# NEW 750 KEV H⁻ BEAM TRANSPORT LINE FOR LAMPF*

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## Summary

The injector complex at LAMPF consists of three
injectors with associated transport lines to deliver
H⁺, H⁻, and P⁻ beams to the linac.  Early in 1984 the
original H⁻ injector (circa 1973) was replaced with one
capable of producing a peak current of 20-mA, a 100X
improvement.  The motivation for this upgrade was the
addition of a proton Storage Ring (PSR) for pulsed neu-
tron research.  To support the new operating modes as-
sociated with the PSR, the H⁻ transport line was
replaced by one having a different design that required
changes to portions of the H⁺ and P⁻ lines, also.  This
paper describes the new transport system and reports on
the initial performance of the H⁻ line.

## Introduction

The most recent addition to the facilities at
LAMPF is a Proton Storage Ring (PSR).[1]  This addition
entailed three major modifications to the accelerator
to support the operation of the PSR while still
retaining the flexibility in delivering beams to the
other beam ports.  The significant changes include:

- a new high-intensity (20-mA peak) H⁻ ion source
  and injector[2],
- a new H⁻ beam-transport line leading to the
  201.25 MHz drift-tube linac,
- a major rebuilding of the beam switchyard, and
- a change in operating modes.

This paper addresses in detail the new H⁻ beam
transport line.

## Design Requirements

The original injector area transport system[3] could
deliver an H⁺ beam and either an H⁻ or a polarized H⁻
(P⁻) beam to the drift-tube linac during a single mac-
ropulse.  The nominal peak intensities of the produc-
tion beams were: 13 mA of H⁺, 100μA of H⁻, and 125 nA
of P⁻.  The decision to add the PSR imposed three new
requirements on the existing H⁻ line:

1. It had to deliver P⁻ followed by H⁻ on the same
   macropulse as shown in Fig. 1(a).

2. The H⁻ line had to provide special time struc-
   tures in the beams to the PSR and WNR facility
   depending on the operating mode of each.  One
   such time structure is shown in Fig. 1(b).

3. The line had to transport a high-intensity H⁻
   beam without inducing a significant growth in its
   emittance.

Taken all together, these requirements forced the
design of an entirely new H⁻ transport line.

## New Transport System

The most difficult aspect of the design effort was
devising a layout of the line that had space for the
new elements at the correct locations along the line.
Figure 2 shows the transport system that emerged after
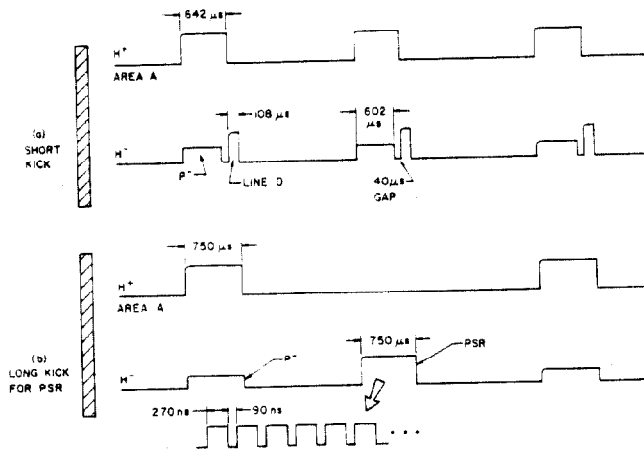all the competing requirements were resolved.  The next



Fig. 1.   Some possible beam time structures from
the injector transport system.

few paragraphs discuss how this design complies with
the given criteria.

Requirement 1:  Multiplexing the P⁻ and H⁻ beams
on the same macropulse was satisfied by introducing an
electrostatic inflector at the intersection of the P⁻
and H⁻ lines.  When the inflector is energized, the P⁻
beam is delivered to the accelerator.  A fall-time
specification of 40μs (see Fig. 1(a)) was placed on the
inflector voltage so that the line can be switched to
H⁻ during the same time a kicker magnet in the
switchyard is energized to deliver the beam to the PSR.

