LHC Injectors Upgrade

Report on the Review of the LIU-SPS High Bandwidth Transverse Damper System

CERN - July 30th 2013

This is the final report of the review committee for the LIU-SPS High Bandwidth Transverse Damper System held at CERN on July 30th, 2013.

The review committee members were:

- Gianluigi Arduini, CERN
- Mike Brennan, BNL
- Fritz Caspers, CERN
- Rhodri Jones, CERN (Chair)
- Dmitry Teytelman, DIMTEL Inc.

The report includes an executive summary followed by comments and recommendations particular to each question posed in the charge.

Charge

The charge given to the reviewers was to answer the following questions, giving recommendations wherever relevant:

1. Are the beam and system specifications clearly defined? If not what studies are still needed?
2. Is the system concept feasible for the required applications?
3. Can the choice of kicker technology for the final system be made now? If not, what information is still needed?
4. Is the additional impedance of the system known and acceptable for the SPS?
5. Is the planned development, construction and installation schedule correct (i.e. complete with all activities and with realistic deadlines conforming to CERN's needs and fitting with collaborator constraints)?
6. Is the project structure clearly defined, including list of deliverables and responsibilities for deliverables and studies?
7. Are the responsibilities correctly assigned, or should some be re-discussed?
8. Are there deliverables or studies which need advancing in time, for example before the LARP construction decision?

Executive Summary

The committee received presentations outlining the motivations for a high bandwidth transverse damper system, summarising simulations showing its possible performance, introducing the key technology choices being considered for the digital signal processing, pick-up and kicker, as well as talks on the planning and budgetary consideration for the project. We found all of these to be informative and well prepared.

This review only considered such a system for implementation in the SPS. Any future LHC system would need to be re-evaluated for power, bandwidth and impedance, in particular if operation at energies higher than 450 GeV is envisaged. Nevertheless the experience gained in the SPS will be extremely valuable if an implementation in the LHC is to be considered at a later stage.

It became clear during the course of the presentations that with the Q20 optics in the SPS raising the single bunch intensity limit for the Transverse Mode Coupling Instability (TMCI) to well above 4×10^{11}, the high bandwidth transverse damper system is currently only foreseen for the damping of vertical electron cloud instabilities. It is at present unclear whether intra-bunch horizontal instabilities also need to be considered and therefore the system chosen should be adaptable enough to work in both planes.

Implementing a system capable of combatting electron cloud instabilities could significantly increase the scrubbing efficiency in the SPS. In addition it would ensure that the quality of beams destined for the LHC can be preserved from injection to 450GeV, possibly also allowing the preparation of doublet bunches for scrubbing the LHC. In view of this, the reviewers recommend that the second phase of this project, the construction and test of a multi-bunch high bandwidth transverse damper demonstrator, proceeds as quickly as possible, to allow a final decision on whether or not to build a fully functional system to be taken at the end of 2016.

Findings, Comments and Recommendations by Charge Question

Question 1: Are the beam and system specifications clearly defined? If not what studies are still needed?

The beam specifications were found to be well defined with the high bandwidth only required for LHC beams using Q20 optics. The existing damper was shown to be sufficient for stable fixed target operation with no strong case presented for high bandwidth operation with 200MHz beams.

In addition to the standard single bunch, 25ns and 50ns LHC production beams there was a clear request to operate with the new 25ns doublet scrubbing beams where the standard 25ns LHC bunches are all split into doublets spaced by 5ns.

The only demonstrated case for which such a system is currently required is for damping the intra-bunch vertical electron cloud instability at injection energy, with the beam data presented dating from 2003 and indicated an instability at around 700MHz.

Additional simulations and/or experimental evidence should be provided to assess the need for a wide-band transverse damping system at energies above the injection energy of 26 GeV/c, considering both the vertical and horizontal planes. Since only a vertical wide-band damping system is currently planned for the SPS, it is important to consider its effect in the horizontal plane given the expected plane-to-plane isolation in the front and back ends, as well as the FIR controller gain and phase near the horizontal tune.

The simulation tools used are well advanced and provide realistic models of the high bandwidth transverse feedback and its action on single bunches in the presence of impedance and electron cloud. Most of the simulations carried out so far have been performed with the Q26 optics at injection showing that both vertical TMCI and Electron Cloud Instabilities can be efficiently damped with a system having a bandwidth of 500 MHz. The simulations shown also concluded that using the current controller architecture such a system would not work for damping either ECI or TMCI with the Q20 optics.

