnetic field due to the current flowing in the electrodes. Each electrode was supported at four points, two of which were the main lead-in bushings, the other two being cast resin supports. The arc was initiated by a capacitor discharge between the cathode and a third electrode.

Two one inch diameter glass windows, 120° apart on the centre plane of the vessel, were provided for arc observation and velocity measurement. This was done by displaying pulses from a photoconductive-cell on an ultra-violet recorder on which arc current, field current and arc voltage were also recorded.

3. Experimental Results

All the results given have been obtained at an inter-electrode spacing of 2 mm. With a d.c. source, all results are for a "static" condition, so that it should be emphasised that transitions which are described have been found between two tests at slightly different conditions. At the present time, tests have not yet been made to discover if they can occur dynamically in one test.

Electrode surface condition as a variable was reduced as far as possible by using well "run-in" electrodes, i.e. velocities were measured after many revolutions of an arc over a surface which was initially polished with fine emery paper whilst in a lathe, so that fine surface scratches were circumferential. The results of Fig. 2 show that in fact there was no substantial difference between the velocity over the first few revolutions after freshly polishing the electrodes and that obtained after many thousands of revolutions. Also, there was no substantial difference between the velocities in air and in nitrogen with freshly polished electrodes. This is in marked contrast with some earlier results(3); e.g. it would not have been expected that "run-in" electrodes would lead to a constant velocity with electrode surface conditions eliminated in nitrogen, and the reasons for this are discussed later.

Two quite distinct modes of arc behaviour were observed during the investigation. One was characterised by severe fluctuations in arc current and voltage and very erratic arc velocities. In the other mode, arc current and voltage were smooth and the velocity uniform. It was evident that the smooth arc voltage and current in the second mode represented the minimum voltage and maximum current values in the fluctuating mode. Transitions between modes occurred quite frequently on one and the same run. As a general rule, when arc velocity was plotted against arc current for various constant values of the other parameters, smooth curves drawn through points representing uniform mode tests, appeared to give the most consistent results. In presenting the results the practice of drawing the curves through points representing smooth arc voltage and current conditions has therefore been adhered to. (In some figures, e.g. Fig. 8, some points relating to the fluctuating mode may be seen below the curve). Furthermore, when transitions between the two modes occurred during the same test, the smooth section(s) of the recording were used. Figs. 3 (a), (b) and (c) illustrate respectively the type of record obtained for the smooth, fluctuating and transition modes.

Fig. 4 shows the variation of velocity with arc current where both the latter and the pressure are low, and the transition from retrograde velocity increasing with increase in current for very low pressures, to forward movement at higher pressures. In Figs. 5, 6 and 7 forward velocities are shown for higher pressures and arc currents. In Fig. 7 the transition to a lower velocity as arc current was increased, can be seen at a number of pressures. Figs. 8 and 9 show some of these transitions in detail and indicate that this was a consistent process. (Tests at intermediate currents may show that the curve for one atm. in Fig. 8 at low currents is similar to that at 0.79 atm. in Fig. 6.) Figs. 10 and 11 give the variation of arc voltage with arc current over a wide range of pressure. All of the above results were obtained in air with brass electrodes. Fig. 12 gives some results obtained using aluminium electrodes and Figs. 13, 14 and 15 show velocities for low currents and several pressures in nitrogen, hydrogen and sulphur hexafluoride. In Fig. 16 velocity is plotted against magnetic flux density for a number of currents and pressures, mainly in air but with two results in nitrogen. Fig. 17 shows arc velocity against pressure up to 14 atmospheres in air, hydrogen and sulphur hexafluoride for a number of currents and magnetic fields, and in Fig. 18 the pressure range is reduced so as to show the fall in velocity at pressures below atmospheric. From these curves, Fig. 19 has been obtained.

4. Discussion and Conclusions

4.1 Assessment of Collective Results

A review of the test results given in section 3 shows that to a considerable extent arc behaviour is characterised by increasing velocity with increasing arc current and magnetic flux density and decreasing arc velocity with increasing density of ambient gas.

There is a transition region, referred to hereafter as transition I, where the velocity increases rapidly with increasing gas density to join the appropriate falling velocity/gas density characteristic. Another transition, referred to hereafter as transition II, takes place where the velocity suddenly drops with an increase in arc current and then continues to rise with arc current, starting from the new, lower level of velocity.

Transitions I and II will be discussed in detail in sections 4.4 and 4.3 respectively, and are excluded from the discussion immediately following. This also applies to retrograde movement and movement at low forward velocities, discussed in sections 4.7 and 4.4 respectively.

After making the above exceptions, it may be said that the results are more consistent with the expected behaviour of an arc moving under column influences than with the behaviour of an arc dominated by the cathode emission processes briefly discussed earlier. Further evidence of the column influence is that particularly at gas pressures above 2 atm., arc velocity was not found to vary substantially with electrode material or electrode surface condition, nor did the velocities observed in air and nitrogen differ to any great extent. This is in marked contrast to earlier results[3].

Neglecting those regions of the arc where electrode processes dominate, Lord[14] has carried out an analysis of the moving arc column by considering it as a problem in magneto-fluid-dynamics. For this purpose, he defines the arc periphery as dividing space into an inner region where electrical conductivity is non-zero, and an outer region where it is zero. One of the equations he derives is,

$$U \propto I^{0.15} B^{0.58} p^{-0.42} \qquad (1)$$

which applies in a given gas to an arc held stationary in a gas stream at right angles to the arc current by means of a magnetic field mutually perpendicular to the arc current and gas stream provided radiation losses are neglected, so that radial heat conduction equals the convection loss. The equation applies equally to an arc moving through a gas under the influence of a magnetic field since it has been shown[15] that for arc lengths up to 10 cm., the velocity of the gas flow required to maintain the arc stationary for a given transverse magnetic field is equal to the velocity attained by a moving arc in still air with the same arc current and magnetic field.

Even though it may be quite reasonable to assume that in a sufficiently long arc, column processes are capable of complete domination and equation (1) can be applied with some confidence, as was in fact found for arcs longer than 6 cm. moving at velocities greater than 50 m/sec.[12], generally speaking the same cannot be true for a 2 mm. arc. Nevertheless, faced with the evidence at hand, it was decided to check to what extent the results would conform to equation (1) for column dominated arcs.

Plotting the results on log-log scales to determine the powers of I, B and p in an equation of the type exemplified by (1), it was found, as table 1 shows, that over a wide range the powers of B and p agree well with what Lord predicts. It may be noted that earlier tests with linear electrodes gave $U \propto B$ for cathode-controlled conditions with similar current, field, electrode material and spacing[16]. The powers of I on the other hand, shown in table 2, do not agree so well, as they are higher than predicted.

TABLE 1. POWERS OF B AND p IN EQUATION $U \propto I^m B^n p^q$

BRASS ELECTRODES, INTER-ELECTRODE GAP 2mm.

		Powers of B(n)			Powers of p(q)		
Gas	Current(A)	1.0 atm	3.72 atm	7.8 atm	0.034 Wb/m^2	0.054 Wb/m^2	0.106 Wb/m^2
Air	20	0.62	0.59	-	-0.46	-0.49	-0.48
Air	20*	-	-	-	-	-	-0.48
Air	87	0.60	0.59	0.44	-0.45	-0.46	-0.45
Air	150	-	-	0.45	-	-	-
Air	275	-	-	-	-	-	-0.38
N_2	20	0.68	0.58	-	-0.46	-0.49	-0.48
N_2	20*	-	-	-	-	-	-0.48
H_2	20	-	-	-	-	-	-0.48
SF_6	20	-	-	-	-	-	-0.57

* aluminium electrodes

TABLE 2. POWERS OF I IN EQUATION $U \propto I^m B^n p^q$

BRASS ELECTRODES, INTER-ELECTRODE GAP 2 mm.

Powers of I_a (m)

Gas	Press. (atm.)	10 - 20 A			40 - 80 A			100-200A	200-350A
		0.034 Wb/m^2	0.054 Wb/m^2	0.106 Wb/m^2	0.034 Wb/m^2	0.054 Wb/m^2	0.106 Wb/m^2	0.106 Wb/m^2	0.106 Wb/m^2
Air	1.0	0.47	0.48	0.46	0.47	0.48	0.46	0.96	0.96
Air	2.36	0.39	0.35	0.37	0.39	0.35	0.37	0.28	0.64
Air	2.36*	-	-	0.62	-	-	-	-	-
Air	3.72	0.37	0.38	0.37	0.37	0.38	0.37	0.29	0.55
Air	4.40	0.41	-	-	0.41	-	-	-	-
Air	5.08*	-	-	0.61	-	-	-	-	-
Air	7.80	-	0.39	-	-	0.39	-	0.42	0.50
Air	14.60	-	-	-	-	-	0.40	0.40	0.40
N_2	1.0	0.45	0.47	0.36	-	-	-	-	-
N_2	2.36	-	0.30	-	-	-	-	-	-
N_2	3.72	0.35	0.30	0.31	-	-	-	-	-
H_2	1.00	-	-	0.52	-	-	-	-	-
H_2	2.36	-	-	0.50	-	-	-	-	-
SF_6	1.00	-	-	0.13	-	-	-	-	-
SF_6	3.72	-	-	0.18	-	-	-	-	-

* aluminium electrodes

In his analysis, Lord[14] equated the driving and retarding forces on the arc column. He also applied other equations; the most important one in this context equates the heat conducted radially in the arc column with the convection loss, thus making arc radius, r, a function of arc current.

$$r \propto I^{0.70} B^{-0.15} p^{-0.15} \qquad (2)$$

This shows r to be heavily dependent on I.

In the present case, since the arc length was only 2 mm., it is no longer reasonable to assume that heat loss from the arc occurs mainly by radial conduction. The electrodes are so close together that axial conduction of heat from the arc into the electrodes, neglected by Lord, must play an important part. This means that the power of I in equation (2) might become smaller and that of I in equation (1) correspondingly larger than predicted, so that the values shown in table 2 are not unreasonable. Electrode gas and vapour jets, and also the fact that the small inter-electrode gap may preclude a complete transition from the restricted arc size near the electrodes into the fully developed column considered by Lord, may have been significant in this respect. These factors will be discussed in section 4.3.

It is evident then that the results of the present investigation are, on the whole, quite compatible with what might be expected of a column dominated type of arc movement if allowance is made for possible differences in the mechanism of energy dissipation from the arc as a result of the close proximity of the electrodes. This statement appears more significant when put as follows: the results are compatible with the expected behaviour of an arc moving under conditions tending to obscure the effects of cathode emission processes.

4.2 Electrode Effect Suppression

The theory proposed for the purpose of explaining suppression of the effects of emission processes is that in the present apparatus the arc moves over the same cathode surface on every revolution and that the surface after passage of the arc becomes seeded with positive ions that remain un-neutralised until the arc returns on the next revolution. Favourable emission conditions already exist, therefore, when the arc arrives, and any retarding tendency due to the finite time required for new emission sites to come into being becomes negligible in comparison with the column retarding effects.

If anything, this theory reinforces the argument for the significance of electrode surface oxide layers in the emission process indicated in section 1. It does, however, require that ions should be capable of persisting for a sufficient length of time on the cathode oxide layer to influence emission on the next revolution. The results of Davies and Fitch(4), have shown that the effect on cathode work function and hence, according to Lewis and Secker(3), on the arc velocity, due to a current of 10^{-7} A passing between anode and cathode, persist for a considerable time. The work function was reduced significantly for times of the order of 10 minutes. Even for a velocity as low as 10 m/sec. in the present apparatus, the arc completes a revolution in 50 milliseconds, and the work function would not recover appreciably in that time if the results of Davies and Fitch apply. Since the reduction in cathode work function is a direct result of positive ions deposited on the cathode oxide layer, this can be taken as evidence that positive ions are quite capable of persisting for periods considerably longer than required to have an effect from one revolution to the next in the present apparatus. Some data obtained by Johnson and Jones(17) is of interest in this connection. After a pulse discharge (1 to 9 microsecond) of several thousand amperes between electrodes a few millimetres apart, they observed light emission to continue for more than 600 microseconds. This light was not due to excited atoms remaining in the gap, nor was it due to direct radiation from the electrodes, and they suggest that it may possibly have been due to ionization produced by continued electron emission from the cathode.

In view of the fact that ion persistence is time dependent, and according to Johnson and Jones may be sufficient to produce continued emission for times greater than 600 microseconds, emission conditions should become more favourable the faster the arc moves, and conversely, the slower the arc moves the less favourable the emission conditions. The concept of a positive feedback mechanism may thus be introduced and will be referred to subsequently.

It is of interest at this point to speculate on how the proposed ion seeding mechanism might lead to increased arc velocity. According to the proposed emission mechanism for the non-refractory arc cathode(5) discussed briefly in section 1, emission takes place from a semi-conducting oxide layer on the cathode surface. The high field required across this layer to cause emission is produced by positive ions from the discharge accumulating on it. Thus, any ions left on the surface from the previous revolution would tend to reduce the time required to establish a new emission site for the arc.

The proposed ion seeding or positive feedback mechanism is of considerable assistance in explaining a number of points relating to the observed arc behaviour apart from the column type behaviour which prompted its promulgation.

However, in order to gain a better understanding of the situation generally and to explain certain phenomena, notably the abrupt velocity transition (II) that takes place as arc current is increased, it is necessary to consider other important mechanisms.

4.3 Restraints Imposed by Thermal and Electrical Conductivities.

Reference to figures 8 and 10 indicates that transition II in air at atmospheric pressure takes place at an arc current of approximately 80 A. This value of current suggests two factors that may have some bearing on the transition.

King[18] states that the sudden formation of a concentrated core in a static arc in nitrogen or air at atmospheric pressure takes place at a current of approximately 50 A. At a pressure of 0.26 atm. in air or nitrogen, the core would probably form at a considerably higher current[19], which may confirm the connection between core formation and transition II (see figure 7).

It has been reported[16] that a change takes place in the velocity/current characteristic of an arc in air at atmospheric pressure, using brass electrodes spaced at 3.2 mm, at a current of about 40 A. While at currents below 40 A, velocity was found to increase with arc current, it was independent of arc current from 40 A up to 670 A, the highest test current used. Later results[12] show that although there is some increase in velocity with arc current beyond 40 A, the rate of rise with current is much less than below 40 A.

The fact that velocity became virtually independent of arc current above 40 A was attributed[16] to the existence of several independently moving electron emitting sites. At atmospheric pressure, it was calculated that each site should carry about 40 A and that for greater currents, more than one site would be required. It does seem a little strange that two apparently unrelated phenomena namely, arc core formation and emission site splitting should occur at nearly the same arc current. However, of greater immediate interest is whether either one or the other of these phenomena or the two acting together could have led to transition II in this case.

It seems unlikely that emission site splitting could have any pronounced effect in this case since the arc movement was apparently dominated by column rather than electrode processes. At the same time it cannot be ruled out that emission site splitting might also lead to an increase in column radius since the arc length was only 2 mm. That an increase in column radius is what triggered the chain of events leading to the much lower velocity after the transition is highly probable; the problem is to isolate the cause of the initial increase in radius.

