LHC INJECTORS UPGRADE

Roland Garoby, Malika Meddahi, CERN, Geneva, Switzerland

Abstract

The performance of the LHC critically depends upon the characteristics of the beam provided by the injectors. Session 9 was devoted to the analysis of the status of the injectors and of the possibilities to upgrade their performance for satisfying the needs of the High Luminosity LHC.

PERFORMANCE REACH OF THE INJECTORS IN 2011

(Rende Steerenberg, BE-OP)

Summary

The results obtained in 2010 are a perfect illustration of the importance of the availability of beams with characteristics which exceed the initially planned needs and can flexibly be changed. After early tests with single bunches, trains with nominal bunch intensity and progressively decreasing bunch spacing (150, 75 and 50 ns) were successively used. The nominal beam (1.15 10^{11} p/b, 3.5 μrad, 25 ns spacing) was readily available, but it was not requested by the collider.

A very satisfying observation is the smaller than budgeted transverse emittance blow-up between the exit of the PSB and the LHC at high energy, leading to smaller than expected transverse emittances in collision (typically 2.5 μrad instead of 3.75) and higher luminosity.

Brighter and more intense bunches were prepared in the PSB and PS for studying the SPS behavior during MDs. Up to 1.5 10^{11} p/b were successfully accelerated up to 450 GeV with 50 ns spacing and nominal emittances. With 25 ns spacing, however, bunches blew up transversely by a large factor, probably because of electron-clouds related effects in the SPS.

A higher Linac2 beam current and double batch injection in the PS will be used in 2011 to try and generate low emittance bunches with 75 and 50 ns spacings.

Discussion

R. Steerenberg: the work required to set-up the 150 ns beam competes with the optimisation of 75 and 50 ns beams. Is the 150 ns beam still necessary in 2011?

R. Assmann: Oliver Brüning has assumed 1.7 10^{11} p/b and 2 μrad with 50 ns spacing in his presentation. Is it feasible? R. Steerenberg: this is anticipated with double batch, but it remains to be confirmed in MD.

G. Arduini: which intensity can be reached with 150 ns bunch spacing? R. Steerenberg: no number can be given yet: to be tested!

M. Ferro Luzzi: why is 75ns bunch spacing less attractive in terms of intensity and emittance than 50 ns? R. Steerenberg: because of longitudinal instability in the PS resulting from reduced Landau damping (h=14 instead of h=21 during acceleration).

S. Myers: are RF tubes in Linac2 the main limiting factor to performance? M. Vretenar: limitations come from the ion source, not from the RF tubes.

W. Höfle (answering to the request of R. Steerenberg to apply transverse blow-up only in the SPS): The transverse blow up is not ppm in the SPS, but a clear procedure exists for the operators to apply.

M. Lamont: what are the CO plans for increasing the number of users? E. Hatzangeli: there is a technical limitation on the hardware. This is being addressed.

R. Steerenberg: There are currently a maximum of 24 possible users -the limit coming from the present electronics in the Front Ends. Up to now, a user was associated to each LHC beam type, leading to these numerous users. It is proposed (and actually will be implemented for 2011) to have 5 types of LHC general users (PROBE, INDIV, Setting-up, Production, MD) and to each of them attach the current requested user which is taken directly from the archive user library. So we will not have anymore a dedicated user to each beam type. Sometime will be requested to prepare the beam in the injectors, but with adequate pre-warning to the injectors, this will be done and ready when LHC will request this beam type. For the MD, again various beam types will have to be set-up and time needed to provide the requested beam.

P. Collier: cycles will also be available in the supercycle at the beginning of the LHC restart, as not all FT users will have to be served. R. Steerenberg: yes, this is an option which will be used for the MD requests, and this option is especially interesting with the new user implementation being performed for 2011.

POSSIBILITY OF A HIGHER PSB TO PS TRANSFER ENERGY

(Klaus Hanke, BE-OP)

Summary

The Task Force in charge of analysing the possibility to increase the transfer energy from PSB to PS has come up with a baseline scenario and drawn the following conclusions [1]:

- the upgrade from 1.4 to 2 GeV of PSB, transfer line and PS injection are technically feasible,
- the foreseeable increase of beam brightness in the PS is of the order of 65 %,
- the total cost (material budget), including consolidation, adds up to approximately 54 MCHF,

the main cost driver being the power supply for the dipole magnets,

- the modifications should rather be implemented simultaneously with the connection of Linac4, during a long shutdown in 2016.

