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ARC-CATHODE INTERACTION STUDY

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OUTLINE

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1. RESEARCH OBJECTIVE

Insufficient electrode life and uncertainties in that life are major problems hampering the development in many plasma application areas which make use of plasma torches, arc heaters, and arc jet thrusters. In spite of a considerable amount of work published dealing with arc-cathode phenomena, our present understanding is still incomplete because different physical phenomena dominate for different combinations of experimental parameters [1-2].

The objective of our present research project is to gain a better understanding of the behavior of arc-cathode surface interaction over a wide range of parameters, and furthermore to develop guidelines for better thermal design of the electrode and the selection of materials.

This report will present the research results and progress obtained on the arc-cathode interaction studies at the University of Minnesota. It includes results which have been obtained under programs other than the NASA funded program. Some of the results have been submitted in an informal interim progress report, and all of the results have been presented in a seminar during a visit to the NASA Lewis Research Center on October 16, 1992.

2. THEORETICAL RESEARCH

A theoretical model [3] has been formulated describing the influence of the arc condition and the cathode material and geometry on arc cathode erosion.

To arrive at a self-consistent description for the entire arc cathode attachment region, a realistic, one-dimensional sheath model has been used. This sheath model is supplemented by an integral energy balance of the ionization zone between the sheath and the arc, and by a differential energy balance of the cathode. The boundary conditions are the arc temperature for a given current, the cathode temperature at the interface to a cooled surface, and closure is obtained by involving the Steenbeck principle of minimum arc voltage. A copy of the thesis is transmitted to the technical program monitor.

For the case of a tungsten cathode in an argon arc, it has been shown that the ion current density is almost 50% of the total current density at low arc currents, while it decreases to about 18% of the total current density, and the thermionic electron current density increases to about 82% of the total current density at high currents. It has also been found that heat conduction within the cathode and radiation from the cathode surface control the energy transport from the cathode spot at low currents, and dissipation by thermionic electron release dominates at high currents. The implications for the design of low erosion cathodes are that improved thermal design will reduce erosion at low currents and current densities, and the choice of materials influencing electron emission will determine the erosion at high currents.

The results were presented at the IEEE International Holm Conference in Philadelphia, PA, on October 19, 1992.

3. EXPERIMENTAL INVESTIGATION

§ 3.1 Design of Experimental Setup

In order to verify the theoretical results, an experimental system has been designed shown in Figure 1. The power supplies are three Westinghouse plasma-arc power supplies. The torch and the chamber are both water-cooled by a high pressure cooling water loop and a low pressure loop, respectively. The vacuum system has a Stokes 2-stage micro-vac pump which has a capacity of 250 CFM at 1 torr.

§ 3.1.1 Chamber Design

Considering the consumption of energy by the torch, which is expected to be between 5 kW to 50 kW, the chamber must be water-cooled. The pressure in the chamber is in the range from 1 torr to 1 atm. At low pressure, the plasma jet is relatively long and the chamber has to be sized accordingly, while at higher pressures the jet is very short.

Considering the above requirement, two small chambers have been designed, both of which have diameters of 20" and lengths of 20". These two chambers can be connected together to form one big chamber of 20" diameter and 40" length for low pressure operation.

Figure 2 shows one chamber with 8 side-ports, and the other one with 4 side-ports for diagnostics, cathode installation, anode mounting, and exhaust. Both of the chambers are stainless steel.

§ 3.1.2 Torch Design

(1) Design Guidelines

The plasma torch is the heart of this installation. The purpose of this experiment is to study the arc-cathode interaction, which had to be fully considered in the torch design.

The following design guidelines should be taken into account: (1) The torch design should make the cathode tip accessible for the optical diagnostics; (2) the anode design should allow for various arc constrictions; (3) the torch should be water-cooled for minimizing the interaction with diagnostic equipment.

(2) Design Details

According to the above guidelines and based on discussions by Bokhari and Boulos [4], Nachman [5], and the torches designed in the High Temperature Lab [6], an arc torch has been designed and built for this experiment (Figure 3). The cathode part and the anode part are sufficiently separated to give optical access to the cathode tip. Both of them are water-cooled. The torch can be operated with a swirl or a straight gas injection along the cathode surface.

