Second MD on BBLR 10/09/2002

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1 Aims

The aims of this second MD are to commission the new inductive coil and then reproduce the LHC situation with the same normalized emittance. An auxiliary aim which may turn out to be the primary one is to continue developing the methods and strategy.

2 MD Plan

1. Test of PC and wire up to 275 A: No beam; follow up the temperature increase; measure the ripple.
2. Beam Machine parameters: same as MD1,i.e. P2 cycle at 26 GeV/c, 12 bunches of LHC beam, intensity 2.3 10^{11} p total, Qx=.178, Qy=.151, small coupling.
3. Set-up:
    - Correct CO, Q, Q', coupling if necessary. record f_s.
    - Center the beam H + V in the BBLR (interpolation).
    - Measure the emittance and its reproducibility from shot to shot.
    - Start the PM monitoring in BA5.
    - Set-up the PC cycle same as last MD.
    - Measure the geometrical aperture.
4. Clarification on the Beam-Wire separation: Measure CO and tunes for:
    - I=0, d=19+1.27=20.27 mm = nominal
    - I=120 A, d=20.27 mm
    - I=267 A, d= 20.27 mm.
    - I= 267 A, d= 16.27 mm.
    - I=267 A, d= 13.27 mm (9.5σ ?)
    - I=267 A, d= 10.27 mm (7.3σ ?)
    - I=267 A, d= 6.5 mm (TIDV)

    The expected tune shift is given by:

$$\Delta Q = 0.013 \frac{I_b\ [A]}{d^2\ [mm]} \tag{1}$$

5. Simulate the nominal LHC
    - Blow-up the emittance up to the LHC emittance with the damper.
    - Verify that the TIDV is at 6.5σ.
    - Set d=9.5$\sigma$and $I_w = 267$ A. Anything observed? (loss pattern on PMT or lifetime).
    - if yes, correct the tunes and CO to avoid a parasitic effect. Any effect left?
6. Effect of the wire on the beam distribution

- Blow-up the beam to get a rect. distribution with the damper.
- Measure the profile with the WS versus I_w for d=9.5σ.

7. Measure diffusion
   - $I_w = 0$ rise time of losses at the V collimator versus amplitude (i.e of coll. position). By how much shall the collimator be retracted?
   - same with I_w=267 A and d=9.5σ
8. same measurements with a reduced separation d if no effect is detected.

3 Efficiency

The MD was scheduled on Tuesday 10/09/2002 from 8:00 to 18:00. The PS set-up took some 45 minutes. The PC test went smoothly and took about 30 minutes. The SPS set-up took about 1 hour. At 12:30 the 18KV tripped and the machine was down for one hour. Around 14:45, the machine was down for 1.5 hours. The set-up of the damper and of the startegy for emittance blow-up took longer than anticipated, i.e. some 2.5 hours. Only 2.5 hours were left for the data taking proper.

4 Commissioning of the New Inductive Coil

The power supply was smoothly adjusted to the new inductive load by MR. The load is now sufficient to reach the maximum current without oscillations.

The ripple at nominal intensity is measured to be $3\ 10^{-4}$ peak-to-peak. By eye, the dominant frequency is 300 Hz with a component at 50 Hz. This means that the ripple in the beam frequencies is bound to be much smaller than 10^{-4}. From simulations, this amount of ripple is totally insignificant.

The temperature increase of the wire is given below: It is surprising to observe that the temperature increase is not consistent with the pressure drop of 7 bar and a calculated water flow of 0.9 l/mn. In MD1, the temperature increase at 120 A was consistent with the above-mentioned values. It looks like the water flow is decreased by about a factor of 3. This is of no concern, as the safety margin is very large but should be followed up in case an obstruction would be developping.

