Available online at www.sciencedirect.com

SCIENCE DIRECT®

Applied Surface Science 252 (2006) 3143–3147

applied surface science

www.elsevier.com/locate/apsusc

The design of the main accelerator for a pulsed positron beam

A. Pelli *, A. Laakso, K. Rytsölä, K. Saarinen

Laboratory of Physics, Helsinki University of Technology, P.O. Box 1100, FIN-02015 HUT, Finland

Available online 23 November 2005

Abstract

The pulsed positron beam at the Helsinki University of Technology is designed for the end energy of 3–30 keV and grounded target. This is achieved with a constant voltage acceleration followed by an adjustable deceleration. In the design of this accelerator–decelerator the possibility for electrical breakdowns and partial discharges must be eliminated.

For designing the electrode and insulator structures for accelerator–decelerator configuration electric field simulations were carried out with the finite element analysis program. In this paper we present the design of the accelerator–decelerator and the results of the electric field simulations. The results of high voltage tests will also be presented and compared with the simulations.

PACS: 29.17; 84.70; 78.70.B

Keywords: Pulsed positron beam; High voltage; Accelerator; Breakdown; Partial discharge

1. Introduction

Slow positron beams are used to study lattice defects at different depths of a sample. In these beams positrons are first slowed down to a constant energy by a moderator and then accelerated to desired end energy which determines the penetration depth in the sample.

In the pulsed positron beam monoenergetic positrons are bunched using alternating electric fields. The stability of the voltage over the main accelerator is essential since breakdown and partial discharge induced voltage ripple will increase the flight time spread and destroy the time structure of a positron pulse. In order to minimize the inevitable HV breakdowns accelerator electrodes and insulators have to be carefully designed. In addition, the accelerator–decelerator structure is optimized to eliminate the annihilation events of backscattered positrons.

In this paper we discuss different breakdown mechanisms and present the structure of the accelerator–decelerator. We also show results of electric field simulations and present the high voltage test results.

* Corresponding author. Tel: +358 9 451 3143; fax: +358 9 451 3116.

E-mail address: asp@fyslab.hut.fi (A. Pelli).

0169-4332/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.apsusc.2005.08.054

2. Breakdown mechanisms

Three types of breakdown mechanisms can be specified; field emission induced breakdowns, partial discharges and complete breakdowns between electrodes. The latter takes place when the dielectric strength of an insulator or vacuum is exceeded.

So called metallic field electron emission (MFEE) induced breakdown can start both from an anode and cathode. In cathode-initiated breakdown a microprotrusion will vaporize as a consequence of heating by a current flowing towards the emitting surface. In anode-initiated breakdown a spot of the anode is heated by electron bombardment so that the metal vapour pressure is increased and breakdown occurs. In both cases the breakdown is a consequence of the increase of the pressure [2]. In order to avoid metallic field electron emission the electrodes should be as smooth as possible and finished with electrochemical polishing.

Partial discharge mechanisms are of a rather complex nature and understanding of these mechanisms is still incomplete. So called external partial discharges, i.e. corona discharges may be induced at sharp points or edges where the electric field can locally exceed the breakdown field strength. These can be avoided by excluding shapes of small radius of curvature in electrode configuration or by shielding them with corona rings.

Insulators are critical components in an accelerator as they have to withstand high voltages for a long time. Insulator material, in addition to having a high enough breakdown field strength, must be of high quality and as uniform as possible. As internal partial discharges may take place inside an insulator if it contains cavities. Partial discharges may also take place in the small vacuum gaps between a high voltage electrode and an insulator. These discharges are very problematic as they tend to form channels through the insulator leading to a complete breakdown and deterioration of the insulator.

3. HV design

In the design of the accelerator two independent sets of design criteria have to be met. On the one hand operational requirements of the positron beam have to be fulfilled, and on the other, the accelerator must have sufficiently high voltage insulation capability. The stability requirement for the accelerator voltages can be easily estimated. The time-of-flight spread caused by the main accelerator should be less than one channel (10 ps) in the time resolution spectra. The total time-of-flight of a positron in the main accelerator of our beam is 14 ns. For the time spread

$$\frac{\Delta T}{T} = \frac{1}{2}\frac{\Delta E}{E}. \quad (1)$$

From this we can assume 40 V for maximum allowed breakdown or partial discharge induced voltage ripple for an acceleration voltage of 30 kV. This requirement demands careful electrode and insulator design, right materials and surface finishing techniques.

Stable high voltage electrode materials for UHV applications are, e.g. titanium, stainless steel and molybdenum [2]. Electrodes for our accelerator were made of non-magnetic stainless steel, because of its low price, availability, and machinability.