The tungsten cathode tip is silver soldered onto a copper support. The diameter of the anode nozzle is changeable by changing a copper nozzle insert. It should be remembered that for different working gases the diameter of the nozzle has to be quite different, for example, the diameter of the nozzle for a hydrogen arc should be much smaller than that for an argon arc because the specific heat and thermal conductivity of hydrogen are much higher than those of argon and the arc diameter is, therefore, much smaller. The arc constriction could be realized by either changing the diameter of the nozzle or by using radial gas flow. The length of the anode nozzle is 0.9".

The distance between the cathode tip and the anode nozzle is adjustable. The cathode is mounted on the front flange of the chamber as shown in Figure 2. The metal bellows makes it possible for the cathode to move relative to the anode. The movement is controlled by a stepping motor. The anode is mounted on the top port flange shown in Figure 2, which also has two-dimensional movements relative to the cathode tip.

§ 3.2 Experimental Setup and Test of the Experimental System

The torch, transmission, and chambers had been machined and the whole system had been setup by the end of last July. Figure 4 presents a photograph of the experimental system.

The experimental system has been tested with a 1/4" diameter anode nozzle using an Ar plasma. Figure 5 shows a photograph of the system in operation. The power supply system, the cooling system, the vacuum system, and the remote control panel have been demonstrated to operate satisfactorily.

§ 3.3 Cathode Spot Observation with Stroboscopic Video Camera

A stroboscopic video camera system has been used to observe the evolution of the cathode spot.

The stroboscopic video camera system consists of a pulsed nitrogen laser strobe unit, a camera unit which has a minimum shutter speed of 50 nanoseconds and a narrow-band optical filter (10 nm) to match the laser wavelength, and a system controller which synchronizes the laser and the camera. The laser is triggered while the shutter is open and the camera records the reflection from the laser light with the bandpass filter eliminating most of the background of the plasma radiation.

The laser beam cross section is 40 mm^2. This is very suitable for the cathode spot observation, usually the cathode spot size of a refractory cathode is around 1-2 mm at a current range of 100 A to 400 A [3]. The laser wavelength is 337 nm. The pulse energy of the laser is larger than 175 mJ.

Figure 6 shows a picture taken by this video camera. The bright spot in the center of the picture is a reflection of the laser light from the anode. The arc cathode attachment is quite stable, but the arc anode attachment (1/4" diameter anode nozzle) moves quickly around the nozzle inlet.

However, to make full use of this system, we will have to use additional optics to magnify the cathode spot. Also, the plasma radiation can not be completely eliminated by the filter and leads to some obstruction of the view of the cathode tip.

§ 3.4 Cathode Spot Temperature Measurement with Single-Color Pyrometer

A Pyro Micro-Therm single-color pyrometer has been employed to measure the cathode spot temperature. The instrument offers a high spatial resolution necessary for determining cathode tip temperatures. However, the plasma radiation introduces a significant error. Two-color pyrometry with an optical magnifying system will have to be used.

§ 3.5 Arc Stability

Different nozzle sizes, different power inputs, and different gas flow rates have been used. The arc voltage fluctuations have been observed with the help of an oscilloscope. Table 1 gives the qualitative results of our observations.

From these observations, the arc attachment at the anode nozzle does not seem to display the restrike behavior. The arc attaches at the inlet of the anode nozzle for all operating conditions investigated until now.

4. FUTURE WORK

It is planned that a spectrograph with an OMA system with CCD array as well as a two-color photo diode will be employed to measure the cathode spot temperature. End-on observations will be made in a transient mode, recording a signal during arc shut-off and extrapolating it to the instant of shut-off. These measurements will be followed by spectroscopic investigation of the arc in front of the cathode.

REFERENCES

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[5] M. Nachman, "A few considerations about the designing of plasma arc torches", *Rev. int. Htes. Temp. et Refract,* **10**(3), p. 65, 1973.

