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AN INDIRECTLY HEATED CATHODE FOR THE ION SOURCE OF NEUTRAL BEAM INJECTOR

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An indirectly heated cathode made of impregnated porous tungsten emitter was prepared for the ion source of neutral beam injector. The cathode was applied to a duoPIGatron hydrogen ion source, where discharge characteristics and the cathode life time were tested. Beam extraction from the source was also carried out. The accumulated discharge time of the cathode was over 20 hours which corresponds to a life time of 2 months for normal use, and the cathode was still usable after the test.

Key words; Indirectly Heated Cathode, Neutral Beam Injector,
Cathode Life Time, Beam extraction, Porous tungsten emitter

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中性粒子入射装置イオン源用傍熱型陰極

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（１９８１年3月１２日受理）

中性粒子入射装置のイオン源用として，バリウム含浸型多孔質タングステン製の傍熱型陰極を試作した。この陰極をデュオピガトロン型水素イオン源に取りつけて，放電特性を調べ，あわせて寿命を試験した。またイオン源からのビーム引出しも行なった。この陰極の累積放電時間は，２０時間以上となったが，この時間は通常使用では２ヶ月の寿命に相当する。陰極は，寿命試験後も使用可能であった。

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1. Introduction

At present, neutral beam injection is condidered as the most effective method for additional heating tokamak plasmas. Several types of ion sources have been devised and developed for the neutral beam injector. The duoPIGatron ion source was originated at Oak Ridge National Laboratory (ORNL) and has been improved and used at ORNL and JAERI[1,2]. The magnetic field-free multi-filament ion source has been developed at Lawrence Berkeley Laboratory (LBL)[3], and the Periplasmatron ion source at Fonteneay-aux-Roses (F-a-R)[4]. Now, more attention is paid to the bucket type ion source recently developed at Culhum Laboratory[5].

Although each of these four types has relative advantage and disadvantage with respect to arc efficiency, gas efficiency, beam composition, and so on, all of them have been successful at any rate in delivering high current ion beams at high energies and are actually used.

In the future, however, ion sources for neutral beam injector (NBI) will be compared in terms of the life, reliability, and toughness as well as the various efficiencies listed above. This is because structual materials of future tokamak and the surrounding components including neutral beam injectors will be radioactivated by neutrons resulting from the thermonuclear fusion reactions in the plasma and it will become difficult for men to approach the neutral beam injectors for maintenance. Therefore it is desirable for the ion source to have long life, good reliability and easiness for assembling and handling. Cathode is one of the most important components which would determine the life and easiness for maintenance of the ion source.

So far, directly heated pure tungsten or oxide-coated filaments have been used as the cathode of ion source for NBI. However, these cathodes have a disadvantage from a viewpoint of the life time. In gaseous discharges, ions from the dense plasma preferably bombard the electrically negative leg of the filament and sputter away the filament material. In addition, a part of the discharge current is superposed on the external heating current at the negative leg. Therefore, the temperature of the filament at the negative leg becomes higher than that at the positive leg. As a result, after many times of discharges, the negative leg selectively becomes thinner than the other part of the filament. Then the resistance and therefore the temperature increases, and evaporation of filament material and electron emission increase. This chain of processes further makes the negative leg thinner. Thus, the directly heated filament used in gaseous discharge tends to be damaged at the negative leg and this tendency reduces the life time of the filament.

In the case of indirectly heated cathode, ions from the plasma uniformly bombard the cathode surface and the discharge current is not superposed on the heater current, and the local sputtering and local heating of the cathode will not occur.

In this paper, we report on the experiment of an indirectly heated cathode applied to a duoPIGatron hydrogen ion source. The cathode is made of impregnated tungsten emitter heated by thermal radiation from a tungsten filament. The purposes of our experiment are firstly to check the life time of this cathode and secondly to study the discharge characteristics when this cathode is applied to the duoPIGatron ion source.

