2.3 *Ion Source for an RF-Accelerator Based HEDP Experiment*

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The primary goal for the ion source is to deliver a Ne^{1+} beam of 8 A current through 16 parallel channels to the main rf accelerator at 2 MeV energy, with a pulse length of 200 ns. The ion optical aspects of this problem had been discussed in depth in Ref. [1], leading to three basic formulae for the maximum beam current I_1 fully transported in one channel with 20 mrad divergence half-angle in the waist; extraction gap width d as a function of gap voltage; and un-normalized, encompassing r/r' emittance ε_r . Note that the formulae given here have already been converted to directly apply to Ne^{1+} beams. Further, it is common experience that for a pulse duration of about 200 ns, the extraction gap width can be significantly reduced as compared to the d. c. case, and the fairly conservative reduction factor already incorporated into to Eq. (2) amounts to 0.7.

$$I_1 = 0.4243\ S^2/(1+1.7\ S^2)\ U^{1.5} \quad [\ mA/kV^{1.5}\ ] \tag{1}$$

with S = R/d being the aspect ratio of the extraction gap with an outlet aperture radius R

$$d = 0.009898\ U^{1.5} \quad [mm\ /\ kV^{1.5}\ ] \tag{2}$$

$$\varepsilon_r = 10\ r \quad [\ \pi\ \ mrad\ ] \tag{3}$$

For Ne^{1+}, the normalized 1-rms x/x' emittance is calculated from a given value of ε_r by:

$$\varepsilon_{x,,\ norm} = 0.125\ \varepsilon_r\ \ \beta_{rel} \tag{4}$$

$$\text{with } \beta_{rel} = 0.00146\ (U/20)^{0.5} \quad [\ kV^{-0.5}\ ] \tag{5}$$

While direct, single gap, extraction of a neon beam at a voltage of 2 MV would in principle lead to the required single-channel beam current of 500 mA, the price to pay lies in having to deal with the exorbitantly large outlet-aperture radius of 106 mm (even with a rather low aspect ratio of 0.12). It would be rather challenging to uniformly fill such a large aperture with plasma in a very short pulse time, and likewise to control the gas load in the MV-type extraction column, and the starting emittance for this beam would be very high as well.

A more practical way consists in inserting an intermediate extractor electrode into the 2-MV gap and utilizing a 7-aperture extraction system for each of the 16 beam channels. For 100 kV primary extraction voltage and an aspect ratio S = 0.5, each beamlet now carries 74.4 mA of current according to Eq. 1, and the aperture radius is reduced to 4.95 mm. The effective configuration radius R_7 for this 7-aperture system relevant for calculating the starting emittance is three times larger than that of a single hole, assuming half a radius as material thickness between inner and out hole and another half aperture radius for the outer envelope of the outer beamlet near its waist:

$$R_7 = 3\ R_1 = 14.85\ mm \tag{6}$$

With an initial divergence half-angle of 20 mrad, this leads to an un-normalized r/r' emittance of 297 π mm mrad and a normalized 1-rms x/x' emittance of

$$\varepsilon_{7,n} = 0.121\ \pi \text{ mm mrad} \quad (7)$$

The current density necessary to yield 74.4 mA of beamlet current is 96.7 mA/cm^2, well in range for many filament-sustained plasma discharges. The arrangement of the 16 beam channels is entirely dictated by the needs of the subsequent rf accelerator structure; a schematic layout is given in Fig. 1. In case a single-channel accelerator structure with attached stacking ring is chosen, the configuration is reduced to just of one of these beam channels.

The extension of the 100-kV multi-aperture extraction system to a full-energy 2-MV accelerating column is straightforward, and there is ample space available to insert more intermediate electrodes of suitable shapes to divide the column into manageable segments, each about 100 mm long, and achieve matching input beam-parameters for injection into the rf accelerator. The detailed electrode contours have still to be designed; several simulation codes are available for this task.

For the plasma generator, a large discharge chamber is chosen, lined with permanent cusp magnets, see Fig. 2. A pulsed gas valve feeds neon into the chamber from the backside, and a diverter speeds up the establishment of uniform pressure across the chamber. 8 thermionic filaments (Ta or W) are inserted into the chamber backside and operated in d. c. mode to best avoid the effects of temperature shocks. A low-power pre-ionization discharge of about 5 μs duration is ignited to facilitate a fast rise time of the main discharge pulse that will have a duration of about 250 ns to offer a sufficiently long flat-top time for beam-pulse generation. With the extremely low duty factors involved, the design of cooling channels is straightforward.

Beams are extracted from the discharge chamber by applying high-voltage pulses to the 100-kV extraction gap as well as to the main 1.9-MV injection column; the circuitry needed to generate these pulses has still to be designed.

Reference

[1] R. Keller, 'Ion Extraction,' in I. G. Brown, ed., "The Physics and Technology of Ion Sources," John Wiley & Sons, New York, 1st edition, pp. 42 - 43 (1989)

