ESTIMATIONS ON THE BEAM HALO COLLECTION AT THE HIGH INTENSITY ACCELERATOR

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Abstract

At the high intensity hadron synchrotron, the importance of the beam loss control grows up from view point of machine maintenance as well as radiation shielding. The beam shaping is carried out during the injection period because the beam has the largest emittance and the minimum energy. Once the beam shape was corrected into the proper shape in emittance, it becomes easier to handle the beam with the minimum beam losses. Halo collectors are introduced in order to keep the hands-on-maintenance area free from residual radio-activities by localizing the beam losses on the collimator area. Halo collection schemes were investigated with various injection energies and machine apertures by using STRUCT code. Especially, the effects from the COD on the ratio of the collimator aperture to the magnet one are described in this report.

1 HALO COLLECTION SYSTEM

Halo collection is an important technique for the high intensity hadron accelerator from the point of view of the radiation shielding and machine maintenance. The purpose of the halo collection is to keep the hands-on-maintenance area free from residual radio-activities. By using the STRUCT[1] code developped in FNAL[1], beam loss in the ring accelerator can be simulated.

When the high intensity beam is treated, amounts of beam loss becomes a serious subject. The average beam loss should be kept at an order of one watt per meter for hands-on-maintenance area. Though generally it is difficult to control beam loss at low level along the whole ring, it is possible to localize the losses in a restricted area.

Test collection system consists of hv-thin tungsten targets and eight iron collimators which is based on the JHF 3GeV ring lattice[2][2]. One of four superperiods is selected as the collimation area. Halo scattering targets are located in both plane with primary collimators. Target thickness is 2 mm and length of collimators is 36 cm. Locations of the secondary halo collimators are listed in Table 1.

Fig.1 shows the test beam distribution. Particles have a Gaussian distribution where the 3σ corresponds to the 312π mm mrad which is the halo collector's aperture. There are four assumptions on the particle distribution:

[1]Notice: Although STRUCT99 has the option for the rectangular bend, the acculacy is not sufficient for the vertical plane and the edge effect is fixed to the half of the bending angle.

[2]Originally this work started as JHF ring design.

Table 1: Phase advances of the secondary collimators from the primary ones. [πrad]

HPRI	col-2H	col-25H	col-3H
0.0	0.6	7.4	15.3
VPRI	**col-2V**	**col-25V**	**col-3V**
0.0	0.5	7.5	15.2

- Beam has a Gaussian distribution in every plane. 3σ corresponds to the halo collector's aperture.
- Transverse distribution is limited up to 3.5σ. This means the fast beam blow-up from the non-linear effects is small.
- Particles which have horizontally large emittance have vertically small one and vice versa. This scheme represents the h-v painting injection.
- Longitudinal distribution is applied only on the particle momentum. Particle momentum distribution is also Gaussian and 3σ corresponds to $\frac{\Delta p}{p}$ = 0.5% without any limitation.

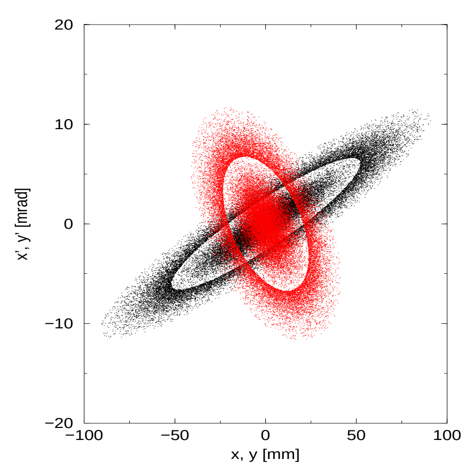

Figure 1: Test beam distribution at the entrance of the ring.

2 RESULTS AND DISCUSSIONS

2.1 Aperture Ratio

At first, we call the apertures of drift spaces and magnets as the bare aperture in order to distinguish the collimator aperture. The bare aperture is often identical to the magnet aperture. For the effective beam halo collection, the collimator aperture must be smaller than the bare aperture. When the design beam emittance was defined, the collimator aperture is also determined uniquely. For big bare/collimator aperture ratio, magnets must be made with wider apertures, and it makes higher the cost of magnet production. Generally bare aperture is limited by the bending magnets in vertical, and by quadrupole magnets at the large dispersion function places in horizontal. Fig.2 shows the beam loss distribution along the ring.

