Comparisons of the CODD and of the Normaliser Systems
For Closed Orbit Measurements in the PS

J.Belleman, J.L.Gonzalez, M.Ludwig, J.P.Potier, R.Steerenberg

Abstract
The PS ring is equipped with 40 position PUs distributed around the ring. These are connected to the CODD system, which performs trajectory measurements of any single bunch, on two consecutive turns, and to 40 Normalisers, which deliver an averaged orbit.

CODD uses a beam-synchronous timing system, which tracks a given bunch all through the acceleration cycle, but needs resynchronization after harmonic changes. It measures at injection or at any given C-timing, albeit with no less than 5ms between acquisitions. It is blind during harmonic changes.

A Normaliser, using a technique originally developed for radial loop control, produces a slow signal, proportional to the average position of the bunches. At beam injection a settling time of 1.5ms is needed; then it follows orbit changes with a 200us time constant. Thus, it will not show rapid position changes, such as betatron oscillations. It does not require accurate timing. In the PS installation, the Normaliser outputs are simply sampled at 1ms intervals.

CODD affords measurements on single bunches right from injection, but needs a complicated timing system and delivers results with mediocre resolution. The Normaliser, on the other hand, has simple timing, but produces the average orbit over the whole beam over a few hundred microseconds, thus missing the injection event. The averaging lends it a better resolution than CODD, though not by as much as could have been expected, based on its time constants.

The aim of this document is to compare both systems and show the superiority of the Normaliser for closed-orbit measurements.
The CODD and the Normaliser Systems

The CODD is sketched on fig. 1; it is composed of:

- A pick-up control which adapts the PU gain to the bunch charge to deliver sum and difference signals suitable for later integration and digitization.
- A beam synchronous timing, controlled by real time software, in order to follow the RF harmonic changes and to drive both the base line restitution and the integrator’s gate that allow the acquisition of the requested bunch and turn. This timing, which is the most critical part of the system, necessitates frequent nursing by specialists.
- Analogue integrators for the sum and difference signals, which are driven by the synchronous timing. The two consecutive turns are acquired using two independent sets of integrators for each PU.
- A data acquisition system to digitize the 240 signals produced by the 40 PUs (sum, X, Y) over the 2 turns.

As a trajectory measurement, the CODD is a performing system, but for closed orbit measurements, its resolution is relatively poor and it is heavy to maintain.

In the PSB a Normaliser technique, developed initially for the radial loop [1, 2], is used: an AGC amplifies the sum signal of the PU up to a well defined level and applies the same amplification to the X or Y signal in order to provide a charge independent low frequency position signal; its principle is shown on fig. 2. As the signals are averaged by the peak detector over 100 to 200 µs the possible perturbations by betatron oscillations are eliminated and a true orbit position is measured. In the PSB version, the dynamic range is 60 dB. Due to the AGC settling-time, which is about 4ms, the injection of the beam in the ring cannot be measured; after this initial delay the Normaliser reacts to position variations with a time constant of 200 µs. This method does not need any synchronization or timing system and the output signal, which is the position of the beam, can be observed directly on a scope and acquired like a simple power supply current.

Considering its robustness and simplicity for closed orbit measurements, a PS version of the PSB Normaliser has been developed, by J. Durand, for the replacement of the CODD closed orbit function. To cope with the PS requests, it treats simultaneously the radial and vertical positions, the AGC settling-time has been reduced to 1.5 ms and the input filter has a larger bandwidth, adapted to the widely changing PS proton and ion bunch conditions. For this reason the dynamic is smaller (50dB in lab) and consequently the noise rejection is not as good as in the PSB version.

In order to compare the present CODD system with the Normaliser, it should be kept in mind that CODD performs only trajectory measurements on two consecutive turns and on a specific bunch, whereas the Normaliser measures only orbits i.e. globally on all bunches circulating in the PS ring. An important point to keep in mind as well is that the analogue part, i.e. the PU gain-control and the calibration electronics are common to both systems – see fig. 1.

Just before the PS annual shutdown, in October 2002, first beam tests were performed with the new PS Normaliser. In summer 2003, a proper software interface was implemented, the tests were pursued and calibrations with dipoles done. Here we give the first results.

