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EXTRACTION SYSTEM DESIGN FOR A 50A, 50 keV, 2 SEC ION BEAM

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Abstract

Injection units for PLT, Doublet III and ORMAK II will require total single pulse energies well in excess of those of existing injection systems. The energy handling capability of the extraction system will be a critical element around which injection unit design decisions must be made. The final design goal for these units is 50A, 50 keV, and 2 sec pulses.

The basic ORMAK injection unit was operated at 40 keV, 6A, 0.3 sec and a 15% duty cycle, while monitoring power loading to the various extraction system electrodes, in order to pinpoint the critical power loading areas. A 40A scaleup of this ORMAK unit is being built.

Thermal time constants for these water-cooled extraction electrodes are about 0.5 sec. Going from 0.3 to 2 sec will therefore increase the power loading. An increase in beam energy above 40 keV will also increase the loading. ORMAK unit data indicate that the ground electrode and the plasma-forming electrode have relatively high power loadings. For the 40 keV, 6A operation these were 400 watts per cm^2 of Cu extraction surface and 200 watts per cm^2 respectively. The extraction electrode loading was relatively small, 40 watts per cm^2.

These loadings and their variation with system parameters indicate that the ground electrode loading is due to direct interception, extraction electrode loading is due to ions formed by beam-gas interactions in the gap, and plasma-electrode loading is due principally to secondary electrons from the extraction electrode. Ground electrode loadings will be reduced as a result of studies including single beamlet optics,

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Meeting the PLT goal then involves getting from 6A to 40A and will be done by a size scaleup. As a first step, the 6A source was scaled up from a 7 cm diam extraction system to a 10 cm diam extraction system.[2] This unit has been operating on a test stand at 25-35 kV, 8-10A, 100 msec and a 10% duty cycle. Further scaleups in size are planned.

The 0.3 sec and 15% duty cycle capabilities were the result of two design philosophies: energy efficiency in the source and water cooled extraction systems. Meeting the ORMAK II goal involves getting from 0.3 sec to 2 sec as well as current increases. Getting to 2 sec requires that the energy handling capability of the extraction system be the critical element around which design decisions must be made.

Extraction System Design

The accel-decel extraction system for the 6A ORMAK unit consists of three, 1.6 mm thick, 7 cm diam, copper disks. Each has 209 holes of 3.8 mm diameter which are carefully aligned for beam extraction. The hole pattern is split into 3 sections by two water lines. Additional water lines go around the periphery

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*Operated by Union Carbide Corp. for USAEC.

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Ground Electrode Loading

Figure 2 shows the calorimetrically measured power loading of the various electrodes, and also total extracted power and ion

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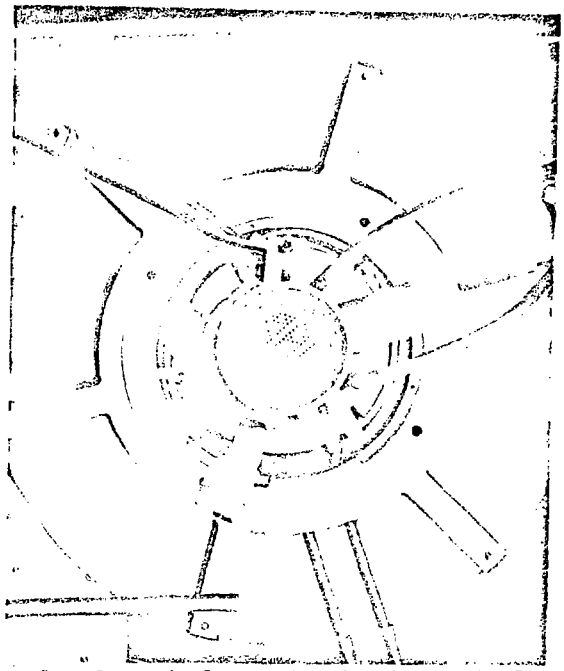

Fig. 1. Ground Electrode with Water Cooling.

