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DESIGN AND PRODUCTION OF THE FAST HESR-INJECTION KICKER MAGNETS

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Abstract

The injection kicker system been build for the High Energy Storage Ring (HESR). The system consist of four magnets, located in the specially developed vacuum tanks, and semiconductor based (IGBT) pulsers connected using coaxial cables. Produced system fully meets designed injection pulse parameters and can be used for the injection of protons, antiprotons and charged ions in the HESR storage ring.

HIGH ENERGY STORAGE RING

The Forschungszentrum Jülich together with industrial partners is in charge of building of the High Energy Storage Ring (HESR) for the Facility of Antiproton and Ion Research (FAIR) in Darmstadt. The HESR is 575 m long normal conducting magnet ring, designed for the particles with magnetic rigidity in a range 5-50 Tm, which in case of protons and antiprotons corresponds to the momentum range of 1.5 to 15 GeV/c. The storage ring is also foreseen to be used for the heavy ions, which puts very strict requirements on the vacuum quality in the complete machine, including the injection system.

INJECTION SYSTEM

The injection system of the HESR is designed to operate at 3 GeV, production energy of the antiprotons, but can also be used for the injection of positive particles and heavy ions. The system consist of injection dipole (7° deflection angle), two magnetic septa (each 3.8° deflection angle), and four injection kicker magnets. Injection magnets are designed for the DC operation during beam accumulation phase, while for the rest of the HESR cycle currents in the injection dipole and septa can be reduced. The beam angle of fifteen degree, between the HESR strait section and the injection beam line, will be successively reduced, using injection magnets, down to the 6.4 mrad in front of the injection kicker. The injection kicker, discussed in a following section, designed to produce a final kick for the injected particles in a time moment predefined by the HESR Barrier Bucket and HF systems and do not disturb particle beam circulating in the ring. Magnetic field of the three kicker magnets is sufficient for the injection in the ring, while fourth magnet is always available as a spare system in case of malfunction. The injection system is designed for the injection every 10 seconds with kicker pulse rise and fall time of 220 ns and a flattop time of 500 ns [1]. Requirements to the pulse quality in individual injection kicker magnet are presented in Fig. 1.

During HESR injection and cooling process it is planned to make one hundred injection for 1000 s. Kicker system is specified to produce not more than one unsuccessful kick processes per day. All those factors put very stringent requirements on the parameters of the injection pulses and made a design and construction of the kicker so challenging.

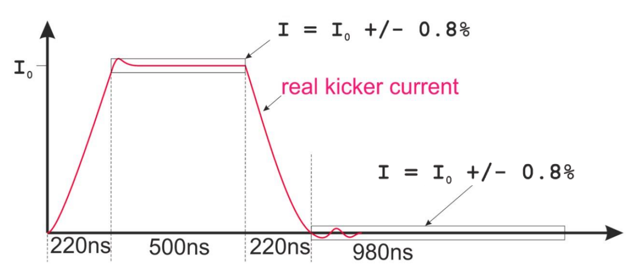

Figure 1: Requirements to the injection magnet pulse parameters. The pulse slope (rise from 2 to 98 %) should be 220 ns or shorter. Amplitude fluctuations (over/under shot) of the 500 ns flat top and after-pulse structures must not exceed ±0.8 % of the top current.

