OBSERVATION OF AN INCREASE OF THE EFFECTIVE THICKNESS
OF THE ELECTROSTATIC SEPTA

R. L. Keizer

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Distribution
B. de Raad
W. Middelkoop
V. Hatton
E. Weisse
Y. Baconnier
F. Corazza
K.H. Kissler
D. Thomas
C. Saltmarsh
R. Dubois
R. Bonvin
X. Altuna
N. Garrel
1. **Introduction**

In order to gain a better understanding of the spark mechanism in the electrostatic extraction channels a data acquisition program has been written. The average intensities and beam losses as well as the instantaneous values, when a spark occurs, are recorded. Data for periods 1B, 1C, 2A and 2B have been taken. This report deals with the latter two half-periods only.

A preliminary analysis (not published) has shown that the spark rate is a linear function of the beam losses. Therefore the analysis may be limited to an investigation of the beam losses only.

This report describes the progress which has been made so far and the practical conclusions which may be drawn.

2. **Measurement of the beam losses**

There are two extraction channels LSS2 and LSS6. The beam losses have been recorded in each channel by monitor BL1 placed near the end of tank ZS1, 40 cm below the beam axis, which is therefore insensitive to what happens further downstream. Monitor BL6 is situated at the downstream end of each extraction channel, consisting of five tanks ZS1 to ZS5, and is placed against the vacuum chamber BL6 therefore measures the small angle scattering from the first septum and, in addition, the further losses downstream.

The monitor signals are integrated over the whole machine cycle.

3. **Beam losses in LSS2**

The beam losses averaged over 75 machine cycles of 12 s each, measured by BL1 and BL6 are shown in Fig. 1 as function of the averaged slowly extracted intensity $I_{\text{SE4}}$.

The graph shows all the characteristic features which have been measured so far:
The points all lie within a region limited by lower and upper straight boundaries which intersect in the origin. Points which lie near the lower boundary represent losses when the SPS is still cold. The values near the upper boundary represent, for lower intensities, a SPS which is not well adjusted and for high intensities, a septum which is very hot.

The ratio BL6/BL1 is constant most of the time and is usually of the order of 2. Sudden changes to a different value have been noted when the extraction system was adjusted.

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**Figure 1** Beam losses, averaged over 15 min as function of the slowly extracted current.
The variation of the beam loss signal is 100%, keeping the extracted intensity constant. Fig. 2 shows that for high intensities the increase is a function of time with a time constant of roughly 0.7 h. The reverse effect, an exponential decrease upon a reduction of the extracted current has also been observed.

After an equilibrium has been obtained the losses remain unchanged for periods lasting as long as 8 hours.

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**Fig. 2.** The increase of the beam loss signal as a function of time after a "cold" restart.
The lower limits which have been encountered so far are shown in Fig. 3. It turns out that those lower limits are somewhat influenced by the kind of extraction which takes place in LSS6. The variation of the lower limit is also of the order of 100% both with BL1 and BL6.

The fact that BL1 and BL6 exhibit essentially the same variation shows that both are measuring losses which originate (stars) in ZS1. However, one should add that on several occasions a near doubling of the BL6/BL1 ratio has been seen during particular time interval after which the usual ratio of 2 was restored. This could be interpreted as a sudden increase of losses in tanks ZS2 or ZS3.

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Fig. 3 - The Lower Beam Loss Limits in LSS2
4. Beam losses in LSS6

A graph showing typical beam losses as function of the extracted current is shown in Fig. 4. The extreme boundaries are again straight lines which, however, do not intercept in the origin.

Beam losses associated with zero fast extracted intensity do not cause the customary spark rate and are therefore not associated with losses sustained by the septum wires. The most likely explanation, because the correlation with \( I_{S2} \) is zero, is that the circulating proton beam \( I_p \) causes occasional losses in LSS6 throughout the machine cycle. This effect is not seen in LSS2. Fig. 5 shows that the scattergraph of the losses in LSS6 as function of the circulating current also exhibits straight upper and lower boundaries. Exceptionally, very low losses are experienced. All the points belong to one particular period of time. It would be very interesting to know what the machine settings were at that moment.

![Graph showing beam losses as function of extracted current.](image-url)
The lower beam loss limits are shown in Fig. 6.

The first tank, monitor BL1, seems to behave independently of the kind of extraction. Monitor BL6 reveals that some additional losses are caused by the downstream tanks depending on the kind of extraction.

