STATUS OF THE PS FOR LHC NOMINAL BEAM


Abstract

The nominal parameters of the PS for LHC beam and the major issues in the PS Booster (PSB) and PS machines are first reviewed. The main achievements of recent studies are then described, including the newly observed electron-cloud phenomena. Conclusions and future plans are also presented.

1 INTRODUCTION

1.1 What is the Nominal LHC Beam at PS Exit?

The PS complex, as part of the LHC injector chain, has to provide protons to the SPS with specific and very tight requirements [1]. The nominal LHC beam at PS exit consists of a train of 72 bunches each of $1.1 \times 10^{11}$ protons to yield the luminosity of $10^{34}$ cm$^{-2}$ s$^{-1}$ in the LHC.

The bunches are spaced by 25 ns, with a rms length of 1 ns to fit the SPS 200 MHz buckets, and a momentum of 26 GeV/c.

The longitudinal emittance at $2\sigma$ should not be smaller than 0.35 eVs to avoid longitudinal single-bunch instabilities in the SPS.

The normalised rms transverse emittances must be smaller than $3 \mu$m to fit the LHC aperture.

1.2 Problems and Solutions

Two main challenges have to be faced in the production of such a beam by the PS complex. The first is to generate the train of very short bunches starting from very long ones (~150 ns) coming from the PSB. This requires complex longitudinal gymnastics. The second is to gain more than a factor two in beam brightness (i.e. intensity to transverse emittance ratio) with respect to the other operational beams.

The adopted solution consists in accelerating in the PSB a beam with the desired transverse emittance, but half the intensity, and injecting two pulses (batches) into the PS machine at 1.4 GeV kinetic energy [2] (instead of 1 GeV previously). This double-batch filling of the PS is used to lower the space charge effects at PSB injection and to double the beam brightness in the PS, while the increased value of kinetic energy (1.4 GeV) helps in reducing space charge effects at PS injection.

Bunch transfer from PSB to PS is performed using a bunch-to-bucket operation: three buckets out of seven available (the PS is operating on $h=7$) are filled with a single PSB shot. The remaining three buckets (one is left empty to have a hole in the bunch distribution for the extraction kicker) are filled with a second shot 1.2 s later. Each bunch is generated by a PSB ring working on $h=1$.

The 6 bunches (3+3) are split into 18, using the new triple splitting technique [3]. They are subsequently accelerated to 26 GeV/c where two double splittings are performed to end up with a bunch train of 72 bunches on $h=84$. A gap of 12 empty buckets (~320 ns) is thus obtained for the rise-time of the extraction kicker.

The bunches are then compressed to a total bunch length of about 4 ns, with a 40 MHz cavity (300 kV) and a $2^{nd}$ harmonic RF system (two 80 MHz cavities delivering 300 kV each).

Finally, the beam is fast extracted towards the SPS through the TT2/TT10 transfer line.

1.3 PSB and PS issues

In the PSB, an $h=2$ RF system is used to reduce space charge, and a longitudinal controlled blow-up is also available. The PSB has a 3-turn injection using a high-peak Linac current (~175 mA with a normalised rms transverse emittance of ~1.2 $\mu$m). The desired nominal parameters are obtained by optimisation of steerings, working points, resonance compensations, and transverse shavers [4].

In the PS, the total emittance increase must be less than 20%. Such a tight budget imposes a rigorous handling of all possible sources of blow-up, i.e. a careful control of the injection oscillations, working points, chromaticities, low energy closed orbit, closed orbit distortions at high energy, and a detailed study of the non-linearities at extraction.

Concerning collective effects, longitudinal coupled-bunch instabilities, which develop between 6 and 20 GeV/c, are cured by controlled longitudinal blow-up. In the transverse plane, the horizontal head-tail single-bunch instability on the injection flat-bottom, due to the resistive-wall impedance, is cured by $x$-$y$ coupling with skew quadrupoles [4].
2 RECENT RESULTS

2.1 In the PS Booster

The intensity of the three PSB rings vs. time, from injection to extraction, is shown in Fig. 1. The beam parameters at PSB extraction, compared to the nominal values, are collected in Table 1. The pulse-to-pulse intensity fluctuations are about ±10%.

