DEVELOPMENT OF AN ELECTROSTATIC SEPTUM FOR THE SLOW EJECTION OF THE CPS

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Abstract

Since the beginning of 1970, an electrostatic septum has been used in the "Machine Development" studies devoted to a new slow ejection scheme of the CPS. Some problems related to various interactions of the beam with the septum are discussed.

1. Description of the septum

In the final scheme for the slow ejection 16 (SE 16) which is being studied, the electrostatic septum (ES) will be installed in the short straight section 83. The overall length of the ES cannot much exceed 1 metre and, therefore, a rather high electric field, 10 to 15 MV/m according to the emittance of the beam, will be required over a gap of 10 to 15 mm.

The anode, at ground potential, is the septum electrode : it consists of a 0.1 mm molybdenum foil stretched on a C-shaped frame. The aperture of the frame, 150 x 70 mm^2, gives a full free passage for the circulating proton beam through the anode when the ES is not in use, as shown in Fig.1. The position and the angle of the septum plane with respect to the proton beam can be remotely and accurately adjusted, as well as the position of the cathode, to provide all the necessary flexibility during the setting-up of the slow ejection.

The cathode, which is the only electrode at a high potential, is made from a light alloy (97 % Al + 3 % Mg) coated with a 6 to 10 μm alumina layer by anodization in a chromic acid bath. This oxide layer is then sealed in boiling water following the technology developped in connection with electrostatic separators at CERN [1].

Different screens, whose functions will be discussed in the next section, have very much increased the impedance for pumping the ES at both ends by the CPS vacuum chamber, so that a 400 l/s ion pump is installed on the ES tank itself to keep the pressure below 10^{-6} Torr.

Without yet trying to minimize the septum thickness, we have used a 0.1 mm foil which is not too delicate to handle and not too sensitive to spark damage. The foil is stretched on two calibrated stainless steel rods resting in accurately machined triangular grooves that define the septum plane to ± 10 μm. After stretching the foil, all its points can usually be made to lie to within ± 25 μm of an ideal plane, so that the apparent thickness of the septum before it is submitted to sparking is about 0.15 mm.

2. High voltage performance

The performance of the ES is higher when it is tested in the laboratory than when it is installed in the CPS, because of various effects related to the circulating beam rather than to an unfavourable environment, since it is in a clean vacuum section of the machine.

2.1 Conditioning and maximum performance

The conditioning of the ES takes place in the laboratory and is achieved in the following way : with a large gap of 4 cm, the voltage is progressively increased while keeping the current constant at about 10 μA. The maximum voltage of the generator, 300 kV, is usually reached in a dozen hours. The gap is then reduced to 1 cm and the conditioning at 10 μA is resumed until a maximum voltage of about 200 kV is reached, which is accomplished in less than one hour. When time is available, a voltage of 180 kV can usually be applied for one week without troubles and the long term operation voltage may be about 160 kV across a 1 cm gap in the laboratory.

2.2 Effect of proton beam on residual gas

As soon as the ES was installed in ss 64 at the beginning of 1970, it became apparent that its high voltage behaviour was strongly perturbed by the circulating proton beam [1]. Whereas the ES could stand 160 kV across 1 cm without current when the beam was off, large current pulses up to several hundreds of microamps or sparks would appear when the beam was accelerated, eventually tripping out the generator. Several possible parameters were varied in order to find the cause of this behaviour, in particular the pressure of the residual gas in the vacuum chamber, and it seemed likely that the origin of the current was the ionization of the residual gas by the proton beam.

With a vacuum around 10^{-6} Torr at that time and a beam of 10^{12} protons, the ion current created by the proton beam is less than half a microamp per metre of vacuum chamber. These ions have a very small energy (< 0.1 eV) and are driven in a short time (a few tens of μs) to the chamber walls by the potential of a few volts generated by the proton beam [2]. Under these conditions, the negative potential of the ES cathode can only drain ions over a short distance and we have a discrepancy of more than two orders of magnitude with this assumption alone.

When positive ions impinge on a surface, a variety of phenomena may result [3] and the most relevant to our problem is secondary electron emission which is dependent on the energy and nature of the incident ions, the angle of impact, the nature and state of purity of the target surface. These ions have an energy corresponding to the potential of the cathode, i.e. 100 to 200 keV, and their nature is determined by the materials of the CPS vacuum system and the pumping stations used. At this ion energy level, the secondary electrons are emitted mostly by the kinetic process. There are important variations in the experimental values of the secondary electron emission coefficient γ when some of the relevant parameters just mentioned are changed.