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Table 1. Observation Results

	Power input	Anode size	Flow rate
Anode attachment stability and voltage fluctuation	(From 1.5kW to 14kW) At lower level of power input, the attachment often stuck to one spot at the anode nozzle, as the power input increases, the anode attachment becomes well distributed. The voltage fluctuations increase as the power input increases	(Three different nozzle sizes: 1/4", 3/16", and 1/8" diameter) The instability increases as the nozzle size decreases	(From 15L/m to 35L/m) The voltage fluctuations slightly increases as the flow rate increases

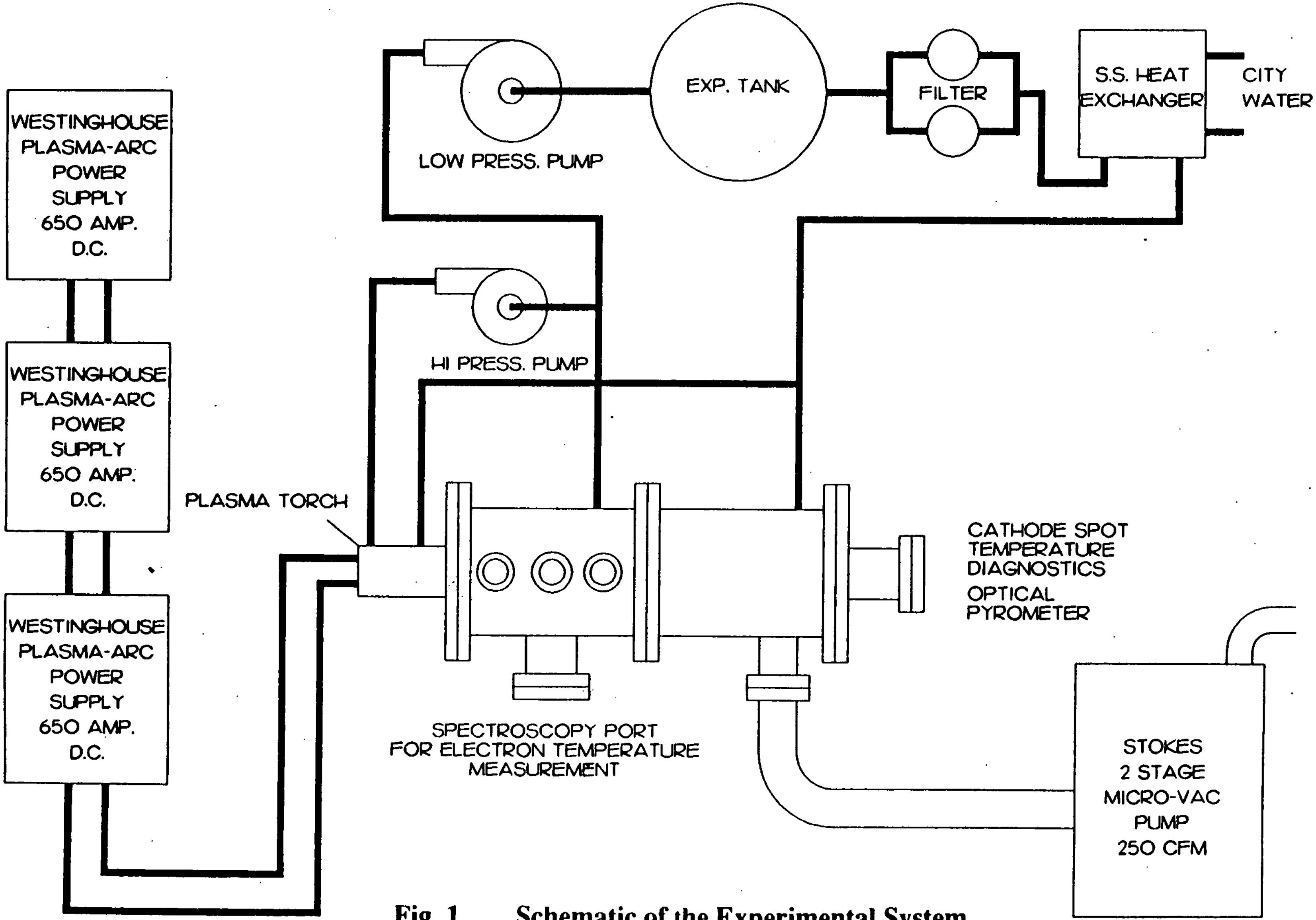

