H^- PAINTING INJECTION FOR THE JHF 3-GEV SYNCHROTRON

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Abstract

The JHF 3-GeV synchrotron is designed to accelerate 5×10^{13} protons at 25 Hz repetition rate. The injection painting of the H^- beam at 200 MeV will be performed in both the transversal planes. Two painting schemes which use different shape of the stripping foils are compared from view point of the beam losses.

1 INTRODUCTION

In order to achieve a uniform particle distribution at the injection stage, H^- painting is planned for the JHF 3-GeV ring[1]. A carbon foil of 200 μg/cm^2 is used for stripping two electrons. The painting area is 214 π mm mrad for both the transversal planes, although the lost beam/halo collection system has an accepatnce of 312 π mm mrad in order to allow for the possible beam blow-up after injection. The simulation code ACCSIM[2] is used to estimate the number of foil traversals of protons, which affects the beam loss due to large-angle scattering. Longitudinal painting is not performed intensionally.

2 PAINTING SCHEME

2.1 Painting with a corner foil

One long-straight section, 5.2 m long, accommodates the eight horizontal bump magnets in order to produce the horizontal closed orbit distortion (cod) while in the vertical plane a pair of magnets, which are located 180 degrees apart in phase, produce the vertical one. A two-edge-support foil (corner foil) is used for charge stripping. Fig. 1 shows the horizontal cod at the beginning and the end of injection. Painting starts near to the border of the ellipse of the circulating beam, and continues until it fills the central region. The vertical cod is, on the contrary, maximum at the beginning to pass through the stripping foil, as shown in Fig. 2. In the figures, beam envelope is shown for 214 π mm mrad by a solid line and for 312 π mm mrad by a dotted line. Each cod at the foil is expressed by,

$$\begin{aligned} horizontal\ cod &= 37.8\left(1-\sqrt{1-\frac{t}{T}}\right)+46.1, \quad mm \\ vertical\ cod &= 40.0\left(1-\sqrt{\frac{t}{T}}\right)+16.9, \quad mm \end{aligned} \tag{1}$$

where T denotes the injection period (0.5 ms). The corresponding phase-spase trajectory is shown in Fig. 3

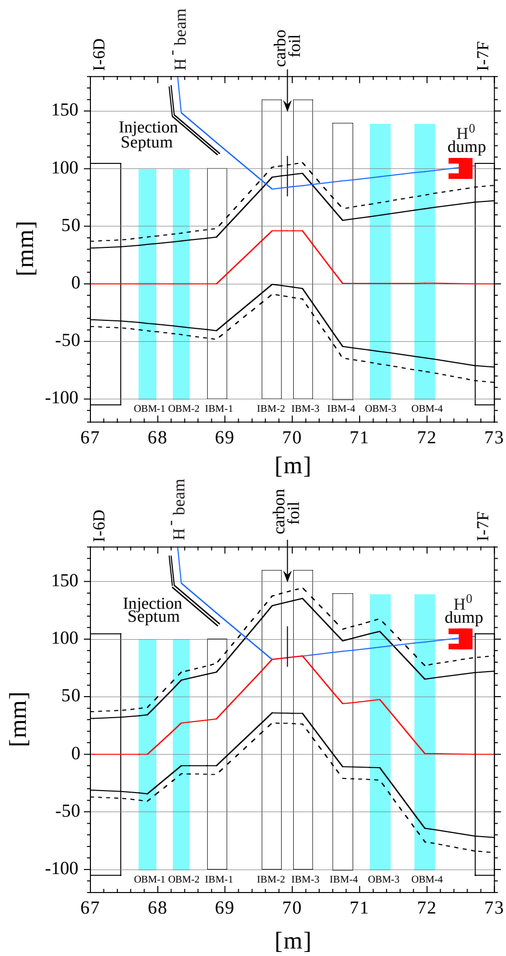

Figure 1: H^- painting in the horizontal plane with a corner foil at the beginning (upper) and at the end (lower). For painting with a one-edge-support foil, time is reversed.

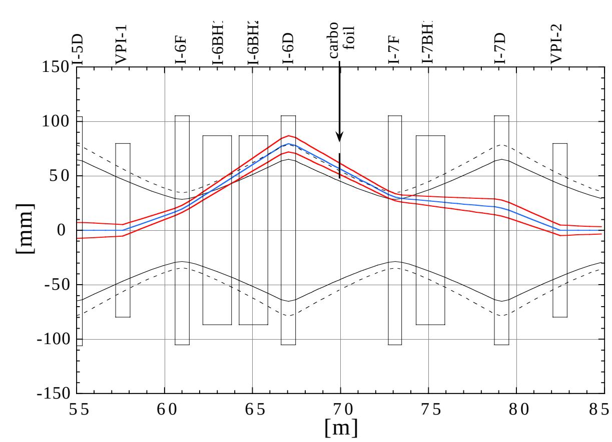

Figure 2: H^- painting in the vertical plane at the beginning with a corner foil.

for the right momentum. The emittance of the linac beam is 2.8 π mm·mrad (90%-emittance) with a momentum spread of ±0.1% (100%-spread).