The published values of γ for metal surfaces under bombardment with high energy ions (10^4 to 10^6 eV) are generally in the range of 1 to 15. It is very difficult to assess a correct value of γ because of all the uncertainties in the values of the relevant parameters defining the conditions existing in the ES for secondary electron emission. The three following remarks lead us to assume still higher values for γ :

1) With grazing incidence of the ions on the cathode ($\alpha \approx 90^o$) the secondary electrons have a shorther path to reach the surface and γ follows a sec α law.

2) Adsorbed layers or oxide coatings enhance γ, since the diffusion length of secondary electrons is much larger in insulators than in metals.

3) Molecular ions break up into their constituent atoms at the electrode surface and each of them produces its own kinetic emission of secondary electrons. This enhancement applies especially to the heavier molecules of the residual gas.

At the present state of the study, no satisfactory quantitative explanation has yet been worked out for the large values of the pulse current induced in the ES by the proton beam. However the assumption that the primary ionization current generated by the proton beam is the origin of the observed large current pulse seems valid since we could drastically reduce the latter by carefully screening the cathode against the ions created in the CPS vacuum chamber.

The screening has been designed so that the ions in the CPS chamber cannot see the cathode and furthermore so that there exists a significant impedance for the flow of gas from the CPS vacuum chamber and anode beam passage to the inside of the ES tank itself. This is obtained, as shown in Figs. 1 and 2, by using tubular screens positioned close to the plane screens. Out of the way of the ejected beam, the plane screens are thick and in the way they are thin and made with 0.02 mm aluminium foil stretched on a frame. It is essential that the thin Al screen be placed almost in contact with the septum foil to prevent ions from leaking through the small passage to the cathode. With this screening, which was improved to the present design through a series of tests, it became possible to withstand the same voltage with and without the proton beam (1 or 2 x 10^{12} protons) in the case of no beam losses on the septum. The current pulse induced by the low energy ions has thus been cut down to a few microamps, which is now perfectly acceptable.

2.3 Effect of beam losses on the ES

If the protons hit only the septum foil, i.e. the anode, and not the cathode the effect on the voltage behaviour is small at beam intensities of 10^{12} protons or so. But it often happens during the setting-up period that protons are sent onto the cathode at grazing incidence and this triggers sparks by intense secondary electron emission. We have also observed this effect at injection, when the chamber is filled most widely with low energy protons, if the orbit has not the right shape to miss the ES but this can be corrected with an adequate low energy bump. The jump of the particles at the position of the septum foil should obviously be smaller than the gap to avoid triggering sparks in this way.

2.4 High voltage performance in the CPS

We have used one or the other ES altogether a score of times during MD slow ejection tests. A voltage of 150 to 170 kV has been required and provided during these tests across a 1 cm gap. Sometimes the voltage could be pushed up to 200 kV but it should be stressed that these tests lasted only for a few hours each time.

We have not yet any long-term operational experience with the ES but it seems reasonable to hope for a field of 120 to 150 kV/cm across a 1 cm gap if all the necessary precautions are taken to protect the cathode so as to have less than a few sparks per hour.

3. ES-beam electromagnetic coupling

When the ES is installed in the accelerator, it is electromagnetically coupled to the proton beam and attention has to be paid not to spoil the structure of the beam by this coupling. In the present design of the ES, the anode is not directly connected to the earth potential but through a damping resistor which is needed to protect the electrodes against spark damage. Harmfull self-oscillations could thus be excited by the beam in the ES. It has been shown in the study carried out with H.H. Umstätter that a strong damping of these oscillations can be provided by using a properly matched coupling loop placed in the ES tank. Other possible damping methods are also studied.

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References

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2) H.G. Hereward, Int. CERN report MPS/Int.DL 64-8

