JHF synchrotron as a proton driver

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Abstract. Japan Hadron Facility (JHF) is approved last year and we are expecting the first beam in 5 years. We will describe the design and status of the synchrotrons.

1. Introduction

Japan Hadron Facility (JHF) is a multipurpose facility with high intensity proton synchrotrons. There are mainly two physics motivations corresponding to two synchrotrons. One is nuclear and particle physics for which the 50 GeV main ring (MR) will provide 3.3×10^{14} particles per pulse. The intense protons produce secondary particles such as kaon, pion, muon, and neutrino [2], [1]. The other is all kinds of science such as material science using spallation neutrons produced by 3 GeV rapid cycling synchrotron (RCS). The beam intensity of RCS is 8.3×10^{13} ppp or 1 MW. The RCS also provides intense muons as secondary particles. The main parameters of the two synchrotrons are listed in Table 1.

Table 1. Main parameters of the two synchrotrons

50 GeV MR	
Protons per pulse	3.3×10^{14}
Repetitions	0.3 Hz
Average current	15 μA
Beam power	0.75 MW
3 GeV RCS	
Protons per pulse	8.3×10^{13}
Repetitions	25 Hz
Average current	333 μA
Beam power	1 MW

The MR has nine buckets and eight out of nine is filled with bunches. There are two extraction channels separately located in the two long (more than 100 m long) straight sections of three fold symmetry lattice. One is fast extraction and the other is slow one. The fast extraction channel extracts a whole beam in a single turn and the slow one extracts a beam gradually in the time scale of a few 100 milliseconds. The single *turn* extraction should be the way of a proton driver for conventional neutrino

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detector. However, the consecutive single *bunch* extraction scheme will be utilized for a neutrino factory.

The construction site is JAERI Tokai which is about 60 km north of KEK. The first beam is expected in 5 years.

2. Design philosophy

The most crucial issue of this facility is the beam loss in those high intensity synchrotrons. The source of beam loss can be space charge effects and all kinds of beam instability. Among them, e-p instability is intensively studied. Those are direct outcomes of high intensity beams. There is also a possible source which may not directly related with high intensity beams but it comes out serious because of large aperture of the beam chamber. One example is fringe field and its nonlinearity. Honestly speaking, the behavior of high intensity beams is still one of research subjects of accelerator physics. Therefore, many attempts have to be incorporated to increase the machine performance in total. The following is a few example to decrease beam loss.

2.1. Injection painting

The most effective way to ease the space charge effects is to dilute particles uniformly in a limited phase space volume. That can be done by transverse painting in the transverse phase space and by a deformed RF bucket with higher harmonic RF. In RCS, both anti-correlated painting, by that small amplitude particles are filled first in horizontal and large amplitude particles in vertical, or vise versa, and correlated painting, by that small amplitude particles are filled first in horizontal and vertical together, are considered. The present hardware is able to make both. The pros and cons of two schemes are eventually clarified by the real beams, although simulations shows that the anti-correlated painting may induce strong emittance exchange at the beginning and produce halo particles.

The transfer between RCS and MR is so-called bucket to bunch one, so that manipulation of transverse phase space is not possible at injection of MR.

2.2. Higher harmonic RF

Also in RCS, the second harmonic RF is added in order to increase the bunching factor. With momentum offset of injection beam with respect to the center of RF bucket, simulation shows that the bunching factor of 0.4 is available as shown in Fig. 1.

In order for the best match between RCS and MR in longitudinal phase space, RF bucket in MR should have the second harmonic. In MR, however, we need to have additional RF cavities for the second harmonic RF whereas the same RF cavities as for the fundamental RF can accommodate second harmonic RF in RCS. That is due to the difference of Q value, that is about unity in RCS and about 10 in MR. It is not clear if we will start commissioning of the beam with second harmonic RF in MR.