If in the present results, the driving and retarding forces on the arc column are equated, without imposing any further restraints, the following equation applies.

$$B\ I = C_D\ \rho\ U^2 r \qquad (3)$$

If C_D, the coefficient of drag, is assumed to have a value of 0.63 (solid cylindrical body), equation (3) can be solved for r by substituting appropriate values of B, I, U and ρ from the test results. Figure 20 shows the values of r, calculated for a flux density of 0.106 Wb/m^2 in air at 1 atm. and at 7.8 atm., plotted against arc current. Compared with values of r found by other workers, those shown in figure 20, except between 80 and 350 A at 1 atm. (after transition II), are very small. Thus in air at 1 atm., with an arc length of 10 cm, allowing the column to develop fully, Spink and Guile[12], for the same values of I and B, have found photographically a luminous radius of 2 mm. Hesse, for the same conditions and again photographically, found a luminous radius of 3 mm. Spink and Guile[12] have shown, also photographically, that the luminous radius of the fully developed arc column at atmospheric pressure is proportional to $I^{0.63}$, while the present results show $r \propto I^{0.1}$ except after transition II, when it is found that $r \propto I^{-0.9}$.

Radii given by King[18] for static arcs in nitrogen at 1 atm. vary only slightly from 7 mm. between about 15 and 200 A.

The fact that the arc radius seems to have been considerably smaller in this case than for an arc, whether static or moving, with a fully developed column, leads to the most plausible explanation for transition II.

Considering the 1 atm. curves in figures 8 and 10, the arc voltage for a current of 25 A is seen to be 35 V. Electrode voltage drops are not likely to be less than 15 V and using that figure leaves 20 V for the arc column which gives a maximum gradient of 100V/cm and a maximum power dissipation of 2.5 KW/cm. The arc radius is seen from figure 20 to be approximately 1.2 mm., so the average current density in the column is in the order of 5.5 A/mm^2. For the fully developed column of a free-burning 25 A arc in nitrogen at atmospheric pressure, the arc radius according to King[18] would be at least 7 mm., giving an average current density of 0.16 A/mm^2. The column voltage gradient would be about 14 V/cm[19]. While the ratio of the current densities in the two cases is therefore about 35, the ratio of voltage gradients is only 7. The average electrical conductivity of the arc thus appears to have been about five times greater in the present case. From the variation of electrical conductivity of nitrogen with temperature, given by King[18], it would appear reasonable to assume that the axial arc temperature was considerably higher in this case than for a static arc of the same current; sufficiently high in fact for a dissociation core to have formed. For a power dissipation of 2.5 KW/cm., the central temperature of the arc would be about 14,000^{o}K[19] whereas for a free-burning arc at the same current (25 A) it would be less than 7000^{o}K. Thus the velocity/current curve in figure 8 for currents up to 80 A may represent an arc with a fully developed core referred to by King as a "high current" arc. This is not at all unlikely since King[18] states that the effect of increased cooling (by axial gas blast) is to bring about core formation at lower values of current. In this case, the increased cooling is brought about by the high arc velocity and probably also by the withdrawal of energy from the arc by axial heat conduction to the electrodes. If, in fact, the arc core temperature is much higher (about 14,000^{o}K) than would normally be expected at 25 A, it is quite probable that as the arc current is increased towards 80 A, without any significant increase in arc radius as has been shown to be the case, the core temperature might then become sufficiently high that the level portion of the electrical conductivity/arc temperature curve is approached.

At 80 A, and at the high velocity immediately before transition II, the arc voltage was found to be about 37 V, so that the power dissipated in the arc was approximately 8 KW/cm. For that level of power dissipation, the central temperature of a cored arc would be 19,000°K[19], at which temperature the electrical conductivity has almost levelled off[18]. Any further increase in arc current would then be expected to require a greater increase in arc radius than at lower currents, i.e. beyond 19000°K $^{dr}/dI$ is increased. The resulting increase in arc radius reduces the velocity. This reduces both the convection loss, which causes a further increase in radius, and the ion layer ahead of the arc, so that a further drop in velocity results. There is also a tendency for electrode surface temperature to rise and this may possibly lead to further vaporisation which by the lower ionisation potential reduces the column gradient and tends to produce a more diffuse arc. It is suggested that these cumulative effects cause the much lower velocity at transition II. On igniting the arc at about 80 A, it is therefore quite possible that it may not be able to operate with a sufficiently small radius to develop the high velocity attained for a slightly lower current. In that case, the electrical conductivity and thermal conductivity will both be lower due to the lower arc temperature, requiring a still larger radius, leading to an even lower potential velocity. These effects are cumulative, and it is suggested that they lead to a stable operating point at a much lower level of velocity. It is probable, in view of the fact that figure 20 shows the arc radius after transition II to be almost 10 times greater than the radius before the transition, that transition II in fact represents a change from a "high-current"[18] cored arc to a "low-current"[18] diffuse arc. This situation is rather paradoxical in that the "high-current" cored arc is seen to exist in the lower current range and becomes a "low-current" diffuse arc in the high current range. It would seem that the terms "high-current" and "low-current" can be misleading, and that "high current density" and "low current density" would be preferable.

It is possible, as suggested above, that electrode metal vapour may play a part in the transition. More electrode vapour would be produced at a lower velocity and the lower ionization potential of the metal vapour has the effect of increasing the electrical conductivity of the medium,[18] thus reducing the power dissipation and hence the arc temperature. The effects of changes in electrical conductivity, therefore, do not necessarily produce the same result at a low level of velocity as at a high level of velocity so that, for instance, the magnetic field is important. An increase in radius to accommodate an increase in current is the predominant effect when the electrical conductivity no longer increases with arc temperature at the high level of velocity, whereas at a lower level of velocity an increase in electrical conductivity may produce a more diffuse arc by reducing the power dissipation.

Spink and Guile(12) and Hesse(21) have found that for inter-electrode spacings below 5 mm. and at arc currents below 500 A, the arc can move in both a high and a low velocity mode, although as in the present experiments, the two modes occurred in different tests. While Spink and Guile(12) used brass electrodes, Hesse(21) used copper electrodes. Pratl and Rieder(22) have shown that for the same arc current and electrode spacing, the velocities on brass and copper electrodes differ considerably. For a current of 100 A and a spacing of 2 mm., the velocity on brass electrodes was 5 m/sec compared with 40 m/sec on copper electrodes. It is possible that the different velocities may be a reflection of a change from a cored "high-current" arc to a diffuse "low-current" arc brought about by electrode vapour. Certainly Hesse(21) attributes the low velocity mode which he observed on electrodes with a square cross-section to anode vapour jets, which he states are more likely to affect arc velocity when square rather than round electrodes are used. On round electrodes he only observed the high velocity mode even though the electrode material in both cases was copper. The effect of vapour jets, likely to be more pronounced with brass than copper electrodes due to the zinc content of the former, may well be the explanation for the low velocity which Pratl and Rieder observed on brass electrodes.

While the complexities of the situation make it impossible to show a simple cause and effect relationship between the many factors involved, it is quite clear that the factors considered, all of which may be significant, have a cumulative effect in determining the mode of operation selected by the arc at the critical value of current. In figure 21 an attempt has been made to show diagramatically the interaction of these various factors.

At currents below the critical value of about 80 A, stable operation in the high velocity mode is possible since any disturbing influence on the current can be counteracted by variations in electrical conductivity and need not affect arc radius significantly. At currents above the critical value, temperatures in the core, if it formed, would be so high that the electrical conductivity would be constant, and the arc radius would vary appreciably with current in such a way as to reduce the velocity and thus trigger the cumulative chain of events of figure 21(b). The arc is therefore capable only of operation as a diffuse "low-current" arc having a low temperature and therefore increasing electrical conductivity with increasing temperature.

These considerations lead to a criterion for stable operation under the conditions considered here, which is that the arc must operate on the positive slope of the electrical conductivity/arc temperature curve and can only operate in a particular mode, i.e. "high-current" cored or "low-current" diffuse, so long as this requirement is met.

After transition II, which should now be considered as a transition from a "high-current" cored arc to a "low-current" diffuse arc, table 2 shows that for the 1 atmosphere arc in air, the velocity is very nearly proportional to arc current. This is only possible, according to equation (3), when the radius decreases with increasing current. Since the values of r plotted in figure 20 were determined by means of equation (3), the decreasing radius with increasing current is a reflection of this requirement. That the radius can decrease with increasing current in the case of a "low-current" diffuse arc is quite possible if either the thermal or the electrical conductivity or both are increasing with increasing current and, at the same time, the velocity is increasing substantially and leading to increased convection. Since the temperature of the diffuse arc is less than 7000^{o}K and the velocity is increasing rapidly those conditions are satisfied. Again, the cause and effect relationship is too complex to be adequately described. The drooping voltage/current characteristic of the 1 atmosphere diffuse arc (i.e. arc currents greater than 80 A) in figure 10 tends to confirm that the electrical conductivity is in fact increasing more than enough to compensate for the increasing current density. The fact that this portion of the voltage/current characteristic starts off at a higher level of voltage is significant, since it indicates that the substantial increase in arc radius (decrease in current density) and the effect of any metal vapour introduced into the arc by vapour jets from the electrodes, is not sufficient to make up for the decrease in electrical conductivity due to the decrease in arc temperature from something like 19000^{o}K to less than 7000^{o}K.

Arcs at higher gas pressures, as already mentioned, show a decreasing transition (II) severity with increasing gas pressure. As a comparison of figures 5, 6 and 7 shows, the pressure at which the transition is no longer noticeable may also decrease with decreasing magnetic flux density and therefore decreasing arc velocity. Arc radii as shown in section 4.2 are not significantly different at 7.8 atm. and 1 atm. (before transition II); the eventual absence of the transition at high pressures must therefore be interpreted to mean that it is the cored "high-current" arc mode, rather than the diffuse mode that persists throughout the whole current range. The lower velocity at higher pressures (and lower magnetic fields) is probably the main cause of this. While the velocity is sufficient to lead to formation of a core, it is not high enough to push the core temperature up to such an extent that the electrical conductivity starts to level off. Heat loss from the arc by radiation may have played some part in this. Lord and Broadbent(23) have stated that radiation is proportional to $p^{5/4}$. It has been found by Spink and Guile(12) that in order to account for the arc voltage being virtually independent of arc current from 100 A to 10,000 A, it was necessary to take radiation losses into account and that even at atmospheric pressure it is possible that these might be as high as almost $^1/3$ of the total losses for arcs having a high temperature core. A similar conclusion has been reached by Lord(24). At 1 atm. in the present experiments, arc voltage was not independent of current, but as figure 10 shows, it appears to become increasingly independent of current as the pressure is raised.

For gas pressures below 1 atmosphere the initial formation of a core as figures 5, 6 and 7 show, probably takes place at a higher current the lower the pressure and the lower the magnetic field (and therefore velocity). This is in accordance with what King(19) has stated to be the case, and is quite reasonable in the light of the foregoing discussion, particularly with regard to the effect of electrode metal vapour. Once formed, the cored "high-current" arc is subject to the same restrictions as outlined above, leading to a transition at a still higher current back to a "low-current" diffuse arc (see figures 5, 6 and 7). One difference appears to be that a point or points of stable operation may be found between the two extreme conditions of transition II. This is particularly evident from figure 9 and may be due to greater amounts of electrode metal vapour in the arc. Low gas pressure might well lead to a substantial increase in metal vapour given off by the electrodes.

4.4 Initial Transition (I) to Cored Arc

"Arc instability" and serious velocity scatter was essentially confined to the region defined as transition I in section 4.1. On the basis of the discussion in section 4.3, it now seems reasonable to assume that the initial transition from a "low-current" diffuse arc to a "high-current" cored arc is the most significant event reflected in transition I, just as the subsequent transition at a higher current back to a "low-current" diffuse arc is reflected in transition II. The severe current and voltage fluctuation and erratic velocities, observed at low currents and velocities are most likely to have been symptons of the initial "low-current" to "high-current" arc transition (I), with multiple, complete or partial transitions between the two modes probably taking place. This explains why the symptoms of arc instability were mild or absent for conditions of gas pressure and arc velocity not conducive to arc core formation, i.e. gas pressure well below 1 atm. and low velocity. The ion seeding mechanism discussed in section 4.2, probably had a considerable influence on the situation after the first revolution. It seems reasonable to think of the arc being a diffuse "low-current" arc and having a high voltage gradient immediately after ignition in all cases at the low currents in question. Acceleration due to the magnetic field would tend to raise the axial temperature of the arc, which would lead to increased thermal conductivity and hence reduce the radius, all factors tending to promote increased acceleration and lead to eventual core formation. At the beginning of the second revolution, the ion seeding mechanism would aid this process. Events during the first revolution would therefore have had an important influence on subsequent developments. These were evidently not always decisive, since transitions in velocity and severe fluctuations of current and voltage often only became evident after several revolutions. They might then disappear for several revolutions and reappear later. Metal vapour from the electrodes may have been important in this connection. As mentioned in section 4.3, Hesse[21] found more evidence of vapour jets on square than on round electrodes. The fact that after changing from round faced ring electrodes to flat faced electrodes, it became easier to maintain the arc, may have been due to the vapour jet effect noted by Hesse. In the presence of electrode metal vapour it should certainly have been easier to maintain the arc. This would have been particularly noticeable in the early stages of the present investigation, when the supply voltage was limited to 460 volts.

It is worth noting here that while the effect of possible errors in the inter-electrode gap setting, is not likely to have been very significant in view of the pre-dominantly column controlled arc movement (driving and retarding forces are both proportional to arc length), gap variations may have had some effect on heat conduction from the arc to the electrodes. In addition, variations in the gap may have been reflected in variations in arc voltage and arc current, but these would have been limited by the inductance in the circuit. The net effect of these factors would have been to aggravate to some extent the symptons of arc instability.

With the many and variable factors involved, it is not really surprising that almost any arc velocity between a maximum determined by the equality of column driving and retarding forces on a cored "high-current" arc and a minimum determined by cathode emission processes could be observed during the initial low current tests.

The rapid rise in velocity with increase in pressure just above the immobility value shown in Fig. 18 is due to the increase in m.f.p. leading to elastic collisions causing more and more electrons to excite on the forward side[5], so that the time for a cathode site to reach full emission is first reduced and then made negligibly small by ions remaining from previous revolutions. The resulting high velocity increases convection to the point where the arc radius is so reduced that it becomes "cored".

The results of Yamamura[6] show a rapid rise in velocity in the forward direction over a small range of pressure after passing through immobility as was the case in the present investigation. However, at a pressure considerably below 1 atmosphere, the velocity ceases to rise and becomes virtually independent of pressure. Although he shows similar results for a number of different electrode materials, results on brass electrodes are not given. Any direct comparison is therefore not possible. However, the fact that the velocity showed no change with pressure when it was increased to above a certain value, is in marked contrast to the results obtained in the present investigation. The difference is probably due to the fact that the arc in this case was column controlled due to suppression of cathode emission effects as a result of the ion seeding mechanism, whereas the arc movement remained dominated by cathode emission processes in the experiments carried out by Yamamura[6], since the arc moved once along linear electrodes. The high velocities (40 - 50 m/sec) obtained by the arc in Yamamura's tests before the velocity became independent of pressure, makes it appear that there may have been a transition to a "high-current" cored arc. Most of his tests were at a current of only 10 A, but the magnetic flux density was 0.075 Wb/m^2 and he used small electrode spacings (1.3 and 2.5 mm.), so according to results obtained in the present investigation, conditions should have been favourable for core formation.

