THE INJECTOR COMPLEX FOR THE LAMPF ACCELERATOR*

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Summary

The present planning and design goals for the LAMPF injector complex include a high-intensity H^+ beam, an H^- beam, and polarized H^+ and H^- beams. Since simultaneous acceleration of H^+ and H^- beams will be attempted by the LAMPF accelerator, a dual beam-transport system for blending these beams into a common channel will be necessary in the injector area. Provision also is made for injecting either H^+ or H^- polarized beams into the system. A high-quality beam of protons (π cm-mrad emittance and 26 mA) has been produced by a von Ardenne duoplasmatron and a Pierce extraction accelerating column. Problems of simultaneous bunching and matching of H^+ and H^- beams of different intensities have been studied. The entire injector complex is under computer control and should provide reasonably sophisticated pulse programming flexibility.

Introduction

The requirements for the injector complex are the following:

Energy	750 keV ± 0.02%
Pulse repetition rate	120 Hz
Pulse duration	500 μsec
Micropulse structure	201.25 MHz
Transverse emittance	3 π cm-mrad
Longitudinal emittance	π MeV-deg
High intensity source	20 mA H^+
Med. intensity source	2 mA H^-
Low intensity source (Polarized)	1 μA H^+ or H^-

A dual beam-transport system has been designed for the injector complex to allow independent pulse shaping and phase space matching of the beams into the remaining portion of the accelerator. The three ion sources will be housed in the high-voltage terminals of three separate 750-kV Cockcroft-Walton generators. The dual beam transport system has both positive and negative lines, which are blended into a common line just before the drift-tube linac. It will afford a means of transporting simultaneously both positive and negative ion beams from the appropriate ion sources and subsequently inflecting them into the common beam line where bunching and final phase space matching will be done.

Ion Sources

H^+ Ion Source

The high-intensity H^+ beam will be produced by a von Ardenne duoplasmatron with an expansion cup. The beam will be extracted using a Pierce geometry accelerating column.[1] This source is capable of providing the required 20-mA peak current at a duty factor up to 12%. Details of this source are described in another paper in these proceedings.[2]

H^- Ion Source

The goal for the H^- ion source is 2-mA peak current at 6% duty factor, emittance less than several π cm-mrad, reasonable gas consumption (2 atm-cc/min, as for the H^+ source), good reliability and lifetime, and compatibility with remote operation in the Cockcroft-Walton high-voltage terminal. Three types of sources are being considered: (1) Offset duoplasmatron;[3] (2) Diode source;[4] and (3) Ehler's source.[5]

Source (2) is claimed to deliver about 1 mA with an emittance (at 750 kV) of 0.3 π cm-mrad and a gas consumption of 1 atm-cc/min. Lifetime of the cathode is about 100 h. Because it is a dc source, it is not obviously adaptable to pulsing. The major drawback is that a large flow of argon must be flushed through the source to get it started. This would probably require valving the source off from the ion pumps and using a mechanical pump until the source is operating on hydrogen alone. A better means of starting this source would make it very attractive.

Source (3) delivers 2 mA with an emittance of π cm-mrad. Since gas consumption is 20 atm-cc/min, the pumping requirements would be a major drawback. Lifetime is about 100 h for dc operation, and this could probably be expanded greatly by pulsing. Power and space requirements could not easily be met with the limited space available in the high-voltage terminal of the Cockcroft-Walton.

Experiments with source (1) are presently being carried out. It is felt to be very promising with a Russian version[6] delivering 8 mA. If it is not suitable for LAMPF, source (2) probably is. Emittance of source (1) is not known.

Polarized Ion Source

A polarized ion source capable of producing either H^+ or H^- polarized beams will be provided. The design goal for the polarized beam is a 1-μA peak beam of either ion species with 80% polarization and with an emittance (at 750 kV) of less than a few π cm-mrad. There are two types of sources that are presently being considered: (1) conventional ground-state source;[7] and (2) metastable hydrogen source.[8]

The conventional ground-state sources are capable of producing several μA of H^+ beam and possibly 0.1 μA of H^-. This type of ion source re-

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quires tremendous hydrogen pumping capability (5 atm-cc/s).

The metastable type of ion source is capable of producing 0.5 μA of H^- and, by simple stripping, a comparable current of H^+. The emittance of this source is a factor of three less than our requirements, but it requires special pumping capabilities for cesium and argon.

Since the high-intensity (unpolarized) proton beam will have the greater demand by the Users of LAMPF, the present planning favors the building of an optimum H^- polarized source, but the final choice has not been made. Experimental work is in progress to investigate the use of cryogenic pumping since the development of a suitable vacuum system is a major problem in the use of either of these sources.

