Machine Protection Working Group

Minutes of the 24th meeting held on July18th 2003

Present: R. Assmann, J.-C. Billy, H. Burkhardt, E. Carlier, P. Dahlen, R. Giachino, B. Goddard, G. Guaglio, B. Jeanneret, M. Jonker, R. Schmidt, J. Wenninger, M. Zerlauth

Excused : E. Cennini, R. Denz, R. Lauckner, B. Puccio, J. Uythoven

Topics of this meeting:

- Status of collimators for TI2 and TI8 (H. Burkhardt)
- Power converter current interlock requirements for TI2 and TI8 (B. Goddard)
- SPS beam and extraction interlocks (J. Wenninger)
- Power converter surveillance in the SPS (M. Jonker)
- AOB :
  - Fast kickers (R. Schmidt)

The minutes of the last meeting were approved. **E. Carlier** commented that he had discussed the distribution of the beam energy information with **B. Dehning**. They will meet **L. d.Jonge** to investigate the use of optical fibres for this purpose.

Transfer line and machine protection

R. Schmidt introduced the subject. There has been a lot of work on collimators for the transfer lines by H. Burkhardt and collaborators. Since there is a collimation project (in AB-ATB), and since the responsibility for the transfer lines is with AB-BT, most of the issues concerning the layout and realization of the transfer line collimator have been discussed elsewhere. The objective for today's meeting is to inform the MPWG about the status, to identify the loopholes in the protection and to trigger appropriate actions.

Status of collimators for TI2 and TI8 (H. Burkhardt)

Scraping of particles that are located outside a defined acceptance should be performed as early as possible, in the SPS or in the transfer lines. It is assumed that all particles with amplitudes beyond 3.5 σ are removed in the SPS.
H. Burkhardt proposes to install three main collimators in each transfer lines:

- One 3.5 m long collimator in front of the injection septum magnet

- One collimator in the horizontal plane upstream of the septum magnet at a phase advance of 90 degrees
- One collimator in the vertical plane upstream of the septum magnet at a phase advance of 90 degrees

An additional collimator at the beginning of the line would ensure the protection against energy errors of transfer line and / or SPS. A decision whether such collimator is required will be taken at a later stage.

Collimators positioned at phases of 0 and 90 degrees allow particles to pass with amplitude of 7σ. In order to reduce the maximum amplitude, additional collimators at 45 and 135 degrees could be installed. Space for such collimators was identified. They could be installed in a second phase, if required. Due to space constraint, some of these collimators would be installed 180 degrees upstream from the ideal position.

The smallest opening between two collimator jaws is about 6 mm. Tables with all proposed collimator positions are appended and can also be found on the WWW:

http://proj-lti.web.cern.ch/proj-lti/TCDI/TCDI_layout.htm
http://hbu.home.cern.ch/hbu/LHCBeamLoss.html

In the discussion the question was raised whether the beam in the SPS will be scraped during normal LHC operation. In fact it is in principle possible to do it, but presently the control of the scraper is delicate. For precise scraping, the orbit in the SPS must either be stabilized at 450 GeV (which is difficult) or the scraper settings must be readjusted on a daily or weekly basis. **B. Goddard** commented that the maximum temperature for graphite should not be exceeded, as it has been shown for similar collimators with the same beam parameters. It is assumed that BLMs are installed behind the collimators. If the losses would be too high, extraction of high intensity beam would be inhibited. Without the collimators at 45 and 135 degrees, amplitudes up to 7σ are possible. This should be still ok, since the LHC has an aperture at injection of about 10σ and is certainly tolerable for the first phase of LHC operation. The question of power cuts was raised. Such cuts could introduce correlated failures (more than one power converter stops at the same time).

ACTIONS :

- Scraping : **R.Schmidt, J.Wenninger**.
- Power cuts : **R.Schmidt, J.Wenninger, M.Zerlauth**.

