80 kV Electrostatic Wire Septum for AmPS

A. van der LINDEN, J.H.M. BIJLEVELD, H. BOER ROOKHUIZEN, P.J.T. BRUINSMA, E. HEINE, P. LASSING, E. PRINS
National Institute for Nuclear and High Energy Physics (NIKHEF),
P.O. Box 41882,1009 DB Amsterdam, the Netherlands

Abstract

In the extraction process of the Amsterdam Pulse Stretcher (AmPS) the extracted beam is intercepted from the circulating beam by the 1 m long electrostatic wire septum. For a bending angle of 4.4 mrad the maximum anode voltage is 80 kV.

An innovative mechanical construction has been developed to create a wire spacing of 0.65 mm between tungsten wires of 50 μm diameter. Stainless steel spring wires, bent on a half-cylindrical carrier, stretch the septum wires two by two. This insures that eventually broken wires are retracted.

Care has been given to the electric field distribution at the entrance and exit of the septum and to the insulators, required to support the anode. Prototype tests have been successful up to an anode voltage of 120 kV.

1. INTRODUCTION

The AmPS ring aims at a 100 % duty cycle operation by means of slow extraction of injected electron beam pulses of 2.1 μs, as described by Luijckx et.al. [1]. The maximum beam energy is 900 MeV. The minimum time for extraction is 2.5 ms and the maximum extracted d.c. current is 67 μA. AmPS can optionally be used as a storage ring with an internal target.

The third integer resonance of the horizontal betatron oscillation is excited to give the circulating beam large horizontal excursions. The electrostatic extraction septum intercepts and separates the extracted beam from the circulating beam. The extracted beam is directed outwards horizontally between the massive anode and the grounded, thin cathode of the electrostatic septum. The cathode, called the septum, acts as knife for the interception of extracted beam and screens the electrostatic field for the circulating beam. The separation between the extracted and circulating beam is enlarged by the next two ring quadrupole magnets, as shown in Figure 1. Finally, the extracted beam is bent outwards horizontally by the magnetic extraction septum [2] and is sent along the AmPS extraction line.

2. OPTICAL REQUIREMENTS

Maas [3] has simulated the extraction process. The pitch of the extracted beam, being its horizontal width, is calculated to be of the order of 8 mm for a horizontal septum location of 30 mm, with respect to the ring axis. The gap width between the anode and the cathode is required to be 20 mm. The position and direction of the septum must be adjustable.

The allowed beam loss, due to interaction with the septum, is about 1 %. This restricts the effective septum thickness to 100 μm. The septum thickness is chosen to be 50 μm.

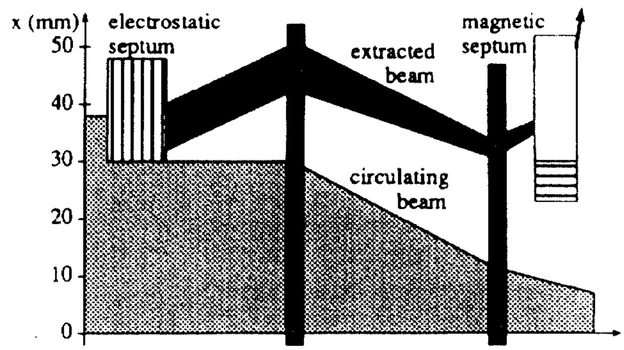

Figure 1 - Schematic layout of the AmPS beam extraction.

Hoekstra [4] has required that the extracted beam arrives at a horizontal position of 220 mm with respect to the ring axis. As a result of optimization, the electrostatic extraction septum is required to be 1 m long and to have a bending angle of 4.4 mrad. This determines the maximum electric field strength to be 40 kV/cm, requiring a maximum anode voltage of 80 kV.

3. WIRE SEPTUM REQUIREMENTS

3.1. Design principles

Based on qualitative grounds, the design of a wire septum is considered. Mechanically, nearly one-dimensional forces can be applied to wires in order to create a flat, thin septum plane, consisting of an array of wires. Concerning the heating of the septum due to the interaction with beam particles, wires have the optimal ratio of radiant surface and heated volume.

