Initial Operation of the CW 8X H⁻ Ion Source Discharge*

H. Vernon Smith, Jr., Paul Allison, Carl Geisik, David R. Schmitt, J. David Schneider, and James E. Stelzer Los Alamos National Laboratory Los Alamos, NM 87545

Abstract

A pulsed 8X source was built and the H⁻ beam current, emittance, and power efficiency were measured. These results were promising, so a cooled, dc version designed for operation at arc power levels up to 30 kW was built. Testing of the CW 8X source discharge is underway. The design dc power loading on the cathode surface is 900 W/cm², considerably higher than achieved in any previous Penning surface-plasma source (SPS). Thus, the electrodc surfaces are cooled with pressurized, hot water. We describe the source and present the initial operating experience and arc test results.

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, highquality H⁻ beams. The pulsed-8X source design and measured performance are described in Ref. [1]. Grumman Space Systems built [2] a cooled version of the 8X source, the CW 8X source [3], that is designed to operate with dc arc. The source is now installed on the high-current test stand (HCTS) at Los Alamos for dc arc tests. The HCTS was modified to accommodate the additional equipment necessary for these tests, including installation of a water-cooling system and a Macintosh IIci-LabView[™]-based set-point, data-archiving computer system [4]. Previous work on cooled or long-arcpulse Penning sources is described in [5], [6], and [7].

II. SOURCE DESIGN

We observed a cathode power efficiency $\zeta = 640 \text{ mA/kW}$ in our pulsed 8X source measurements [1] ($\zeta = j_{\text{H}}$ -/F_C, where j_{H} - is the emission current density and F_C is the cathode power loading). Researchers at Novosibirsk claim [8] dc operation of an H⁻ planotron SPS at cathode power loads F_C = 1 kW/cm². Thus, we speculate that j_{H} - $\geq 640 \text{ mA/cm}^2$ would be possible for dc operation of the 8X source (a Penning SPS).

The CW 8X source predicted performance, based on the measured pulsed-8X-source performance [1], is shown in Table I of Ref. [3]. We assume that for the dc source the effective H⁻ transverse temperature is 6.7 eV, the value found in the pulsed-8X-source emittance measurements [1]. For a 0.40-cm-diam emitter, 60-mA dc H⁻ beams with rms normalized emittances $\epsilon \approx 0.01 \pi$ cm mrad are anticipated. We estimate a cathode power density of 900 W/cm², low enough to permit dc operation. However, the discharge power is 88 V × 340 A = 30 kW, with 20 kW estimated to go to the cathode and 10 kW to the anode. Vigorous cooling of all surfaces contacting the source plasma is provided.

The approach taken to cool the cathode and anode [2,3] operating at power loads as high as 1.4 and 0.26 kW/cm², respectively, is illustrated in Fig. 1. To cool the cathode, water

is transported up seven squirt tubes (0.22 cm o.d. x 0.013 cm walls) to the end of each cathode tip. The water then reverses direction (180° bend) and is transported down the annulus between the squirt tube and the 0.30-cm-i.d. cavity machined into the cathode. The power deposited on the cathode is transported through a 0.17-cm-thick layer of molybdenum to the coolant passages. Good heat transfer is achieved by using the fluid velocity to suppress local burnout. The 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. Because the anode power loading is four times lower than the cathode loading, and because the emission-aperture-cap power loading is assumed to be the same as for the anode, both are cooled using conventional coolant passages [3]. A conical collar in the drift region (Fig. 2) provides maximum e⁻ suppression with no degradation of the H⁻ beam output [9]. The anode, cathode, and emission-aperture cap are molybdenum, which has good thermal and structural properties in addition to excellent H⁻ production. More design details, and the results of the design calculations, are given in [2] and [3].

Figure 2 shows a CW 8X source assembly drawing. The variable magnetic field is provided with an electromagnet coil. Cesium vapor is provided by heating a mixture of titanium and cesium-chromate powders contained in a separate oven (not shown). The source is heated initially to 185° C by the water system. Once the arc is struck, the water temperature is kept $\geq 150^{\circ}$ C to maintain the proper cesium coverage on the electrode surfaces.