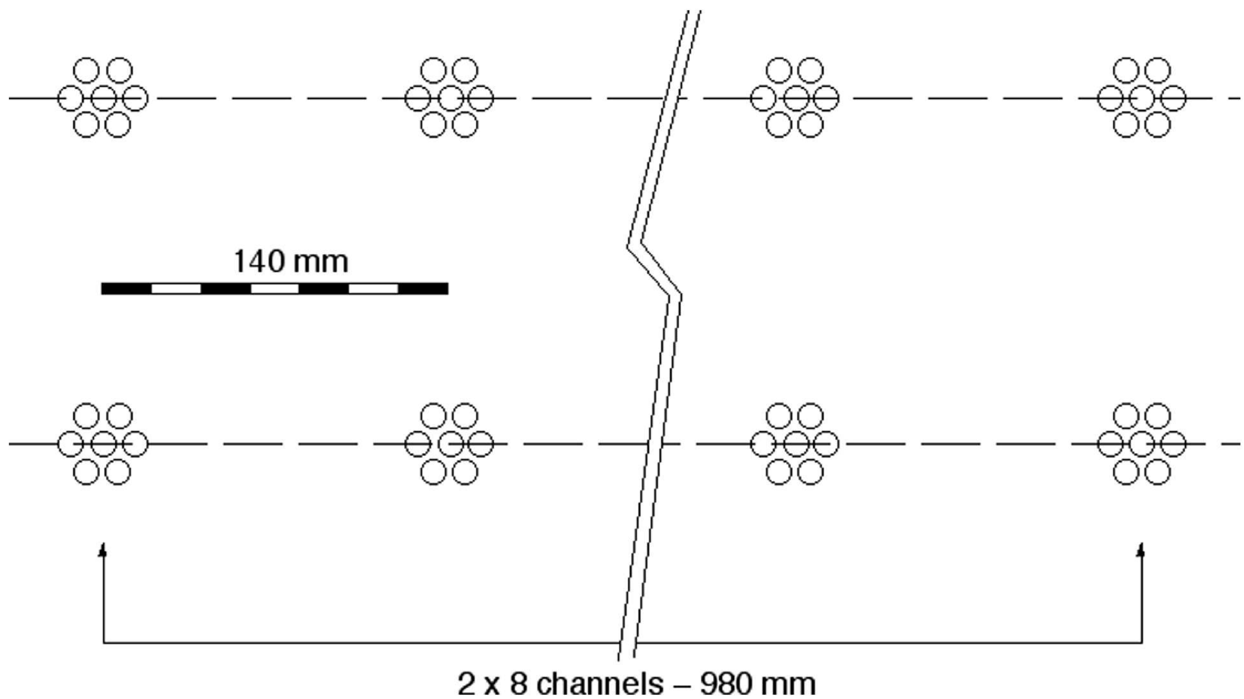

Fig. 1. Beam Channel Pattern for RF Linac Scenario

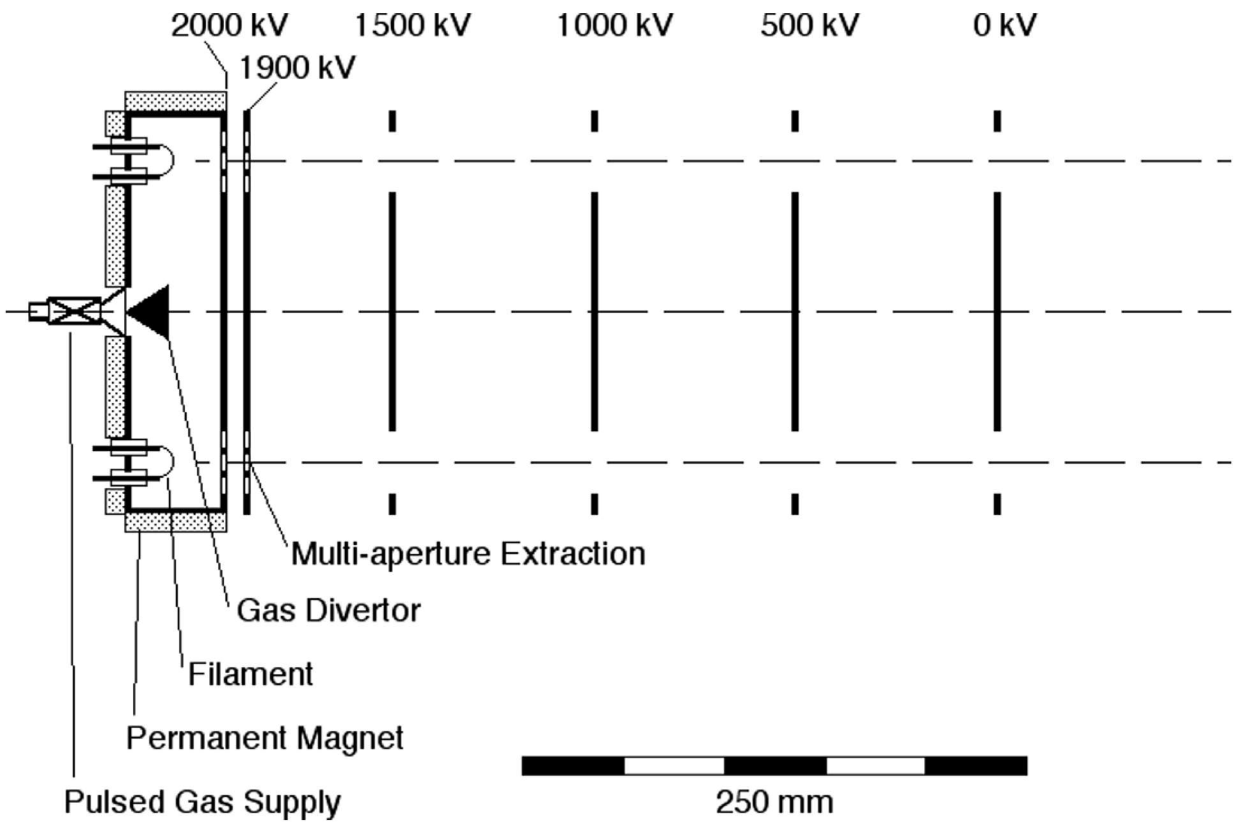

Fig. 2. Schematic of a multi-cusp ion source with multi-aperture, multi-gap extraction system. There is a total of 112 beamlets, grouped into 2x8 channels of 7 beamlets, each. The illustration shows a section of the narrow side view, with two beam channels.