Preliminary tests with bumps in October 2002

In October 2002 comparisons between CODD and Normaliser measurements of horizontal and vertical bumps were done using provisional software for data access and calibration.
All the measurements were done on EASTB, 1 bunch of 1E11 protons, no RF gymnastics and a standard working point. In order to avoid any problem with the treatment of electrical or mechanical offsets of the PUs, only bumps i.e. differences between two orbits have been studied. In the horizontal plane PR.DHZ15 or PR.DHZ60 were used to produce bumps at a PS field of 6130 Gauss. To compensate for the drifts produced by the radial loop, the orbits were re-centered numerically during the analysis. In the vertical plane, PR.DVT30 and PR.DVT34 were powered around 1071 Gauss to produce bumps and the data used directly. The analysis was performed using MICADO routines in OPTICS (thanks to M.Martini) and in ORBCOR (thanks to T.Risselada). In all cases, we have used the average of the two trajectories provided by the CODD as closed orbit. The results are summarized in fig. 3 and fig.4.

Horizontal plane: there is relatively good agreement between the kick amplitude deduced from the Normaliser and the CODD data analysis and the kick installed in the ring as can be seen on fig. 3. For the horizontal bumps the difference between the applied kick and the analyzed one is of the order of +3%/- 5% for the Normaliser and +1%/-11% for the CODD. Looking into the detailed values, it seems that the Normaliser data are closer to the expected ones than the CODD data which gives systematically lower displacements. The rms residuals between CODD and Normaliser data (i.e. rms of the differences between the measured data and the reconstructed data) versus the computed bumps are generally smaller for the Normaliser than for CODD.

Vertical plane: there is a rather good agreement between CODD and Normaliser results but the kicks found are systematically lower by about 13% to 18% than expected from the calibration of the dipoles and the current applied (wrong calibration of power supplies or dipoles, differences between CODD and Normaliser calibrations?).

CODD and Normaliser comparisons beginning of 2003

Since the beginning of 2003, an equipment interface and a calibration program is available for the Normaliser and the data collection is done through the passerelle. Different measurements have been done on different users with stable conditions to compare the behavior of both orbit measurement systems.

How to compare CODD trajectories and Normaliser orbit measurements? Data reproducibility

In our measurements the beam is not oscillating and the trajectories delivered on the two consecutive turns by the CODD should only differ by noise or small differences in calibrations; for this reason the data of the two turns are usually averaged. In order to evaluate this procedure we have done measurements checking the reproducibility of such data and their relevance for comparisons with the Normaliser orbits. For that the differences between the two turns of CODD and of their average are compared with the Normaliser data.

On EASTB, C600 we have collected CODD data; an example is shown on fig. 5 with a table of the most important results:
The differences between the two turns on all the PUs have rms values in the horizontal plane of ~1.0 mm and in the vertical plane of ~0.45 mm,
In the horizontal plane between the first turn, the second turn and the average of both collected with the CODD and on the Normaliser, the rms differences are similar and close to 1.20mm. In the vertical plane the results are similar, the rms differences being around 0.45mm.
The average of the differences between the two turns of CODD is close to 0 which is consistent with random errors in the processes of BLR, gating and integration.
To have more systematic data, the same kind of measurements has been done on SFTPRO at C176 over 16 different cycles in the horizontal plane (refer to fig. 6); the results are:

1. the rms of the differences between the two CODD turns for all the PU in the different measurements are of the same order as before ~1.10 mm; for a specific PU the rms of the differences between the two turns varies between 0.36 mm and 2.15 mm.
2. The Normaliser orbit data are stable and the rms of the readings on one PU varies between 0.12 to 0.37 mm, the rms on the ensemble being 0.27mm (refer to fig. 7).

It should be noted that here we don’t compare exactly the same quantities as for the CODD the data come from the same pulse and the beam reproducibility don’t contribute to the errors. On the contrary for the Normaliser the data come from different cycles and some part of the variations come from the pulse to pulse reproducibility of the PS beam. In conclusion, as expected the Normaliser data are more reproducible than the CODD data by a factor 2 to 3. To perform the comparison between the CODD and the Normaliser the CODD averaged over two turns is marginally better than single turn data.

