Upgrade of LAMPF's 750-keV, H^+ Transport

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Abstract

The results of the upgrade to the 750-keV H^+ transport at LAMPF are reported. The transport takes the beam from the exit of the 750-kV column to the entrance of the 201-MHz drift tube linac. Components of the transport are used to bunch the beam, to match the beam to the linac, and to adjust the peak current of the beam. The transport is a critical section of LAMPF's accelerator system; a properly tuned and stable beam significantly reduces high-energy losses in the accelerator. The transport was upgraded to decrease the emittance growth of the beam, to facilitate tuning, and to eliminate the time-dependent transients associated with space-charge neutralization of the beam. The new transport was installed and used for beam operations in 1990. The upgrade design goals were successfully achieved. The unnormalized emittance for 95% of the beam was measured at 0.8 π cm-mrad compared with 1.2 π cm-mrad in the previous transport.

I. INTRODUCTION

At LAMPF there are three 750-keV transports, one for each of the three types of beams, H^+, H^-, and P^- (polarized protons). These beams are transported from the sources and 750-kV acceleration columns, bunched, merged into one beam line, and matched into the 201-MHz side-coupled linac. This paper describes the successful upgrade of the H^+ transport.

Approximately 30 mA (peak) of H^+ beam from a duo-plasmatron ion source and 750-kV CW is injected into the transport. About 5 mA of H_2^+ and other contaminants are also present. The peak current injected into the linac is adjusted with jaws to be between 14 and 24 mA. In the first rf module, 70% of the beam is captured in the longitudinal bucket and better than 99.9% of the captured beam is accelerated through the rest of the linac to 800 MeV. A good transport tune is needed to achieve the high transmission which is necessary to limit the activation of the linac.

Several features of the transport design help to limit the growth of transverse tails and subsequent beam losses. Design requirements include magnets with small higher-order field harmonics, a transport tune for uniform beam size, and a good match to the linac. Also, the beam size needs to be kept constant in time throughout the 1 millisecond beam pulse, otherwise there will be an effective emittance growth. The new transport addresses these considerations.

II. DETAILS OF NEW TRANSPORT

Design Methods

The upgraded transport design is based on measurements of the beam in the previous H^+ transport and the recent upgrade of the 750-keV H^- transport [1]. The transverse phase space distribution of the beam was measured at three locations along the transport using a slit and multi-wire harp. Given this input beam, the match to the linac at the output of the transport, and intermediate constraints on the beam, all the necessary information was available to design the new transport.

The code TRACE was used for first-order modeling of the new transport. The integrating code SCHAR [3,4] was then used to model the beam to all orders for selected cases. The SCHAR studies showed that quadrupoles introduced fewer aberrations than solenoids in the first section of transport, and therefore quadrupoles were used. SCHAR also showed that unacceptably large transverse tails would not be introduced by the new transport.

One point of uncertainty in the design model was space-charge neutralization. Space-charge neutralization is believed to occur in regions of the LAMPF transport and it is suspected to be the cause of observed time-dependent behavior of the beam [5]. The problem is that the degree of neutralization and the region of the transport that is neutralized are not well known. Moreover, it is not clear how measurements of the beam affect neutralization. To overcome these uncertainties, the transport was designed to tune beams with space charge between the two extremes of completely neutralized and unneutralized beam.

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Transport Configuration

The basic layout of the new transport is shown in Fig. 1. There are three beam diagnostic measurement stations: TAEM1 after the 750-kV column, TAME2 after the pre-buncher, and TDEM1 at the end of the transport before injection into the linac. There are two bends, an 81-degree bend and a 9-degree bend. The 81-degree bend has large dispersion but the energy spread is small, on the order of 500 eV. The energy spread becomes large, on the order of several keV, after the pre-buncher, but the following bend is small, only 9 degrees.

