Design of the Kicker Systems for the JHF 50-GeV Main Ring

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Abstract

The 50-GeV main-ring synchrotron in the JHF (Japan Hadron Facility) uses three sets of kicker systems. They include: ·injection kickers, ·abort kickers at the injection energy, and ·fast-extraction kickers for the neutrino oscillation experiment line. All the kickers are of a full aperture type and are energized by Blumlein PFN lines and thyratron switches. The designed parameters for the kickers to fulfill required strength and speed are discussed.

1. Introduction

The main ring in the JHF (Japan Hadron Facility) project[1,2] accelerates 3-GeV proton beams from the booster to 50-GeV. The proton beams are injected into, and extracted from, the main ring by kicker magnets. Since the main ring has two fast-extraction lines, the one being an abort line at the injection beam energy of 3-GeV and the other being a 50-GeV fast-extraction line to provide beams to the neutrino-oscillation experiments, there are three sets of kicker systems in total.

The parameters of the kickers are determined in order to meet the required strength and time structure, the latter includes a rise-time, a flat-top length and a fall-time. Those numbers are derived from the optical design of the accelerator systems. In the next section, an overview to define the parameters of three kicker systems are given. In section 3, more detailed discussions on each kicker system are described.

2. Overview of the Main-Ring Kicker Systems

The requirements to the time structures of the kickers are schematically shown in Fig. 1. The booster accelerates four bunches in each acceleration cycle. These four bunches are extracted from the booster and injected into the main ring. After four injection cycles, numbered 1 to 4 in the figure, the main ring is filled with sixteen bunches and starts acceleration. Since the harmonic number of the main ring is seventeen, one bucket is left open. This empty bucket gives a longer bunch-to-bunch interval, and thus allows the kicker magnets longer periods to establish or to extinguish the necessary magnetic fields.

At injection of the main ring, the RF frequency is 3.43 MHz. One RF cycle is 292nsec, which includes one bunch and one bunch-to-bunch interval, as is shown in Fig.1. Assuming that about 40% of each cycle is left unoccupied by the bunch, the time interval allowed for the kickers becomes around 120nsec. At extraction, the RF frequency is slightly increased to 3.51 MHz and the bunch-to-bunch interval stays almost the same. Thanks to the above-mentioned empty bucket, however, one full RF cycle can be added to this 120nsec spacing. The main ring, accordingly, has sixteen small bunch-to-bunch intervals of 120nsec and one large interval of ~400nsec. These intervals define the required time structures of the kicker magnets.

There are three kicker systems in the main ring. Each system has a different function, and, therefore, must be designed with a respective optimized set of parameters. These systems include:

- Injection Kickers at 3-GeV,
- Abort Kickers at 3-GeV, and
- Fast-Extraction Kickers at 50-GeV.

The designed parameters for the kicker systems are summarized in Table 1. In this table, the dimensions and the time structures of the kickers are mainly defined by the optical design of the ring. The other parameters are selected to fulfill the required strength and speed within existing technologies. In the following section, each kicker system is described in further detail.

3. Detailed Parameters of the Kicker Systems

3-1 Injection Kicker Systems at 3-GeV

The proton beam from the 3-GeV booster is injected vertically into the main ring using the short straight sections around the QFX magnet in one of the arc sections. In order to inject four successive bunches from the booster,

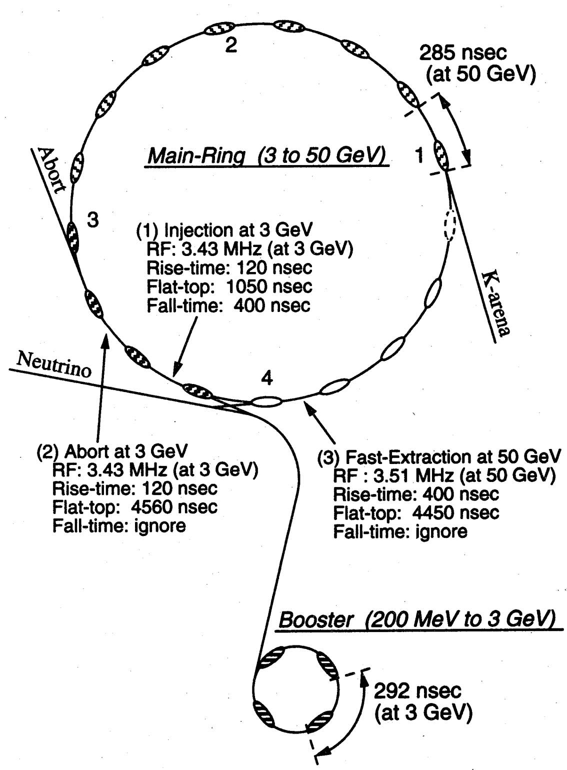

Fig. 1 Overview of the Main-Ring Kickers.

