H^0 Injection for the JHP Compressor / Stretcher Ring

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Abstract

An H^0 injection system is proposed for the JHP compressor / stretcher ring (which had been formerly called as the JHF I-A ring). It is based on the two step stripping using a stripper magnet and a stripping foil. The H^0 beam is formed to match the ring optics at the stripping foil. In order to reduce the foil hitting probability to as low as 10 %, not only a corner foil but also a phase space painting by varying the bump orbit are proposed.

Introduction

At 1 GeV of the beam energy, one of the most important phenomena with respect to the transport of H^- beam is the Lorentz stripping [1], [2]. This phenomenon usually puts restrictions on the transport line of a high energy H^- beam. But it can also be a very useful technique, using a stripping magnet to produce an H^0 beam [3], [4].

For the JHP compressor / stretcher ring [5], a higher symmetric ring with 16 FODB cells has been proposed. And an H^0 injection scheme has been adopted, because the short straight section of the lattice could not contain the H^- injection system with a beam transport for the H^- beam which missed the foil.

JHP Compressor / Stretcher Ring

The JHP compressor / stretcher ring is planned to supply 1 GeV proton beam with an average current of 100 µA to both N (Neutron science) and M (Meson science) arenas. The function of the ring is as follows. The ring forms in its circumference two beam bunches 200nsec long from a beam pulse 400 µsec long and 10 mA high which is supplied by a 1 GeV linac at a repetition rate of 50 Hz. One of the two beam bunches is extracted from the ring just after injection and supplied to N arena.The remaining one destined to M arena is further changed in the bunch length depending on the operation mode. In the short bunch mode, it is further compressed to 20 nsec at the shortest and extracted by a fast extraction method. In the continuous beam mode, it is stored in the ring for as long as 15 msec at the most and extracted little by little with a slow extraction method.

The plan view of the ring presently designed is shown in Fig. 1. The circumference of the ring is 174.88 m. Betatron and dispersion functions for a cell is shown in Fig. 2. Acceptance of the ring and emittance of the ring beam are 120 πmmmrad and 30 πmmmrad respectively in both planes.