A number of subjects deserve further investigation before a detailed project proposal can be submitted [1, 2].

Discussion

K. Hanke: although declared feasible, the 2 GeV injection equipment for the PS is still in work.

S. Myers: why is the PSB upgrade so expensive? K. Hanke: because the PSB has 4 rings with the same total beam pipe length than the PS, combined with complexity due to compactness.

S. Baird: are you planning for significant work during the first and second long shutdowns? K. Hanke: YES!

L. Rossi: there is clearly competition for resources! This will impact on the work that can be accomplished during the Long Shutdowns and on the overall planning of the PSB upgrade. R. Garoby: this is a goal of the LIU project to clarify these issues and propose a coherent approach for all injectors, in close collaboration with the Consolidation project.

A. Siemko: No upgrade of magnets and beam interlock systems were mentioned, are they not needed? B. Mikulec: They are indeed already included within work packages of the Linac4 project.

PS POTENTIAL PERFORMANCE WITH A HIGHER INJECTION ENERGY

(Simone Gilardoni, BE-ABP)

Summary

The expected performance increase of the PS remains to be demonstrated with beam. Transverse emittances may blow-up because of multiple mechanisms beyond space charge (dilution due to imperfect injection, head-tail instability, TMCI, e-clouds effect…). The same is true in the longitudinal phase plane, where coupled bunch instabilities and transient beam loading in the RF cavities must be mastered.

Taking into account the observed preservation of transverse emittances through the cascade of injectors, the following guesses can be made when the PSB will operate with Linac4 and inject into the PS at 2 GeV:

- with 25 and 50 ns spacing, between 1.9 10^{11} (realistic) and 3 10^{11} p/b (stretched) could be obtained within 2.5 μrad,
- the minimum emittance achievable at ultimate intensity with 25 ns spacing may be as low as 1.8 μrad,
- even smaller emittances can potentially be expected with up to 3 10^{11} p/b with 50 ns spacing.

For that purpose, numerous equipments must be upgraded or built (for injection, beam loading compensation, instability damping with feedbacks...). Consolidation shall not be forgotten as well as additional radio protection measures (e.g. shielding above road Goward).

Discussion

S. Gilardoni: a bunch intensity of 3.5 10^{11} p/b (as assumed by O. Brüning in his presentation) is not achievable due to longitudinal considerations. The optimistic goal after machine upgrades is of the order of 3 10^{11} p/b to SPS. Moreover, it is important to know the tolerance of LHC to imperfections in the longitudinal beam parameters (equality between bunches, ghost bunches...). A long list of MDs is being prepared and it is questioned if all of them can realistically be scheduled.

R. Garoby: the extensive need for magnets consolidation has to be added to this upgrade programme. Concerning cost, only the injection system equipment has been accounted for in the Task Force estimate, and not the other hardware required for upgrading the PS.

V. Mertens: is it possible to increase the PS transfer energy to the SPS? S. Gilardoni: the question is being studied for the 14 GeV Fixed Target beam (non-LHC). This is not possible for the LHC beam, due to transfer equipment limitation.

S. Myers: the cost of actions which are not for LHC has to be declared and approved separately from the LHC upgrade. Moreover, the PS could in the past extract at 26.6 GeV: what are the current limitations? R. Garoby: this needs to be revisited.

F. Zimmermann: What is missing for going beyond 3 10^{11} p/b? S. Gilardoni: longitudinal instabilities and transient beam loading in the RF cavities limit the intensity to about 2.8 10^{11} p/b! Don't forget that the PS would probably have to provide more than 4 10^{11} p/b for getting 3.7 10^{11} p/b in LHC.

E. Shaposhnikova: experimental evidence has shown that increasing the RF voltage in the PS does not necessarily reduce the losses in the SPS.

LESSONS FROM SPS STUDIES IN 2010

(Elena Shaposhnikova, BE-RF)

Summary

MDs in 2010 were focused on improving the understanding of SPS limitations in the transverse and longitudinal phase planes and on studying/experimenting possible solutions. This was helped by the lower energy accelerators which provided beams of unprecedented intensity and brightness.

