

DEVELOPMENT OF A COMBINED ELEMENT WITH AN ELECTRIC AND MAGNETIC FIELDS FOR THE JEDI EXPERIMENT

K. Grigoryev*, R. Gebel, M. Schubert, Yu. Valdau,

GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

N. Bongers, N. Demary, G. Langenberg, F. Scheiba, H. Zens,

Institut für Kernphysik (IKP), Forschungszentrum Jülich GmbH, 52428 Jülich, Germany

J. Böker, Medical Systems Particle Therapy GmbH, 53842 Troisdorf, Germany

Abstract

Precision measurements of the permanent electric dipole moment (EDM) of fundamental particles require the development of new methods and techniques. The precursor experiments to measure the proton and deuteron EDM at the Cooler Synchrotron COSY in Jülich led to the structure of a ring concept with combined magnetic and electric field elements. The building of high-stability electric and magnetic field deflectors is one of the technical challenges of this project.

The previous studies on small-size deflectors have shown promising results in achieving high electric field strengths. For the present tests, a large-gap dipole magnet with a suitable vacuum chamber is equipped with a real-size prototype 1 m long deflector plates. Using high-voltage (200 kV) precision power converters we are aiming to achieve the design values of the prototype electrostatic ring of the order of 7 MV m^{-1} with 60 mm spacing between the electrodes in a presence of a necessary magnetic field.

The setup for studying the electric and magnetic field strength at various distances, as well as the results of the measurements, will be presented.

INTRODUCTION

A new JEDI prototype storage ring [1] requires development of an unique electromagnetic bending elements. To investigate possibility of reaching desired electric field strength (see Table 1) [2] at the gap distances of 60 mm between the plates a real-size deflector prototype was produced.

For testing the electrodes of this size a new experimental area inside the COSY storage ring was organized. An existing large-gap dipole magnet was picked to provide necessary magnetic field. It was already equipped with a 1400 mm large vacuum chamber suitable for the installation of real-size electrodes.

Table 1: Design parameters of the deflector for the JEDI prototype ring [2]

Experiment conditions	E [MV/m]	B [mT]	D [mm]	HV [kV]
E Field 30MeV	6.67	-	60	400
ExB Field 30MeV	4.56	28.5	60	274
ExB Field 45MeV	7.00	32.7	60	400

* k.grigoryev@gsi.de

Two 1080 mm long aluminium electrodes on ceramic insulators were mounted on the flanges of the vacuum chamber and precisely positioned inside it. The thin titanium foils stretched above and below the electrodes are foreseen to keep the distance to the grounded surface constant. Additionally it helps to protect the chamber walls from an electric discharge damage.

THE EXPERIMENTAL SETUP

The setup for the measurements (shown in Fig. 1) consist of two rogowski-shaped TiN coated aluminum electrodes (a) mounted on the vacuum flanges (b) with help of two linear drives for precise positioning inside the chamber. The deflector is separated from the chamber by set off two 0.5 mm Ti-foils (c). The high-voltage feedthroughs (d) are located in the middle of each electrode. The linear actuators (e) are supported by the mounting profile (f) which can be used from both sides. The maximum distance between the electrodes can reach 120 mm whereas the minimum distance is limited to 20 mm. It should be sufficient to produce a good-field region $20_{\text{hor}} \times 60_{\text{vert}} \text{ mm}^2$ at the nominal distance between the electrodes.

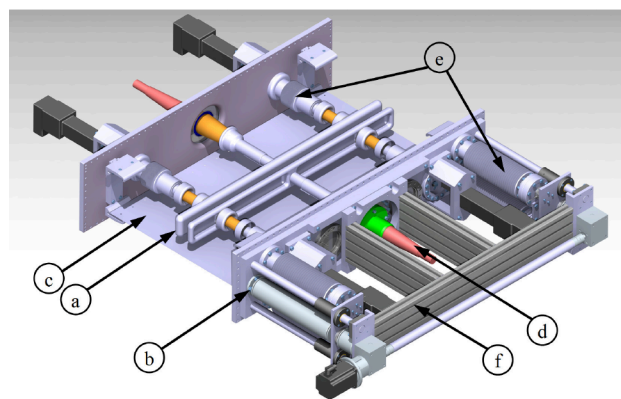


Figure 1: CAD drawing of the electrodes in the vacuum chamber with infrastructure. Labeling of individual parts described in the text.