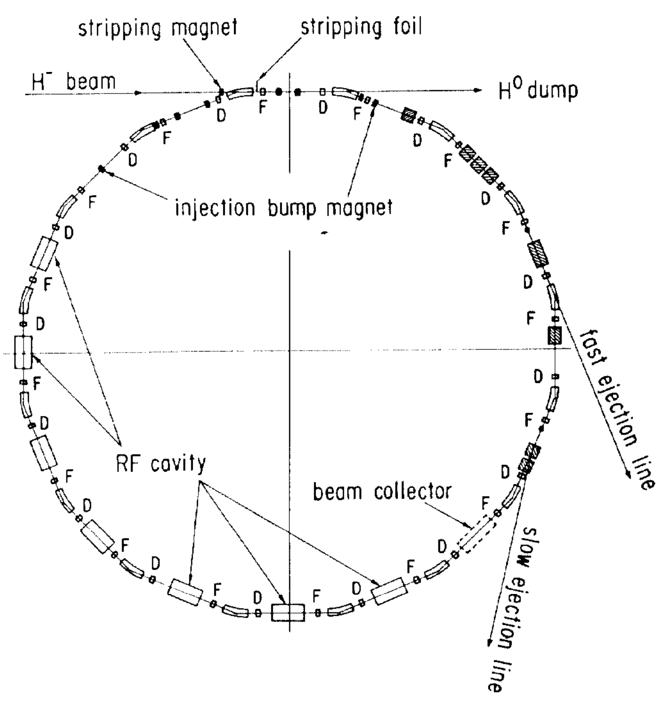

Fig. 1 Plan view of the JHP compressor / stretcher ring

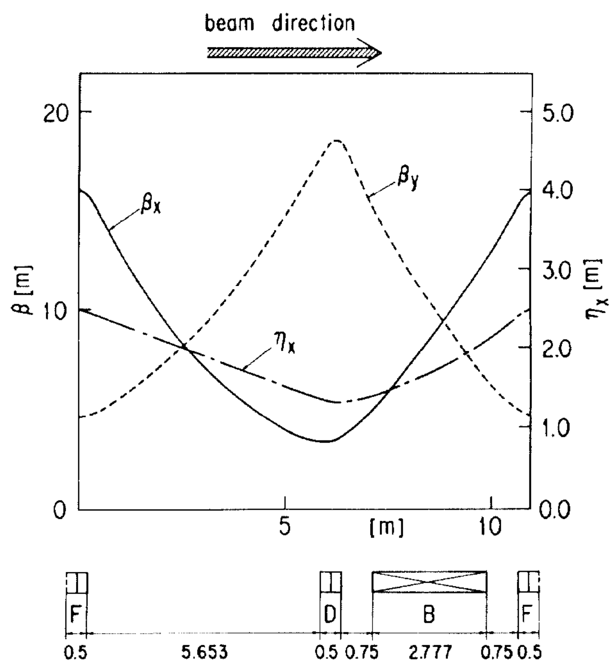

Fig. 2 Betatron and dispersion functions for one cell

H^0 Injection Scheme

The H^0 injection scheme shown in Fig. 3 is described in detail in a report [6]. It is based on a two step stripping using a stripper magnet and a stripping foil. In order to make the distance between the stripper magnet and the stripping foil as short as possible, the stripper magnet is placed just in front of the ring bending magnet and the stripping foil is inserted between the bending magnet and the ring quadrupole magnet.The polarity of this quadrupole magnet is selected as focussing in the horizontal plane so that the injection plane is horizontal. The stripping foil is a corner foil and placed just outside the ring acceptance and a bump orbit is formed in the horizontal plane during the injection so that the proton beam formed by the stripping foil comes into the required emittance of the ring beam. The bump orbit is variable in both horizontal and vertical planes to form a uniform beam by a proper phase space painting. Fig. 4 shows the injection bump orbit projected to both planes.

Fig. 5 shows the H^0 beam injection into the emittance ellipse of the ring beam. In this scheme, cares were taken not only to make the mismatch small between the H^0 beam and the ring optics, but also to make the foil hitting probability as low as possible. The H^0 beam is injected in such a manner that the envelope of the H^0 beam is tangent from inside to the 30 πmmmrad emittance ellipse in the phase space of each plane. For the phase space painting the bump orbit is varied in a proper way between (17.786, 2.085)and (0, 0) in the horizontal and also between (7. 965, -1.972) and (0, 0) in the vertical plane.

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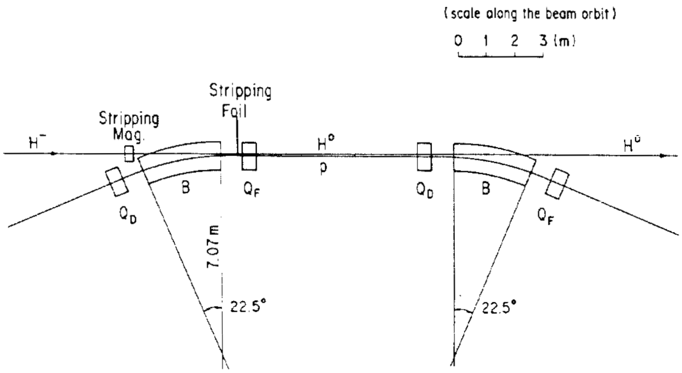


Fig. 3 H^0 injection scheme for the JHP compressor / stretcher ring

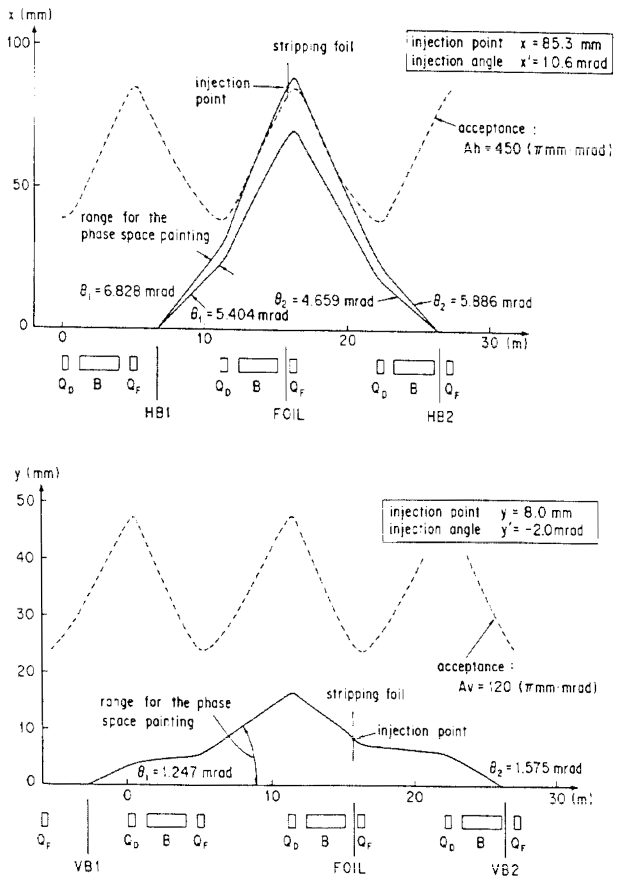


Fig. 4 Injection bump orbit in the horizontal (upper) and vertical (lower) plane.