No clear statement was made on the two main specifications required for the final design of the system, namely the bandwidth and maximum kick strength required. The maximum kick strength has been determined by considerations related to the expected “resolution” of the pick-up system when compared to the maximum deflection possible at 450GeV, although no full analysis of the noise expected from the position detection system has yet been carried out. In defining the kicker requirements a bandwidth of up to 1GHz has been considered, although simulations show that the frequency of the instabilities could be higher when operating at 450 GeV/c.

To address all these issues there is a need for more realistic simulations with the following priority:

- Use open loop simulations to look at the frequency of the modes and compare them to available beam data. For example can the 700MHz line identified by ECI beam studies be reproduced?
- Look at how the energy change from 26GeV to 450GeV affects the frequency of these instabilities and consequently the bandwidth requirements of the transverse damper system.
- Use an ideal kicker to understand if the available phase margins allow the system to be used with a single pick-up.
- Add realistic chromaticity values when considering the full closed loop system.
- Adapt the feedback algorithm to verify that stability can be achieved with Q20 optics.
- Ensure that the observed performance of the 2012 single bunch demonstrator (SLAC) is fully understood and reproduced with simulations.

Question 2: Is the system concept feasible for the required applications?

The proposed system is only considered for the damping of vertical e-cloud instabilities in the SPS up to 1GHz. If simulations prove that this is sufficient then all the building blocks are available to put such a system into operation.

The signal processing chain proposed leaves room for higher bandwidth operation, however this may not be optimal if the instabilities to be damped are at lower frequencies and the position resolution determines required kick strength. In this case a lower bandwidth system with higher resolution ADCs might be a better choice. Partitioning the digital signal processor in a way that provides flexibility in the ADC resolution and sampling rate is therefore advisable.

The available phase margins also need to be fully understood to ensure that higher order modes are successfully suppressed rather than excited. If phase margins attainable in the proposed single pick-up topology prove to be insufficient a backup option of generating the necessary betatron phase shift via a vector sum of two pick-ups must be considered. Since the choice of processing topology dramatically influences many design decisions it must be made as early as possible. To that end, both simulations and experimental studies in the SPS with Q20 optics are needed. Flexible dual-ADC architectures, mentioned in the presentations, can simplify transition between single and dual pick-up topologies and should be pursued.

Stripline pick-ups (long with time domain gating or exponential) were presented as the preferred candidates for wideband operation. Both have their drawbacks, with the exponential stripline suffering from phase variations over the frequency range of interest, while for the conventional stripline it may be difficult to achieve the required impedance match over the long length required to fully resolve the 5ns doublet bunches. However, with a correct design both look capable of providing the required signals. A short slotted-coaxial structure could be considered as an alternative, as its phase response would be expected to be considerably more linear. In all cases a full noise analysis needs to be carried out to determine the limit on the pick-up resolution, distinguishing the contributions from thermal noise, ADC quantisation and EMC. The expected common mode suppression is also a key parameter to determine the final resolution of the system and needs to be carefully evaluated.

A combination of hardware and software amplitude and phase equalisers should be studied to give a reasonable and robust compensation over the entire operational bandwidth.

Any electronics intended to be installed in the tunnel should be qualified, with some safety margin, for the radiation exposure levels expected in those regions taking into account the higher beam intensities foreseen in the future. The benefits, in terms of maintenance and reliability, to move part of the power electronics for the feedback to the surface should be considered and weighted against the possible increased requirements in power to compensate attenuation.

Additional work is required to understand the behaviour of the feedback system during the splitting process at injection required to produce the special scrubbing beams with doublets, and to demonstrate that the high bandwidth damper can successfully co-exist with the current low frequency damper. The one major concern regarding this last point is whether the system can be made to function correctly in the presence of injection oscillations.

Question 3: Can the choice of kicker technology for the final system be made now? If not, what information is still needed?

The installation as soon as possible of a high bandwidth kicker in the SPS is seen as a priority. Since the required bandwidth and kicker strength are yet to be fully defined the committee recommends that the design of both stripline and slotted-coaxial structures proceed in parallel. Stripline kickers are clearly preferable for operation below 1GHz, while slotted-coaxial structures look the only option if the bandwidth needs to be extended beyond 1GHz. A combination of the two systems could turn out to be the most effective way of obtaining large kick strength over the whole frequency range. In view of this recommendation the vacuum interfaces and supports in the machine should be prepared during LS1 in such a way as to allow the installation of up to 2m worth of kicker hardware, which would ultimately be capable of housing a 1m slotted-coaxial structure and 4 short stripline kickers. A modular design should be considered to allow the installation of any of these units as they become available.

