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A SCALED, CIRCULAR-EMITTER PENNING SPS FOR INTENSE H^- BEAMS*

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ABSTRACT

The Los Alamos versions of the Penning Surface-Plasma Source (SPS) routinely generate H^- ion beams with pulsed currents over 100 mA. However, these sources employ geometries that result in the extraction of slit beams (0.5 x 10 mm^2). Our modeling with the SNOW code indicates that the beam from a 5.4-mm-diam circular emitter will have lower emittance and divergence for transport to and injection into our radio-frequency quadrupole (RFQ) accelerator. This paper describes a newly constructed Penning SPS that has most of its discharge chamber dimensions scaled up by a factor of 4 to accommodate this circular emitter.

INTRODUCTION

As part of an ongoing effort to study the acceleration of H^- ions in a RFQ accelerator[1], we studied[2,3] several H^- SPS sources and built an injector[4] incorporating a Penning SPS.[5] We find that after extracting, accelerating, and transporting the slit beam from the injector source to the emittance scanners (~30 cm total distance), coupling effects cause the transverse plane emittances to be nearly equal,[4] even though the initial transverse-plane-emittance ratios almost reflect the 0.05:1 ratio in slit dimensions. Using this finding, it is straightforward to show that use of a circular emitter having the same H^- emission current density and total current as the slit emitter results in a lower H^- beam emittance. For a slit emitter of area 4ab ($20a = b$) and total current I, the emission current density is $5I/b^2$. For the aperture emitter of area πR^2 and total current I, the emission current density is $I/\pi R^2 = 5I/b^2$, so $R = 0.25b$. Since the two-dimensional, normalized emittance ϵ_y is proportional to the emitter dimensions whether ion temperature or aberrations dominate the optics, a circular emitter is expected to produce a lower emittance H^- beam than the slit emitter.

Even if the 0.05:1 ratio in transverse beam emittance at extraction could be preserved in transporting the slit beam to the RFQ, coupling of the two transverse and the longitudinal plane emittances, mostly by space-charge effects in the RFQ, will cause the ratio of the transverse plane emittances to be nearly 1:1 at the RFQ exit[6]. Therefore, we built a new Penning SPS incorporating a circular emitter and a spherical extractor. See Ref. 7 for an account of our previous Penning SPS circular aperture work.

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SOURCE DESIGN

We used the SNOW code[8] to study the ion-extraction and beam-formation optics. The extraction system is designed to provide a total H^- current of 160 mA. The electrode design resulting from the SNOW calculations is shown in Fig. 1A. The emission aperture is 5.4-mm diam: the extraction electrode, 3.4-mm diam; the extraction gap, 4.7 mm; and the gap voltage, 29 kV. We succeeded in keeping the designed extraction gap electric field below 120 kV/cm. The emittance predicted by the SNOW code for the H^- beam at the exit of the extraction electrode ($z = 12.5$ mm in Fig. 1A.) is 0.009π cm•mrad. This number is derived in the following manner. A total of 670 rays were launched from the injection plane, located at $Z = 0$ in Fig.1A. The rays were given a distribution of angles with respect to the Z-axis appropriate for an H^- ion temperature of 4 eV, the average of our previous estimates for this parameter (3 eV in Ref. 4, 5 eV in Ref. 3). SNOW self-consistently calculated each ray through the extraction optics to the extractor exit. The distribution in phase space of the surviving 519 rays at $Z = 12.5$ mm is shown in Fig. 1B. The two-dimensional normalized rms emittance is calculated from this distribution according to the formula

$$\epsilon_{x,y}^{\text{aperture}} = (\beta\gamma/\sqrt{2}) \left[\overline{r^2}\;\overline{r'^2} - \overline{r r'}^{\,2} \right]^{1/2} , \qquad (1)$$

where β and γ are the usual relativistic parameters. If the H^- beam current fluctuates no more than $\pm$ 20% about the 160-mA design value, the SNOW code predicts the time-averaged emittance will increase by a factor of 1.9 because of variations in the phase-space orientation after extraction. Thus, it may be possible to keep $\epsilon_{x,y}$ below our previously recorded lowest value of 0.02π cm•mrad.[3,4] The SNOW calculations assume an injected ion energy of 100 eV to avoid nonuniform current density build-up, thereby probably underestimating the H^- beam emittance.

Since the SNOW design calls for an H^- emission density of 700 mA/cm^2 compared to our previously measured values of 2-3 A/cm^2, we decided to scale the source size up by a factor of 4 and reduce the plasma density and the H^- emission current density by a factor of 4 according to the law of similarity. This reduction of the plasma density results in a similar decrease in the cathode-power loading, thus allowing a substantial increase in the arc duty factor. The enlarged source, shown in Fig. 2, has a cathode-cathode gap of 17 mm, large enough to accommodate the emission aperture. We refer to this enlarged Penning SPS as the 4X source. A comparison of the source dimensions and anticipated operating parameters of the 4X source with the values for 100 keV injector source is given in Table I.

