CONCEPT AND DESIGN OF THE INJECTION KICKER SYSTEM FOR THE FAIR SIS100 SYNCHROTRON

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Abstract

The SIS100 synchrotron at GSI, Germany is designed for acceleration of protons and ions. For the injection into the synchrotron a kicker magnet system, which consists of 6 ferrite kicker magnet modules, installed in one vacuum tank with a required vacuum quality better than 10^{-9} Pa, will be needed. The magnetic field should be 118 mT in a 65 mm gap. These kicker magnet modules will be supplied with 6 separate pulser circuits. Each pulser has to produce a pulse current of up to 7 kA at a PFL (pulse forming line) voltage of 80kV at an impedance of 5.7 Ohm. The rise time has to be 130 ns and the variable pulse length is between 0.5 to 2.0 µs. The design concept for this kicker system from Ampegon PPT and Danfysik and the specific challenges will be described.

SIS100 KICKER MAGNET SYSTEM

The SIS100 is a heavy-ion synchrotron to be built as part of the FAIR (Facility for Antiproton and Ion Research) project at the GSI Helmholtzzentrum für Schwerionenforschung GmbH in Darmstadt, Germany. To inject ions into the 1086 m long SIS100, a kicker magnet system is required.

To reach the required horizontal deflection angle of 7.5 mrad and to keep the current rise time below 130 ns using a reasonable voltage, the system is separated into 6 ferrite kicker modules, each with its own pulsed power unit (“pulser”). All these modules will be housed in one common vacuum chamber. Each module has a ferrite length of 180 mm, an aperture of 120 mm horizontally and 65 mm vertically. The current of 6.14 kA (maximum current in normal operation) in the single coil within the module produces a magnetic field of 118 mT.

To reach the required current, a system with impedance of 5.7 Ω is chosen. The pulse forming line that is to be used to produce a nearly rectangular current pulse is charged to a voltage of up to 70 kV. The calculated inductance of the module is ~ 0.57 µH.

A simplified electrical circuit of one module is shown in Fig. 1 and the resulting current pulse shapes are shown in Fig. 2 and Fig. 3. In Fig. 2 and Fig. 3 can be seen that the required current rise time of less than 130 ns was achieved in the simulation and a flat-top error of less than 2% can be reached. The results shown in Fig. 2 show that different pulse lengths are achievable by different timing of the main and dump switch.

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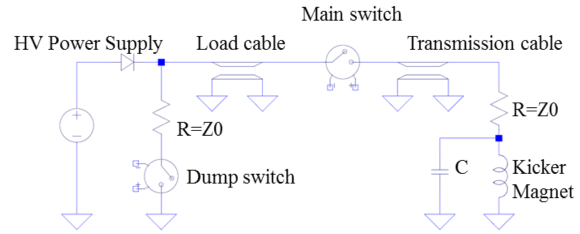

Figure 1: Simplified electrical circuit of one injection kicker module [1].

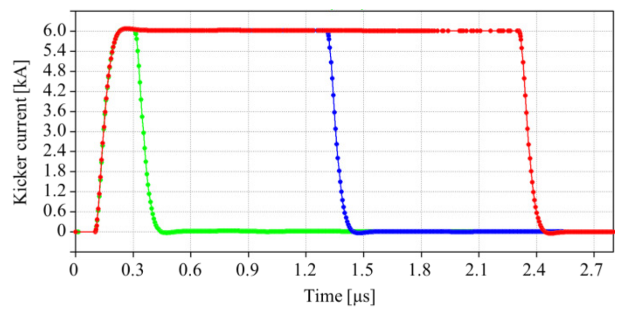

Figure 2: Current pulse shape at the magnet for different pulse durations. Simulated with LTSpice [1].

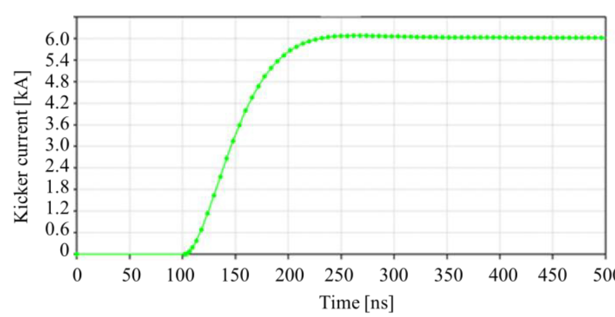

Figure 3: Simulated current rise [1].

ELECTRICAL COMPONENTS

The high voltage level and the required fast current rise require carefully chosen components. Especially the choice of the cables that are used to store and transmit the energy and the used switches will be discussed here.

