ISR PERFORMANCE REPORT

Run 1180 26th March 1981
Run 1182 30th March 1981
Ring 1 and Ring 2 - 26 GeV/c

Seventh and eighth tests with the superconducting insertion

Aim: High intensity stacking in both rings, test of space charge compensation. Test of physics stacks.

Conclusion: The space charge compensation was made very accurate after a modification of the F coefficients of QCOM. Stable beams of 30 A were stacked, the luminosity was measured to be about $1.3 \times 10^{32}$ cm$^{-2}$ s$^{-1}$. A procedure was established and applied to limit the losses in I8 at injection at the end of stacking.

1. Run 1180

This run was a preliminary study of high intensity stacking in ring 1.

1.1 Set up

The insertion was on during set-up, using the currents file SL26 previously created$^1$). Only 1 h 10 min was needed to switch on the ISR and to obtain a circulating beam. The reproducibility of the line was as good as in $^1$).

The outer collimators were positioned by "find beam" (the top of the stack being at $+35$), the inner and vertical ones were positioned by POCO and then were moved towards the beam as long as no losses, measured on the ionisation chamber of the machine, occurred.

The B-pulse corresponded to injection at $-41.2$ mm according to the closed orbit measurement, but the RF system transferred the injected pulse at the position $-38.8$ mm before the shutter opens.
Under these conditions the maximum losses in I8 at injection at the beginning of stacking were between 4 and 5 \(10^{10}\) in SL7 according to the calibration in ref.2.

1.2 Stacking

The top of the stack was set at +35, the girder at -23 looking at the losses in the injection kicker, POCO computed -33 for the girder.

A first stack was made on the line currently used for stacking which is defined by:

\[
Q_h = 8.887 \quad Q_v = 8.862 \quad Q_h'v = 2.5 \quad Q_h''v = 0
\]

A loss of about 1 A occurred before 4 A were stacked, the space charge compensation (SCC) was made at 4 A. This stack was lost at 7.3 A due to an horizontal coherent instability, as seen on the transient recorder. The loss induced a quench in SL7, and the loss measurement was \(8 \times 10^{11}\) protons.

In order to look at the effect of the proximity of the integer \(Q\) value, the working line was shifted by:

\[
Q_h = Q_v = - 0.03
\]

The SCC was made at 4 A, the stack was lost at 7.5 A due to a horizontal coherent instability as indicated by the transient recorder, for which the "brick wall" signal was saturated. The beam loss induced a quench in SL7, the loss measurement in SL7 was at the maximum (more than \(10^{12}\) protons).

As a cure of the coherent instability, the working line was modified by:

\[
Q_h'' = + 40
\]

which increases the derivative of \(Q_h\) (and hence the \(Q_h\) spread) at the top of the stack by:

\[
Q_h' = 2 Q_h'' \Delta p/p = + 1.6 \%
\]

under these conditions it was possible to stack 28 A. At the end of stacking, the girder was moved inwards to make place; the losses in SL7 at injection increased up to 10" which was considered to be safe.

However for one pulse the loss went up to 6 10", this induced a quench in SL7 and the beam was dumped. The transient recorder indicated that there was no collective instability, which confirmed the origin of the quench.
A fourth stack was made under the same conditions as above, but with the top at + 40, which made it possible to stack 31 A. At this point a Q-digram measurement was made; about 100 mA were lost at each sweep, which produced losses of $2 \times 10^{10}$ protons in SL7 and less than $2 \times 10^9$ protons in the other quadrupoles.

The working lines so measured had both Q shifts w.r.t. the starting line and the initial $Q''_h$ had almost disappeared, which means that the SCC is not perfect at the top of the stack. However, this fortunately leads to a satisfactory working line with the stack.

After the Q diagram measurement the RF system had not been reset for stacking: then the next injection produced a loss of $7 \times 10^{11}$ protons in SL7 which induced a quench in this magnet. The transient recorder did not show any beam unstability.

A fifth stack was made in the same conditions as the fourth one. The Q-digram meter was used at 31 A, it produced a slow loss larger than 1 A so that the beam was dumped without any quench.

A sixth stack was made in the same conditions as above except that the F coefficient in QCOM were corrected according to the measurements above. The new coefficients are in the table below.

\[
\begin{align*}
FH &= 1.11 \\
DFM &= 0 \\
D2FM &= 0 \\
FV &= -1.40 \\
DFV &= 0 \\
D2FV &= -0.14
\end{align*}
\]

Note: The radial variation of the coefficients to be applied to the measured charge density is defined as follows:

\[
F = \frac{x}{40} + \frac{D2F}{40} \times x^2
\]

x being the radial position. For instance the vertical coefficient applied to the piece of beam at the top of the stack (x=40) is $-1.20$, whereas it is $-1.40$ for the centre line, for the above table.

