Transferred Type Plasma Jet Using Gas Tunnel†

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Abstract

The characteristics of an arc superposed on the gas tunnel type plasma jet are investigated experimentally, not only on its electrical characteristics but also on its thermal characteristics such as thermal efficiency and energy balance. When the plasma jet current is 200A, the V-I characteristic of the superposed arc for R.P. changes at the arc current 200A, from low voltage 35V to high voltage 80V, though the S.P. arc characteristic is a simple one. On the distribution of the potential gradients in the axial direction, the influence of the gas tunnel plasma jet on the arc voltage is clarified; the gradient is about 10 V/cm for the distance within plasma jet length and about 25 V/cm for the larger distance.

KEY WORDS: (Transferred Type Plasma Jet) (Gas Tunnel) (Vortex Flow) (Electrical Characteristics) (High Energy Density Heat Source)

1. Introduction

A plasma jet has been widely used in the field of heat processings. It having the special features as a high energy heat source, various applications have been examined and good results obtained in such fields as material processings (cutting, coatings, welding, melting, forming), testings of high melting materials, chemical synthesis and so on.

Recently the new type high-powered plasma jet using a "gas tunnel" has been developed[1] and has been studying in order to apply to heat processings. The plasma beam produced in the gas tunnel is constricted by the strong thermal pinch effect.[2–4] Then the jet ejects into the air with high energy. The conventional plasma jet is generally used as "transferred type", which has the merits on the power and the thermal efficiency, and which is named as a plasma arc. So in this study the arc is superposed on the gas tunnel type plasma jet and the characteristics of this arc are investigated. When a high voltage is applied between the water cooled copper (as a workpiece) and the gas divertor nozzle of a plasma jet torch exit, an arc current flows through the gas tunnel type plasma jet. This new type plasma arc is studied not only on the electrical characteristics but also on the thermal characteristics, and are discussed the energy balance and its thermal efficiency.

2. Experimental apparatus

An axial sectional view of the plasma arc generator is shown in **Fig. 1**. This apparatus consists of three parts: (A), (B) and (C). (A) is the same arrangement of a conventional type plasma jet torch, and (B) is the gas tunnel type plasma jet torch. Large amounts of working gas

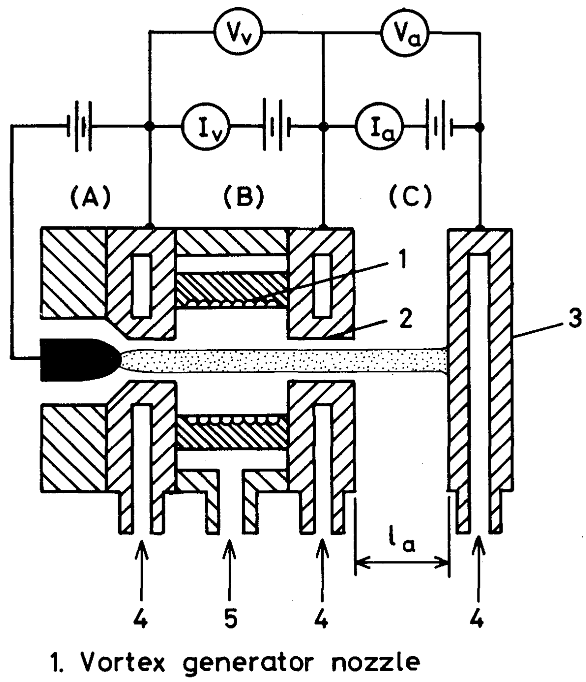

Fig. 1 Schematic diagram of the plasma arc generator.

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ejected from vortex generator causes a vortex flow with high speed in the vortex chamber by using the gas divertor nozzle. This strong vortex flow produces the low-pressure gas tunnel along the center axis of the torch (B). The gas tunnel discharge whose distance is 46 mm occurs between two electrodes. (C) is a generator of the arc superposing on the plasma jet. One electrode is a water cooled copper and the other is a gas divertor nozzle of the plasma jet torch. The copper electrode is movable in the axial direction by a motor, which can change the distance l_a between those electrodes as shown in Fig. 1. These apparatus are located in the experimental chamber.