Fig. 1. Schematic of the Experimental System

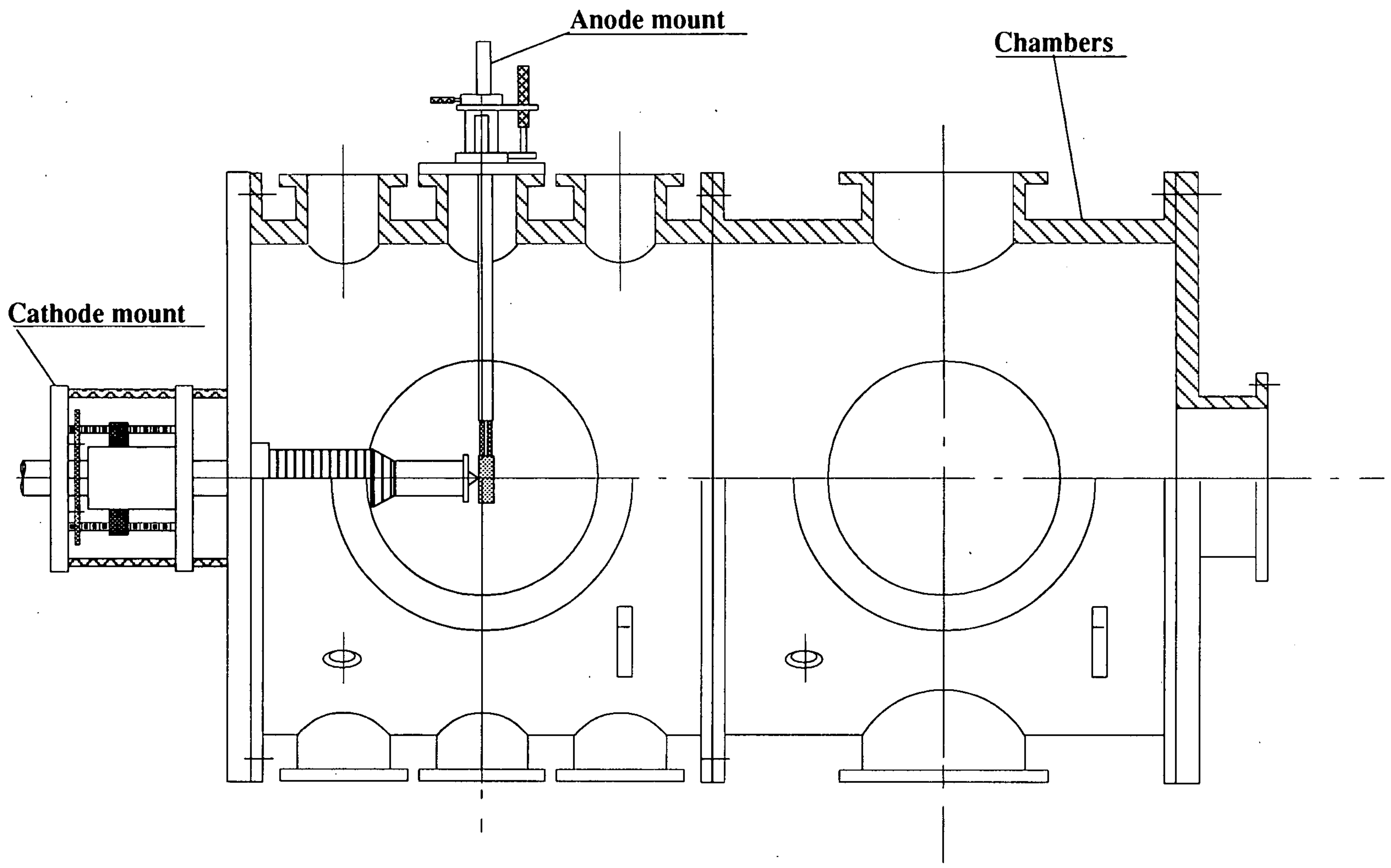

Fig.2 Schematic drawing of experimental setup

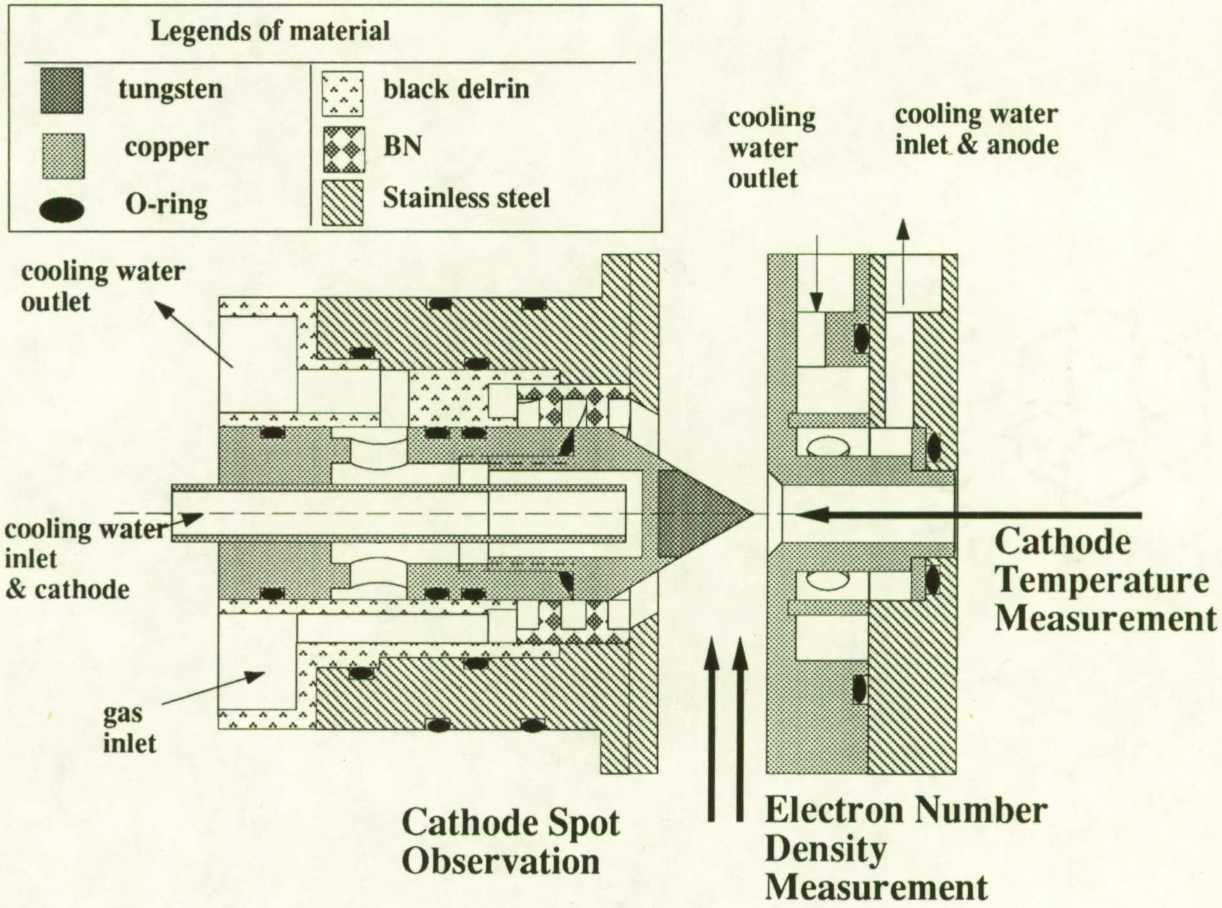

Fig. 3 Schematic of Plasma Torch

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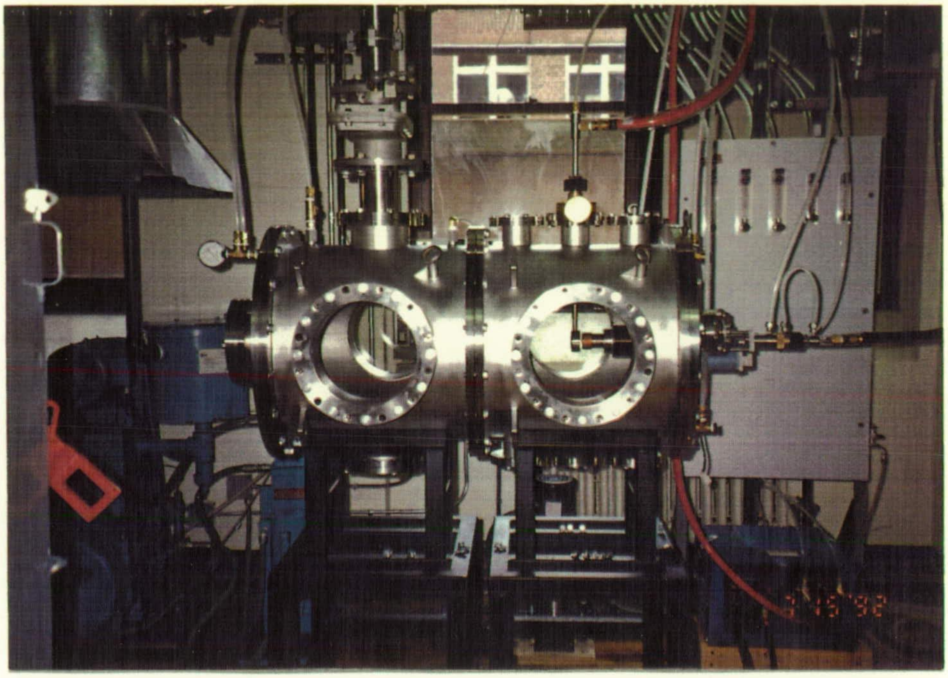

