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TESTS OF THE INTENSE NEUTRON SOURCE (INS) PROTOTYPE*

D. D. Armstrong, C. R. Emigh, J. C. Hyde, E. A. Meyer, J. D. Schneider
Los Alamos Scientific Laboratory, Los Alamos, NM 87545

Abstract

A prototype of the INS accelerator system was constructed to produce an intense dc beam of protons at energies up to 200 keV. Using a Pierce geometry accelerating system, a 250-mA dc beam of hydrogen ions was extracted at an energy of 125 keV from an annular duoplasmatron. Of this beam, 100 mA of H^+ ions were transported into a 1-cm-diam supersonic jet target, with backstreaming gas minimized by differential pumping. Both the jet target and the differential pumping system functioned satisfactorily. No substantial increase in backstreaming of the nitrogen jet gas occurred for a beam power equivalent to 150 kW of tritons onto deuterium.

Introduction

The INS prototype was a full scale model of most of the major subsystems of the INS accelerator and target system: 1.1-A ion source, accelerating column, differential pumping system, and supersonic jet target. The prototype was designed to ultimately produce and transport a 1-A dc beam of 200-keV protons into a jet target of 1-cm diameter. After the first year of development a 100-mA dc beam of 125-keV protons was transported through the target aperture.

The prototype was tested using a nitrogen gas target because only 7 kW of beam power into the nitrogen jet would yield nearly identical hydrodynamic conditions as would have resulted from the deposition of 300 kW into a deuterium jet using a 1-A, 300-keV triton beam. The performance of the jet target with 3.5 kW of beam power deposited, as well as the performance of the other subsystems, is summarized below.

Prototype Configuration

The high voltage to the test stand was provided by a 200 kV, 2 A power supply, with a 2-μF (40-kJ) output filter capacitor. Sparkdown protection was provided by a 1-kΩ series resistor and a triggered spark-gap crowbar with an 8-μs discharge time.

The duoplasmatron ion source and a six-electrode accelerating column were mounted inside a 2-m-long by 2-m-diam vacuum tank, as shown in Fig. 1. Power for the ion source came through the high voltage feedthru from an isolated-equipment-dome/isolation transformer combination. This 200-kV feedthru was graded by the adjacent corona tube.

The beam transport system consisted of an electron trap and three focus solenoids with electrical centers located 10, 48, 238, and 368 cm from the ground electrode of the accelerating column. The electron trap is depicted in Fig. 2. The solenoids were 36.8-cm long with a 12.7-cm-diam aperture with fields ranging from 3-6 kG.

The supersonic jet was designed to produce a nitrogen gas target 1 cm in diameter with a density sufficient to stop the beam in 1 cm. The large amount of heat deposited in the jet by the beam would then be carried away by the supersonic gas flow in the jet. The beam and the jet gas flow were coaxial and codirectional. During the tests the plenum pressure for the jet target was varied between 400 to 600 psi. The heated nitrogen gas was exhausted to the atmosphere.

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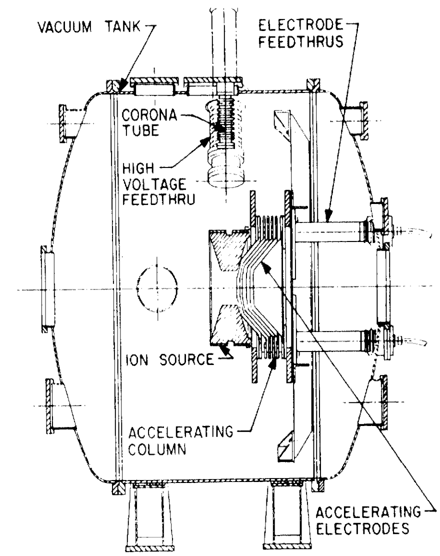

Fig. 1. Prototype 200-kV accelerator showing accelerating column, ion source, and high-voltage feedthrus in vacuum tank.

Ion Source

The annular-ion-source design was based on a concept described by Becherer et al.[1] An operating-lifetime requirement of ~2000 hours indicated the need for a large-area well-cooled ion source. Early bench tests on this source showed that lifetimes greater than 700 hours could be achieved with an oxide-coated nickel-gauze filament. A dc beam of more than 2.5 A of positive-ion current was produced with a hydrogen gas flow of 0.65 torr l/s. Langmuir-probe data showed an apparent electron temperature of about 4 eV.

The rather unique structure of the annular duoplasmatron led to serious fabrication problems. To simplify assembled parts, machined parts of steel and copper were electron-beam welded together. The presence of voids in the copper eventually caused an intermittent water leak into the arc chamber. This leak was the limiting factor in preventing the continued upward scaling of total extracted ion currents.

Ion-species-ratio measurements indicated that the H^+ ion current normally accounted for 70-85% of the total beam current. Transport of a high percentage of ion current into the jet target was limited by an apparent high emittance. The source of this high emittance was never identified, but it is suspected that the radial-arc geometry of the ion source was largely responsible, contributing as much as 20 eV of transverse energy to the ion motion.