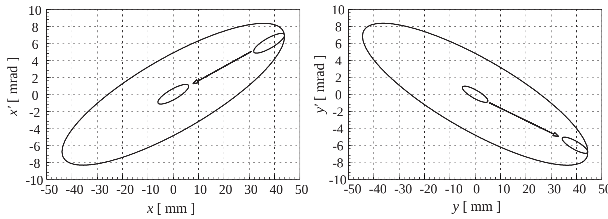

Figure 3: Phase-space trajectory of the injected beam in the horizontal (left) and vertical (right) planes with a corner foil. Area of a large ellipse is 214 π mm mrad.

2.2 Painting with a one-edge-support foil

As can be seen in eq. (1), the horizontal cod increases with time and has a sharp peak at the end of injection, which is not easy to produce by a conventional circuit; the peak current of the bump magnets is as high as 59 kA. Instead, the incoming beam is kicked vertically at the π-radian upstream of the linac-to-ring transport line as

$$vertical\,kick = 4.1\sqrt{1-\frac{t}{T}}, \qquad mrad. \qquad (2)$$

The horizontal cod then decreases with time although the same bump magnets are used, which is given by,

$$horizontal\,cod = 37.8\left(1-\sqrt{\frac{t}{T}}\right)+46.1, \quad mm. \qquad (3)$$

The phase-space trajectory is shown in Fig. 4. With this method, a one-edge-support foil or a postage stamp foil[3] must be used in order to reduce the number of hits of protons upon the stripping foil.

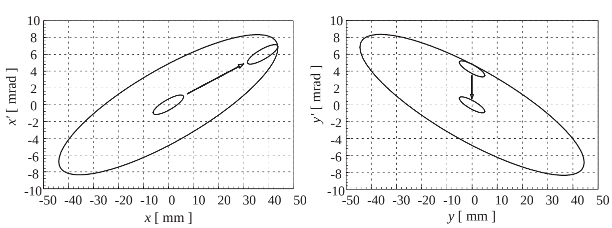

Figure 4: Phase-space trajectory of the injected beam with a one-edge-support foil.

3 ACCSIM CALCULATIONS

A simulation of painting with eqs. (1)-(3) is made by the computer code ACCSIM. The injection starts at 0.3 ms before and ends 0.2 ms after the field minimum of the ring magnets. In order to achieve an efficient RF capture, the beam is chopped between –100 and +100 degrees of the RF phase. Although the longitudinal painting is not performed intentionally, some painting can be expected due to the momentum mismatch at injection (-0.27% max.). The number of injected particles per 250 turns is 10,000. Figs. 5 and 6 show the result of the ACCSIM run, where the space-charge-force calculation is on for longitudinal, and off for transversal planes. The average number of hits per one proton is 4.2 for a corner foil, and is 3.2 for a one-edge-support foil, where the distance of the injected beam to the nearest border of the foil is taken to be 3 mm for both cases. For the latter case, the beam

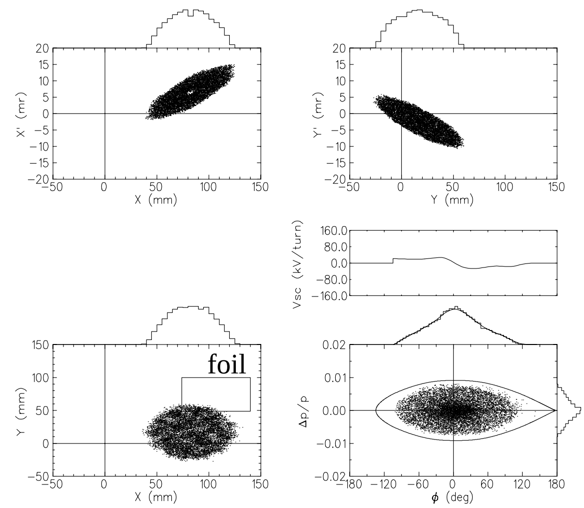

Figure 5: ACCSIM calculation with a corner foil at the end of injection. Foil is supported at the right and upper edges by the frame.