Current	temperature	
	measured	expected increase
0	23	
200 A dc	32	3
275 A dc	41, slowly increasing	6
275 A only P2	26	0.4

Table 1: Temperature increase versus current

5 Parasitic beam observations during the PC test

During the PC test, the physics beam was only switched off when the PC went close to 200 A and above. The PC was operated in dc mode, i.e. was liable to perturb all the SPS beams. We observed that the beam suffered a loss of about 10% for $I_w > 100$ A at 14 GeV.

6 Machine and Beam Set-Up

The MD is carried out on the P2 cycle at 26 GeV. The standard LHC beam is reduced both in number of bunches and in intensity to 12 bunches representing a total charge of $3\ 10^{11}$ protons. We started actually with more current and had to retune when decreasing it further.

The closed orbit was globally corrected to 1mm rms (H) and 0.7 mm rms (V). The vertical positions close to the BBLR are: BPM517 0.0 mm, BPM 519 0.3 mm. This was considered as fully satisfactory.

The tunes were left at Qx=.175 and Qy= .152, i.e. the horizontal tune was slightly different from its value in MD1 (.178).

The chromaticity was: $\xi = 0.03$, i.e. Q'≈ 1.

The synchrotron frequency was measured with the help of Philippe to be 231 Hz. This is well away from the PC ripple frequency of 300 Hz.

7 Adjustment of the Emittance

The normalized emittance provided by the PS changes with the beam intensity. This is another reason to adjust the beam current to its wanted value directly during the PS set-up. For 12 bunches representing a total charge of 3 10^{11} protons, the normalized emittance is about 1.7 10^{-6} rad.m. We need to increase it to 3.75 10^{-6} rad.m

For this step, the wire was switched off.

The principle of the emittance blow-up is to excite transversely the beam with the vertical damper (WH) by a number of "chirps". These chirps started after about 160 ms, and were applied in intervals of 250 turns. The number of chirp excitations can be varied and was finally set to 40 (corresponding to a time span of 230 ms). Rather than a dilution, we observed coherent oscillations and beam losses. To speed up the dilution, a chromaticity bump was created near the end of the damper excitation and before the wire is turned on. The chromaticity was increased by $\Delta\xi_y = +0.3$.

Time 0	Event injection
7	wire scan IN (tuning of blow-up)
160	damper on
(250–) 300 ?	start Q' bump
390	damper off
400 (–500) ?	finish Q' bump
980	wire scan IN (experiment proper)
1000	start rise of wire excitation
1500	start flat top for wire excitation
2000	tune measurement
2300	wire scan OUT
4000	start fall of wire excitation
4500	wire off
4500	dump beam

Table 2: P2 cycle used in MD2 for the BBLR experiment

We finally got a reproducible normalized emittance of $(3.72 \pm 0.15 \text{ rms})10^{-6}$ rad.m. The beam losses are large (25% of the beam). They occur during the excitation by the damper and not during the Q' bump (exact??). This may show that, either the geometrical aperture is smaller than expected, or that we excite strong resonances when sweeping the beam or both.

For the next experiment, we should consider using the octupoles during the damper excitation to produce a significant detuning. The effect of resonances would thereby be decreased, unless the octupoles themselves produce strong resonances, e.g., $2Q_x - 2Q_y$.

8 Set-up of the Beam Loss Monitoring

The BBLR is equipped with a local detection of beam losses with an ionization chamber and a photo-multiplier for increased sensitivity. In this experiment, we only use the PMT.

8.1 Launching the program

Operation > New programs > SPS collimator monitors

Set 'Extraction' to BA5 and select monitor 3 (BBLR).

Settings used: Interval 430 (44 is 1 ms) and Start event 5000 (from the beginning of the supercycle; there appear to be a feature with the time scale: JJG informed).

GlobLoss is the loss over the supercycle while PartLoss is the loss over the range selected.

8.2 Counting rates

The counting rate over the P2 cycle when the dampers, Q' bump and wire are off is less than 1000 Hz, i.e. similar to what it was in MD 1 (with the small injection emittance).