Parameters of the H^- beam at the stripper magnet and the H^0 beam on the foil are summarised in Table 1. The H^- beam at the stripper magnet is a waist in the horizontal plane and convergent in the vertical plane.

Stripper Magnet

The stripper magnet is a special type of magnet that generates a very high field gradient to make Lorentz stripping localize in a very short range of beam flight path. As the field gradient is higher, enlargement of the beam angular spread, or emittance growth, is smaller. This type of stripper magnet was first developed at LASL[3]. It consists of a main gap to generates a very high field not lower than 1.8 T and an auxiliary gap to generates an opposite field lower than 0.4 T. The field gradient is about 1.3 T/cm.

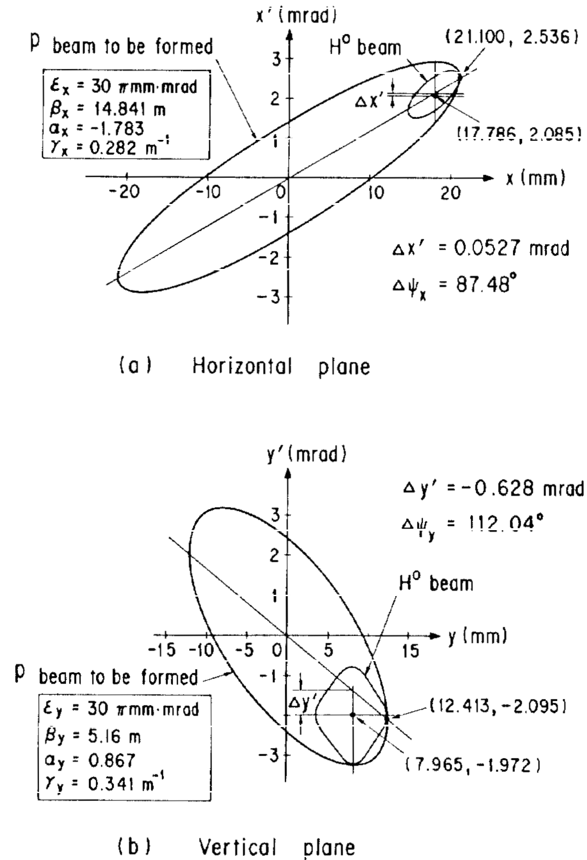
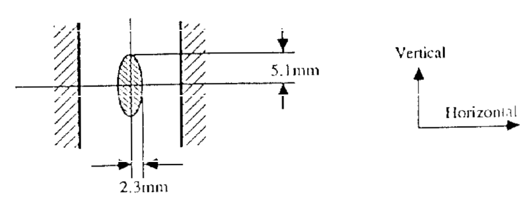


Fig. 5 H^0 beam injection into the emittance ellipse of the ring beam

Table 1 Summary of the H^- beam and the H^0 beam

Stripping magnet

Location	m	3.812 (upstream of foil)
Gap direction		Horizontal
Gap height	mm	≥11



H^- beam at the center of the stripping magnet

		Horizontal	Vertical
β	m	3.674	17.798
α		0	2.325
γ	1/m	0.272	0.360
ε	π·mm·mrad	1.44	1.44
Half width	mm	2.30	5.06
Half angle	mrad	0.63 (waist)	-0.72 (convergent)

H^0 beam on the foil

		Horizontal	Vertical
Half width	mm	3.31	4.45
Half angle	mrad	0.63	1.22

Fig. 6 shows examamples of calculated angular distribution for 1 GeV H^0 beam, where k is the field gradient in T/cm. When the field gradient is 1.3 T/cm, it is expected that the 95 % half width will be no more than 0.5 mrad.