2. Experimental Apparatus

A cross-sectional view of the indirectly heated cathode is shown in Fig.1. The shape illustrated by the broken line in the figure indicates the cross-sectional view of the cathode chamber of the ion source. The cathode is made of impregnated tungsten emitter which was formed into a cylindrical cup of 22 mm in outer dia., 1 mm in thickness and 35 mm in length. The emitter is welded to the supporting tube made of molybdenum. The tube is fixed to a water-cooled copper flange with stainless steel screw through ceramic rings which are sandwiched between the tube and the flange. Thus the emitter incorporated with the supporting tube can be easily exchanged with another, if it loses its life. The copper flange has a hole for gas inlet near the cathode supporting tube.

The cathode is heated from the inside wall by thermal radiation from the heater which consists of three tungsten spirals welded to the molybdenum current lead. The heating current is fed through the central molybdenum rod into the tungsten spirals, and flows out to the copper flange. The heater requires the electrical power of about 700 W to keep the temperature of the emitter at 1100°CB. Thermionic electron current-density of the impregnated tungsten emitter varies from 2.1 A/cm^2 to 5 A/cm^2 at the temperature of 1075°CB to 1150°CB (the maximum DC current density in the space charge limited region).

This cathode was applied to a 10 cm diam. duoPIGatron hydrogen ion source as shown in Fig. 2. The ion source was set up at one port of a 870-litre vacuum chamber evacuated by four diffusion pumps with total pumping speed of 2×10^3 ℓ/s.

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3. Experimental Results and Discussions

3.1 Discharge Characteristics

Heater power dependence

Figure 3 shows the voltage-current characteristics of discharges as a parameter of heater power, P_h, when hydrogen gas was continuously fed. The pressures in the cathode chamber and the large vacuum chamber were 16 mTorr and 5.9×10^{-4} Torr, respectively, and the current of the source magnetic field coil, I_b, was 50 A. From the figure it is seen that the discharge current is limited below 65 A and there is no influence of the heater power on the V-I curve of the discharges. That is, even though the temperature of the cathode is raised, the discharge current does not increase. The reason for this will be discussed later.

Gas pressure dependence

Figure 4 shows the V-I relation of discharges as a parameter of pressure in the cathode chamber when the gas was continuously fed. It is seen that the higher the pressure in the cathode chamber is, the larger current and the lower voltage of discharge can be obtained. The reason for this is explained as follows; According to Ref.(6), the electron current density that can be drawn from a double sheath surrounding the hot cathode is limited as,

$$J_e \leqq \gamma \sqrt{\frac{m_i}{m_e}} \; J_i \quad , \tag{1}$$

where m_i/m_e is the ratio of ionic and electronic masses, J_i is the ion current density reaching the sheath from the plasma, and γ is a numerical factor varying from 1/3 to to 2/3. The ion current density J_i is proportional to the plasma density surrounding the cathode sheath and the rate of plasma generation is proportional to the gas pressure. Thus, if the pressure is low, the plasma density, and then J_i becomes low. Therefore, when the pressure is not high enough, the actually obtainable electron emission current density is limited to the value expressed by Eq.(1), even if the temperature of the cathode is sufficiently high and the ability of thermionic electron emission exceeds the value of right hand side of Eq.(1). If the inequality of Eq.(1) is not satisfied, it becomes difficult to sustain the cathode sheath, and the arc will become hashy and at last go out.

Dependence on magnetic field strength

When the gas is fed into the ion source in pulse, a larger flow rate can be allowed if the pulse width is much shorter than the time constant of the vacuum system.

Figure 5 shows the V-I relation of discharges as a parameter of source magnetic field coil current in the case of pulsed gas feed. In this case, the gas flow rate is 22 Torr.l/s. Compared with Fig.4, the V-I curve becomes flat and the larger current of discharge are easily obtained since the gas is introduced at a larger flow rate. The discharge current was limited below 120 A due to capacity of the arc power supply.

From Fig.5 it is seen that for a fixed arc current the arc impedance increases with the source magnetic field coil current. This may be interpreted as follows; Around the nozzle of ion source, there is an inhomogeneous magnetic field which is generated by the source magnetic field coil current. The field lines emerge from the inner surface of the mild steel at the nozzle and diverge into the PIG chamber. By increasing the magnetic field strength, the region becomes narrow where electron diffusion due to collisions with neutrals overcomes the preventing effect by the magnetic field. Namely, effective cross-sectional area of the nozzle for electrons to pass through decreases, and as a result, discharge current density at the nozzle and hence electric field strength there increase. Thus, the discharge voltage increases with the source magnetic field.