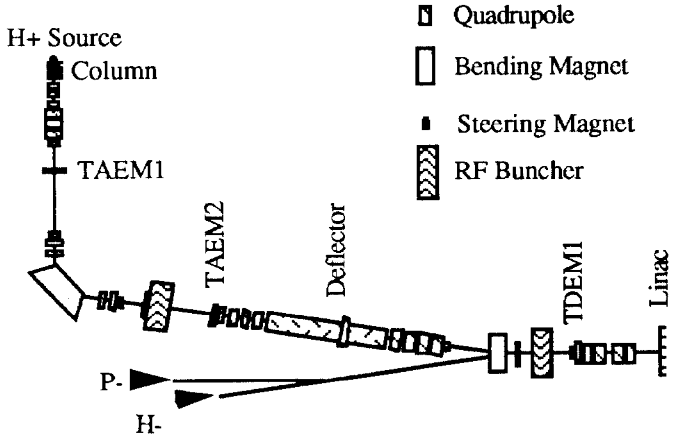

Fig. 1. Basic layout of the new H^+ transport. Also shown are inputs representing the two negative beams, H^- and P^-. The devices labeled with "EM" are slit and multi-wire harp beam diagnostic devices (e.g., TAEM1).

The quadrupoles are configured for the tune shown in Fig. 2. The tune attempts to minimize the peak-to-valley ratio of the beam radius. The previous transport tune had a very small waist in the region of TAEM1 that led to an emittance growth by a factor of about 1.5.

An important feature is the deflector, located near the center of the transport. The deflector is used to control beam injection into the linac. Jaws and apertures upstream of the deflector are used to set the beam current and eliminate unwanted tails.

III. ADVANTAGES OF THE NEW TRANSPORT

Reduced Emittance

The new transport provides a brighter beam with fewer tails so beam losses at higher energies are easier to control and higher peak-current beams can be run. Several factors contribute to the increased brightness. One improvement is the redesigned 750-kV column and the new quadrupole triplet at the exit of the column. The beam out of the previous 750-kV column was large and divergent. The large beam at the exit of the column was focused in the previous transport to a very small waist that resulted in large tails and emittance growth for the space-charge dominated beam. The design of the new transport addresses this problem by shortening the 750-kV accelerating column and by using a set of short, strong field quadrupoles that fit as close by to the exit of the column as possible.

In the previous transport, the beam was turned on into the linac at the same time the source was turned on. Not only was a source turn-on transient observed, but the beam tune in the transport took about $100\ \mu s$ to stabilize as neutralization occurred in the upstream section of the transport; some linac losses were associated with these transients. The time-dependent transient problem was solved by turning the source on first and allowing the beam to stabilize in the transport, and then turning the beam on into the linac with the deflector [6].

Nonlinear forces due to higher-order fields in transport magnets lead to tails and effective emittance growth. The quadrupole magnets were designed to keep the higher-order harmonics small in the region of the beam. Efforts were made to keep the harmonic amplitudes in the quadrupoles below 0.1% for the n=3, 4, and 5 harmonics, below 0.3% for the n=6 harmonic, and below 0.6% for the n=8 and higher harmonics.

