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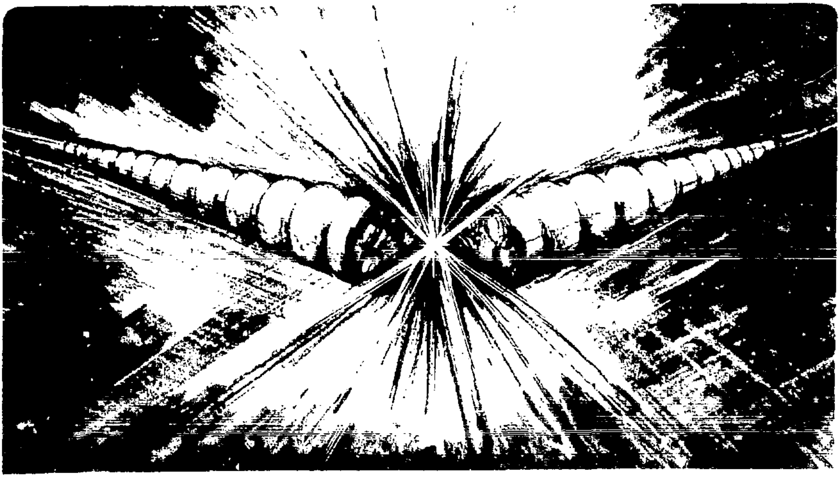

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Steady-State Gas Efficiency of Ion Sources For Neutral Beams*

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Gas present in the acceleration grids of a neutral beam line is one cause of divergent beam power. A measure of this problem is the gas efficiency (nuclear) of the ion source,

$$\varepsilon_g = I_b / I_g , \tag{1}$$

where I_b denotes the extracted current of beam nuclei, and I_g the total current of nuclei to the source as gas. For a short pulse beam, $\lesssim 0.1$ sec, gas transients make ε_g difficult to observe. Using the fractional size Berkeley LPA[1] (nominally 120 keV, 10A), the gas efficiency of a positive ion, hydrogen neutral beam has been studied with pulses from 0.5 to 28 sec at 80 keV, 5.7 A, and 0.5 sec at 120 keV, 10A. The observed gas efficiency, 20% - 40%, is shown to agree with a simple steady state model. The model indicates that gas efficiency is determined by the degree of arc ionization. Efficiencies greater than 30% were obtained by stepping the arc power during beam turn-on.

A standard field-free ion source[2] was used, with species[3] of H_1: H_2: H_3 in an approximate ratio of 60: 25: 15. The normal operating procedure is to adjust the arc power to obtain the desired accel current, at a given gas flow. The usual timing sequence is: gas-on; arc-on; beam-on. From

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Fig. 1a, at 80 keV, 5.7 A and 3.7 Tℓ/s, accel current was nearly constant. In this way, the beam was run for as long as 28 sec. Gas efficiency corresponds to, $\epsilon_g = 5.7*(1*0.6 + 2*0.25 + 3*0.15)/(3.7*5.6*2) = 22\%$, where 1 Tℓ/s = 5.6 A. From Fig. 1b, at 3.0 Tℓ/s, a 2.4 A sag in 0.1 sec is apparent in the accel turn-on. The accel current stabilized at 5.7 A, or, $\epsilon_g = 27\%$. At 2.7 Tℓ/s, no fixed arc power was found which allowed both turn-on and continued operation. A typical shot is shown in Fig. 1c. After turn-on, the accel sagged to 5.4 A, or $\epsilon_g = 29\%$, but the shot was terminated by the protection logic after 0.1 sec.

The cause of the accel current sag after beam turn-on was inferred to be a reduction in arc neutral density (and, therefore, in plasma density) due to beam pumping. With fixed arc power, raised to produce the desired accel current after turn-on, the beam turn-on is over-dense until the arc gas density falls. To compensate for this change in gas density, a technique has been developed to "step" the arc power by phasing-back the electronic contactor of the arc power supply. The arc is brought on at 5% - 10% reduced power. At beam-on, the degree of phase back is reduced, which increases the arc power, maintaining a constant plasma density and accel current. Since the arc power supply has an inherent time constant of ~0.03 sec, a reasonable match to the accel sag (~0.1 sec) was possible. By adjusting the degree of phase-back, the LPA was run up to design voltage for the first time. A significant improvement in gas efficiency was also found to be possible, e.g., from Fig. 1d, at 120 keV, 9.9 A, and 3.3 Tℓ/s, $\epsilon_g = 42\%$.