With the increase of arc impedance, the energy of electrons which are accelerated by the potential jump at the nozzle increases. These energetic electrons can ionize more neutrals than those accelerated in the case of weak magnetic field. Then the plasma density in the PIG chamber becomes higher in the case of stronger magnetic field. This is experimentally shown in Fig.6, which indicates the beam current extracted from the source as a function of gas flow rate for three cases of source magnetic field coil current. At that time, the discharge current is fixed to 100 A and the beam acceleration voltage is 20 kV. Since beam current is in proportion to the plasma density in the PIG chamber, it increases with the source magnetic field coil current.

From Fig.6, it is also seen that the beam current decreases with the gas flow rate. This might be because the loss of energetic electrons to the anode, the electron energy loss by elastic collisions with neutrals, and the ion loss towards the wall of PIG chamber due to collisions with neutrals increases with the gas pressure.

3.2 Cathode Life

To check the life time of the cathode, we counted the time during which the ion source was in operation. In the course of this work, the operating conditions of the ion source was that the discharge current was below 120 A, the pulse width and the time interval of discharges were 100 msec and 1 to 5 seconds, respectively.

The results are as follows; The total number of working days of this cathode was 37 days. Accumulated time during which the cathode heater was on was 256 hours, out of which 112 hours were spent for the beam extraction from the source. The accumulated discharge time was 1210 minutes, of which 400 minutes were spent for the beam extraction. The total number of discharge pulses was about 6×10^4. The cathode was exposed to air 4 times in the course of this work.

The cathode life of about 2 months was from the first an objective of our test because the time interval between refreshments of cryo-panels in the neutral beam injector for JT-60 at JAERI7) is expected to be 2 months. The accumulated discharge time of 1210 minutes corresponds to the cathode life of 2.4 months assuming that the ion source will be used for 5 days a week, 8 hours a day, and the duty of discharges will be 1/20. Therefore, we stopped the life test on the way when the running time exceeded about 20 hrs.

After the test, the cathode was still usable to obtain the discharge current. Then we can say that the life time of the cathode is over 2 months for the normal use.

Due to the uniform ion bombardment, the surface of the impregnated tungsten emitter lost its luster after the test, but there was no trace of damage such as melting, burning together, or thermal deformation of the cathode structure. In the cource of life test, we noticed that with the lapse of time discharges became difficult to start unless the heater power was raised and the gas flow rate was increased. It is because the barium oxide impregnated in the porous tungsten is consumed by evaporation and decreases with the time when the heater is on.

4. Summary

An indirectly heated cathode was designed and prepared for the ion source of neutral beam injector. The cathode was made of impregnated porous tungsten emitter which had a form of cylindrical cup and was heated by thermal radiation. It was applied to a 10 cm diam. duoPIGatron hydrogen ion source and the discharge characteristics and the life time of it were

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tested. Beam extraction from the source was carried out and hydrogen ions of up to 3.5 A at 20 keV were extracted. The accumulated discharge time of the cathode was over 20 hours which corresponds to a life time of over 2 months for normal use, of which 6.7 hours were used for the beam extraction. The cathode was still usable after the test.