In order to generate the plasma arc, at first the conventional plasma jet (A) is ignited by the high frequency ionizer, next the gas tunnel discharge of (B) is generated, and lastly the water cooled copper electrode remains close to the gas divertor nozzle electrode. If the high voltage is applied between two electrodes, the plasma arc starts.

Electrical input to the plasma arc is provided by six DC power sources with a rated current of 1500A and a load voltage of 50V. Three power sources of the six are supplied for the gas tunnel type plasma jet and the others are connected to the water cooled copper and the gas divertor nozzle. Allowing the electric arrangement by simply switching over the wiring, the water cooled copper is used as an anode (called as Straight polarity: S.P.) or a cathode (called as Reversed polarity: R.P.). Argon is used as a working gas. The thermal characteristics of these apparatus are clarified by calorimetric measurements.

3. Results and Discussion

3-1. Volt-ampere characteristics of plasma arc

Figure 2 shows the volt-ampere (V-I) characteristics of the plasma arc for the S.P. or R.P., when the argon gas flow rate Q is 400 l/min, the current of a gas tunnel type plasma jet I_v is adjusted to 200A and the distance between the arc electrodes l_a is 23 mm. The V-I characteristic of the S.P. arc is a positive one which has a small gradient, a similar tendency of that of TIG arc at high current. The increase of an arc current I_a doesn't affect on the voltage of plasma jet V_v. And V_v is constant, about 155 V.

In the case of the R.P. connection, the arc voltage V_a is as low as 35 V below 200A of the arc current I_a, but at I_a = 200A, V_a rises suddenly up to 80V, and over 200A the increasing rate of V_a is the same as the case of S.P. The arc voltage of R.P. is higher than that of S.P. at the current I_a over 200A. Corresponding to this phenomenon the plasma jet voltage V_v decreases from 155 V to about 120 V, at the same current level I_a = 200A.

The gas divertor nozzle of the R.P. connection takes a role as both the anode of arc and the cathode of the plasma jet torch. At this nozzle electrode, electrons are ejected to the plasma jet, while they flow from the superposed arc. So, the currents of the arc is counter flow against the plasma jet near the gas divertor nozzle. When those two currents are equal, $I_v = I_a$ = 200A, the current doesn't flow between a gas divertor nozzle electrode and the plasma beam, and the voltage drop is estimated to zero. Therefore, the V_a seems to be smaller than the case of without plasma jet.

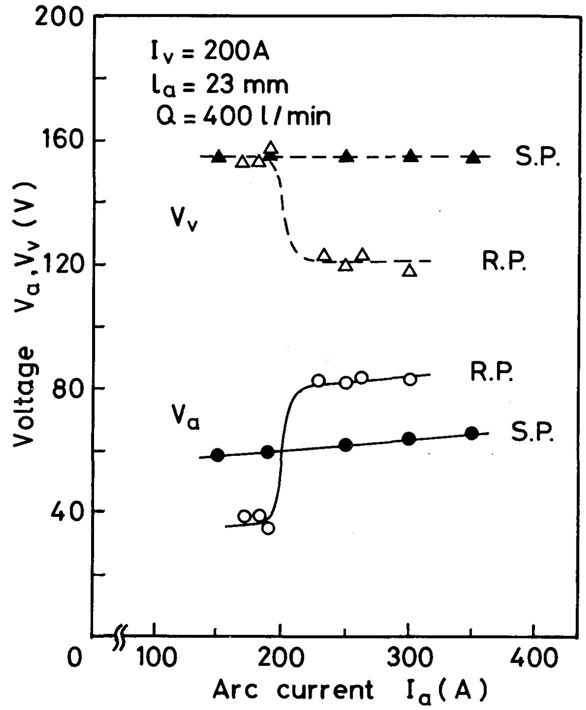

Fig. 2 Volt-ampere characteristics of plasma arc and plasma jet.

However, when the arc current I_a becomes some greater than the plasma jet current I_v ($I_a > I_v$), the direction of the current near the gas divertor nozzle becomes the same one of the arc. This causes the arc voltage to rise higher as shown in Fig. 2. This is also explained by the reason that the change of the current path occurs. The path of the plasma jet current is thought to change from the hairpin course to the shortest one as the plasma jet voltage V_v decreases as shown in Fig. 2, and that the arc voltage suddenly rises by adding the voltage near the gas divertor nozzle.