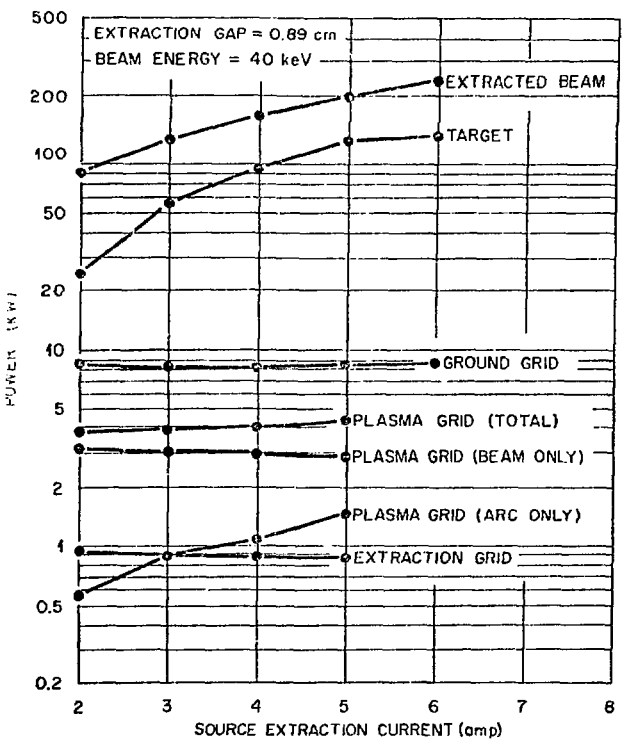

Fig. 2. Grid Loading, Extracted Beam and Target Powers vs Source Extraction Current.

beam power delivered through a simulated ORMAK beam line, as a function of extracted current at 40 kV, 0.3 sec and a 15% duty cycle. The ground electrode receives the most loading, 9 kW or 400 watts per cm^2, and this is due to direct interception. It is expected that this loading will be reduced by studying single beamlet optics, both experimentally and with computer simulation. Electrode thickness and gap variations and hole size and shape variations are planned. It should be noted that aperture displacement beam focusing, such as used with the ORMAK units,[1] can increase direct interception by the ground electrode. Consideration of the converging beamlet trajectories and placement of the individual ground electrode holes accordingly was found to reduce ground electrode loading by a factor of two.

Loading of Plasma Forming and Extraction Electrodes

Plasma-forming electrode loading, at 200 watts per cm^2, is composed of about 25% loading from the plasma and about 75% loading due to the presence of the beam. The latter comes from beam-gas interactions in the extraction gap. Extracted ions ionize and charge-exchange with the background gas, creating cold ions and electrons in the gap. The electrons are accelerated back towards the source and some fraction of them are intercepted by the plasma electrode causing power loading. The ions are accelerated towards the extraction electrode and some fraction of them are intercepted, causing the 40 watts per cm^2 loading indicated in Fig. 2 and also generating secondary electrons. These secondaries are accelerated back towards the source where about one-third are intercepted and cause the remainder of the beam-generated loading of this electrode.

This model predicts a loading of the plasma electrode due to the beam which is:

$$P = C(\bar{\gamma} + 0.5)\, V\, j\, z\, \bar{\sigma}\, \rho$$

where $\bar{\gamma}$ is the secondary emission coefficient for the extraction electrode and is averaged over the incident ion energies, V is the potential difference of the extraction gap, j is the extracted beam current density, z is the extraction gap length, $\bar{\sigma}$ is the sum of the ionization and charge exchange cross sections averaged over the ion energies of the gap, ρ is the background gas density and C is a geometry factor, < 1, to account for the fractions of ions and electrons which pass through the apertures without striking the electrodes.

