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DESIGN OF THE COMPRESSOR/STRETCHER RING FOR THE JAPANESE HADRON PROJECT

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Abstract A conceptual design of the Compressor/Stretcher Ring for the Japanese Hadron Project (JHP) is described in this paper. Emphasis is put on a general overview of the ring and beam lines.

INTRODUCTION

The accelerator complex of the JHP consists of 1 GeV Proton Linac, Compressor/Stretcher Ring and Heavy Ion Linac.[1] The purpose of the ring is to compress long beam pulses from the linac and to supply the compressed short pulses to the Neutron arena (N arena) and the Meson arena (M arena) with a repetition rate of 50 Hz. Supplying the average current of 100 μA to each arena is a design goal to be achieved.

Functions of the ring [2]

(1) A long H^- beam pulse of 400 μsec from the linac is injected into the ring by a charge exchange method and compressed into two short proton pulses of about 200 nsec. (2) Soon after the injection is completed, one of the short pulses is extracted from the ring in order to supply it to the N arena. (3) Another pulse remaining in the ring is further compressed into an ultra-short pulse of a few tens of nsec by a method called bunch rotation, and then extracted to the M arena. (4) In addition some kind of continuous beam is also supplied to the M arena using a slow extraction scheme. This continuous beam will be produced by stretching the stored beam or by slowly extracting the bunched beam itself.

OUTLINE OF THE BEAM TRANSPORT LINES

The injection line from the end of the linac to the ring and the ejection lines to the two arena are schematically depicted in Fig. 1.

Injection Line

The injection line consists of an arc of about 50 m and a long straight section of about 200 m. The beam from the linac is deflected along the arc by bending magnets with a low field of 3 kG in order to avoid the Lorentz stripping. In the arc several stripping foils will be located to scrape the halos of the beam emittance and momentum. Near the front end of the long straight section, there is a pulse magnet to deliver the average beam current of 10 μA to the ISOL. The aperture in the long straight section will be about 60 mm, almost equal to or more than that of the linac. At the end of the line as well as two ejection lines of fast and slow extraction, a differential pumping system of vacuum will be equipped to protect the ultra-high vacuum of the ring against the linac and the injection line.

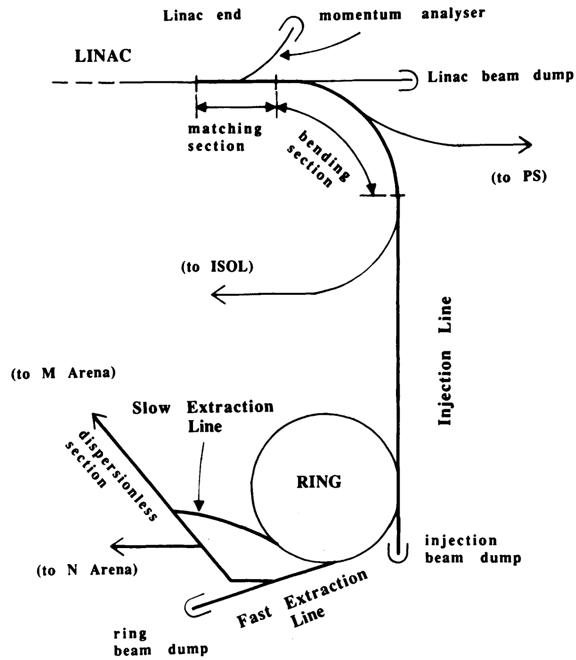

FIGURE 1 Ring and beam transport line.

Ejection Lines

Short beam pulses compressed in the ring are vertically extracted to the fast extraction line. The first section of this line is a vertically achromatic section with a beam dump for the ring. The next follows a horizontal bending section to make it horizontally dispersionless, and then the line is split into two branch lines at a pulse magnet: a deflected line to the N arena and a straight line to the M arena. The latter line is made dispersionless in order to reduce the aperture required for a large momentum spread of ultra-short pulses. The slow extraction line departing from the ring merges to the fast extraction line halfway to the M arena as shown in Figure 1.

COMPRESSOR/STRETCHER RING

The layout of the ring is schematically shown in Figure 2. The principal parameters of the present ring design are also given in Table I. The ring has a relatively large circumference of 175 m in order to accommodate injection system, fast and slow extraction systems, and many RF cavities required for producing ultra-short pulses. The ring lattice has a high symmetry in order to avoid the beam loss due to structure resonances induced by the space charge effects, and it consists of sixteen identical FODO cells, each cell composed of two quadrupole magnets, a bending magnet and a long straight section of about 6 m, as shown in Figure 3.