Unlike the 100-keV injector source whose arc magnetic field is driven by a permanent magnet circuit, the 4X source magnet circuit is driven by an electromagnet coil, allowing the arc magnetic field to be varied. The lower arc field, coupled with the higher gap voltage, results in a bend angle of 4.6° for the 4X source, compared to 8.1° for the injector source. The low bend angle will allow the 4X source to be close-coupled to the 100-keV injector column as is the present injector source, shown in Fig. 7 of Ref. 4.

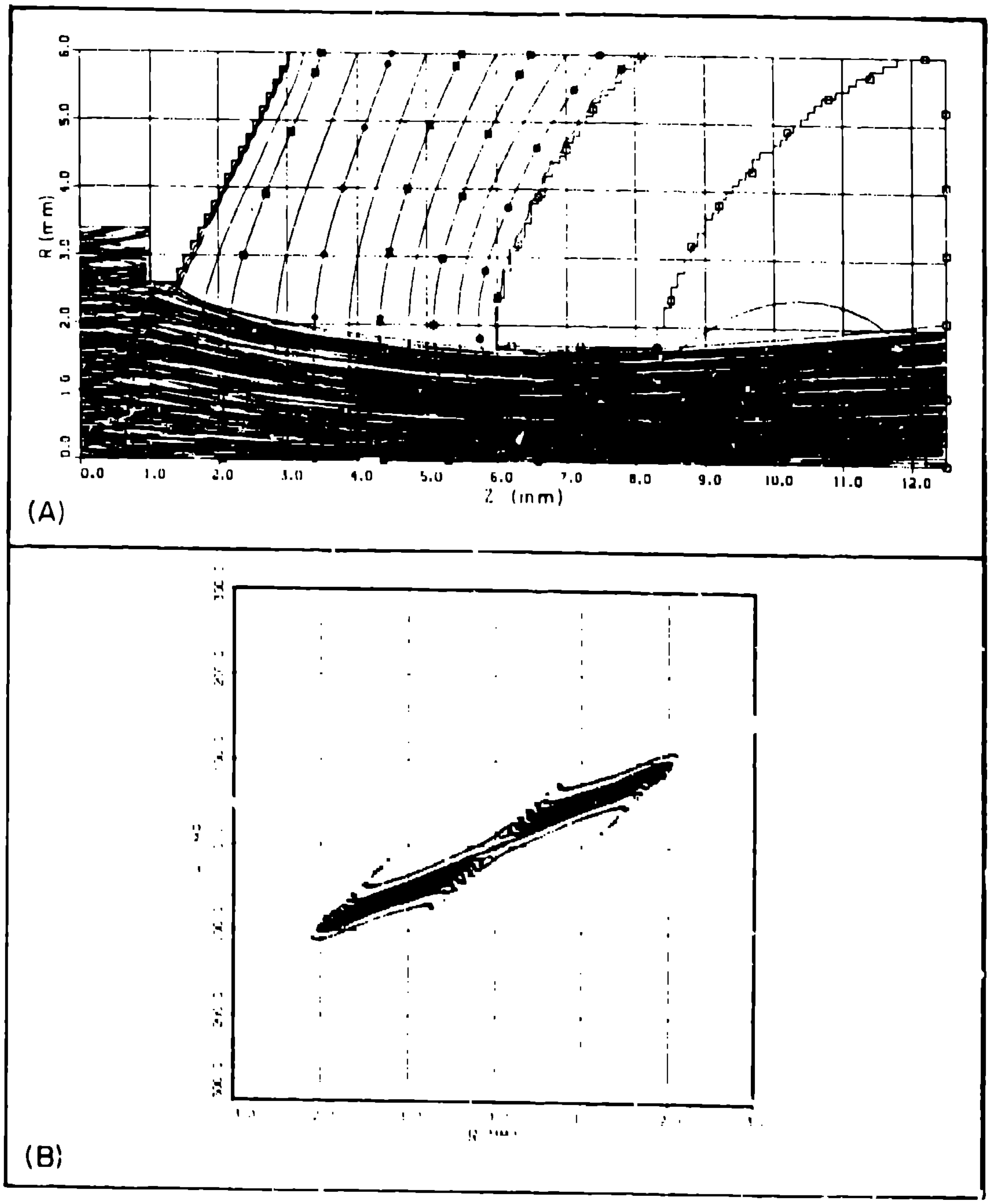

Fig. 1. (A) SNOW-code calculation of the H^- ion trajectories for the 4X source extraction optics; (B) Phase-space diagram at Z = 12.5 mm calculated by the SNOW code.