When the emittance blow-up is set up, but without wire excitation, the losses increase to about 3.7 10^3.

9 Description of the Experiment

<table>
<tr><th>Time</th><th>I_w
A</th><th>d
mm</th><th>C.O.
filename</th><th>Q_x</th><th>Q_y</th><th>ϵ_{NIN}</th><th>ϵ_{NOUT}</th><th>Ploss
kHz</th></tr>
<tr><th></th><th></th><th></th><th></th><th></th><th></th><th colspan="2">10^{-6} rad.m</th><th></th></tr>
<tr><td>14:00</td><td>0</td><td>nominal</td><td></td><td>.1757</td><td>.1510</td><td></td><td></td><td>3.3</td></tr>
<tr><td></td><td>120</td><td>nominal</td><td></td><td>.1722</td><td>.1542</td><td></td><td>3.74</td><td>3.8</td></tr>
<tr><td>14:26</td><td>267</td><td>nominal</td><td></td><td></td><td></td><td></td><td>3.7</td><td>4.3</td></tr>
<tr><td colspan="9">SPS down for 1.5 hours</td></tr>
<tr><td>16:30</td><td>0</td><td>nominal</td><td></td><td></td><td></td><td>3.81</td><td>3.66</td><td>4.9</td></tr>
<tr><td></td><td>120</td><td>nominal</td><td>sps-orbit_16-41-21_10-09-02</td><td></td><td></td><td>3.68</td><td>3.59</td><td>4.3</td></tr>
<tr><td></td><td>200</td><td>nominal</td><td></td><td></td><td></td><td>3.88</td><td>3.71</td><td>4.3</td></tr>
<tr><td></td><td>267</td><td>nominal</td><td></td><td></td><td></td><td>3.60</td><td>3.57</td><td>4.3</td></tr>
<tr><td colspan="9">The nominal d is measured to be 23.5 mm from the tune shift.
The beam size is $\sqrt{50 \times 3.75\,10^{-6}/28.7} = 2.6$ mm. The nominal d is therefore 9.2σ</td></tr>
<tr><td>17:15</td><td colspan="8">Vbump by -7.33 mm at BPM517, i.e. -5.2mm at BBLR = 2σ</td></tr>
<tr><td></td><td>267</td><td>7σ</td><td></td><td></td><td></td><td></td><td></td><td>500</td></tr>
<tr><td>17:25</td><td colspan="8">The tune shifts due to the wire causes the tunes to cross. We shift Qx by -0.2.
Following the tune shift the loss pattern changes somewhat.</td></tr>
<tr><td></td><td>267</td><td>5σ</td><td></td><td></td><td></td><td>3.73</td><td>3.13(4 meas.)</td><td>460</td></tr>
<tr><td></td><td>267</td><td>5.5σ</td><td></td><td></td><td></td><td>2</td><td></td><td>4000</td></tr>
</table>

Table 3: Simulation of the LHC

time	wire current	bump at 517 [mm]	Q_x	Q_y	distance [mm] expected	inferred
14:02	0	0	0.1757 ± 0.0002	0.1510 ± 0.0001	20.27	N/A
14:12	120	0	0.1726 ± 0.0004	0.1543 ± 0.0003	20.27	19.7 ± 0.4
14:24	267	0	0.1691 ± 0.0001	0.1576 ± 0.0003	20.27	20.7 ± 0.1
16:21	0	0	0.1760 ± 0.0001	0.1503 ± 0.0002	20.27	N/A
16:33	120	0	0.1734 ± 0.0002	0.1535 ± 0.0003	20.27	21.1 ± 0.3
16:43	200	0	0.1714 ± 0.0001	0.1565 ± 0.0001	20.27	19.7 ± 0.1
16:46	267	0	0.1697 ± 0.0001	0.1583 ± 0.0003	20.27	19.9 ± 0.1
17:00	267	-3.7	0.1686	0.1590	17.6	N/A
17:09	267	-7.4	0.1656 ± 0.0003	0.1623 ± 0.0002	15.0	
17:30	267	-7.4	0.1400 ± 0.0001	0.1619 ± 0.0003	15.0	17.0 ± 0.3
17:38	267	-11.1	0.1370 ± 0.0004	0.1651 ± 0.0004	12.3	14.9 ± 0.4
17:46	267	-14.8	0.1325 ± 0.0004	0.1700 ± 0.0004	9.7	12.9 ± 0.3
18:00	267	-14.8	0.1251 ± 0.001	0.1758 ± 0.0004	7.1	11.0 ± 0.3