TABLE I Principal parameters of the ring.

kinetic energy	1 GeV	magnetic rigidity	56.57 kG·m
circumference	174.88 m	average radius	27.83 m
repetition rate	50 Hz	revolution frequency	1.5 MHz
RF frequency	3.0 MHz/1.5 MHz	number of bunches	2
circulating current	6 A (max. 12 A)	average current	200 μA
lattice type	FODO	number of cells	16
horizontal tune	4.25 (typical)	vertical tune	3.25 (typical)
emittance (hori.)	30 πmm·mrad	emittance (verti.)	30 πmm·mrad
acceptance (hori.)	120 πmm·mrad	acceptance (verti.)	120 πmm·mrad
energy spread	~ ±0.2 %	momentum acceptance	~ ±1.5 %
pulse length	~200 nsec	(for ultra-short pulse)	~20 nsec [a]
chromaticity (hori.)	-3.932	chromaticity (verti.)	-3.970
α	0.0606 [b]	η $(= \alpha - 1/\gamma^2)$	-0.1737

a: a target value, b: momentum compaction factor

Injection[3]

The H^- pulsed beam from the linac is injected into the ring by a charge exchange method. The method adopted is first to convert H^- to H^0 by a stripping magnet just upstream the injection point and then to strip H^0 of its electron at a stripping foil located at the injection point. This method is very similar to that used at the PSR. The direction of magnetic field in the stripping magnet is, however, horizontal rather than vertical, and the beam has a waist at the magnet in the horizontal direction while converging in the vertical one. Thus the beam injected into the ring would well match with its phase ellipses at the foil that is located just before a focussing quadrupole. This scheme is being tested at the PSR.

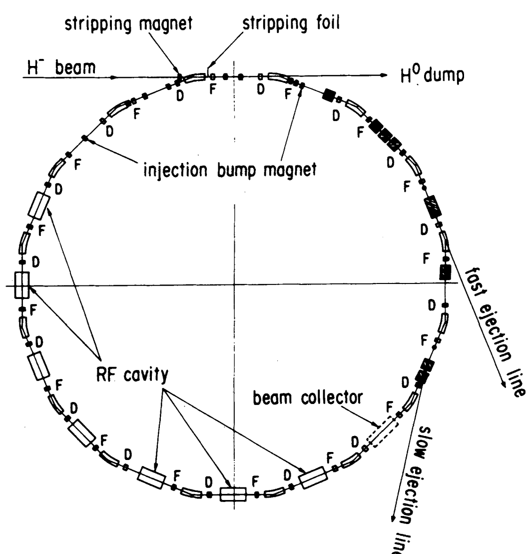

FIGURE 2 Layout of the ring.

The emittance of the ring is chosen to be around 30 πmm·mrad, while the beam coming from the linac is expected to have an emittance of less than 2

πmm·mrad. Therefore, A scheme of phase-space painting can be employed to cope with the space charge effects and it is also needed to reduce the hitting probability on the foil. The scheme adopted here can make the circulating beam have an elliptical cross section with a uniform density.

Emittance and Aperture

The emittance was determined by simply applying the Laslett's tune shift. As the space charge effect becomes very serious for ultra-short pulses, we chose as the emittance a rather large value of 30 πmm·mrad (100 % of the beam with a uniform density). With this emittance, the tune shift is only about 0.075 for short pulses, whereas for the ultra-short pulse of about 40 nsec it would go up to about 0.2 and 0.3 in the horizontal and vertical directions, respectively. On the other hand, both transverse apertures for betatron amplitudes were determined to be 120 πmm·mrad, four times

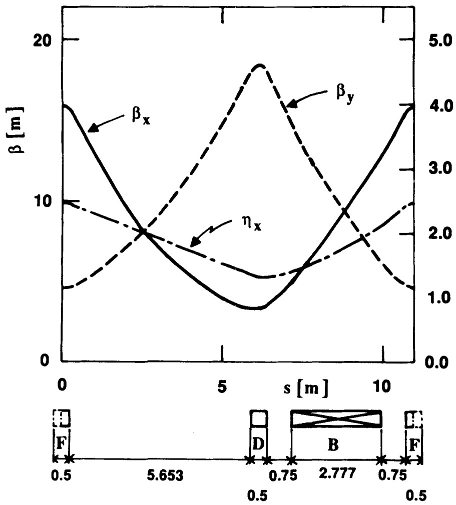

FIGURE 3 Optics of a cell.