3.2. Septum heating requirements

The interaction of the electron beam with the wire material is characterized by the heat production due to the beam energy loss. The maximum current, interacting with a 50 μm thick wire, is calculated as 0.42 μA. According to Koechlin [5], the maximum temperature of a tungsten septum wire is 1600 °C for a beam height of 1.6 mm, assuming cooling by radiation only. However, the tensile strength of 2 kN/mm^2 starts to decrease at 1200 °C due to recrystallization processes.

3.3. Electric field strength requirements

Considering the septum wires as the field emitting cathode, the electric field strength at the wire surface is determined by the conservation of the flux of electric field lines:

$$E_o \cdot a = E_w \cdot \pi\, t \qquad (1)$$

where E_w is the field strength at the wire surface and E_o is the average electric field strength between anode and cathode, a is the wire spacing and t is the wire diameter.

Dubois and Garrel [6] have determined experimentally the maximum average field strength for a tungsten wire septum. According to (1), the maximum field strength at the tungsten wire surface is calculated as 167 kV/cm. The wire spacing for the AmPS electrostatic septum is then restricted to 0.65 mm, according to (1). These results have been confirmed by the theory of planar triodes, described by Kleijnen and Jonker [7].

According to Durand et.al. [8], a wire spacing of 0.65 mm results in an effective average field strength of 39.7 kV/cm at the maximum anode voltage of 80 kV. The field strength, experienced by the circulating beam, is 78 V/cm, which makes the transparency of the septum 0.2%.

If all wires have the maximum temperature of 1600 °C, the field emission of the 1 m long septum is 0.82 mA in worst case. The high voltage power supply requirements are met by the 100 kV/1.5 mA supply of the Gamma RR series.

3.4. Mechanical requirements

To prevent a high voltage short-circuit in case of a broken wire, the construction of the plane array of thin wires requires a springloading force. This has been approached by an innovative technique of spotwelding septum wires to cylindrically curved spring wires. The spring wires are curved along half a cylinder, called the carrier. The bending moment of one spring wire is used to stretch two septum wires. The two ends of a piece of septum wire are spotwelded at the same parallel end of a spring wire. Then the septum wire is looped around the other end of the spring wire. Figure 2 shows the principle design.

The spring wires of 0.6 mm diameter are placed in grooves with a spacing of 1.3 mm. The septum wires are positioned by precision machined grooves in the two ridges of the carrier. Due to electrostatic forces acting upon the septum wires, the high voltage electrode is located inside the carrier construction.

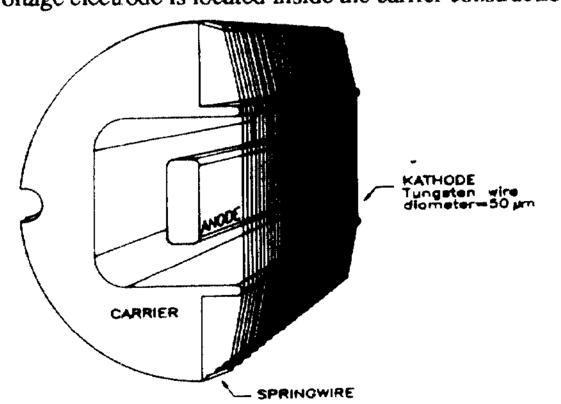

Figure 2 - A 3-D view of the principle wire septum design.

To restrict the electrostatic repulsion of adjacent wires, the minimum stretching force is determined by the proportional chamber wire instability. According to Anderson et.al. [9], using Durand et.al. [8], the minimum force is 0.09 N for a 80 mm long wire. The resulting minimum stress is 45 N/mm^2.

Taking into account the decrease of the tensile strength of tungsten at high temperatures the septum wire stress is optimized as 200 N/mm^2. This results in a required stretching force of 0.4 N. The length of the parallel ends of a spring wire and its radius of curvature are optimized as 19 mm and 86 mm respectively. Regarding the tensile strength of stainless steel spring wires of 1000 N/mm^2, the resulting maximum stress in a spring wire is 720 N/mm^2.

