INJECTOR OPERATIONS AT LAMPF*

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Summary

The injector complex at LAMPF consists of three on-line 750-kV injectors, which provide simultaneous H^+ and H^- beams for LAMPF production and an off-line 200-keV injector for ion source and beam diagnostic development studies. The present operation now entails a 500-μA_a H^+ beam accelerated simultaneously with either a 6-μA_a unpolarized or 10-nA_a polarized H^- beam. In order to obtain the low-beam spill required for the operation of the LAMPF accelerator, it has been necessary to increase the brightness of the high-intensity H^+ beam. The operating experience and development work that has been carried out on all of these injectors to improve the quality and intensity of these beams will be presented. The details of the construction of the test stand injector and the development program planned for this injector will also be outlined.

Introduction

The injector complex at LAMPF is now fully operational and consists of three 750-kV on-line injectors that provide high-intensity H^+ beams simultaneously with lower-intensity H^- beams, which may be either polarized or unpolarized. The utilization of H^- beams is now approximately equally split between polarized and unpolarized operation. At present, LAMPF is operating at a 7.5% duty factor with a 9% duty factor planned for the coming year. The overall operation of all the injectors at these duty factors continues to be relatively reliable and stable with most of the operating problems now being associated with changes incurred due to ion source development. In order to preclude these operating problems which result from on-line development of ion sources, a test stand injector is now being constructed which will provide off-line capability for developing new ion sources and beam diagnostic systems.

H^+ Beam Operation

After 1.6-mA_p (100-μA_a) beam current operation[1] was obtained in the LAMPF accelerator in 1976, it was found that the aperture limit in the accelerator was the transition region between the 201.25-MHz linac and the 805-MHz linac. Operation with the accelerator would then have been limited to currents less than 10 mA_p because of beam spill in the transition region. Studies of beam emittance growth in the linac indicated that there was little, if any, difference in the emittance growth in the 201.25-MHz linac between the low-brightness H^- beams and the higher-brightness H^+ beams then being used. It was, therefore, concluded that for the relatively low-peak currents required at LAMPF, it would be useful to increase the brightness of the H^+ beams being injected into the linac. Theoretical studies[2] of stationary distributions also indicated that a significant increase in beam brightness could be accommodated in the LAMPF accelerator. Thus, a program was initiated to increase the beam brightness for the H^+ beams.

During the past three years, a variety of approaches have been explored for increasing beam brightness. These range from optimization of ion source parameters and extraction geometry to exploration of different modes of beam transport and emittance tailoring on the low-energy beam transport lines. It was decided to retain the present ion source and optimize its operation for these relatively low-peak currents (20 to 30 mA_p). These efforts have resulted in an improvement in beam brightness by approximately a factor of four over the original beams and have permitted the desired operation of LAMPF at the 6.4-mA_p (500-μA_a) level. The present constraint for increasing H^+ beam current now is a power limitation in the pion production targets. A history of the beam emittances that have been run at LAMPF for the past three years is shown in Table I.

The major improvement in beam quality has occurred as a result of changes in the ion source and extraction system. The original LAMPF duoplasmatron was patterned closely after the BNL duoplasmatron and employed an extraction system with exact Pierce optics. This ion source has now been replaced with a different, empirically determined design employing a higher gradient extraction system. In this design, the Pierce anode has been replaced by a modified focus electrode having a much smaller aperture (6 mm instead of 14 mm) with a shape determined from calculations with the plasma simulation code SNOW. The extraction electrode has been moved closer to the ion source (1.27 instead of 2.5 cm) and now has a 6-mm aperture instead of a 14-mm aperture. This design entails higher-arc current (24 amperes instead of 8 amperes) and somewhat higher gas flow (1.5 std cc/min instead of 1.2 std cc/min). The beam profiles in the LAMPF column as calculated by the plasma simulation code SNOW are shown in Fig. 1 and a schematic diagram of the present LAMPF ion source extraction system is shown in Fig. 2.