Cables

The cables used for energy storage and transmission are of the DRAKA CPP20 [2] type. It has a characteristic impedance of ~17 Ω. 3 cables in parallel will be used to reach our required impedance of ~5.7 Ω. The cable is rather stiff, it has an outer diameter of ~32 mm and a minimum bending radius of 800 mm (500 mm installed). Its capacitance is ~350 pF/m and its weigh is ~1.85 kg/m. To reach the required pulse length of up to 2 µs, the storage cable has to be ~200 m long. They will be stored on cable drums, as shown for a similar system in Fig.4.

Figure 4: Cable drums for energy storage cables.

Switches

To reach 6140 A in less than 130 ns, a current rise rate of at least ~ $5*10^{10}$ A/s is required. The switch should not be the bottleneck, therefore a switch is required that can easily surpass this value. The switches also have to withstand a voltage of 70 kV in operation and 80 kV for maintenance and testing purposes. To cope with these requirements, thyratrons from e2v were chosen, type CX2593X [3]. It is a four-gap hollow anode type thyratron. The four gap system was chosen to prevent any misfire and the hollow-cathode increases the lifetime in case of current reflections. Trigger amplifiers built by Ampegon PPT, type THT-100 will be used to reliably trigger the switches, independent of the required voltage level (down to 20 kV in normal operation).

ELECTRICAL SETUP

While the vacuum chamber with the kicker magnets is situated in the ring tunnel, the pulsed power units will be situated in a supply room. The pulsed power unit of each kicker magnet module will be situated in a separated cabinet. One of these cabinets is sketched in Fig. 5. On the left hand side of Fig. 5, the main switch supplies can be seen, on the right hand side the controls, the main power supply (HVPS) and the dump switch supplies. In the middle cabinet, the thyratrons are situated. To allow maintenance, the switches are connected to a cover plate and the whole setup can be pulled out of the oil bath with a crane. All auxiliary power supplies, i.e. reservoir heater power supply and cathode heater power supply, of the thyratron have to be stabilized to ensure reliable operation. As the thyratrons are floating on a high potential during operation, also the auxiliary power supplies have to be floating. This has to be taken into account designing the cabinets. This can also be seen on the left hand side of Fig. 5: The Power supplies are situated in an additional box isolated from the ground.

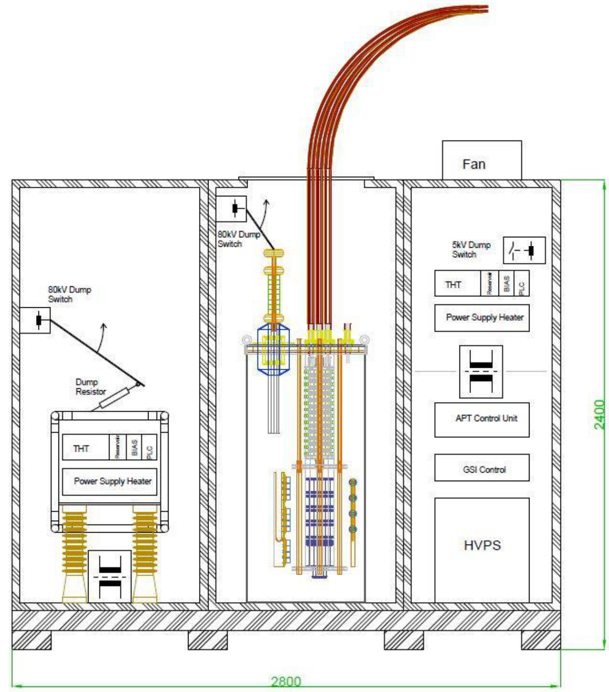

Figure 5: Pulsed Power cabinet.

As can be seen in Fig. 1, a termination resistor is required at both ends of the circuit. The resistor at the magnet side is shown in Fig. 6. The termination resistors will be made from a series connection of disc resistors that are situated in oil. In parallel to the magnet, two high-voltage capacitors are included that can also be seen in both pictures. They improve the current rise time at the kicker magnet.

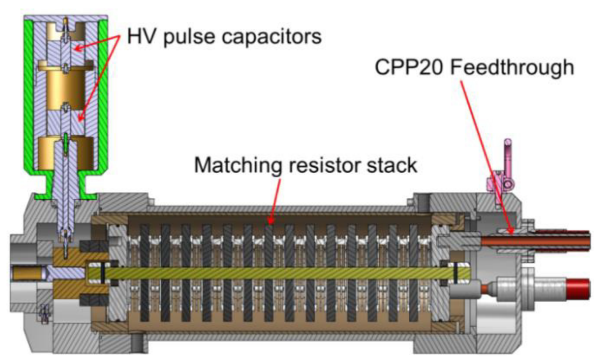

Figure 6: Termination resistor.

