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PULSED SYSTEMS FOR eRHIC BEAM INJECTION AND EXTRACTION*

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Abstract

The electron-ion collider eRHIC requires a variety of kickers and septa for injection and extraction of beams throughout the entire collider complex. We plan to use pulsed systems for beam injection and extraction in Electron RCS, Electron Storage Ring, and Hadron ring. In this paper, we describe the pulsed systems required for beam transfer in the eRHIC Ring-Ring Pre-conceptual Design. We will outline the parameter ranges, technology choices, and opportunities for research and development in pulsed power technology.

OVERVIEW

The pulsed systems will use a series of pulse generators and pulsed magnets to accomplish rapid beam transfer during injection and extraction in the eRHIC chain of accelerators.

The electron accelerator chain will start with an electron source. The electron bunches generated by the source will be accelerated by a Linac to 400MeV and then will be injected into a Rapid Cycling Synchrotron (RCS), which will further accelerate the electron bunches up to 18 GeV. Subsequently the electron bunches will be extracted from the RCS and injected into the electron storage ring where they will circulate to collide with the hadron bunches which will circulate in the hadron ring. This hadron ring, which is virtually identical to the "Yellow" RHIC ring, will undergo some upgrades, such as modification of the injection system from the AGS-to-RHIC (AtR) transfer line into the hadron ring. Many pulsed systems such as kickers, bumps, and septa will be needed at the injection and extraction areas for these purposes. The design concepts for these pulsed systems are described in this paper.

In general, there will be two categories of pulsed systems. One category will be nanosecond fast-pulsed systems, which are at the forefront of accelerator pulsed power technology requiring substantial research and development effort; the other category will be the advanced systems, which utilize technology that has already been demonstrated but may need further development depending on stability and regulation requirement. We will describe the pre-conceptual design of nanosecond fast kickers of electron storage ring extraction and hadron ring injection in the same section, and rest of the pulsed systems in another section with emphasis on high power septa.

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ELECTRON RCS AND STORAGE RING PULSED SYSTEMS

The electron Rapid Cycling Synchrotron (RCS) and storage ring have many pulsed system requirements in common such as pulse width, power range, etc. The electron storage ring pulsed systems will have very stringent stability and regulation specifications, which will be challenging.

The arbitrary single bunch extraction from the storage ring will require a nanosecond fast kicker system as described in the next section.

The RCS injection will use a septum and a kicker without bumps. The electron beam extraction from the RCS and the injection to the storage ring will be complimentary to each other and use kickers, bumps, and septa.

RCS and Storage Ring Bumps and Kickers

Except the Storage Ring single bunch nanosecond extraction fast kicker, rest of the electron ring related pulsed systems are microsecond systems. They are within commercial or existing capability.

Electron Injection/Extraction Septa

The design parameters for the RCS injection and extraction septa, the Storage Ring injection septa are listed in Table 1. RCS injection and extraction pulsed septa are within commercial or existing capabilities. We will focus on higher power septa in this section.

RCS Extraction and SR Injection DC Septum Due to the high beam energy and the large required deflection angle, five sequentially arranged 1 meter long extraction DC septa will be needed in the RCS extraction area before the extraction pulsed septum to deflect the beam into the transfer line to the electron storage ring. Conventional C-shape dipole magnets are chosen for this application. The magnets will consist of a C-shape low carbon iron yoke with a single-turn excitation coil.

Design parameters are shown in Table 1. The proposed vacuum chamber will be made of solid 316 SST. Due to the high magnet current, water-cooling will be provided for both the coil and the magnet core.

The mechanical design of the storage ring injection DC septum will be the same as that described for the RCS extraction DC septum, except for a larger vacuum chamber aperture and bigger two-turn excitation coils. Due to the high magnet current, both the conductor and the laminated steel core will be water-cooled.

The RCS extraction DC septa will be connected in series and powered by a single DC power supply. The storage ring injection DC septa will be connected in a similar way.

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Storage Ring Injection Pulsed Septum The storage ring injection pulsed septum will be a core-in-vacuum design, which requires a thin 2mm septum. The core length of the septum is 1.5 meter. The core will be made of insulated, laminated, low carbon steel sheets. A 2mm thick copper septum, strengthened by a Mu-metal sheet, and a copper box enclosure around the iron sheets core will contain and dissipate the eddy currents generated by the pulsed field. Due to the high magnet current, additional cooling methods will be investigated in the conceptual design.

