CHALLENGES IN THE DEVELOPMENT OF THE SIS100 ELECTROSTATIC EXTRACTION SYSTEM

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Abstract

The "Facility for Antiproton and Ion Research" (FAIR) is a new international accelerator complex, which is currently built in Darmstadt, Germany. Part of this complex is the SIS100 heavy ion synchrotron with a circumference of ~1086 m. One of the extraction systems is the electrostatic septum. This septum was built by Danfysik. It is operating with voltages up to 180 kV. The requirements on the vacuum quality (low 10e-11 mbar region) combined with voluminous chambers (in total ~6m long), the reproducibility and precision of the applied voltage as well the mechanical stability and exact positioning even after bakeout cycles up to 300 °C have been the biggest challenges on this project. Specifications on rise and fall times for the high voltage implies the need of a bleeder resistor, used for improved voltage accuracy, too. During this project numerous problems had to been solved to end up with a stable system. The results of the tests and lessons learned are presented.

SYSTEM OVERVIEW

The electrostatic septum (Fig. 1) is a device for so called slow extraction of the ion beam from the ring accelerator.

Figure 1: The SIS100 Extraction Septum currently build at DanFysik [1] in Denmark

During extraction most of the particle beam circulates undisturbed through the septum, a small fraction of the beam reaches the region between anode wires and cathode.

The high electric field leads to a deflection (Fig. 2), magnified by following quadrupole magnets and can be extracted out of the ring by a magnetic septum.

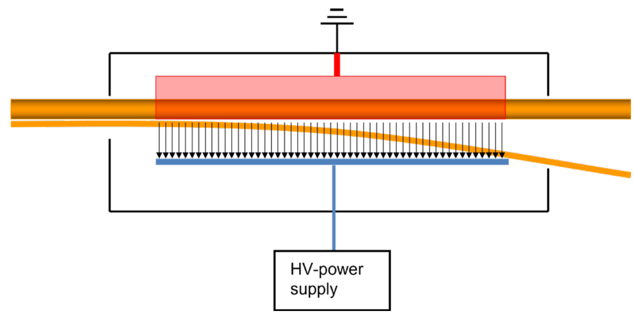

Figure 2: Deflection of part of the beam.

To achieve the required deflection angle, a high voltage between -5 kV and -180 kV is used. Due to the required length, two electrode systems of 2.5 m length each are used in this septum. Protection resistors (Fig. 3) are used to absorb the energy stored in the cables in case of a flashover. This prevents severe damage of the electrodes. Both electrode systems are supplied with the same voltage, a T-shaped resistor is used to absorb the power of the long cable between HV power supply and the device in the ring tunnel.

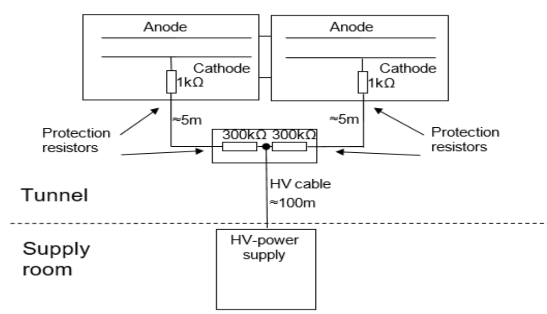

Figure 3: Protection resistor system for electrode and wires.

The high precession positioning of the electrodes is realized by eight stepper motors.

The intensity of the beam can destroy the anode wires if the beam parameters are chosen wrong. To reduce the damage, broken wire detection in multiple independent sections rises an alarm and switch of the accelerator immediately.

NEG-Modules have to build into the chambers to reach the required vacuum quality. The area between the electrodes is protected by a screen from the dust of the NEG modules mounted above.

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MECHANICAL CHALLENGES

Bake out cycles are necessary to reach the necessary vacuum quality. The heating process up to 300°C elongates the chamber more than 2 cm. It has to be ensured, that after cool down, everything is in the original position again. Some parts of the system cannot withstand the high temperature and have to be removed during the bake out process.

The cathodes are connected by contact springs in each center of the bars. Using very long cathodes, measurement of the flatness of the electrodes revealed a significant bend of about 0.7 mm (Fig. 4) over the length of 2.5 m.