Beam Transport

The original beam-transport system designed for the LAMPF injector area was intended to transport a single H^+ beam from one of three ion sources to the input of the drift-tube linac. Since it now appears feasible to accelerate both H^+ and H^- beams simultaneously, provision must be made to transport these beams from their ion sources, inflect them into a common beam line, and subsequently match them to the drift-tube linac. A further complication arises in that bunching and beam pulse shaping must be provided for both beams prior to injection.

Several schemes for effecting the required dual-beam transport have been considered. The most promising is shown in Fig. 1. In this design, the H^+ and H^- beams are transported along separate beam lines until they are inflected into a common buncher. Following the buncher is a quadruplet which must match both beams to the drift-tube linac. One wants to set the gradients in the quadrupole magnets of the common transport quadruplet to match the high-intensity H^+ beam and then to adjust the quadrupole magnets in the H^- beam in order to obtain matching of the low-intensity H^- beam with the same quadruplet gradients. Provision has been made to inject polarized beams into either beam line so that either H^+ or H^- polarized beams may be transported to the drift-tube linac. Beam envelopes for the transport of a 50-mA H^+ beam through the H^+ transport line are shown in Fig. 2.

Preliminary design calculations for the final phase matching have been carried out using a beam envelope transport code which was modified to simulate bunching, and then checked with a (slower) particle tracing transport code. The results of these calculations indicate that (1) a common matching quadruplet may be used to transport a high-intensity H^+ and a low-intensity H^- beam from a common buncher to the input of the drift-tube linac, and that (2) the beam envelope calculations can be used to establish further designs, once the final common buncher parameters are determined.

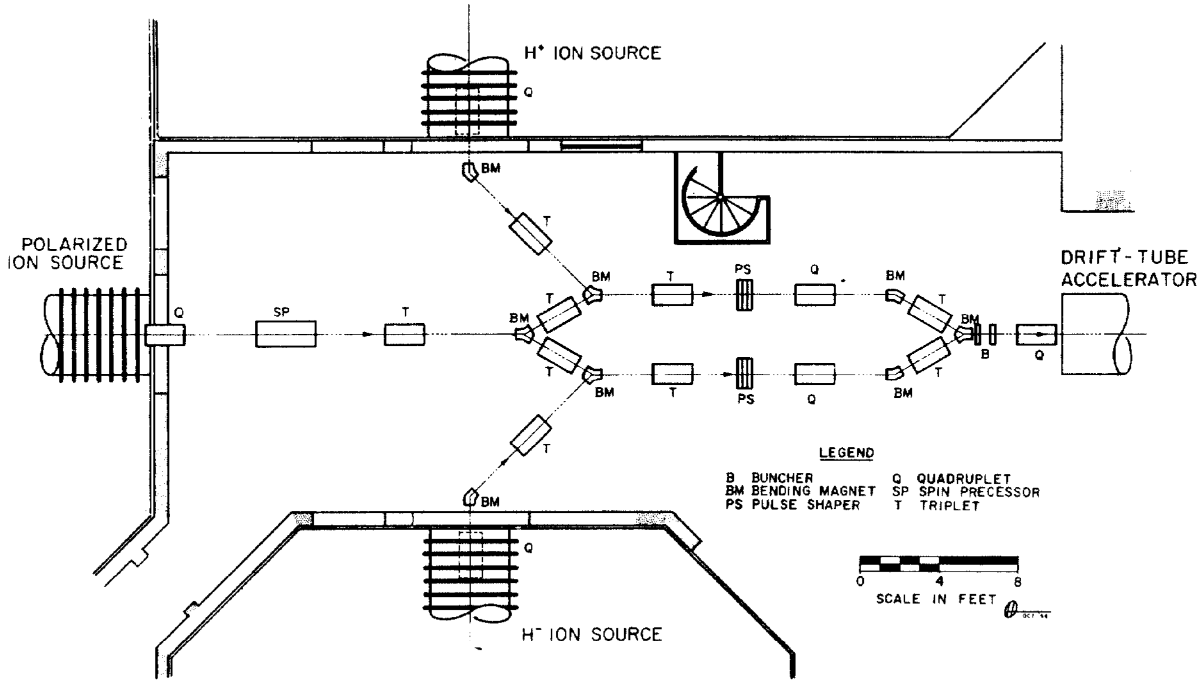

Fig. 1. Layout of Dual-Beam Transport System.

