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Improvement of the Extraction Channels of the CERN-SPS Accelerator

R.L. Keizer, K.H. Kissler, R. Oberli CERN, 1211 Geneva, Switzerland

## Summary

Extraction tests made between 1979 and 1981 revealed that after a certain time of operation, 15 minutes to a few hours depending on the accelerator settings, the spark rate of the electrostatic septa, which are the first deflecting devices of the SPS extraction channels, increased strongly and the losses per extracted proton tripled. It was then demonstrated that heavy losses resulted in short circuits in the 15 kV ion-traps and the occasional loss of a 300 kV - feedthrough. These effects limited the upper intensity which could be extracted reliably at 450 GeV/c to roughly 1  $\times 10^{13}$  protons per pulse for both fast-resonant and slow-resonant extraction.

Accurate measurements of different parameters, in particular spark rates and losses over extended periods led to the discovery that the stainless steel bodies of the anodes which suspend the septum wires deformed due to radiation induced thermal stresses thereby increasing the effective septum thickness. The feedthroughs were lost due to the accumulation of gas bubbles in the insulating dielectric liquid.

Septa of an improved design including INVAR anode bodies, thinner wires, sliding ion-traps and improved 15 kV and 300 kV-feedthroughs, were then conceived and made operational reducing the losses by a factor of 3 and capable of extracting more than 3  $\times$  10<sup>13</sup> protons per pulse per extraction channel.

## Introduction

The first deflecting devices of the SPS extraction channels are electrostatic septa 1],2]. The beam splitting plane of a septum consists of a row of vertical W-Re wires, spaced at 1.5 mm intervals. The wires are suspended by a U-shaped body and are at ground potential. Parallel to the plane of wires an oxydized aluminium cathode is placed which is charged to a negative potential of some 250 kV. The distance between the wires and the cathode can be remotely adjusted and is typically 20 mm.

The circulating beam passes through the gap of the U-shaped anode body. In order to collect the ions which are created by collisions of the accelerated protons with the residual gas, electrodes are mounted inside the anode body. These ion-traps are insulated from the anode and normally charged to  $-5 \ kV$ .

The original design of the electrostatic septa was made with extracted intensities of  $1 \times 10^{13}$ protons per pulse and per extraction channel, in mind. These intensities were exceeded in both SPS extraction channels only a few years after the start-up of the accelerator in 1976.

Already in 1979 first signs of excessive spark rates of the electrostatic septa were recorded when for fast-resonant extraction of 9  $\times$  10<sup>12</sup> ppp the ion-traps developed short-circuits and became inoperative after only 15 min. of stable running.

By carefully observing the relationship between extracted intensity, beam loss and spark rate it was also discovered that the stainless steel anode bodies deformed thermally in a measurable and repeatable way due to radiation heating. As a result, when the SPS was started up from cold, the extraction losses steadily increased, until thermal equilibrium was reached. Already at intensities of  $1 \times 10^{13}$  ppp an increase by as much as a factor 2 was measured.

A third problem arose in 1983 when simultaneous slow resonant extraction at 450 GeV/c to both experimental areas came into operation. The increased losses inherent in this type of extraction led to frequent failures of the 300 kV-feedthroughs.

For all these reasons several components of the electrostatic septa had to be improved considerably or even to be entirely re-designed.

Points limiting the performance of the old system

The construction of the 3120 mm long stainless steel anode is shown in Fig. 1. The body consists of



Fig. 1 Construction of the stainless steel anode

a stainless steel U-profil which acts as a frame on which the 100  $\mu m$  thick septum wires are stretched and aligned. The effective septum thickness is 150  $\mu m.$ 

The problem with the anode body is that the secondary particles scattered by the septum wires heat the body of the anode by some 10°C. These secondaries move forward in a sharp cone. Therefore the stainless steel tips near the septum wires heat faster than the more remote parts of the anode body. The sensitivity of the effective septum thickness to the temperature gradient is  $85 \ \mu m \ ^{\circ}C^{-1}$ . This implies that the thickness doubles with a temperature difference across the anode of only  $1.8^{\circ}C$ .

1 mm thick upper and lower ion-traps are mounted inside the anode. Alumina stand-offs insulate these electrodes electrically and link them rigidly to the anode body.

The weakness of this construction is that there is a strong tendency for the 1 mm thick electrodes, spaced at 2 mm from the anode, to buckle when heated by the secondaries. Calculations show that a temperature difference between anode and ion-trap of only 7 °C causes a short circuit. Visual inspection of the ion-traps indicates the presence of regions half-way between the stand-offs where strong spark erosion occurred.

The 2000 septum wires are made of 100  $\mu$ m thick W-Re material. Wire springs stretch the wires to 20% of their breaking strength. The minimum useful wire diameter depends on the straightness of the anode which can finally be obtained and the onset of field emission. The latter happens in the case of polarity reversal which is required for anti-proton injection.