Pulse Generators for RCS Injection/Extraction and SR Injection Pulsed Systems

The pulse generators for the proposed RCS pulsed systems will be based on demonstrated technologies, such as half-sine wave capacitor discharge pulse generators, pulse-forming network pulse generators, Marx generators, or inductive adder pulse generators. The typical pulse base width will be in the range of 4 msec to 48 msec, except Storage Ring injection pulsed septa. These systems are either commercially available or can by Brookhaven in collaboration with other institutes or industrial partners.

The storage ring injection pulse septum and bumps will be similar to the RCS pulsed systems, except they will require higher stability, better waveform regulation, and smaller timing jitter. The pulsed septa will be able to use longer pulse widths while the bump pulse width will be two machine revolutions. To minimize power loss in the cable of the pulsed septa, the use of pulse transformers between the pulse generators and septa will be considered. For the purpose of pre-conceptual design, the stability and regulation of kickers will be considered in the 1 to 2 percent range, and the bumps and septa in the 0.25 percent range. These parameters will be refined as the design moves along.

All pulsed systems mentioned in this section will be a few hundred volts to a few kilovolts, well within existing capabilities and experience.

Table 1: RCS and Storage Ring Septa Parameters

Parameter	RCS Pulsed Septum		RCS DC Septum	SR Injection Septum	
	Injection	Extraction	Extraction	Pulsed	DC
Beam Energy [GeV]	0.4	18	18	18	18
Rep. Rate [Hz]	1	1	n/a	1	n/a
Def. Angle [rad]	0.02	0.006	0.009	0.006	0.009
Gap Height [cm]	2	2	2	3	3
Gap Width [cm]	3	3	3	4	4
No. of Turns	1	1	1	1	2
Bending Strength [Tm]	0.027	0.36	0.54	0.36	0.54
Mag. Field [T]	0.027	0.36	0.54	0.24	0.54
Mag. Length [m]	1	1.5	1	1.5	1
Mag. Current [Ampere-Turns]	425	3822	8600	5733	12900
Coil Current, [A/Turn]	425	3822	8600	5733	6450
Septum Thickness [mm]	4+	4	4+	2	4+
Quantity	1	1	5	1	5
Style	C Magnet	C Magnet	C Magnet	C Magnet	C Magnet

NANOSECOND FAST KICKER SYSTEMS

The electron storage ring beam extraction will be in a single-bunch fashion. At beam extraction, the bunch frequency is around 112MHz which implies a bunch spacing of 8.9 nsec. The rise time of the extraction pulse will be nanosecond fast and short. A series of 18 pairs of parallel-plate strip-line kicker with push-pull drivers are the ideal candidates for this application. The storage ring extraction kicker will be operated at a 1 or 2 pulse per- second repetition rate in continuous mode. It will be a challenge to minimize timing jitters to the sub-nanosecond range, especially when considering system integration with control system and RF synchronization. The pulse generator must achieve this tight jitter range in a continuous pulsing mode. In the pre-conceptual design, a reasonable timing tolerance was selected. A commercially available unit, the FID pulse generator with a 1.5 to 2 nsec electrical pulse rise time, a 7 nsec pulse flat top duration, a 4 or 5 nsec pulse fall time, and a combined electrical pulse base width of less than 14 nsec, is a good choice for this application.

The hadron ring injection kickers will be upgraded to allow a three times higher injection bunch number then at present. We will inject 330 bunches into 360 buckets with a reserved abort beam gap of 30 bucket spacing. The bunch frequency at injection is around 28 MHz. Hence, this kicker system must be nanosecond fast and powerful. The typical bunch length will be 15 nano-seconds; and the beam center-to-center time will be around 35.7 nano-seconds. A series of 20 parallel-plate strip-line push-pull structure kickers is proposed. They will be arranged in series in the hadron injection section. The kicker deflection angle will be reduced from 1.84 mrad to 1.0 mrad and the kicker aperture will be enlarged from the existing 41.2mm to 50mm. This kicker series will pulse in a burst mode during injection. The burst mode stability will be a critical parameter in this design. Each pair of hadron ring injection kick-