The V-I characteristic of the S.P. arc doesn't show such a change as the R.P. arc. Because for the S.P. arc the gas divertor nozzle is the common pole, i.e. cathode for both the plasma jet and the arc, and the current path of the S.P. arc agrees with that of the plasma jet at the gas divertor nozzle, and the voltage near the gas divertor nozzle acts as a part of the arc voltage at any arc current.

This arc is affected by the strong thermal pinch effect due to the vortex flow with high speed, even at the outside of the torch. The plasma arc is constricted by this thermal pinch effect, and the radius doesn't broaden even at the surface of water cooled copper electrodes.

3.2 Effect of the arc length on the arc voltage

Figure 3 shows the dependences of the arc voltage V_a and plasma jet voltage V_v on the arc length l_a at I_a = 190A on the R.P. and S.P. respectively. In the case of the S.P. the arc voltage V_a rises gradually as l_a is increased up to 30 mm, whereas over 30 mm V_a increases linearly with large gradient. It is thought that the plasma jet length of 30 mm influences the arc voltage. So, in the region which plasma jet dosen't exist the increasing ratio of the arc voltage is bigger than that in the region where plasma jet exists. In the case of the R.P., though the arc voltage is lower than that of S.P., the similar tendency is obtained as shown in Fig. 3. In spite of the arc porality, the arc length doesn't give influence on the V_v of the plasma jet.

Then the electrical potential gradients E determined by the gradient of the V_a–l_a curve in Fig. 3 are shown in **Fig. 4**. The traverse axis represents the axial distance z from the gas divertor nozzle exit. In both cases, the gradients E are very low values at the axial distance z below 30mm, because the current flows easily through the plasma jet, E becomes greater as the distance z increases between 20 and 30 mm, and then over 30 mm it becomes a constant value 25–28 V/cm. These results are due to the electrical conductivity of gas tunnel type plasma jet affects the arc voltage.

In the case of R.P., the arc voltage V_a – arc length l_a

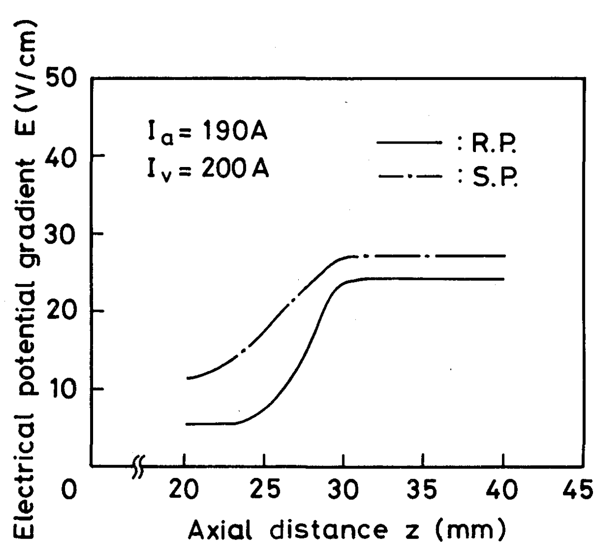

Fig. 4 Axial distance dependences of electrical potential gradient at different arc polarities.

characteristics at I_a = 190 A and 250 A are shown in **Fig. 5** respectively. The V_a for I_a = 190 A rises up gradually to the arc length 25 mm and over 30 mm it rises linearly. Each curve at I_a = 190 A and 250 A has the same tendency, though the change point of V_a curve for I_a = 250 A is nearer the gas divertor nozzle than that for I_a = 190 A. The differences of those voltages are constant value in spite of the change of the arc length. So, it is thought that the difference is due to the voltage drop near the gas divertor nozzle as described above.