4.5 Electrode Material and Surface Condition

Since, in the present apparatus, electrode emission effects were capable of almost total suppression, it is not surprising that electrode material and surface condition were found to have little effect on arc behaviour. Figure 2 shows that surface condition in both air and nitrogen make no appreciable difference to arc velocity. Figure 18 illustrates best the slight differences that were observed between aluminium and brass electrodes. The difference is seen to lie mainly in the greater pressure range over which transition I was accomplished on aluminium compared with brass electrodes. The fact that Yamamura(6) found the rate of increase in forward velocity with pressure to be less on aluminium than on copper electrodes, is of interest in this connection. Even after the transition, the velocity on aluminium electrodes is seen to remain slightly below the velocity on brass electrodes, although the variation with gas pressure is shown by table 1 to be the same on brass and aluminium electrodes. Table 2 shows the rate of rise of velocity with current for low values of current to be higher for aluminium electrodes than for brass electrodes. That $U \propto I^{0.6}$ suggests in fact that the arc radius is probably diminishing slightly with increasing arc current. The electrical conductivity of the arc must be increasing more rapidly than with brass electrodes for this to be the case. This may possibly be due to the fact that the thermal conductivity of aluminium is about twice that of brass and the axial flow of heat to the electrodes is therefore correspondingly greater. As King(18) points out, such an increased rate of energy dissipation from the arc column would lead to an increase in axial arc temperature and therefore electrical conductivity at any given current. On the other hand, increasing amounts of electrode metal vapour with increasing current might be sufficient to account for the increase in electrical conductivity.

The fact that the transition (I) to the cored "high-current" arc takes place over a greater range of pressure with aluminium than with brass electrodes suggests that electrode vapour jets and sputtering may be more pronounced with aluminium electrodes. Secker[25] found when using aluminium electrodes that a considerable amount of electrode material was condensed on nearby surfaces, which is certainly indicative of electrode vapour and sputtering. Vapour from the cathode in addition to reducing energy dissipation in the arc and thus counteracting tendencies to core formation, might also affect the velocity by carrying away positive ions, thus reducing the effectiveness of the ion seeding mechanism, and consequently the arc velocity.

4.6 Ambient Gas

Above about 1.5 atmospheres the velocities obtained in air and nitrogen under otherwise identical conditions were not found to differ appreciably, and this might be expected on the basis of the similar relative densities of air and nitrogen for a column-controlled arc. However, figure 18 shows that the initial transition (I) to a "high-current" cored arc takes place more readily in nitrogen than in air. It is unlikely that this is due to any significant difference in the processes taking place in the gas since air consists of about 78% nitrogen. King[18] states that the transition from a "low-current" to a "high-current" arc takes place at almost the same current in both gases. The difference in this case is thought to be due to the absence of oxygen when the arc is run in nitrogen. The results obtained by Secker[25] in nitrogen, show that this limits re-oxidation of the electrode surface after passage of the arc and thus leads to a thinner cathode oxide layer. It is thought that the thinner oxide layers may in this case have led to velocity enhancement via improved efficiency of the ion seeding mechanism. A secondary effect of the higher velocity would be decreased amounts of electrode vapour which would again tend to aid the transition to a "high-current" cored arc.

From Fig. 19, the velocity was found to be proportional to the relative gas density to the power of -0.57 for a pressure of 3.72 atmospheres, and this close agreement with the value of -0.5, for gases including one electronegative one, strengthens the evidence for column-control.

Hydrogen, according to King[18], having a low dissociation temperature, may form a high-current core at a current of only 1 A rather than 50 A for air and nitrogen. The transition from a "low-current" diffuse arc to a "high-current" cored arc should therefore have taken place readily in this case. The low density of the gas explains the high velocities observed in hydrogen, shown in figure 14. Again, the absence of oxygen and the reducing action of hydrogen would lead to improved ion seeding efficiency.

The test results gave some indication that in hydrogen transition II back to a "low-current" diffuse arc may have taken place occasionally at an arc current as low as 15 A. This statement is based on the fact that above about 15 A there was considerable scatter in the results, but that this was not attributable to severe fluctuations in voltage and current since the low velocity points were characterised by remarkably stable voltages and currents.

It is rather interesting that table 2 shows powers of I for hydrogen (0.51) and sulphur-hexa-fluoride (0.15) that bracket the powers of I for air and nitrogen (considering only brass electrodes). Both gases have a low dissociation temperature, 3500°K for SF_6 and 4500°K for H_2, that of SF_6 being approximately the same as for CO_2 (3800°K) which may form a core at a current of 0.1 A[18]. The considerable difference between the powers of I shown by table 2 is, therefore, most likely to be a reflection of the almost 100/1 ratio of relative density between the two gases. The large difference in arc velocity caused by this and illustrated by figure 17, probably means that at the low velocities in sulphur-hexa-fluoride, an increase in arc current must be accompanied by an increase in arc radius to maintain the heat balance, whereas at the high velocities attained in hydrogen, the resulting velocity increase gives rise to additional convection, higher core temperature and higher thermal conductivity, and therefore no increase in radius is required. No obvious effect of the electro-negative characteristics of sulphur-hexa-fluoride was observed. It was found that at a gas pressure of 0.066 atm., a magnetic flux density of 0.106 Wb/m^2 and a current of 6 A, an arc in air would move in the retrograde direction whereas an arc in SF_6 would be stationary. This, however, can be accounted for by the density difference alone, since increases in pressure (or density) tend to favour the forward direction of motion. A more realistic comparison would be to compare the velocity in SF_6 at 0.066 atm. and in air at 5.1 x 0.066 atm. or 0.306 atm. The nearest comparable pressure in air is therefore 0.26 atm., where, for the same conditions, the arc in air was found to be practically stationary (figure 4).

It is possible that the movement of an arc dominated by cathode emission processes would have been slowed down due to the capture of emitted electrons by the sulphur-hexa-fluoride. Any such tendencies would tend to have been masked by the ion seeding mechanism in this case, but may account for the rise in velocity with SF_6 occurring at a higher pressure (nearly 1 atmosphere) than in other gases as shown in Fig. 18, since, in this region, the deflection of electrons in the cathode fall is critical.

4.7 Immobility and Retrograde Conditions

Generally speaking the arc velocity near to and on both the forward and retrograde side of immobility was probably too low to be appreciably affected by the ion seeding mechanism. Thus, it is reasonable to expect that under those conditions fairly good agreement should exist between the present results and those obtained by other investigators.

In both air and nitrogen it was found that for any given magnetic flux density, reversal of the direction of arc movement occurred at a lower pressure as arc current was increased. For a given arc current, the reversal occurred at a higher pressure when the magnetic flux density was increased. These trends do agree with the results of Gallagher(7), St. John and Winans(8) and Yamamura(6). The latter, using copper electrodes 2.5 mm. apart in air found a reversal pressure of 100 mm H_g for a magnetic flux density of 0.034 Wb/m^2 and an arc current of 10 A. For the same arc current and flux density, the present work indicates a reversal pressure of between 100 and 200 mm. H_g in air. Since Yamamura's results also show that decreasing the inter-electrode gap increases the reversal pressure, the reversal pressure found with the present 2 mm. gap is quite reasonable.

In air at 0.0018 atm. (1.4 mm. H_g) and a flux density of 0.106 Wb/m^2, the arc velocity was found to increase rapidly in the retrograde direction with increasing arc current (see figure 4). The results of St. John and Winans(8) and Breitholtz(26) show that this can occur in the case of a vacuum arc. The pressure at which Breitholtz obtained his results varied from 5×10^{-7}mm. H_g to about 10^{-4} mm. H_g after 0.5 sec. arcing. The fact that a "vacuum arc" was observed in the present experiments at a pressure as high as 1.4 mm. H_g and that the retrograde velocity for any given current was very much higher than observed by Breitholtz, is interesting, and indicates that the ion seeding mechanism may also enhance retrograde velocities. This is quite reasonable, but the result is not likely to be the same as for an arc moving in the forward direction, since the column only experiences forward forces.[9] At a gas pressure of 0.0018 atm. the aerodynamic drag would be insignificant. It would certainly be negligible compared with the "drag" due to forward driving forces on the column. In the retrograde direction, therefore, the arc velocity, while controlled by cathode emission processes, is simply enhanced due to the ion seeding mechanism reducing the site conditioning time (see section 4.2).

4.8 Conclusion

It has been shown that, under certain conditions, a 2 mm. long arc is capable of column-dominated movement in a transverse magnetic field. The observed behaviour of such an arc is in good agreement with predictions by Lord[14] who has treated the column of a high pressure arc on the basis of continuum magnet-fluid-dynamics. For a 2 mm. arc, however, some allowance must be made for heat loss to the electrodes, so that radial heat conduction cannot be taken as being equal to the energy dissipated in the arc.

The column-dominated behaviour of a 2 mm. arc is conditional on suppression of the cathode emission effects. This condition occurred in the present apparatus with continuous ring electrodes causing the arc to run over the same surface repeatedly. Positive ions remaining on the cathode oxide layer after a previous passage(s) of the arc, was the probable cause of emission effect suppression.

Under these conditions, tests carried out in transverse magnetic fields between 0.034 and 0.106 Wb/m^2, showed that the transition from a "low-current" diffuse arc to a "high-current" cored arc, in air and nitrogen at atmospheric pressure could take place at an arc current as low as 5 A. This transition takes place at about 50 A with a free-burning static arc in air or nitrogen at atmospheric pressure[18]. The reduction in the critical current observed in the present investigation was probably due to the high rate at which energy was extracted from the arc. High arc velocity enhancing the convection loss and axial conduction of heat from the arc to the electrodes were dominant factors in this process.

A second transition, back to a "low-current" diffuse arc, was found to take place at a higher arc current, about 80 A in air at atmospheric pressure.

This is thought to have occurred mainly because the arc core temperature could reach a value high enough (about 20,000°K) to make the electrical conductivity of the arc independent of temperature. The results are such as to suggest that it was only possible for the "high-current" cored arc to operate stably on the positive slope of the electrical conductivity/temperature characteristic.

It should be noted that the results given are only preliminary ones, and that much remains to be done to explore the effects in more detail.

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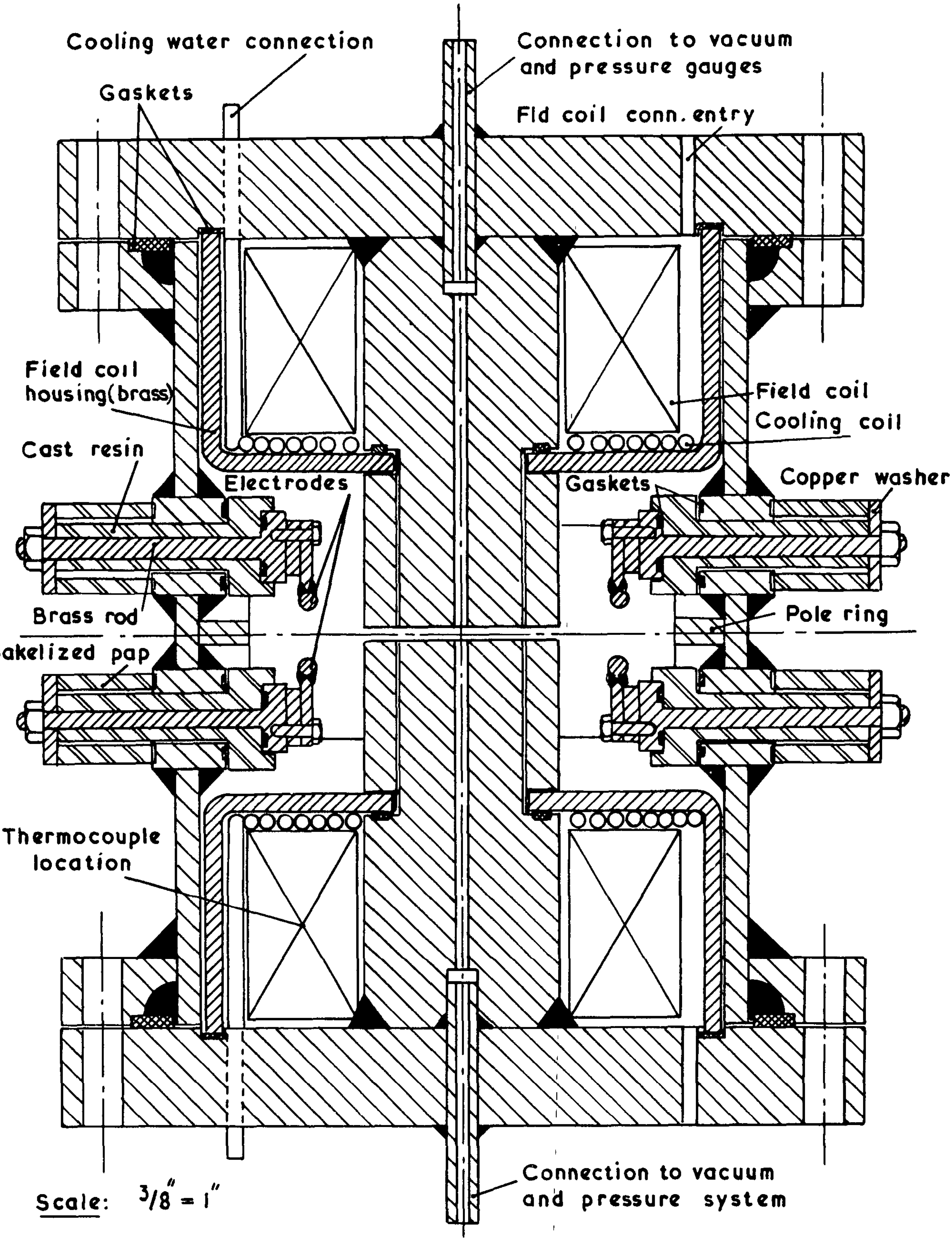
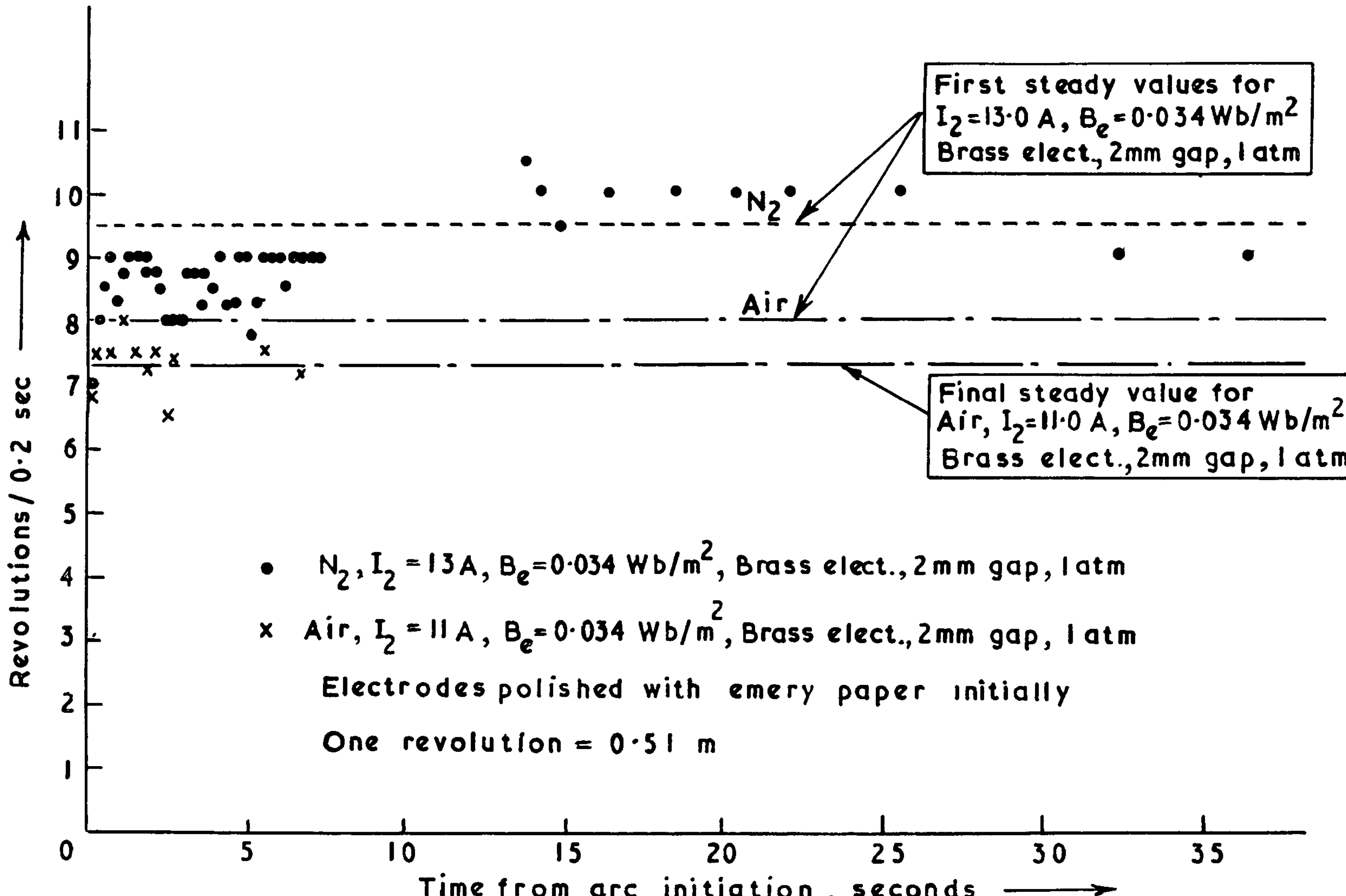
FIG. 1