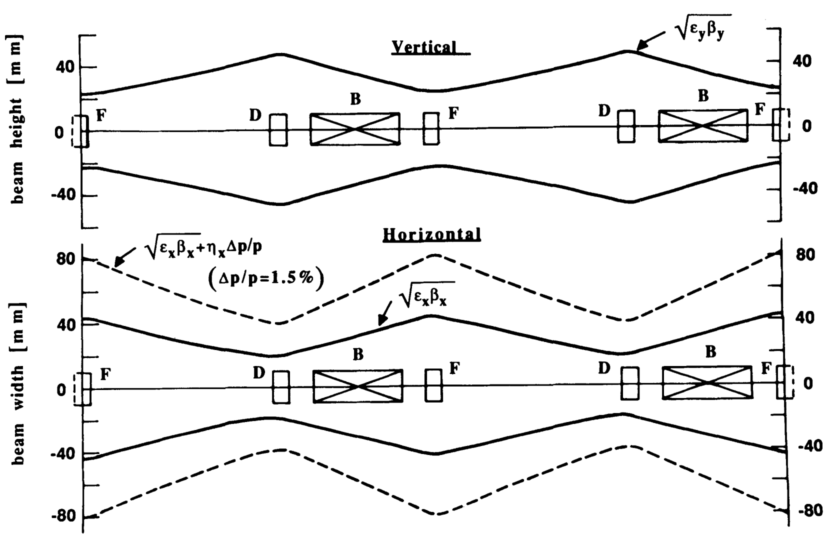

FIGURE 4 Aperture requirement ($\varepsilon_x = \varepsilon_y$ = 120 πmm·mrad).

larger than the emittance. Furthermore, an extra margin corresponding to the momentum spread of ±1.5 % was added to the horizontal aperture (see Figure 4), since the bunch rotation method requires a momentum acceptance larger than ±1 %. Main parameters of the magnet system that can allow such large apertures are listed in Table II.

TABLE II Main parameters of the ring subsystems.

	Bending magnet		
number	16	bending angle	22.5°
magnetic field	0.8 T	magnet type	C-type sector
effective length	2.777 m	bending radius	7.0715 m
gap height	134 mm	power supply	0.6 kV × 1.6 kA
	Quadrupole magnet		
number	32	effective length	0.5 m
$B'l_Q/B\rho$ (F)	0.2447 m^{-1}	$B'l_Q/B\rho$ (D)	-0.2315 m^{-1}
bore radius	116 mm		
	RF		
number of RF cavities	~16	cavity length	1.3 m
length of an RF station	2.2 m	RF voltage per cavity	~15 kV
shunt impedance per cavity	2 kΩ	power loss of PA[a] per cavity	~280 kW
	Kickers (number: 10)		
gap	95 - 120 mm wide × 100 - 160 mm high		
core length	320 - 580 mm	PFN voltage	60 kV
current	3.0 kA	impedance	10 Ω
gap field	236 - 377 G	transfer time	43 - 49 nsec
kick angle	2.13 - 2.58 mrad		
	Septum magnets for fast extraction (number: 2)		
gap height	100 - 130 mm	gap width	124 - 200 mm
septum coil thickness	30 - 90 mm	core length	1400 mm
kick angle	80 - 200 mrad	gap field	3.2 - 8.0 kG
	Electric septum		
length	2.5 m	gap	15 mm
electric field	70 kV/cm	septum thickness	0.15 mm
	Septum magnets for slow extraction (number: 2)		
length	1 m	septum thickness	15 - 50 mm
magnetic field	5 - 10 kG		

a: power amplifier

RF and Ultra-short Pulse

Since the ring is demanded to supply ultra-short pulses to the M arena, total RF voltage required is more than 200 kV at the frequency of 1.5 MHz (or 3 MHz), so that the RF system will become a large and complex system. A new method called "loading cancellation method" to compensate the heavy beam loading will be adopted for this ring and tested in advance at the existing Booster Synchrotron with a new RF system now under construction.[4] Details of the generation of ultra-short pulses by the bunch rotation method are described elsewhere.[5] The results show that the beam pulses of several tens of nsec could be generated by this method. However, the feasibility of generating such a highly compressed pulse must be further studied.

Fast and Slow Extractions

For fast extraction, ten full-aperture kickers with a rise time of less than about 100 nsec and two DC septums are installed in the ring. Some parameters of them are listed in Table II. Though it has not yet been decided whether third order resonance or half resonance is applied for slow extraction, the beam loss for the slow extraction should be as little as possible, e. g., less than 10^{-3}, that may be attained by using a pre-septum with an effective thickness of about 20 μm. With a high repetition rate of 50 Hz, the slow extraction will make use of the chromaticity to change the tune, that is almost linear over a wide range of momentum deviation. The momentum change will be made by accelerating the bunched beam or by phase displacement acceleration.

Others

The vacuum chambers will be made of aluminum alloy having a property of low residual radiation, and the main pumping system of vacuum will consist of ion pumps and NEG's. Preliminary study of the coupling impedance has been made to estimate the thresholds and growth rates of various instabilities, but detailed study will be needed to clarify their influence on the ring design and performance; aperture requirement, maximum attainable beam current, required smoothness of vacuum chambers, beam loss and so on. Halo collectors will be installed at a few places around the ring together with the scrapers put on upstream in order to localize the beam loss. The remote handling of vacuum flanges, power cables and cooling water pipes is being developed.

SUMMARY

The present conceptual design of the ring has been described. Details of this design and important issues to be addressed are described in Ref. 1 and some of the issues have already been studied in detail. Yet there are still many items to be studied in future so as to settle on a final design. The authors would like to acknowledge all members of the RDG, the Ring Design Group.

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