Calibration of the Normaliser and of the CODD using vertical orbit bumps

The comparison between orbit bumps recorded using the CODD and the Normaliser performed in the horizontal plane in October gave good qualitative results. Here with the availability of the interface module and of the calibration program we focus on the vertical measurements which are more reproducible. The measurements have been done with 1 bunch of 1E11 protons on EASTB at C220 (~B1071). An example of the bump data collected is shown fig 7 and the results in fig.8.

Bump symmetry
To evaluate the behavior of the system we collect orbits with both polarities of the dipoles and subtract one from the other; the result should be a flat line if the system is fully symmetric and linear. On fig 8, bottom part, the bump symmetry results for VDIP 30 are summarized. It can be seen that the Normaliser data amplitude is smaller by a factor ~ 3 compared to the CODD data (see table on bottom fig.8).

MICADO analysis
Using MICADO routines via ORBCOR with the optics of the PS, we have analyzed the CODD and the Normaliser bump data in order to find the perturbation imposed onto the machine. The results are shown on fig 7. On the top left graph the Normaliser data can be seen as red squares and the reconstructed bumps as a red line; the top right fig 7 shows in blue the equivalent CODD data; on the bottom right an example of the discrepancies between the CODD and the Normaliser data and of the corresponding numerical reconstruction can be seen. As for the symmetry data, the differences are smaller for the Normaliser.

All the results are summarized in fig. 8 as well as the correlation between the installed kick and the computed ones. In summary:

1. The rms between the measured bump and the MICADO one is smaller by a factor ~2 for the Normaliser compared to the CODD,
2. Both systems see less kick than expected from the current in the dipoles, 6% for the Normaliser and 10% for the CODD. The Normaliser seems to provide positions closer to the expected ones than the CODD, at least in the vertical plane

These results are in agreement with October 2002 preliminary experiments.

CODD and Normaliser measurements at different MRPs

Geneva, Switzerland
January, 2004
Orbit data have been collected with the Normaliser and the CODD during a radial steering placed around C258 on an EASTB cycle with 1 bunch of 1E11 protons. They are shown on fig 9.

1. The radial steering has been varied between -25 mm and + 25 mm providing MRP excursions from -40 mm to + 30 mm. In all cases, the orbits collected by the Normaliser are very close to the CODD orbit, but with slightly higher amplitudes for the Normaliser, with is consistent with the calibration results seen above.
2. On the left bottom graph it can be seen that the rms difference between the two turns acquired by the CODD increases by up to ~7% at 40 mm of radial excursion.
3. On the right bottom plot one can see the Normaliser MRP versus the CODD MRP which shows a good linearity with a small systematic difference of ~2% between the Normaliser and the CODD MRP readings in agreement with the higher amplitudes seen with on the orbit displays of fig. 9.

**MRP versus time measurements**

All orbit data are collected each ms and the average radial position worked out (the horizontal dispersion is not taken into account as in CODD) producing the evolution of the MRP along the cycle. In the same way the evolution of the positions H and V along the cycle in a PU is available. The MRP, the positions in PU60 and the usual CODD MRP along standard EASTB and SFTPRO cycles are shown on fig 10 and fig. 11.

1. It should be noted that the Normaliser data are available each ms simultaneously with the orbit measurements while the CODD data are delivered only every 5ms and exclusive with trajectory measurements, due to software limitations.
2. The MRP data taken on EASTB by the Normaliser and the CODD are very similar black triangles for Normaliser and light blue crosses for the CODD. The Horizontal position in PU00 along the cycle – rhombuses blue markers - is similar to the MRP as expected and around transition a clear jump in position corresponding to the doublet jump can be seen on the zoomed graph.
3. On SFTPRO the behavior is similar; on the zoomed graph, it should be noted that the CODD-MRP data are ~5ms in advance in respect to the Normaliser data. This difference in behavior (which could happen only in the software) will have to be investigated.
4. On SFTPRO data, zoomed graph, there is a strong horizontal jump during the triple splitting on all signals (it is seen as well on the radial loop error signal, not represented here) and it can be seen that the Normaliser doesn’t show discontinuities during the splitting process as can be seen in particular on the vertical PU signal.

