DESIGN OF THE PULSE BENDING MAGNETS FOR THE INJECTION SYSTEM OF THE 3-GEV RCS IN J-PARC

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Abstract

The pulse bending magnets for the injection system of the 3-GeV RCS in J-PARC [1] [2] has been designed. The injection system consists of the pulsed bending magnets, which are four horizontal bending magnets (shift bump) and four horizontal painting magnets (h-paint bump) for the injection bump orbit, and two vertical painting magnets (v-paint magnet). The injection beam energy and the extraction beam power are 400 MeV and 1 MW at 25 Hz repetition rate, respectively. The acceptance to include the injection beam, the painting beam and the circulating beam at the shift bump points is a 388 mm wide and a 242 mm high. The shift bump has been designed using a 3D magnetic analysis code [3], which accomplished less than 0.4 % field deviation under 0.26 T excitation level.

INTRODUCTION

J-PARC consists of 400-MeV Linac, 3-GeV RCS, and 50-GeV synchrotron ring. The incoming beam emittance of the 400-MeV linac is 4 π mm-mrad and the collimator acceptance in the 3-GeV RCS is 324 π mm-mrad.

In the first stage, the energy of the injection beam and the extraction beam is 181 MeV and 3 GeV, respectively. And the extraction beam power is 0.6 MW at a repetition rate of 25 Hz. In the second stage, the injection beam energy and the extraction beam power is to be upgraded to 400 MeV and 1 MW, respectively.

The machine acceptance of the linac and its transport line are designed by 30 π mm-mrad, and that of 3-GeV RCS is 486 π mm-mrad. It is very important to decrease a beam loss. Therefore, a wide aperture of the magnetic gap and a wide good field region of the magnet field are required.

CONSTRUCTION OF THE INJECTION BUMP SYSTEM

The injection system of the 3-GeV RCS in J-PARC is composed of eight horizontal bump magnets and two vertical paint magnets. The horizontal bump magnets are divided into two types. One type named “shift bump” produces a fixed main bump orbit to merge the injection beam into the circulating beam in the horizontal plane. They are realized with four magnets connected in series, which are located at the long straight section. Another type named “h-paint bump” performs to shift the circulating beam horizontally for painting the injection beam in the injection period. They consist of four magnets, which are divided into two pairs. One pair is arranged for the upstream of the F quadrupole magnets, and another pair is arranged on the downstream of the D quadrupole magnets. Each magnet is excited individually.

The vertical paint magnets named “v-paint magnet” perform to vary the injection angle and position vertically for painting the injection beam. They are placed in the transport line at a betatron phase of π upstream of the stripping foil.

INJECTION PULSED MAGNETS

Magnets

The hardware of the injection pulsed magnets is designed to accept 400 MeV injection beams. The parameters of the three type magnets (shift bump, h-paint bump, v-paint magnet) are given in Table 1.

Table 1: Parameters for injection pulsed magnets

	shift	h-paint	v-paint
Number of magnets	4	4	2
Structure	W- frame	C-type	C-type
Core Length [mm]	400 - 400	400	400
Field [T]	0.2611	0.2603	0.0855
Maximum Current [A]	32200	29000	3400
Turns per Coil	2	2	2
Gap Height [mm]	310	280	100
Coil Inside Distance [mm]	616	400	240
Beam Stay Area [mm] [Horizontal / Vertical]	388 / 242	257 / 250	44 / 91
Lamination thickness [mm]	0.15	0.1	0.1

The aperture of the shift bump and the h-paint bump are required to have the full acceptance. The shift bump has the largest gap and a longitudinal split type structure to insert a foil for H0 beam stripping. A cross sectional view and a plane view is shown in Fig.1. The parameter of the gap height is 310 mm and the inner distance of the coil is 616 mm. The magnets have the structure, which is

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divided in 400 mm and 400 mm in the 800 mm core and excites the core with one coil. The structure of the magnet is composed of two-turn coils and window frame core made by laminated silicon steel cores of which thickness is 0.15 mm.