Requirement 2:  To make space for a low-frequency
(201.25/12 = 16.77 MHz) buncher and a 5-ns rise time
chopper, the two 45° bending magnets were collapsed
into a single bend of 90 – 9 = 81°.  Because the
buncher adds a large energy spread to the beam, it had
to be located downstream of the highly dispersive bend;
the chopper was placed upstream.  The 9° bend to the
accelerator center line was a compromise that keeps the
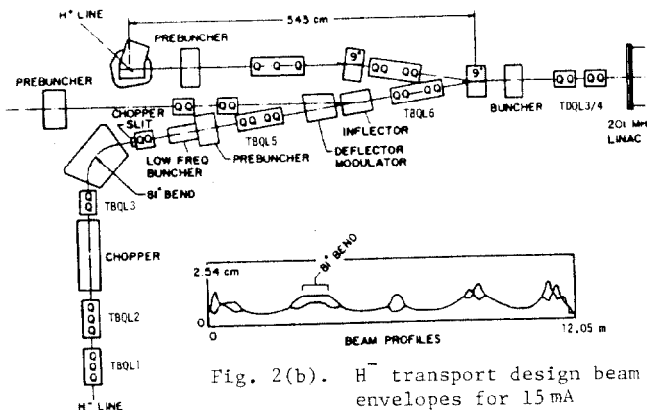dispersion at an acceptable level but allows enough



Fig. 2(b).  H⁻ transport design beam
envelopes for 15 mA
3 mr-cm beam.

Fig. 2(a).  The design for the new injector
area transport system.

separation between the H⁻ and H⁺ lines for the focusing elements.

Requirement 3: The emittance growth of the H⁻ beam was minimized by judicious placement of the quadrupole lenses along the beam. The beam optics with space charge was studied using a code[4] developed by Hayden and Jakobson of the University of Montana. These calculations showed that if the minimum size of the beam were kept larger than a 4- to 5-mm radius and if the peak-to-valley ratio (maximum beam size ratioed to the nearest waist) were kept less than 4:1 then the emittance would not grow significantly from space charge effects. The beam profile calculated for the new H⁻ line adheres to these guidelines, as seen in Fig. 2(b).

After the design requirements for the H⁻ line were satisfied, the existing H⁺ and P⁻ lines were modified to conform to the new design with a minimum number of changes. Figure 2 shows only those parts of the transport system that were changed significantly.

## Tuning Algorithm

There was another design goal in addition to those imposed by the new requirements, namely, that the resulting line be easy to tune. To achieve this goal, the focusing elements were arranged in modules at intervals of about 2.5 meters so that the tuning algorithm was partitioned into a series of 3- and 4-knob problems. The output beam from one matching operation becomes the input beam for the succeeding match. Figure 2(b) shows the resulting profile predicted for a 15-mA peak beam having an input emittance of 3 mr-cm. The tuning algorithm which is supposed to match the beam from the dome to the drift-tube linac in both planes is outlined below.

- The initial pair of quadrupole triplets (TBQL1 and 2) are used to capture the beam coming out of the dome at 750 keV and transform it to a double waist of radius 4- to 5-mm half way through the chopper.

- The 81° bending magnet with edge angles of 24° (focusing in the vertical plane) and the flanking doublets (TBQL3/4) are tuned to transport this waist to an analogous waist at the entrance to the prebuncher.

- The four quadrupole magnets in TBQL5 are used to image the second waist onto a point approximately at the entrance of the inflector.

- The pair of doublets, TDQL3/4, which are common to both the H⁻ and H⁺ lines, are preset to satisfy conditions on the H⁺ beam. Specifically, they are adjusted to match a 4-mm double waist in the center of the main buncher to the admittance of the drift-tube linac.