A systematic survey of the effect of varying the ion source geometry and operating parameters has been carried out in order to arrive at this design. The basic approach has been to reduce the

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TABLE I

HISTORY OF LAMPF BEAM EMITTANCES

	INJECTOR				TRANSITION REGION			
Date	Current (mA)	2% Threshold Emittance (cm-mrad)†	Brightness 2% Threshold (mA/cm^2-mrad^2)	RMS Emittance (cm-mrad)†	Current (mA)	2% Threshold Emittance (cm-mrad)†	Brightness 2% Threshold (mA/cm^2-mrad^2)	RMS Emittance (cm-mrad)†
Mar 1977	2.0 mA_p	V 1.46π		0.23π	1.6 mA_p	V 0.65π		0.07π
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July 1977	4.6 mA_p	V 1.34π	0.40π	0.21π	3.7 mA_p	V 0.51π	3.7π	0.05π
		H 1.51π		0.20π		H 0.40π		0.04π
Aug 1978	6.5 mA_p	V 1.50π	0.56π	0.25π	4.8 mA_p	V 0.44π	4.9π	0.05π
		H 1.57π		0.21π		H 0.45π		0.05π
Mar 1979	7.8 mA_p	V 1.00π	1.53π	0.13π	6.2 mA_p	V 0.36π	10.5π	0.04π
		H 1.03π		0.13π		H 0.28π		0.03π
Aug† 1979	8.0 mA_p	V 1.30π	0.96π	0.18π	6.4 mA_p	V 0.36π	10.2π	0.04π
		H 1.33π		0.19π		H 0.35π		0.04π

†The emittance values quoted are phase-space area/π and are un-normalized.

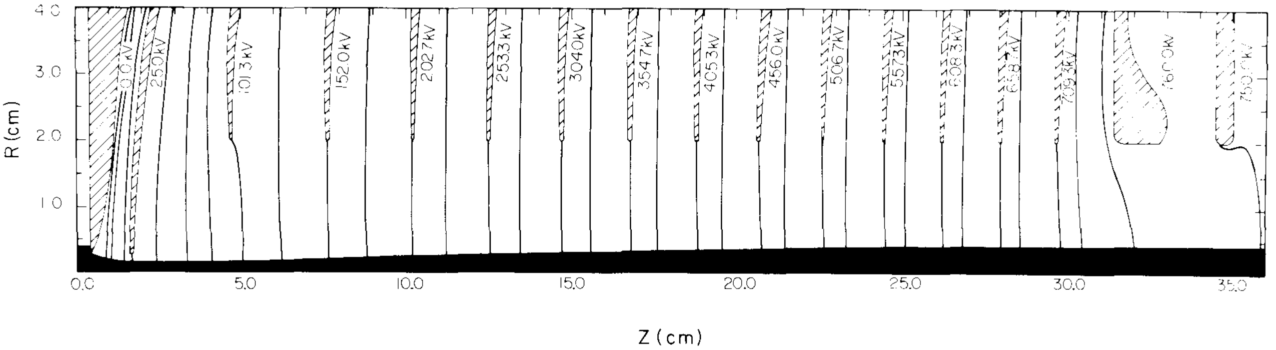

Fig. 1 Beam profiles in the H^+ accelerating column.

size of extracted beam and at the same time increase the extraction gradient so as to keep a constant extracted current. For each change in ion source geometry, optimum operating parameters were established to produce the smallest beam emittance. In general, it was found that arc current and arc-magnet current were the most critical parameters to be optimized for maximum beam current with the focus electrode potential being important for minimizing beam emittance.

The changes in operation of the ion source systems to obtain brighter beams have resulted in some on-line operating problems. Cathode failures are now much more frequent; lifetimes under best conditions are now only 500 hours instead of 3000 hours. Anode aperture units now require the use of molybdenum inserts to prevent premature melting.

A number of other ion source components have failed as these changes were made and better designs have had to be employed. The arcdown rate of the injector, however, has continued to decrease as beam brightness has been increased. The only serious high-voltage problems that occurred during these development periods resulted when spalling of the focus electrode led to ion exchange loading with the electron trap electrode. This problem was corrected by replacing the titanium focus electrode with one made of stainless steel.