The nominal beam (1.15 10^{11} p/b, 3.5 μrad, 25 ns spacing) is readily available and suffers from less losses than in the past. From an injected beam in three batches of 1.9 10 ^{11} p/b within 5 μrad with 25 ns bunch spacing, 1.5 10^{11} p/b was accelerated up to 450 GeV where an emittance of 10 μrad was measured. With 50 ns bunch spacing, a similar intensity could be accelerated which stayed within the nominal emittances of ~3.5 μrad.

Promising results were obtained with a reduced γ_T lattice which increases the threshold of instabilities.

It seems nowadays reasonable to estimate that the SPS could provide bunches of ultimate intensity within nominal emittances for 75 and possibly 50 ns bunch spacings (provided that a higher intensity is injected within smaller emittances). After upgrade (200 MHz RF, e-cloud counter-measures, upgraded transverse feedback...), ultimate intensity bunches of nominal emittances can probably be obtained with 50 and 25 ns bunch spacings.

Using a reduced γ_T lattice appears as a potential option for reaching even better performance.

Discussion

J. Jowett: the low γ_T optics seems indeed to be very promising for protons, but what would be the impact on heavy ions? E. Shaposhnikova: the plan is to switch between the optics from cycle to cycle and to use the normal lattice for ions.

V. Mertens: is kicker heating still an issue, because it is excessive only during persistent running, e.g. during MDs, but not during LHC injection which is a quicker process. E. Shaposhnikova: the SPS must be ready for a long injection process, such as sometime experienced in 2010.

ELECTRONS CLOUDS IN THE SPS: PROGRESS IN THE ANALYSIS OF CURES/MITIGATION MEASURES AND POTENTIAL SCHEDULE OF IMPLEMENTATION

(Jose Miguel Jimenez, TE-VSC)

Summary

The demonstration has repeatedly been made that beam with 25 ns bunch spacing in the SPS suffers from electron clouds induced instabilities. This is comforted by simulations. Threshold with nominal emittance is nowadays slightly above nominal intensity. Among the possible counter-measures (suppression, mitigation or cure), low SEY amorphous Carbon (a-C) coating has been intensively studied since a few years. Before taking a decision, the advantages/drawbacks of other possibilities like clearing electrodes, feedback and scrubbing must be evaluated. In any case, prototype(s) of the preferred solution(s) shall be installed during the first long LHC shutdown (~2013) to be tested with beam during the following run. The full-blown solution shall be implemented during the second long LHC shutdown (~2017)

Discussion

V. Mertens: much effort has already been put in scrubbing and coating. Shouldn't we try to preserve the sectors which have been scrubbed in order to keep what has been achieved? J. M. Jimenez: indeed, we are trying to reduce as much as possible the number of sectors which are vented during shutdown. In the coated zones, we observed in any case that the machine re-start situation is only a little worse after venting.

S. Fartoukh: Why should 1 mm aperture reduction introduced by the clearing electrodes be a problem in the SPS? Paul Collier: this is due to the non-LHC beams which have much larger physical emittances.

E. Métral: why not use another bunch spacing to perform scrubbing? Jose Miguel Jimenez: this is certainly a possibility, depending upon other limitations. To be studied.

L. Rossi: If magnets are moved for coating purposes, we should profit to renovate them.

E. Shaposhnikova: clearing electrodes will increase the imaginary part of the impedance. Carbon coating is definitely better in that respect. With the feedback, coherent effects can be damped but incoherent effects will remain and lead to emittance growth.

S. Baird: moving all SPS magnets to coat vacuum chambers is envisaged during the first and second long shutdowns. Can it be done at the rate of 3 magnets/day? Jeremie Bauche: yes, provided that adequate support is available for transport.

R. Garoby: how can we get enough confidence in coating (e.g. because of ageing)? Jose Miguel Jimenez: tests can be made on samples in the laboratory with electron bombardment, and in HiRadMat with proton beam.

To the question "can magnetic measurements be performed on a coated magnet, without damaging the coating?", Jeremie Bauche replied: yes, a solution exists which avoids using a tool insertion in the magnets to perform measurements.