A steady state model for source gas efficiency can be obtained from particle balance,

$$I_g = I_b + (I_o)_{grid}, \qquad (2)$$

where all ions passing through the grid are counted as beam and $(I_o)_{grid}$ denotes the neutral current lost through the grids. Ion losses are written,

$$I_i = A_g\ t_i\ e\ n_i v_i, \tag{3}$$

where A_g denotes the area of the grid, t_i the transparency to ions, n_i the ion density and v_i the mean speed. Neutral losses are written,

$$(I_o)_{grid} = A_g t_o\ e \left[(n_o v_o/4)_{at} + (n_o \overline{v}_o/4)_{mol} \right], \tag{4}$$

where t_o denotes the neutral transparency, and $(n_o v_o/4)$ the atomic and molecular thermal fluxes. The neutral species mix in the source is unmeasured, but an estimate of half atomic and half molecular has been found to give good agreement with ion species in source model calculations.[4] If the atomic temperature[3] is taken to be ~0.3 eV, the molecular temperature, 0.1 eV, and the mean ion energy is assumed to be approximately the electron temperature,[5] ~5 eV, (4) gives,

$$\varepsilon_g \approx (1 + 0.043\ \frac{t_o}{t_i}\frac{n_o}{n_i}\ )^{-1}. \tag{5}$$

This suggests that, given grid transparencies, gas efficiency is determined by the degree of source ionization, n_i/n_o. For Berkeley grids (slots), ion and neutral transparencies are 0.6 and 0.3, respectively.[6] Without stepping, the arc is ~1% ionized,[5] from Eq. (6), this would give ε_g=30%, in agreement with the experiment results.

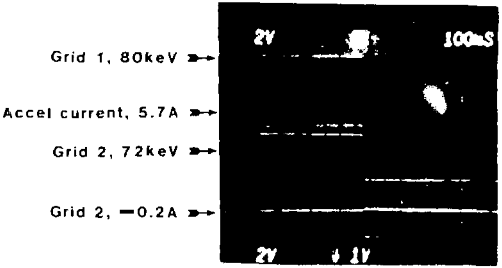

Fig. 1a. Gas efficiency, 22%.

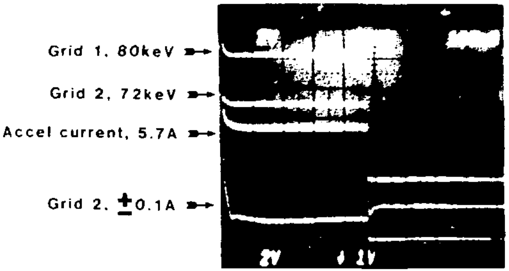

Fig. 1b. Gas efficiency, 27%.

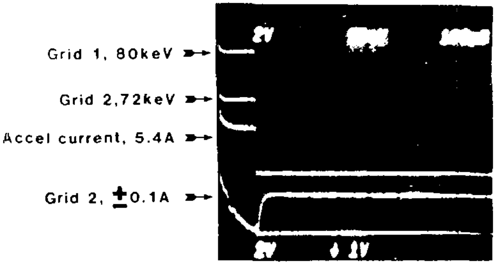

Fig.1c. Gas efficiency, 29%.

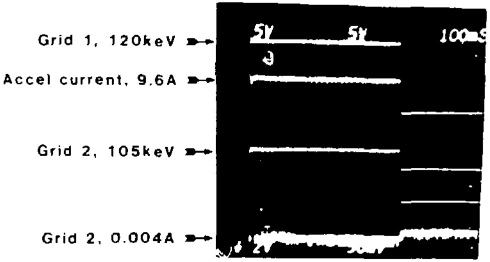

Fig. 1d. Gas efficiency, 42%.

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Figure Captions

Fig. 1 Scope traces are shown for 0.5 sec beam to illustrate the effect of gas flow on accel current: (1a) 80 keV, 5.7 A, 3.7 Tℓ/s, $\epsilon_g = 22\%$; (1b) 80 keV, 5.7 A, 3.0 Tℓ/s, $\epsilon_g = 27\%$; (1c) 80 keV, 5.4, 2.7 Tℓ/s, would not run at fixed arc power; (1d) 120 keV, 9.9 A, 3.3 Tℓ/s, $\epsilon_g = 42\%$, with arc stepping.

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