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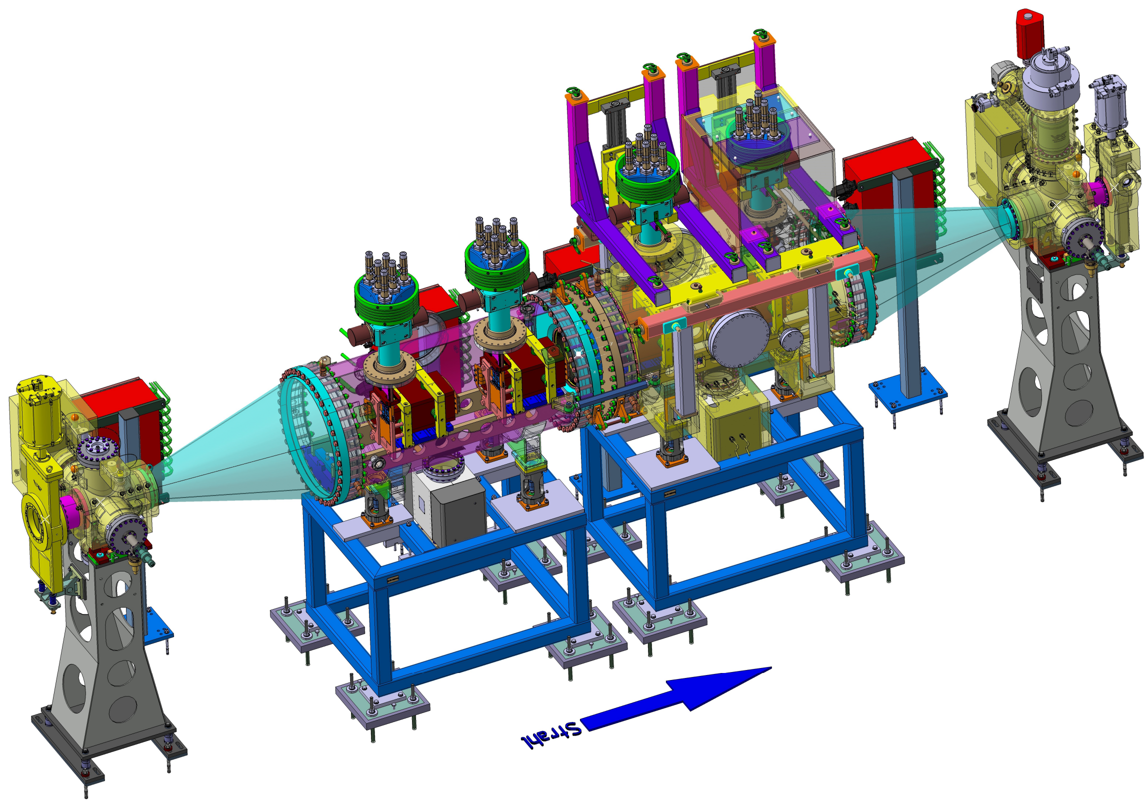

Figure 2: Design of the HESR injection kicker system. The system consist of four magnets inside of two vacuum tanks. The tanks are delivered separately and connected together at place using special bellow. Each magnet is connected to semiconductor based pulser using six coaxial cables which are joint together in one HV feed-trough at the top of the vacuum tank. A lifting system is designed to prevent damages of the ceramic feed-trough due to the external forces at the cable and disconnect the systems from the pulsers for the time of the bake-out process. Special conical tubes are designed to smoothen injection section impedance for the particle beam. In addition to the turbo and ion pumps at each vacuum tank, there are also standard HESR pump systems installed at both sides of the kicker section.

INJECTION KICKER SYSTEM

The HESR kicker system consist of four kicker magnets inside of two vacuum tanks, connected to four semiconductor based pulsers by a six coaxial cables in a Blumlein topology. The final design of the system is presented in Fig. 2. The kicker magnets are mounted on a rail system inside of a vacuum tanks. Each magnet has a single coil with one winding and a ferrite yoke. Every magnet is connected to the semiconductor pulser using a six coaxial cables, which are joined together in one HV-feed-through per magnet at the vacuum tank. To remove unnecessary forces from the ceramic feed-through and disconnect the system during bake-out process a special lifting system is installed at the tanks for the cables of each magnet. The two tanks are connected together using specially designed bellow, which allows quick exchange of the complete tank in case of malfunction. The controllable change of the HESR storage ring impedance is assured using a specially designed conical elements at the both sides of the kicker magnet tanks.

The third vacuum tank, with only one magnet inside, and corresponding cables and pulser, was produced to perform all kind of the experiments and tests necessary to develop a HESR kicker system. This system will allow further studies of the kicker magnet performance during a normal operation of the HESR ring.

All vacuum tanks can be heated at 250°C in a specially developed bake-out procedure after which a vacuum of 5E-10 mbar can be guaranteed. The vacuum and heat control systems, built and developed by Forschungszentrum Jülich, together with a description of heating procedure, can be found in Ref. [2].

The pulser of each magnet consist of commercially available high voltage power supply connected to the magnet in Blumlein topology by coaxial cables and a specially developed IGBT based switch. The polarity change is realised in a pulser cabinet by a simple commutation of HV lines.