**Normaliser and CODD measurements around transition**

These data have been taken as above on an EASTB cycle July 9th, 2003. On fig. 12, the top graph shows the vertical and the horizontal Normaliser orbit evolution from the start of the triplet to the maximum of the doublet before transition. The middle graph shows the evolution from the minimum of the doublets - after the jump - to the end of the triplet.
On the bottom graph the closed orbit jumps in the horizontal and vertical planes seen by the CODD and the Normaliser are shown. Their rms differences are respectively 0.62 and 0.25 mm which is similar to the other measurements.

**CODD and Normaliser dynamics**

Geneva, Switzerland
January, 2004
During the tests (performed in parallel with physics) it has not been possible to change the charge per bunch. To get some estimate of the dynamics of both systems, for the EAST beam, 1E11 protons/bunch at C258 we have collected the orbits using different sensitivities from 1E10 per bunch to 5E12 per bunch. The horizontal orbits collected are shown in fig. 13 top for the Normaliser and middle for the CODD. It can be seen that:

1. From 2 E10 to 5 E11 per bunch the Normaliser is providing data very similar to the CODD and to the data collected with the sensitivity 1E11 (see both bottom graphs on fig. 13; the rms differences between CODD and Normaliser stays at low level up to the sensitivity 5E11.
2. At the sensitivity 1E12 the differences between the two turns of CODD explode and the comparison becomes meaningless.
3. At 1E12 the CODD data are unreliable with rms differences with 1E11 data of 3 mm in H and 5 mm in V; from 2E12 to 5E12 the Normaliser, thanks to its AGC like functions, is still providing positions close to 1E11 data with some errors while the CODD cannot provide any data as expected from the ADC resolution.
4. From 1E11 down to 2 E10 where we get into saturation, both systems provide stable data and on the 1E10 sensitivity the Normaliser starts to suffer from saturation.

On fig. 14 we show 17 sets of orbits taken with the Normaliser using the 5E12 sensitivity superimposed with the data corresponding to 1E11. The different orbits are identical within an rms of ~0.7 mm, but the systematic differences with the 1E11 sensitivity data will have to be understood (calibration of the PU?).

In conclusion the dynamics seems to be large, but to get fully representative data one must setup a proper 1E10 protons beam to collect data and try other bunch configurations.

**Orbits with MDLHC (LHC pilot beam)**

Taking the opportunity of the setting up of a Pilot beam for LHC, some preliminary data on the MRP and one orbit have been taken with the Normaliser. The pilot beam for LHC was 1 bunch, 5E09 protons, no RF gymnastics.

1. On fig. 15, the MRP data taken by the CODD and the Normaliser are shown as well as the evolution of the positions H & V in PU60 along the cycle. The Data from the MRP CODD are a cloud of points between -8 mm to +8 mm, but the data from the Normaliser MRP are good. It should be noted that in these conditions many of the CODD readings are out of range and the others are very poor due to the ADC resolution.
2. The H position follows more or less the MRP data and both H and V positions are relatively noisy but still usable.
3. On fig. 16, two orbits taken at C175 and C320 are shown but to a lack of beam availability, comparisons with a bigger beam but with the same magnetic conditions have not be done.

These measurements are preliminary and should be checked.

**Measurements on SFTION**

On lead ions the MRP and the positions in PU17 along the cycle have been measured with 1.8 E10 total charges at injection (~1.1E09 charges per bunch). They are shown on fig. 17. The Normaliser MRP has only small fluctuations while the CODD MRP shows data spread between -10mm and +10mm. The H and V positions in PU15 are relatively noisy, the horizontal position evolution is in agreement with the MRP values and the horizontal bump in section 16 at extraction is clearly visible.

To complete the observation 10 horizontal and vertical orbits at C 175 have been taken on different ion cycles. Their average is shown on fig. 18 with the fluctuation limits at +/- 1*σ. As could be expected, the accuracy is not very good, but the results can still be useful for
beam diagnostics. At C175, the fluctuation of the MRP is 0.35 mm which is consistent with the MRP data along the cycle.