ALTERNATIVE / COMPLEMENTARY POSSIBILITIES

(Christian Carli, BE-ABP)

Summary

For the generation of the LHC beam in the PS, either 3 out of 4 or 6 out of 8 PSB rings are used and not all the protons available from the PSB are exploited. New scenarios are being proposed which make use of all the intensity that the PSB can deliver. However, because of size and harmonic number constraints, the ratio between the harmonic numbers at ejection wrt injection cannot be an integer, and batch compression is necessary. A direct consequence is that the number of bunches per PS cycle is lower than usual (72). In the first proposed scenario, 8 bunches are injected from the PSB and transformed into 64 bunches spaced by 25 ns before ejection to the SPS. With respect to the usual scenario, brightness and bunch intensity can in principle be increased by a factor 1.5. In the second scenario, the 8 PSB bunches are transformed into 48 bunches spaced by 25 ns before ejection to the SPS and the bunch intensity and brightness can potentially be two times larger than usual.

These scenarios are not expensive to implement in terms of material budget, but they need MD time and they add significant complexity to the already sophisticated PS beam control.

Considering the high cost of upgrading and consolidating the PSB (~60 MCHF), its replacement by a Rapid Cycling Synchrotron (~10 Hz) is another interesting alternative. Adding the requirements that (i) the energy range has to be 160 MeV – 2 GeV, (ii) beam characteristics have to be competitive with the PSB at 2 GeV and (iii) the PS operation has to be simplified, the most interesting size is 1/7 of the PS and the RF system should be able to operate on harmonic 2 or 3. To generate 25 and 50 ns bunch trains (72 or 36 bunches), the PS would be filled in 6 pulses of 3 bunches, giving 18 bunches on h=21 and suppressing the need for triple splitting. To generate 150 and 75 ns bunch trains (12 or 24 bunches), the PS would be filled in 6 pulses of 2 bunches, giving 12 bunches on h=14 and suppressing the need for double splitting at low energy.

Discussion

A great advantage of the RCS is that it could be built independently of the LHC operation in the centre of the PS ring, without much impact on existing buildings. In addition, beam commissioning could take place without interfering with LHC operation.

Y. Papaphilippou: collimators might be required in the RCS which will be hard to fit within the tiny straight sections.

L. Rossi: what would be the cost of such a machine? R. Garoby: no detailed study has yet been done. The RCS circumference being ~equal to the length of Linac4, it should not exceed the cost of Linac4 (100 MCHF).

S. Myers: the cost of the upgrade of the PSB makes it a very expensive machine. It should be understood why an RCS was not built instead. R. Garoby: this question has to be addressed during the pre-study of the RCS. For this work to take place, the proposal is to liberate resources from the PSB upgrade by "freezing" the work on the energy upgrade until the summer of 2011, when the first conclusions will be submitted to the management.

E. Métral: 48 bunches/ PS batch sounds very interesting.

M. Vretenar: operation at 10 Hz for the RCS has implications on Linac4. Some may be costly (e.g. klystron modulators) and deserve analysis.

MAIN MESSAGES

The specification of the beam required at LHC injection is essential for guiding the choices in the injectors. It should result from close interactions between the HL-LHC and LIU projects.

Testing a batch compression scheme in the PS can immediately bring important information for the generation of beyond ultimate 25 ns bunch trains. If successful, it will provide the possibility to explore the SPS potential without waiting for Linac4, PSB and PS upgrades.

Increasing the energy of the PSB is the primary solution for substantially upgrading the brightness that the PS can deliver.

However, a small size RCS replacing the PSB is an especially interesting alternative option.

The SPS remains the limiting accelerator in the injector chain. The well-identified improvements shall be implemented as soon as possible to allow studying the other limitations.

The possibility to connect Linac4 to the PSB during the first long shutdown is worth investigating.

Final remark: most of the subjects treated in this session have been addressed in more detail during the "LIU day" workshop [2] web page.

REFERENCES

[1] K. Hanke (editor), "PS Booster Energy Upgrade Feasibility Study, First Report", EDMS no. 1082646 v.3

[2] R. Garoby, S. Gilardoni, B. Goddard, K. Hanke, M. Meddahi, M. Vretenar, "Outcome of the LIU day", EDMS no. 1109677.