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Dynamic Characteristics of Variable Frequency Pulsed TIG Arc†

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Abstract

The dynamic characteristics of TIG arc supplied by pulsed current have been studied. Square and triangle waveforms of current pulsation have been applied over the range of frequency from 0.05 Hz up to 5,000 Hz. In order to define the influence of the kind of anode on relaxation phenomena of arc both stainless steel molten anode and water-cooled copper anode have been used.

The outcomes of the reported experimental studies allow conclusions to be drawn about the influence of pulsed current frequency, kind of the anode and current waveform on dynamic behaviour of the TIG arc. On the basis of high frequency current and voltage waveforms a mechanism of relaxation process of arc in the vicinity of anode has been suggested.

KEY WORDS: (Welding Arc) (Arc Welding) (Arc Characteristics) (Dynamic Characteristics) (TIG Welding) (GTA Welding) (Pulsed TIG Arc) (Pulsed GTA Welding)

1. Introduction

Many years before pulsed current arc welding methods were developed and practically applied, some properties of an electric arc supplied by direct current with sinusoidal oscillations were described.[1] It was found that the dynamic characteristics of the arc between carbon electrodes in air depended on the frequency of the variable component of current. For extremely low frequencies the dynamic characteristics coincide with the static characteristics. At higher frequencies with the quick rise in current the burning voltage is higher than that of decreasing current, i.e., the volt-ampere dynamic characteristic indicates a hysteresis similar to an ellipse, the axis of which has a negative slope. At very high frequencies the axis of hysteresis has a positive slope and the figure becomes flat. This big change in the dynamic characteristic is observed in such cases when the voltage corresponding to both maximum and minimum values of current in the static characteristics is different. In the pulsed TIG welding the range of current frequency is very wide. Low frequency pulsed current up to several Hz is widely used to control the pool size as well as the regulation of thermal cycles near the bead, whereas the high frequency pulsed current as high as 20 kHz is used for welding in very high speed because of excellent stiffnes of low current arc.[2)]

The pulsed current is an independent variable governed essentially by the power supply and the arc voltage is a dependent variable governed by the arc itself and is a measure of the arc response to the effect of current through it. Therefore, the knowledge of variation in dynamic characteristics has a fundamental meaning to clarify the properties of welding arc itself as well as their influence on welding process.[2–4)] In this paper will be described some results of experimental studies on dynamic characteristics of the TIG arc between a tungsten cathode and both stainless steel and water-cooled copper anodes supplied by square and triangle waveforms of pulsed current over wide range of frequency.

2. Experiments and Results

2.1 Experimental procedure

The arc current was supplied from an analogue transistor power source by both square and triangle pulsed current waveforms. For the square waveform the pulse time was equal to the time of background period and similarly for triangle waveform the time of linear rise in current was equal to the time of current fall. The pulse frequency was changed within the range from 0.05 Hz up to 5,000 Hz. The current was changed between background level equal to 10 A and pulse level equal to 150 A. Both current levels were selected on a basis of the static characteristic of the arc shown in **Fig. 1** in such way to get different value of voltage concerned as indicated by dotted lines in the figure.

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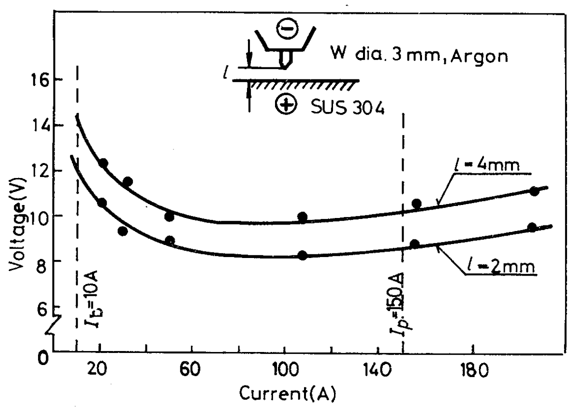

Fig. 1 Static characteristic of TIG arc between thoriated tungsten cathode and SUS 304 stainless steel plate in Argon

A 2% thoriated tungsten electrode of 3 mm in diameter was a cathode and as an anode both stainless steel (SUS 304) plate of 3 mm in thickness and water-cooled copper plate were employed. Argon was used as a shielding gas. The arc length was constant during the course of experiments and was equal to 3 mm. In case of experiment with a molten anode an arc was travelled under the constant speed of 1.6 mm/s in order to prevent the burnthrough. It was confirmed that with a water-cooled copper anode no significant change was observed in the stationary and moving arcs.