After ultra high vacuum cleaning all mechanical parts were assembled in the dust-free conditions of the flow-box close to the experimental area. It allows mounting all vacuum elements together in the clean environment without time pressure. The vacuum flanges are different for each side of the vacuum chamber.

THE VACUUM SYSTEM

The large vacuum chamber of the dipole magnet was equipped with turbo-molecular, cryo and ion-getter pumps separated with valves (see Fig. 2). Initial pumping with a turbo pump will evacuate the chamber to the pressures up to 10^{-7} mbar. Further pumping of the system with cryopumps will make vacuum dry by removing water layers from the surface of the chamber.

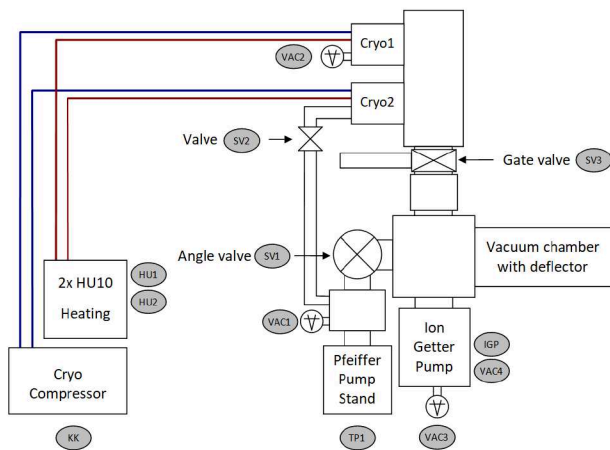


Figure 2: Vacuum layout of the experimental setup.

The final experiment has to be conducted at the pressures below 10^{-8} mbar with ion-getter pump only. In order to minimize environment vibrations during the measurements all other pumps will be separated from the main vacuum chamber using the gate valves and stopped. The operation of all vacuum devices is monitored by the standalone control system (see Fig. 3) in fully automatic or manual mode. The vacuum level, measured by the ion-getter pump parallel to its operation, is also used in the interlock system.

THE INTERLOCK SYSTEM

During the tests the experimental setup has to operate at the voltages up to 400 kV between the electrodes. Any accidental breakdown in the vacuum will produce X-rays. Therefore it was obligatory to protect personal not only from a high-voltage shock due to a direct contact with electric parts but also from possible radiation exposure restricting unattended access to the main accelerator hall. A special interlock system has been built to meet safety precautions in place. The Siemens Logo electronics was used to control the high-voltage level. At the moderate voltages below 1 kV access to the inner experimental area, secured with the metallic fence, is allowed without restrictions. Increasing the voltage between the deflectors to 30 kV allowed only if all doors of the experimental area are locked and the absence of people inside the fence is manually confirmed by an interlock button. This status is monitored locally and the high-voltage power converters will be immediately switched off in case of opened doors. Further increase of the high-voltage to 400 kV is allowed only if there are no persons in the accelerator hall.