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ers will be 0.9m in length and be driven by a pair of nano-second fast pulse generators in push-pull fashion. The high voltage pulse generator must have a 10 nsec pulse rise time from 2% amplitude to 98% amplitude, a pulse flat top width around 50 nsec, and be capable to deliver 500A into a 50W load. The pulse fall time of the hadron ring injection kicker is not critical, as long as the pulse falls within the duration of the large beam gap. Almost all nano-second pulse generators will have a much shorter fall time than the 900 nsec beam gap. However, the pulse waveform, amplitude repeatability, pulse flat top regulation, and timing stability of the kick are extremely important for the hadron beam injection.

The design parameters for the nanosecond fast kickers are listed in Table 2.

Parallel-plate strip line deflectors for nanosecond fast kickers are proposed. They will be used in the single bunch electron beam extraction from the storage ring and in the hadron beam injection system. The proposed strip line kickers will be made of 316L stainless steel, which includes a surrounding circular chamber, two strip lines, and four HV coaxial feed-through rated at 30 kV. Each strip line has a 90 degree opening angle. The effective deflection length, per section, will be less than a meter. The characteristic impedance of the plate to ground will be around 50W.

The FID pulse generator has the potential to satisfy our design specifications for the storage ring extraction nano-second fast kicker and the hadron ring injection nanosecond fast kicker. An FID pulse generator has been tested at Brookhaven [1-3] and similar ones have been under test at several other institutes, see Figure 1.

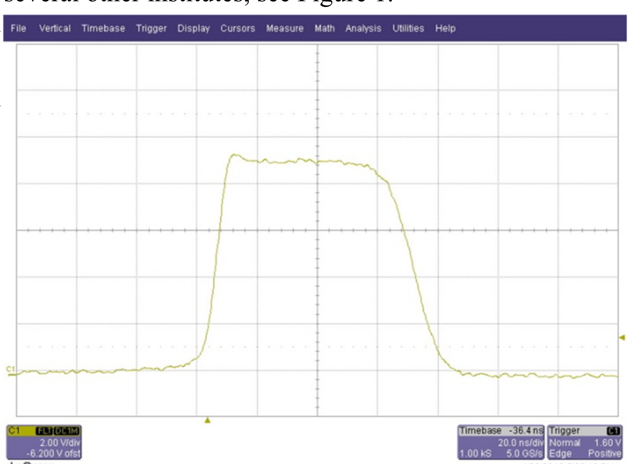

Figure 1: A 50 kV output pulse waveform of the FID pulser tested at BNL.

Other technologies have been tested at Brookhaven to support our nano-second pulsed power technology demand as well. For example, the Blumlein pulse-forming line (PFL) with solid-state switch, the inductive voltage adder (IVA), the parallel-plate with capacitive discharge, etc.

Surveying the field of pulsed power technology, the potential of the IVA may one day be fast enough to support the hadron ring injection kicker. We have just received encouraging preliminary test result, from a U.S. based commercial company, demonstrating a fast IVA with different circuit topology that achieved a fast pulse rise time and pulse width close to eRHIC pre-conceptual design specification. Further development of compact Blumlein PFLs or multi-layer PFLs with solid-state switch might offer another technological choice. While the superconducting harmonic RF cavity kicker and the SLAC DSRD kicker may someday be suitable for this application, the DWA kicker and other advanced concepts in the pulsed power field need substantially more development to be practical.

Table 2: Design Parameters for the Nanosecond Fast Kicker

Parallel-Plate Strip Line	Hadron Inj. Kicker	SR Ext. Kicker
Beam Energy [GeV]	24	18
Rep. Rate [Hz]	Burst Mode	2
Total Def. Angle, Rad	0.001	0.001
Gap Height [cm]	5	5
Gap Width [cm]	3	3
Voltage per plate [kV]	±16.65	±11.24
Current [A]	±333	±225
Deflector length per section [m]	0.9	0.667
Number of Sections	20	18
Style	Push-Pull	Push-Pull

CONCLUSION

In summary, we believe we have made reasonable choices to support eRHIC pre-conceptual machine design.

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