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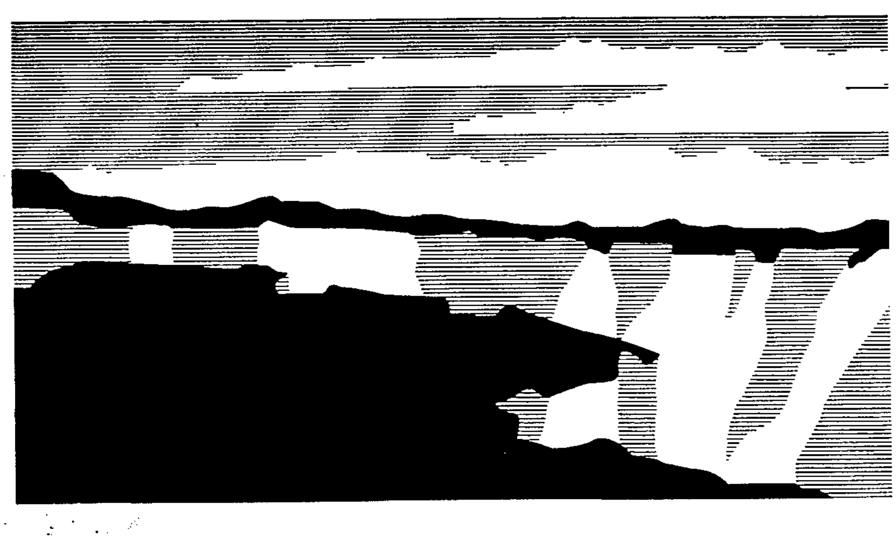

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A dc Penning Surface-Plasma Source*

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Abstract

After developing a pulsed-8X source for H^- beams, we are now testing a cooled, dc version. The design dc power density on the cathode surface is 900 W/cm^2, much higher than achieved in any previously reported Penning surface-plasma source (SPS). The source is designed to accommodate dc arc power levels up to 30 kW by cooling the electrode surfaces with pressurized, hot water. After striking the arc using a 600-V pulser, a 350-V dc power supply is switched in to sustain the 100-V discharge. Now our tests are concentrating on arc pulse lengths $\leq$1 s. Ultimately, the discharge will be operated dc. The source is described and the initial arc test results are presented.

I. Introduction

The 8X source is under development for possible use in the neutral-particle beam program. It may also be of interest to other projects that require either dc or high-duty-factor, high-quality H^- beams. The pulsed-8X source design and measured performance are described in Ref. 1. In consultation with Los Alamos, Grumman Space Systems designed[2] and built a cooled, dc version of the 8X source.[3] It is now installed on the high-current test stand (HCTS) at Los Alamos for dc arc tests. The HCTS was modified to accommodate the necessary additional equipment, including installation of a hot-water cooling system and a Macintosh Quadra-LabView™-based set-point, data-archiving computer system.[4] Other work on cooled or long-arc-pulse Penning sources is described in Refs. 5-9.

II. Source Design

In our pulsed 8X source measurements[1] we observe a cathode power efficiency $\zeta = 640$ mA/kW ($\zeta = j_{H^-}/F_C$, where j_{H^-} is the emission current density and F_C is the cathode power density). Researchers at Novosibirsk report[10] dc operation of an H^- planotron SPS for $F_C = 1$ kW/cm^2. Thus, $j_{H^-} \geq 640$ mA/cm^2 may be possible for dc operation of the 8X source (a Penning SPS).

Based on the measured pulsed-8X-source performance,[1] we predict the CW 8X source performance shown in Table I. For the dc source we assume the same effective H^- transverse temperature found in the pulsed-8X-source emittance measurements,[1] 6.7 eV. For a 0.40-cm-diam emitter, we anticipate 60-mA dc H^- beams with rms normalized emittances $\varepsilon \approx 0.009\ \pi$ cm mrad for $F_C = 900$ W/cm^2, low enough to permit dc operation. The discharge power is 88 V $\times$ 340 A = 30 kW, with 20 kW estimated to go to the cathode and 10 kW to the anode. Vigorous cooling is provided for all surfaces that contact the source plasma.