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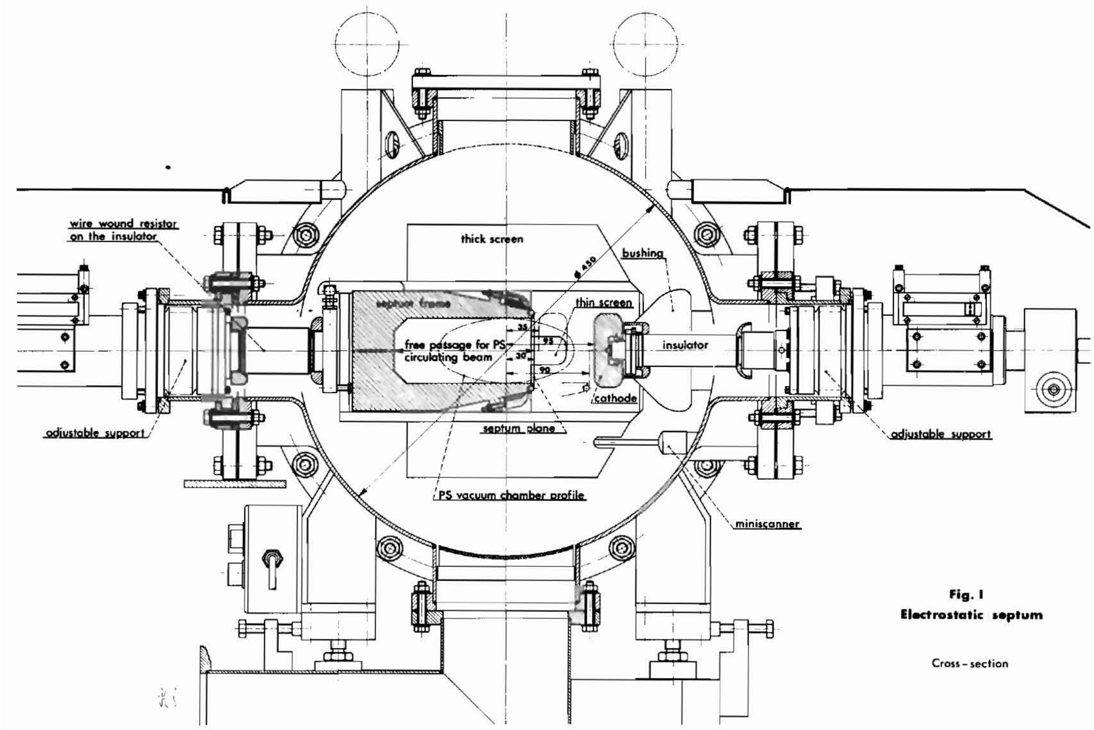

Fig. I
Electrostatic septum

Cross-section

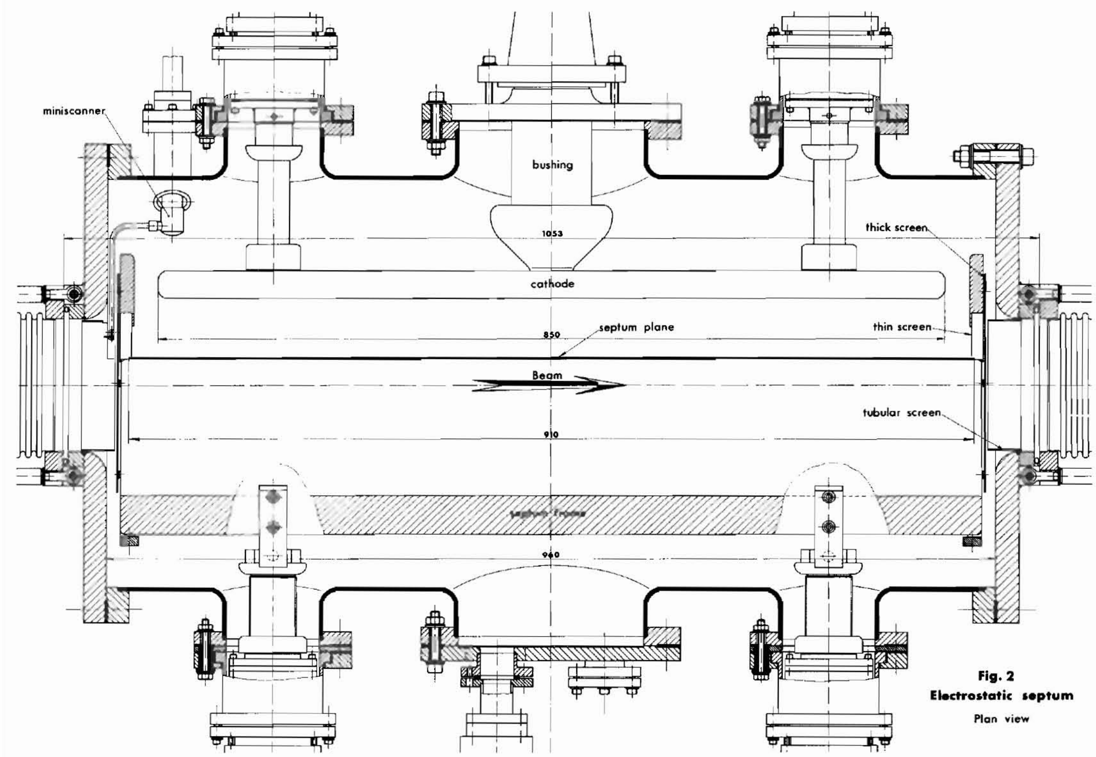

Fig. 2
Electrostatic septum

Plan view