After having stacked 31 A the girder was displaced away from the stacked beam in order to have more place, but this increased the first loss at injection in SL7 from $3 \times 10^{10}$ to $4 \times 10^{10}$ then $10^{11}$, and with a particular pulse it was $6 \times 10^{11}$ and induced a quench in SL7. The transient recorder confirmed that there was no beam instability.
Conclusion from run 1180

The main fact was that the stacked beam is stable, with QCOM using the above coefficients, provided that the starting line has $Q''_h$ outer = +40.

The stability problem being solved up to 30 A, it appeared that great care must be taken of the losses at injection by accurate positioning of the injection kicker.

2. Run 1182

2.1 Ring 2

The last run with ring 2) was very successful and there was little fear about the present experiment.

Indeed the losses at injection in I8 during stacking were always below $6 \times 10^{10}$; this maximum value was obtained at the end of stacking when the girder was moved away from the beam. The collimators and the girder had been positioned by POCO.

The working line was the same as in the previous experiment). In fact $Q''_h$ of the reference line, used for the SCC, was increased by about 50 during stacking in order to improve the stability of the stack. The top of the stack was set at about +40. 30 A were stacked easily, the SCC was made each time 4 A were added.

The vertical Q-values with 30 A were measured by the Q-diagram meter. As they were 0.01 below the expected line, it is recommended to use the same vertical F coefficients as in ring 1(see above) in order to have a better compensation. It was not possible to obtain measurements in the horizontal plane.

The outer collimators were positioned by "find beam" for a pulse at +42. The inner collimators were positioned first by POCO and afterwards moved away from the beam by the quantities in the table below:

<table>
<thead>
<tr>
<th>number of collimator:</th>
<th>304 (upstream)</th>
<th>316</th>
<th>328</th>
<th>344 (downstream)</th>
</tr>
</thead>
<tbody>
<tr>
<td>displacement towards the beam (mm):</td>
<td>+0.1</td>
<td>0</td>
<td>+5.9</td>
<td>+2.8</td>
</tr>
<tr>
<td>$\beta_h$ central (m):</td>
<td>47.6</td>
<td>4.06</td>
<td>45.0</td>
<td>5.2</td>
</tr>
</tbody>
</table>

The vertical collimators were positioned first by POCO and afterwards moved away from the beam by the quantities in the table below:

<table>
<thead>
<tr>
<th>number of collimator:</th>
<th>264</th>
<th>320</th>
</tr>
</thead>
<tbody>
<tr>
<td>displacement from POCO position mm:</td>
<td>upper 0</td>
<td>upper 1.5 upwards</td>
</tr>
<tr>
<td></td>
<td>upper block 0.2 downwards</td>
<td>lower 1.8 downwards</td>
</tr>
</tbody>
</table>
2.2 Ring 1

The same working line as that used in run 1180 above was used. Special attention was paid to the position of the injection kicker (i.e. position of the girder) and to the RF drift at injection, because of the large value of $\beta_h$ of 93 mm at the place of the kicker.

2.2.1 Positions of the injection kicker and shutter protector
- The RF frequency at injection was carefully adjusted so that the RF trapped pulse stays on the injection orbit.
- Then, a pulse having been put on the injection orbit (position - 41.1 mm RF):
  - The girder was displaced outwards until the pulse is touched: girder position: - 15.0 mm
  - The girder was displaced inwards until the pulse is touched: girder position: - 33.6 mm

Hence the average position of the girder was - 24.3 mm. As POCO specifies - 34.0 mm (i.e. position corresponding to maximum stacking aperture), it was set at the position - 26.3 and a pulse was injected and accelerated to the central orbit. Afterwards:
- the shutter was closed and the pulse was decelerated until it touches it,
- the shutter protector scraper (sps) was moved until it touches the pulse, it's position was then - 12.2.

The conclusions were for this particular run:

a) the difference between the position of the sps and that of the girder must not be smaller than 14.1 mm,
b) the position of the girder must not be below -33.6.

2.2.2 Collimators

The inner horizontal collimators were first positioned by POCO and afterwards were displaced towards the beam, until losses are seen on the ionisation chamber of the machine, by the quantities in the table below:

<table>
<thead>
<tr>
<th>number of collimator</th>
<th>265 (upstream)</th>
<th>253</th>
<th>237</th>
<th>229 (downstream)</th>
</tr>
</thead>
<tbody>
<tr>
<td>displacement towards the beam (mm)</td>
<td>1.5</td>
<td>4.1</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>$\beta_h$ central (m)</td>
<td>10.6</td>
<td>42.2</td>
<td>5.64</td>
<td>37.9</td>
</tr>
</tbody>
</table>

- the outer horizontal collimators were positioned by "find beam" for a pulse placed at + 42,
the vertical collimators were positioned by POCO and afterwards they were withdrawn by the quantities in the table below:

<table>
<thead>
<tr>
<th>Number of Collimator</th>
<th>Displacement from POCO Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>301</td>
<td>upper 1.3 upwards, dump block 0.3 downwards</td>
</tr>
<tr>
<td>249</td>
<td>upper 2.3 mm upwards, lower 1.6 mm downwards</td>
</tr>
</tbody>
</table>

2.3.3 Losses in I8 at injection

The larger loss in I8 at injection occurred in SL7, its maximum value was $2 \times 10^{11}$ at the end of stacking. At the beginning of stacking the losses in SL7 were smaller by a factor between 2 and 3 with respect to run 1180.