2.2 Dynamic characteristics of arc with square wave current pulsation

Figure 2 shows the current and voltage waveforms and their *v-i* hysteresis in wide range of current pulsation frequencies when a water-cooled copper anode is used. At very low frequencies less than 1 Hz, the arc voltage changes between two levels corresponding to both peak and base currents in accordance with the static characteristics. The change of current from background up to pulse level results in the decrease in voltage, while the converse change of the arc voltage is observed with the background level and the *v-i* characteristic has a negative slope as seen in Fig. 2(a).

With the rise in frequency the average level of arc voltage corresponding to both peak and base periods become almost equal as shown in Fig. 2(b). The further rise in frequency results in further decrease of background period arc voltage and small increase in arc voltage during pulse period. Thus the *v-i* characteristics progressively take the positive slope as represented in Fig. 2(c) – (f).

As seen in Fig. 2(b), (c) and (d), the leading edge of arc voltage for a current pulse clearly shows an overshoot and undershoot corresponding to the quick rise and fall of current. These instantaneous voltage peaks are observed within the range of low and medium frequencies, as if the arc were for that instance behaving as a constant resis-

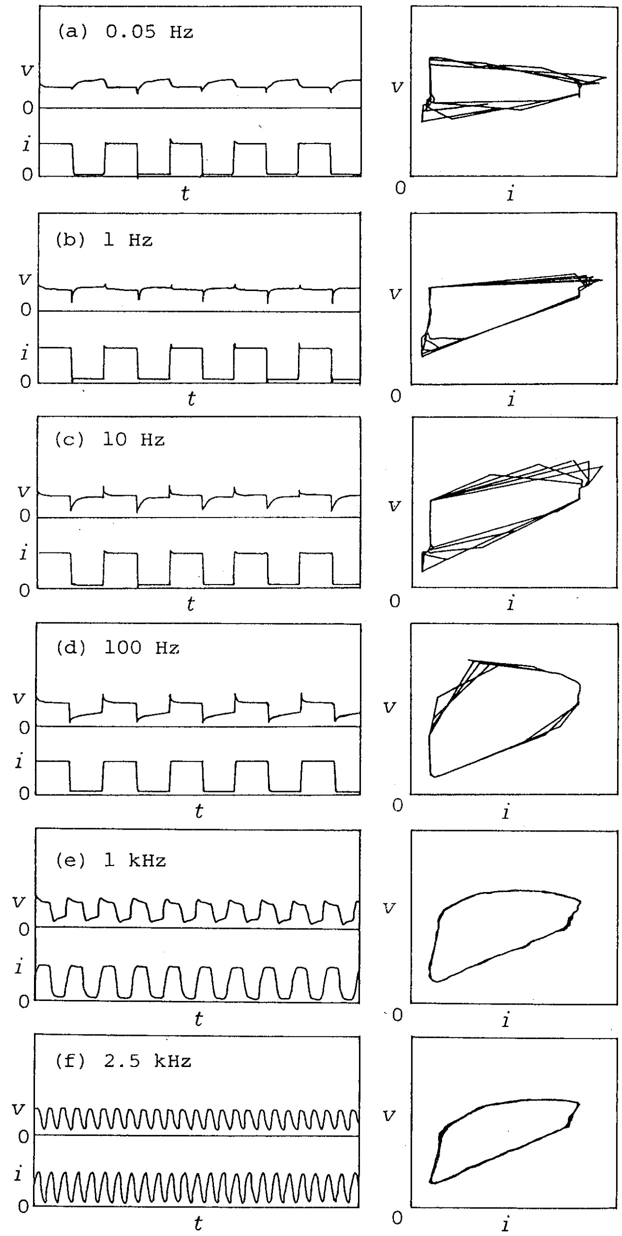

Fig. 2 Square shape of current and voltage response waveforms (left) and *v-i* dynamic characteristics (right) of 2%Th·W-SUS 304 arc in Argon showing tendency of dynamic change of arc behaviour as a function of frequency

tance which plays a significant role in a dynamic characteristics at higher frequencies above 1 kHz.