Table 4: Tune shifts and the inferred beam-wire distance.

10 Tune Measurements

The betatron tunes were measured 2s after injection (500 ms after the start of wire excitation).

Typically, 4 or 5 measurements were taken for each case. The actual distance between the center of the wire, d, is then inferred from the formula

$$d = \left(\frac{r_p I_w l_w \beta_{x,y}}{2\pi\gamma ec(\Delta Q_{x,y})} \right)^{1/2} , \tag{2}$$

where l_w denotes the effective length of the wire. The radius of the wire is taken to be 1.27. We obtain estimates from the horizontal and vertical tune shift, respectively, by inserting the measured tune shifts and assuming the design values for the beta functions at the wire, $\beta_x = 47.13$ m and $\beta_y = 50.26$ m. We fist compute the average tunes and rms spread in each plane, and, for each nonzero wire current, then the average tune shifts and rms error in the tune shift for each plane, weighting with the initial and final tune errors. Finally, we take the weighted average ΔQ of the two planes and its weighted error $\delta(\Delta Q)$, and from this we compute the distance d and its uncertainty $\delta d = (d/2)(\delta(\Delta Q))/\Delta Q$.

At 17:30 the base tune was changed by $\Delta Q_x = -0.02$ to stay further away from the coupling resonance.

If a local orbit bump is applied at a constant wire current, the tune shift ΔQ arises from the change in the distance d. The new distance d_2 and old distance d_1 are related via

$$d_2 = \left(\frac{1}{d_1^2} - \frac{(\Delta Q) 2\pi\gamma e c}{r_p I_w l_w \beta} \right)^{-1/2} . \tag{3}$$

We have used this relation to estimate the change in distance d for the set of data taken after 17:30. In this case, the error for the orbit change $(d_2 - d_1)$ was estimated as

$$\delta(d_2 - d_1) \approx \frac{1}{2} d^3 \left(\frac{2\pi\gamma e c}{r_p I_w l_w \beta} \delta(\Delta Q) + 2 \frac{1}{d_1^3} \delta d_1 \right) , \tag{4}$$

and the total error in the distance d_2 follows from the errors in d_1 and $(d_2 - d_1)$, added in quadrature.

We have applied (3) to infer the distances listed in the last three rows of Table 4, taking as reference point the value of d_1 for an orbit bump at BPM 517 of 7.4 mm (17:30). We have taken the distance d_1 at this reference point to be equal to the theoretical self-consistent value (see below).

The dipole deflection θ imparted by the wire will change the closed orbit at the wire by an additional Δd_{co}, which in first order approximation is given by

$$\Delta d_{\mathrm{co}} \approx \frac{\beta_y \theta}{2\tan(\pi Q_y)} = \frac{\beta_y r_p I_w l_w}{\gamma e c d \tan(\pi Q)} . \tag{5}$$

This effect was neglected in the foregoing analysis. It is not small. For 267 A and $d = 20$ mm the orbit change is about 11%, for the same current and $d = 10$ mm, it is 33%!

