Stefano Redaelli, 08-12-2006

80th Meeting of the LHC Collimation Working Group, December 4th, 2006

Present: Ralph Assmann (chairman), Giulia Bellodi, Chiara Bracco, Francesco Cerutti, Barbara Eva Holzer, Daniel Kramer, Michel Jonker, Jacques Lettry, Roberto Losito, Elias Métral, Manfred Mayer, Valentina Previtali, Stefano Redaelli (scientific secretary), Guillaume Robert-Demolaize, Federico Roncarolo, Benoit Salvant, Mariusz Sapinski, Lucia Sarchiapone, Peter Sievers, George Smirnov, Maciej Sobczak, Ralph Steinhagen, Thomas Weiler.

1 Overview of collimator MD's and beam measurement data (S. Redaelli)

S. Redaelli gave an overview of the 2006 collimator tests with beam. The main goals and the planning of these tests were extensively discussed in recent meetings of the collimation working group and at the APC meeting of October 13th, 2006. Stefano reminded that we had **two 24-hour MD's with circulating beam at the SPS** (MD1 on October 31st and MD2 on November 7th) and **one 16-hour MD with extracted beam at TT40** (November 9th). In addition, tests on the acquisition of the fast beam loss transient were parasitically performed during a 4 hour SPS scraper MD on November 15th. This meeting was focused on the tests with circulating beams at the SPS whereas the other topics will be addressed in future meetings.

Stefano also reminded that the **main goal** of the MD's with circulating beam was to test of the LHC controls. In addition, we wanted to study systematically beam losses, beam-based alignment issue and tail re-population. Impedance-wise, focus has been put on the investigation of the so-called inductive by-pass effect. The main goal of the TT40 test was to assess the robustness of the final collimator design with nominal injection batches. In addition, beam-induced vibration of the collimator jaw were performed. More details can be found in the minutes of the collimation working group meeting of October 2nd, 2006.

S. Redaelli presented the **SPS MD's** starting from the plots of stored beam current as a function of time. In the first SPS MD (Oct. 31st, 2006) we had tests with low intensity beams (1 to 4 nominal LHC bunches of 1.1×10^{11} protons). The beam was used for approximately 10 hours whereas the rest of the time was devoted to the beam setup (OP), to the preparation of the collimator low-levels (AB-ATB) team and to the commissioning of the controls (ABP, CO). Michel Jonker will address the last two items in his talk. In the second MD was devoted to the high intensity beam studies (1 to 4 nominal LHC bunch trains of 72 bunches). The beam availability was of about 11 hours, limited this time by RF problems at the PS that were solved only in the evening. The largest part of the beam time in both MD's was devoted to the collimator beam-based alignment and to the impedance measurements (see talk by Chiara Bracco).

S. Redaelli also showed some **highlights of the TT40 test**. The beam commissioning up to the nominal LHC injection intensity was successfully carried out. Tests were done with 6 bunch trains of 48 bunches instead than with the nominal LHC filling scheme of 4 trains of 72 bunches. The total intensity is the same and we expect no significant effect form the slightly different bunch time structure and length. All the desired measurements (jaw temperature, jaw positions, vibrations and sound due to impacting beams) were successfully performed and are being analyzed in details. There were no apparent signs of major collimator damage nor of system failures. Detailed measurement of the jaw flatness will be performed after January 2007 (before we will not be allowed to take the collimator out due to RP issues) and we will know then if the robustness of the final jaw design has been achieved.

Next S. Redaelli showed highlights of **SPS beam measurements** that were carried out during the tests in addition to the dedicated collimator measurements (dedicated LHC-type

BLM's and monitoring of collimator jaw positions will be addressed in the talks of C. Bracco and T. Weiler):

- Beam losses around the ring: like in 2004, beam losses were recorded all around the ring with the 216 SPS beam loss monitor. This year's measurements were significantly improved because beam loss data were available at 50 Hz instead that once per SPS cycle, i.e. every 20-30 seconds. This data will be used for more detailed benchmarking of the LHC collimation tracking tools (see for example the minutes of the APC meeting of February 16, 2006).

- Beam profile measurements: wire scanners were systematically used to monitor the beam emittance for each new coast beam and before critical beam manipulations such as full beam scraping witht the collimator jaw. The wire measurements are in good agreement with the beam size values inferred during from full beam scraping (see talk by T. Weiler).

- Slow beam current measurements: Beam current measurements were performed continuously during both MD's at an acquisition frequency of 100 Hz. These data will be used for detailed calculations of beam lifetime, beam size and position during beam scraping and to monitor the intensity cuts from collimator movements.

