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H- Injection for the AGS Booster

Y. Y. Lee

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Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

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Y. Y. LEE AND L. G. RATNER

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ACCELERATOR DEVELOPMENT DEPARTMENT

Brookhaven National Laboratory

Upton, N.Y. 11973

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I. INTRODUCTION

The AGS Booster will use H^- injection, as is presently done on most of the world's accelerators, for both polarized and unpolarized proton operation. The advantage of H^- charge exchange injection in permitting brighter beams because one can continue to inject into already occupied phase space in apparent violation of Liouville's Theorem, is well known. The use of a charge stripping foil converts H^- into protons, thus changing the direction of curvature in a magnetic field. This is an irreversible process and thus Liouville's Theorem is not applicable.

For H^- charge exchange injection, the closed orbit of the synchrotron is moved to the injection orbit where a stripping foil is located. For 200 MeV H^-, the foil is made of 100 - 200 μ gms per sq. CM. of carbon or aluminum oxide. The foil should be located downstream of or in the middle of the dipole field which separates the circulating proton orbit from the injected H^- from the Linac. Because of the difference in sign of the charges, the circulating beam and the injected beam merge tangentially at the foil location. If the foil is located downstream of the dipole field, the injected beam should be on an orbit which merges with the circulating beam at the edge of the dipole field. (Fig. 1)

There are several factors that dictate the particular injection geometry used on the booster. The chief of these is that it is very desirable to be able to inject polarized protons where β_V is a minimum and β_H is a maximum. Since the booster's function in the polarized proton mode is that of an accumulator, one wants to accumulate the maximum possible intensity, maximize the ratio of the admittance and foil area (β_H = max.), while at the same time minimizing vertical emittance growth due to multipole scattering because depolarization is proportional to the vertical amplitude (β_V = min.). This leads to positioning a foil near a magnet end and injecting through the magnet rather than at the center of a long straight section (Fig. 2) where both β_H and β_V have average values.

One might argue that some dilution of intensity and polarization is acceptable if one could avoid other complications such as injecting through a displaced dipole yoke. However a closer look at this scheme, which creates orbit bumps is one straight section, indicates other problems. Because the booster must maintain a 10^{-10} Torr vacuum for polarized proton accumulation and heavy ion acceleration, special ferrites must be used and a septum magnet required to deflect the incoming beam to the bumped orbit must be outside the vacuum chamber.

In addition, the circulating beam goes through several additional magnet edges which slightly changes the tune of the ring. There seems to be no simplification in this scheme and it is certainly prudent to minimize the number of insertions into the vacuum chamber and to accumulate a beam with the highest intensity and best polarization possible.

II. INJECTION SCHEME FOR HIGH INTENSITY UNPOLARIZED PROTONS

As in the case of the AGS, the stripping foil position must be experimentally determined to utilize the maximum available aperture and to achieve the maximum possible intensity. We wish to minimize the closed orbit bump and yet to maximize the available aperture. The good field region of the magnet is ± 3 inches and the foil will be located somewhere between 1" and 3" from the central orbit as determined by maximizing the accelerator intensity. This is shown schematically in Fig. 3.

The final foil position determines the useful aperture and when this is set, a D.C. orbit bump, produced by using extra windings at three lattice dipole locations, will move the closed orbit to the center of this aperture. If the optional foil position is 3", then this D.C. Bump is zero. As the magnet field ramps, the effect of this D.C. Bump becomes smaller and smaller and is essentially zero at full energy. See Fig. 3.

Next a fast orbit bump is used to move the circulating orbit on to the foil. The foil is located downstream of the C5 dipole and upstream of the C5 quadrupole. The trajectories of the H^- beam injected through the displaced yoke of the C5 dipole are shown in Fig. 3 for the 1", 2" and 3" foil positions.

With the DC and fast bumps on, injection starts at the center of the booster acceptance and moves towards the outside of the phase space as we decrease the size of the fast bump. The bump amplitude should decrease parabolically with a slope that matches the phase space area located at the orbit bump position. This will uniformly populate the available phase space. The fast bump is turned off at the end of injection and the size of the orbit bump at this time is the size of the injected beam plus the momentum space required after capture. Figure 4 shows the time sequence of this process.

Fig. 5 Shows the bump location in the ring lattice

The bump magnet has a rise time of 5~10 μ-sec. and the length of injection is 300-400 μ sec. One can also introduce a vertical fast dipole to spread the beam uniformly in the vertical phase space if this proved advantageous.