The cathode and anode[2,3] are designed to operate at power densities as high as 1.4 and 0.3 kW/cm^2, respectively. Figure 1 shows how water is transported up seven squirt tubes (0.22 cm o.d. $\times$ 0.013 cm walls) to the end of each cathode tip. The water then reverses direction and flows down the annulus between the squirt tube and the 0.30-cm-i.d. cavity machined into the cathode. Heat is transported through 0.17-cm-thick molybdenum to the coolant passages. Good heat transfer is achieved by using the fluid velocity to suppress local burnout. Heated water from the annuli surrounding the 14 squirt tubes (7 in each tip) is returned to a common plenum. The water is then transported to a specially-built unit capable of removing up to 46 kW. The anode and the emission-aperture cap are both cooled with conventional cooling passages[3] because the assumed power density on each is only 0.3 kW/cm^2.

A conical collar in the drift region (Fig. 2) provides maximum e^- suppression with no degradation of the H^- beam output.[11] The anode, cathode, and emission-aperture cap are molybdenum, which possesses good thermal, structural, and H^- production properties. More design details, and design-calculation results, are given in Refs. 2 and 3.

Figure 2 shows the CW 8X source assembly. The variable magnetic field is provided by the electromagnet coil. Cesium vapor is supplied to the discharge region by heating a mixture of titanium and cesium-chromate powders in an external oven (not shown). The source electrodes are initially heated to 185°C by the water system. Once the arc is struck, the water temperature is kept ≥180°C to maintain the proper cesium coverage on the electrode surfaces.

III. Water System

Figure 3 shows the layout of the HCTS. The 500 psi (3.4 MPa), 200°C water system (Wellman Thermal Systems, Shelbyville, IN) provides the deionized, hot water. During start up, the water is heated by a 12-kW electrical heater coil and circulated to the source by a 22-gpm (83-ℓpm) pump. Once the operating temperature is reached, a Honeywell UDC 5000 controller maintains the water temperature at the

preset value by sending a portion of the water through a heat exchanger with 46-kW-maximum cooling capacity.

If a water leak is sensed, fast valves isolate the water system from the manifolding and the source. Pressure-relief valves automatically guard against over-pressure conditions.

IV. Source Electronics

Approximately 400 V are needed to initiate the Penning SPS discharge. We estimate that 340 A of arc current is needed to produce the desired H^- current density. For these initial source tests, we use a 600-V arc pulser to strike the discharge and two 30-kW dc power supplies (providing 350 V at 150 A) to sustain it (Fig. 4). Figure 5 shows schematics of the idealized CW 8X source discharge voltage (V_d) and discharge current (I_d) waveforms.

The low-power transistor switch closes at time $t = 0$, initiating the source discharge. At $t = 1.0$ ms the high-power transistor switch is closed and the low-power switch is opened. Large power diodes prevent cross-talk between the 350-V, 150-A power supply and the arc pulser. The 350-V, 150-A power supply keeps the discharge running until the high-power transistor switch is opened.

V. Initial Results

Figure 6 shows the measured discharge voltage and current waveforms for a 1-ms-long arc-pulser and a 30-ms-long dc-power-supply pulse. The source parameters for the waveforms shown in Fig. 6 are arc magnetic field = 420 G, water temperature = 200°C, and H_2 and N_2 gas flow = 0.8 and 0.03 $T\dot{\ell}/s$, respectively. The droop in the arc-pulser-driven discharge current is due to the drain of the pulser capacitor bank. The droop in the dc-power-supply-driven current pulse is from the turn-on response of the power supplies — if the source arc is replaced with a short, the same shape is measured. We know of no reason why the arc pulse length cannot be extended from 31 ms to ≈1 s. This will be done, or the discharge will be run dc, before we extract dc H^- beam from this source. To our knowledge, this is the first report of a Penning SPS hydrogen-cesium discharge that operates with massively-water-cooled electrodes.

Acknowledgements

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Table I.

A comparison of the measured pulsed 8X source performance[1] and the predicted CW 8X source performance.

	Pulsed 8X Source Measured	CW 8X Source Predicted
Cathode-cathode gap (L), cm	3.4	3.4
Discharge slot depth (W), cm	3.4	3.4
Discharge slot length (T), cm	3.4	3.4
Discharge magnetic field, G	270	300
Emitter diameter (2R), cm	0.26 ϕ	0.40 ϕ
Extraction gap, cm	0.30	a
Extraction voltage, kV	25	a
Discharge voltage, V	88	88
Discharge current, A	490	340
H^- current, mA	37	60
j_{H^-}, mA/cm^2	700	480
F_C (cathode power density), kW/cm^2	1.3	0.88
ζ (cathode power efficiency), mA/kW	540	540
F_A (anode power density), kW/cm^2	0.33	0.22
ε, π cm mrad	0.0055	0.009[b]
Discharge duty factor, %	~ 1	100

a) The extraction system design has not been determined.

b) Estimated from $\varepsilon = (R/2)\,(kT_{H^-}/mc^2)^{1/2}$, where kT_{H^-} is the effective transverse H^- temperature.