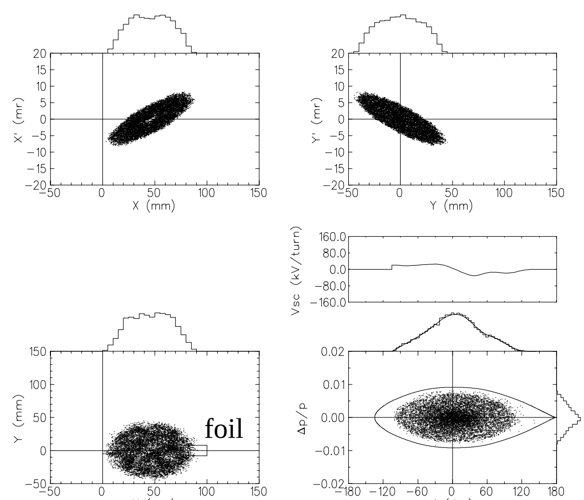

Figure 6: ACCSIM calculation with a one-edge-support foil at the end of injection. Foil is supported at the right edge by the frame.

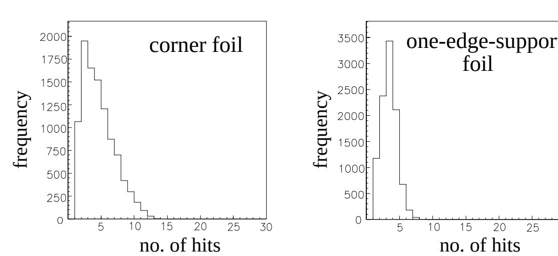

Figure 7: Frequency distribution of hits of protons with stripping foil; corner foil (left) and one-edge-support foil (right).

center always stays at y=0. Fig. 7 shows the frequency distribution of hits, where the width is much narrower for a one-edge-support foil.

4 BEAM LOSSES

4.1 Lorentz Stripping

The H^- beam passes through the injection septum magnet and the bump maget (IBM-2) in Fig. 1. Neutralization of the beam due to Lorentz stripping[4] occurs depending upon the bending radius and the magnetic length. For the parameters in Table 1, neutralization is less than 10^{-5}.

Table 1: Injection magnet parameters

	bending radius [m]	magnetic length [m]
Septum	2.59	1.31
Bump (IBM-2)	5.37	0.30

4.2 H^0 Excited State

Using a carbon foil of 200 μg/cm^2 thick, 99.6% of the H^- beam is converted to protons[5] and the rest into each excited state of $H^0(n)$ atoms, where n is the principal quantum number of the excited state. Significant amount of the excited states will decay into protons on the way to the H^0 dump unless the bump field is properly adjusted. Those particles become a beam halo, and are lost somewhere else in the ring. In order to minimize such a halo, the field strengths of the IBM-3, IBM-4, OBM-3 and OBM-4 in Fig. 1 are selected as 0.50~0.55 Tesla, so that those particles with $n \geq 5$ promptly become protons when they enter the bump field, and those with $n \leq 4$ have a longer lifetime than the transit time through each magnet (1.8 ns)[6]. Total yield of the excited state having $n \geq 5$ is estimated by assuming that the branching ratio to the excited state (n) is proportional to the statistical factor (n^{-3})[7]. Then,

$$\begin{aligned} total\, yield(n \geq 5) &= (1 - 0.996) \times \sum_{n=5}^{\infty} 1/n^3 \Big/ \left(\sum_{n=1}^{\infty} 1/n^3 \right) \\ &= 8.1 \times 10^{-5} \end{aligned}$$

4.3 Large-angle scattering

Multi-traversal of beam through a carbon foil, as shown in Fig. 7, leads to the beam loss due to a large-angle scattering of protons. For simplicity, such effect is estimated by assuming a single-pass of protons through a thicker foil; the thickness is taken to be nine-times the real thickness (1.8 mg/cm^2). The angular distribution $\sigma(\theta)$ for such a case is calculated by MARS code[8] as shown in Fig. 8. The loss rate where the scattered particles are intercepted by a chamber wall is higher for painting with a corner foil than that with a one-edge-support foil because the vertical cod passes very close to the vacuum chamber for the former case. Using $\sigma(\theta)$, the loss rate is calculated as 3×10^{-3} at most at the vertical chamber wall of I-6BH' in Fig. 2. However, it is 3×10^{-4} for the latter case.

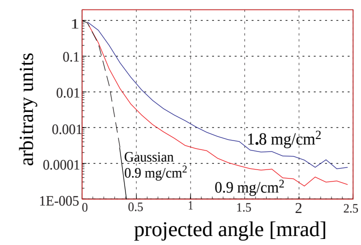

Figure 8: Projected angular distribution of 200 MeV protons scattered by a thicker foil. Gaussian distribution is also shown for comparison.

5 CONCLUSIONS

Beam loss during injection is considered on the two painting schemes using a corner foil and a one-edge-support foil. As for a large-angle scattering, the loss rate with a corner foil is 3×10^{-3}, which is one order higher than that with a one-edge-support foil. Beam loss due to Lorentz stripping and the H^0 excited states are estimated to be less than 10^{-5} and 8.1×10^{-5}, respectively, for both schemes.

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