The accelerator–decelerator is located inside the grounded main measurement chamber and consists of electrode rings connected to each other by voltage divider resistors (Fig. 1). In our system, the possibility

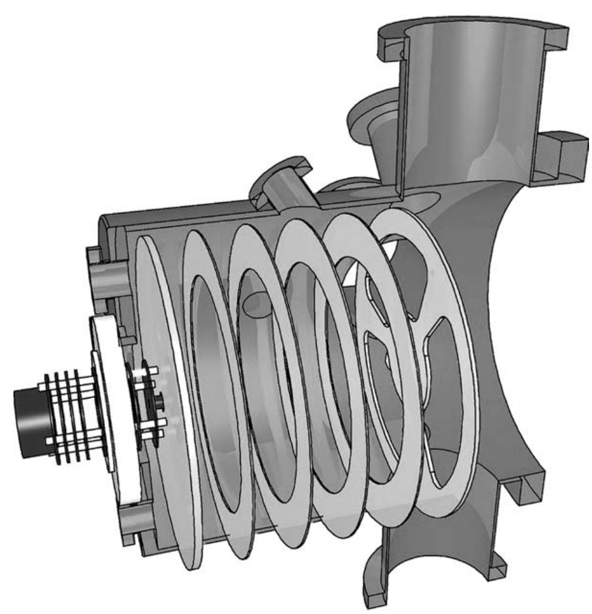

Fig. 1. Structure of the accelerator–decelerator.

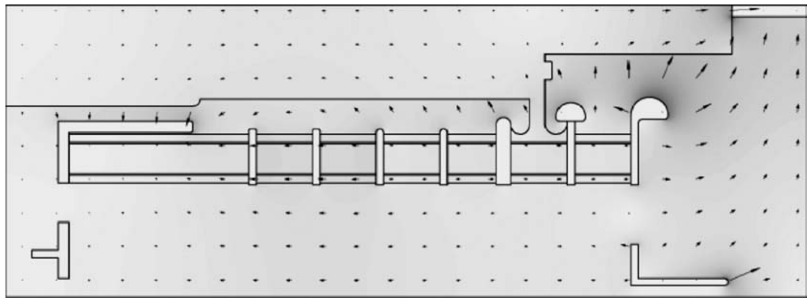

Fig. 2. A two dimensional axis-symmetric finite element calculation of the electric field in the accelerator. Maximum electric field (3.3 kV/mm) is located at the outer edge of the rightmost electrode.

of complete breakdowns is eliminated in 'plane-parallel' configuration, as the dielectric strength of a high vacuum is of the order of 30 kV/mm and the measurement chamber is large enough to maintain a sufficient electrode separation. The mechanical support for electrodes is made of polyoxymethylene (POM) rods and spacers. POM has a sufficient dielectric strength of 20 kV/mm, it is easily machinable and its mechanical properties are sufficient.

The target for high voltage strength of the accelerator and the decelerator was 40 kV, to allow for the recommended safety factor of 25% [2]. We used a design criterion of 4 kV/mm for maximum electric field strength at electrode surfaces. This makes the HV tests possible also at atmospheric pressures.

4. Field strength simulations

The calculation of high voltage strength of the electrode arrangement is quite complex so we used a finite element analysis program [3] to simulate many different electrode and insulator shapes and configurations. The main problem in the acceleration structures was the electric field enhancement at the edges of the electrodes. This problem can be overcome by the use of corona rings with large enough radii of curvature. According to simulations these were, however, necessary only at the electrodes of highest potential.

Another problematic part of the accelerator was the supporting structure between the third and second last electrodes. Small gaps and small-angle corners between an electrode metal and an insulator must be avoided since they are potential places for partial discharges to take place. Simulated field strength plots of the final configurations of the accelerator and decelerator are presented in Figs. 2 and 3.

5. High voltage test setup

The high voltage strength of the accelerator–decelerator structure was tested by applying dc voltages, with both polarities, and ac voltages up to 40 kV over it. In the dc tests the output voltage and current of the power supply was monitored. A breakdown event can be observed as a fast voltage dip with a simultaneous current peak.

Partial discharges (PD) were studied with both ac and dc voltages. In these tests a 1 nF capacitor was connected parallel with the main accelerator and a pulse transformer was used to measure the fast PD-induced pulses. A capacitive voltage divider (consisting of a 100 pF and a 100 nF capacitor) was used to produce a reference ac signal for measurement of phase angle (time of occurrence) of PD-pulses. The test setup is illustrated in Fig. 4.

6. Experimental test results

The accelerator–decelerator was firstly tested in air to localize problematic spots in the accelerator which are most probably initiating breakdowns also in vacuum. At atmospheric pressure we could not test above +33 kV because of the corona discharge appearing inside the vacuum-feedthrough. With voltages lower than +33 kV no visible breakdowns were observed.