the injection kicker magnets keep a field flat-top for ~1050nsec. To pack the next four bunches right after the first four, the kicker field rises within the short bunch-to-bunch interval of 120nsec. At the end of the fourth injection cycle, the long interval with the empty bucket arrives. The kicker fall-time should therefore be shorter than 400nsec.

In order to accept a vertically injected beam, the kickers cover an area of 0.13m in horizontal and 0.12m in vertical. Since the magnetic flux lies horizontally, the horizontal 0.13m span becomes the height of the kickers and the vertical 0.12m span the width. The effective length and the kick angle of each kicker unit are 0.6m and 3.0mrad, respectively. The injection system comprises four kicker magnets, resulting in a 2.4m length and a 12.0mrad kick in total.

The switching element is assumed to use a deuterium-filled thyratron CX2171 from EEV Co. The maximum voltage and current of the tube are 90 kV and 10 kA, respectively. The pulse-forming network will comprises co-axial cables in a Blumlein line configuration. In order to avoid bulky low impedance cables, the co-axial cable is designed to have a moderate 20 Ω impedance and a

Table 1. Designed Parameters for the Main-ring Kicker Systems.

	Injection	Abort	Fast extraction	
Optical requirements				
Kinetic energy of beams	3	3	50	[GeV]
Momentum	3.82	3.82	50.9	[GeV]
Magnetic rigidity	12.76	12.76	169.9	[T·m]
Effective length	0.6	1.2	1.5	[m]
Kick angle	3.0	6.0	0.6	[mrad]
Number of kicker units	4	3	11	
Total effective length	2.4	3.6	16.5	[m]
Total kick angle	12.0	18.0	6.6	[mrad]
Kick direction *	Vertical	Horizontal	Horizontal	
Aperture height *	0.13	0.10	0.11	[m]
Aperture width *	0.12	0.13	0.12	[m]
Time structure				
Rise-time (1% to 99%)	120	400	400	[nsec]
Flat-top (100% ±1%)	1050	4560	4450	[nsec]
Fall-time (99% to 1%)	400	ignore	ignore	[nsec]
Thyratron				
Type	Deuterium filled	Deuterium filled	Deuterium filled	
Model#	EEV/CX2171	EEV/CX2171	EEV/CX2171	
Maximum voltage	90	90	90	[kV]
Maximum current	10	10	10	[kA]
PFN				
Type	Co-axial cable	Co-axial cable	Co-axial cable	
Line configuration	Blumlein	Blumlein	Blumlein	
Cable impedance	20.0	20.0	20.0	[Ω]
Parallel number of cables	2	1	1	
Line impedance	10.0	20.0	20.0	[Ω]
Maximum voltage	100	100	100	[kV]
Kicker magnets				
Type (mechanical)	Full aperture	Full aperture	Full aperture	
Type (electrical)	Transmission line	Lumped	Lumped	
Field strength	638	638	680	[Gauß]
Current	6.60	5.08	5.95	[kA]
Total inductance	696	1960	2056	[nH]
Impedance	10.0	—	—	[Ω]
Operational voltage	66.0	50.8	59.5	[kV]
Transmission velocity	0.0086	—	—	[m/nsec]
Transmission time	69.6	—	—	[nsec]
Time constant	—	49.0	51.4	[nsec]
99% rise/fall time	—	226	237	[nsec]

*When the 'Kick direction' is 'Vertical', the 'Aperture height/width' means the horizontal/vertical span of the kicker aperture.

maximum 100 kV insulation voltage. These two numbers, impedance and voltage, define the inner and outer conductor diameters as 20mm and 33mm, respectively, assuming that a polyethylene-insulated cable is used.

The kicker magnets are of a full aperture, transmission-line type. The current of the kickers to generate a necessary field strength of 638 Gauß is 6.60 kA. In order to keep the operational voltage within a manageable range, the line impedance is selected to be 10 Ω. The PFN line comprises two 20 Ω cables in parallel. The operational voltage results in 66.0 kV.