III. POLARIZED PROTON INJECTION

The booster is acting as an accumulator in this mode and we must therefore inject for some 20 - 30 linac pulses (2 to 3 seconds). One cannot keep the beam on the foil for this long without losing it due to multiple coulomb scattering. The solution for this is to bump the injected beam on the foil between the 300 - 400 μ sec injection pulses. Since pulses occur only every 100 msec, this leads to a good beam survival efficiency. Because of this bump, we have to equally divide the available aperture for injected and circulating beam. This dictates that the foil position is at -1" and the D. C. bump at +1". This allows 4" of aperture for both the injected and circulating beam. See Fig. 6.

Every time the linac is ready to inject into the booster, the circulating beam is bumped over to the stripping foil position. To minimize the multiple scattering losses, the bump rise time should be made as fast as possible, say 5 - 10 μ sec.

Another difference in this mode from the high intensity mode is the geometry of the stripper foil. As shown in AGS Tech. Note 186, it is important to focus the linac beam at the foil and to make the foil as small as the horizontal dimension of the linac beam. This is necessary to make the maximum number of circulating particles miss the foil. Also as previously mentioned, the foil is at a horizontal β max which also helps the accumulation efficiency.

IV. BOOSTER APERTURE

It was desirable that the booster performance with regard to intensity per pulse be equal or better than that of the AGS ($Q \approx 1.8 \times 10^{13}$). Since the AGS injector and the booster injector is the same machine, the injected emittance and momentum spread will be identical. If one then chooses the booster admittance equal or larger than that of the AGS, since the booster radius is smaller than that of the AGS, the space charge limit will be higher and we would expect that the booster should easily be able to perform as well as the AGS. Table 1 compares the booster and the AGS acceptance.

Both the booster and AGS tunes are close together and make both machines have strong coupling. When vertical and horizontal tunes are both in the same ½ unit of tune space, the coupling is such that the vertical aperture (smaller dimension) becomes the limiting aperture. This allows great freedom in the injection scenario (e.g. stripper foil radial placement) since the horizontal physical aperture is significantly larger than the vertical. However, if this proves a problem in practice (not expected since AGS works well) there is enough control to move the tunes apart by a ½ unit of tune.

TABLE 1 Comparison of Acceptance

	AGS	BOOSTER
Horizontal		
Physical size	127 mm	127 mm*
Momentum space (.5%)	11 mm	14.7mm
Betatron space available	116 mm	112.3
Maximum beta function	22.75 m	13.8 m
Betatron admittance	$127.9\pi x10^{-6}$	$228.5\pi x10^{-6}$
Vertical		
Physical size	75 mm	66 mm
Closed orbit error	5	5
Betatron space available	70	61
Maximum beta function	22.75	13.8 m
Admittance	$54\ \pi x1-^{-6}$	$67.4\pi x10^{-6}$

* Nominal position of injection stripping foil at 2 inches from center.