![Intensity of the three PSB rings](image1)

**Figure 1:** Intensity of the three PSB rings (in units of $10^{10}$) vs. time (in ms), from injection to extraction (~500 ms).

<table>
<thead>
<tr>
<th>Achieved</th>
<th>Nominal</th>
</tr>
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<tbody>
<tr>
<td>Protons / bunch</td>
<td>$1.4 \times 10^{12}$</td>
</tr>
<tr>
<td>Hor. emittance $\varepsilon_x^{\text{norm,1}\sigma}$ [µm]</td>
<td>2.2</td>
</tr>
<tr>
<td>Ver. Emittance $\varepsilon_y^{\text{norm,1}\sigma}$ [µm]</td>
<td>1.8</td>
</tr>
<tr>
<td>Long. emittance* $\varepsilon_{l_{2}\sigma}$ [eVs]</td>
<td>0.9</td>
</tr>
<tr>
<td>Tot. bunch length* $\tau_b$ [ns]</td>
<td>150</td>
</tr>
<tr>
<td>Momentum spread* $2\sigma_p / p \times 10^5$</td>
<td>2</td>
</tr>
</tbody>
</table>

* Without blow-up.

2.2 In the PS

The intensity of the PS ring vs. time, from injection to extraction, is shown in Fig. 2, and the longitudinal beam structure in the last turn of the PS is given in Fig. 3. The beam parameters at PS extraction, compared to the nominal values, are collected in Table 2. Finally, the plot of the evolution of the normalised rms transverse emittances from the PSB exit to the TT2 transfer line entrance is represented in Fig. 4.

![Intensity of the PS ring](image2)

**Figure 2:** Intensity of the PS ring (in units of $10^{10}$) vs. time (in ms), from injection to extraction (~2.2 s).

![Longitudinal beam structure](image3)

**Figure 3:** Longitudinal beam structure in the last turn of the PS. The horizontal scale changes in the two plots: (upper) 30 ns/div, (lower) 1 ns/div.

<table>
<thead>
<tr>
<th>Achieved</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons / bunch</td>
<td>$1.1 \times 10^{11}$</td>
</tr>
<tr>
<td>Hor. emittance $\varepsilon_x^{\text{norm,1}\sigma}$ [µm]</td>
<td>2.5</td>
</tr>
<tr>
<td>Ver. Emittance $\varepsilon_y^{\text{norm,1}\sigma}$ [µm]</td>
<td>2.5</td>
</tr>
<tr>
<td>Long. emittance $\varepsilon_{l_{2}\sigma}$ [eVs]</td>
<td>0.35</td>
</tr>
<tr>
<td>Tot. bunch length $\tau_b$ [ns]</td>
<td>≤ 4</td>
</tr>
<tr>
<td>Momentum spread $2\sigma_p / p \times 10^5$</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Electron-cloud effects seem to lead only to instrumentation problems as preliminary observations indicate that the beam quality is not affected. This is probably due to the fact that the time of e-cloud-beam interaction before extraction is too short compared with the instability rise-time.

4 CONCLUSIONS AND OUTLOOK

The nominal beam is within reach, but one item is still missing, namely the quantitative analysis of non-linear effects due to stray-field at PS extraction. These phenomena could induce an optical mismatch at the SPS injection, generating an emittance blow-up. These measurements are difficult to carry out, and they will be the main topic for the next MDs. Moreover, four other subjects need to be investigated in the near future.

- The nominal beam needs to be consolidated. This includes improvements in pulse-to-pulse injection mis-steerings, kicker ripples, PSB-PS transverse and energy matching, bunch to bunch intensity fluctuations, instrumentation, etc.
- Multi-gap/multi-spacing beams have to be prepared for SPS MDs (e.g. 50 and 100 ns bunch spacing). In particular, cures for longitudinal instabilities have to be investigated (feedback systems, HOM damping).
- The so-called initial beam, which has ~1/6 of the intensity and ~1/4 of the transverse emittance should be prepared. This beam has 2/3 of the nominal brightness, which is good for collective effects, but the smaller emittance is bad for injection mis-steerings. The transverse damper at PS injection will certainly be useful for this beam.
- Finally, some efforts should be devoted to the preparation of the so-called ultimate beam, which has ~60% more intensity than the nominal one.

REFERENCES

[5] F. Zimmermann, these proceedings.