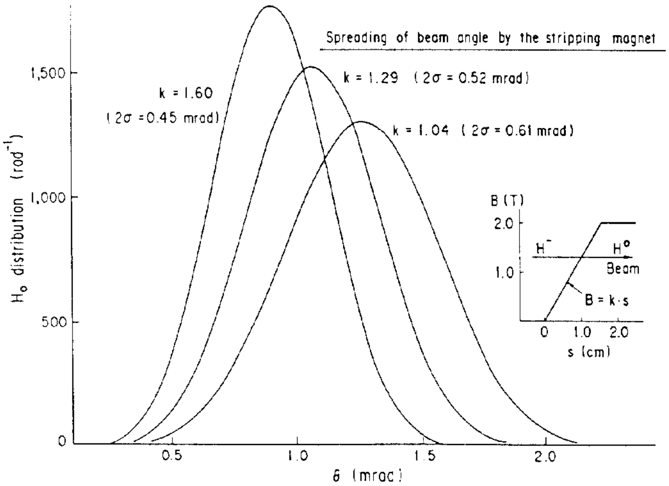
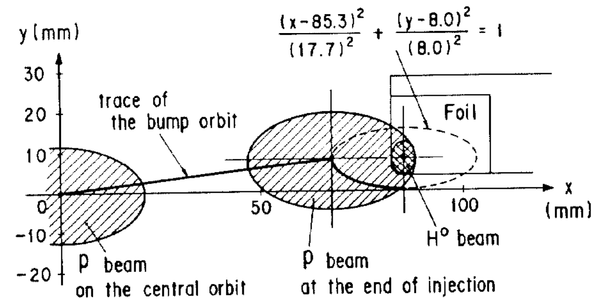


Fig. 6 Angular distribution of 1 GeV H^0 beam in the downstream of the stripper magnet

injection point	injection angle
x = 85.3 mm y = 8.0	x' = 10.6 mrad y' = -2.0



- variation of bump orbit at the foil location

$$x = 85.3 - 17.7\sqrt{(t/T)} \quad (\text{mm}) \quad (0 \le t \le T)$$
$$67.6\ (t-te)/(T-te) \quad (\text{mm}) \quad (T \le t \le te)$$
$$y = 8.0 - 8.0\sqrt{1-(t/T)} \quad (\text{mm}) \quad (0 \le t \le T)$$
$$8.0\ (t-te)/(T-te) \quad (\text{mm}) \quad (T \le t \le te)$$

- foil hitting probability = 8.3 %

Fig. 7 Phase space painting to form an elliptic beam

Stripping Foil

For the stripping foil a corner foil is proposed. The corner foil which is now under development is a double layer foil made by folding an annealed carbon foil. In an irradiation experiment with 3 MeV nitrogen beam, a 250 μg/cm^2 foil was given a 5 hour irradiation with the same energy dissipation rate as the JHP compressor / stretcher ring. Although slight deformation took place, such a serious deformation or breakage that would make the foil useless did not occur. It appeared that the foil would last much longer without serious damage.

The stripping efficiency of a 250 μg/cm^2 is estimated as about 98 %. The r.m.s. emittance growth due to the multiple scattering estimated by the formula in the ref.[7] is 0.23 πmmmrad for protons injected at the beginning, provided that the foil hitting probability is 10 % and a 250 μg/cm^2 carbon foil is used.

Beam loss due to large angle scattering includes the nuclear reaction and the Coulomb large angle scattering. As the total cross section of the elastic scattering of a 1 GeV proton by ^{12}C has been measured to be 370 mb [8], the loss rate due to the nuclear reaction is estimated to be 1.4×10^{-4}. Also loss rate due to the Coulomb scattering is estimated to be 7×10^{-5} by the formula in the ref.[9]. So total loss rate due to large angle scattering is 2.1×10^{-4}.

Beam loss rate due to large momentum transfer by a slngle Coulomb scattering is roughly estimated to be 3.2×10^{-4} using the formula in the ref.[10]. As for beam losses, a computer simulation is undertaken using a Monte Carlo tracking code ARCHSIM [11].

Phase Space Painting

A phase space painting is proposed not only to make particle distribution as uniform as possible but also to reduce the foil hotting probability as low as possible. When the injected beam emittance is very small, an elliptic beam with uniform particle distribution is formed by varying the bump orbit in such a way that the trace of the orbit at the foil location depicts an ellipse centered on the injected beam. Fig. 7 shows a case where the method is applied to the JHP compressor / stretcher ring. The bump orbit is varied with a function of time described in the figure. In this case, the foil hitting probability, which is estimated as the mean ratio of the beam area intercepted by the foil to the beam cross sectional area weighted by instantaneous proton number, becomes as low as 8.3 %.

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