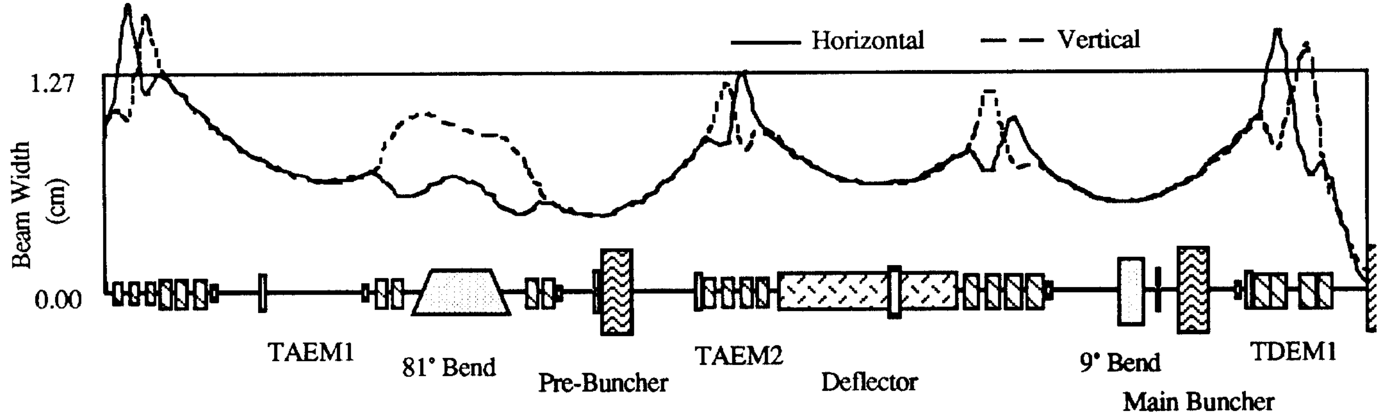

Fig. 2. The horizontal and vertical extent for 95% of the beam is shown for the new transport. Critical facets of the tune are the 0.45-cm waist at the pre-buncher, the relatively small peak-to-valley ratio of the beam envelope though the transport, and the match of the beam to the linac at the end of the transport.

These amplitudes are expressed as a percent of the quadrupole amplitude at a radius of 2.5 cm. For the newly designed, short, strong-field quadrupoles, pole faces were shaped to reduce the n=6 term to 0.7% at 2.5 cm radius.

The present beam has fewer tails and smaller emittance when compared with the previous transport. With the previous transport, the unnormalized transverse emittance of 95% of the beam was approximately 1.2 π cm-mrad. The beam from the new transport has an emittance of 0.8 π cm-mrad and the time-averaged emittance was further reduced by eliminating the time-dependent turn-on transient. The general tune of the linac and the beam losses have qualitatively improved with this improved beam.

Transport Operation

The new design was intended to make the transport easier to tune. This was accomplished by providing an additional slit and multi-wire diagnostic monitor at the front of the transport, by carefully measuring the relation between current and field for all quadrupoles, by using quadruplet assemblies in place of triplets, and ensuring that there were "orthogonal" pairs of steering magnets for steering angle and position at each diagnostic station. The new slit and multi-wired diagnostic station is much closer to the first set of quadrupoles; this makes tuning these elements simpler. Using a quadruplet simplifies the matching problem with four variables (the quadrupole fields) for the four conditions (matching the transverse Twiss parameters). In order to minimize the correction steering needed, pairs of steering magnets were placed such that the steering at a diagnostic station was as independent as possible in position-angle space. This also makes the steering problem easier to solve. Even with orthogonal steering, precise alignment is important in the transport. Steering is only used for small corrections.

Another detail of tuning at LAMPF is the interactive use of the code TRACE. For this model to be usable, it is important to use accurate first-order approximations. These approximations are based on magnet measurements. Quadrupoles were measured with rotating coils [7] and bending magnets were mapped with Hall-probe scans [8].

Once a tune is established for a particular source and current into the accelerator it must be reliably maintained. Typically this can be done by maintaining bending-magnet currents to 0.01%, quadrupole currents to 0.1%, and steering magnet currents to 1%. After a power failure, it is necessary to return the magnetic fields to within these tolerances. This was accomplished in the new transport by the addition of a multiplexed NMR system for the bending magnets and by development of a cycling procedure for the quadrupoles.

IV. FUTURE ENHANCEMENTS

Though the new H^+ transport has been run and is operating well, additional work remains to be done. The transport alignment work is being completed. The last set of quadrupoles common to all three transports has been measured. Measurements indicated much higher than expected components of n=3 at 0.4% of the quadrupole amplitude and n=6 at 3.0% of the quadrupole amplitude at 2.5 cm radius. Tracking studies indicated that these harmonics lead to significant aberrations. New quadrupoles of the standard design are being installed. Other work consists of studies to reduce column arc-downs in the 750-kV column.

Another component in the design stage is an intensity modulator. Beam duty factor could be increased to the H^+ users if an intensity modulator were added to the transport. This device would change the peak intensity in 10-20 μs with minimal change to the beam tune or steering. The physics design for this device is complete and is undergoing engineering review.

V. CONCLUSION

The design goals of the new H^+ transport have been met. The emittance and tails of the beam are reduced. The transport is easier to tune and is more reliable to operate. Standardization has made the transport easier to operate. The troublesome time-dependence has been eliminated by turning the beam on with a deflector downstream of the region where the beam is neutralized.

Further improvements will be achieved by replacement of older style quadrupoles, by alignment of the transport, and possibly by further redesign of the 750-kV column. Higher duty factor could be delivered to the experimenters by installing an intensity modulator, the design of which is currently under review.

VI. REFERENCES

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