4. HIGH VOLTAGE REQUIREMENTS

4.1. High voltage electrode dimensions and location

In order to obtain a stiff carrier construction the high voltage electrode has been optimized with regard to the electric field strengths. As shown in Figure 2, the cross-sectional area within the carrier is restricted to be 70 mm wide and 80 mm high. The cross-section of the electrode is optimized as 20 mm thick and 40 mm high with rounded corners of 7.5 mm radius. At the maximum anode voltage of 80 kV the maximum field strength has been calculated to be less than 75 kV/cm near the corners opposite to the plane of wires.

To obtain a uniform electric field distribution at the exit and entrance of the septum, field clamps are added to the symmetric anode design. As a result of Poisson calculations, the anode is bent backwards by 30°, as shown in Figure 3. At the septum exit the anode is folded back around the carrier to be connected to the centred high voltage vacuumfeedthrough.

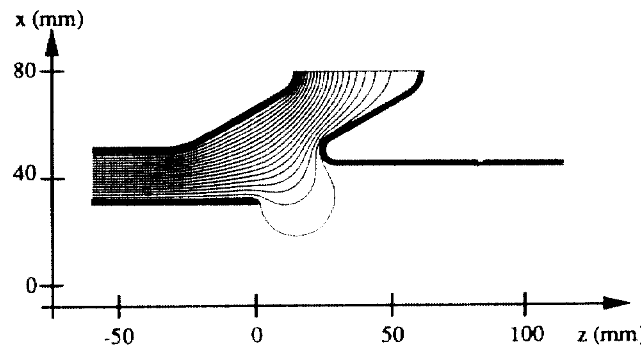

Figure 3 - Poisson plot of equipotential lines for the design of the field clamps and anode at the septum entrance and exit.

4.2. High voltage insulator design

For mechanical reasons, the high voltage electrode has to be supported by the grounded carrier at 3 places along its 1 m length. From prototype tests, the 30 mm wide area in between the backside of the anode and the grounded carrier is found too narrow for an aluminumoxide insulator to hold off the required 80 kV long enough for operational use. This is explained by breakdown in splits between carrier and insulator and by flashover along the insulator, due to upbuilding of positive charge by secondary electron emission.

The final insulator design consists of a deep pit in the carrier and a shallow pit in the anode to decrease the field strength near the metal surfaces. The insulator is a 57.5 mm long rod of aluminumoxide of 10 mm diameter. The rod ends are metallized and provided with metal screw-threads at both ends to prevent breakdown in splits.

As shown in Figure 4, Poisson calculations have proven that the field strength in the area of the insulator is lower than elsewhere between anode and cathode. Therefore it is expected that breakdown and flashover processes are less likely to occur and that the insulator area is also screened from the free charge particles, which are possibly present during ring operation.

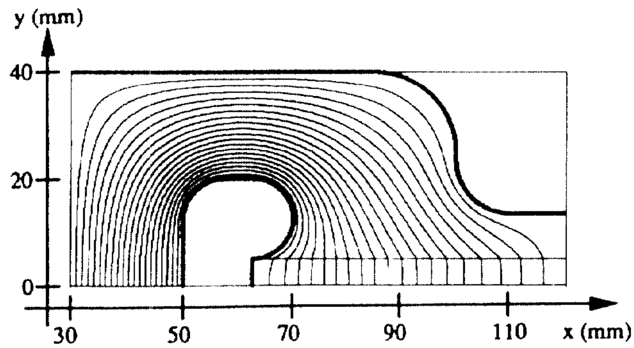

Figure 4 - Poisson plot of equipotential lines for the design of the support insulator between anode and cathode.

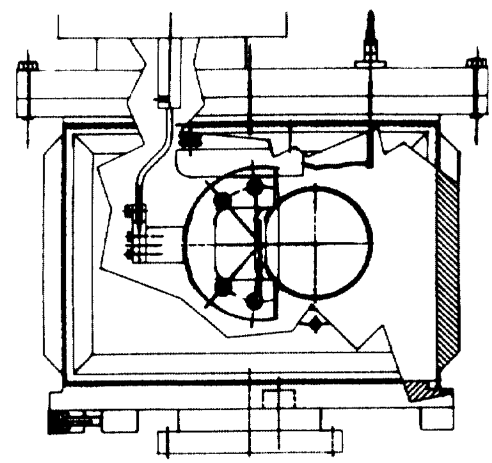

Figure 5 - Assembly drawing of the electrostatic wire septum.