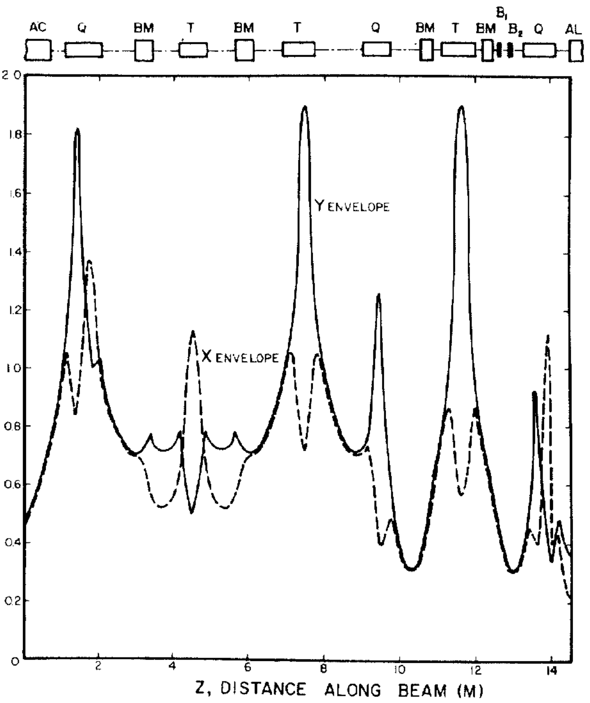

Fig. 2. Beam Envelopes for High-Intensity Proton Beam Line.

Simultaneous Bunching

The bunching of both H^+ and H^- beams for simultaneous acceleration in the drift-tube linac has created a new problem. The double drift buncher,[9] in its original configuration, can no longer be used, since the second cavity operates at the second harmonic of the first cavity and thus cannot provide the proper phase for simultaneous bunching of both H^+ and H^- beams. Three approaches to the problem of H^+,H^- bunching have been studied: (a) single-cavity bunching or double drift bunching with both cavities operating at the same frequency; (b) H^+ and H^- beams having separate beam transport systems, each with its own double drift buncher; and (c) a simultaneous double drift buncher (SDDB)[10] to provide suitable phase shift for simultaneous bunching of H^+ and H^- beams.

The first approach to the problem is quite simple; however, the bunching may not be satisfactory as the compactions into phase spread of < ± 30° cannot be obtained efficiently. The second solution results in the need for achromatic bending systems for blending the two beams into the linac. The buncher drift distances allow very little space to accommodate the required quadrupole and bending magnets. The third approach is to modify the double drift buncher to accommodate both the H^+ and H^- beams, i.e., the SDDB.

The SDDB differs from an ordinary double drift buncher in that two drift tubes have been added, one following each of the buncher cavities. These drift tubes are operated at specified dc potentials such that they impart a dc velocity modulation after the first cavity and then remove the modulation after the second cavity. This modulation is such that when the H^+ and H^- beams reach the second cavity the phase of the synchronous H^+ particle is advanced while that of the synchronous H^- particle is retarded. A relative phase shift of $\pi/4$ is thus achieved for the proper bunching condition of both the H^+ and H^- beams at the second cavity. The second drift tube is biased so as to restore the original phase relationship for proper acceptance into the drift-tube linac.

To illustrate the operation of the SDDB, drift tubes have been added to the MRA double drift buncher code.[11] Figure 3 shows the transverse and longitudinal phase space population density for the H^+ particles, and Fig. 4 shows the same distribution for the H^- particles at the entrance to the linac. Also shown are the real space particle density distributions. The beam is compacted so that 82% of the particles are bunched into a phase spread of < ± 20°, and the H^- beam is compacted so that 86% of the particles are bunched into a phase spread of < ± 30°.

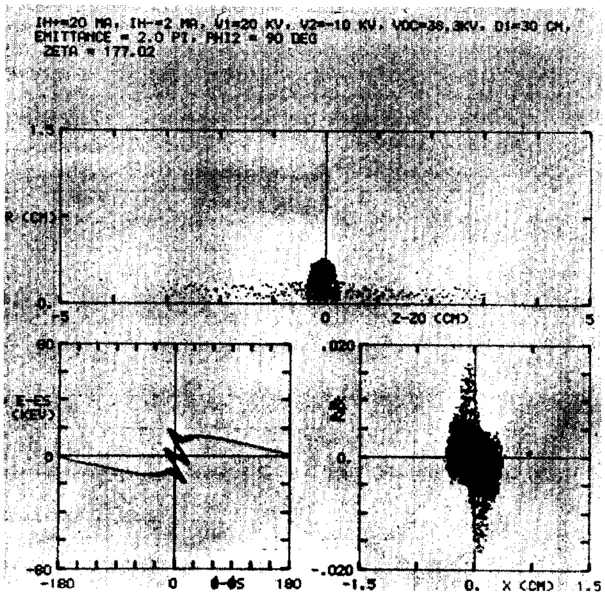

Fig. 3. Transverse and Longitudinal Phase Space Population of H^+ Beam.