This loading can then be reduced by decreasing $\bar{\gamma}$. Electrode materials other than copper or electrode coatings should change $\bar{\gamma}$, but little data are available for V > 20 keV. Comparing the plasma electrode loading with the extraction electrode loading for the copper electrodes of Fig. 2 indicates $\bar{\gamma} \sim 3$ for V = 40 keV. A tungsten coating on the extraction electrode was found to affect the loading very little. The available data

suggest that $\bar{\gamma}$ for tungsten is not very different from that of copper. A gold coating was tried and initial indications were that the plasma electrode loadings were reduced. It was found that these coatings had a short lifetime in that they quickly became coated with copper from the source and the rest of the extraction system. In future experiments, coatings will need to be applied to all metal surfaces which can supply sputtered atoms.

Secondary emission loading can possibly also be reduced by using suppression electrodes such as those of Hamilton, et al.[3] This will be studied with computer simulation and with single-aperture experiments.

Looking at other factors in the power loading of Eq. 1, it can be seen that both V and z can be reduced by splitting the acceleration up into stages. Combining Eq. 1 with the Child-Langmuir law gives:

$$P \propto N^{-7/4},$$

where N is the number of acceleration stages. Increasing the number of stages then effectively divides the power loading up among the stages. This gain may be offset by the increased complexity of the system and by detrimental effects such as poorer optics and increased direct interception. Multi-stage systems may be useful for > 50 kV systems and will be studied experimentally with single aperture and full systems and with computer simulation.

The power loading of Eq. 1 also varies with j. We have found with our duoPIGatron ion sources that the cold gas flux from the source, and therefore ρ is approximately proportional to j.[2] Combining this with the Child-Langmuir law then gives:

$$P \propto j^{3/2},$$

indicating that P can be reduced by decreasing j, while keeping the total current up by going to larger area ion sources. This is made feasible by the success of displaced aperture focusing.

The direct dependence of P on ρ can be exploited by some combination of pumping on the extraction system, separating the source and the gas cell, or pumping on the duoPIGatron source in the region next to the extraction system. Source pumping is being done and appears to have additional advantages.[2]

It may be possible to affect the geometry constant C of Eq. 1. This means somehow making larger fractions of the gap-generated ions and electrons pass through the apertures rather than striking them. This will be investigated with computer simulation and with single-aperture experiments. Comparing the plasma electrode loading of Fig. 2 with the decel supply loading indicates that approximately one-third of the power is incident on the plasma electrode structure with the remainder passing on through into the ion source. source.

Attaining 2 Second Operation

With 300 msec pulses and a 15% duty cycle, unoptimized operation gave ground electrode power loadings of about twice that shown in Fig. 2, 800 W per cm^2, and minor distortion appeared on the aperture pattern. A calculation of the thermal time constant[4] for this electrode system gives a value of about 0.5 sec. Optimized operation of this system as illustrated by Fig. 2 is then at $\sim$ 3/5 of a thermal time constant and at about half the power loading required for damage. This type of operation then should give essentially DC operation. This premise will be tested, at least to the extent that power supply capability will allow. The 10 cm diam scaled-up extraction system has a more conservative cooling design with a calculated time constant of $\sim$ 0.25 sec. Power loading tests on this system are in progress. Tests at the eventual goal of 2 sec must await power supply delivery.

A design for a 50 kV, 50A, essentially DC unit can be put forth based on all of the above information. The unit should be a direct scaleup of the 6A ORMAK unit with the more conservative cooling system for $\sim$ 0.25 sec thermal time constant. The extraction system diameter then would be $\sim$ 21 cm. Geometry perturbation studies and optics studies will yield methods of reducing ground electrode loading. These methods should be applied for a conservative design, although not necessary. Reducing the plasma-forming electrode loading, by pumping, area expansion, coatings and materials, extra electrodes, etc., could be done as a contingency and for > 50 keV systems, but should not be necessary for this unit.

Conclusion

Higher energy neutral injection units require the development of extraction systems capable of handling more energy. ORMAK injection unit test data indicate the critical power loading regions to be the ground electrode and the plasma-forming electrode. Combining this data with models for the power loading indicates many potential methods of reducing power loading or of better handling of existing loading. Experimental data

relating to some of these methods were discussed. A design for a 50 keV, 50A, essentially DC system, based on the data and the model for the power loading, was presented.

References

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