It was noted that the inner collimator 237 which was installed for SL operation protects SL7 very efficiently indeed: it was possible to reduce the losses at injection at the beginning of stacking by a factor 10 by moving this device by 0.4 mm with respect to the POCO position (which is very surprising!).

At the end of stacking the girder was moved from - 26.3 to - 29 (it was above the touch limit defined in §2.2.1) in order to make place, and the sps was moved accordingly. This did not increase the losses in I8 at injection as expected. It has to be noted that injection was stopped before the aperture was filled because of time limitation.

2.2.4 Space charge compensation

It was made with the F-coefficients for QCOM given above in §1.2. The working line measured by means of the Q-diagram meter is shown in Fig. 1; 31 A are circulating in ring 2, which makes a $Q_L$-shift equal to the difference between the reference line (i.e. the line measured with one pulse) and the measured line. As the horizontal line is below the starting line, the coefficient FH could be changed from 1.11 to 1.04 in order to have a perfect compensation.

2.4 Luminosity measurements

Two measurements were made:
- one with 30 A in ring 2 and 23 A in ring 1 gave:
  \[ L = 10^{32} \, \text{cm}^{-2} \, \text{s}^{-1} \quad (h_{\text{eff}} = 0.69 \, \text{mm}) \]
- one with 31 A in ring 2 and 30 A in ring 1 gave:
  \[ L = 1.3 \times 10^{32} \, \text{cm}^{-2} \, \text{s}^{-1} \quad (h_{\text{eff}} = 0.73 \, \text{mm}) \]

The values of $h_{\text{eff}}$ are computed from the theoretical amplitude of the vertical bumps applied during the measurements. These amplitudes have not been checked experimentally and furthermore the amplitude of the bumps change when a high intensity is stacked; therefore the above values for the luminosity are only know within 10 % of uncertainty.
The theoretical value of $h_{\text{eff}}$ at 26 GeV is 0.56 mm (for a vertical emittance $0.35 \times 10^{-6}$ mrad m and $\beta_y = 0.285$ mm). However for a high intensity stack there is a certain vertical blow-up of the beam, and for the SL insertion $\beta_y$ varies across the stack, which increases the value of $h_{\text{eff}}$ calculated for the central orbit by 4%\(^2\); finally the coupling was not compensated in ring 2.

2.4 Compensation of the vertical kick due to the AFM

The compensation system is made using the AFC's and the two H magnets adjacent to the insertion. This system does not change the position of the vertical closed orbit at the intersection nor its slope, hence it is valid for $\bar{p}$ operations\(^5\).

Although the compensation system creates a local vertical closed orbit distortion, a modification of the vertical closed orbit in the machine appeared after the AFM and its compensators were turned on. Furthermore the p.to p. amplitude of the horizontal closed orbit also was multiplied by about two when the AFM and its compensators were turned on; hence the modification of the closed orbit distortions could be attributed to the perturbation of the field in SL3 and SL4 by the AFM.

These perturbations were easily corrected by COCO.

The theoretical increments for the compensation system are:

R1  H749B  5.66 %; AFC3  4.70 %; AFC1  3.42 %; H817  4.16 %
R2  H752  4.16 %; AFC2  3.46 %; AFC4  1.7  %; H816  4.13 %

The increments obtained in ring 1 after orbit correction are:

- compensators:  H749B -2.39 %
- vertical orbit correctors:  H749A -5.9  %; H253 -8.45 %  COCO comput.
- horizontal orbit correctors: CR861 -3.42 %; CR413 -1.93 %

We have to note that during the setting of the AFM the sextupoles SL3 and SL4 tripped (not the quadrupoles).

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A. Verdier
References:


2. ISR Perf. Rep., Test of ion chamber to be used as local beam loss detector in the superconducting magnets to be installed in I8, ISR-OP/LV/ah, 19.5.1980.


**Fig. 1:** Measurement of the working line in ring 1 at the end of the stack in run 1182 (30 A in ring 1, 31 A in ring 2). The reference is the line of the machine without stack. The vertical shift between measured line and reference is due to the beam-beam effect.