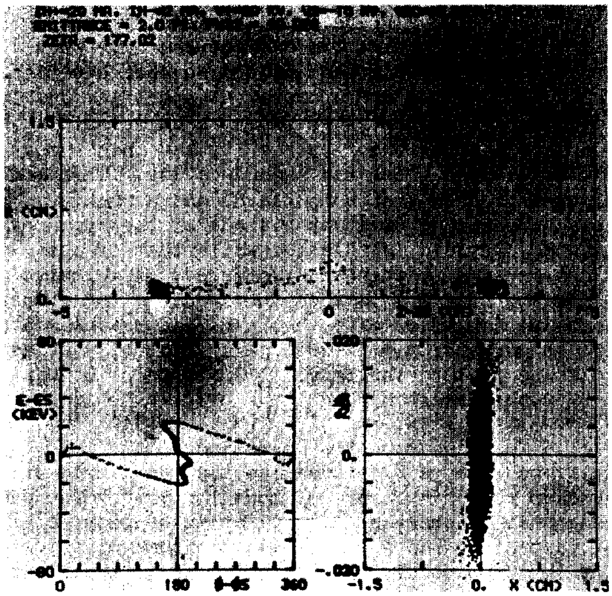

Fig. 4. Transverse and Longitudinal Phase Space Population of H^- Beam.

Common Beam Transport

In transporting both H^+ and H^- beams from the ion sources to the buncher, it is economically desirable to have only one transport system for as much of this distance as possible. However, space charge effects between the two continuous beams severely restrict the length of a single transport system.

A numerical study was performed on the simultaneous transport of a 40-mA H^+ beam and a 2 mA H^- beam through a simple transport system consisting of three thin lenses spaced 320 cm apart. Both beams were assumed to have an emittance of π cm-mrad and to start at a double waist with a radius of 0.7 cm at a distance of 160 cm from the first lens. The lenses focused the 40-mA beam (if it were traveling alone) to a 0.7-cm waist at a distance of 160 cm after passing through each lens.

Some results of the numerical simulation are presented in Figs. 5 and 6. The left half of each figure concerns the 40-mA H^+ beam, and the right half shows the 2-mA H^- beam. The bottom graph on each half shows the radius of the beam along the transport system. Displayed at the top is the x - x' phase space of each beam.