Comments on low charge measurements

The accuracy of the readings, both for the CODD and the Normaliser are limited by the low frequency noise level of the PU head amplifiers originating in the high value of the low frequency cut-off of the PU (~8Mhz for the PU itself in respect to the ~0.5 MHz PS revolution frequency) compensated electronically with the adverse effects on noise. This very important point is currently addressed by a change of the coupling between the PU electrodes and new high impedance hybrids, used to produce the difference signals, and by the development of new low noise electronics. This upgrade, once introduced, will profit to both trajectory and orbit measurements and will allow to measure ion-beam positions with a good signal to noise ratio.

A few exotic cases of measurements done with the Normaliser

The CODD system cannot measure the orbit during harmonic changes. Within certain limits, the Normaliser can do it; here we have done a few tests under conditions forbidden to the CODD to evaluate the limits of the Normaliser.

MRP and Orbits measurements along on TSTLHC cycle and during the splittings

For the production of the LHC beam, a first triple splitting occurs close after injection producing 18 bunches out of the 6 original using a 21st harmonic for the RF acceleration system. Before extraction two double splittings are done increasing the bunch number to 72, with RF harmonics of 42 then 84. All bunches are consecutive and 72/84th of the ring circumference is filled. The production scheme of the TSTLHC beam is the same but using only 4 consecutive bunches injected from the PSB.

The PS ring PUs have a Bessel filter, limiting their bandwidth to 30 MHz. On bunches at distances of 50 ns (RF harmonic 42) or 25 ns (RF harmonic 84) only the bunches envelope can be seen; the Normaliser will see a hole in the beam, followed by a long rectangular bunch. On fig. 19 top, scope traces of the dB/dt, of the PR.TRADC and of the analog output of the PU 00 Normaliser 00 are shown for an LHC beam; on fig. 19 2nd to 4th positions, the direct signals of PR.PU100 Sum and deltaH are shown during the RF harmonics 21, then 42 and 84. It should be noted that during all these RF gymnastics the Normaliser signal stays flat, as it should. On a TSTLHC beam, the signals are similar except the size of the hole in the beam that becomes 48/84th of the PS ring circumference.

In order to have sounder results, the behavior of the Normaliser has been tested in the lab with simulation pulses. The results show a change of about 5% of the calibration coefficients in the conditions of TSTLHC or LHC during the double splittings.

On fig. 20 the Normaliser MRP and the Normaliser positions H and V in PU17 along the cycle are shown with two zooms during the splittings. On the triple splitting zoom, the behavior of the horizontal position is very similar to the MRP and in the vertical plane no discontinuities or variations are visible during the splitting, showing that the Normaliser is not affected by the changes in bunch structure. The same argument applies for the data shown on the second zoom during the two double splittings and the extraction bump is clearly visible on the horizontal position before extraction.

To cross check these measurements, orbits have been taken at C172, C199 and C210 i.e. before during and after the triple splitting. They are shown on fig. 21 top and middle. In the horizontal plane, the data are similar at C199 and C210, the C172 data differing by a drift in radial position occurring at injection. In the vertical plane the orbits are identical within the measurements errors.
The closed orbits have been collected as well on the extraction flat-top, before the first double splitting - C1070, between the two splittings - C1138, after the second splitting - C1178 and on the top of the extraction bump – C1194; they are shown on fig. 21 bottom. Outside the extraction bumps (C1070, 1138 and 1178) the closed orbits are mostly identical and at C1194 the extraction bump and its small residual are clearly seen. For comparisons the extraction orbit on the top of the extraction bump has been collected at C2394 on an LHC beam: the results are equivalent.

**Observations on AD**

On the AD beam, Normaliser and CODD MRP have been taken as well as the horizontal and vertical position in PU 17 along the cycle. It can be seen that:

1. The Normaliser and CODD MRP follow each other along the cycle fig. 22 bottom).
2. During the RF harmonic sweep from 10 to 20 on the 26 GeV flat top, the Normaliser is still giving correct averaged positions while the CODD is blind, as expected. In particular, the horizontal position varies in +/- 2.5 mm due to the gymnastics, but the results in the vertical plane are flat as can be expected.
3. The extraction bump is maximum at C1074, but at C1075 which is the extraction timing it has already disappeared (fig. 22 top right) which implies that the Normaliser software gives values at a C 1ms later than the requested.
4. 1 ms after injection (“C170” on the graph in fig. 21 see later) the horizontal and vertical position seems to be roughly measured by the Normaliser despite the fact that it needs 1.5 ms to be tuned when the beam is injected.