Although the primary improvements have occurred from ion source changes, the details of beam transport to the linac are also important in providing high-quality beams. It is apparent, from tuning and matching exercises carried out during beam tuneup, that there can be significant emittance

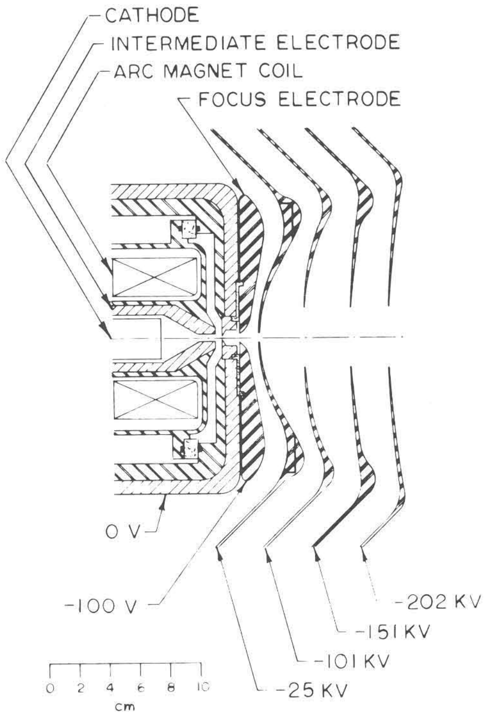

Fig. 2 Present LAMPF duoplasmatron extraction system.

distortion introduced in the low-energy beam transport system, particularly in the rf gaps of the bunchers, and that this distortion will be a limiting factor in obtaining still further improvement in the quality of beams injected into the linac. The dual-beam requirements of the linac also impose constraints on transport tunes. The original transport design of employing fixed aperture collimators to ensure axial transport into the 201-MHz linac had to be abandoned because dual-beam operation could not be effected with axial injection into the linac with the present linac misalignments.

H^- Beam Operation

There are two injectors available for providing H^- beams for LAMPF operation. One injector houses a duoplasmatron hydrogen-charge-exchange canal source while the other injector houses a Lamb-shift polarized ion source. Present operation with these injectors entails 10 μA_a of unpolarized H^- beam, which is limited by experimental area shielding, and 10-nA_a polarized H^- beam, which is limited by the ion source.

The unpolarized H^- beam is produced in the hydrogen charge-exchange canal from several molecular species of hydrogen ions. It has been necessary at LAMPF to analyze the various components of the H^- beam in the low-energy beam transport line and select that portion of the beam formed from a particular species; in this case the H^- ion formed from H_2^+ ions in the canal is used. Although the energy spread of the various components is only a few kilovolts and in itself not important, the multiple component beam has a transverse emittance distribution which is non-ellipsoidal and cannot be matched to the linac with the precision required for spill-free operation in a dual-beam operating mode. This energy analysis has resulted in a reduction of the available H^- current to only 250 μA_p, but this current is still adequate to provide the required 6-μA_a operation. Beam emittances from this injector are typically twice as large as those from the H^+ injector.

The polarized H^- beams are produced in a Lamb-shift polarized ion source, which is housed in an independent 750-kV injector. Beam currents on target of 10 nA_a are now routinely produced with 20-nA_a operation planned for the coming year. Beam polarization of 80 to 90% is produced by a spin filter system which permits on-line measurement of polarization by the quench-ratio method to better than 1%. Beam emittances are typically one-half to one-third those of the high-intensity H^+ beams and essentially 100% transmission of polarized beam captured in the linac can be obtained in spite of the poor matching obtained for H^- beams. No depolarization of polarization enhancement effects to the 1% level have been observed in the operation of the accelerator. A rapid spin-reversal capability which can flip orientation of the proton spin at a rate of up to 3 kHz has recently been put into operation for a parity violation experiment; the normal spin-reversal clocking system is generally run with a three-minute period. A spin precessor on the low-energy beam transport line permits production of beams with any desired polarization orientation in the experimental areas.

Test Stand Injector

A 200-kV test stand injector is now being constructed in the injector area to provide a means for developing new ion sources on an off-line basis. A diagram of the high voltage portion of the injector is shown in Fig. 3, and a photograph of the present construction is shown in Fig. 4.