- Fast (bunch-by-bunch) current measurements: In addition to the slow beam current measurements, also bunch-by-bunch measurements were performed. This is not normally relevant for collimation issues because the beam scraping occurs in the transverse plane and is not coupled with the fine train time structure. However, Stefano pointed out that during the impedance measurements we could see interesting head-tail effects possibly triggered by the collimator impedance: for some combination of chromaticity and collimator settings, only the tails of the bunch trains were lost. These results are being investigated by E. Métral and B. Salvant.

In addition, also bunch length measurements were recorded by Thomas Bohl for various collimator settings. Thomas will report his results at a future meeting.

In conclusion, **the 2006 collimator tests were very successful**. While S. Redaelli left to the following speakers the detailed conclusions on the performance versus the various MD goals, he commented that in terms of availability of beam measurements this year we have significantly advanced what we achieved in 2004. We had a constant monitoring of the main beam parameters throughout the various beam tests and an improved monitoring of critical observables such as the losses around the ring and the beam current. This will allow us to understand in more detail what is relevant for the LHC performance.

2 Performance of collimator controls (M. Jonker)

Michel Jonker discussed the **performance of the collimator controls** during the SPS MD's with circulating beams. Michel reminded that collimator controls issues will be discussed in detail at an upcoming **review** that will take place on **December 18th**. The main goal of this review is to approve the architecture of the collimator low-level controls. In this respect, the SPS tests have represented an important milestone because we have tested for the first time the PXI architecture. This is not a standard solution at CERN and therefore it was important to validate this architecture before the final approval. In addition, also the communication between, and the performance of the various levels have been investigated (see also the goals for the controls tests as specified in the 76th meeting of the collimation working group of October 2nd, 2006).

Michel Jonker acknowledged that the tests with beams have been a **good success**. The performance of the control system was satisfactory and fulfilled all the requirements for the MD's. The basic choices for the LHC proved to work as required. Michel took the opportunity to thank all the people involved for the good work. Nevertheless, Michel also pointed out the **various problems** that were encountered and commented on their impact and on how to tackle them. As far as the **hardware** is concerned, we had problems of (1) motor-induce noise on the switch cables. This was a serious problem that had to be fixed during the MD time, which required a few hours; (2) poor resolution of the potentiometers used for the jaw position measurements and bad performance of the LVDT's for the gap measurements; (3) One temperature sensor sensitive to RF noise; (4) mechanical plays. Michel pointed out that **none of these problems is expected to be an issue for the LHC** because they were all related to specific hardware choices implemented in the SPS collimator prototype, which have been changed for the LHC series production.

In addition, we also encountered **structural problems** like (1) system hanging due to too many phantom TCP/IP connection from the low-level; (2) crashed of CORBA and CMW directory servers and (3) hanging of the control application. The latter was occasionally preventing the collimator control. These issues are under investigation.

Michel pointed out that we also had some **performance problems**, such as (1) motors loosing steps without being recognized by the operators; (2) time stamping of low-level data out of step (delays of up to 1 s within the same data structure); (3) poor performance of the position sensors and problems with the temperature measurements.

Michel Jonker concluded with the proposal that a **permanent controls test bed** should be made available for performance tests of the collimator control system. Both a dedicated collimator setup in building 525 as well as collimators already installed in the tunnel (ring or transfer lines) could be used. The beam time has proven to be very valuable because the schedule MD imposed a hard deadline but for future controls test we should rather rely on a permanent test bench.

Thjis Wijnands asked what make us confident that at the LHC the noise from the motor cables will be under better control that was has been found at the SPS. If one wants to prepare filters also for the LHC, one should better make them adjustable in order to be prepared in case of unexpected noise sources. Michel Jonker replied that what we had at the SPS was a problem related to the specific hardware, which has been understood and it is known that it will not occur at the LHC. Roberto Losito also commented that electromagnetic noise in the tunnel is a well know problem for many LHC system and one cannot anticipate all the possible sources.

3 Timing issues (M. Sobczak)

Maciej Sobczak presented some statistics of the time required to perform collimator movements. This statistics is based on some 3000 settings requests performed throughout the MD's. The requested step sizes range from 5 μm (motor step size) to more than 30 mm (jaw full stoke). Maciej found that the minimum required time for steps below 20 μm is always longer than about **15 milliseconds**. In fact, the execution time can even reach 80 ms. Maciej refers to the time delay between a movement request send to the low-level and the time when the notification of "executed motion" arrives back to the middle-lavel. For larger required step values the execution time increases. For steps sizes above some hundreds of micrometres the execution time is given by the step size divided by the jaw velocity, as expected.