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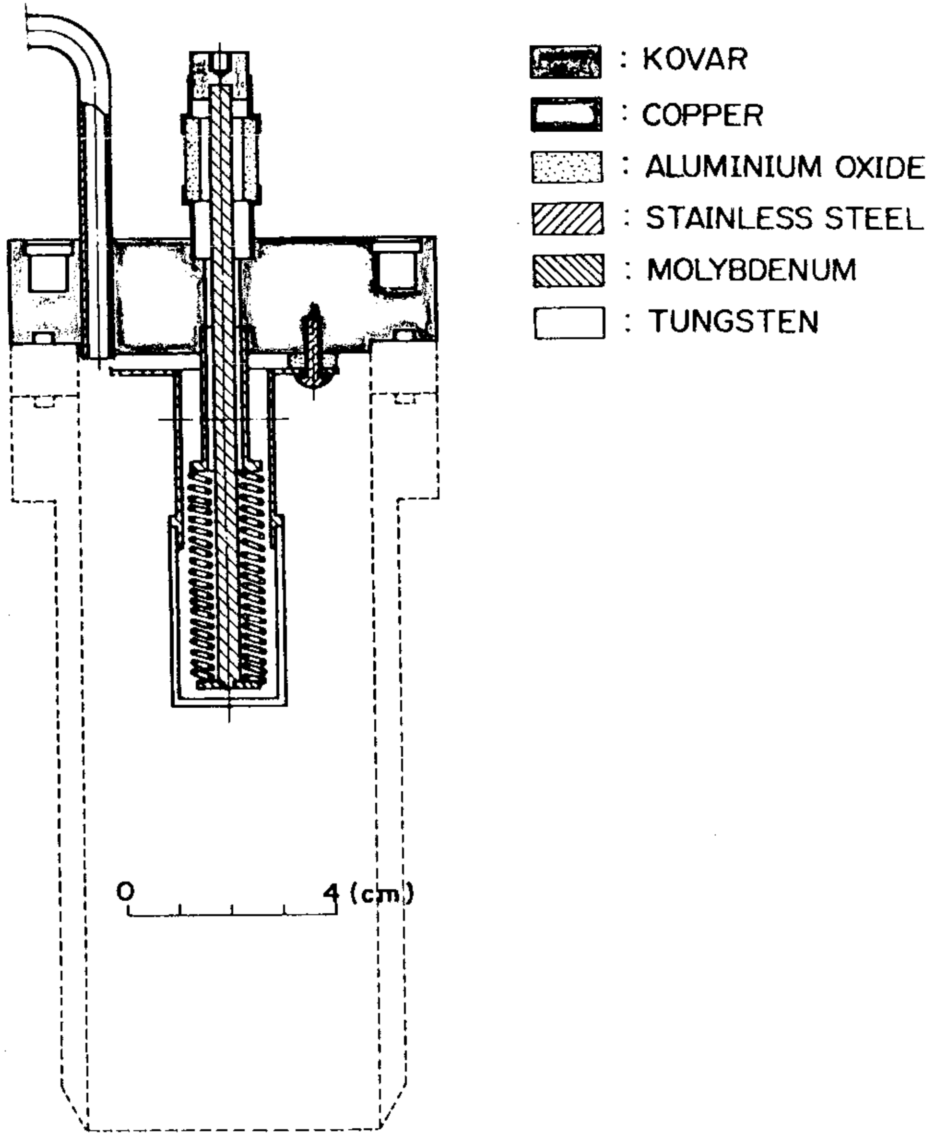