Scale: 3/8" = 1"

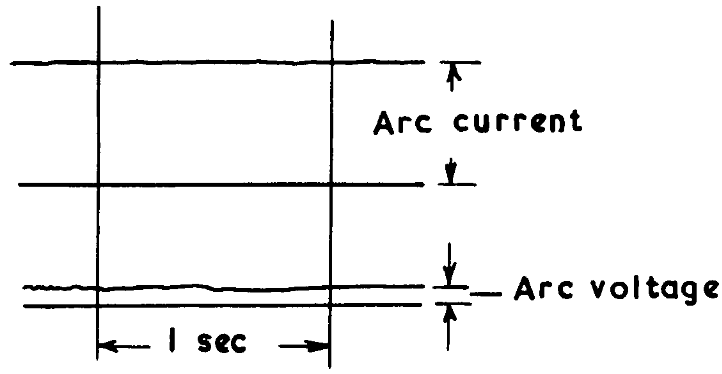
Test cell — vertical section



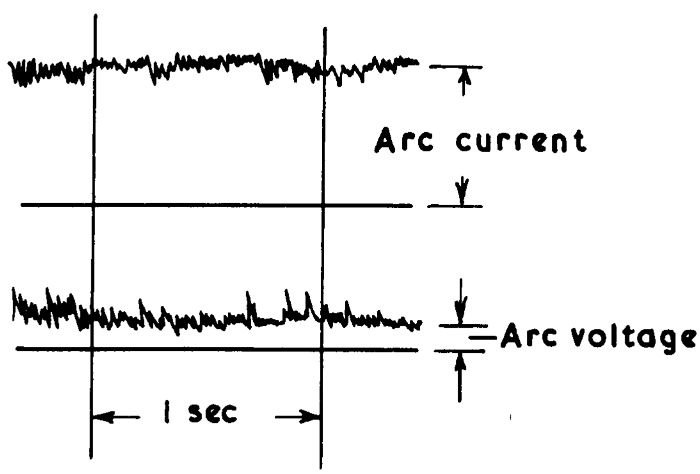
Arc velocity vs. arcing time

FIG. 2

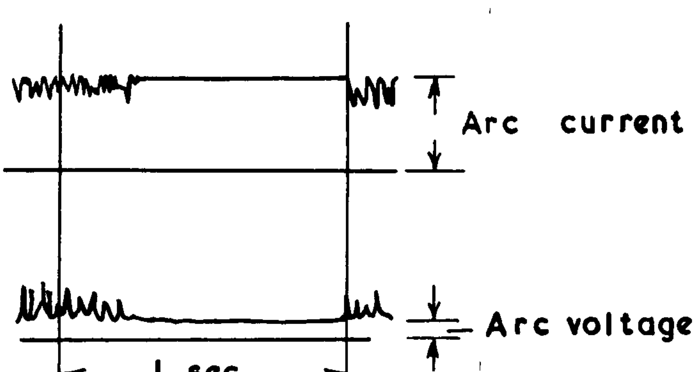
FIG. 3



(a) Smooth current and voltage with uniform velocity



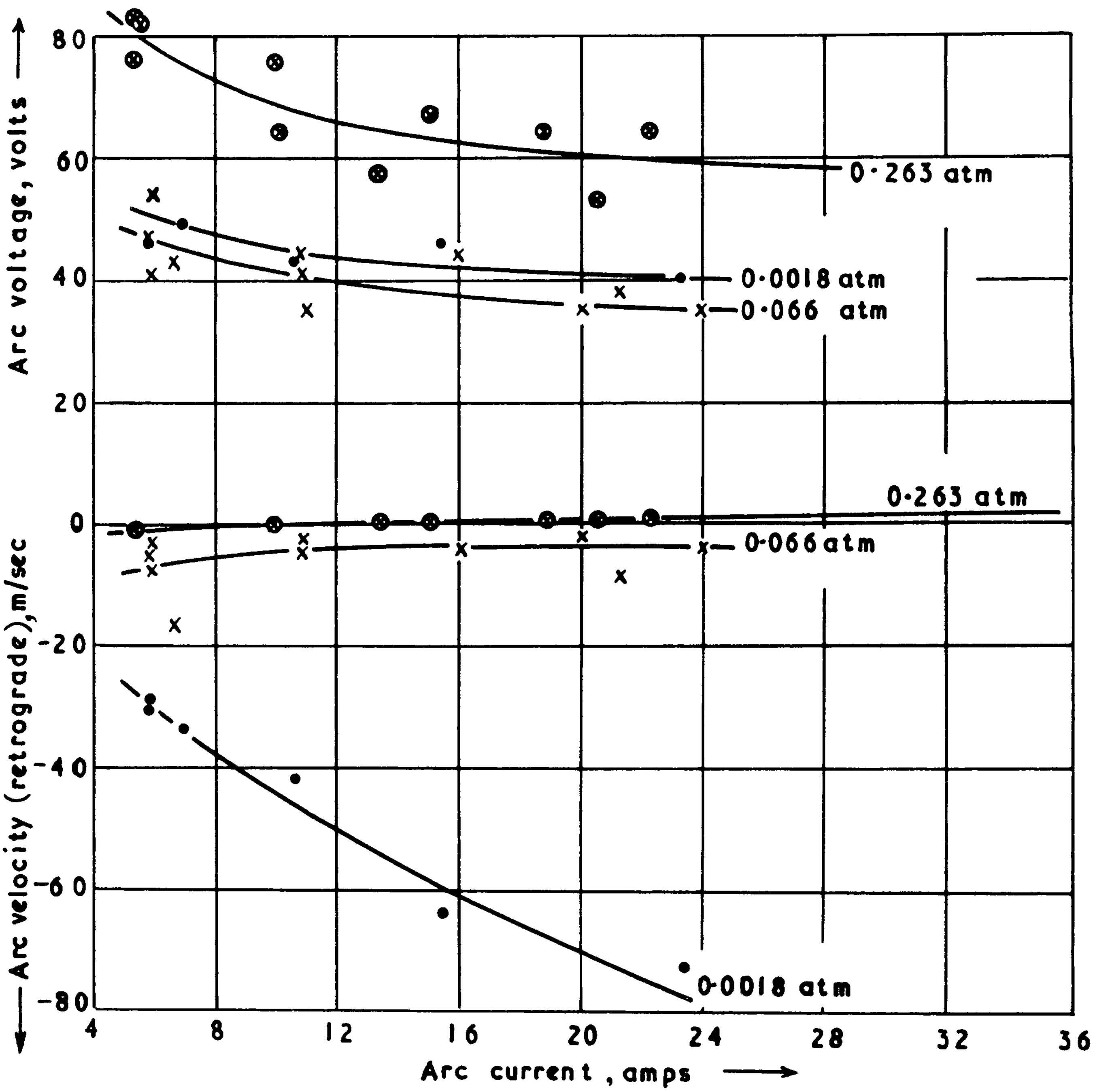
(b) Fluctuating current and voltage with erratic velocity