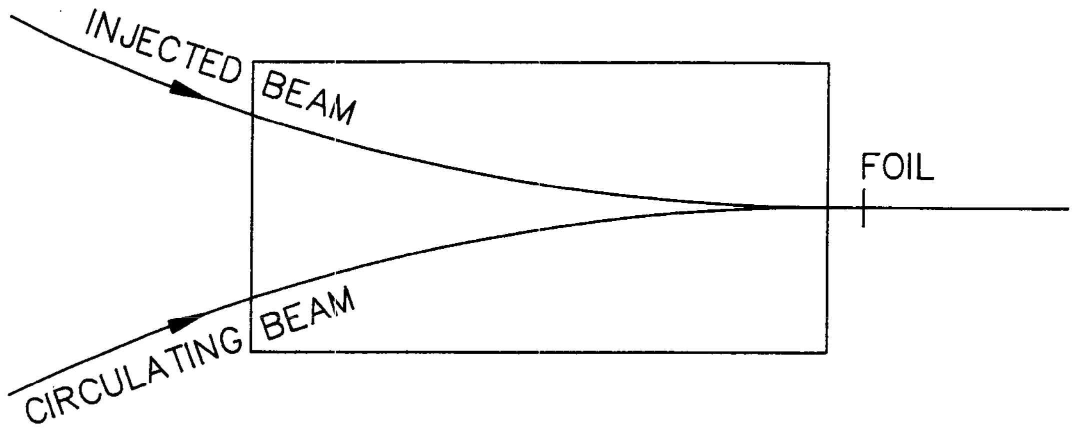

INJECTED BEAM
FOIL
CIRCULATING BEAM

Fig. 1

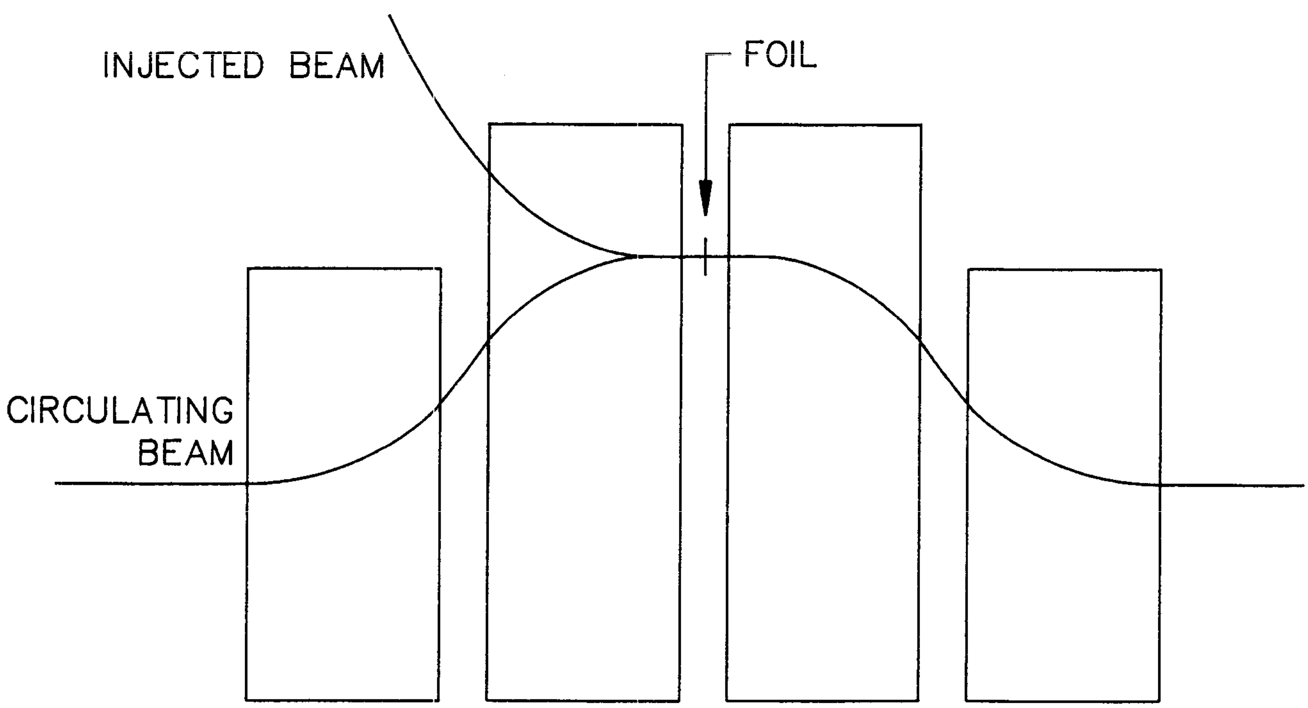
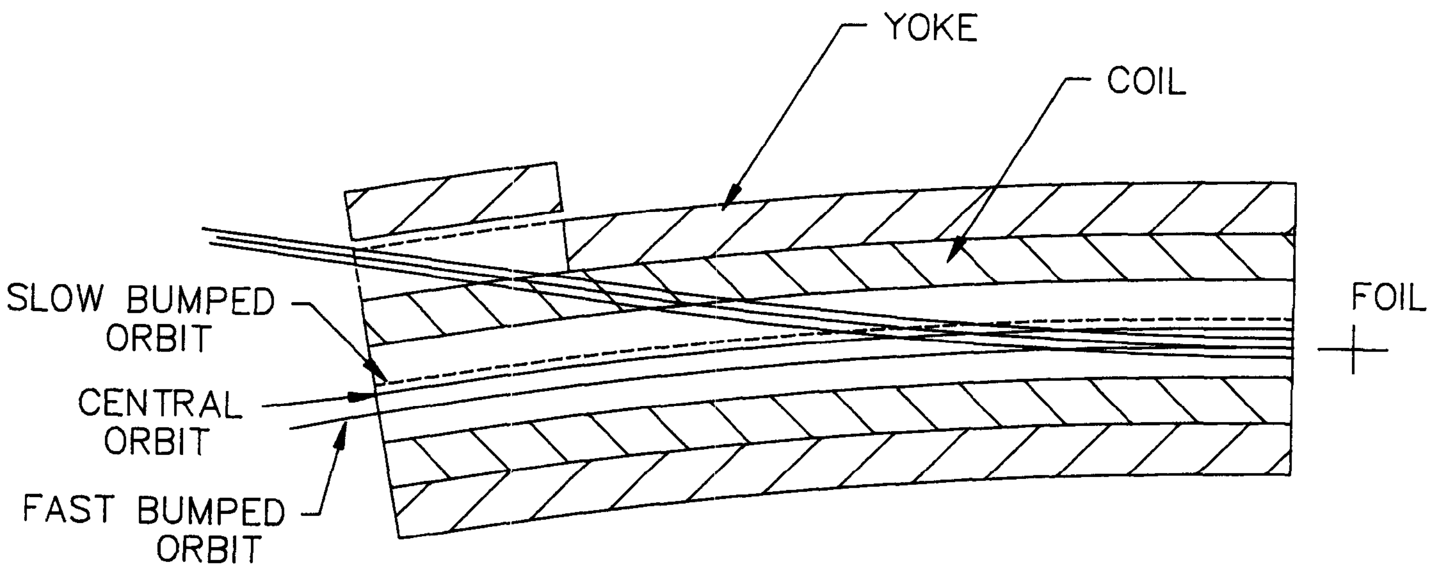