Fig.1 A cross-sectional view of the indirectly heated cathode

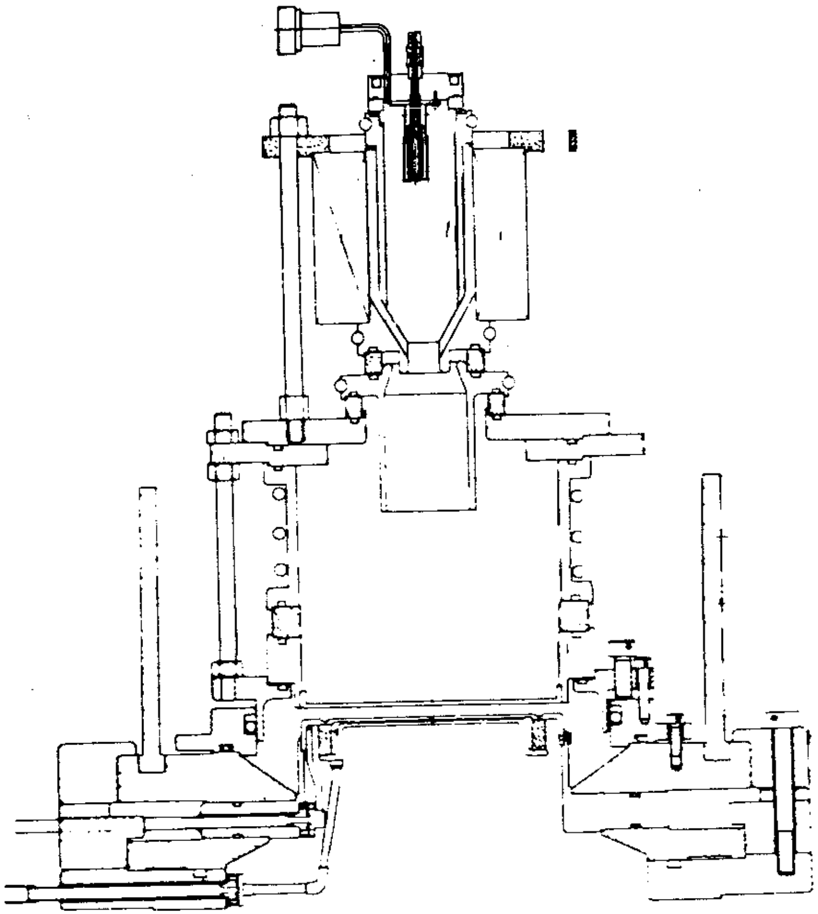

Fig.2 A cross-sectional view of the 10-cm diam. duoPIGatron ion source

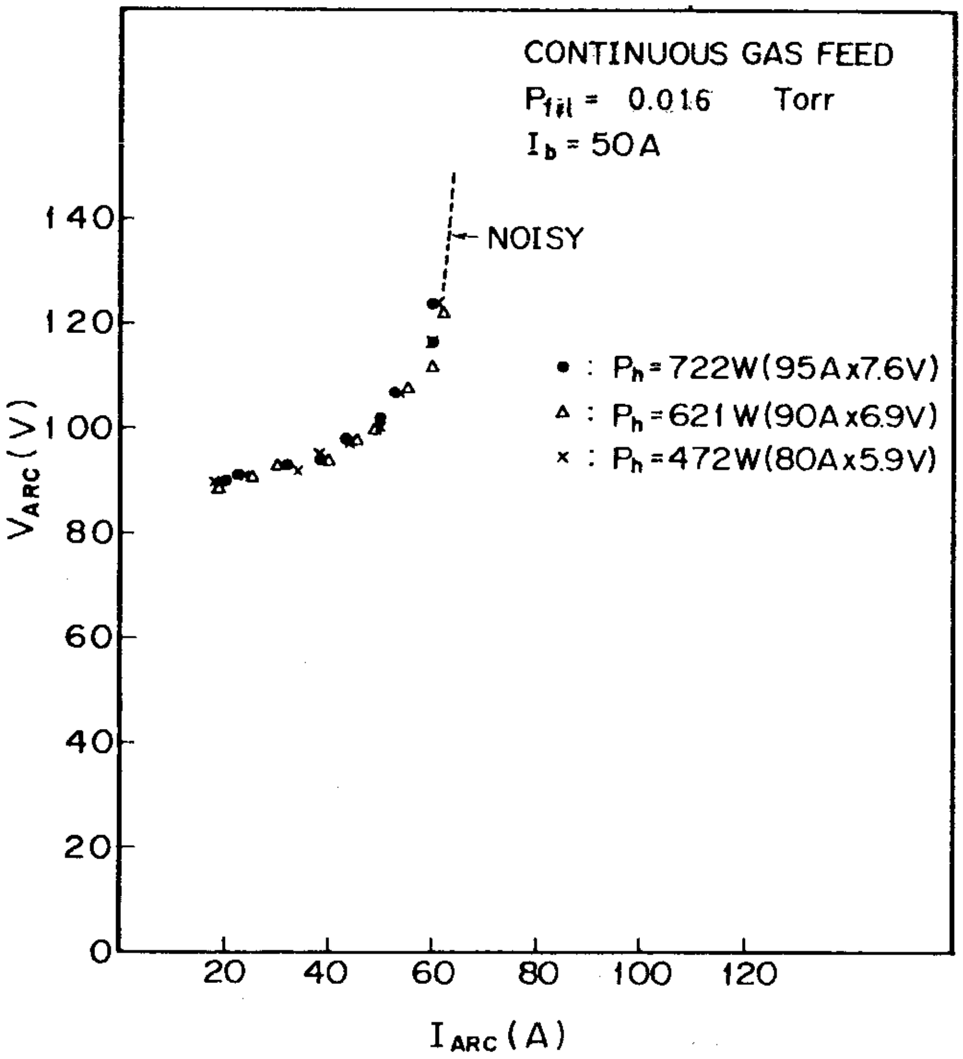

Fig.3 Discharge voltage-current curve of the ion source as a parameter of heater power, P_h