Observations of the trigger used to digitize the Normaliser signal confirm that the first pulse supposed to be at C170 is in fact delivered at C171. This default is the same as on the CODD trigger in its present state: it displays a measurement as Cxx but the data are gathered at Cxx-1.

**A few non exhaustive comments on software tests on CODD and Normaliser**

The 1 ms timing error shown in the case of AD is completely general but other problems have been encountered as for example:

- Sets of measurements delayed by some 400 ms at injection, the first part being “filled” with non significant values; this occurs frequently on supercycles without ZERO cycles.
- On a display of the horizontal and of the vertical positions along the cycle, from around the middle of the data collection, the values transmitted for the vertical position are wrong and identical to the horizontal values!
- Difficulties to get the first user’s data in a sequence of several occurrences of this user.
- The present implementation of the access to the orbits via the present standard interface is inadequate as it doesn’t allow reliable readings at a given C in presence of several users.

**Provisional conclusions**

Our purpose was to check what could be got from an analogue Normaliser system, i.e. averaged orbit measurements, compared to what the CODD system presently in use can provide in the same field, the individual bunch trajectories which are measured by CODD being obviously out of the scope of the Normaliser. The tests have confirmed that:

Geneva, Switzerland
January, 2004
1. The analogue electronics part of the system behaves correctly on all beams, without any need of synchronization adjustment, nor tuning or nursing when it is setup.

2. For orbit measurements, the accuracy, the reproducibility and the linearity of the values are better by a factor 2 to 3 in respect to the CODD.

3. The dynamic range of the Normaliser is better by a factor 5 at least in respect to the CODD.

4. The time response when the beam arrives is \(~1.5\) ms to be fully in range, but after 1 ms sensible orbit measurements on an oscillating beam can be obtained.

5. The cross calibration with the CODD in MRP-mode is good.

6. The calibration of the Normaliser with vertical bumps gives more accurate results than for the CODD, the absolute value having to be checked with the dipole calibration.

To go further, if an operational implementation is decided, in order exploit the potential of the analogue electronic part:

- the software interface and access routine should be upgraded and detailed RT tests performed,
- the PU sensitivity management should be separated from the CODD system to which it is presently hooked.

As expected, the Normaliser is a very reliable and robust orbit measurement system. It has a large dynamic and gives the orbit even during the numerous RF and bunch gymnastics which are done on the PS-beams. Due to its principle it is unable to measure bunch trajectories and it cannot replace all the functions of the CODD (see specification of the beam position measurements in the PS machine by the AB specification board [Ref 3]) which will have to be provided in another way. The future of this normaliser has to be decided depending on user requests, BDI possibilities and AB priorities.

References


Geneva, Switzerland
January, 2004
The PS orbit measurement system

Figure 1

Geneva, Switzerland
January, 2004
Normaliser principle

PSB normaliser
Tests have been performed on the PS beams with a normaliser developed for the PSB. The principle is shown below:

This system doesn't need any synchronization or nursing and has a dynamic of ~50dB
Horizontal Kick applied values found by Norm & Codd

Kick from Codd vs Norm

Vertical Kick applied values found by Norm & Codd

Kick from Codd vs Norm

rms between Horizontal correction and measured horizontal bump for CODD and Normaliser

DHZ15 & 60 kick mrad

rms between vertical correction and measured vertical bump for CODD and Normaliser