INJECTED BEAM
FOIL
CIRCULATING
BEAM

Fig. 2



INJECTION TRAJECTORIES (CD5)

Fig. 3

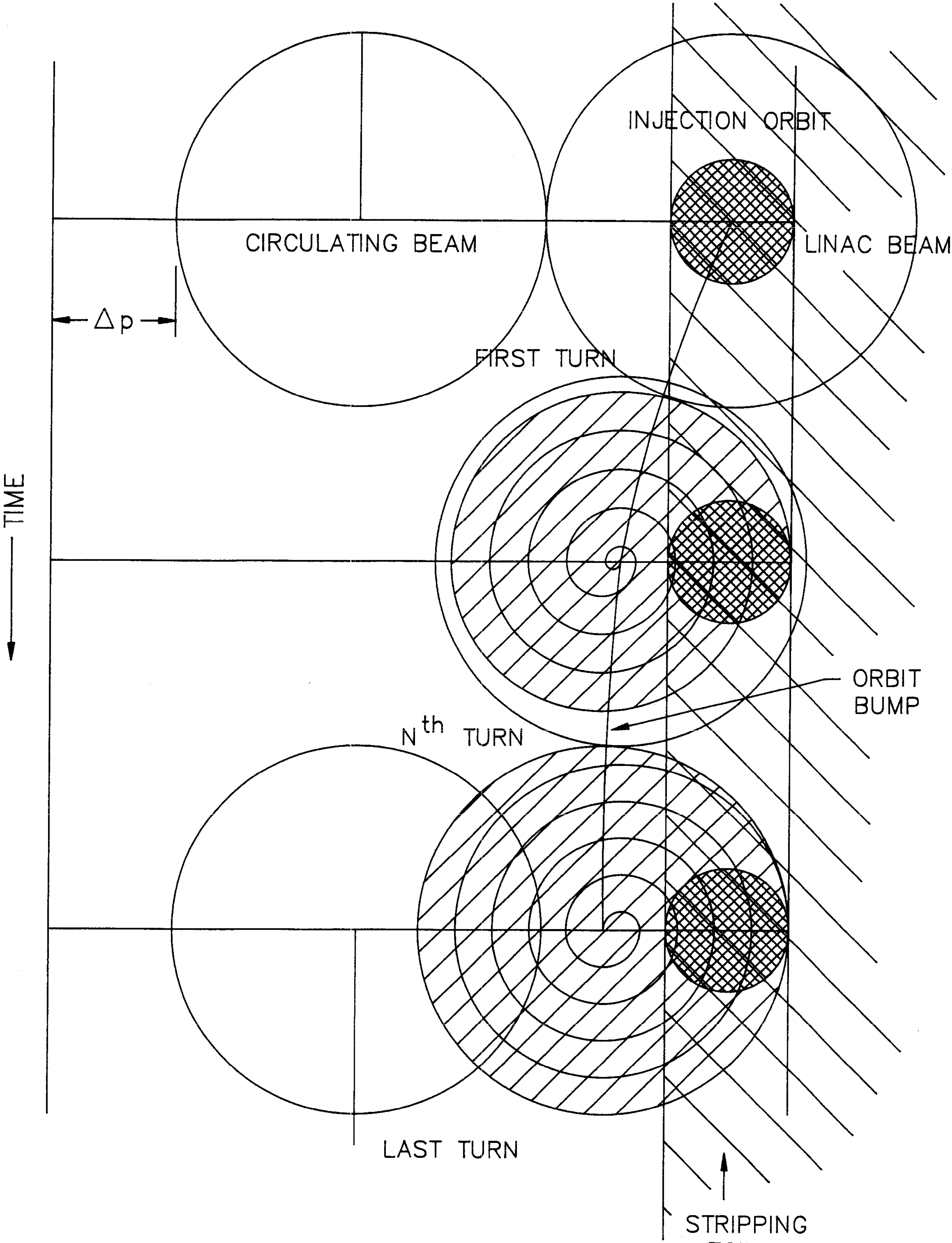

INJECTION ORBIT
CIRCULATING BEAM
LINAC BEAM
Δp
FIRST TURN
TIME
ORBIT
BUMP
Nth TURN