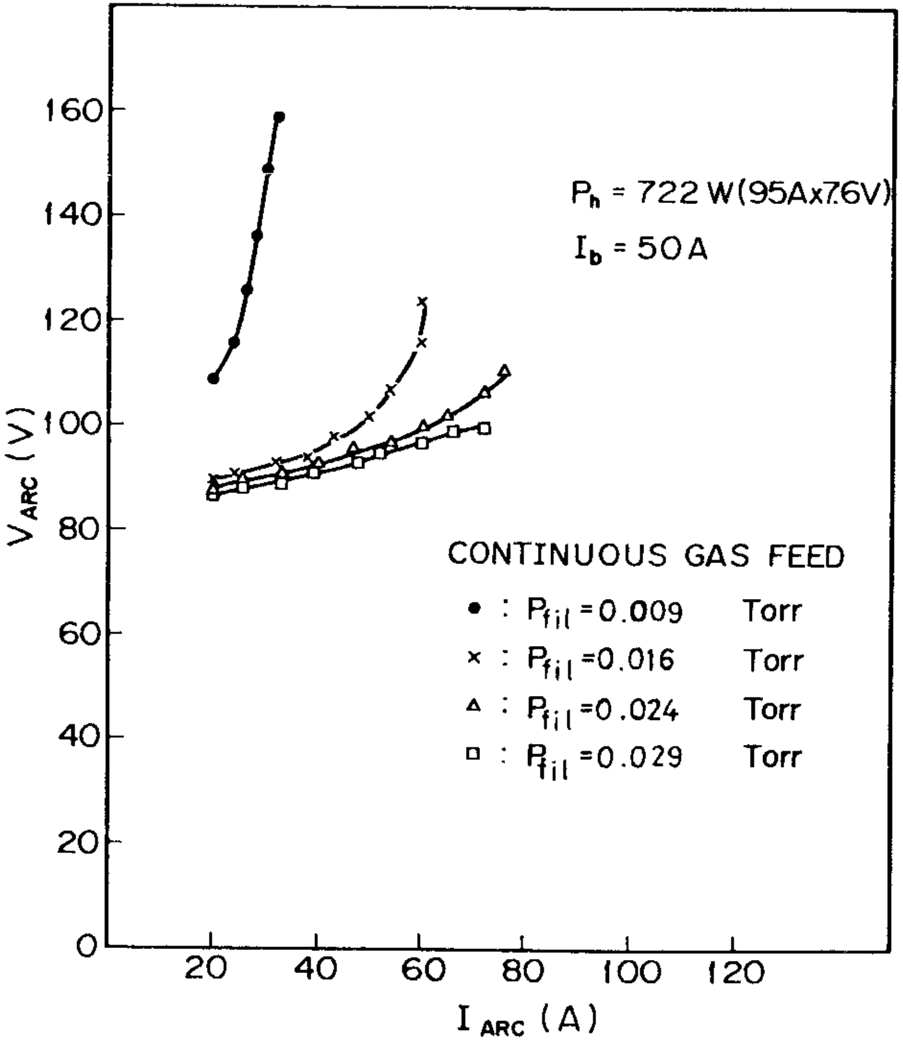

Fig.4 The V-I relation of discharges as a parameter of pressure in the cathode chamber