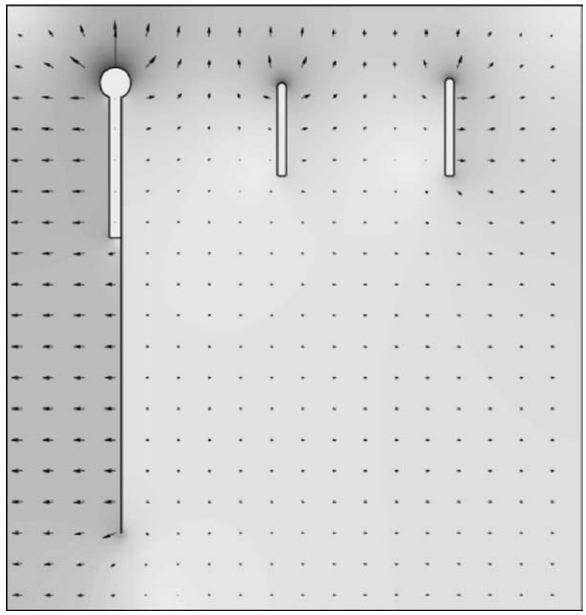

Fig. 3. The first three electrodes of the decelerator. The edge of the first decelerator electrode has to be shielded by a corona ring. Maximum electric field strength is reduced to a value of 4.3 kV/mm.

The main accelerator was tested in vacuum over a long time (24 h) with constant dc voltage. Before the tests, short electrode conditioning was done, i.e. measurement was started after the current through the component under investigation had stabilized. We did not observe any complete breakdowns or voltage dips in test with +40 kV. Voltages of negative polarity induced small discharges at −40 kV at intervals of 1 h. Voltage dips were not observed below −35 kV.

Partial discharges in the main accelerator were observed with dc voltages at atmospheric pressure and in vacuum. They appeared in air at voltages as low as 3 kV. In vacuum the starting voltage was 17 kV but the discharges died out after a while also at higher

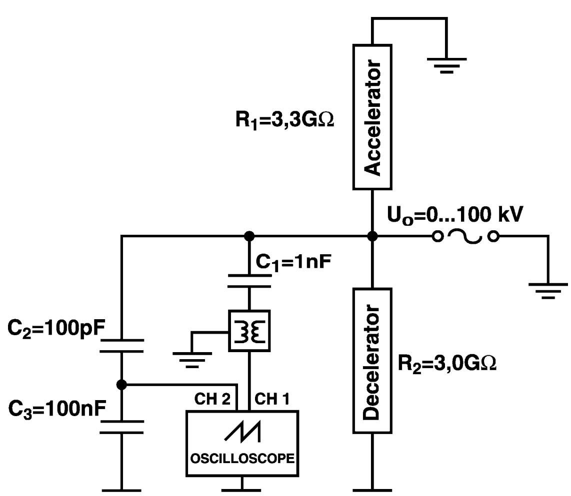

Fig. 4. Test setup for partial discharge measurement.

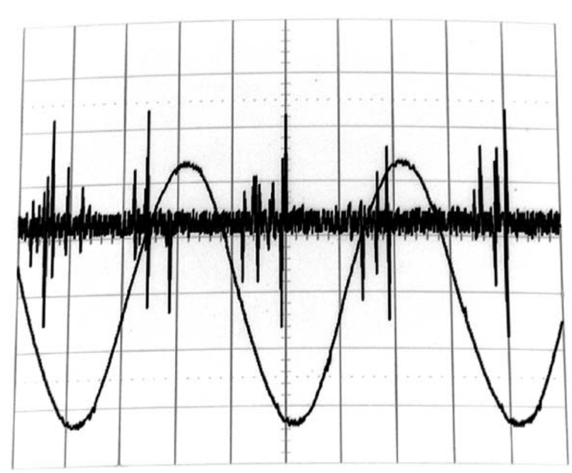

Fig. 5. Oscilloscope trace showing internal partial discharge pulses. They appear at rising edges of an ac signal.

voltages. With an ac signal partial discharges started as the peak voltage was raised to 27 kV. These discharges were observed (Fig. 5) at a certain phase of the ac signal which is characteristic of internal partial discharges [4].

7. Conclusion

In this paper, the structure of the main accelerator for pulsed positron beam at Helsinki University of Technology was presented. A finite element analysis program was used to calculate the electric field strength at electrodes. High voltage tests for accelerator–decelerator were carried out with dc and ac voltages. Internal partial discharges were observed with ac and dc voltages but because of the temporary character of dc-induced discharges they are considered harmless for measurements.

Acknowledgments

The authors would like to acknowledge the Antti and Jenny Wihuri Foundation for providing financial support for this research. We would also like to thank J. Hällström and J. Piiroinen from the Laboratory of Power Systems and High Voltage Engineering at Helsinki University of Technology for the discussions, comments and help with the partial discharge measurements.

References

[2] R.V. Latham, High Voltage Vacuum Insulation: The Physical Basis, Academic Press Inc., London, 1981.
[3] QuickField 5.1, Tera Analysis Ltd., http://www.quickfield.com.
[4] D. Kind, K. Feser, High Voltage Test Techniques, second ed., Reed Educational and Professional Publishing Ltd., Delhi, 2001, pp. 101–109.