LAST TURN
STRIPPING
FOIL

Fig. 4

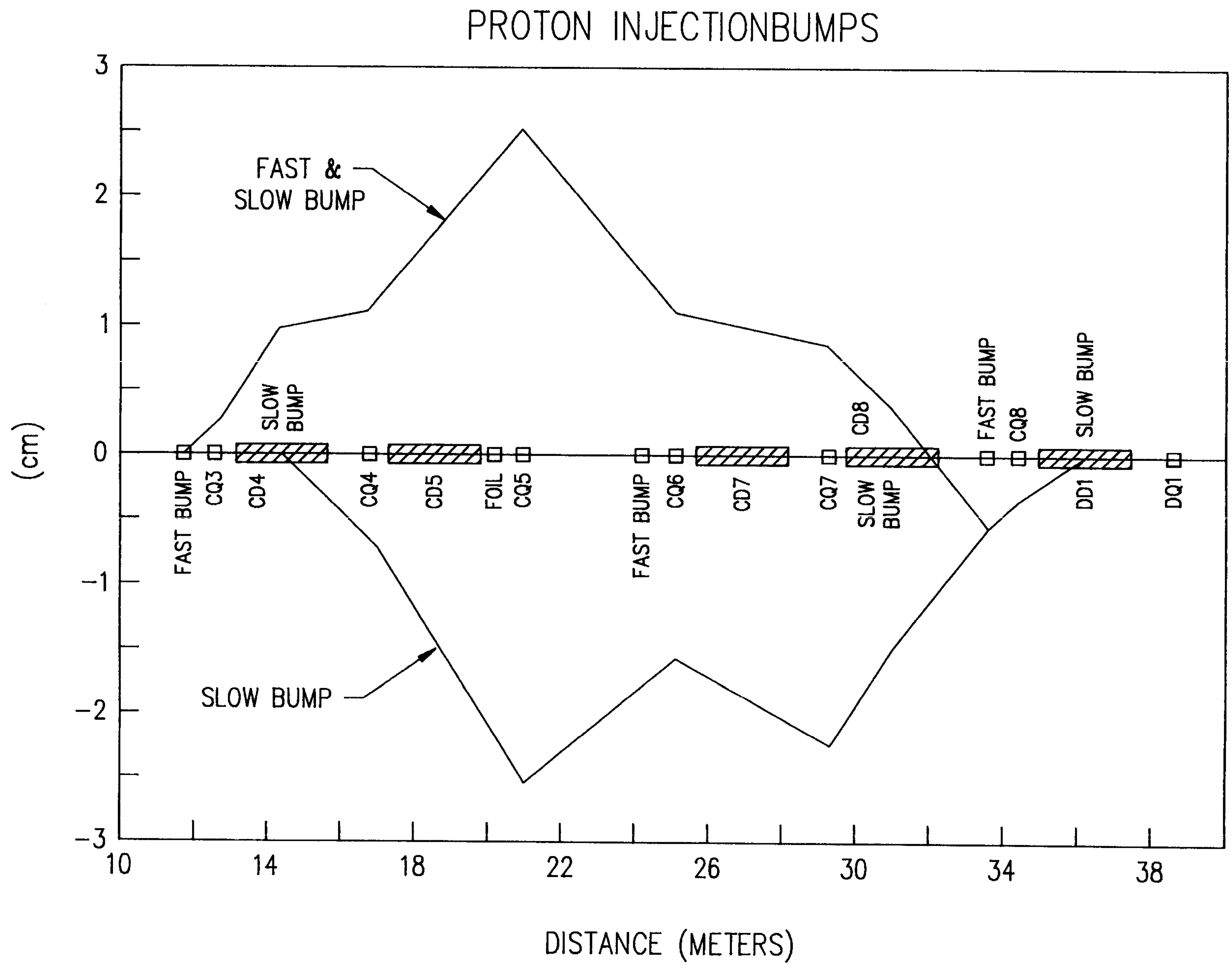

PROTON INJECTIONBUMPS
FAST &
SLOW BUMP
SLOW BUMP
FAST BUMP
CQ3
CD4
SLOW
BUMP
CQ4
CD5
FOIL
CQ5
FAST BUMP
CQ6
CD7
CQ7
CD8
SLOW
BUMP
FAST BUMP
