OPPOSITE FIELD SEPTUM MAGNET SYSTEM FOR THE J-PARC 50- GEV RING INJECTION *

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Abstract

The opposite field septum magnet system has been applied to the injection system of the J-PARC 50-GeV proton synchrotron. The features of the system are a force-free structure, easy pulse excitation and the possibility of a large-aperture, thin-septum structure. The septum magnet has the structure of an inside-vacuum to eliminate the thickness of the vacuum-chamber walls and electric-insulation layer to make the septum thickness as thin as possible. However the magnet cores and return coils are outside of the vacuum to reduce the out-gassing rate of the vacuum system. Finally, the larger beam aperture than the full acceptance of the ring can be obtained at the septum magnet for low-loss injection..

INTRODUCTION

The J-PARC Project 50-GeV proton synchrotron is designed to accelerate 8.3×10^{13} protons (8 bunches) every 3.64sec repetition. The injection energy is 3GeV. The acceptance of the transfer line from the RCS and the ring of the 50-GeV synchrotron are designed to be 81π mm mrad in both the horizontal and vertical planes. The incoming beam emittance from the 3-GeV rapid cycling synchrotron (RCS) is shaped to 54πmm mrad in both the horizontal and vertical planes using a scraper and collimator system. High-intensity high-energy accelerators impose tight demands on the injection / extraction septum magnets because of its large aperture and high magnetic field. Especially regarding the injection system, their large-size injection beam and a circulating beam, before adiabatic damping, must be separated in the limited length of the straight section. A thin structure, large aperture and high operating magnetic field septum magnet are required. To cope with these tight demands, a new design concept of the opposite-field septum magnet system has been invented[1].

In this paper we will describe the structure and hardware of the opposite field septum magnet system for the injection of the J-PARC 50-GeV proton synchrotron.

CONCEPT OF THE OPPOSITE FIELD SEPTUM MAGNET

The concept of the opposite-field septum magnet system is shown in Fig.1. The same grade of opposite magnetic field is produced both inside and outside of the septum. The electromagnetic force on the septum conductors is canceled out by each other by opposite magnetic fields on both side of the septum.

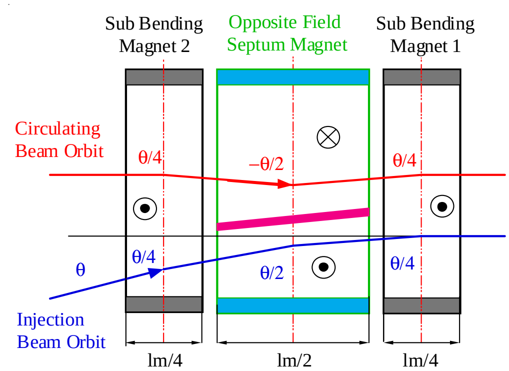

Figure 1: Principle of opposite-field septum magnet

The magnetic field of the circulating beam side is compensated by two sub-bending magnets set up-stream and down-stream of the opposite-fields septum magnet. These three magnets are connected in series and excited by the same power supply for simultaneous excitation. The thin septum conductor will be available without any mechanical support, and pulse excitation for power saving becomes easier than that for the normal septum magnet. The leakage flux is canceled out by each other and the beam-separation angle per magnet length is twice as large as that of the normal septum magnet with the same magnetic field. The two sub-bending magnets also enhance the injection angle. The thin septum makes it possible to obtain a sufficient aperture at the septum magnet.

INJECTION SYSTEM FOR THE 50-GEV PROTON SYNCHROTRON

An outline of the injection system is shown in Fig. 2.

The injection system is composed of a high field (1.36T) normal septum magnet, the opposite field septum magnet system (0.60T) and 7 kicker magnets (0.065T) not shown in Fig.2. The parameters of the magnets for injection are shown in Table 1. With the limited length of the straight section and the restriction of the kicker magnets, the bending angle of the septum magnet is required to be as large as possible to clear the yoke of the upstream quadrupole magnet. The opposite-field septum magnet has a thin structure (8mm). The beam apertures of the injection beam and circulating beam at the injection septum magnet for the 50-GeV ring are 90π mm mrad, which is larger than the full acceptance (81π mm mrad) of the ring. This high field and thin septum magnet makes the injection system simple and compact.