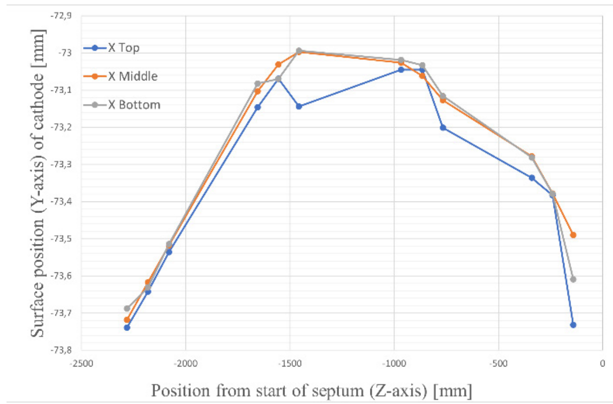

Figure 4: Measurement of the flatness of the cathode along the bar in three different heights.

Simulations (Fig. 5) show, that this is due to the contact springs. To reduce the force by using weaker springs would solve this problem but can't guarantee sufficient contact of the electrodes to the HV source at each position in the moving range.

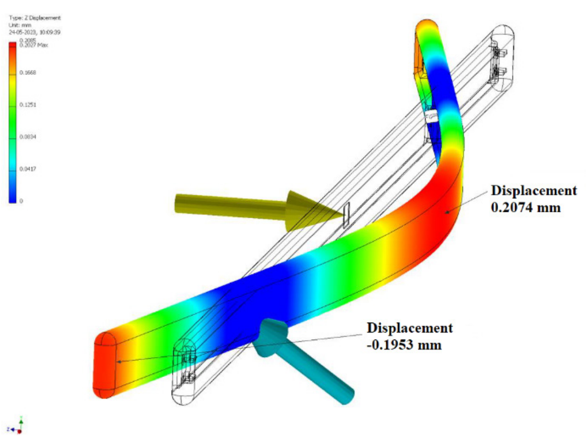

Figure 5: Simulation results of spring-loaded cathode.

Recalculations of the beam dynamic shows, that the effect of the bended bars (and changes of the electric field strength along the electrodes) is acceptable and can be compensated.

The anode itself is a build as a cage (Fig. 6), where the circulating beam is not affected of the field between cathode and anode wires. Clearing electrodes inside this structure are used to compensate for electric field reaching through the gaps between the wires.

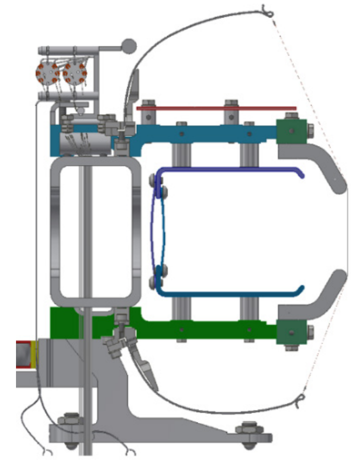

Figure 6: Structure of the anode cage.

Springs are used to straighten these wires. A compromise between straightness and tension limit has to be found. Low spring forces lead to bending of the wires due to the force caused by the electric field (Fig. 7, Fig. 8), while strong forces break the thin wires (0.1mm), heated up by the beam.

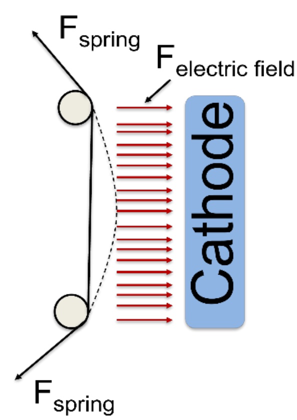

Figure 7: Influence of the electrostatic field to the wire position.

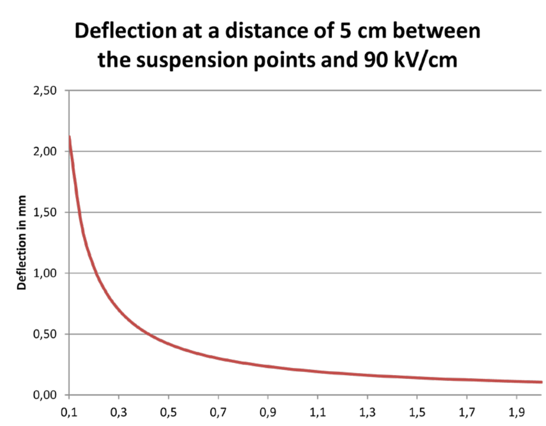

Figure 8: Calculated bending in dependence of the spring tension on the wires.