The electrical potential gradients E at I_a = 190 A and 250 A from Fig. 5 are shown in **Fig. 6** respectively. The E

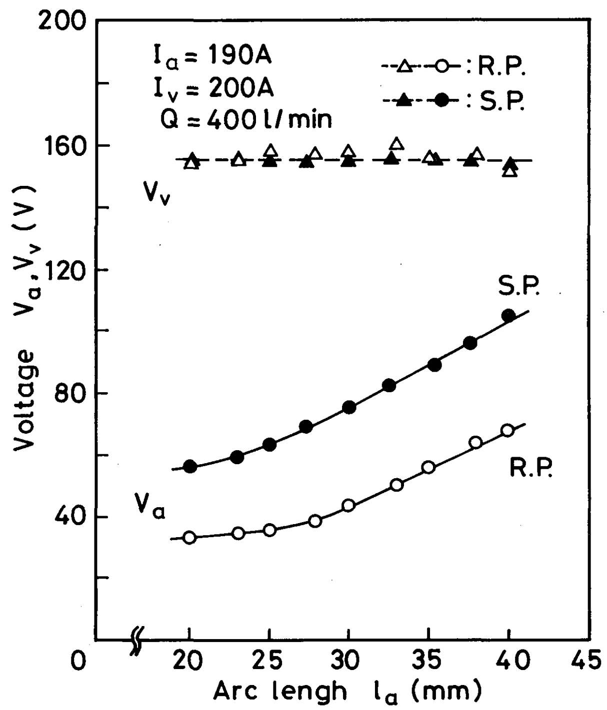

Fig. 3 Dependences of plasma arc voltage and plasma jet voltage on arc length at different arc polarities.

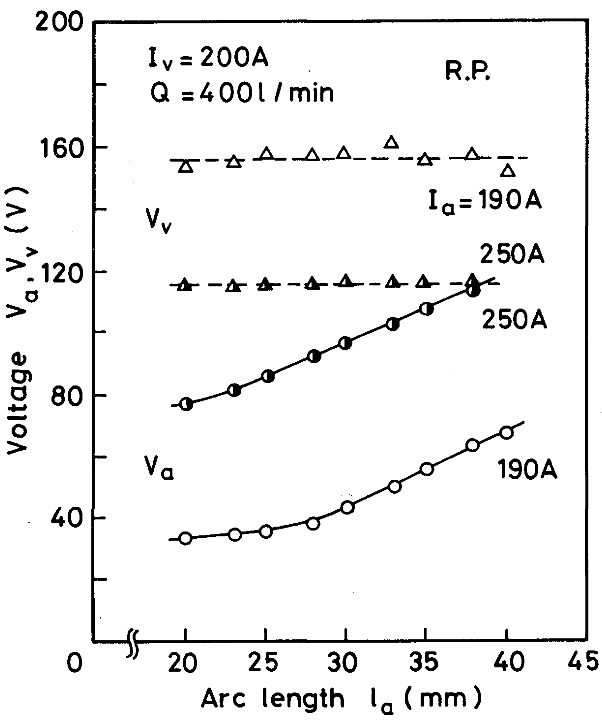

Fig. 5 Dependences of plasma arc voltage and plasma jet voltage on arc length at different currents.

at I_a = 250A rises at smaller distance, z = 20–24 mm in comparison with E at I_a = 190A. This is explained as follows. The plasma jet length causes this difference of the curves. The plasma jet voltage V_v in the case of I_a = 250A is less than that in the case of I_a = 190A as shown in Fig. 5, so that the input energy to the plasma jet in the case of I_a = 250A is smaller, and the plasma jet length becomes shorter than that in the case of I_a = 190A.

3.3 Effect of working gas flow rate on the arc voltage

Figure 7 shows the dependence of the arc voltage on the working gas flow rate Q, when the plasma jet current I_v is adjusted to 200A, the arc current I_a is 190A, and the arc length l_a is 23 mm. The voltages of the V_a and V_v are measured at the gas flow rate of 250–400l/min. With increasing the gas flow rate the voltage V_a increases as well as V_v, but the increasing rate of V_a is so small. This reason is thought as follows. The increase of the Q causes the strong thermal pinch effect for the plasma arc and the arc voltage V_a rises, while the thermal pinch effect also works to the plasma jet and rises the plasma jet voltage as shown in Fig. 7, then the plasma jet length is longer and the arc voltage is decreased. These two factors are superposed together, and as the results the arc voltage V_a rises slightly with the increase of the gas flow rate.