(c) Transitions between uniform and erratic modes

Typical recordings of arc current and voltage

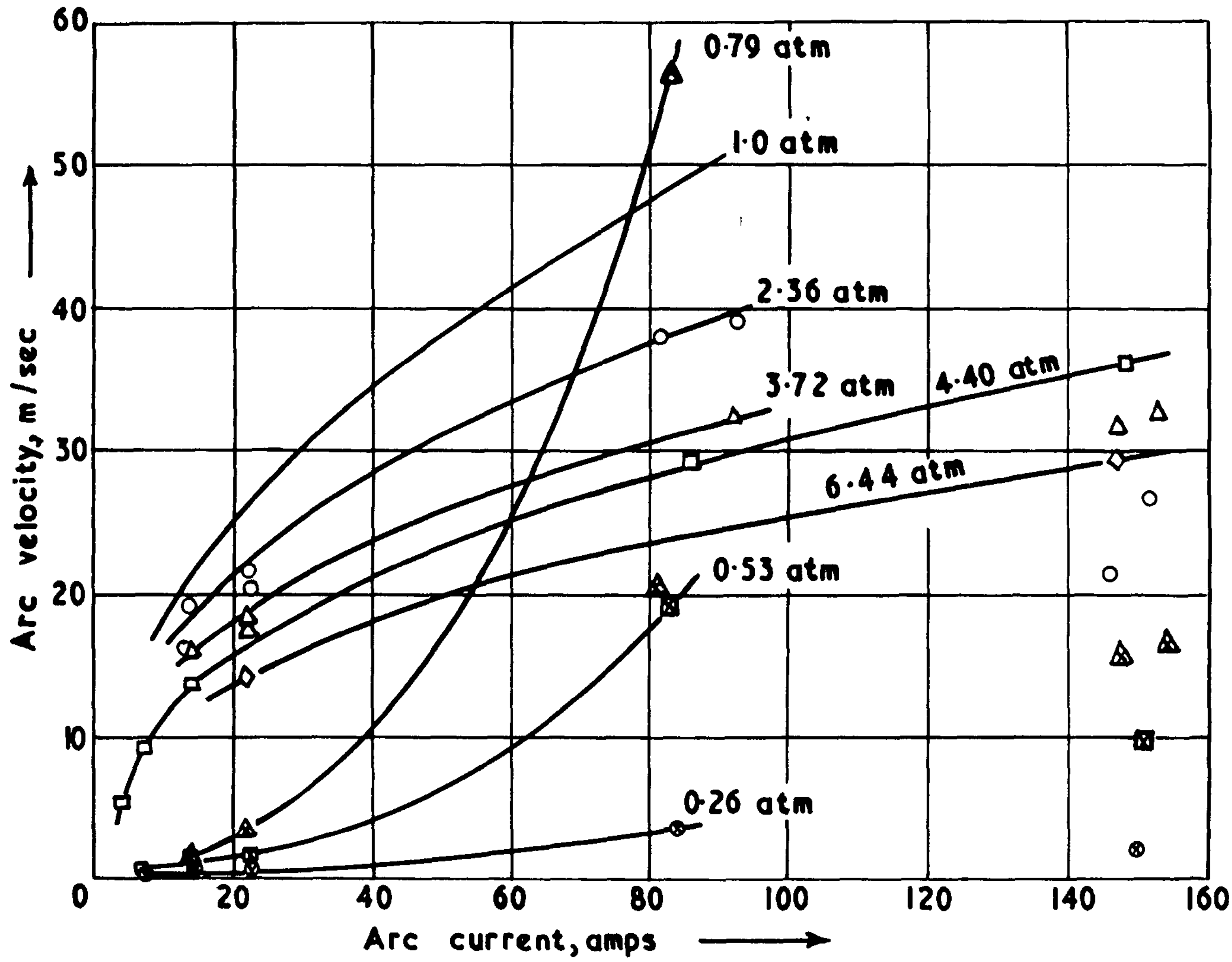
FIG. 4



Arc velocity and total voltage vs. arc current

Flux density — 0·106 Wb/m^2
Gas — Air
Electrodes — Brass
Gap — 2 mm

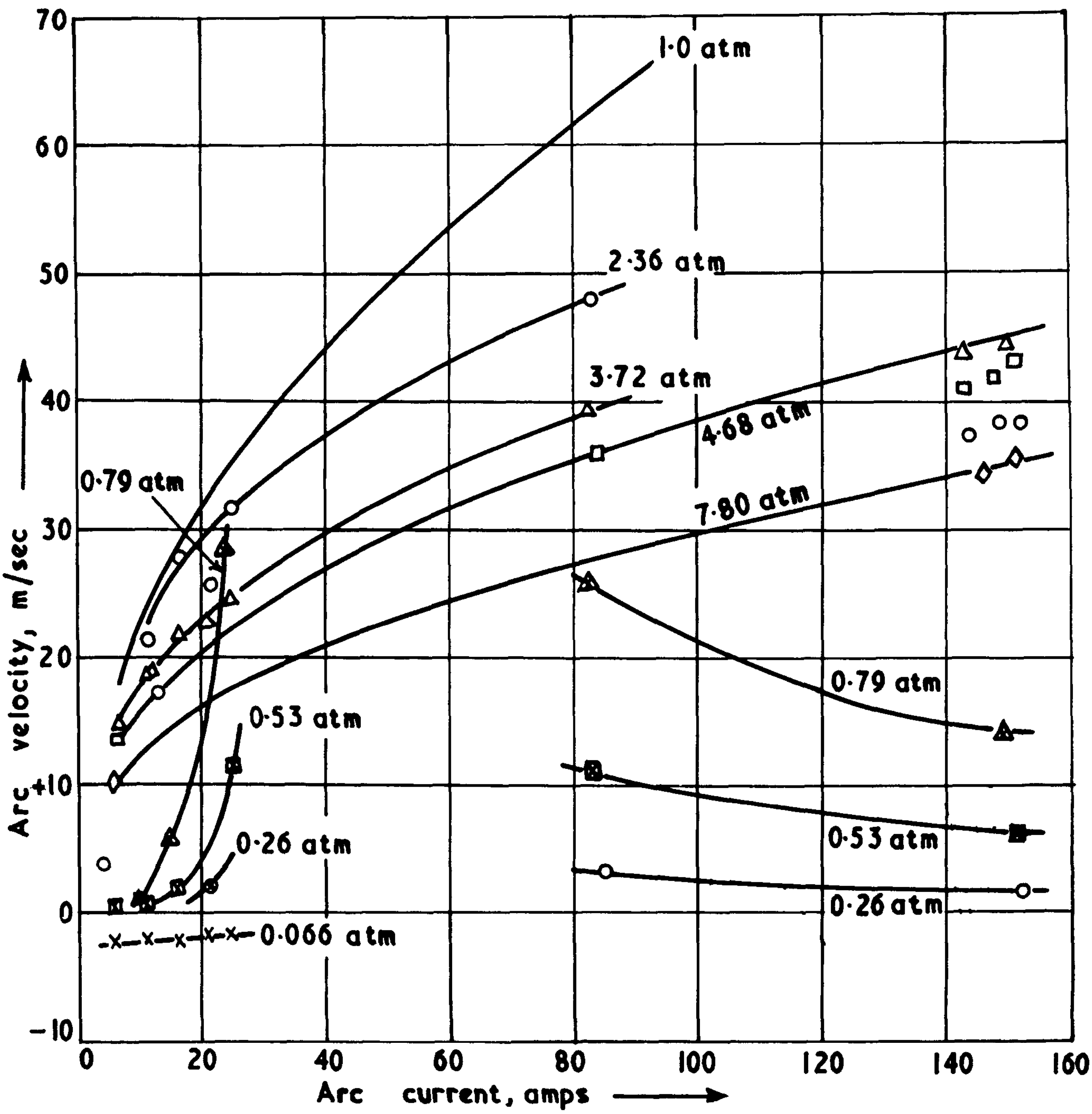
FIG. 5



Arc velocity vs. arc current

Flux density 0·034 Wb/m²
Gas Air
Electrodes Brass
Gap 2mm

FIG. 6



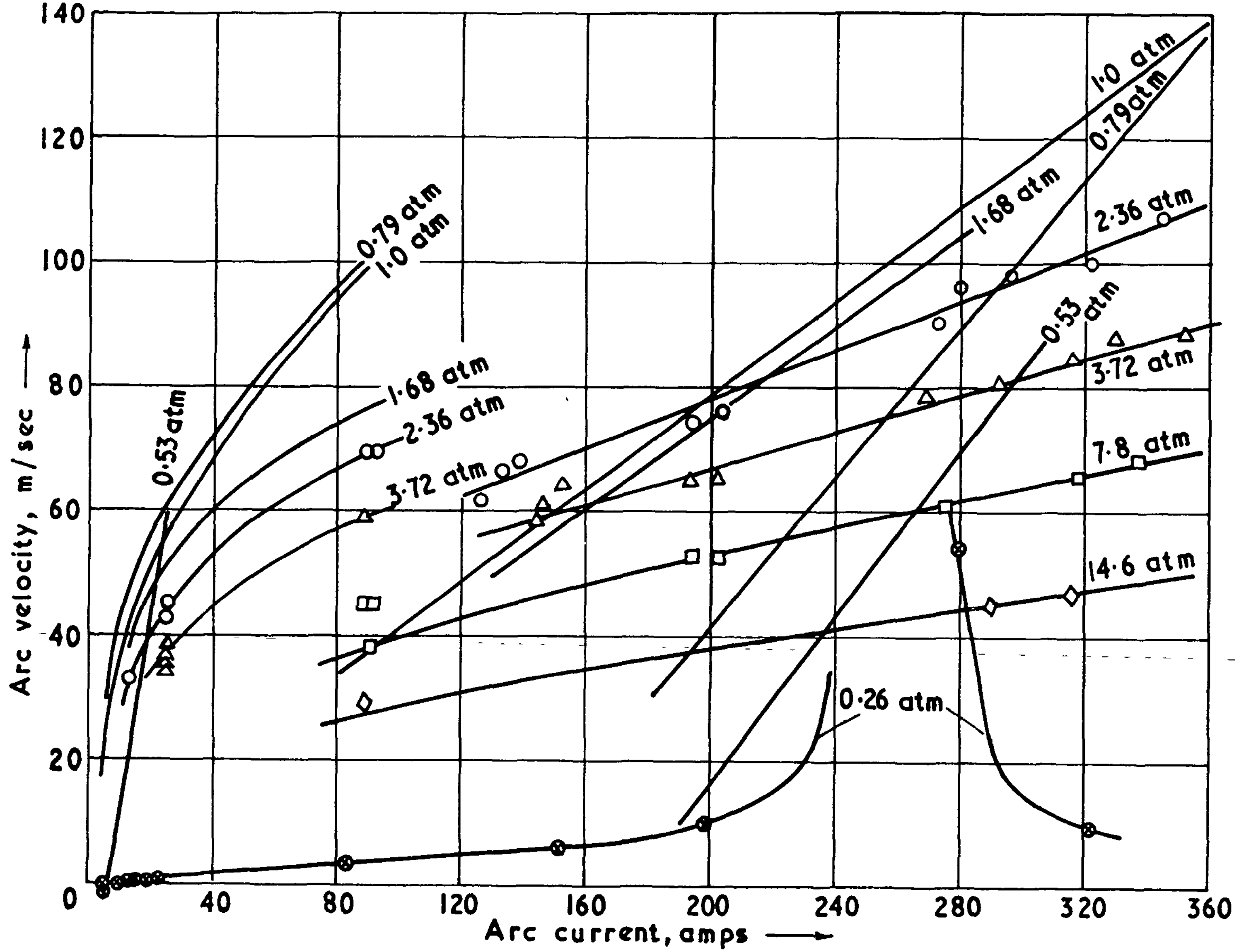
Arc velocity vs. arc current

Flux density 0·054 Wb/m²

Gas Air

Electrodes Brass

Gap 2mm



Arc velocity vs. arc current

Flux density — 0·106 Wb/m^2 Gas — Air

Electrodes — Brass Gap — 2 mm

FIG. 7

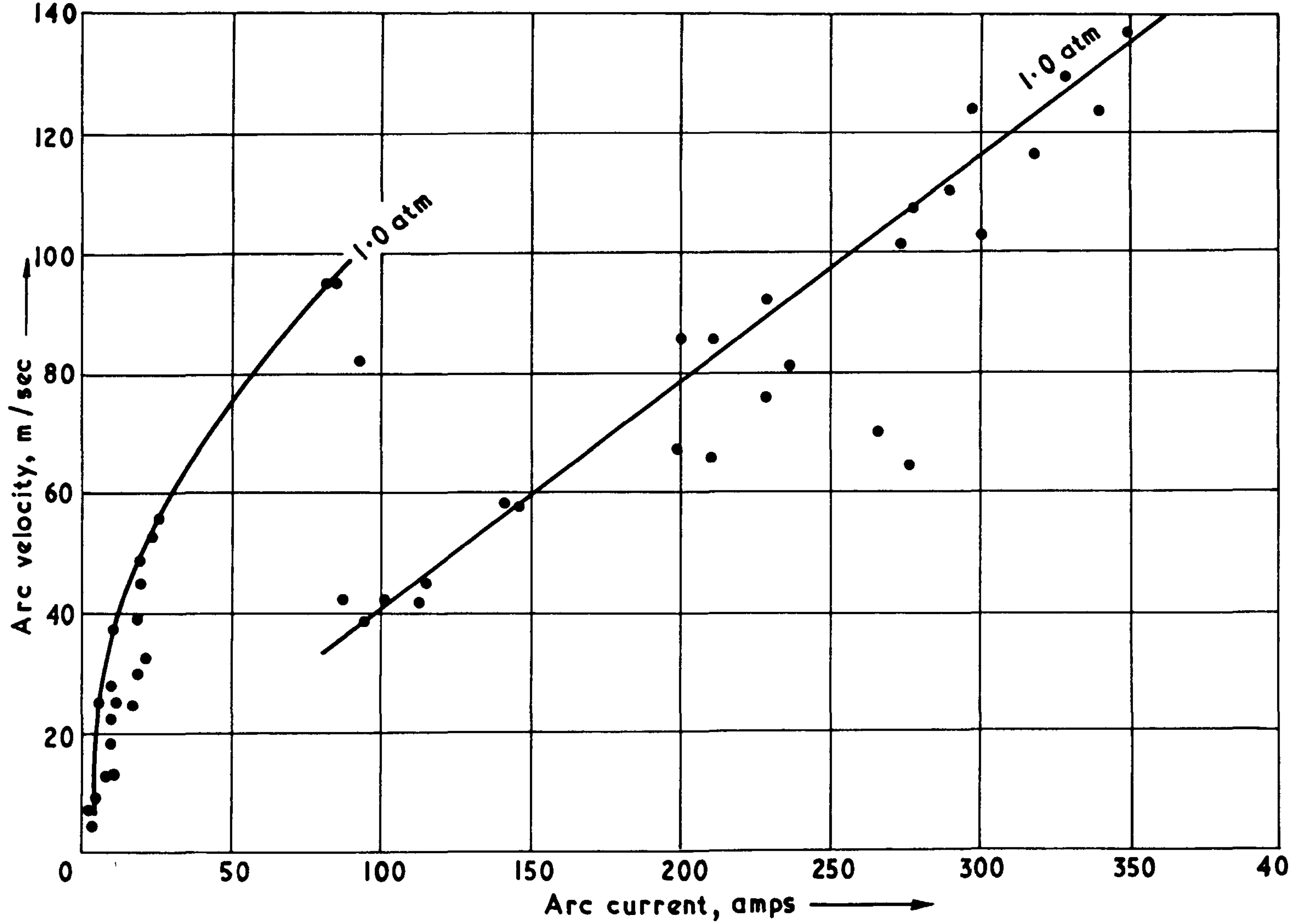
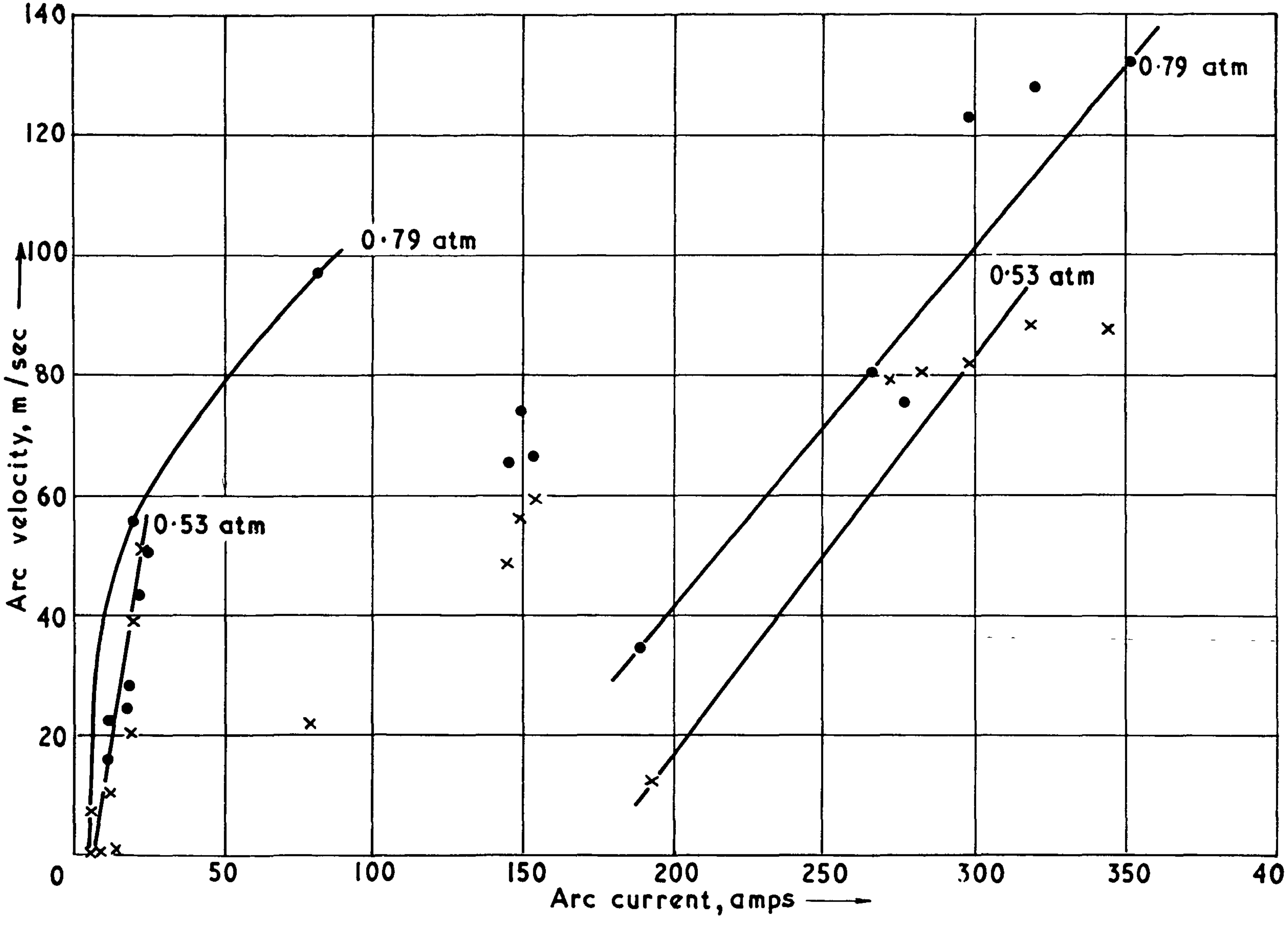