A comparison of the lower limits in LSS2 and LSS6 shows that the slopes of the lower boundaries are of the same order of magnitude.

For BL1 the slope for LSS2 is 30% smaller than the minimum slope for LSS6. For BL6 this difference is slightly less. The could be interpreted as a measure of the relative extraction efficiencies.
The extraction efficiency of the slow extraction in LSS2 therefore would be 30% better than the fast extraction in LSS6, both under optimal conditions of course.

**Figure 5** The Lower Beamloss Limits in LSS6
5. Increase of the effective septum thickness

It is clear that a reversible thermal effect with a time constant of 0.7 h influences the beam losses. This effect has been traced back mainly to ZS1 and, at extracted intensities of $1 \times 10^{13}$ ppp, seems to double the apparent thickness which is 0.15 mm.

Two explanations are possible assuming that the septa are mis-aligned:

- The losses on the anode wires heat the anode inhomogeneously which therefore becomes warped (banana shape). It is expected that during the heating up periods (transient) the anode will be more warped than during the thermal equilibrium period which follows (steady-state). The beam losses should therefore slightly diminish after having reached a maximum. This effect has never been observed.

- The losses heat the downstream end of the anode more than the upstream end. The downstream activating mechanism, orientated horizontally which is 400 mm long, heats more than the mechanism of the upstream end. A temperature difference of $20^\circ$ C would explain the septum thickness increase which is 100% or 0.15 mm.

Tests should therefore been designed to distinguish between the two mechanisms. The easiest would be to readjust the first septum once the tanks are hot. If no improvement can be obtained the anode is warped. If a negative displacement of the downstream end improves the situation, assuming that the SPS was well adjusted cold or at lower intensities, than the second mechanism is dominating.

It has been noted in the past that the measured extraction efficiencies were worse than the theoretically predicted values. The hypothesis of an septum thickness increasing with temperature might correctly explain this disparity.

6. Displacement of the beam on the target

It has been noted that the beam position changes in a regular manner depending on whether the SPS is cold or hot.
If all the tanks would heat up say $40^\circ$ then the electrode gap, which is 20 mm nominally, would diminish by 0.13 mm or 0.64%.

It would therefore be interesting to bring back the beam on target by changing the HV and to see whether the sign and magnitude of the adjustment agrees with the observed temperature increase as measured with the ZS station.

7. Diagnostics and improvement

By showing graphs of the form of Figs. 1 or 4 on permanent display the diagnostics could be rendered more transparent.

The graphs then would show the average or instantaneous beam losses as function of the extracted current. A lower boundary would be indicated depending of the kind of extraction and the latest acquisition would have a colour different from say the previous 100 acquisitions.

Finally, if the thermal effect turns out to be due to rotation of the first septum then a program should be written which optimises the septum position every 15 min. for medium currents and every 5 min. for high currents. All the hardware to do this seems to be present.

8. Acknowledgements

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Appendix

Parametrisation of the measured lower beam loss boundaries

The beam losses $BL_1$ and $BL_6$ are given by:

$$BL_i = A_i + \alpha_i I_{ext}, \quad i = 1 \text{ or } 6. \quad (1)$$

where $A_i$ and $\alpha_i$ are constants. $I_{ext}$ is the extracted intensity in units of $10^{13}$ ppm.

For $BL_1$ has been measured:

$$BL_1: LSS_2 = 0.7 I_{ext}' \quad (2)$$

$$BL_1: LSS_6 = 0.5 + 1.0 I_{ext}'. \quad (3)$$

For $BL_6$ was found:

$$BL_6: LSS_2 = 1.4 I_{ext}' \quad (4)$$

$$BL_6: LSS_6 = 0.9 + 2.0 I_{ext}'. \quad (5)$$

The following features are characteristic:

- The ratio $BL_6/BL_1 = 2$ both in $LSS_2$ and $LSS_6$.

- The quantity $A_1$ does not cause any sparks and is proportional to the circulating beam $I_{pp}$. For instance:

$$A_6 = 0.4 I_{pp} \quad (6)$$

For formula (5) for $I_{pp}$ the value of $<I_{pp}> = 2.2$ should be used.

- The slope $\alpha_1$ is $30 - 40\%$ higher in $LSS_6$, as compared to $LSS_2$. 