Accelerating Column

The accelerating column (Fig. 2) consisted of six titanium accelerating electrodes held by a voltage-graded support box that also provided cantilever support for the 340-kgm ion source. At 200-kV operating voltage, a 10-mA voltage divider provided voltages

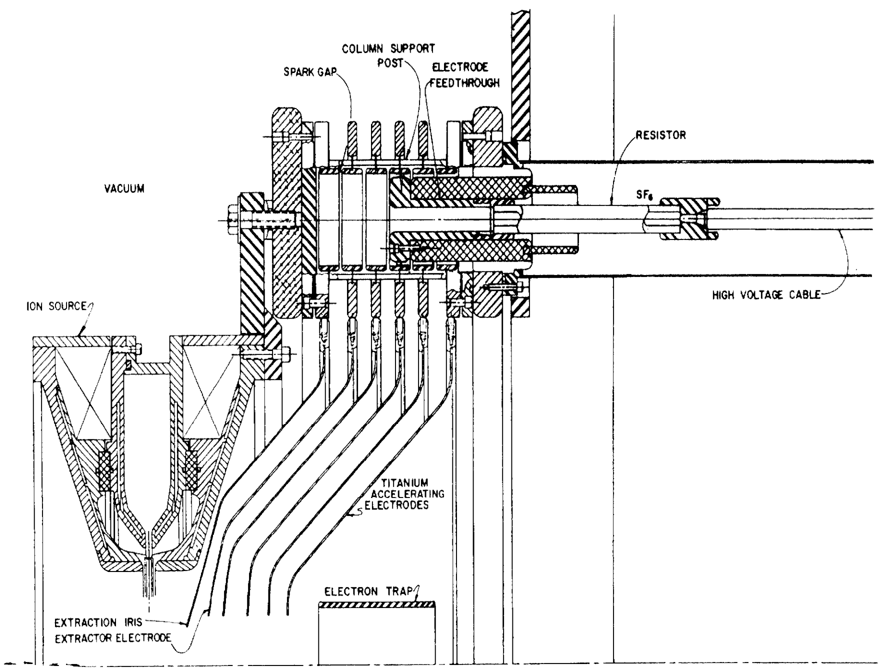

Fig. 2. Accelerating column and ion source.

of 50, 100, and 150 kV to the titanium electrodes through the center of three of the box support posts. The extractor electrode obtained a nominal 175-kV potential through the fourth post from a negative 0 to 30-kV power supply in the 200-kV equipment dome.

The electrodes were Pierce design with beam diameter determined by a 6.35-cm-ID extraction iris at the ion source and a water-cooled 8-cm-ID annular ring attached to the exit electrode. The electron trap was biased at -2.5 kV to reduce electron backstreaming.

Accelerator Vacuum System

The accelerator vacuum system utilized a 41-cm 10 000-l/s oil diffusion pump using polyphenyl ether fluid. A 41-cm refrigerated valve/trap was mounted directly over the pump. Diffusion pump backing and tank rough down were handled by a blower and mechanical pump. There were no high-voltage breakdown problems caused by backstreaming diffusion pump fluid. Furthermore, no polymerization of the fluid was observed from pumping the atomic-hydrogen-species as is usually observed from atomic beam source dissociators.

Differential Pumping System

The differential pumping system, shown in Fig. 3, was used for efficient pumping of the gas that flowed back from the gas target into the evacuated beam line. To minimize beam scattering, the pressure must be kept as low as possible right up to the gas target. This was accomplished by use of 1800-l/s Roots blowers on Stages 1 and 2, a 9000-l/s turbomolecular pump on Stage 3, and a 18 000-l/s oil diffusion pump on Stage 4. Further enhancement was obtained by the aspirating action of the coaxial jet and by use of a skimmer in Stage 1.

The aperture sizes and their locations are shown in Fig. 3. Table I lists the beam-line pressure at each stage and the corresponding backflow rate of nitrogen from the jet target with the beam both on and off.

Beam Transport

Empirically a beam of hydrogen ions of optimum quality was produced when 250 mA of 125-keV ions were extracted from the ion source plasma cup while using a 6.35-cm-diam extraction iris. For these conditions the column was operating at 60% of the Pierce-design current. This behavior of the column was later corroborated by using the computer program SNOW,[2] which was used to model and study the extraction dynamics.

The beam profile in the critical region of the differential pumping system and jet target is shown in Fig. 3. For this pumping-system geometry and with no gas flow in the jet, 100 mA of 125-keV protons were transported into the jet, which corresponded to 95% of the proton beam measured in Cup 1.

Comparisons of beam profiles, measured and calculated, indicated a nearly complete space-charge neutralization except for the electron-trap region where it averaged 80%.

Little power (~3.5 kW) was delivered into the flowing nitrogen gas jet because nearly 70% of the proton beam was converted to neutrals in the last solenoid. Using hydrogen rather than nitrogen gas would reduce the charge-exchange cross section by a factor of ten.

The beam ionized the residual gas in the transport system forming a mini-plasma. This conducting plasma rendered electrical measurements of beam losses meaningless; calorimetric measurements were required.