Maciej commented that, if this preliminary results were confirmed also for the final LHC hardware, this could compromise the performance of the automatic beam based alignment. Michel Jonker commented that strictly speaking one will not need the notification from the motor hardware for confirming that the motion has occurred but one would rather rely on

the response of dedicated beam loss monitoring. These issues will be followed up in the COCOST working group.

Triggered by a question from Peter Sievers, Roberto Losito pointed out that the time estimates provided by Maciej refer to the notification of "completed motions" up to the FESA level. The low-level has a faster response but estimated of the measured performance are not yet available.

4 Precision of collimator positioning and gap values (S. Redaelli)

S. Redaelli discussed the accuracy of the measurement of collimator positioning and gap values during the SPS tests. Stefano pointed out that the results that he was going to present could not be easily extended to the LHC case because the SPS collimator prototype differs significantly from the LHC series production: motors, resolvers and jaw position sensors are not the same that will be mounted on the LHC collimators. Nevertheless, we should understand the accuracy of the gap measurements because the physics outcome of the MD depends on the gap values.

S. Redaelli briefly reviewed the **hardware of the 2004 collimator prototype** and suggested look for more details at the collimation working group meeting of September 20th, 2004, when the results of the metrology measurements were extensively discussed. He commented that since then nothing has been changed nor metrology measurements have been re-done. Therefore, the positioning accuracy for the 2006 tests can only rely on the reproducibility of the mechanics positions that were taken as a reference in 2004. Notably, the position of the four full-out switches has to be used because this is the only reference that was measured at metrology that can be operationally accessed with the jaws (also the mechanical stops behind the switches were measured but they cannot be reached without by-passing the switches and compromising the collimator safety).

In order to assess whether the mechanics is still as good as in 2004, S. Redaelli extracted from the available data a measure of the **full stroke** between full-out and full-in switches, for all the 4 jaw corners (left-upstream, left-downstream, right-upstream and right-downstream). Only the data of the first MD could be considered for the moment. According to the count of motor steps, the full stroke measure is reproducible to the **20 micrometer level** and is consistent with what is expected from the 2004 metrology data. This is a good result that suggest that the absolute jaw position did not move significantly. The values of jaw full stroke measured with the resolvers differ from the motor estimates by up to 100 μm whereas the potentiometer measurements are out by up to several millimetres, which suggest that the direct jaw position measurements are not usable.

Therefore, S. Redaelli proposed to use as an **absolute position reference** the **position of the full-out switches** and to infer the jaw position (and hence the collimator gap) from the **count of motor steps from the switches**. The accuracy of this method relies on the assumption that the switch position did not change significantly from the 2004 values. This assumption is supported by the good reproducibility of the jaw full stroke measurements but cannot be given for granted. The only way out would be to take the collimator out of the tunnel and repeat the metrology measurements. S. Redaelli believes that one could rely on the proposed method to within 100 μm and asked that the collimation working group expresses recommendation on whether or not a new calibration campaign should be done.

S. Redaelli also presented performance limitations that were encountered. The resolver measurements present offsets up to 200 μm with respect to the motor step count. In addition, it seems that there are **delays up to at least 1 second** between the measured data that arrive to the FESA level with the same timestamp. The corresponding difference of measured jaw position can be larger than 1 mm. The source of this problem has to be understood.

Another problem was that the motor controller progressively lost the knowledge of the full-out switch position as the time went on. Errors at the end of the first MD reach the

level of more than 300 μm for some jaw corners. S. Redaelli believes that this is due to lost steps which are not recognized by the system. Mechanical plays should be compensated after full loops of the mechanics and should not add up to a average value different than zero. In addition, they were smaller than 50 μm according to the 2004 metrology data (R. Assmann).

S. Redaelli also commented on the value of the collimator gap when the anti-collision switches are activated. He finds a value of about 900 μm, which is consistent with what we had in 2004. This is another element that suggests that the proposed calibration of the jaw positioning is reliable.

S. Redaelli **concluded** by stating the for this year's tests we had to live with an hybrid situation where the old hardware was used with the new collimator controls architecture. In several cases (motors, position sensors, gap sensors, noise from motor cables, ...) this limited the possibility of extrapolating reliably conclusions for the LHC and therefore **jeopardized a real demonstration of the validity of the control architecture**. If one relied on the reproducibility of the full-out switch positions, one could achieve an accuracy of jaw position measurements of about 100 μm. In order to verify this value and possibly improve it, one should take out the collimator and calibrate it again. Whether this is necessary or not should be agreed within the collimation working group. However, S. Redaelli commented that for the 2007 beam tests it will certainly be necessary to improve the position measurements of the collimator jaws otherwise the outcome of the test will be inconclusive for the LHC.