Figure Captions

Fig. 1. A cross-sectional view of the CW 8X source cathode, anode, and emission-aperture cap.[2,3]

Fig. 2. The CW 8X source assembly.[3]

Fig. 3. Schematic of the test-stand layout, including the water system.

Fig. 4. CW 8X source electronic-circuit schematic.

Fig. 5. Idealized CW 8X source V_d and I_d waveforms.

Fig. 6. Measured a) V_d and b) I_d waveforms for a 1-ms-long arc-pulser pulse and a 30-ms-long dc-power-supply pulse.

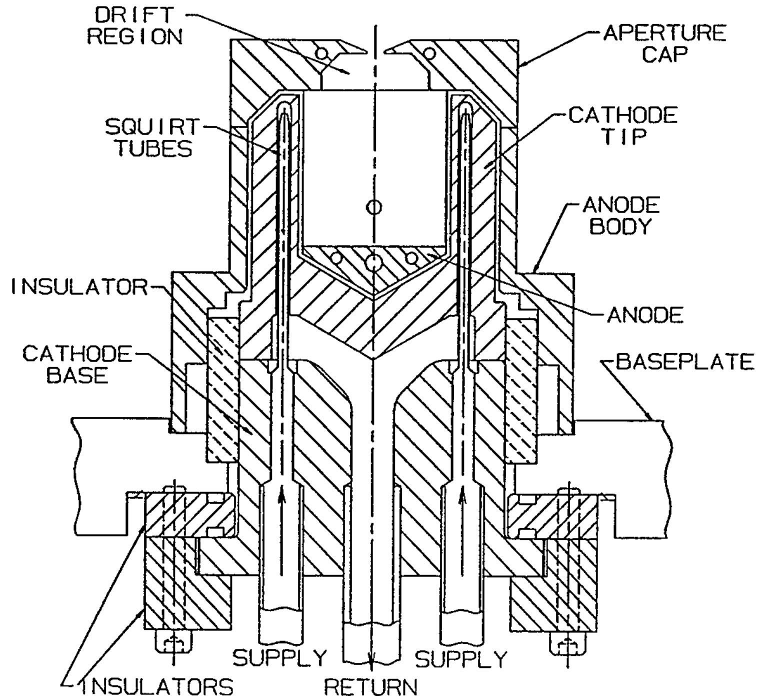

Figure 1