Over the whole range of frequency a hysteresis effect in *v-i* dynamic characteristics is seen in the right column of Fig. 2. At low frequencies a figure similar to a triangle and next at higher frequencies a figure similar to an ellipse is followed with a higher burning voltage with the rise in current than with the current fall. The higher voltage with the rise in current is due to the fact that the number of ionized species in the arc column is less than that required for sustaining arc in higher current level so that a higher voltage gradient is necessary to increase the ionization. Similarly, with the fall in current the ionization lags behind the current and the arc has a greater ionization than is required so that the current flows with the lower voltage gradient. Here it is noted that the rate of change in ionization is relatively slow, especially after the fall in current when a recombination of ionized particles plays a main role in the relaxation process of the arc plasma. This is a reason that with the rise in frequency a significant decrease of the voltage corresponding to the base current takes place as it is shown in **Fig. 3**.

The kind of anode representing different rates of heat loss results in the arc voltage. In case of water-cooled copper anode the arc voltage is higher than for the steel anode over the whole range of frequency. The general tendency of changes in the arc dynamic characteristics for both types of anode are similar as a whole. However, as shown in **Fig. 4**, some differences are seen in the relaxation process of arc depending on the kind of anode. For the water-cooled copper anode with the increase in current from background to pulse level the overshoot of voltage is higher than that for molten steel anode. With the converse change of current, i.e., from the peak to base level for the water-cooled copper anode the course of relaxation processes is more complex than that for the steel anode. At first the arc voltage momentarily drops to the very low level of about 3 V which may be caused by sufficient ionization achieved in the previous peak duration. This phenomenon happens within the shorter time than the time constant of recombination, but soon after the intensive process of bulk recombination of ionized particles occurs in the arc plasma near the cold anode surface. A large number of ions and electrons undergoes the recombination that is required for the current flow through the arc. In order to increase the number of current carriers the voltage instantaneously tends to high level as it is seen in Fig. 4(b) representing a sharp peak of voltage before recovering to the level corresponding to the base current. The time of this phenomena is constant equal to approximately 0.35 ms and is independent to the current frequency.

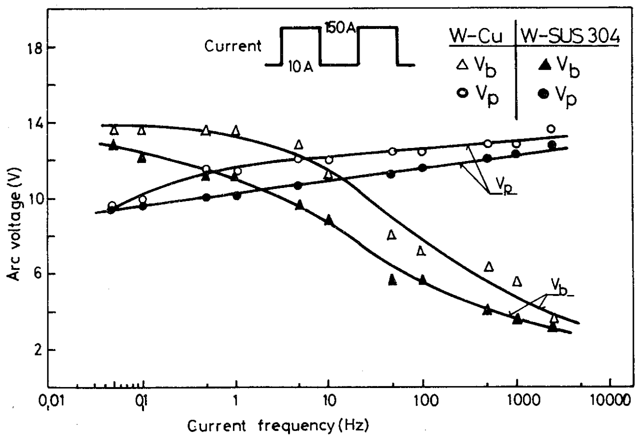

Fig. 3 Change in voltage (average value) during pulse current V_p and background current V_b for 2%Th·W-Cu and 2%Th·W-SUS 304 arcs as a function of frequency