The cathode is made of an anodized Al Mg alloy. The 8 - 10  $\mu m$  thick oxide layer acts as a getter pump in high vacuum and outgasses strongly when heated by secondary particles. The spark rate especially after a long shutdown can be very high.

The HV-feedthrough, Fig. 2, which links the HV-cable and the cathode is very sensitive to radiation damage because the dielectric liquid, Freon, is organic. One of the decay products, hydrofluoric acid is removed by continuously circulating the liquid through an active chemical filter. Other decay products in gaseous form cause small bubbles which are trapped because the flow is directed downwards. The space around the cable itself is not ventilated at all. Strong dark currents develop along the PVC surface which therefore has a tendency to carbonize.



Fig. 2 The existing HV-feedthrough and HV-plug

#### Construction of the improved septa

An Invar (36Ni 54Fe) anode replaces the stainless steel body. The sensitivity of the effective septum thickness to a temperature gradient is reduced by one order of magnitude so that a temperature difference of  $1.8^{\circ}$ C will increase the septum thickness by 6% only (instead of 100%). Furthermore, compared with the old system, 3x more p-intensity is needed to cause this difference of  $1.8^{\circ}$ C.

The anode body is assembled from 3 pieces as shown in Fig 3.

The beam shrinks during acceleration. Therefore the free height between the noses may be somewhat reduced, the advantage being that the anode is rigidified and the length of the septum wires is shortened.

The sliding ion-traps are shown in Fig. 4. The spherical insulator centres the ion-trap and allows longitudinal expansion. The 15 kV-feedthroughs are made of one cylinder of alumina and at the same time

constitute the fixed points of the electrode system. In order to exploit the new possibilities of a thermally much more stable anode the septum wire diameter was reduced from 100 to 65  $\mu$ m. The effective



Fig. 3 Construction of the 3160 mm long INVAR anode



Fig. 4 Construction of the sliding ion-trap

septum thickness thereby decreases from 150 to 100  $\mu$ m. Thinner wires do not seem to lead to stronger field emission in the case of polarity reversal for collider operation. This is because the wires are quite rough on a microscopic scale. The frictional force between wire and anode has been diminished by doubling the radius of the contact area which reduces the friction by some 30%.

The feedthroughs have been improved by inversing the flow of the dielectric fluid as shown in Fig. 5 and by injecting this fluid into the cylindrical volume between cable and cable support. The cable end itself has been chamfered and the space between cable and support enlarged.

In addition, some of the mechanical fixtures of the HV-plugs have been improved so that connecting and disconnecting can be done much faster which is crucial in a strong radioactive environment.



Fig. 5 The improved HV-feedthrough and HV-plug

#### Improved performance

Measurements made just before and immediately after the changeover show that the beam losses were reduced considerably.

This is illustrated in Fig. 6 where all the beam losses which occurred during a run are plotted as a function of the p-beam intensity. The beam loss is not only reduced but also the spread has diminished considerably. This behaviour has been observed during all the subsequent runs showing that septum deformation mainly causes the spread and not machine or extraction parameter variations.



Fig. 6 The beam loss (arbitrary units) as function of the extracted beam intensity (x 1013) recorded before and after the modification.

As shown in Fig. 7, reduced beam loss is even more visible if measurements are made after one hour of stable running with a resulting stabilization of the anode temperature.

The following conclusions may be drawn:

- The beam loss has been reduced by a factor of 2 to 3.
- The effective septum thickness no longer changes with the anode temperature
- The beam loss rises linearly with p-intensity up to the highest values (2.5 \* 10<sup>13</sup> ppp) yet extracted by the SPS in one channel.



Fig 7 The beam loss measured under very stable running conditions over a limited period of time.

As a consequence the extraction efficiency is improved from 97 or 98 to 99%, the induced radioactivity is diminished and considerable savings on maintenance effort have been made. The latter points are illustrated by Table 1.

Year	p-Intensity (x 1013ppp)		Dose received	Number of feed-
			by	throughs
	Average	Peak	mSv	lost
1980	1.9	2.6	36	0
1981	1.2	2.6	44	0
1982	2.0	2.8	21	0
1983	1.7	2.8	47	10
1984	2.2	3.4	87	13
1985	1.9	3.1	19	2
1986	3.0	3.5	15	1

Table 1. Extracted proton intensity and maintenance problems

The SPS p-beam intensity is presently higher than ever before, but the dose received by the extraction crew and the number of feedthroughs lost after this improvement program was completed, is minimal.

# <u>Acknowledgements</u>

The authors are indebted to R. Bonvin, R. Dubois, R. Ducrêt, N.Garrel, R. Guinand, S. Long, Y. Sillanoli, and J. Soubeyran who all participated in the septum improvement program.

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