The correction Δd_{co} becomes large for our distances of interest, and thus we should rather take the self-consistent solution:

$$d_{\mathrm{co}} = \frac{d_{I_w=0}}{2} + \sqrt{\frac{d_{I_w=0}^2}{4} + \frac{1}{2\tan \pi Q_y} \beta_y \left(\frac{2 r_p I_w l_w}{\gamma e c} \right)} . \tag{6}$$

Figure 1 illustrates the theoretical dependence together with the measurements for various bump amplitudes.

The formula (6) does not include second-order effects arising from the finite beam size and the nonlinear force of the wire, which could become important at short distances, and which might explain the slight deviation between measured and predicted position on the left side of the figure.

11 Interpretation of the experiment

Thanks to...

G. Arduini, Guy,...

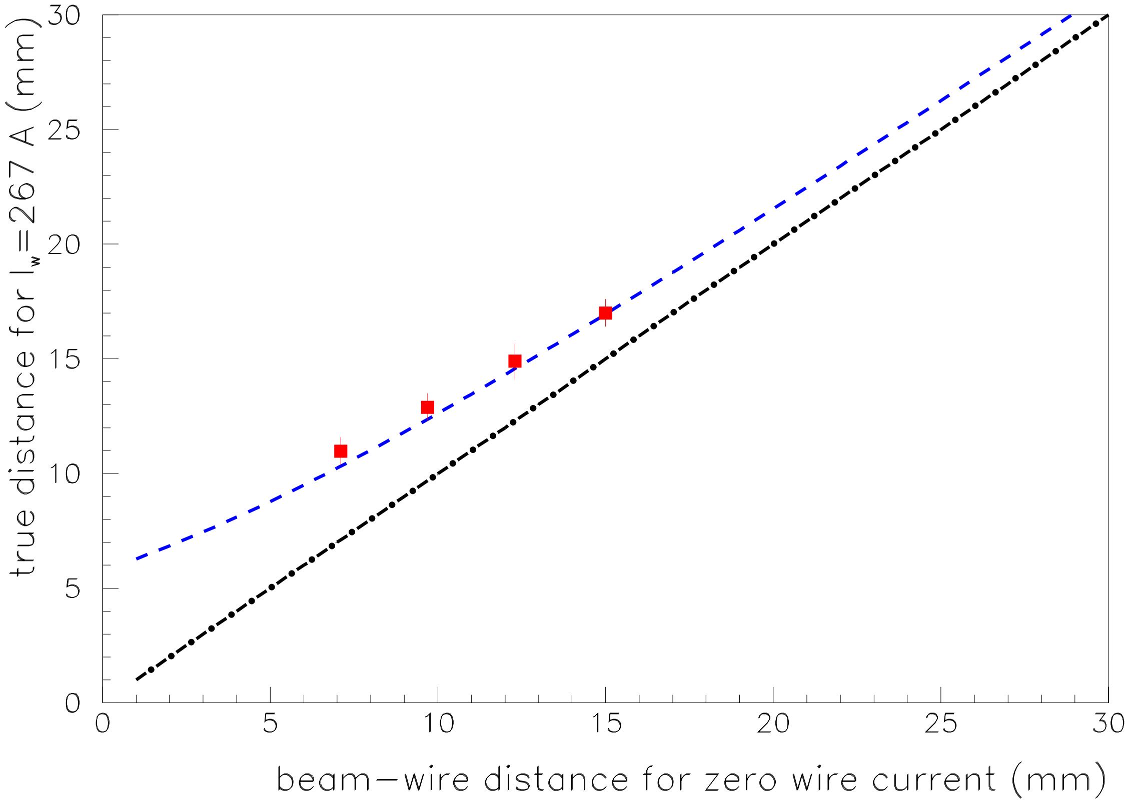

Figure 1: The actual distance between wire and beam for $I_w = 267$ A as a function of the same distance without wire excitation. The dahsed line is the theoretical prediction according to Eq. (6), the plotting symbols refer to the four tune shift measurements after 17:30. The first point (15.0 mm on the horizontal axis) serves as a reference and was set to the predicted value of 17.0 mm.