During the bake-out cycles the tension of the spring forces are reduced (Fig. 9), further complicating the issue.

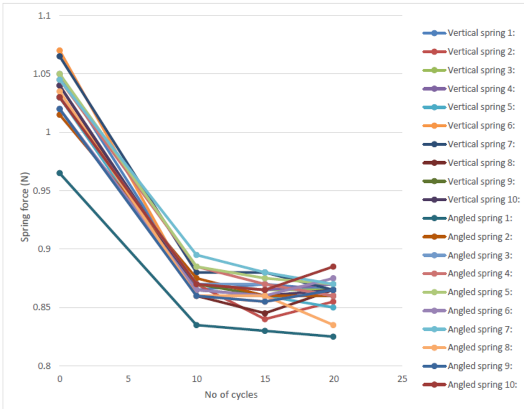

Figure 9: Measured spring forces over bakeout cycles.

VACUUM CHALLENGES

The requirements are a pressure below 2*10e-11mBar despite numerous components featuring large surface areas. To reach this vacuum level the system must baked out up to 300°C. During cool down, the COF flanges may cause leaks and have to be retightened afterwards.

ELECTRICAL CHALLENGES

Different ion types and energies require different electric fields in the septum. We want to be able to adapt the different voltages (between -5 kV and -180 kV) in ~500 ms.

The power supply is powerful enough to raise the voltage in this time. To dump the energy stored in the cables and the septum a bleeder resistor is used. This bleeder (Fig. 10) had to be redesigned due to internal arcs.

The internal voltage measurement of the power supply is not accurate enough. Therefore, a calibrated voltage divider was implemented into the bleeder oil tank.

Space restrictions forced a development of high-voltage withstand capability in a compact design.

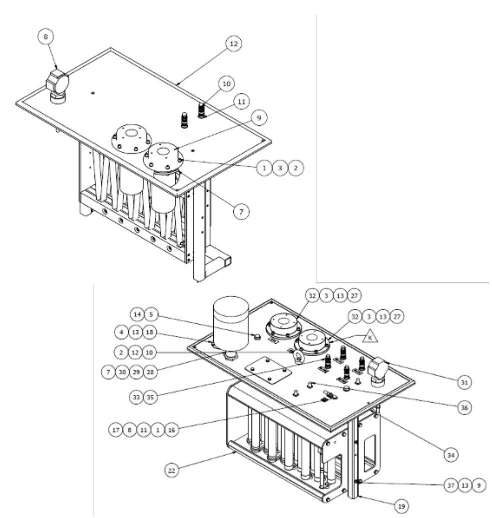

Figure 10: Bleeder resistor form first to final design.

During tests, a flashover at the septum led to voltage reversal on the line and a power supply unit fault. To prevent further faults, a loading resistor was implemented into the power supply.

Measurements of the risetime by switching from low to high voltage shows, that the control behavior of the power supply unit leads to overshoot (Fig. 11). This effect can be reduced significant by a controlled voltage ramp-up with several interpolated setpoints.

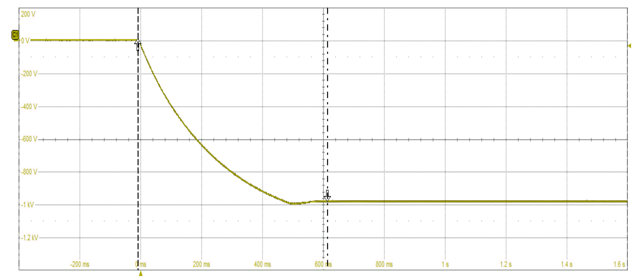

Figure 11: Overshoot caused by mismatched control loop to the load in the power supply.

Originally the connection between the HV-parts of the system (bleeder resistor, T-shaped pre resistor, HV feedthroughs) was realized by direct connection of the core of the cable in oil, but the capillary effect of the stranded cable necessitates the use of custom-designed HV connectors. The high radiation level in the ring tunnel restricts the choice of materials therefore – especially soft isolation materials are not available. The solution now is a silicone sheathing, that allows quick replacement in a radiation area and has to be replaced every one to two years.

SUMMARY

The project is currently under final acceptance test. Pushing the limits of field strength, vacuum quality and available space, the development of the septum system was combined with many changes and adaptions. But we are looking forward to complete this project within the next two months.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Danfysik A/S, Taastrup, `https://danfysik.com`