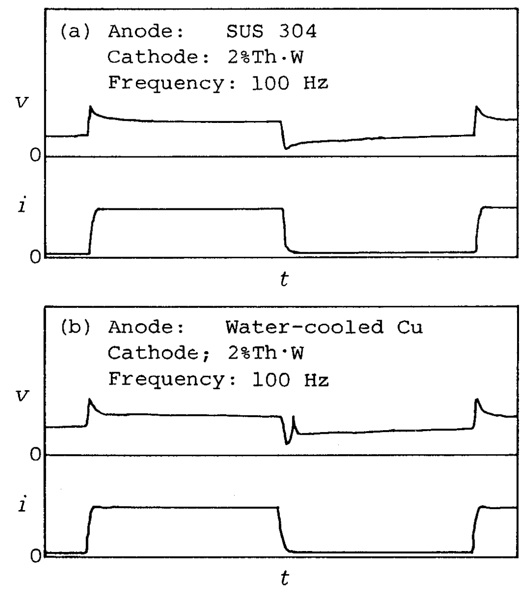

Fig. 4 Difference in voltage response waveforms in molten SUS 304 and water-cooled copper anodes at 100 Hz square wave current pulsation

Therefore, at high frequency for which the time of background current period is shorter than 0.35 ms the above described instantaneous overshoot of voltage is not observed in the frequency over approximately 1.5 kHz. This tendency is shown in **Fig. 5**. For the frequency above 1.5 kHz the waveform or arc voltage follow the current waveform and the arc behaviour is the same as for pure resistance as seen in Fig. 5(d). In case of steel anode the rate of heat loss is slower due to considerable amount of heat energy accumulated in the molten pool, the relaxation processes are much gentle and no instantaneous changes of voltage are observed as in Fig. 4(a).

2.3 Dynamic characteristics of arc with triangle wave current pulsation

If the pulsed current changes between the base and peak levels progressively as for the triangle shape of the current waveform, the arc voltage exactly coincides with the static characteristic at low frequency as seen in **Fig. 6(a)**. Also, the hysteresis effect is almost not observed. The effect of current pulsation occurs in the *v-i* dynamic characteristics above the frequency of approximately 50 Hz as shown in Fig. 6(c), i.e., if the rate of current change is more than 1.5×10^4 A/s.

With the rise in current frequency the slope of *v-i* dynamic characteristic changes from negative to positive. This is a result of significant decrease of the voltage corresponding to the background (minimum) current as shown in **Fig. 7**. The voltage during pulse period increases slightly with the rise in frequency. The changes of the arc