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

^{*} Work supported by the Dept. of Defense, US Army Strategic Defense Command under auspices of the US Dept. of Energy.



Figure 2. An assembly drawing of the CW 8X source [3].

III. WATER SYSTEM

Figure 3 shows the layout of the HCTS. The 500 psi (3.4 MPa), 200°C water system, purchased from Wellman Thermal Systems in Shelbyville, IN, provides the deionized, high-temperature water. During start up, the water is heated by a 12-kW electrical heater coil. A 22-gpm ($83-\ell pm$) pump circulates the water to the source through the manifolding. Once the operating temperature is reached, a Honeywell UDC 5000 controller maintains the water temperature at the preset



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

value by sending a portion of the water through a heat exchanger that has 46-kW cooling capacity. If a water leak is sensed, air-actuated fast valves isolate the water system from the manifolding and the source. Pressure-relief valves automatically protect against over-pressure conditions.

IV. SOURCE ELECTRONICS

In addition to the requirements imposed by having to cool a 30-kW dc discharge, an additional complication is introduced by the arc requirements. Approximately 400 V is needed to initiate the Penning SPS discharge. We estimate that 350 A of arc current is needed to produce the desired H⁻ current. One option is to use a 400-V, 350-A dc power supply to start and to sustain the discharge. Instead, we use a 600-V arc pulser to strike the discharge and two 30-kW dc power supplies (one rated at 150 V, 200 A and the other at 200 V, 150 A, arranged in parallel) to sustain it (Fig. 4). Schematics of the expected CW 8X source discharge voltage (V_d) and discharge current (I_d) waveforms are shown in Fig. 5.



Figure 4. CW 8X source electronic circuit schematic.

Two power supplies charge the 17.2-mF arc-pulser capacitors. Zener diodes placed in the control circuits of the 500-V power supplies limit their outputs to 300 V. At time t = 0, the low-power transistor switch closes initiating the source discharge. The 150-V, 350-A power supply continually draws current through the 8- Ω resistor to improve its response to the pulsed current demand. That demand comes at t = 1.0 ms, when the high-power transistor switch closes and the low-power switch opens. Large power diodes prevent crosstalk between the 150-V, 350-A power supply and the arc pulser. The 150-V, 350-A power supply keeps the discharge running until the high-power transistor switch is opened.

V. INITIAL OPERATING EXPERIENCE

NiOro brazing compound (82% Au, 18% Ni) was used to join the molybdenum components together. A silver-copper over-braze was used to provide a vacuum seal for the cathode and anode assemblies (the emission-aperture cap did not need the over-braze). Before the source was assembled, pressure tests at 750 psi (5.2 MPa) revealed no leaks in the cathode, anode, and aperture cap assemblies. After 70 hours of pulsed operation, the braze joints are still intact. The cathode assembly must be electrically isolated from source ground (the anode, emission-aperture cap, and water system) in the high-



Figure 5. Expected V_d and I_d waveforms.

temperature water loop. This is done with KEVLARTM-reinforced, silicone-rubber hose assemblies that were specially made for this application by Preece, Inc. of Irvine, CA. We have not had any hose failures at temperature. The hose crimp joints developed leaks after several thermal cycles. Recrimping the hose connectors sealed these leaks—no failures have occurred in the recrimped assemblies.

A heater power of 9 kW maintains the water unit, the manifolding, and the source at 184°C, leaving 3 kW to raise the temperature further if necessary (200°C is the design maximum). We add 5 ppm each of NaNO₂ and Na₂MoO₄•2H₂O to the deionized water to suppress corrosion of the molybdenum components. We also add 30 ppm of NaOH to the deionized water to elevate the pH of the water from ≈ 6 to ≥ 9 to prevent corrosion of all the materials that contact the water: 316L, 304L, and 316 stainless steels; molybdenum; copper; silicone; teflon; KALREZTM and Parker compound E962 O-rings; PEEKTM seals in the ball shut-off valves; and NiOro and silver-copper brazing compound.