4.1 Discussion

Roberto Losito commented that we should not spend too much time on understanding the issues specific to the SPS hardware because the nothing can be extrapolated from these measurements to the LHC performance. S. Redaelli agreed that in most of the cases the results of the SPS test are not at all conclusive for the LHC case due to the difference of the hardware setup. However, he stressed that it is important to get the best estimate of the absolute collimator positioning (distance from the beam and gap values) because the physics outcome of the MD strongly depends on these parameters. Michel Jonker agrees and stated that is it important to understand the system as it is available now. R. Assmann also added that in addition it would be important to understand if there are significant deterioration of the mechanical performance and accuracy that we had in 2004. If the effect of several hundred microns comes from changes of the mechanics occurred in the last two years, we should understand this as soon as possible.

Jacques Lettry expressed concerns about the fact that one can rely on the absolute positions of the switches as it was measured in 2004. The error on the switch position measured by the motors (which was assumed to be induced by lost steps), could very well be real. S. Redaelli agrees but stressed that the switch position is the only absolute measure that we have. If the switch position moved significantly during the MD, one would not always find the same value for the jaw full stroke measure nor the same value for the gap on the anti-collision switches.

Roberto Losito stated that the delay between the position measurements could be induced by the fact that we use old sensors. This effect is not expected for the LHC harware. S. Redaelli replied that Alessandro Masi stated that at the low-level all the acquisitions were synchronized at least to the 100 Hz level and therefore the delays must be introduced from the levels above. This could then have a relevance for the LHC and therefore this issue definitely deserves further investigations: Maciej Sobczak and S. Redaelli could not see how the could introduce such delays at their levels.

Michel Jonker commented that the one second delay can be easily explained if there was a pile up in the communication between the PXI and the low level FESA system where the time stamping is done. This has to be analyzed in more detail and if needed a timestamping in the PXI system, which will be more reliable, has to be implemented.

5 First results of the 2006 collimator impedance measurements (E. Métral)

On behalf of the impedance team, Elias Métral presented the preliminary results of the collimator impedance measurements at the SPS. This year two types of measurements were performed: (1) tune shift versus collimator gap with low-intensity single bunches (which provides the imaginary part of the collimator impedance) and (2) rise time of instability versus collimator gap (which provide the impedance real part). El.ias pointed out the the measurements relied on the BBQ system, already tested in 2004, which can basically provide continuous tune measurements (data provided by Ralph Steinhagen).

The tune shift measurements are in preliminary agreement with the findings of 2004. The bunch length differs from the 2004 values and this is not yet taken into account in the data analysis. This effect could explain the observed differences. Elias mentioned that the vertical tune shift is not affected by the changes of the horizontal collimator gap, as expected by theory. The estimated vertical impedance is consistent with the one of the SPS which is a good cross-check for the tune measurements.

Elias pointed out these good results for the tune shift measurements are nice however it is known that they do not provide information on the by-pass effect. This effect is difficult to measure even with instability rise-time measurements because according to theory the effect on the SPS is barely distinguishable from the overall SPS impedance. It is even more difficult to discriminate between inductive by-pass and classical resistive thick-wall theory. For example, the two theories predict a difference of growth rate smaller than 30% for collimator gaps of 3 mm.

Nevertheless, Elias pointed out than several measurements were carried out in different experimental conditions in order to find differences of instability growth rates as a function for chromaticity and collimator gap values. He showed various examples that prove that indeed different growth rates have been measured for different collimator gap values. The experimental data are being studies in detail and more updates will be provided later on. For the moment, it has been confirmed that with small collimator gaps the rise-time of instability is reduced, as predicted in theory.

By injecting the beam with collimator close and positive chromaticity, evidence has been found of a stabilizing effect of the collimator: the beam become instable after that the collimator gap was increased. Frank Zimmermann proposed a theory that could explain this effect.

In conclusion, the preliminary analysis of the impedance measurements suggests that the tune shifts versus collimator gaps are in agreements with the results of 2004. As for the instability rise-time, the collimator effect seems to be fairly small, as predicted by theory. The sign of the collimator effect is consistent with the predictions. Even if more detailed studies are ongoing, it seems that it will be difficult, based on these measurements only, to distinguish between the inductive by-pass and the resistive thick-wall theories.

The next meeting will be Dec. 11th, 2006.