SLOW EJECTION EFFICIENCY

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1. Introduction

During the last few months a series of measurements have been made on the efficiency of slow ejection system 62. During these tests a few points have appeared which should be stressed in this note.

2. Measuring Methods

2.a. Comparing the circulating beam with the ejected beam

In this case the overall efficiency is directly obtained. Relative errors of the beam monitors, however, enter directly into the result for efficiency. This means that an uncertainty of 10% remains. Moreover this method gives no indication on the irradiation in different parts of the machine.

2.b. Measuring the losses

This method would permit to measure a smaller fraction of the circulating beam. The relative error would therefore be heavily reduced when calculating the efficiency. This method gives also very useful indications on the irradiation in different parts of the machine. Unfortunately a consistent calibration in protons lost is very difficult, as well be explained below.

3. Measuring devices

3.a. Primary Beam Monitors

Essentially three systems are available. Both, the "Unscr" and "Hereward" current transformer and the RF pick-up electrodes, depend on the bunch shape. The transformers actually read 10 to 15% lower values of beam current than the pick up electrodes. An absolute calibration, which takes into account the bunch shape, is not available. We have therefore to take into account an uncertainty of some 10% in primary beam current.
3.b. Extracted Beam Monitors

Usually the extracted beam is measured using the charge on a plate. An absolute calibration has been made by means of irradiating aluminium foils. The remaining uncertainty is low with respect to the primary beam current. The actual calibration gives $220\,\text{mV per }10^{10}\,\text{protons}$.

3.c. Loss Detectors

Loss detectors have been installed in all straight sections in order to measure the irradiation of the different machine parts. They give a very useful indication on the radiation damage to be expected for various components. Their reading depends strongly on the way protons are lost. In certain cases (losses in the middle of a magnet unit) the detectors will be strongly shielded against the radiation produced and will read very small values. A calibration in protons lost is thus very difficult. Possible figures for calibration are:

- Loss on a septum: $6\,\text{V} \pm 1\,\text{V} / 10^{12}\,\text{protons}$
- Loss on the chamber wall: $500\,\text{mV} \pm 250\,\text{mV} / 10^{12}\,\text{protons}$

Another way of calibration is to switch off the septum magnet in slow ejection. The values read out then add up to about $4\,\text{V for }10^{12}\,\text{protons}$. According to the traces on the oscilloscope the noise level is about $1\,\text{mV per detector}$. It is therefore possible, but not probable, that random losses of up to $40\%$ are not detected at all. This would assume the lowest calibration ($250\,\text{mV} / 10^{12}\,\text{protons}$) and evenly distributed losses in all magnet units. A more probable figure of $5\%$ possibly undetected losses is obtained if one assumes the average calibration for losses on the chamber ($500\,\text{mV} / 10^{12}\,\text{protons}$) and losses in both magnet units adjacent to each extremum of resonant oscillations.

4. Possible Losses in the Ejection Process

4.a. Adiabatic Phenomena

At the end of acceleration the protons have a Gaussian distribution in phase space which is limited by the machine aperture. When the lenses are switched on, only the protons within the limits of the nominal beam size are trapped by the stable area, whereas the tails of the Gaussian distribution may
become unstable in an uncontrolled way and be partially or totally lost. This phenomenon seems to depend on the debunching scheme and may account for between 0 and 5% losses. A part of this loss will occur on the thick septum (see below).

4.b. Losses on the Chamber Walls

Due to non-linearities in the main magnet field, the beam width in the last turn may be larger than its theoretical value, and some protons will be lost on the chamber. In fact, when operating with the septum lens, some losses are detected around the machine. Without the septum lens losses mainly occur near straight section 63.

It is possible that some losses on the chamber are due to vertical or coupling resonances. This problem has to be investigated further.

4.c. Losses on the Thin Septum

The thin septum being not perfectly straight and the angle of the incident varying slightly the apparent septum thickness will be between 0.4 and 0.5 mm. Taking into account this value the theoretical loss will reach 4%. This value has in fact been measured. The total beam was first dumped onto the iron yoke of the lens, giving 7.2 V on the loss detector. During ejection the detector reads 260 mV, which is in good agreement with the theoretical losses.