5. PROTOTYPE TEST RESULTS

A 15 cm long prototype of the wire septum has been built to test its high voltage performance in vacuum. Regarding the required wire spacing of 0.65 mm, no signs of breakdown or excessive field emission between the wire plane and the anode have been observed up to anode voltages of 120 kV. Leaving spring wires out does not change the performance.

Without processing, the final insulator design is adjustable up to an anode voltage of 120 kV. An anode voltage of 100 kV has been maintained for more than 100 hours.

6. SEPTUM CONSTRUCTION DESIGN

The attractive force between septum wires and anode is less at the entrance and exit of the septum, due to the field clamps. To achieve a same bending for all wires, in order to minimize the effective septum thickness, the wire stretching force is adjusted for the first and last wires by making the carrier circumference less than half a circle and thus increasing the length of the parallel ends of the spring wires. Regarding the maximum expected beam power, this approach has been optimized for an anode voltage of 56 kV.

The positioning of the wire plane with respect to the beam is achieved by a horizontal support table for the whole septum tank, involving separate systems for a translation and rotation in the range of ±12.5 mm and ±0.5° in steps of 0.1 mm and 0.1 mrad respectively.

The whole tank is 1200 mm long, 400 mm wide and 300 mm high. The carrier and anode construction is supported from the top flange. Opposed to the wire plane an open piece of beampipe surrounds the circulating beam, as shown in Figure 5, in order to avoid that the tank will act as a cavity in storage mode operation. Because of the expected radiation levels due to beam losses, aluminum has been used as construction material as far as possible.

7. PROJECT STATUS

The construction of the electrostatic extraction septum is finished recently. Installation of the wire septum will follow after the system tests, in order to be in operation during the commissioning of the AmPS ring before the summer of 1992.

8. ACKNOWLEDGEMENTS

The AmPS project is made possible by financial support of the foundation for Fundamental Research on Matter (FOM).

The authors would like to thank Marco Barens and Marco Kraan (Hogeschool Utrecht) for the contribution in the septum positioning table design. The workshops of NIKHEF are regarded highly for the applied expertise in constructing the septum. The vacuum experts from NIKHEF-K must be thanked strongly for their support in the prototype test set-up.

8. REFERENCES

[1] G.Luijckx et.al., "The Amsterdam Pulse Stretcher Project (AmPS)", Proceedings 1989 IEEE Particle Accelerator Conference, 1989, Chicago, IL, pp. 46-48.

[2] A.v.d.Linden et.al., "High Power Density, Thin Magnetic D.C. Septa for AmPS", this conference.

[3] R.Maas, "Injection Parameters and Beam Oscillations during extraction", report NIKHEF-K/AmPS/89-07, August 1989.

[4] R.Hoekstra, "Beam Optics of the AmPS Extraction Line", report NIKHEF-K/AmPS/91-01, January 1991.

[5] F.Koechlin, "Un Séparateur Electrostatique pour l'Extraction du Faisceau d'un Anneau d'Electrons", DPh-N/Saclay n°2378, October 1986.

[6] R.Dubois, N.Garrel, "Tension Positive sur le Septum Electrostatique", report CERN/SPS/Note Techn./78-4, April 1978.

[7] J.H.L.Jonker, "The Internal Resistance of a Pentode", and P.H.J.A.Kleijnen, "The Penetration Factor and the Potential Field of a Planar Triode", Philips Research Reports, Vol. 6, Nr. 1, February 1951.

[8] A.Durand et.al.,"Champ de Fuite des Septums Electrostatiques à Fils", Nuclear Instruments and Methods 165(1979)361-370

[9] D.Anderson et.al., "Particle Detectors", Physics Letters B, Volume 204, 1988, p. 63.