The injector consists of a 200-kV high voltage power supply which floats an equipment rack and ion source at the desired potential. The ion source is mounted at one end of an accelerating column cantilevered from a grounded vacuum chamber. The accelerating tube consists of glass rings which have been bonded with torr seal epoxy to stainless steel washers and is mounted inside a Lucite jacket containing SF_6. Vacuum pumping is provided by two 1500 ℓ/s turbopumps mounted at ground potential; the base vacuum of the system is in the low 10^{-7} range. The ion beams are accelerated to ground potential, analyzed in a 45° bending magnet and transported to an emittance scanning station. A solenoid lens has been placed at the exit of the accelerating tube to focus these low-energy beams into the transport system.

A detailed study of the LAMPF duoplasmatron is planned as soon as construction of the injector is completed. It is anticipated that this effort will develop a duoplasmatron which will provide the required 1-mA$_a$ beams for the present operating mode with a single high-intensity beam. Further development of H$^-$ ion sources required for new applications at LAMPF is then planned.

Acknowledgements

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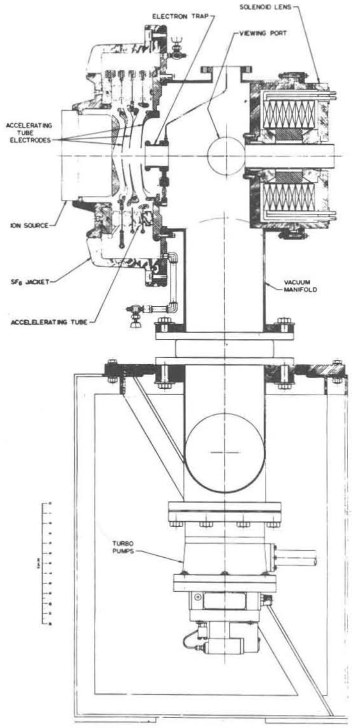

Fig. 3 The 200-kV accelerator for the ion source test stand.

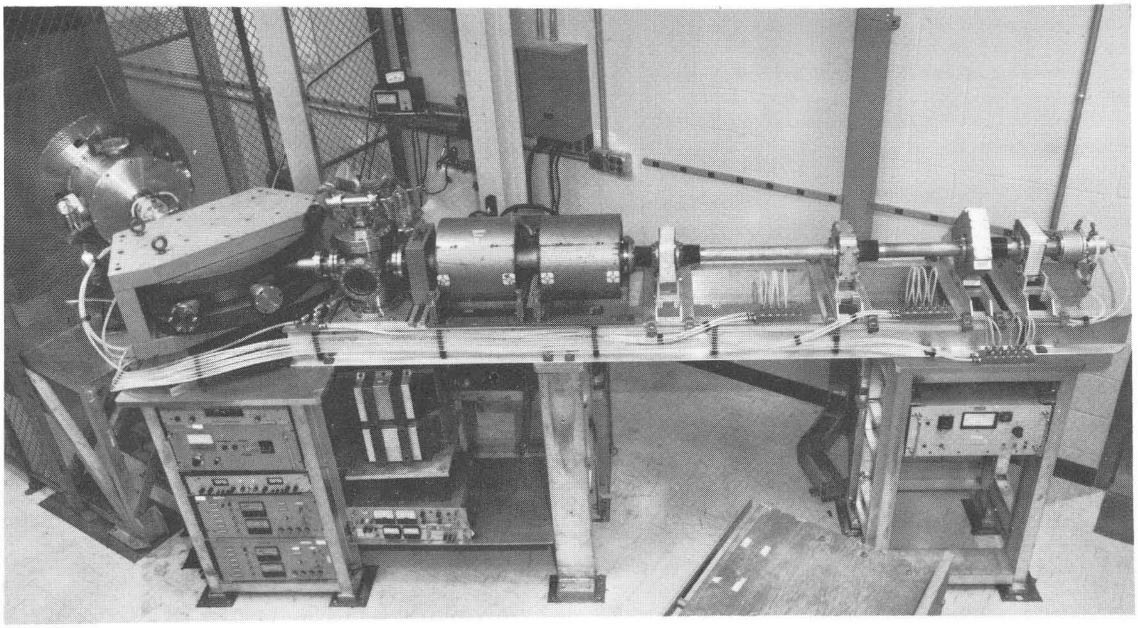

Fig. 4 Present construction of the ion source test stand.