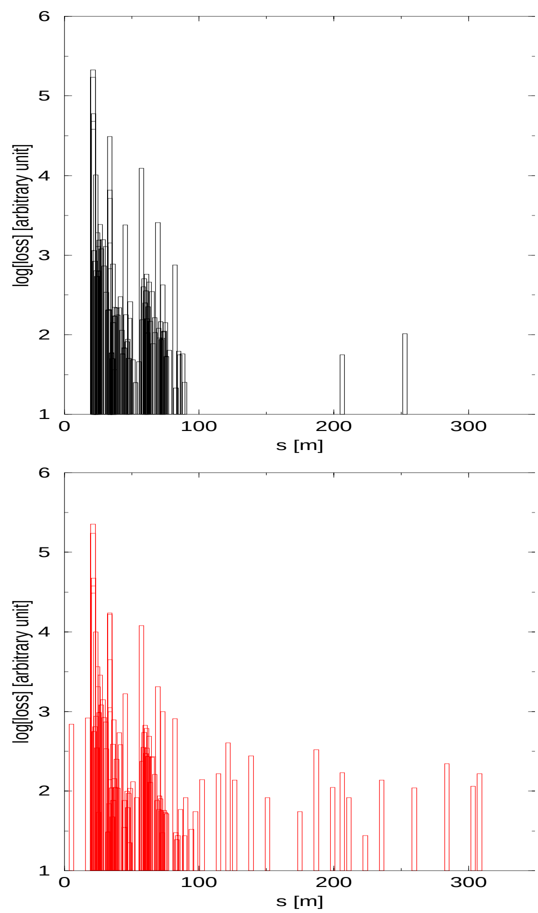

Figure 2: Beam loss distribution with different bare aperture. $A_{b/c}$ = 1.73 (upper), 1.40 (lower)

The first superperiod is the collimation area which is about 85 m long. The ratio of the energy deposit from the first halo scattering target to the last halo collimator with respect to the total energy loss is defined as the area collection efficiency. When the halo collector works well, beam loss can be localized into the stricted area, but when bare aperture is small with respect to the collimator aperture, beam loss occurs in the hands-on-maintenance area and the area collection efficiency decreases.

Now, we introduce one parameter $A_{b/c}$ as the aperture ratio, that is,

$$A_{b/c} = \frac{(bare\ aperture)}{(collimator\ aper.) + (COD\ contribution)} \quad (1)$$

On the aperture definition, the contribution from $\eta\frac{\Delta p}{p}$ is not included here.

The ratio between the bare aperture and collimator aperture $A_{b/c}$ should be larger than 1.4 in phase space. Lower graph of Fig.2 corresponds to $A_{b/c}$ = 1.4 and the area collection efficiency is 93.9%. When bare aperture is less than 1.4, the area collection efficiency gets worse rapidly.

2.2 Effect from the Closed Orbit Distortion

The area collection efficiencies with various closed orbit distortions up to 15 mm are shown in Fig.3 with respect to the various bare/collimator aperture ratio $A_{b/c}$. The injection orbit was corrected according to the amount of orbit deviations in order to match the injection condition in phase space. The larger bare/collimator aperture ratio gives the better area collection efficiency and critical $A_{b/c}$ value becomes a little smaller. As the similar simulation was also carried out with unmatched injection condition, there are no remarkable difference.

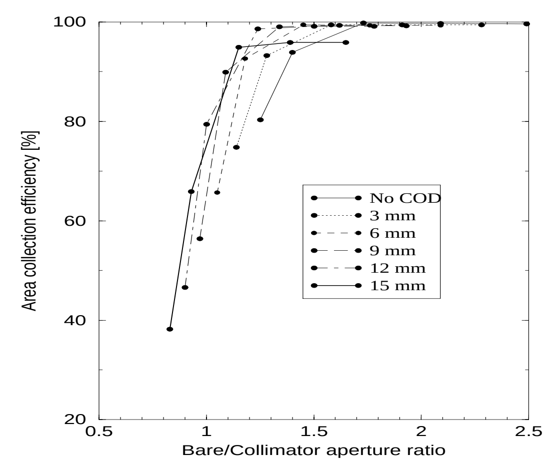

Figure 3: Area collection efficiencies with various CODs. (0 $\sim$ 15 mm)

Halo collectors are located partly in the ring. Then, the effect from the closed orbit distortion is not equivalent to that from the small bare aperture. The collimator collection efficiency is shown in Fig.4 of the same condition. Collimator collection efficiency means the ratio of the energy deposits on collimators and scattering targets with respect to the total beam loss energy. The orbit distortion gives rather higer collection efficiency. When closed orbit distortion exists, particles survive with large emittance and hit the smallest aperture elements, that is, collimators a few turns later.