Fig. 4. The Experimental System for Arc-Cathode Interaction

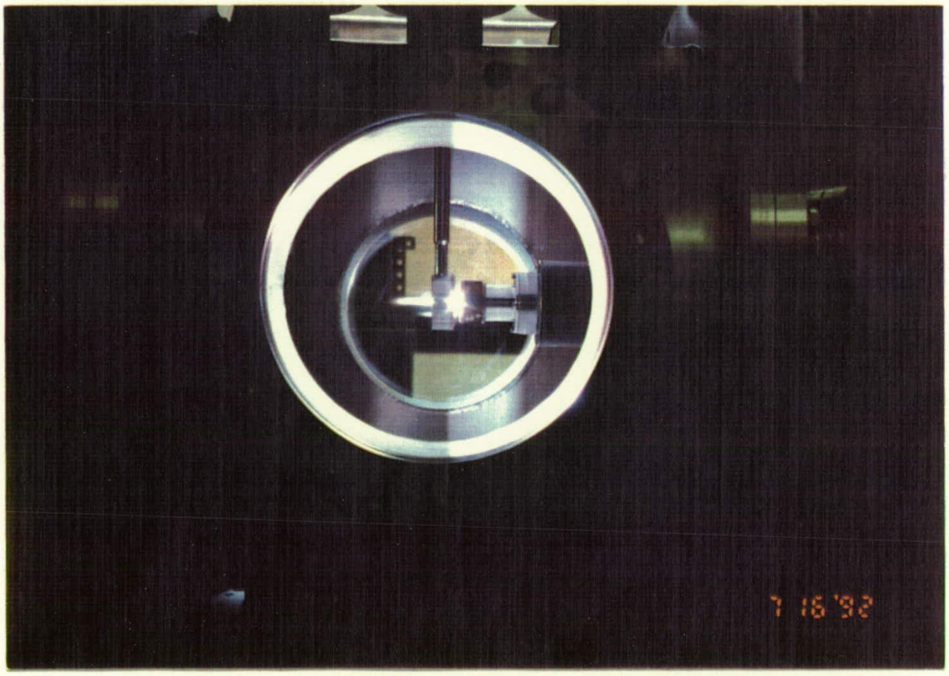

Fig. 5. The Plasma