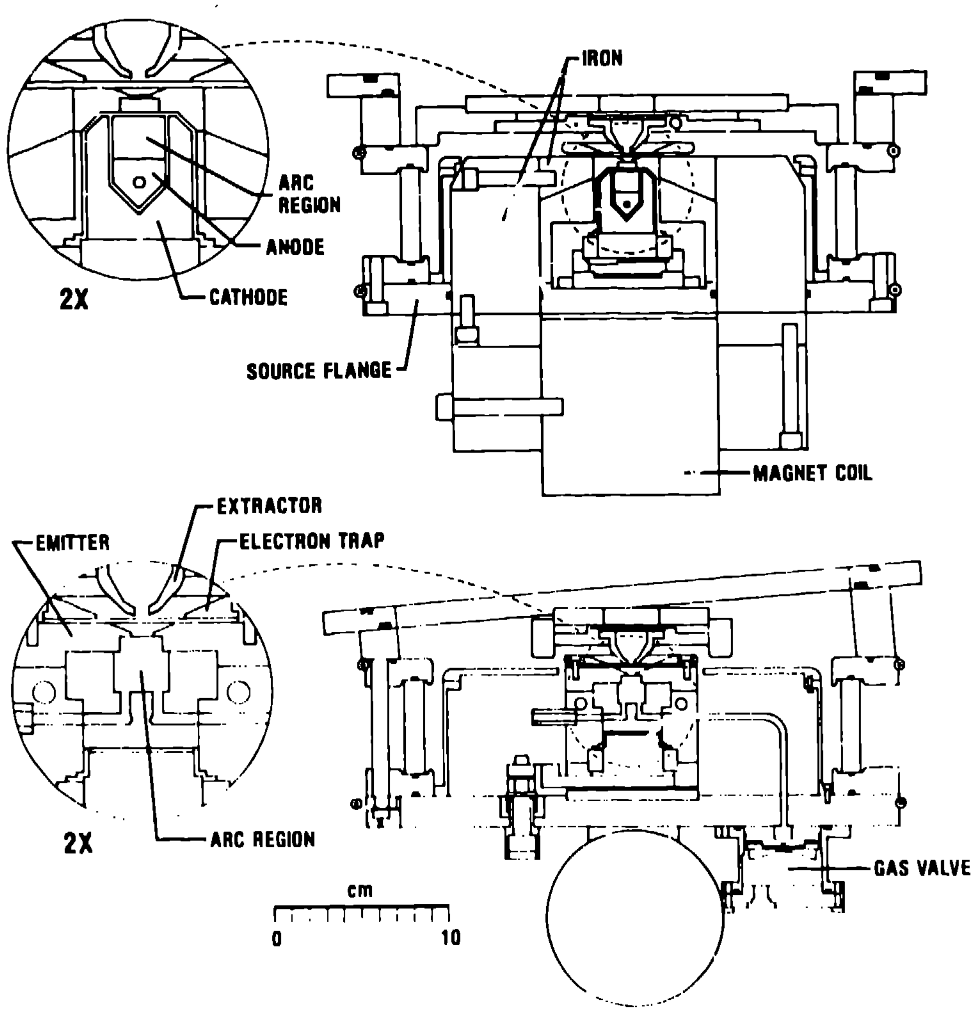

Fig. 2. The 4X scaled source. Top view: arc magnetic field in the plane of the paper; lower view: arc magnetic field direction (x) out of the paper. At the left are 2X blowups of the arc region.

SOURCE STATUS

A photograph of the assembled 4X source is shown in Fig. 3. We will study the arc discharge, H^- beam extraction, and discharge oscillations, as well as the H^- beam emittance. The enlarged arc volume may allow some discharge plasma measurements. We also plan to study the electron loading of the extraction electrode and ways to control and/or alleviate this problem.

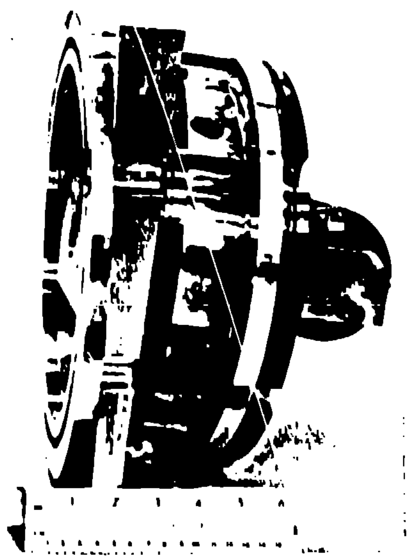

Fig. 3. The 4X source.

Table I. Comparison of 4X Source with 100-keV Injector Source

DIMENSION/PARAMETER	4X SOURCE	100-keV INJECTOR SOURCE[a]
Cathode-cathode gap, mm	17	4.3
Arc slot width, mm	12	3
Arc slot length, mm	16	12
Arc magnetic field, T	0.05[b]	0.22
Emitter dimensions, mm	5.4 diam	0.5 x 10
Extraction gap, mm	4.7	2.5
Extraction voltage, kV	29	22
Arc voltage, V	100	100
Arc current, A	210	180
H^- current, mA	160	160
Cathode power load, kW/cm^2	1.5-4	7-16
Duty factor, %	∿5	0.5

a) Ref. 4.
b) 0.14 T if magnetic field suppresses electrons in extraction gap.

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