Though the total beam loss increases when the beam orbit displaced by error fields, 99% area collection efficiency

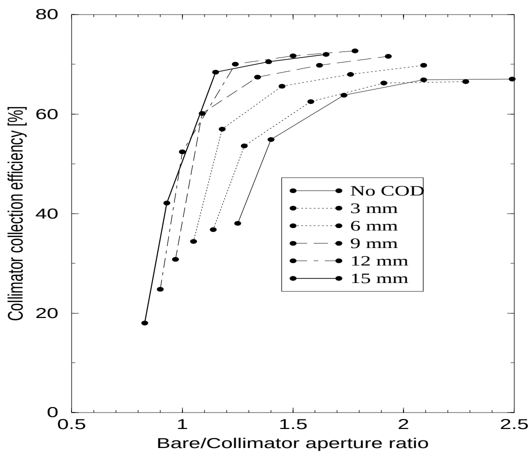

Figure 4: Collimator collection efficiencies with various COD. (0 $\sim$ 15 mm)

can be kept with proper $A_{b/c}$ value and collimator collection efficiency improves. But amount of efficiency improvements doesn't catch up the increase of the total beam loss. It causes the radiation damage on magnets in collimation area. The smallest COD presents the best injection condition. Anyway, the effect by the closed orbit distortion is not so serious and generally, closed orbit distortion is corrected into about a few millimeters by the correction dipoles in actual operation.

2.3 Energy Dependencies

With the various beam energies: 200, 400 and 600 MeV, the same lattice and same collection system were taken into consideration. The collimator collection efficiency gets better according to the energy increase. The difference mainly comes from the particle scattering condition on targets. Extremely large scattered particles are hits downstream magnets right away. On the other hand, when the energy is higher, particles are scattered to the forward direction and particles which have a large emittance but survive several turns in the ring increases. This is a very simillar situation of COD effects. Survived particles with large emittance will be lost at the collimators which have the minimum aperture in the ring after all.

When the target thickness was scaled to have the same rms scattering angle, the energy dependency disappered.

2.4 Collimator Length and Large Halo Beam

Although the area collection efficiencies are more then 99%, the collimator collection efficiencies stay around 70%. This means that the magnets located in the halo collection area are hitted by the beam and damaged radiatively . As collimators are located according to the betatron phase from the halo scattering targets, beam halo has a ditribution according to the scattering angles. The longer collimators are tested but there is only 5% improvement for at the maximum with twice and 3 times longer collimators. When COD becomes large, this improvement vanishes. The lengthenning of collimators is not efficient. In order to improve the collimator collection efficiency, some extra collimators are necessary before the elements which require the radiation protection.

For the test beam distribution, 3.5σ transverse emittance limitation was assumed. The similar test with the large beam halo was also carried out up to 4σ transverse emittance. When beam emittance is larger than the bare aperture, halo collection system doesn't work well and energy deposition onto the hands-on-maintenance area cannot be ignored. Bad quality of the beam transport process at the injection and fast beam blow-up with non-linear effects in the ring must be avoided. This type of halo collection system cannot handle them.

3 CONCLUSIONS

- Bare aperture must be 1.4 times larger than that of collimators.
- In order to improve the collimator collection efficiensy, extra collimators are necessary before the hot elements. Lengthenning of collimators is not effective.
- The effect from the closed orbit distortion is not so serious because the halo collection efficiency increases according to that. However, since the total beam loss also increases, it should be avoided.
- There is no energy dependence on the halo collection efficiency.
- Extreme large halo and fast beam blow-up must be avoided with other treatment.

4 REFERENCES

[1] A. Drozhdin, N. Mokhov, ”The STRUCT Program User's Reference Manual”, FNAL, December 1999.

[2] JHF Project Office, “JHF ACCELERATOR DESIGN STUDY REPORT”, KEK Report 97-16, JHF-97-10, March 1998.