DVT30 & 34 current A

Geneva, Switzerland
January, 2004
### H Dipoles

<table>
<thead>
<tr>
<th>Dipole</th>
<th>Kick set</th>
<th>Kick Applied</th>
<th>P to P mm bump produced</th>
<th>Norm mrad</th>
<th>Codd mrad</th>
<th>residual mm</th>
<th>DHZ15 Norm residual mm</th>
<th>DHZ15 Codd residual mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHZ15</td>
<td>-250</td>
<td>-1.832</td>
<td>67.72</td>
<td>-1.92</td>
<td>-1.82</td>
<td>1.34</td>
<td>1.85</td>
<td>5.24</td>
</tr>
<tr>
<td></td>
<td>-125</td>
<td>-0.916</td>
<td>34.71</td>
<td>-0.98</td>
<td>-0.93</td>
<td>0.67</td>
<td>1.05</td>
<td>2.52</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>0.916</td>
<td>32.86</td>
<td>0.94</td>
<td>0.86</td>
<td>0.72</td>
<td>0.96</td>
<td>3.05</td>
</tr>
<tr>
<td>DHZ15</td>
<td>250</td>
<td>1.832</td>
<td>67.20</td>
<td>1.93</td>
<td>1.93</td>
<td>1.70</td>
<td>1.68</td>
<td>6.70</td>
</tr>
</tbody>
</table>

Calib found/set 1.050 1.010

### V Dipoles

<table>
<thead>
<tr>
<th>Dipole</th>
<th>Kick set</th>
<th>Kick Applied</th>
<th>P to P mm bump produced</th>
<th>Norm mrad</th>
<th>Codd mrad</th>
<th>residual mm</th>
<th>DHZ60 Norm residual mm</th>
<th>DHZ60 Codd residual mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVT30</td>
<td>-8</td>
<td>-0.270</td>
<td>6.51</td>
<td>-0.23</td>
<td>-0.21</td>
<td>0.22</td>
<td>0.26</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>-4</td>
<td>-0.136</td>
<td>3.27</td>
<td>-0.12</td>
<td>-0.11</td>
<td>0.14</td>
<td>0.27</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.136</td>
<td>3.30</td>
<td>0.11</td>
<td>0.12</td>
<td>0.14</td>
<td>0.21</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.272</td>
<td>7.04</td>
<td>0.24</td>
<td>0.22</td>
<td>0.22</td>
<td>0.29</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Calib found/set 0.970 0.890

### Figures

Figure 4
Averaged Codd and Normaliser Horizontal orbits, differences between the 2 Codd turns on EASTB C600

Averaged Codd and Normaliser Vertical orbits, differences between the 2 Codd turns on EASTB C600

Figure 5
Normaliser and CODD reproducibility C175 SFTPRO

STAT on H2-H1 and Ncodd reproducibility over 16 pulses June 170603

<table>
<thead>
<tr>
<th>pu ss</th>
<th>H2-H1 average</th>
<th>Codd H1-H2 rms</th>
<th>Average Norm</th>
<th>rms Norm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>-0.49</td>
<td>1.03</td>
<td>-7.29</td>
<td>0.24</td>
</tr>
<tr>
<td>5</td>
<td>0.28</td>
<td>1.06</td>
<td>-1.75</td>
<td>0.27</td>
</tr>
<tr>
<td>7</td>
<td>-0.11</td>
<td>0.36</td>
<td>-2.54</td>
<td>0.29</td>
</tr>
<tr>
<td>10</td>
<td>0.34</td>
<td>0.83</td>
<td>2.69</td>
<td>0.12</td>
</tr>
<tr>
<td>95</td>
<td>0.47</td>
<td>1.22</td>
<td>4.56</td>
<td>0.17</td>
</tr>
<tr>
<td>97</td>
<td>-0.90</td>
<td>1.53</td>
<td>0.31</td>
<td>0.24</td>
</tr>
<tr>
<td>100</td>
<td>-0.65</td>
<td>1.55</td>
<td>-2.00</td>
<td>0.21</td>
</tr>
<tr>
<td>Rms</td>
<td>0.66</td>
<td>1.10</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>P-P</td>
<td>2.88</td>
<td>2.15</td>
<td>0.37</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6
Vertival bumps calibration tests summary