The transmission velocity of the pulse inside the kickers is 0.86 cm/nsec. An effective length of 0.60m of one kicker unit requires 69.6nsec of transmission time for a pulse to propagate from the entrance to the exit of the kicker. The transmission time is short enough, even when the thyratron rise-time is added, compared to the bunch-to-bunch interval of 120 nsec.

3-2 Abort Kicker Systems at 3-GeV

The main ring provides a beam-abort system at the injection energy. When an abort event occurs while the proton beam is being injected and circulated in the main ring at 3-GeV, the abort system fires at the large bunch-to-bunch interval. The rise-time should be within ~400nsec. In order to eject all of the circulating bunches during one turn, the abort system has a 4560nsec flat-top. Once the main ring is evacuated, there is a sufficiently long time to extinguish the kicker field until the next injection cycle starts. The fall-time requirement can therefore be ignored.

The beam simulation for the abort channel shows that the necessary aperture for the abort kickers is 0.10m in the vertical height and 0.13m in the horizontal width. The abort kickers are at present designed to have the same kick angle per unit length, 5mrad/m, as that of the injection kickers. Each abort kicker has a kick angle of 6mrad and an effective length of 1.2m, which result in almost twice the aperture volume as that of the injection kickers. The long rise-time of the abort system allows such a large aperture volume.

The number of the abort kicker magnets is three. Tha abort channel accordingly has in total an effective length of 3.6m and a kick angle of 18mrad. The larger kicker volume allows the smaller number of the kicker units to produce the same total kick, resulting in the reduced sets of thyratrons, PFNs etc. That is beneficial for saving the total construction and operation costs.

The same components are used for the switching thyratrons and for the PFN systems as in the injection systems. Actually these components are designed to be common among three kicker systems --- injection, abort and fast-extraction --- in the main ring. The basic idea is to minimize the variety of the employed components, and, thus, to avoid unimagined device malfunctioning as much as possible.

Each kicker unit is a lumped-type magnet with a full aperture. Since the kick strength per unit length is the same as that of the injection kickers, the field strength is also the same, 638 Gauß. The smaller aperture height, however, requires a smaller current of 5.08 kA. When a lumped magnet is connected to a PFN with a Blumlein configuration, the effective voltage is doubled by reflection. In the present case, the PFN with a 20 Ω line impedance results in an operational voltage of 5.08 kA x 20Ω / 2 = 50.8 kV. In order to avoid sparks at the magnet units, the abort kickers are charged to high voltage only when an abort request occurs.

The lumped inductance, L, of one kicker unit is 1960 nH. With a Blumlein PFN with a line impedance Z_0 = 20 Ω, the lumped magnetic field rises and falls exponentially with a time constant t = $L/Z_0/2$ = 49.0nsec. With this time constant, the field rises (falls) for 99% of its final (initial) value in 4.6t = 226nsec.

3-3 Fast-Extraction Kicker Systems at 50-GeV

The fast-extraction line with a beam energy of 50-GeV is equipped at the long straight section of the main ring. The required time scheme for the fast-extraction kicker system is almost the same as that for the abort systems. The rise-time and the flat-top should be ~400nsec and ~4450nsec, respectively. The fall-time can be ignored.

In the present design, eleven kicker units are to be arranged in line. In order to keep a full aperture for both the injected 3-GeV beam and the kicked 50-GeV off-axis beam, the kickers must have a large aperture with a height of 0.11m and a width of 0.12m. Each unit has an effective length of 1.5m and a kick angle of 0.6mrad. The fast-extraction system occupies 16.5m in total effective length and has 6.6mrad in total kick.

The types of thyrartons, PFNs and kicker units are same as that in the abort kicker systems described in the previous sub-section. The kicker current and voltage necessary to produce a field strength of 680 Gauß are 5.95 kA and 59.5 kV, respectively. The large kicker volume of 0.11m x 0.12m x 1.5m results in a large lumped inductance of 2056 nH. The time constant of the magnet, however, still stays in a tolerable range of τ = 51.4nsec. The 99% rise/fall time is 4.6τ = 237nsec. The sum of the thyratron rise-time and the kicker rise-time can therefore be sufficiently shorter than the large bunch-to-bunch interval of 400nsec.

4. Conclusion

The parameters for the kicker systems in the JHF 50-GeV main ring is discussed. It is found that the required speed and strength to the kicker systems can be realized within existing kicker technologies. More detailed studies on the structures of the kicker magnet units and the PFN systems, along with the developments of preliminary test-benches, will be continued further.

Acknowledgment

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