2.3. Careful selection of bare tune

It is clear that the particles should stay away from any harmful resonances for the whole cycle. The selection of bare tune becomes straight forward if the all particles

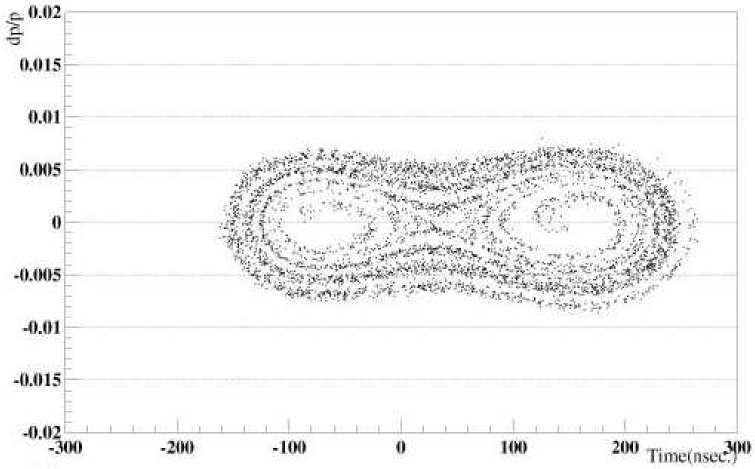

Figure 1. With second harmonic RF, there is two fixed points in a bucket and particles are distributed uniformly in longitudinal direction. Bunching factor becomes 0.4.

have the single tune, but less obvious when there are tune spread among particles. With multi-particle tracking including space charge effects, the beam loss behavior is studied.

Figure 2 shows the tune diagram of RCS near the nominal bare tune and Fig. 3 shows the beam loss behavior at some tune points for the first 1.5 ms after injection. When the vertical tune is too close to integer resonance of 6, the rapid beam loss occurs right after injection. When the vertical tune goes up, the loss is decreased. The further up of vertical tune hits other harmful tune area where presumably the coupling resonance of $\nu_x - \nu_u = integer$ or its higher order and $\nu_x - 2\nu_y = integer$ exist. Needless to say, the tune dependence is also a strong function of beam intensity.

2.4. Transitionless lattice

Crossing of transition energy during acceleration has been a cause of beam loss in many proton synchrotrons. Although the transition crossing in a newly built machine such as Fermilab Main Injector, transition crossing does not show as bad beam behavior as the one in old machines, still it is worth avoiding if there are no side effects. The MR will be the first lattice of hadron machine with imaginary transition gamma. The RCS lattice is designed based on similar idea although the transition gamma is not imaginary but still higher than conventional FODO. Figure 4 shows one superperiod of the MR lattice where we see waves of dispersion function. One concern of transtionless lattice is the stronger sextupole for chromaticity correction because of the smaller dispersion at the place of sextuples. The tracking results shows, in fact, the dynamic aperture is less than that of simple FODO lattice, but it is enough compared with physical aperture determined by the vacuum chamber.

2.5. Localizing beam loss

In any events, the beam loss cannot be zero and some should be allowed. One way to handle unavoidable beam loss is to localize it. In other words, we will separate controlled loss and uncontrolled loss: the former is the one localized and the latter is

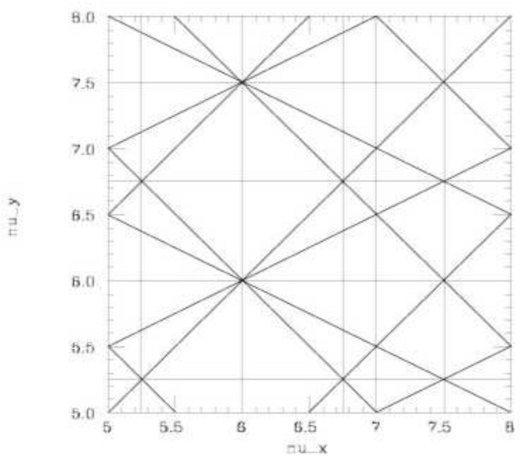

Figure 2. Tune diagram of RCS with resonances up to 4th order (previous version of the lattice).

really out of control. Once we localize the beam loss, strategy of radiation shielding becomes simple and special type of maintenance device for that area can be considered before the area becomes hot.

In RCS and MR the controlled beam loss occurs at collimator area. The allowed beam loss at that point is set to be 4 kW in RCS and 450 W in MR. In the MR, the loss at electro static septum (ESS) for slow extraction is also controlled and its maximum allowed loss is 7.5 kW which is the largest beam loss area in the whole accelerator complex.