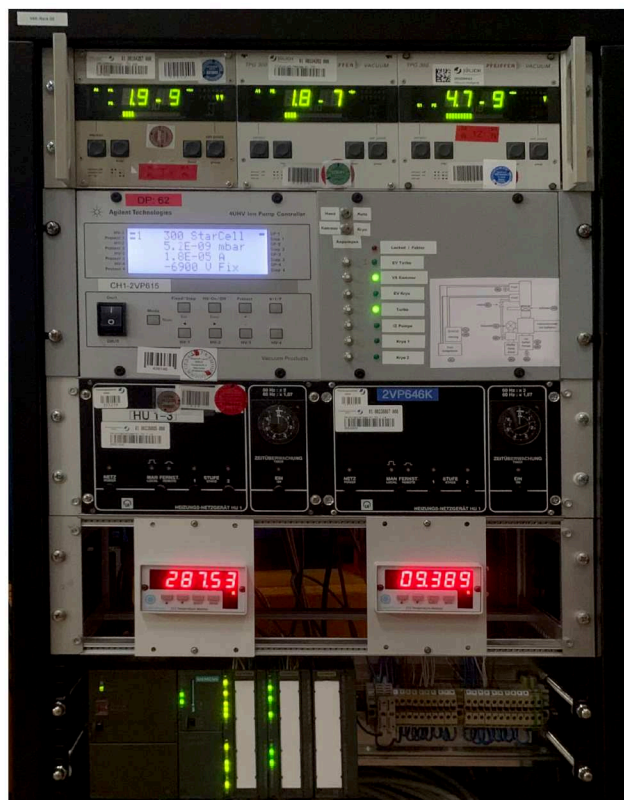


Figure 3: Vacuum control system.

It is monitored together with main personal security system controlling all possible accelerator entry points. The high voltage will be immediately turned off if any interlock is opened.

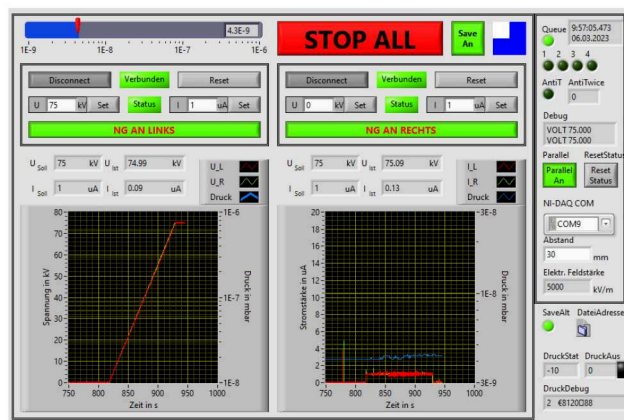


Figure 4: High-voltage and vacuum remote control software.

Since most of the time the setup will operate at the voltages above 30 kV between the electrodes, a special remote control software (see Fig. 4) was developed to monitor and operate high-voltage power converters. It also monitor the vacuum conditions in the chamber, set up the high-voltage individually or teamwise and measure the dark current on both power converters.

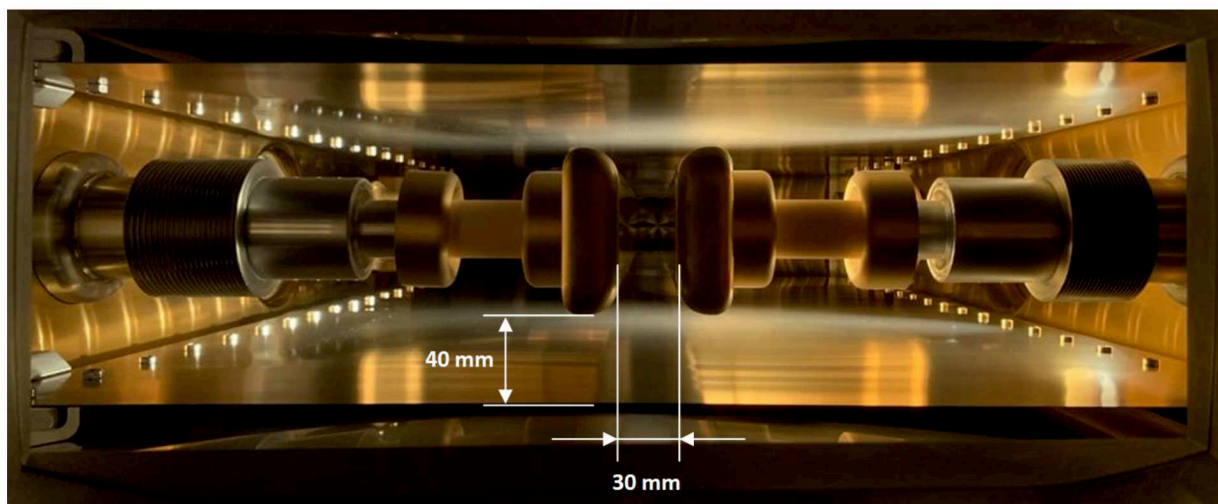


Figure 5: The electrodes at the distance of 30 mm inside the vacuum chamber.