- With the last quads thus fixed, the linac admittance for the H⁻ beam is transformed back to the center of the main buncher. Then the quadrupole configuration TBQL6 is used to match the beam orientation at this point back to the double waist in front of the inflector.

## Emittance Stations

Successful matching operations require an adequate number of emittance-measuring stations. A decade of experience in tuning the high-intensity H⁺ beam at LAMPF has shown that an emittance measurement can be projected reliably through three quad magnets if one includes space charge effects whereas efforts to

project through 5-6 quads often gave highly uncertain predictions. Consequently, as shown in Fig. 3, the design for the H⁻ line includes four emittance stations in addition to the one already in the portion of the line shared with the H⁺ beam.

## Steering Strategy

Seven dual-plane steering magnets were incorporated in the new H⁻ line, each located to be effective in the steering algorithm. The strategy is to steer both the position and angle of the beam to a null at selected locations using a pair of magnets in conjunction with a pair of position-measuring devices. For example, in Fig. 3, steer with SM6 and SM7 to make the beam coincident with the geometric axis at the entrance to the quads TDQL3/4. The position and angle of the beam at that point are calculated from measurements of beam position at TDHP2 and TDEM2. Both devices -- harps and the collectors in the emittance stations -- are multiwire devices from which the position of the centroid of the beam can be extracted.

## Current Monitors

To keep track of beam losses along the line, a total of five current monitors were installed. These devices have a frequency response in the range of 10 kHz. Signals from all five are available at the operator's console in both digital and analog formats.

## Beam Chopper

The capability for beam chopping is needed in the H⁻ transport line to support the PSR operating modes and to aid development activities in the LAMPF experimental areas. The chopper[5] which was installed is an improved version of the helical-wound, slow-wave deflecting structure built earlier for the H⁺ line. It can deflect the beam by 16-24 mr referred to the middle of the chopper. The deflecting voltage pulse has a rise time of 5-ns or less. The chopping aperture is located after the exit of the 81° bend.

The low-frequency buncher can be operated in conjunction with the chopper to compress a 10-ns segment of beam into a single nanosecond pulse for experiments.

## Deflector/Modulator

Measurements made previously at LAMPF have shown that during the first 200 μs of the beam pulse, the beam parameters can vary markedly from their stable values. A deflector can be used to prevent this part of the beam from entering the accelerator. The rise- and fall-time of the deflector pulse must be short (~ 20 ns) because the beam can be spilled during those transients since it is improperly steered. On the other hand a quick turn-on is not compatible with the requirement for a 30-50 μs beam rise time in the linac so the rf control system can maintain the proper amplitude in each cavity. The solution[6] to these conflicting requirements is to pulse-width modulate the end of the deflector pulse for a period of 30-50 μs so the beam appears to the rf system to have the proper rise time.

The H⁻ line includes a device[7] labeled deflector/modulator which performs these functions. Deflection occurs in the vertical plane. The beam is stopped on the deflector jaws FJ3 in the middle of QL6.

## Trimming the Phase Space

During the course of tuning a beam line, it is necessary to make numerous measurements of the emittance of the beam. The values for emittance and
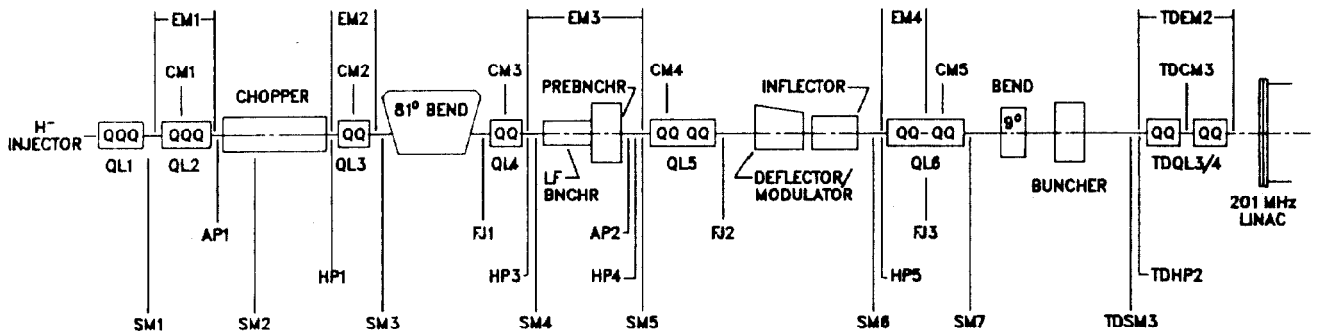
Fig. 3. Layout of H⁻ line with locations marked for quadrupole lenses (QL), steering magnets (SM), current monitors (CM), emittance stations (EM), harps (HP), variable apertures (AP), and collimating jaws (FJ).