<table>
<thead>
<tr>
<th>Bumps data</th>
<th>MICADO results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rms mm</td>
</tr>
<tr>
<td>Norm Bmp 50</td>
<td>2.43</td>
</tr>
<tr>
<td>DVT30 +6.46A</td>
<td></td>
</tr>
<tr>
<td>C-Bump 51 V30 +6.7A</td>
<td>2.40</td>
</tr>
<tr>
<td>N-Bump 52 V30 - 6.44A</td>
<td>2.39</td>
</tr>
<tr>
<td>C-Bump 53 V30 - 6.44</td>
<td>2.26</td>
</tr>
<tr>
<td>N-Bump 54 V34 +6.74A</td>
<td>1.82</td>
</tr>
<tr>
<td>C-Bump 55 V34 +6.74A</td>
<td>1.78</td>
</tr>
<tr>
<td>N-Bump 56 V34 - 6.74A</td>
<td>1.81</td>
</tr>
<tr>
<td>C-Bump 57 V34 - 6.74A</td>
<td>1.74</td>
</tr>
</tbody>
</table>

Kick found versus kick installed mrad

\[ y = 0.94x + 0.00 \]
\[ y = 0.90x + 0.00 \]

Bump Symmetry

<table>
<thead>
<tr>
<th>Bump Symmetry</th>
<th>average mm</th>
<th>P-P mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norm Sym. DVT34</td>
<td>0.13</td>
<td>0.56</td>
</tr>
<tr>
<td>Codd Sym. DVT34</td>
<td>0.33</td>
<td>1.35</td>
</tr>
<tr>
<td>Norm Sym. DVT30</td>
<td>0.09</td>
<td>0.34</td>
</tr>
<tr>
<td>Codd Sym. DVT30</td>
<td>0.35</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Figure 8

Geneva, Switzerland
January, 2004
Figure 9

Geneva, Switzerland
January, 2004
Figure 11

Geneva, Switzerland
January, 2004
Normaliser measurements at transition and around with Norm and Codd

V closed orbit evolution during Triplet and Doublet rise C292 to 310 and during their fall C316 to C362

H closed orbit evolution during Triplet and Doublet rise from C292 to 310 and during their fall from C316 to C362

Fast jump in Closed Orbit at transition C310 to C316 seen by Normaliser and CODD

Figure 12
Normaliser CO at C258 with various PU sensitivities and 1E11 protons

Codd CO at C258 with various PU sensitivities and 1E11 protons

Rms differences between Normaliser and CODD readings and between the 2 turns of CODD for different sensitivities

Rms changes in mm of CO readings in respect to sensivity 1E11 for Normaliser and CODD on EASTB, C258 12E10 protons

Figure 13

Geneva, Switzerland
January, 2004
Normaliser data collected at C258 EASTB with 1E11 protons over 17 pulses on PU sensitivity 5E12

Figure 14
**Table SCL1 DELAY train**

<table>
<thead>
<tr>
<th>Table</th>
<th>Pos H</th>
<th>MRP COD</th>
<th>Pos V</th>
<th>MRP C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR.SMPC</td>
<td>0.10</td>
<td>170.00</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

**Table Posit interv**

<table>
<thead>
<tr>
<th>Table</th>
<th>Pos H</th>
<th>MRP mm</th>
<th>Pos V</th>
<th>MRP mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR.ORBIT-1</td>
<td>26</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table CCV AQN**

<table>
<thead>
<tr>
<th>Table</th>
<th>PX.EMEASTRAIN</th>
<th>PX.EMEASTRAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Single bunch of 5E9 H+ for pilot test

Pos H and V in PU 60 with Normaliser around transition on MDLHC

-15
-10
-5
0
5
10
15
Ctiming
MRP mm
Pos H mm
Pos V mm

Pos H and V in PU60 and MRP Normaliser along MDLHC

320 340 360 380 400 420
Ctiming
MRP mm
Pos H mm
Pos V mm

Figure 15
Orbits taken on MDLHC for a Pilot LHC with 1 bunch 5E09 H+ August 4, 2003

Figure 16
H averaged orbit at C175 on SFTION and +/- 1\sigma limits over 10 pulses 1.5
E10 total charges

V averaged orbit at C175 on SFTION and +/- 1\sigma limits over 10 pulses 1.5
E10 total charges

Figure 18
The signal PR.UES93GATE is the signal from the Normaliser of PU 00 with a sensitivity of 10 mV/mm

Geneva, Switzerland
January, 2004
Figure 20