Items identified for further study are:

- The required bandwidth of the system
- The required maximum kick voltage
- The definition of the "good field" region.
    - What deviation from nominal field can be tolerated?
    - How wide a transverse region does this have to cover?
    - Is there any effect on the beam from the multipoles generated?
- The heating of the structures both with LHC and 200MHz fixed target beams.
- The possible application of damping material, preferably not seen directly by the beam, and/or "all mode suppressors" with heat dissipation outside vacuum in external RF loads.

Question 4: Is the additional impedance of the system known and acceptable for the SPS?

Detailed calculations of the impedance were presented for the slotted-coaxial kickers. The low frequency longitudinal impedance of 0.024 Ω obtained seems negligible when compared with the overall SPS longitudinal impedance budget of 10 Ω. This would not be the case were such a structure to be used in the LHC, where this would represent a significant fraction of the total impedance.

The 100 kΩ/m contribution of the real and imaginary parts of the total transverse impedance also does not seem to pose a problem when compared with the ~7 MΩ/m provided by the other SPS kickers.

Calculations of both the longitudinal and transverse wakes showed that they decay in less than 25ns. However this assumed a perfect structure and did not take into account the fact that bunches are more closely spaced with the 200MHz fixed target beam and the special scrubbing beam with bunches separated by only 5ns. The effect of the slotted-coaxial kicker structure on these types of beam should therefore be studied.

Some calculations on the stripline kicker were also presented, suggesting an acceptable contribution to the overall SPS impedance budget, however the effect of wakes on short spaced bunches should also be studied for this structure.

In both cases the lost power was significant and careful design will be required to avoid excessive heating.

Question 5: Is the planned development, construction and installation schedule correct (i.e. complete with all activities and deadlines, realistic, conforming to CERN's needs and fitting with collaborators' constraints)?

A clear timeline to a fully operational system was presented within the constraints given by the overall CERN schedule, the aim being to install and test a bunch train demonstrator with a 1GHz bandwidth in the years 2013-2016, to be followed by a decision on a full implementation in the SPS, with a view to having this full system operational after LS2 in 2019.

As the main aim of the system is to damp the vertical e-cloud instability a fully operational system would be of most use directly after a long shutdown, when a re-scrubbing of the SPS will be necessary. This would imply that in order to be effective the full system needs to be installed during LS2, and commissioned very early on, with no room for delays.

The reviewers recognize the importance of installing a kicker capable of providing the 1GHz bandwidth required for the bunch train demonstrator as soon as possible and for that reason they recommend that the design and construction of two prototype kickers, one based on the stripline technology and the other on a slotted-coaxial structure, start immediately. The infrastructure to install either or both of these systems during a short shutdown should be fully prepared during LS1.

The extent of the US-LARP contribution to the project, in particular for the construction phase, is a source of concern. Alternative solutions should therefore be studied in case of additional budget pressures on the US-LARP high bandwidth feedback programme.

Question 6: Is the project structure clearly defined, including list of deliverables and responsibilities for deliverables and studies?

The short term deliverables for the construction and test of the high bandwidth demonstrator in the years 2013-2016 were clearly defined, with a few open questions as to exactly who would perform some of the specific tasks identified as still needing to be addressed. In view of this the review committee recommends that a collaboration agreement be drawn up by all participating parties to obtain clear commitments on which deliverables, both hardware and simulations, will be supplied by whom and on which timescale.

The deliverables for the full system are yet to be fully defined and will depend on the outcome of the tests with the demonstrator.

Question 7: Are the responsibilities correctly assigned, or should some be re-discussed?

All the participating parties represented at the meeting showed through their presentations that they had the appropriate expertise to deliver on the tasks for which they are currently working. The continuation of this collaboration with all partners is therefore highly encouraged.

With the uncertainty surrounding the US-LARP funding for the US contribution to the full system, the committee recommends that CERN become more involved in the electronic development, to ensure that they have the capability to run and adapt the system in the future. The US-LARP contributors are therefore encouraged to supply full documentation, firmware source code and feedback algorithms to CERN, while CERN is encouraged to identify engineers who could help in the development. The possibility to use the "open hardware" platform (http://www.ohwr.org/) for this development could also be considered.

Question 8: Are there deliverables or studies which need advancing in time, for example before the LARP construction decision?

The short term aim is clearly to get a working multi-bunch high bandwidth demonstrator operational in the SPS, even if this is using a reduced power kicker, a pick-up which is not suitable for the damping of doublet bunches and an electronics which cannot handle a full LHC bunch train. The knowledge gained from this will be invaluable for defining the architecture of the final system.

The two critical parameters which remain to be defined are the kick strength required and the bandwidth of the final system. Simulations and beam studies should therefore be targeted to give this input as soon as possible, as this choice will impact both the kicker type and electronic architecture.