phase space orientation calculated from these measurements is often suspect because the phase space is not elliptical; it can be distorted by wings produced by magnet aberrations and other non-linear effects. To remove these distortions it is necessary to have collimating jaws at judicious locations along the line.

Figure 3 shows the locations of the jaws and variable-diameter apertures. Those locations were determined by computer studies which transformed a slit (a line in phase space) through an array of elements. The jaws are mounted on opposing, independently-operated actuators.

### Initial Beam Tuning

The new H⁻ transport line was tuned for the first time during the week of 18 March 1985. A total of 8 mA of H⁻ beam was delivered to the drift-tube linac and about 6 mA was accelerated to 800 MeV. The following observations summarize our experience with that initial tune.

The 11 mA input beam had an emittance of 5 mr-cm. Upon entry to the line, the phase ellipse was near a waist with a radius of 0.7 cm. The design tune for such a beam, assuming constant current and emittance down the line, is shown in Fig. 4(a). This profile is quite similar to the one in Fig. 2(b) calculated for a 15 mA, 3 cm-mr beam, showing that the new line can handle a wide range of beam parameters.

While the new line can transport a 5 mr-cm beam, the linac cannot; it can only accelerate 2.5 mr-cm without excessive beam spill. Hence, it was necessary to collimate the beam severely at FJ2 and FJ3 and less so at other locations. Trimming the emittance reduced the beam current so that only 8 mA peak was delivered to the linac. The changes in emittance and current
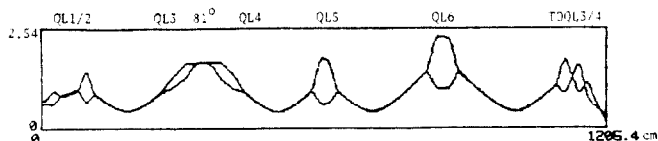

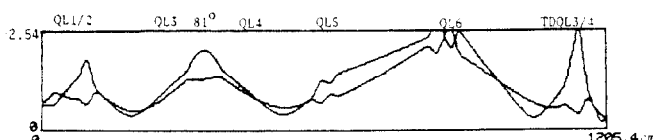
Fig. 4(a). Design profile for 11 mA, 5 mr-cm beam



Fig. 4(b). Preliminary tune for new line delivering 8 mA in 2.5 mr-cm to linac.

down the beam line made it difficult to calculate the envelope but Fig. 4(b) is thought to be a nominal profile.

The main difference between this profile and Fig. 4(a) is the large beam size in QL6 which resulted from the following circumstances. The admittance of the linac was given. The quadrupoles TDQL3/4 were fixed by the H⁺ tune. When the H⁻ beam was transformed backwards from the linac to QL6 assuming only 8 mA of space charge force, the large beam resulted. To effect a match on the upstream side of QL6, the quads QL5 had to be tuned to give a corresponding large beam at QL6.

Our conclusion from this initial tuning experience is that the new H⁻ transport line satisfies the design requirements and is easy to tune. We know of no reason why the line will not deliver the full 15 mA to the linac when the input emittance is improved to its design value of 3 mr-cm.

### References

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