Torch in Operation

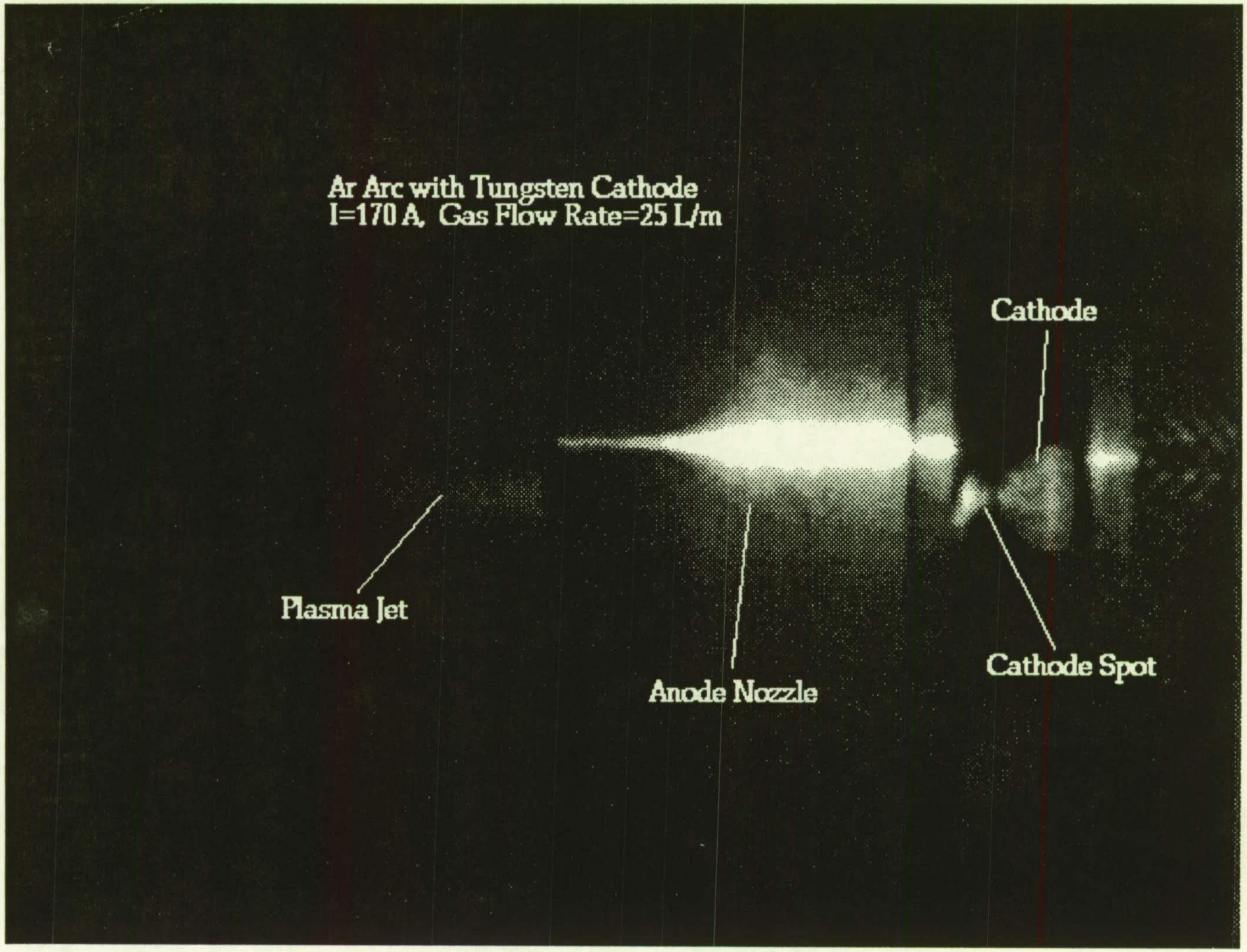

Fig. 6 Stroboscopic Video Camera Image of Electrodes and Arc