4.d. Losses on the Thick Septum

The protons which are not trapped by the stable "fish" (see 4.a) do not jump correctly over the thick septum. In fact a loss of 1 to 2% is detected on the thick septum at the beginning of the flat top of the lenses. Some more of these protons may be lost within the beam transport, as is shown by a small tail appearing on the TV screens in the ejection channel.

Another 1 to 2% are lost during the actual ejection. A scanning of the proton density in straight section 62 shows that the jump is really 7 mm. On both sides of the shadow there is a Gaussian tail which accounts for the losses. This is probably due to scattering in the thin septum, stray field of the thin septum and maybe some statistical effects.

When operating without the septum lens, a similar method of calibration as for the septum lens indicates about 20% losses on the thick septum, as expected from theory.

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4.e. Closed Orbit Errors

The space available for resonant oscillations can in certain cases be limited by closed orbit deviations. For slow ejection 62 these deviations are particularly large since the orbit bump and the quadrupole strength are coupled. As the optimum quadrupole setting is lower than expected from theory, an inward kick in straight section 61 remains. Fortunately the phase of resulting oscillation is nearly opposite to the resonant oscillation and does therefore not affect the efficiency. The effect of closed orbit errors will have to be further investigated.

4.f. Beam transport acceptance

Due to the defocusing effect of the fringe field the beam may become too large for the acceptance of the beam transport system. When operating with the septum lens, it seems that this problem does not exist. Without the lens a careful adjustment is necessary.

5. Measured Efficiencies

The best results which could be obtained were for slow ejections:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary current (&quot;Unser&quot; transformer)</td>
<td>$7.18 \times 10^{10}$ p/pulse</td>
</tr>
<tr>
<td>Extracted beam (plate, calibrated with foil)</td>
<td>$5.89 \times 10^{10}$ p/pulse</td>
</tr>
<tr>
<td>Corresponding efficiency</td>
<td>82%</td>
</tr>
<tr>
<td>Loss on thin septum</td>
<td>230 mV =</td>
</tr>
<tr>
<td>Loss on thick septum</td>
<td>70 mV =</td>
</tr>
<tr>
<td>Random losses</td>
<td>260 mV =</td>
</tr>
</tbody>
</table>

For fast ejection 1 the corresponding figures were:

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary current (&quot;Unser&quot;) transformer</td>
<td>$8.64 \times 10^{10}$ p/pulse</td>
</tr>
<tr>
<td>Extracted beam (foil)</td>
<td>$7.85 \times 10^{10}$ p/pulse</td>
</tr>
<tr>
<td>Random losses</td>
<td>160 mV =</td>
</tr>
<tr>
<td>Efficiency</td>
<td>91%</td>
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Thus the ratio of slow to fast ejection is 90%. If the measured beam currents are correct, then for both types of ejection approximately the same number of protons are lost randomly in the ring in addition to the theoretically expected 7% for slow ejection and Q% for fast ejection.

Using the "Hereward" transformer both efficiencies would be measured at about 5% higher. According to controls group the "Unser" transformer has the more reliable calibration.

6. Conclusions

On the theoretical side the random losses should be further investigated. The losses on the septa seem to agree with the theoretical values. Another problem is given by the adiabatic phenomena and the debunching scheme. Investigations on RF structure in the ejected beam have shown that it might be desirable to cut off the radio frequency for debunching. This could also help to reduce the losses in adiabatic trapping.

On the equipment side it would be useful to check the primary beam monitor calibrations in order to be able to find a more reliable figure for the efficiency. A more sophisticated calibration of the loss detectors giving the number of protons lost could be of great help, but it is improbable that an easy to use method would result for efficiency measurements.

The tests have shown that the irradiation doses for the septa are most probably within the expected theoretical values. The irradiation of other parts of the machine, however, may be higher than tolerable.

References

(1) R. Gouiran: Private communication on possible losses.
(2) C. Bovet: Variation des paramètres de l'éjection lente
MPS/DL Int. 65-6, 5.5.1965

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