THE HIGH VOLTAGE SYSTEM

Each deflector is connected to an individual precision bipolar high-voltage 200 kV power converter. In order to achieve the design conditions for the pure electric field case at the distance of 60 mm (see Table 1) the system has to run at its maximum voltage.

The upper and lower flanges of the vacuum chamber sag slightly inward after pumping is started (see Fig. 5). In order to keep a constant distance from the positively and negatively charged electrodes to the neutral grounded chamber two titanium foils were installed below and above the deflector. They are also used to protect the chamber surface from the damage by the electric discharge.

After assembly of individual components on the flanges, the electrodes were aligned to the flange surface within the measurement accuracy of $50\ \mu\text{m}$. Due to the different geometry of the vacuum flanges the distance from the flange to the flat area is different for both electrodes. The mounting position of the electrodes corresponds approximately to the gap distance of 91 mm.

THE MEASUREMENTS

First attempts to condition the electrodes were conducted without magnetic field. The distance between the electrodes was set to 91 mm during installation into the vacuum chamber. The field strength of $1.75\ \text{MV m}^{-1}$ was achieved at 80 kV (see measurements over the blue curve on the Fig. 6) with a dark current below 100 nA.

Further measurement were made with a minimum possible magnetic field of 150 mT. The time constraints for the high-voltage measurements were combined with allowance to restrict access to accelerator facility for other persons. Unfortunately, preparation for the future experiments at the COSY storage ring requires frequent access to the tunnel and limits time for deflector experiments. In order to complete the process of conditioning and testing the electrodes

in time, the distance between the electrodes was reduced to 60 mm, 30 mm and finally 20 mm as it shown on Fig. 6.

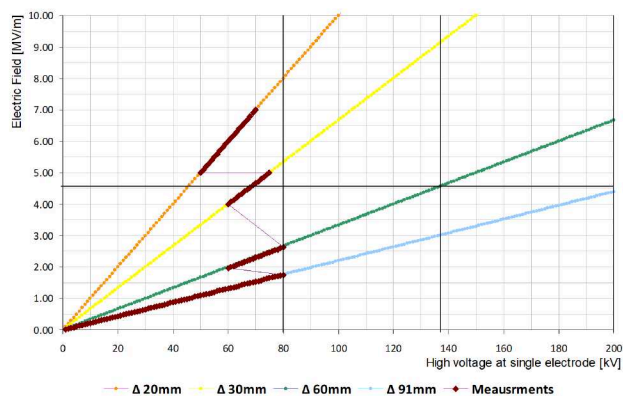


Figure 6: The measurement sequence of the electric field between the electrodes with respect to the displacement.

CONCLUSION

The real-size electrostatic deflector was tested at high electric fields at different displacement between the electrodes with and without presence of the magnetic field. Due to a time constraints measurement procedure was shortened. The maximum electric field strength of $7\ \text{MV m}^{-1}$ was successfully reached. During the measurements at higher fields the dark current do not exceed 100 nA.

REFERENCES

- [1] *F. Abusaif, et al.*, "Feasibility Study for an EDM Storage Ring", arXiv:1812.08535 (2019).
- [2] *F. Abusaif, et al.*, "Storage Ring to Search for Electric Dipole Moments of Charged Particles - Feasibility Study," CERN Yellow Report 257 (2021).
- [3] *K. Grigoryev, et al.*, "Electrostatic deflector studies using small-scale prototype electrodes", Rev. Sci. Instrum. 90 045124 (2019).