FIG. 8

Arc velocity vs. arc current

Flux density — 0·106 Wb/m^2
Gas — Air
Electrodes — Brass
Gap — 2 mm



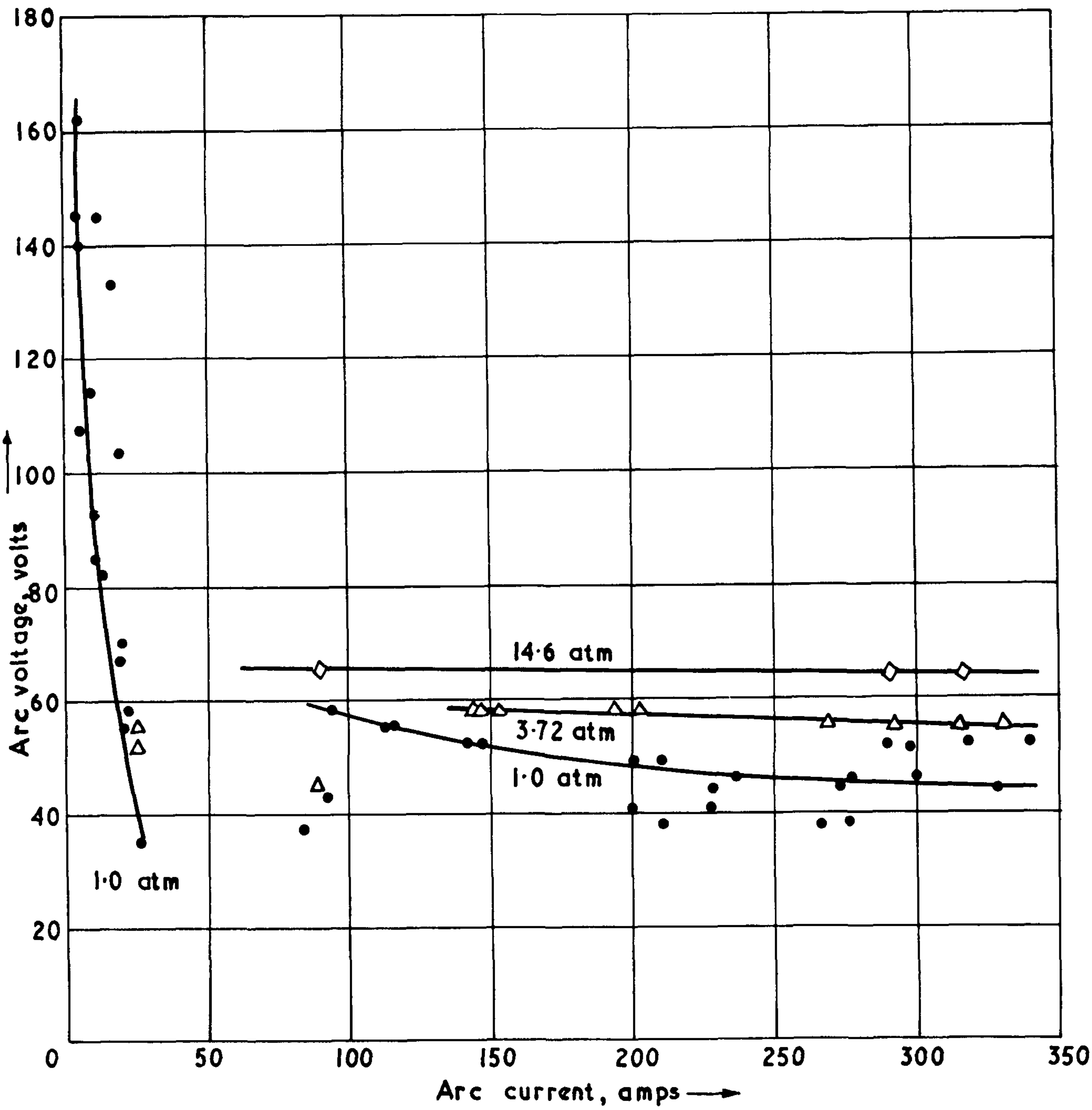
Arc velocity vs. arc current

Fluid density — 0·106 Wb/m²   Gas — Air

Electrodes — Brass   Gap — 2 mm

FIG. 9

FIG. 10



Total arc voltage vs. arc current

Flux density — 0·106 Wb/m^2
Gas — Air
Electrodes — Brass
Gap — 2 mm

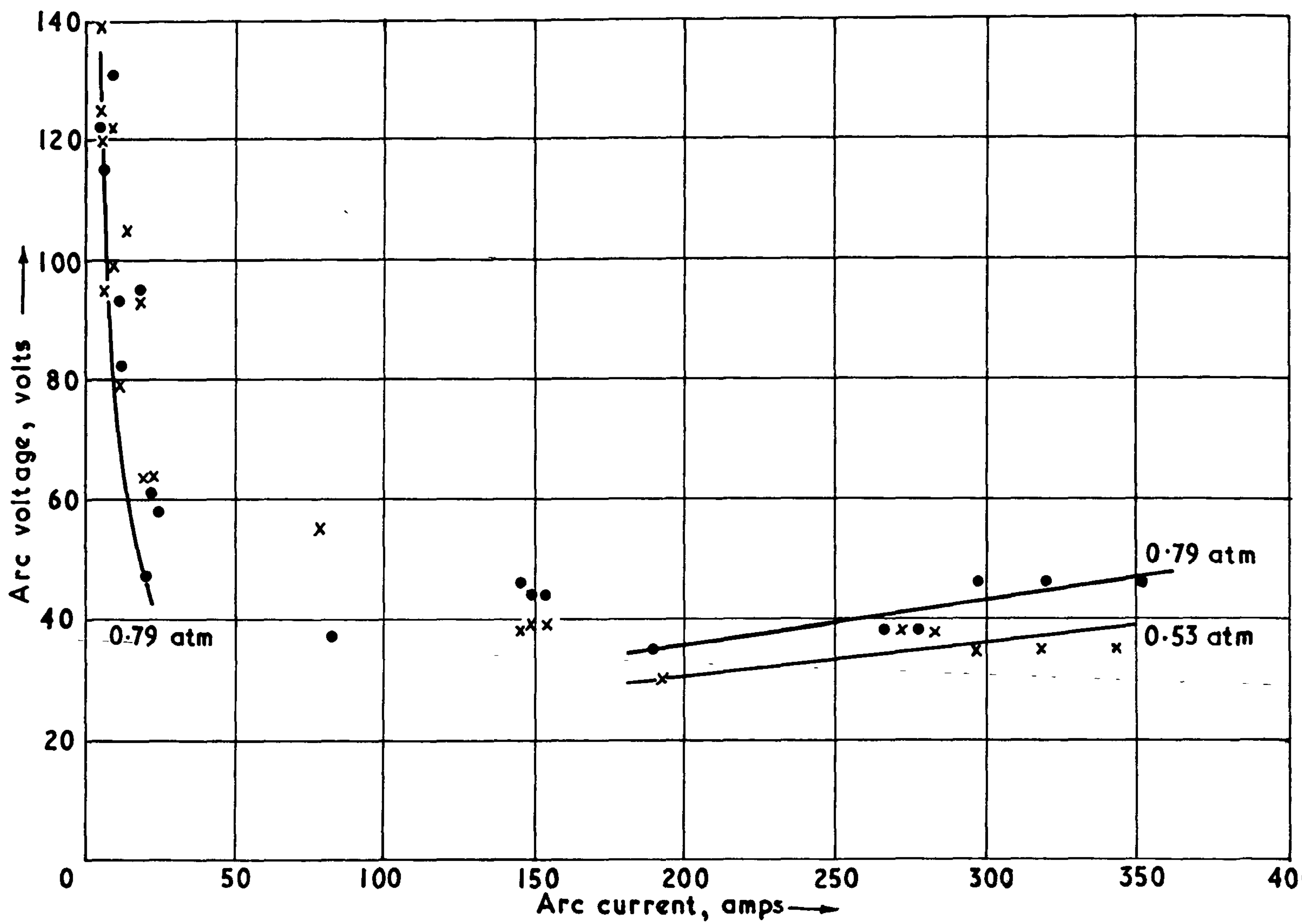
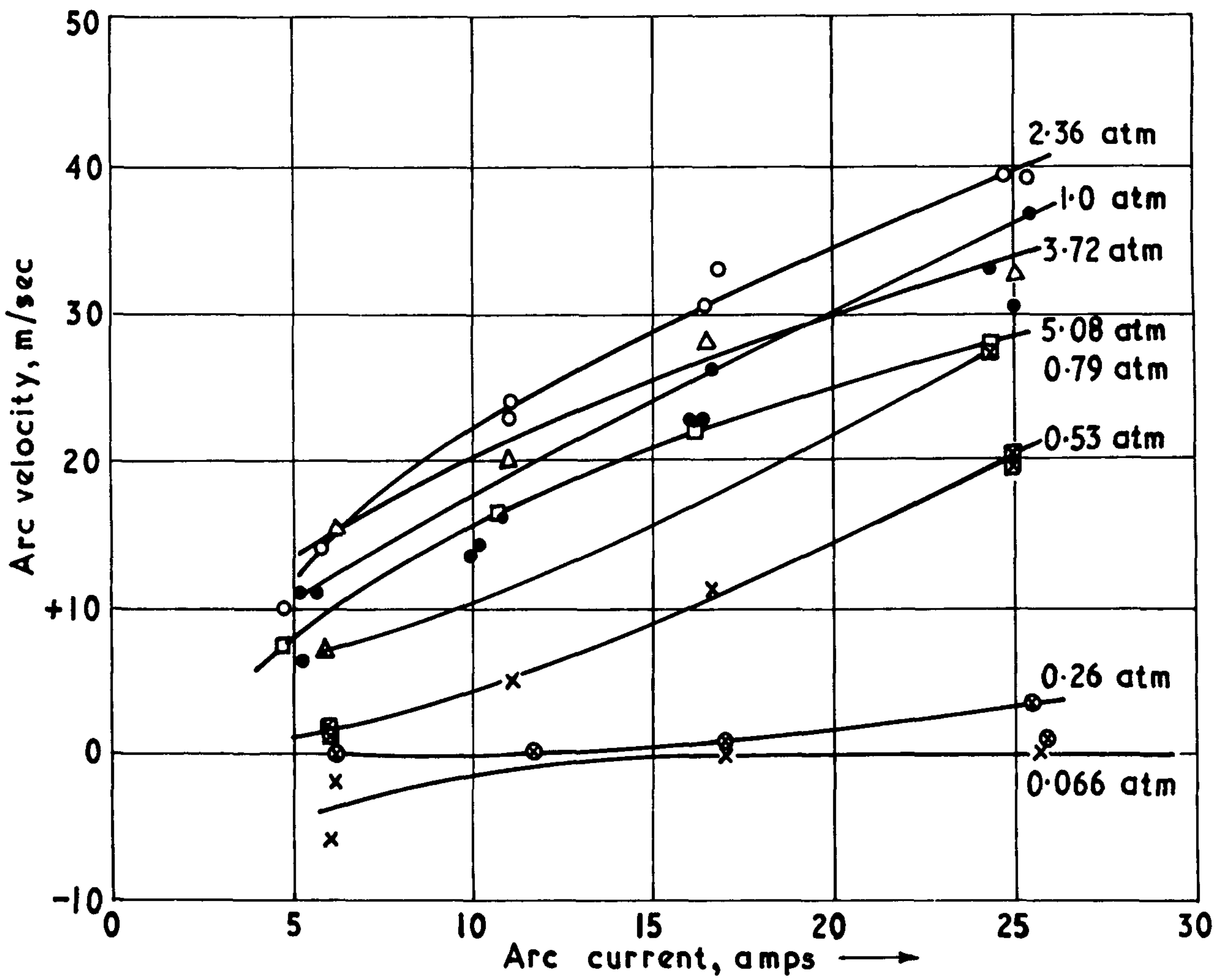


