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Citation	Transactions of JWRI. 1995, 24(1), p. 127-128
Version Type	VoR
URL	https://doi.org/10.18910/11718
rights	
Note	

Development of an LaB_6 Cathode for High Power Electron Beam Welding†

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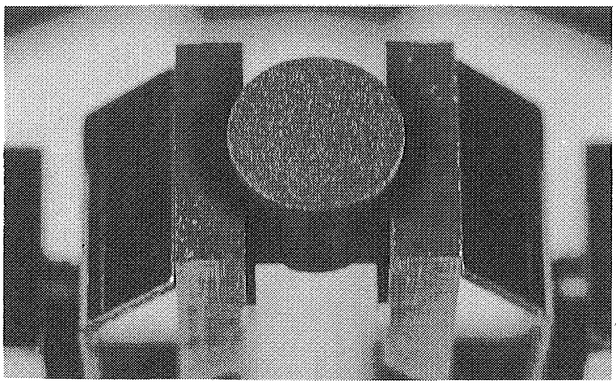
KEY WORDS: (LaB_6 Cathode)(Electron Beam Welding)(High Power)(Long-Term Stability)

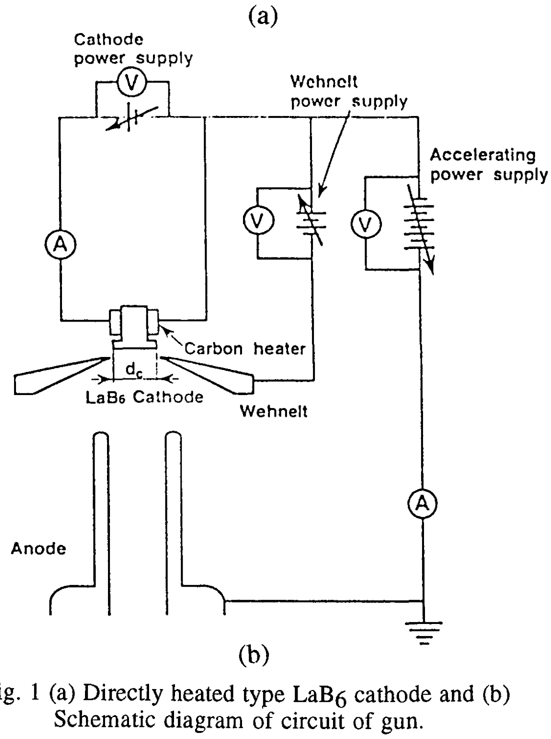
The requirements of the cathode for thermal electron emission used for an electron gun in the field of thermal processing , especially for electron beam welding, are the ability to generate high power and a high energy density beam for long times with stability and flexibility of control. A tungsten cathode which is usually is used needs a very high temperature for thermal electron emission. Decreasing this temperature suppresses the thermal distortion of the cathode and its supporter and stabilizes the fluctuation of the output beam. From this view point, the authors selected LaB_6 for cathode material because it has low work function and the ability to emit electrons at very low temperatures, and developed a directly heated type sintered LaB_6 cathode for high current electron beam generation. Furthermore, the characteristics of beam generation were investigated for this cathode.

Figure 1 (a) and (b) show the directly heated LaB_6 cathode which is mounted on an electron gun and its electric circuit. Carbon heaters set on both sides of the LaB_6 cathode increase the temperature of the cathode by thermal conduction through electric heating of the heater. Although any diameter can be used because the Joule heating method is involved, the cathode diameter for this experiment was selected by considering the required beam current and beam diameter for beam focusing with a magnetic lens. Under these conditions, cathode diameter of 4.0 mm and 5.0 mm were selected.

Cathode temperature T_c and cathode heating power W_c are plotted in **Fig. 2** for cathode diameters d_c of 4.0, 4.5 and 5.0 mm. At the upper limit temperature of 2015 K of the cathode, a heating power W_c of 92 W for 5.0 mm cathode was required. A tungsten cathode which emits the same thermal electron emission density requires a temperature of 3000 K and a heating power of 400 W. It can be seen that the heat consumption of a LaB_6 cathode is much more lower than that of a tungsten cathode.



(a)



(b)

Fig. 1 (a) Directly heated type LaB_6 cathode and (b) Schematic diagram of circuit of gun.

† Received on July 21, 1995
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Transactions of JWRI is published by Welding Research Institute of Osaka University, Ibaraki, Osaka 567, Japan.

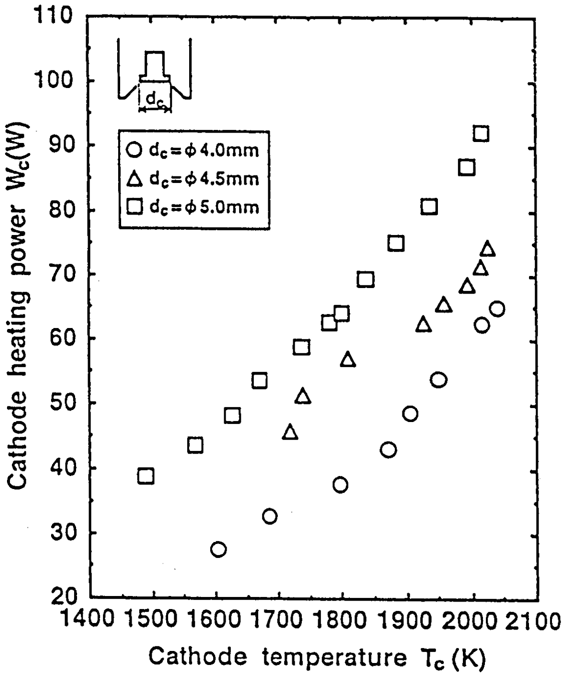

Fig. 2 Relation between heating power and cathode temperature at various cathode diameters.