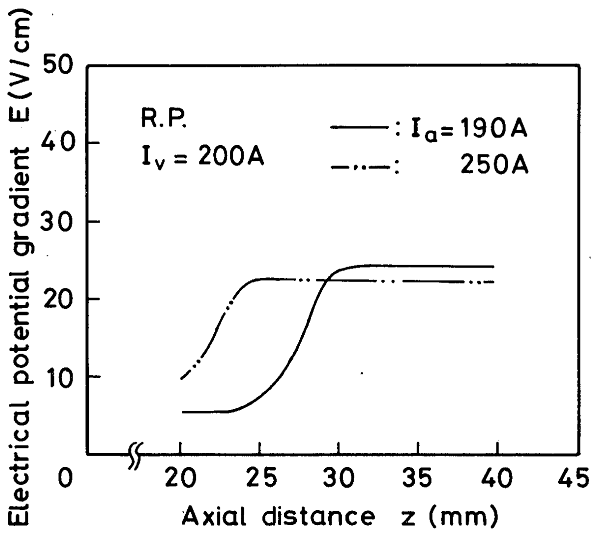

Fig. 6 Axial distance dependences of electrical potential gradient at different currents.

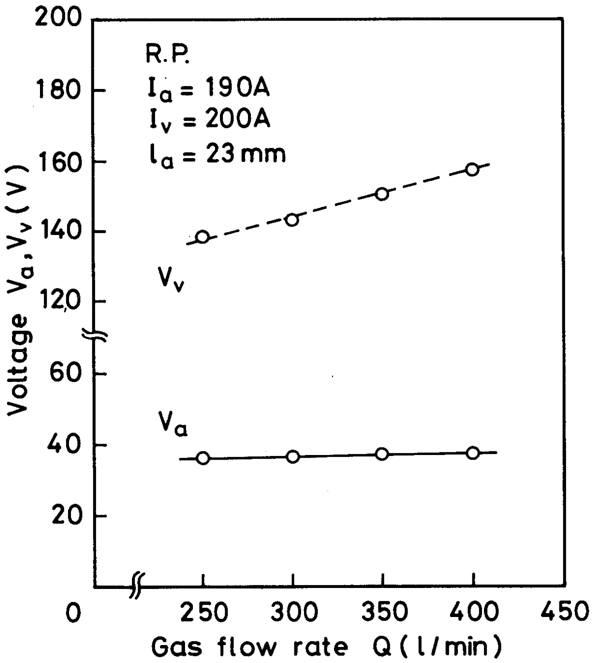

Fig. 7 Dependences of plasma arc voltage and plasma jet voltage on working gas flow rate.

3.4 Thermal efficiency and thermal loss on the plasma arc

Thermal efficiency η, the rate of transferred energy to the water cooled copper is shown in **Fig. 8**. The efficiency η is calculated $\eta = w_c/w \times 100(\%)$, where w is the total input to the plasma jet and the plasma arc, and w_c is the heat transfer to the water cooled copper. The efficiency η for the R.P. is 20–25% and rises a little with increasing I_a, while the η for the S.P. is 17–20% and is somewhat lower than that for R.P. **Figure 9**, moreover, indicates each heat loss to the atmosphere or the plasma jet torch. The 55–65% of the total input w is released to the atmosphere. Generally the thermal efficiency for the conventional plasma torch is the range of 35–64%.[5] The thermal efficiency for this plasma arc will be possible to improve by means of changing to the transferred plasma arc type without the electrode of gas divertor nozzle and so on.