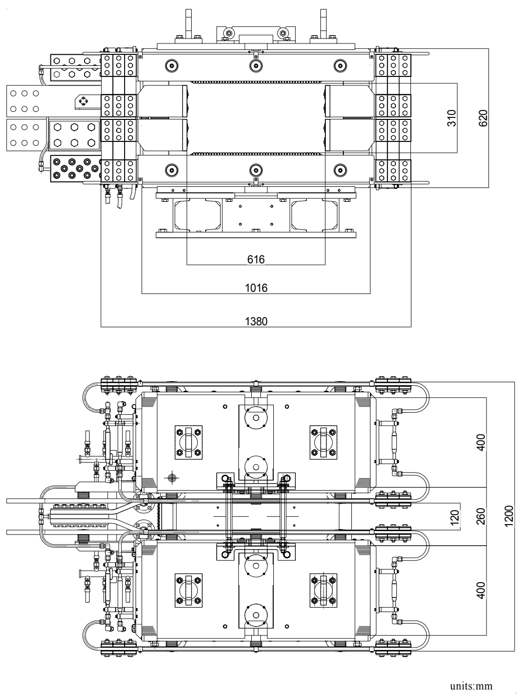

Fig.1 Cross sectional view and a plane view of the shift bump

The beam stay area at each shift bump point, which is shown in Fig.2, includes the circulating and the injection beam for the various injection conditions. The inner size of the ceramic duct is a 460 mm width and a 270 mm height. The gap height of the ceramic duct is designed to be 9mm higher than 486 π mm-mrad beam size. Then, the beam loss can be decreased to 1 W/m. The all bump magnets are out of vacuum and the ceramic vacuum chambers are included in the gap.

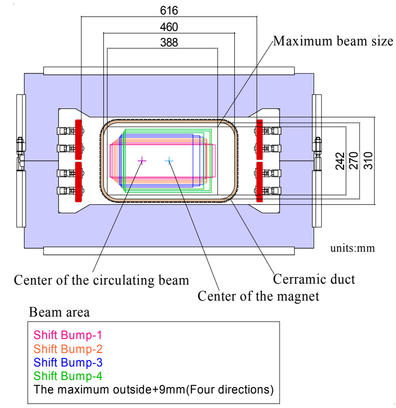

Fig.2 Beam area at each shift bump point

Power supply

The power supplies of the injection bump system requires fast and flexible current pattern. Furthermore, to realize the high power operation with a tracking error less than 1 %, the rectifiers and chopper of the power supplies utilize many IGBT units in series and parallel.

In the first stage, the power supplies are manufactured by the specification of 181 MeV injection beams, and can be upgraded 400 MeV in the second stage. The specifications of the power supplies are listed in Table 2.

The operation parameters of the beam deflection angles by each bump magnet and the exciting current of 181 MeV and 400 MeV injections respectively are given in Table 3. In the case of the painting injection, the beam emittance is 216 π mm-mrad for MLF (3N-mode), and 144 π mm-mrad for 50-GeV ring injection (50MR-mode). The horizontal painting area is controlled by the shift

Table 2: Specification of the power supplies for 400 MeV operation

	Current [kA]	Voltage [kV]	IGBT Rating	Rectifier		Chopper		
				Composition	**Total number of arms**	**Composition**	**Total number of arms**	**Resultant switching frequency [kHz]**
Shift	32.2	12	3300V 1200A	8 stages, 1 parallel 3 phase rectifiers	48	8 stages, 35 parallels 4-quadrant choppers	1120	64
H-Paint 1	29.0	1.2	1200V 300A	2 stages, 1 parallel 3 phase rectifiers	12	2 stages, 26 parallels 4-quadrant choppers	208	600
H-Paint 2	23.4	1.2	1200V 300A	2 stages, 1 parallel 3 phase rectifiers	12	2 stages, 20 parallels 4-quadrant choppers	160	600
H-Paint 3,4	21.0	1.2	1200V 300A	2 stages, 1 parallel 3 phase rectifiers	12	2 stages, 20 parallels 4-quadrant choppers	160	600
V-Paint 1,2	3.4	0.6	1200V 300A	1 stage, 1 parallel 3 phase rectifier	6	1 stage, 3 parallels 4-quadrant choppers	12	300

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bump and the h-paint bump by changing the excitation level in a pulse-to-pulse mode. Both correlated and anti-correlated painting injections are available by changing the excitation pattern of the vertical painting magnet. The current wave forms of each magnet are shown in Fig.3. The beam injection period (τ) is 500 μs.