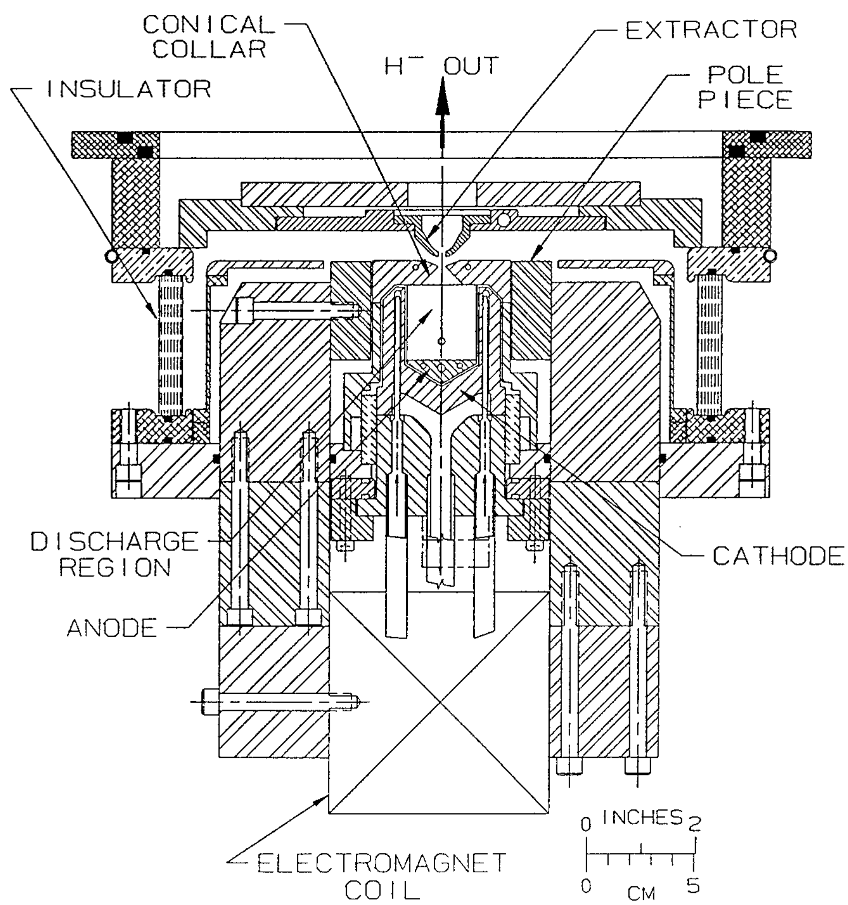

Figure 2

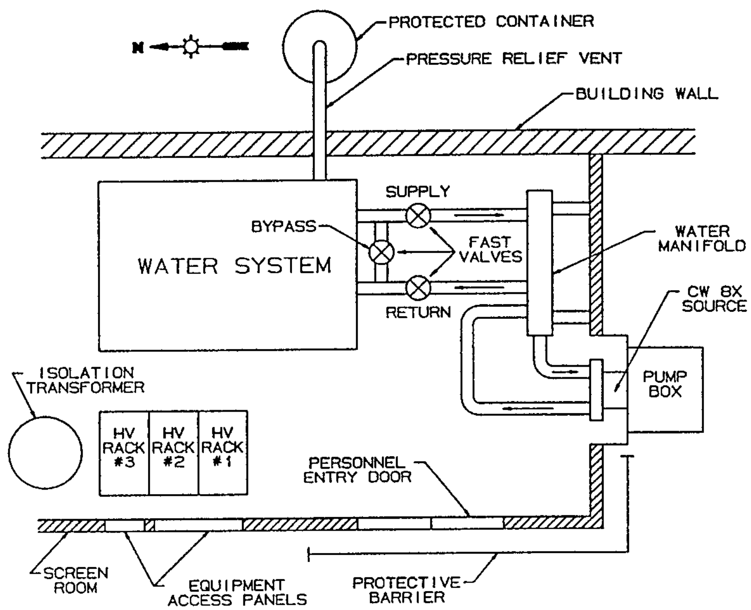

Figure 3

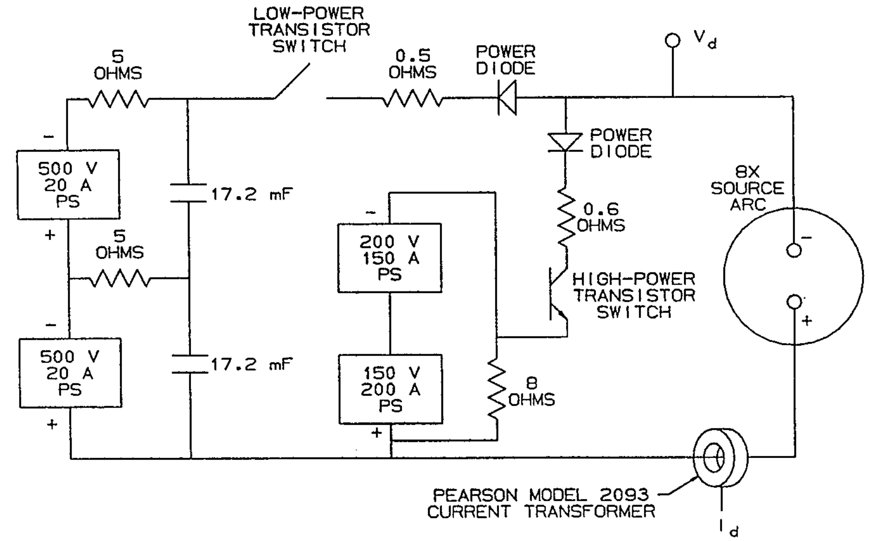

Figure 4

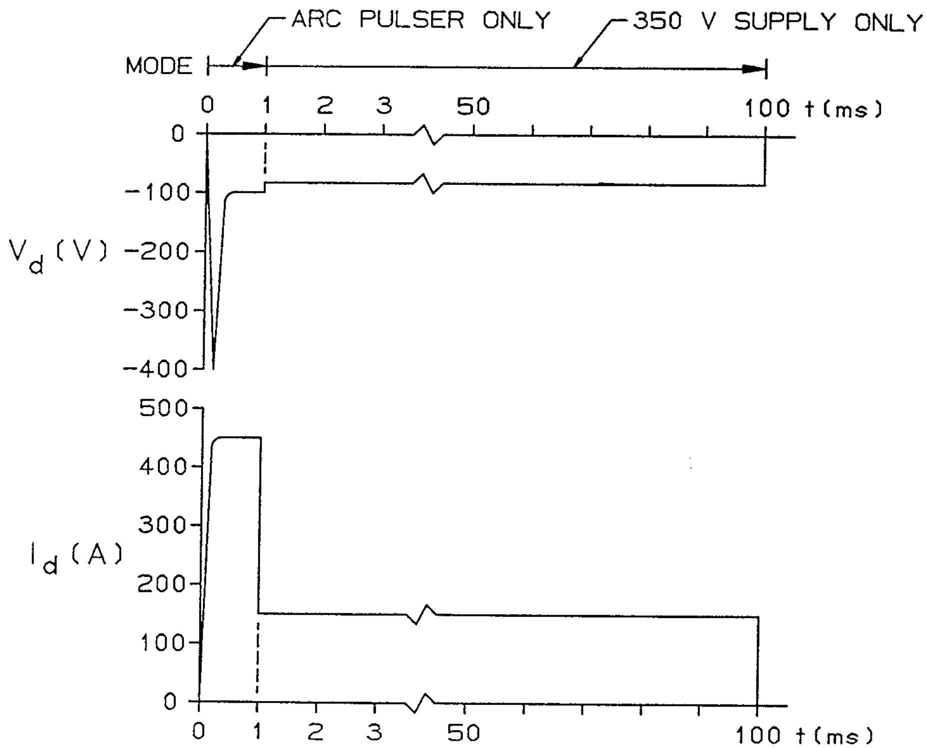

Figure 5

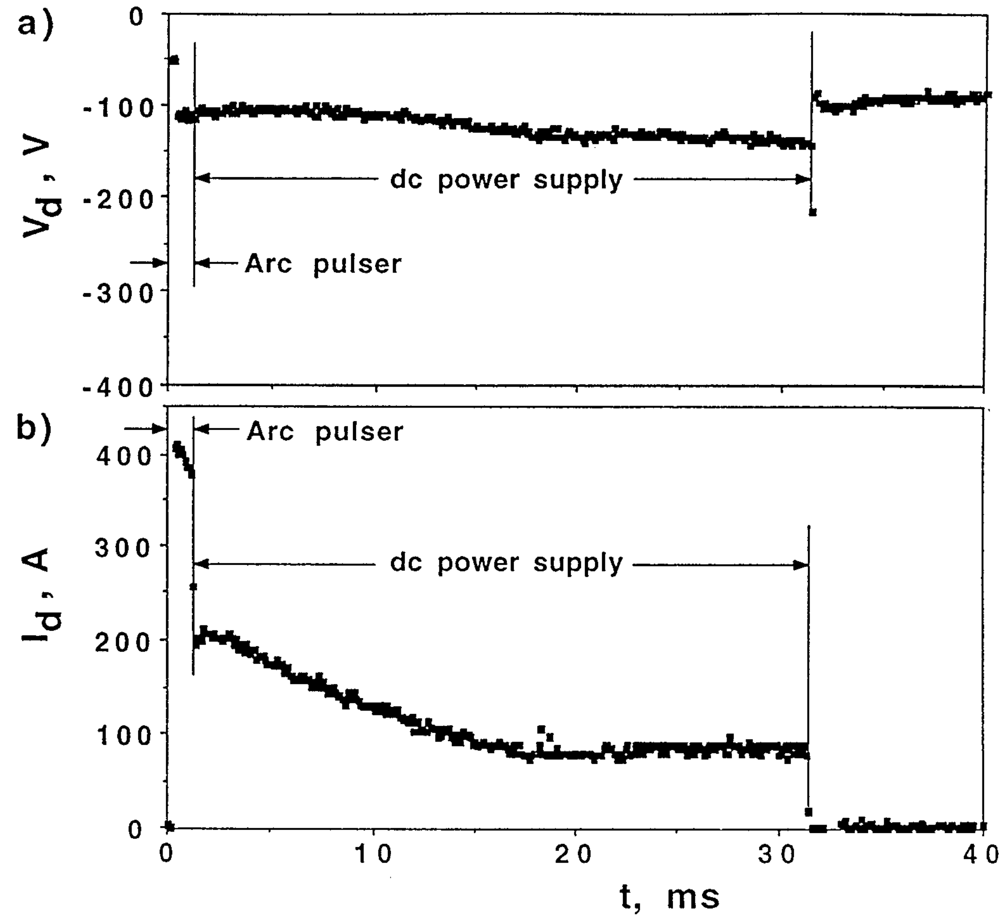

Figure 6