By distinguishing the controlled and uncontrolled beam loss, we are expecting the radiation level around the ring can be 1 W/m in RCS and 0.5 W/m in MR. If those cannot be satisfied, the beam power has to be simply reduced until a better operation

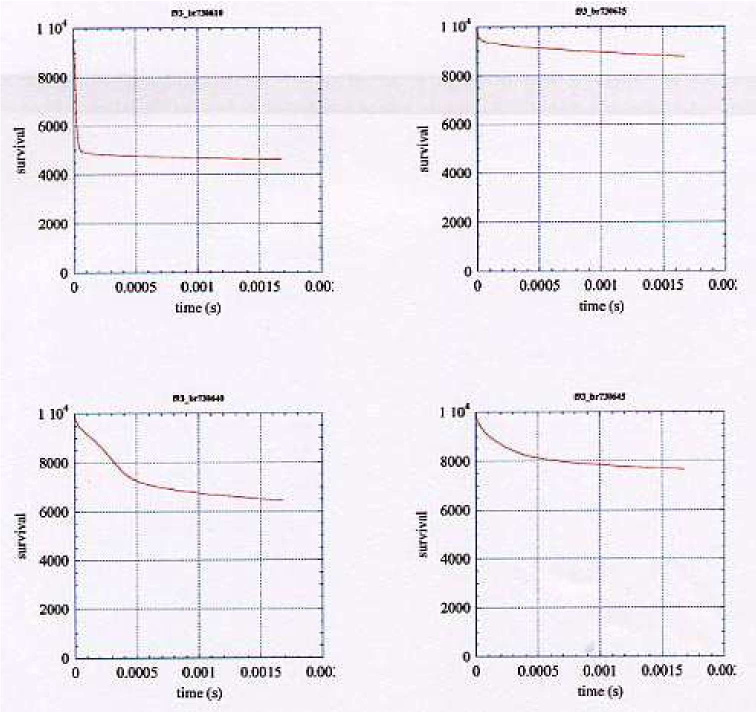

Figure 3. Beam loss right after injection. Horizontal bare tune is fixed at 7.30 and vertical one is varied. It is 6.10 (top left), 6.25 (top right), 6.40 (bottom left), 6.45 (bottom right).

is established.

3. Hardware components

The R&D model magnets of MR shows satisfactory performance. Figure 5 shows a quadrupole magnet for R&D purpose. This is just one example and the ordering of main components of MR goes in front of RCS. After the fabrication and testing of model magnets for MR, both bend and quad magnets have been under mass production. Power supply of magnets using IGBT and vacuum chamber of major parts are also on order. The development of the RF cavity using Magnetic Alloy (MA) material is already finished. The ordering of major components for RCS will follow soon.

4. Summary

Although JHF is not just for a proton driver, but for multi purpose facility including spallation neutron source, it has an adequate machine specifications at present for a neutrino facility and future upgrade path to a few MW. The main concern is the beam loss in the synchrotrons. The design allows 4 kW beam loss at the collimator of RCS and 7.5 kW at the electro static septum (ESS), which is for slow extraction. The major accelerator components of MR are already ordered and a beam is expected within 5 years.

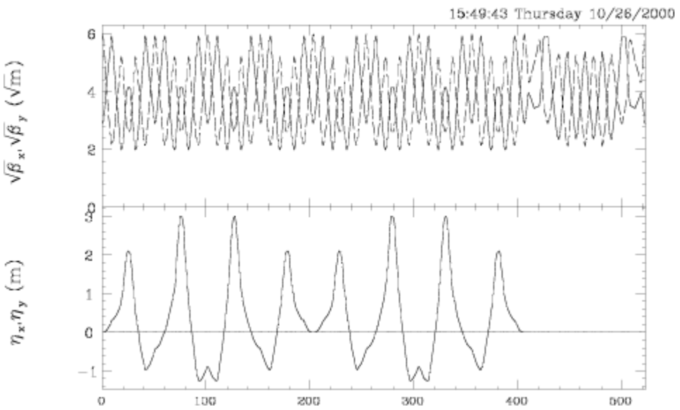

Figure 4. Lattice functions in one superperiod of MR. Solid line of top figure is horizontal beta function and dashed line is vertical. Solid line of bottom figure is horizontal dispersion function. Vertical dispersion function is zero.

References

[1] Y. Mori, Review of Japanese Neutrino Factory R&D, these proceedings.
[2] S. Machida, Neutrino factory design based on FFAG, to be published.

Figure 5. Quadrupole magnet for R&D purpose. The maximum gradient is 18 T/m.