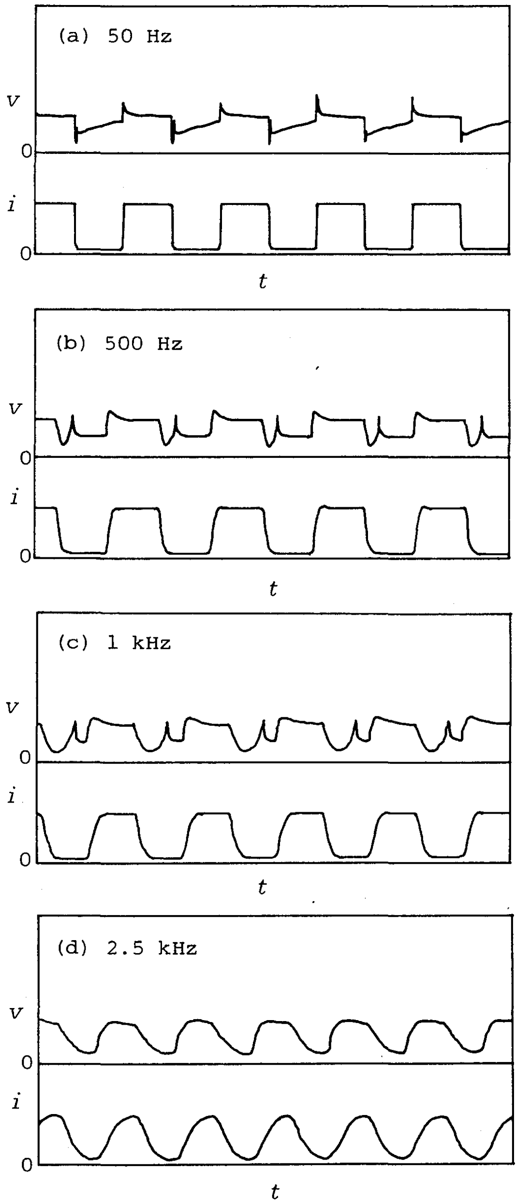

Fig. 5 Current and voltage waveforms of 2%Th·W-Cu arc at different frequencies

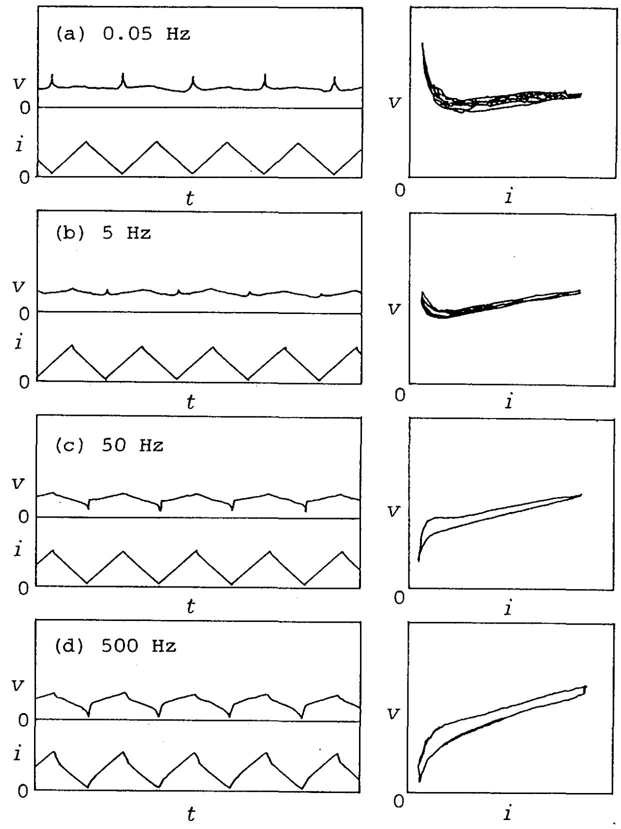

Fig. 6 Triangle shape of current and voltage response waveforms (left) and v-i dynamic characteristics (right) of 2%Th·W-SUS 304 arc in Argon at different frequencies

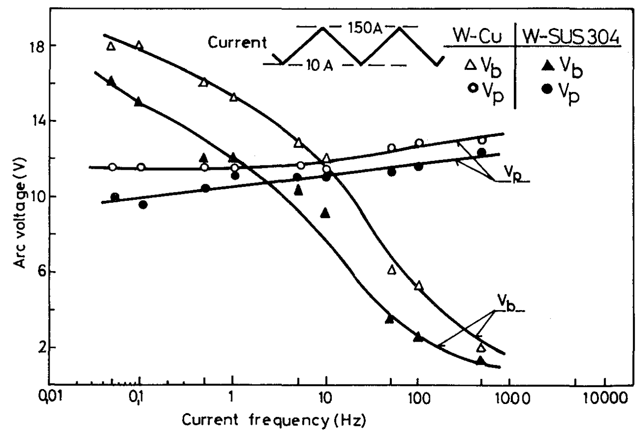

Fig. 7 Changes of voltages during pulse current (maximum value) V_p and background current (minimum value) V_b for 2%Th·W-Cu and 2%Th·W-SUS 304 arcs as a function of frequency

voltage under both background and pulse conditions have similar tendency as for the previously described square shape of pulsed current. Also, at higher frequencies above 500 Hz the similar course of the relaxation process of the arc is observed for the water-cooled copper anode. During the decrease of current, when its value reaches the background level, first the rapid fall and next the sharp peak of voltage occur as described in **Fig. 8.** This is due to the above suggested mechanism of the relaxation process of arc near the anode surface. The only difference between the square and triangle current waveforms is the time of undershoot of voltage, which for the triangle waveform of current is equal to approximately 0.05 ms. However, for the triangle waveform the decrease of current is relatively slow compared with the square waveform, but still for high frequency it is fast enough that the over-cooling effect of the plasma near anode surface may occur. The conclusion may be drawn that the above described complex course of relaxation process of arc plasma takes place if the rate of fall in current is higher that 1.5×10^5 A/s. Naturally the progressive change of current in triangle wave shape attenuates the dynamic behaviour as well as the course of relaxation process of arc plasma when it is compared with square waveform pulsed current.