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System Parameters

The HESR injection system has been produced by SigmaPhi company in a cooperation with the Forschungszentrum Jülich. Each tank has been delivered separately together with pulsers and cables matched for every magnet. Each kicker magnet together with a pulser has been fully optimised and tested in laboratory during factory acceptance test. The system parameters are optimised for the nominal and maximal currents of 3.6 and 4 kA, respectively.

The kicker magnet inside of the vacuum tank is presented in Fig. 3. Magnetic field of each magnet has been tested during factory acceptance test using a titanium wire placed inside of a magnet as a passive probe. The high voltage in the system was limited to 15 kV to avoid discharge in the system during the experiment done at normal atmospheric pressure. Current induced in the wire has been measured and analysed for the five positions inside of the magnet aperture (in the middle and at all four sides). Integrated mean field factor of 5.53 mT.m/kA with homogeneity of ±1.5 % over the five trajectories has been obtained for the magnets inside of the first tank. Measured field value is 3 % under the theoretical estimation (done with OPERA) and well within the specifications.

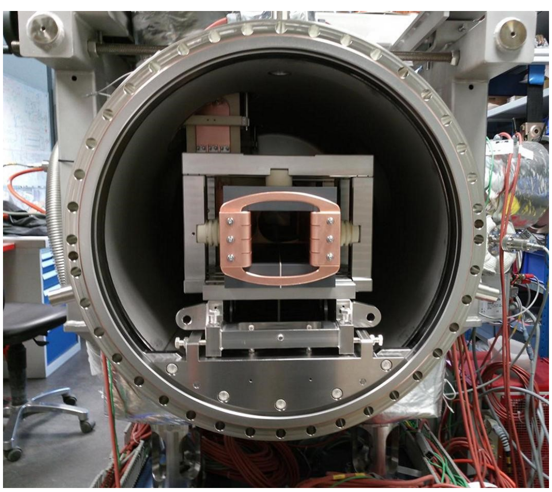

Figure 3: Kicker magnet inside vacuum tank. The vacuum tanks are bake-able to 250 °C. The magnets are installed and positioned on a rail system inside the tanks. Magnets have a single winding, ferrite joke and inductivity of ≈700 nH.

Kicker pulse shape measured for the third magnet with polarity for the antiproton injection is presented in Fig. 4. Measurements are done under vacuum of 5E-10 mbar at nominal injection current of 3.6 kA and at high voltage of 30.6 kV. The "flatness" of the pulse flat top in Fig. 4A is determined mainly by the parameters and impedance regularity of the Pulse Forming Line (PFL). Parameters of the rising and falling edge of the pulse, presented in Fig. 4C and D, are determined by the performance of used IGBT's (max. 150 ns at 42 kV) and matching of all the elements of the system. After-pulse fluctuation, presented in Fig. 4B, depends on all the system components but needs in addition a fine tuning of resistors to absorb the reversed waves.

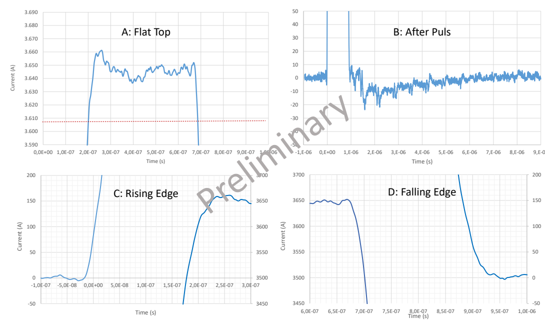

Figure 4: Example of injection kicker pulse measured with system three at polarity for the antiproton injection obtained during the factory acceptance tests. Details of the: flat top (A), after-pulse structure (B), rising (C) and falling (D) edges of the injection pulse are presented.

CONCLUSION

The injection kicker system of the HESR has been fully produced in cooperation of SigmaPhi company and Forschungszentrum Jülich. The system consists of four kicker magnets located in two vacuum tanks. Each magnet is connected to the semiconductor based pulser using six coaxial cables in a Blumlein topology. Produced system meets design specification and is ready for the installation in the HESR storage ring.

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