The effect of the arc length on the thermal efficiency η for the R.P. arc is examined. For large l_a (33 mm), the total input energy and the heat to the water cooled copper are also increased, but the η is the same in the case of l_a = 23 mm. Because the longer length arc causes the increase of the heat loss to the atmosphere by the thermal

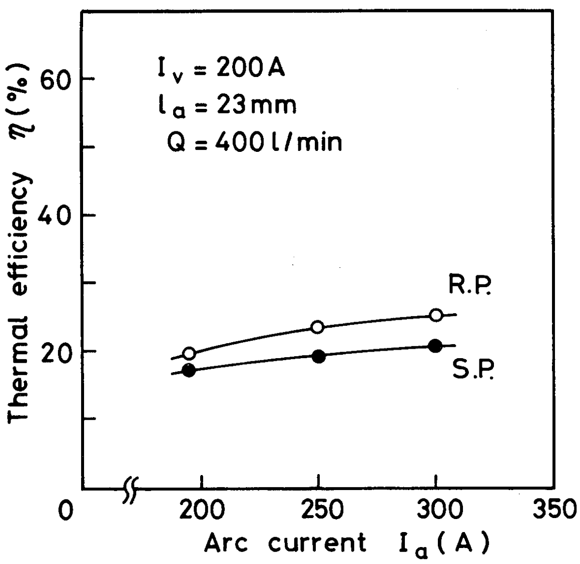

Fig. 8 Effects of arc current on thermal efficiency.

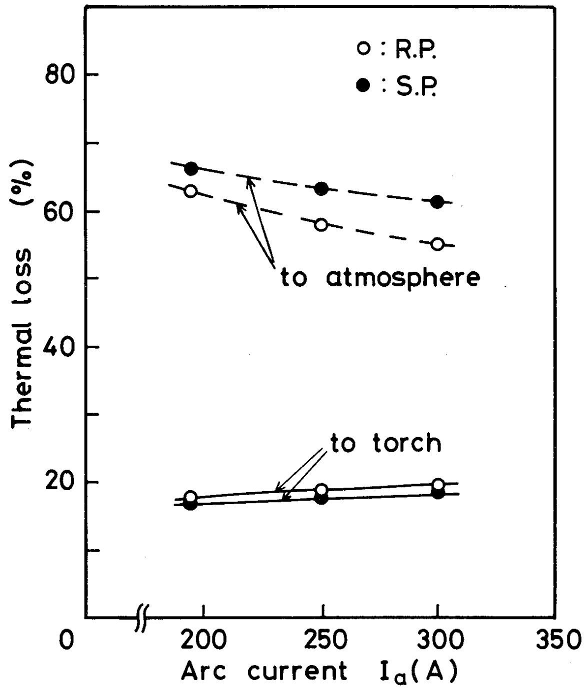

Fig. 9 Thermal loss of plasma arc.

radiation and thermal conductivity. So, it is not proper to enlarge the arc length for the purpose of the increase of the heat to the water cooled copper (workpiece).

4. Conclusion

In this study the arc is superposed on the gas tunnel type plasma jet and the characteristics of this arc are investigated experimentally. When a high voltage is applied between the water cooled copper (as a workpiece) and the gas divertor nozzle of a plasma jet torch exit, an arc current flows through the gas tunnel type plasma jet (200 A). This new type plasma arc is studied and discussed concerning its electrical characteristics and thermal characteristics. Those results are as follows.

1) The V-I characteristic of superposed arc in the case of R.P. shows particular variation, namely the voltage to 35 V for low current and 80 V for high current. On the other hand, in the case of S.P. the V-I characteristic appears a simple positive one.
2) The arc voltage—arc length relation has a similar characteristic in each polarity. By considering the potential gradient in the axial direction, the influence of the gas tunnel plasma jet is clarified. Corresponding to the jet length, the gradient changes from low value to high value.
3) The effect of working gas flow rate on arc voltage is small due to the relation between the thermal pinch effect on the arc and the plasma jet length.
4) On the characteristics of this superposed arc, its thermal efficiency is also measured for energy balance to the plasma jet torch and the water cooled copper, and the value is 25% for R.P.

References

1) Y. Arata and A. Kobayashi: J. High Temp. Soc., **11** (1985) 124.
2) Y. Arata: J. Phys. Soc. Japan **43** (1977) 1107.
3) Y. Arata and A. Kobayashi: Trans. JWRI, **13** (1984) 173.
4) Y. Arata, A. Kobayashi and Y. Habara: Trans. JWRI, **14** (1985) 235.
5) M. Okada and Y. Arata: "Plasma Engineering", Nikkan Kogyo Shinbun-sha, Tokyo, (1965) 429.