The beam currents, I_b, at various beam accelerating voltages, V_b, are shown in **Fig. 3** for a 5.0 mm cathode. A high beam current is obtained with increasing cathode temperature. The beam current is 1000 mA at T_c=2015 K and V_b=65 kV and an output power of 65 kW is obtained. The electron gun used is a triode type with a Wehnelt electrode. Its perveance is calculated to be 5.5 x $10^{-8}[A/V_b{}^{3/2}]$ through Langmuir's 3/2 power law ($I_b=GV_b{}^{3/2}$). At T_c=2015 K, the relation of acceleration voltage and beam current follows the 3/2 power law. However, in the case of low cathode temperatures, the characteristics of a temperature limited region appear, which do not follow the 3/2 power law. Furthermore, beam current I_b was measured at various Wehnelt voltages, V_w. At V_b=65 kV, I_b is 900, 700 and 500 mA and for V_w=200, 500 and 900 V. It shows a good relationship between beam current and Wehnelt voltage. Wehnelt voltage for beam cut off is estimated to be about 2.5 kV.

The long-term stability of high power and high energy density electron beam generation was investigated for a 4.5 mm cathode. The beam parameter for the stability test was selected as I_b=300 mA and V_b=60 kV, for the requirement of 1) obtaining a fine focused beam wuth the magnetic lens 2) emitting a beam current for actual welding conditions 3) warming up quickly to the required beam current. The time dependence of cathode heating power W_c was measured with 10 cycles of beam on and off. The fluctuation of cathode heating power was below 5 % during a time range of 72 ks (20 hours) at I_b=300 mA as shown in **Fig. 4**.

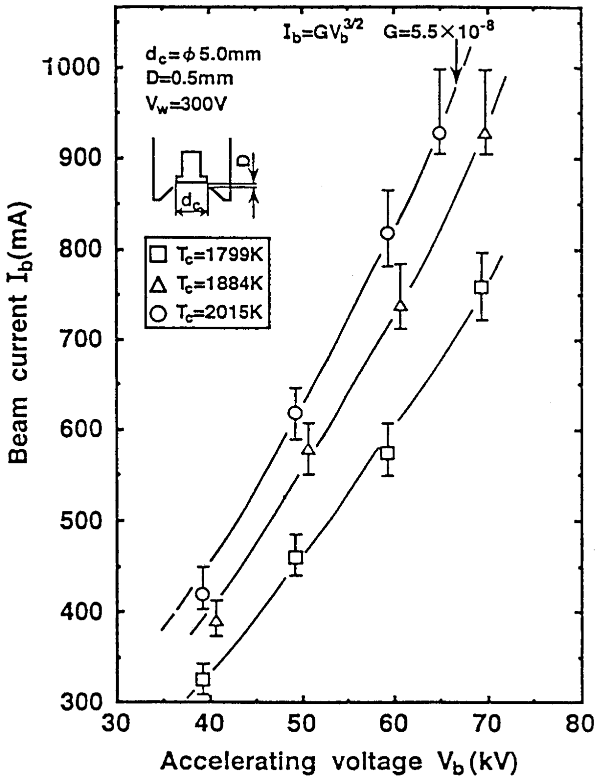

Fig. 3 Experimental result of beam current versus beam accelerating voltage. (d_c = 5.0 mm)

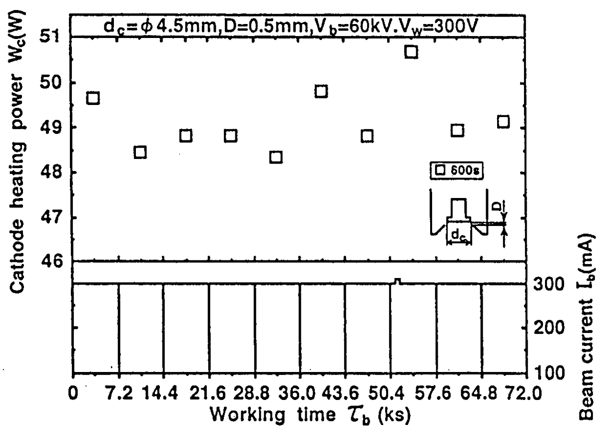

Fig. 4 Result of life time test for directly heated type cathode (d_c = 4.5 mm).

Finally, the LaB_6 cathode can reduce the heating power and heat distortion of the whole electron gun compared with other metal cathodes. It is shown that a stable high power electron beam is obtained for long operating times and it can thus be applied for electron guns for thermal processing.