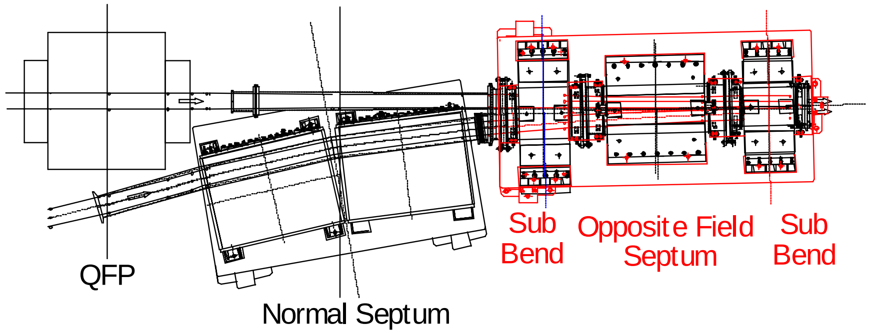

Figure 2: Layout of injection system

Table 1; Components of the injection magnets

Element	Gap	Length	B	Angle
Septum I	98 mm	1800 mm	1.48 T	191 mrad
Sub-bend 1	120 mm	350 mm	0.56 T	17 mrad
Septum II	120 mm	700 mm	0.56 T	34 mrad
Sub-bend 2	120 mm	350 mm	0.56 T	17 mrad
Kicker (x7)	~90 mm	300~680	0.065T	15.4mrad

TECHNICAL ASPECT OF THE OPPOSITE FIELD SEPTUM MAGNET

Structure of the magnet

A transverse cross-sectional view is shown in Fig. 3. As shown in Fig.1, twice as much as return current must flows on the septum part. The two coils are arranged vertically to form a single line of septum conductors to form a thin septum.

A longitudinal cross-sectional view is shown in Fig. 4.

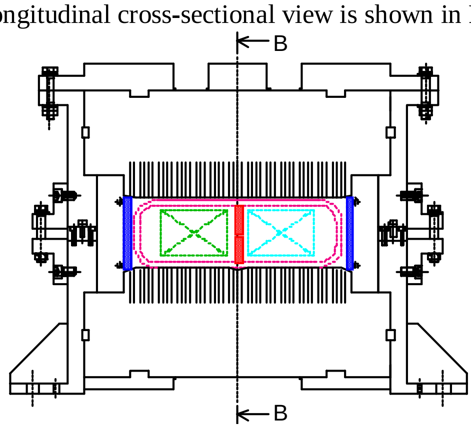

Figure 3: Transverse structure of opposite-field septum

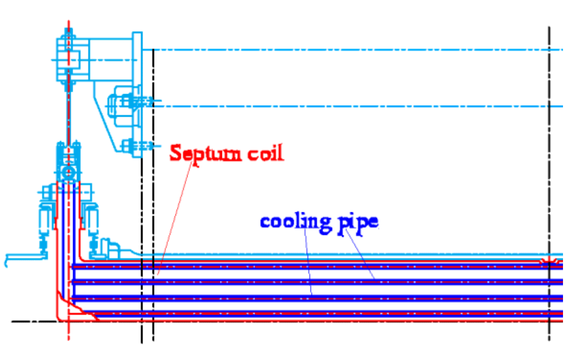

Figure 4: Longitudinal structure of opposite-field septum

The core of the magnet and the return coils are set outside of the vacuum chamber to decrease the out-gassing rate, and only the septum conductors are set inside of the vacuum chamber, which is made of alumina ceramic. The main parameters of the opposite field septum magnet system are shown in Table 2.

Table 2; Main parameters of the opposite field septum

		Sub Bend1	Opposite Field Septum	Sub Bend2
Bending angle	mrad	15	30	15
Magnetic field	T	0.556	0.556	0.556
Pole length	mm	350	700	350
Pole gap	mm	120	120	120
Pole width	mm	374	355	272
Inductance	μH		5293	
Resistance	mΩ		0.221	
Current	kA		53.5	
Voltage	V		356	

Conductor shape and field distribution

The detailed structures of the septum coils and magnet poles including ceramic vacuum chamber are shown in Fig. 5. The incoming beam and the circulating beam both have rectangular shapes. A uniform magnetic field distribution is required not only near the medium plain but also at the edge of the septum. To obtain a uniform magnetic field, the thickness of the ceramic vacuum chamber is a partially thin structure so as to approach the septum conductor to the pole surface as close as possible. Nevertheless, the minimum gap between the septum coil and the magnet pole is 6 mm. Furthermore, four stainless-steel cooling water pipes, which are gathered to one pipe at the end of the conductor, are sandwiched in the septum conductor (copper) by the Hot Isostatic Pressing (HIP) technique. These gaps and holes in the conductor disturb the uniformity of the magnetic field near to the septum. The cross section of the conductor is shaped so as to form a uniform distribution of the average current along the vertical axis of the septum.

The field distribution calculated by Poisson is shown in Fig.6.