Table 3: Operation parameters

		Beam Deflection Angle [mrad]	Current [A]	
			181MeV	400MeV
3N-mode	Shift	56.0	17580	27480
	H-Paint1	25.1	14230	22250
	H-Paint2	18.5	10490	16400
	H-Paint3	15.6	8850	13830
	H-Paint4	16.8	9530	14900
50MR-mode	Shift	61.4	19270	30130
	H-Paint1	19.6	11110	17380
	H-Paint2	14.5	8220	12860
	H-Paint3	12.3	6970	10910
	H-Paint4	13.2	7480	11700
	V-Paint1	8.0	1620	2530
	V-Paint2	6.0	1220	1900

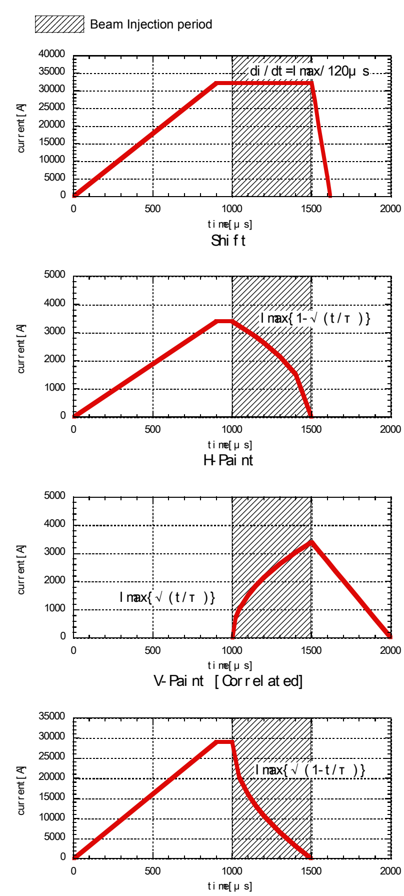

Fig.3 Current wave forms

3D MAGNETIC ANALYSIS

The magnetic structure of the shift bump magnets have been deigned using a three-dimensional magnetic analysis code (OPERA-3D). Fig.4 shows the 3D calculation model. The integration value of a magnetic field of the calculation results by OPERA-3D are shown in Fig.5. By optimising the form of the core and the coil, the shift bump has realized a uniform field with less than 0.4 % deviation over a wider aperture (388 mm wide and 242 mm high).

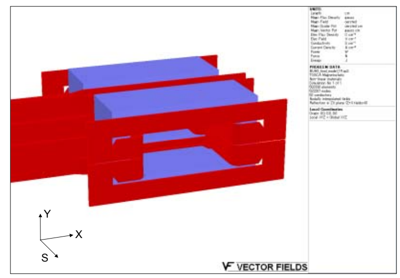

Fig.4 3D calculation model of the shift bump magnet

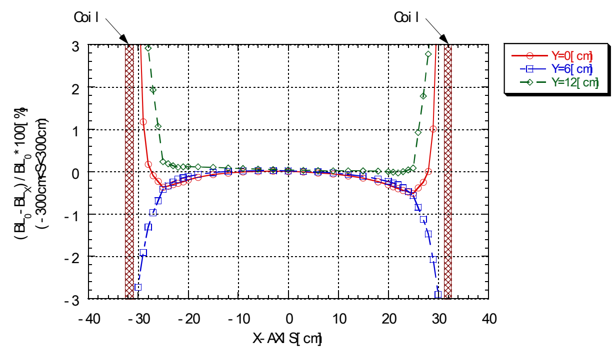

Fig.5 Integrated value of a magnetic field with respect to beam direction

SUMMARY

The bump orbit for painting injection has a full acceptance for the circulating beams. A full-acceptance bump orbit will enable both correlated and anti-correlated painting injection. The beam line can be designed so as to have a sufficient acceptance for low-loss injection. The painting area is optimized for both 3-GeV users and 50-GeV users in a pulse-to-pulse mode operation.

The injection bump system of the 3-GeV RCS has been designed by the specification of 400 MeV injection beams. The power supplies are operated by the specification of 181 MeV with the first stage, but it upgradeable to 400 MeV injection.

REFERENCES

[1] Y.Irie, et al, EPAC'04, Lucerne, July 2004, p.113.

[2] I.Sakai, et al, PAC'03, Portland, May 2003, p.1512.

[3] TOSCA, OEPRA-3D, Vector Field.