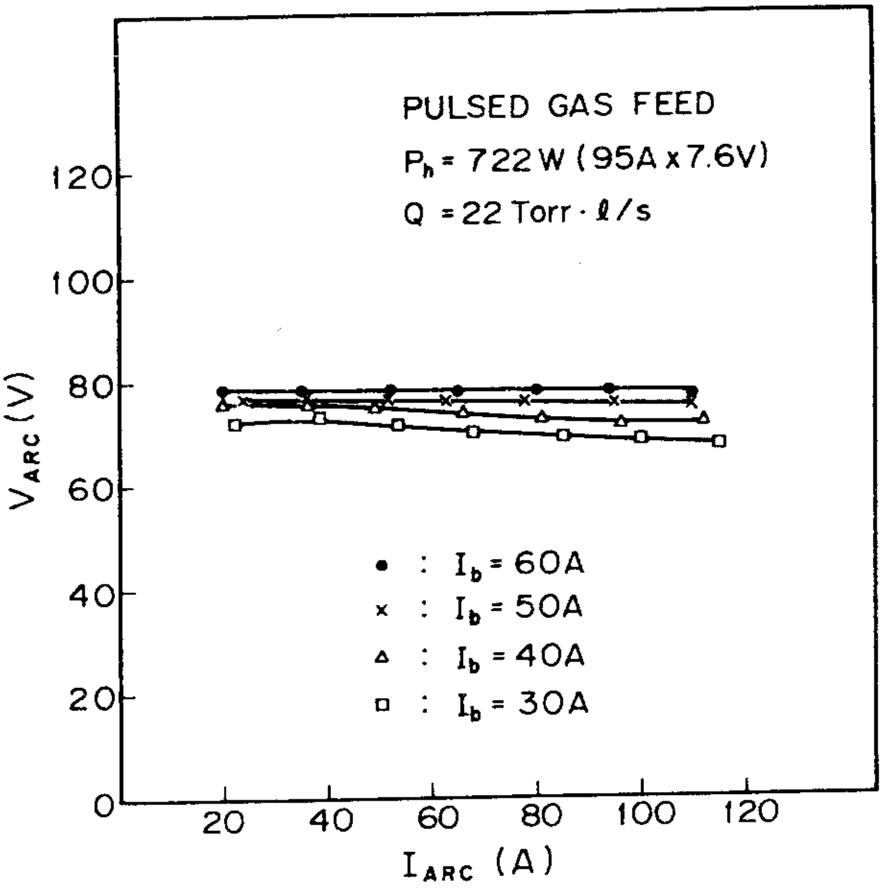

Fig.5 The V-I relation of discharges as a parameter of source magnetic field coil current, I_b, in the case of pulsed gas feed.

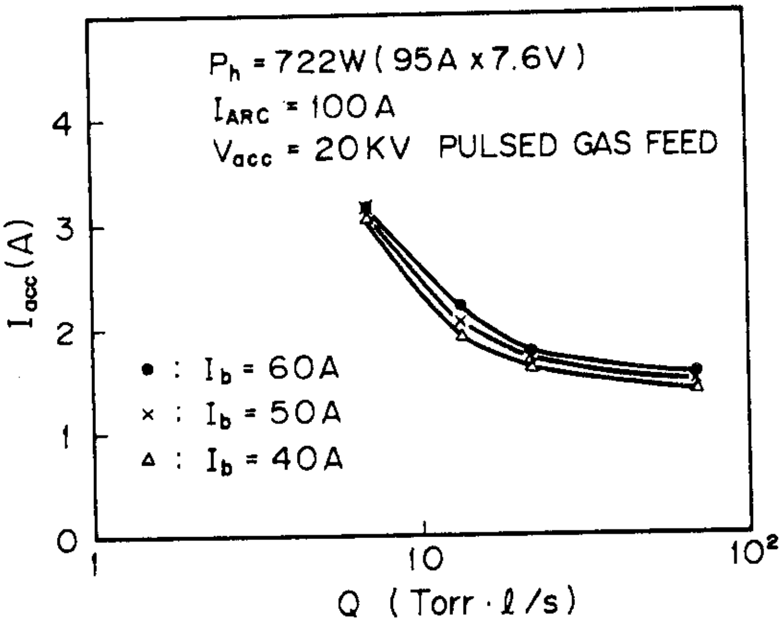

Fig.6 The beam current extracted from the source as a function of gas flow rate for three cases of source magnetic field coil current.