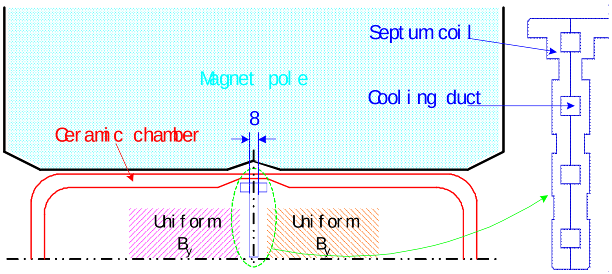

Figure 5: Cross section of septum

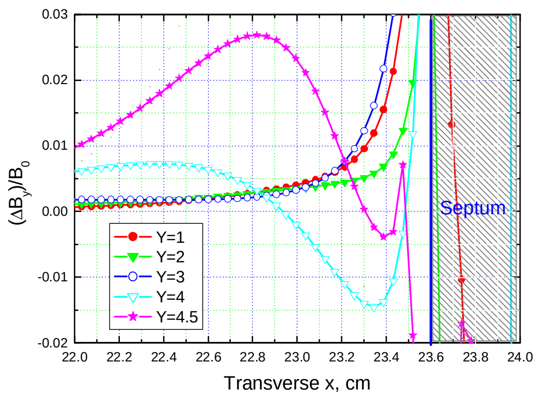

Figure 6: Magnetic field distribution near septum

The required vertical aperture at the septum is ± 36 mm at the septum. The field distribution normalized by the value of the circulating beam center has been achieved less than 0.5% within the area more than 6mm far away from the surface of the septum.

Compensation of the error field

As shown in Fig.1, the opposite field septum magnet system is composed of the main septum magnet and two sub-bending magnets. The integrated magnetic field along the circulating beam axis is designed to be zero to suppress the closed-orbit distortion around the whole ring.

The fabrication errors and the difference in the effective length will be compensated by a fine adjustment of the sub bending magnets, which are initially designed to have variable gaps, as shown in Fig. 7. The transverse crossing coil positions are replaceable after field measurement. The disproportion of the eddy current will be compensated by back-leg windings on the return yoke of the sub bending magnets, which have a short circuit, including a variable resistor to control the counter phase-induced current. These compensation techniques have already been verified by experiments on the H^- injection bump magnets for the 500-MeV booster synchrotron in the KEK 12-GeVPS.

MODULATION OF THE β FUNCTION BY A "DOG LEG BUMP ORBIT"

The opposite field septum magnet system inevitably forms a "Dog leg bump orbit" at the circulating beam side. The vertical edge focusing is accumulated irrespective of a reversal of polarity of the magnets.

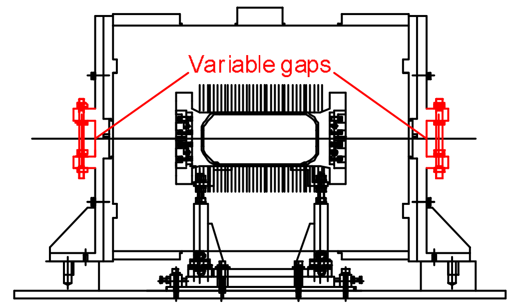

Figure 7: Sub-bending magnet with variable gaps

β modulation by the integrated edge focusing in the vertical plane has been carefully examined by the simulation code of orbit analysis. The increment of the beam aperture is 2%, which is within the tolerance of the design of the beam optics.

POWER SUPPLY

Waveform of Excitation current

Since the opposite field septum magnet has a force-free structure, pulse excitation is easily acceptable to escape the problem of heat generation at the septum. The thin septum structure is available because of pulse operation. The injection septum magnets are required to operate at a period of 900ns x 4 repetition for the two bunches x 4 repetition mode injection and the maximum repetition rate of 16 for the one bunch x 16 repetition mode injection with a repetition cycle of 25Hz of the 3-GeV RCS.

Required accuracy of the excitation current

The injection system is designed to suppress the emittance growth by injection errors to be less than 2%. In this situation, the stability of the magnetic field is required to be less than 2 x 10E-4. The output voltage of the power supply is fed backed by the current monitor of the excitation current.

SUMMARY

The opposite-field type septum magnet combined with sub-bending magnets has unique features compared with normal septum magnets as a force-free structure and cancellation of the leakage flux at the septum.

The force-free structure permits thin septum magnets, pulse excitation and a structure such that the septum conductor is set inside of the vacuum for a low evacuating load. In the case of the injection septum magnet for the J-PARC 50-GeV proton synchrotron, the larger beam aperture than the full acceptance of the ring can be obtained for low-loss injection. The system is applicable to injection / extraction septum magnets for many kinds of accelerators.

REFERENCES

1. Sakai, et. al., IEEE Trans. on Applied Supercon., Vol.12, No.1, March 2002