This termination resistor block in front of each Kicker includes several devices with the following aims:
- HV insulation up to 80kV
- Pulse form matching in the rise and fall time using pulse capacitors

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- DC high power termination (3 kW) with peak powers during flat-top of more than 200 MW.
- Pulse current measurement with a bandwidth of 20 MHz
- Beam induced pulse filtering (> 5 MHz) to avoid misfiring of the thyratron
- HV coupling to the vacuum feedthrough; insulation materials and shape profile

VACUUM CHAMBER

All 6 kicker magnet modules will be situated within one vacuum chamber. It is sketched in Fig. 7. The total length of the chamber will be ~2.2 m (without bellows).

The beam height and therefore the middle axis of the vacuum chamber is 1400 mm above ground. The inner diameter of the vacuum chamber will be ~500 mm. The final pressure within the system has to be 10^{-9} Pa or less. A large number of pumps will be required to achieve this ambitious goal. As shown in Fig. 7, the termination resistors are located directly at the vacuum chamber.

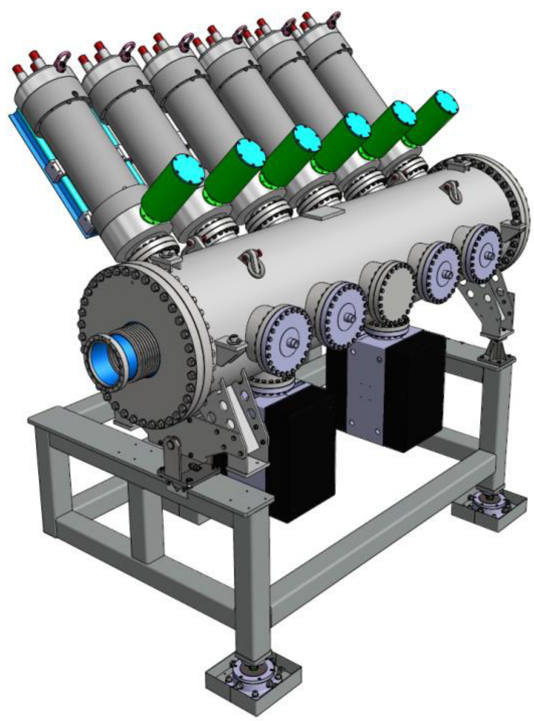

Figure 7: Vacuum chamber of the kicker magnet system.

To achieve the required vacuum quality, the vacuum chamber has to be able to be heated up to 300 °C during bake-out. The termination resistors are filled with oil to improve insulation and, using flowing oil, to get rid of the heat produced in the disc resistors (up to ~3 kW average, more than 200 MW during pulse). The resistors have to be separated from the vacuum chamber during heating process because the insulating oil is not to be heated. This is done by a lifting mechanism. Due to the stability and weight of the cables, and the weight of the termination resistor setups, this lifting mechanism is to be designed carefully. Counterweights will be included to allow lifting without excessive manual work. The cable routing has to be done accordingly that the forces of the cables onto the resistor boxes are manageable. The high-voltage feedthroughs require an insulation voltage of 40 kV.

The whole chamber including all its internals have to be designed to allow the bake-out heating mentioned above. Due to the expansion of the materials a careful design is required to ensure that after cool-down the magnets are again at the exact position they had before the heating cycle. A new alignment of the inner components is not possible after bake-out therefore the positioning has to be reliable independent of the bake-out cycles.

In contrast to Fig. 7, the whole vacuum chamber will be situated on a stand on three adjustment feet that will allow the proper positioning of the chamber.

KICKER MAGNETS

To simplify alignment, the six modules will be situated on a common rail system, as can be seen in Fig. 8.

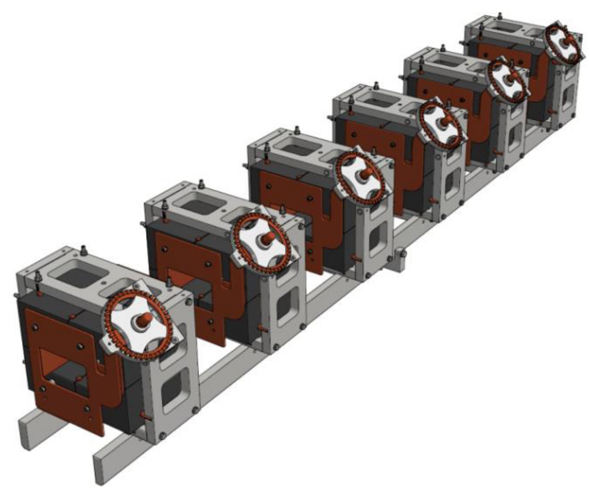

Figure 8: Magnet modules on rail system.

After the six modules are well aligned on the rail, the rail is inserted into the vacuum chamber. On top of the vacuum chamber, fiducials are situated. A transfer measurement between position of the modules and the vacuum chamber allows alignment of the magnets after the system is integrated into the accelerator.

REFERENCES

[1] Linear Technology, http://www.linear.com

[2] Draka, Datasheet of CPP20

[3] e2v, http://www.e2v.com