FIG. 11

Total arc voltage vs. arc current

Flux density — 0·106 Wb / m^2
Gas — Air
Electrodes — Brass
Gap — 2 mm

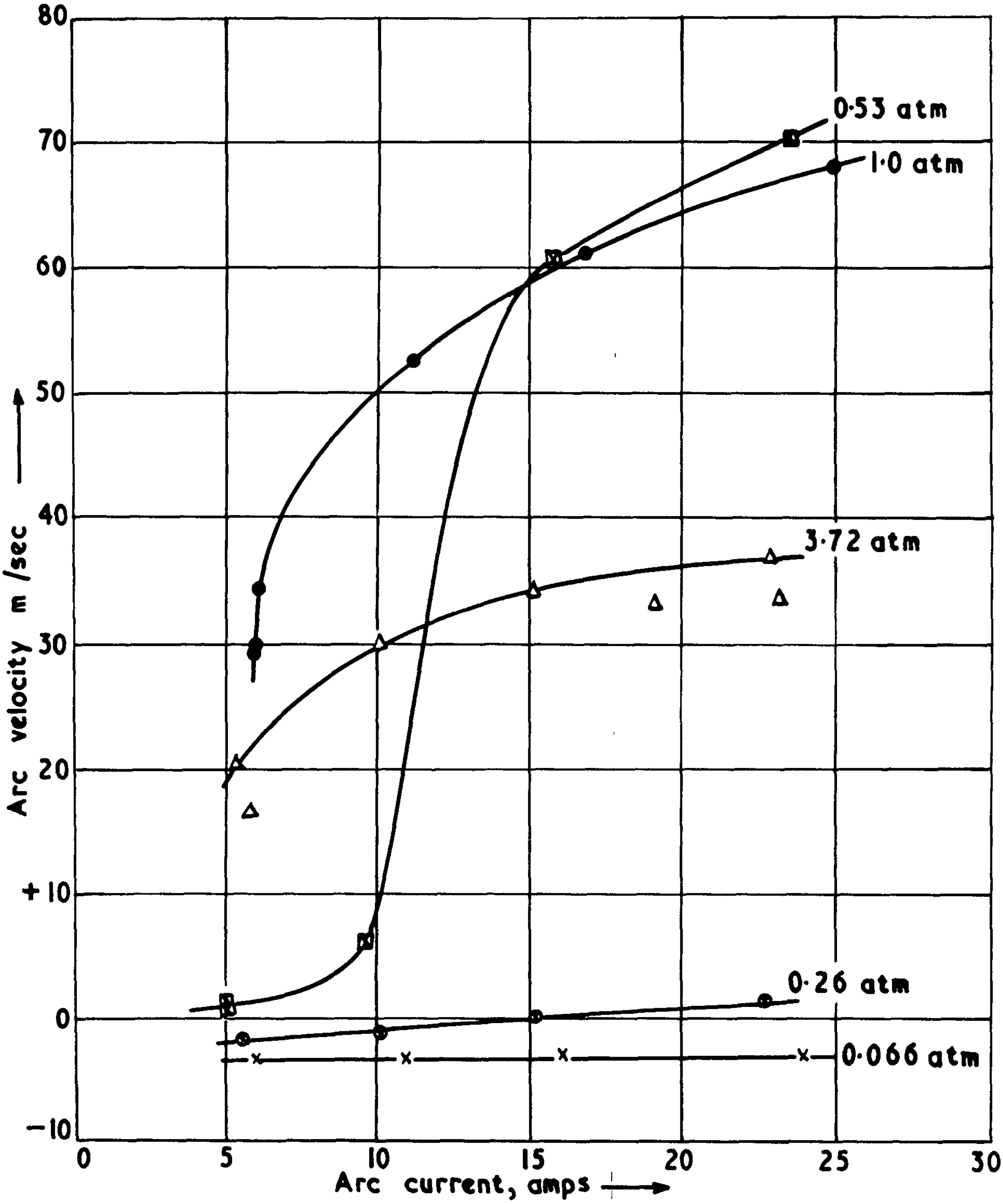
FIG. 12



Arc velocity vs. arc current

Flux density	$0 \cdot 106\ Wb/m^2$
Gas	Air
Electrodes	Aluminium
Gap	2mm

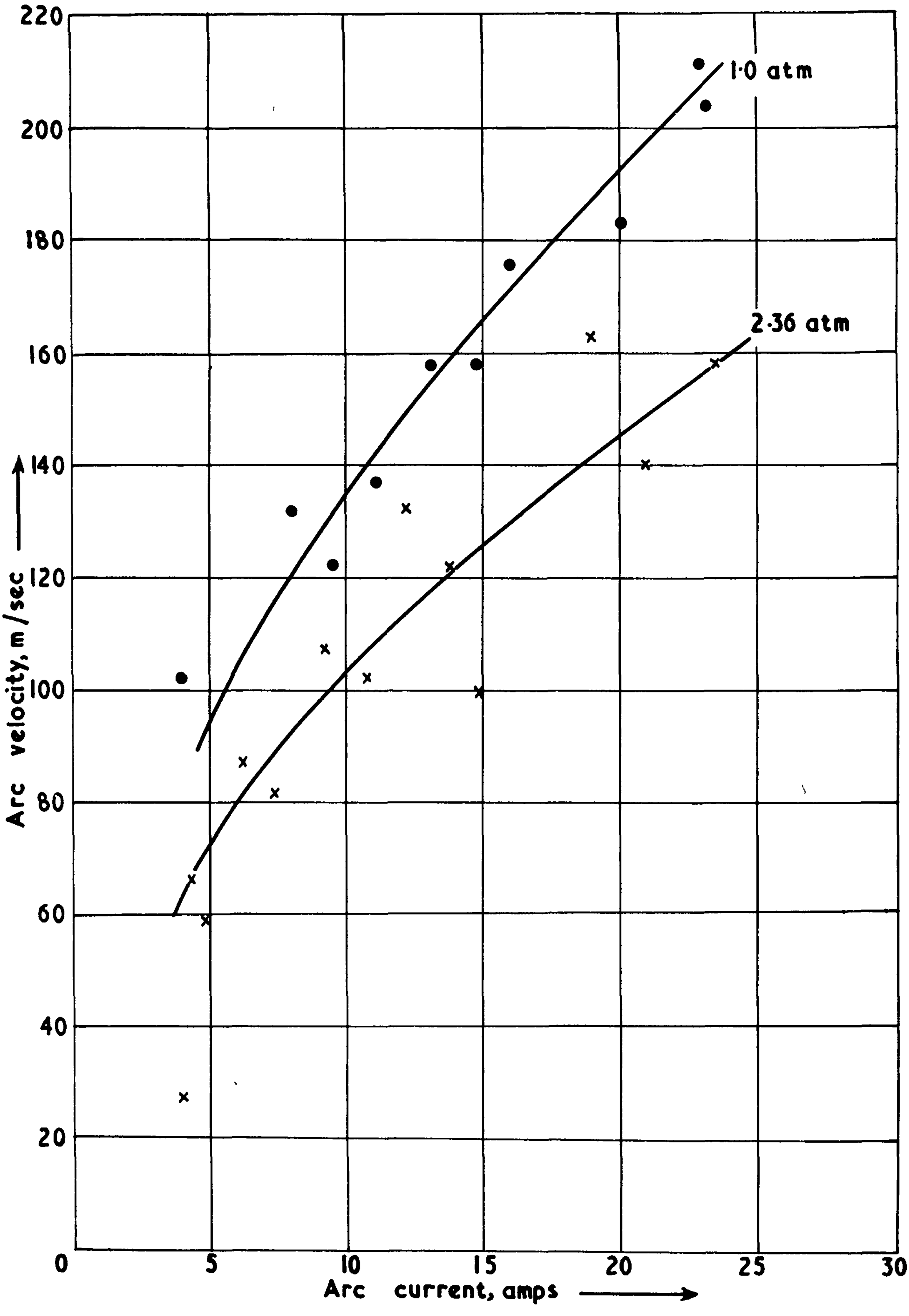
FIG. 13



Arc velocity vs. arc current

Flux density	0·106 Wb/m^2
Gas	Nitrogen
Electrodes	Brass
Gap	2mm

FIG.14

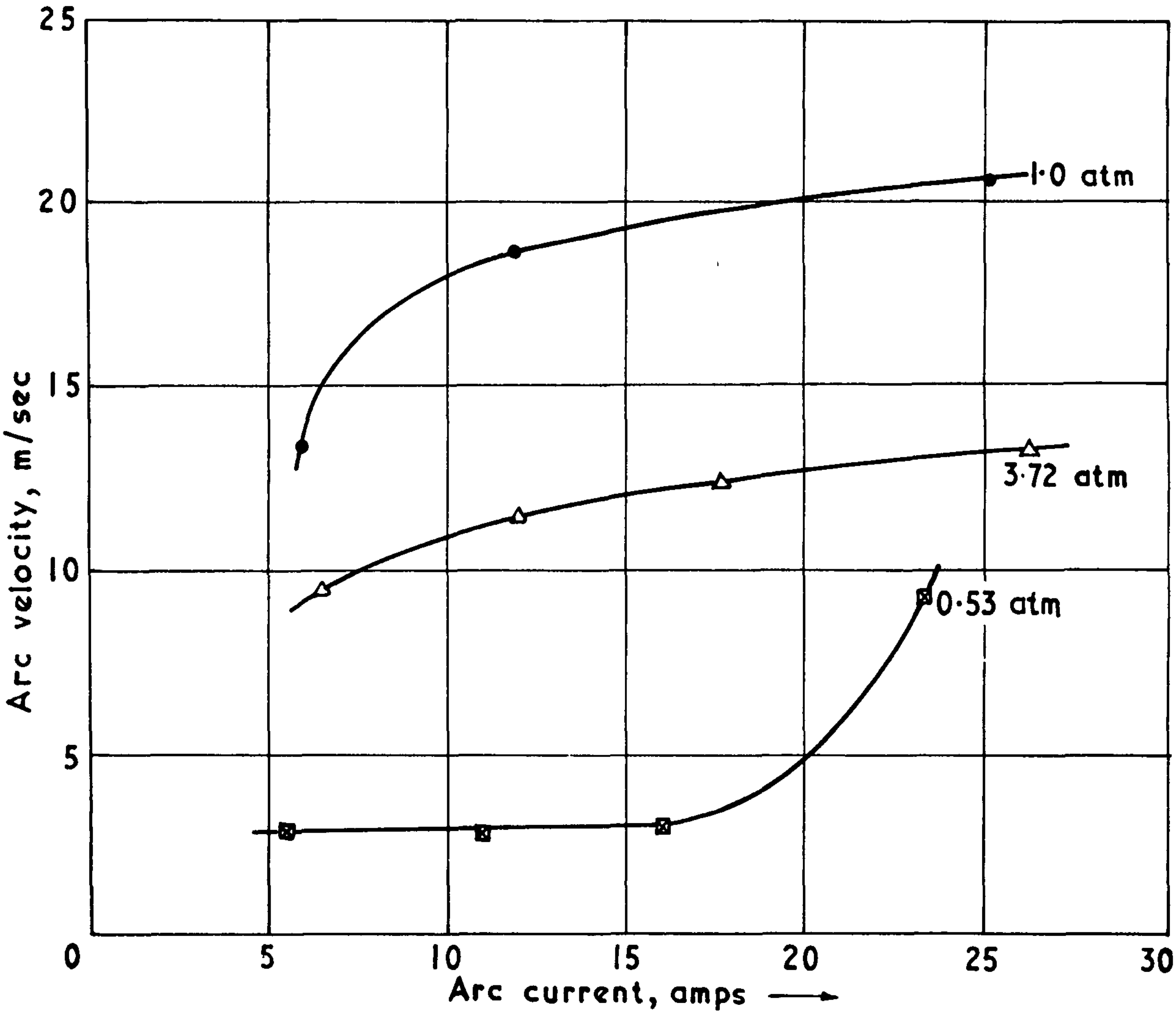


Arc velocity vs. arc current

Flux density — 0·106 Wb/m^2 Gas — Hydrogen

Electrodes — Brass Gap — 2 mm

FIG. 15



Arc velocity vs. arc current

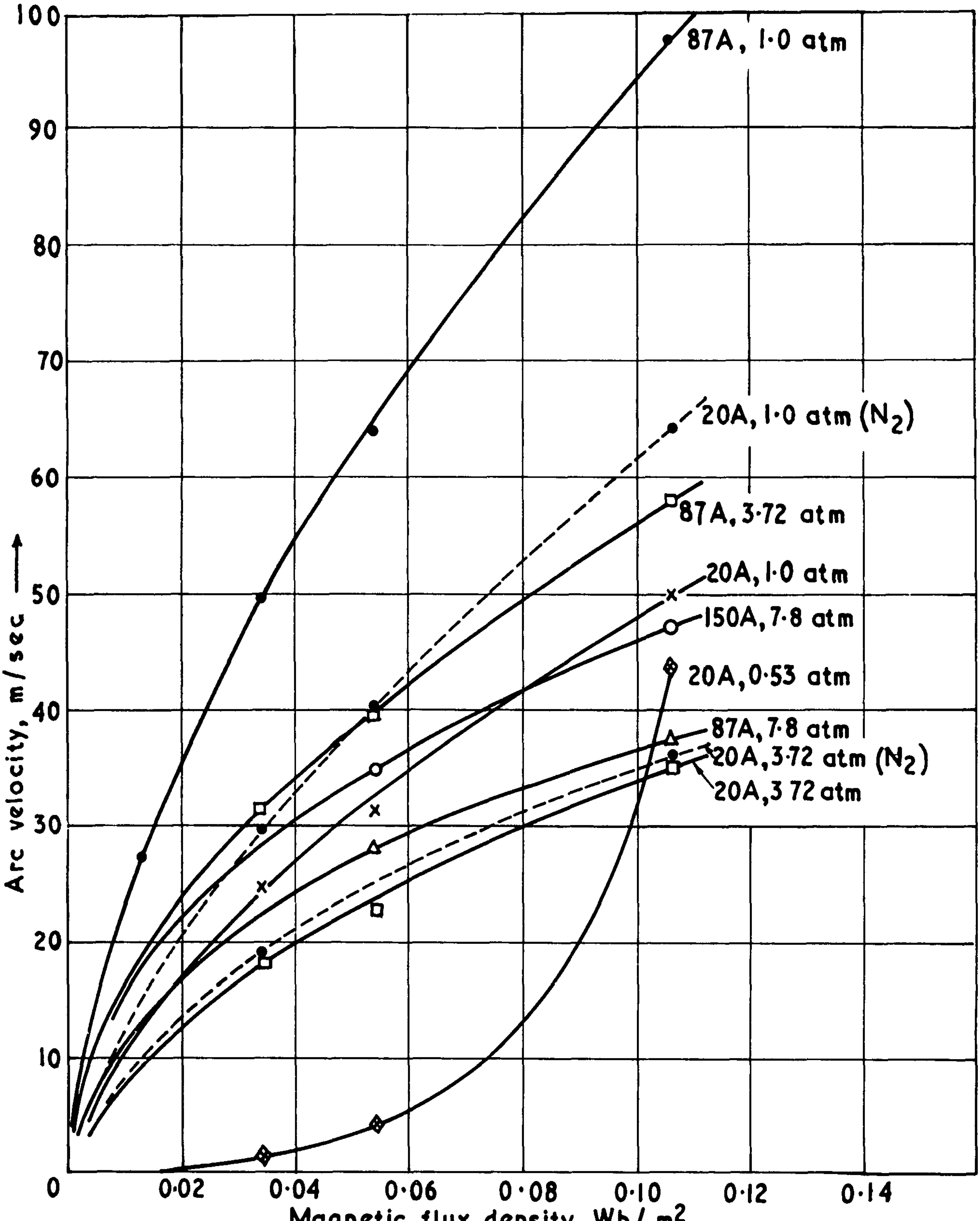
Flux density — 0·106 Wb/ m^2

Gas — Sulphur-hexa-fluoride (SF_6)

Electrodes — Brass

Gap — 2 mm

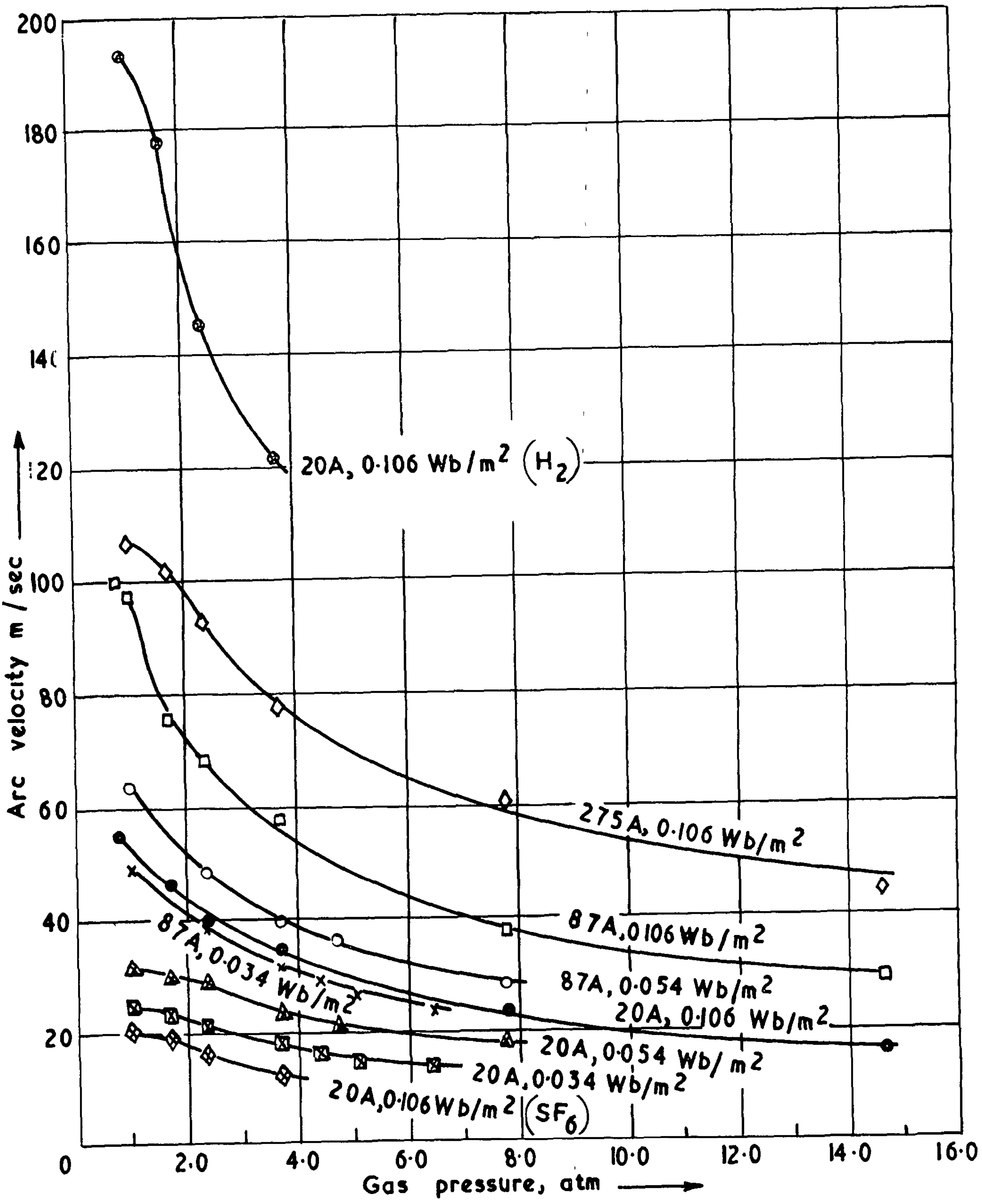
FIG. 16



Arc velocity vs. flux density

Electrodes	—	Brass
Gap	—	2mm
Gas	—	Air (except as noted)