CQ8
SLOW BUMP
DD1
DQ1
(cm)
3
2
1
0
−1
−2
−3
10
14
18
22
26
30
34
38
DISTANCE (METERS)

Fig. 5

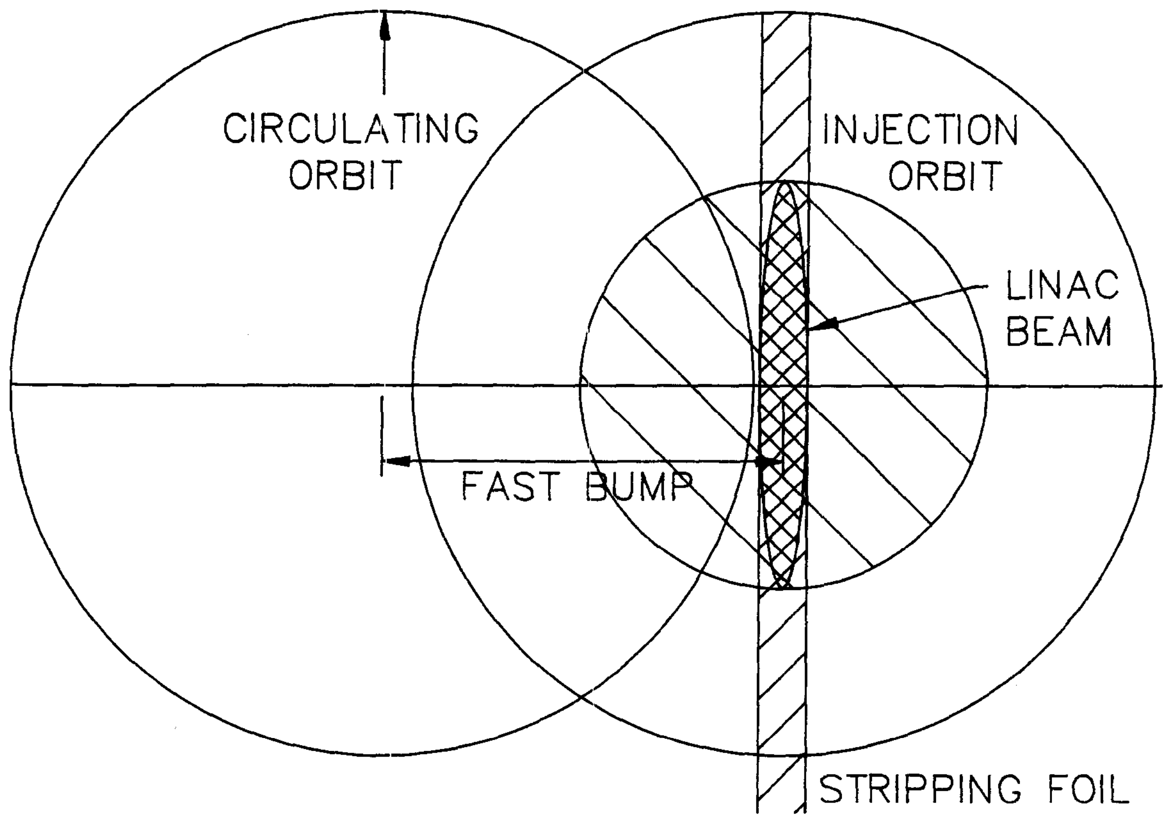

CIRCULATING
ORBIT
INJECTION
ORBIT
LINAC
BEAM
FAST BUMP
STRIPPING FOIL

Fig. 6