Jet Target

The jet tests were designed to study the beam-heating effect of the jet gas flow on the gas backstreaming from the jet into the beam transport system. Theoretical considerations indicate that breakdown of the jet flow occurs for an f factor approaching unity. (The f factor is defined to be the ratio of the heat deposited in the jet to the kinetic

TABLE I

BEAM LINE PRESSURES WITH NITROGEN JET WITH BEAM ON AND OFF
BEAM POWER = 3.5 kW

Beam	Jet Plenum Pressure (psi)	Backflow through Jet (torr l/s)	Pressure in Stage 1 (torr)	2 (torr)	3 (torr)	4 (torr)
Off	600	172	0.36	0.03	4.2×10^{-3}	7.8×10^{-5}
On	600	202	0.45	0.04	4.1×10^{-3}	7.5×10^{-5}

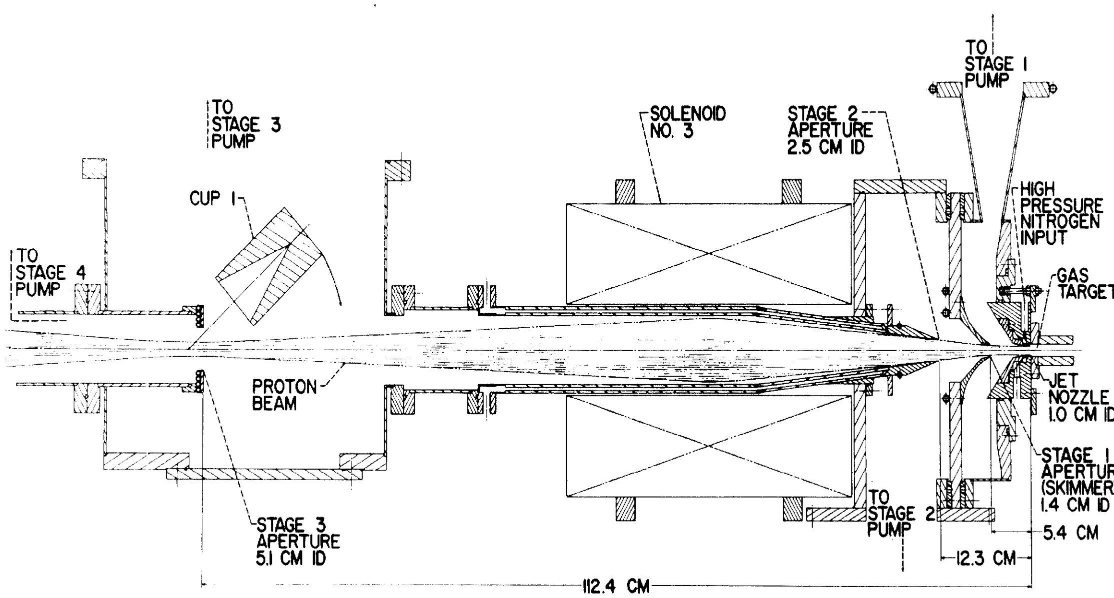

Fig. 3. Differential pumping system on the beam line.

energy of the jet flow.) Figure 4 shows the leak rates measured at beam-power levels of 0, 1.2, 1.6, and 3.5 kW. A measurable but unimportant increase in the backflow leak rate was detected with increasing f during these tests. Because of the atomic neutralization of the beam discussed above, it was not possible to deliver enough power to the jet to observe where the jet breakdown occurs. At breakdown the leak rate may increase catastrophically as shown by the dashed line. Beam heating had a surprisingly small effect on the leak rate. This suggests that the jet can operate at a considerably higher f factor than the 0.37 obtained in these tests without much effect.

Conclusions

The supersonic jet target was demonstrated to operate satisfactorily during tests simulating one-half of the design beam power. The beam formation and transport systems can be improved by incorporating recent advances in these fields: the accelerating column should be changed to a modified Pierce design, the requirement for a structurally simple ion source that produces a uniform plasma with low emittance could probably be satisfied by using a version of the cusp-field ion source, and the aberrations of the beam can be reduced by using quadrupoles instead of solenoids.

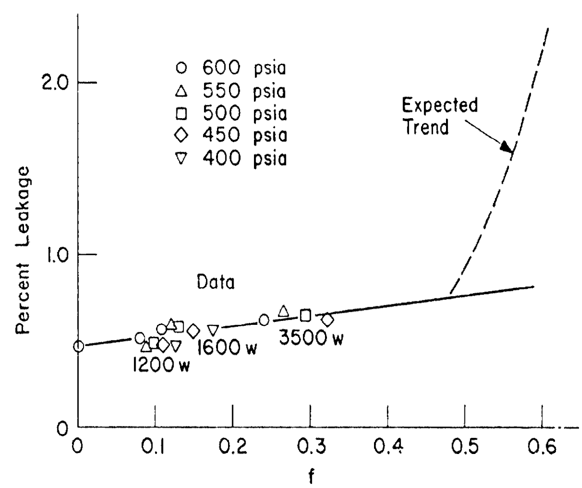

Fig. 4. Experimental backflow leak rates.

References

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