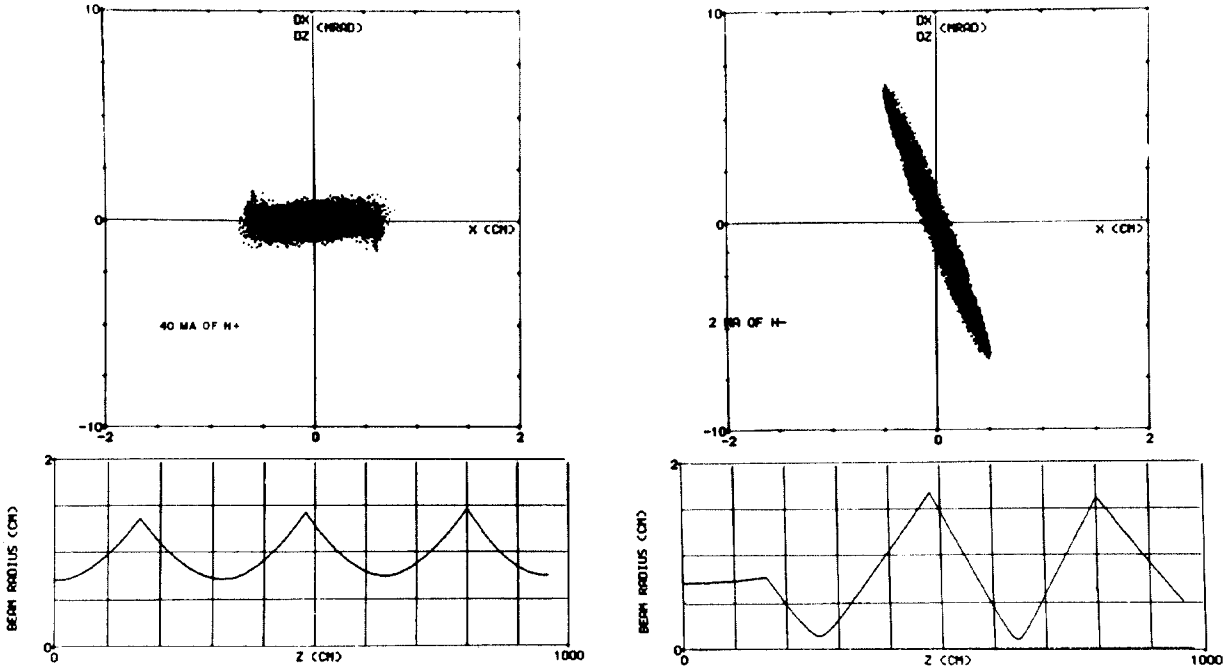

Fig. 5. Resultant Phase Spaces and Beam Profiles Obtained when the Beams are Sent Separately through the Transport System.

Figure 5 shows the results obtained from sending each beam separately through the transport system. The minor distortion in the phase space of the H^+ is caused by the failure of the charge density to remain uniform. Figure 6 shows the situation when both beams are transported simultaneously through the lens system. The H^- beam is seen to be drastically influenced by the H^+ beam. Moreover, when the H^- beam becomes quite small, it affects the inner core of the H^+ beam, causing the small "wings" to appear on the phase space of the H^+ beam.

The large interaction of the two beams in this numerical simulation indicates that a long single transport system for both beams will probably not be satisfactory.

Beyond the buncher, the H^+ beam and the H^- beam are separated in real space by the action of the buncher, and the interaction between the two beams is significantly reduced. A common beam transport from the buncher to the drift-tube linac will be used.

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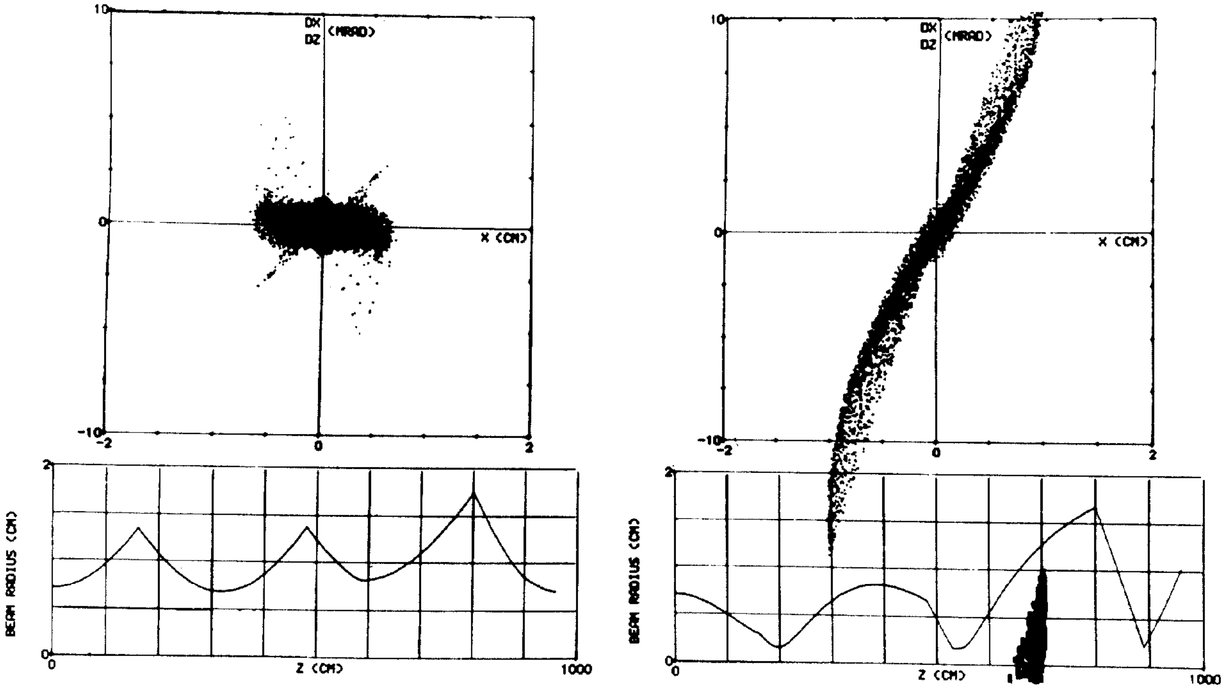

Fig. 6. Resultant Phase Spaces and Beam Profiles Obtained when the Beams are Sent Simultaneously through the Transport System.