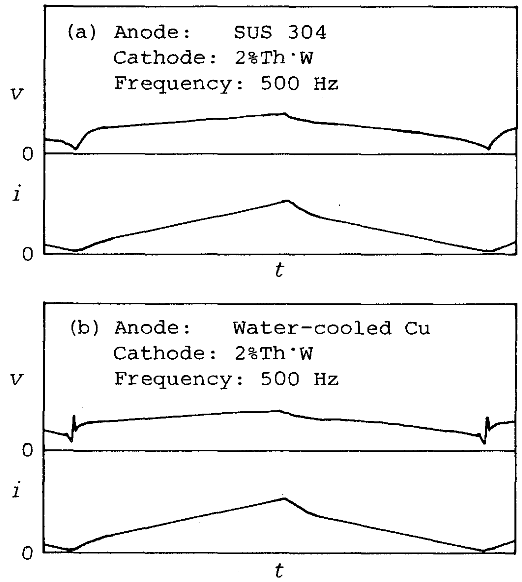

Fig. 8 Difference in voltage response waveforms in molten SUS 304 and water-cooled copper anodes at 500 Hz triangle shape current pulsation

3. Conclusion

As a result of experimental study reported here it has been confirmed that the dynamic properties of TIG arc supplied by pulsed current depends on the frequency and the shape of current waveform as well as the kind of anode. The analyses of outcomes allow conclusions to be drawn as follows:

(1) For very low frequencies of pulsed current below 1 Hz the change of arc voltage coincides with the static characteristic of the arc. Within the range of frequency from 1 to 2.5 kHz, even if specific points on the static characteristic corresponding to base and peak current have different levels of voltage, the burning voltage is almost constant with typical instantaneous overshoot and undershoot at moments of rise and fall in current. These instantaneous peaks of voltage occur if the rate of change in current is in excess of approximately 1.5×10^5 A/s. For higher frequencies the arc dynamic behaviour gradually becomes same as for a constant resistance. This is due to slight increase of voltage during the pulse current and drastic decrease of voltage during the background period.

(2) For the rate of change in current in excess of 1.5×10^4 A/s the hysteresis effect is clearly observed in *v-i* characteristics of the arc. This effect is depended on the current frequency and the rate of heat loss through electrodes, particularly at anode.

(3) The relaxation processes of TIG arc plasma mainly depends on the rate of heat loss through electrodes and in the arc column. For greater rates of heat loss the relaxation processes are more complex. In case of water-cooled copper anode the rapid rise in current results in higher instantaneous overshoot of voltage than for molten steel anode. Similarly, the rapid fall in current above 1.5×10^5 A/s caused the sudden drop of voltage under the level corresponding to required current and next due to the insufficient number of current carriers the instantaneous peak of voltage appears. The time constant of this process is consistent and independent to the current frequency as far as the shape of current wave form is constant. The lower rate of heat loss, in case of molten steel anode for example, attenuates the relaxation process of arc during current pulsation.

(4) The change of mean value of arc voltage is mainly influenced by the voltage at the base current period and is a function of frequency. The arc voltage during background level decreased remarkably as the frequency increases, while the peak voltage increases slightly. Therefore, the highest average arc power takes place at very low frequency and gradually decreases with the rise in frequency. On a basis of simple calculation it is shown that for square waveform of current the average arc power at frequency of 2.5 kHz gives approximately 70% of the heat input at frequency of 0.5 Hz.

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References

1) J. D. Cobine: **Gaseous Conductors**, Dover Publications, Inc., New York (1958), pp. 344–352.

2) A. Matsunawa, H. Yamamoto and S. Hiramoto: "Pulsed Arc Welding", J. Japan Welding Society, Vol. 53 (1984), No. 6, pp. 284–322. (in Japanese).

3) J. C. Needham: "What do you mean by current? What do you mean by voltage?", IIW Doc. XII-968-86.

4) A. Kolasa, A. Matsunawa and Y. Arata: "Experimental Study on Dynamic Properties of Power Sources for MIG/MAG Welding", Trans. JWRI, Vol. 14 (1985), No. 2, pp. 256–265.