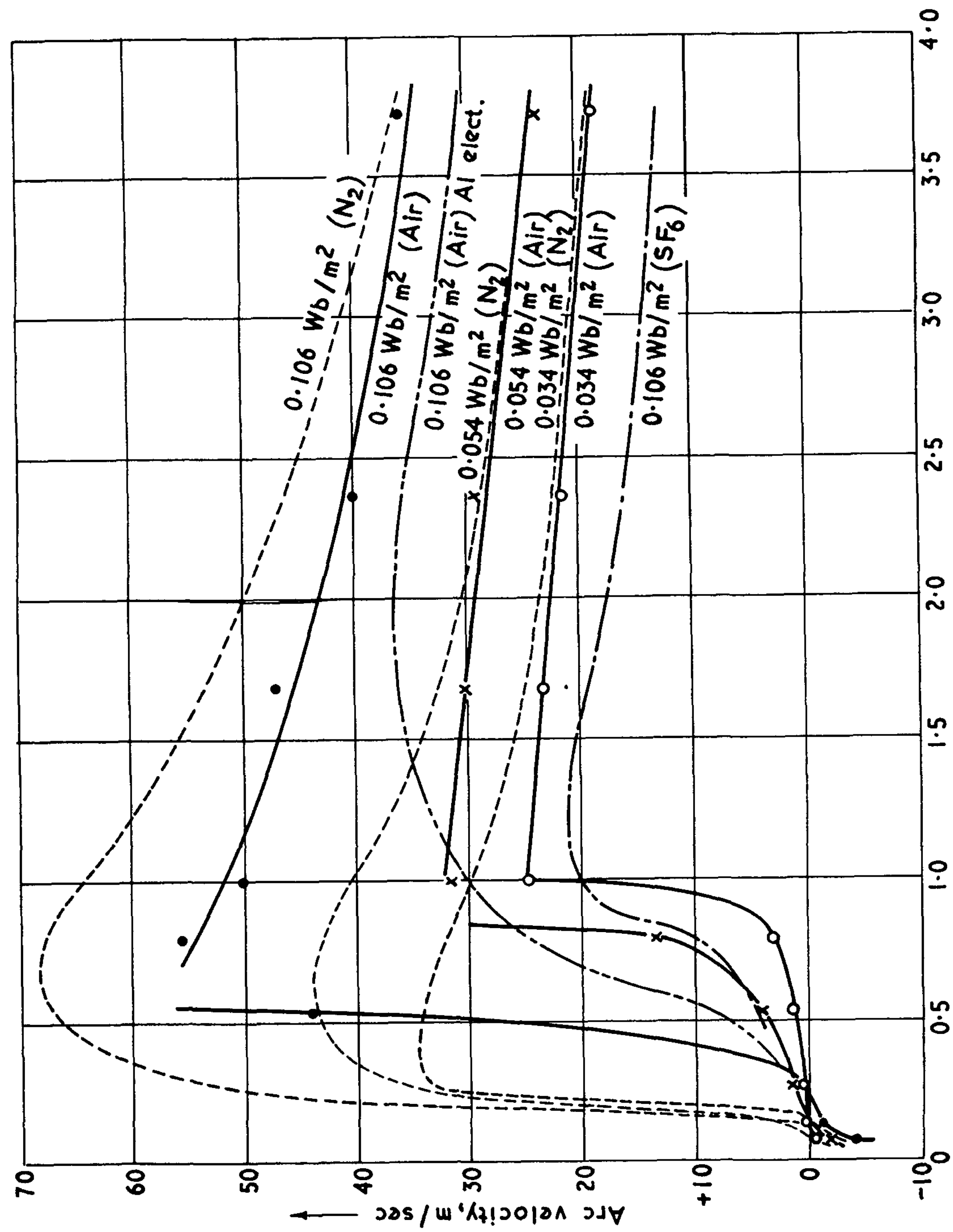
FIG 17



Arc velocity vs. gas pressure

Electrodes	Brass
Gap	2mm
Gas	Air (except as noted)

FIG. 18

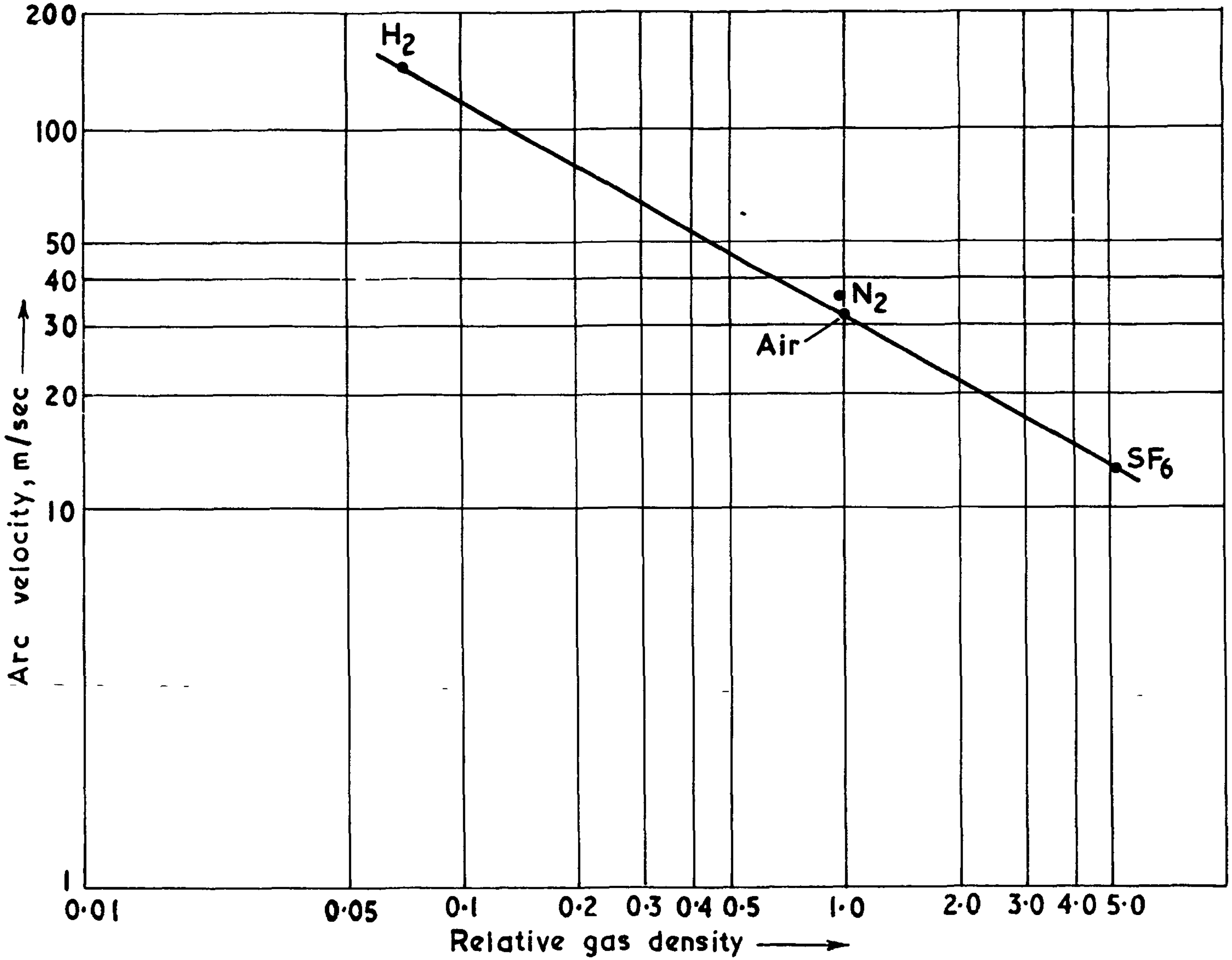


Arc velocity vs. gas pressure

Electrodes — Brass (except as noted)

Gap — 2mm

Arc current — 20 A

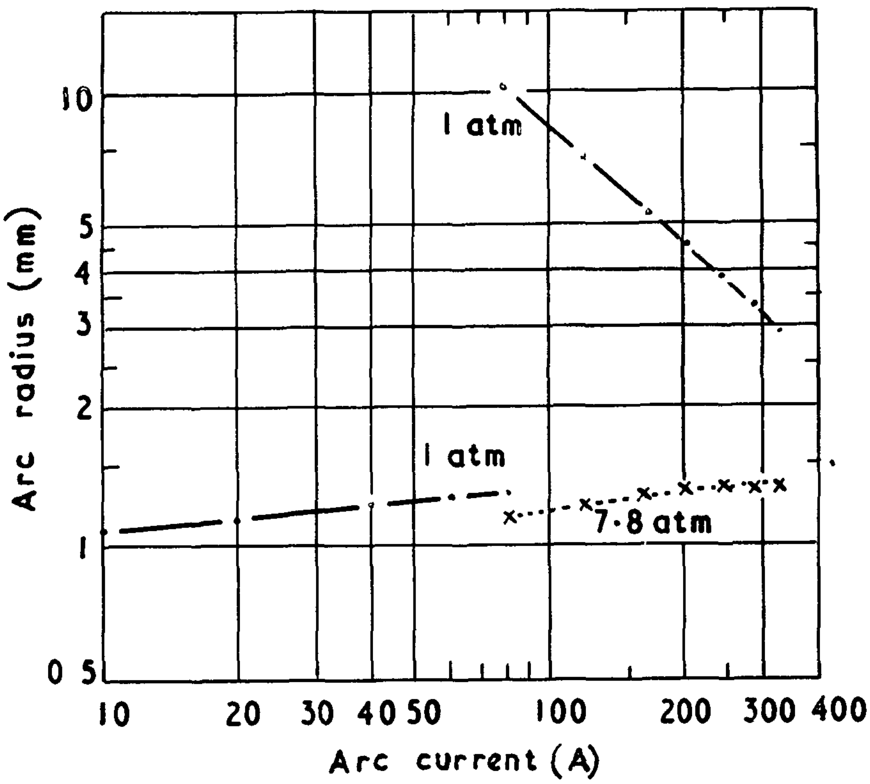


<u>Arc velocity vs. relative gas density</u>

Electrodes —	Brass	Gap —	2 mm
Flux density —	0·106 Wb/m^2	Arc current —	20A
Gas pressure —	3·72 atm		

FIG. 19

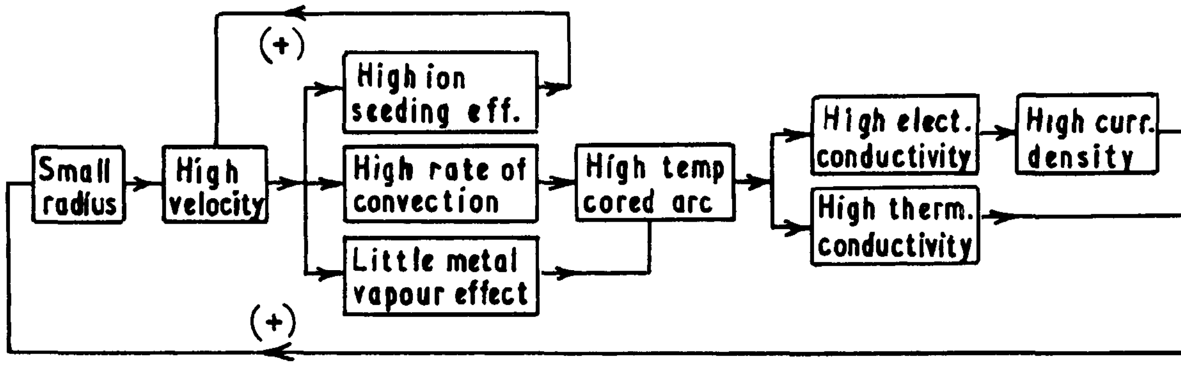
FIG. 20



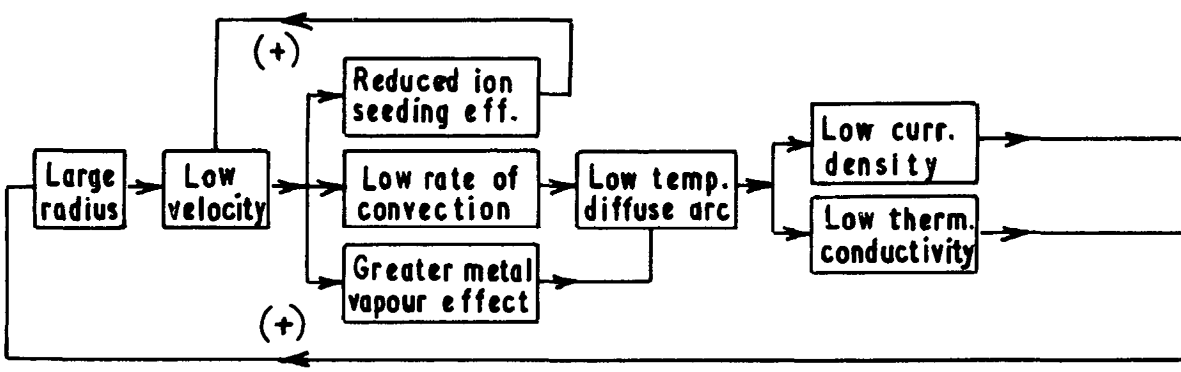
Arc radius (r) vs. arc current (I)

Flux density—0·106 Wb/m^2, Gas—air,
Electrodes —brass, Gap —2mm

FIG. 21



(a) "Feedback" loops of high velocity mode



(b) "Feedback" loops of low velocity mode

Interacting effects in selection of mode

A.R.C. C.P. No.843
October, 1964
Blix, E. D. and Guile, A. E.

THE MAGNETIC DEFLECTION OF SHORT ARCS ROTATING BETWEEN ANNULAR ELECTRODES ABOVE AND BELOW ATMOSPHERIC PRESSURE

An apparatus has been designed and constructed in which arcs of up to 5 kA, at inter-electrode spacings up to 2·5 cm, can rotate around ring-shaped electrodes in radial magnetic fields up to 0·2 Wb/m^2, in different gases between vacuum and 20 atmospheres.

Preliminary results are described for arcs in air, nitrogen, hydrogen and sulphur hexafluoride, at a spacing of 2 mm, at pressures between 1·5 torr and 14 atmospheres and at currents up to 350 A, on brass and aluminium electrodes.

In contrast to earlier experiments under similar conditions, except that the arc then ran once along rail electrodes and the cathode site transfer conditions were critical, these experiments have shown that the interaction of the arc column with the gas has been predominant at pressures above one to one and a half atmospheres.

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