Cathode material is worn away by sputtering. In our pulsed 8X source tests, the sputtered molybdenum occasionally bonded poorly to the anode and aperture cap, causing flakes to form which degraded source performance. Thus, erosion of the cathode can present a problem for long-term, dc operation. Based on the 4X source pulsed operation data [10], we project that the erosion of the CW 8X source cathode due to sputtering will be ~0.02 mm/h. Experience does not necessarily indicate a problem with this level of sputtering, but long-term effects are unknown. The dc erosion rate may be much less than the pulsed rate because the dc discharge voltage is normally lower than the pulsed voltage. So far in our tests, we have immeasurably small erosion of the CW 8X source cathode, and the very-thin layers of sputtered molybdenum that deposited on the anode bonded securely (no flaking has been noted).

VI. INITIAL RESULTS

Figure 6 shows the measured discharge voltage and current waveforms for 1-ms-long arc-pulser and 4-ms-long dc-power-supply pulses. The source parameters for the waveforms shown in Fig. 6 are arc magnetic field = 420 G,



Figure 6. Measured V_d and I_d waveforms for a 1-ms-long acpulser pulse and a 4-ms-long dc-power-supply pulse.

pulse repetition rate = 1 Hz, and H₂ and N₂ gas flow = 100 and 1 sccm, respectively. The droop in the arc-pulser-driven discharge current is due to the RC drain of the pulser capacitor bank. The droop in the dc power-supply-driven current pulse is the turn-on response of the power supplies; the same shape is measured when the source arc is replaced with a short.

VII SUMMARY

The dc version of the 8X source is installed on the HCTS at Los Alamos and the arc tests have begun. The arc pulse length will be extended from 6 ms to >1 s before we prepare to extract dc H⁻ beam from this source.

REFERENCES

- [1] H. V. Smith, Jr., P. Allison, and J. D. Sherman, "Penning Surface-Plasma Source Scaling Laws – Theory and Practice," Proc. 6th Intl. Symposium on the Production and Neutralization of Negative Ion and Beams, Brookhaven National Laboratory, November 9-13, 1992 [to be published in the AIP Conf. Proc. series, 1993]. Also LA-UR-92-3664.
- [2] R. Heuer, J. Porter, I. Birnbaum, T. Schultiess, and J. Sredniawski, "Final Design of the 8X CW Negative Ion Source," Grumman Aerospace Corporation, Bethpage, NY, Report, 1991.
- [3] H. V. Smith, Jr., et al., "CW 8X Ion Source Development," in Ref. 1. Also LA-UR-92-4075.
- [4] C. Geisik, D. R. Schmitt, J. D. Schneider, and J. E. Stelzer, "Computer System for the High-Current Test Stand," Los Alamos National Laboratory report LA-CP-92-232.
- [5] R. B. McKenzie-Wilson, K. Prelec, and R. Hruda, IEEE Pub. No. 79CH1441-5 NPS, 225 (1979).
 [6] W. K. Dagenhart, C. C. Tsai, W. L. Stirling, P. M. Ryan,
- [6] W. K. Dagenhart, C. C. Tsai, W. L. Stirling, P. M. Ryan, D. E. Schechter, J. H. Whealton, and J. J. Donaghy, AIP Conf. Proc. No. 158, 366 (1987).
- [7] H. V. Smith, Jr., N. M. Schnurr, D. H. Whitaker, and K. E. Kalash, IEEE Catalog No. 87CH2387-9, 301 [1987].
- [8] Yu. I. Bel'chenko, G. I. Dimov, V. G. Dudnikov, and A. S. Kupriyanov, Revue Phys. Appl. 23, 1847 (1988).
- [9] H. V. Smith, Jr. and P. Allison, "Electron Suppression in the H⁻ Beam from a Penning Surface-Plasma Source," Rev. Sci. Instrum. 64, (June, 1993). Also LA-UR-92-3337.
- [10] W. B. Ingalls, Los Alamos National Laboratory, private communication.