Power converter current interlock requirements for TI2 and TI8 (B. Goddard)

B. Goddard presented the consequences of power converter failures in the transfer lines on the LHC assuming that :

- The TCDI collimators are set to ±5σ.
- Shot-by-shot trajectory variations of ±1σ.
- The SPS power converters with their ROCS control system are surveyed before extraction. The delay between the last surveillance and extraction kick is assumed to be 5 ms.

The required current interlock level for the 37 quadrupole families is $\Delta I/I \sim 10^{-3}$, while for the 20 dipole families it ranges between 10^{-3} and 5×10^{-3}. In the event of a power converter failure happening exactly 5 ms before extraction from the SPS into the LHC, which are not detected in time to abort the extraction, the magnet currents decay by up to a few percent in most dipoles and quadrupoles. For the SPS extraction septum (MSE) on the other hand, the decay reaches 10 to 20% due to the very short time constant. The analysis indicates that there are in total 6 dipole families that are potentially dangerous. Assuming a power converter failure rate of 1 per year (excluding power cuts!), the probability to inject a beam with very large oscillations into the LHC is 1 in 10 years. This figure can be reduced by tighter surveillance, in particular if the delay of the ROCS surveillance can be reduced to 1 or 2 ms.

In the discussion, **R. Assmann** pointed out that such an event frequency could be accepted since the collimators should be able to survive the impact of one injection at 450 GeV. **B. Jeanneret** noted that while in the vertical plane the LHC is protected by the TDI and the TCL collimators, the horizontal plane is un-protected. **M. Zerlauth** said that he is investigating the possibility to generate fast interlock signals on the initial dI/dt due to a failure using special devices that include current transducers.

ACTIONS :

- Investigation of possible locations for horizontal TCL-type collimators for the LHC.
- Detection of dI/dt variations as fast interlocks for power converter failures (**M. Zerlauth**).

SPS beam and extraction interlocks (J. Wenninger)

J. Wenninger presented a short summary of the interlocks that are foreseen in the SPS for the LHC, CNGS and fixed target beams. More details on the SPS interlock system and its architecture can be found in the report **CERN-AB-2003-010** (available from the MPWG WEB page under link **SPS**). The present SPS hardware interlock system must be renovated and adapted to handle the LHC and CNGS high intensity beams. Its architecture will be very similar to the LHC architecture, with a beam interlock system based on BIC modules connected by an interlock loop. In addition the system requires three extraction interlock systems to handle the extraction of fixed target, CNGS and LHC beams in 3 distinct SPS long straight sections. The extraction interlock system for the TI2 and TI8 transfer lines will include one interlock crate on the 'LHC side' of the transfer lines, i.e. in SR2 and SR8. With this architecture, it is possible to add new interlock from the LHC without pilling cables up to the SPS ring.

The new interlock system will essentially take over the existing SPS HW interlocks and incorporated all the required interlocks for extraction. The main improvement over the present situation is the addition of a powerful current interlocking system on any power converter that is considered to be critical. In particular all transfer line power converters will be surveyed (see also the presentation by **M. Jonker**). During the discussion **R. Schmidt** wondered how magnet failures (temperature…) are handled in this system. Presently the interlock is transmitted to the power converter control system which shuts down the power converter. The question was raised if it is possible to delay the power converter failure by a few milliseconds such that the interlock can be sent out in time before the current changes. The same could be envisaged if the power converter has a fault that requires no immediate shutting off (for example for a cooling problem).

Action :

- Investigate the possibility to improve the handling of magnet failures to ensure that beam interlocks are set before the power converter trips (**J. Wenninger, R. Giachino).**

Power converter surveillance in the SPS (M. Jonker)

M. Jonker summarized the concept as well as the present state of the power converter current surveillance for the SPS and its transfer lines. The surveillance is triggered by an event and the current average over a number of samples is compared to a Golden reference value. Groups of power converters can be assigned to a partition corresponding for example to a certain geographical location. The principle of the surveillance has been tested, but a number of improvements must still be done in the coming year(s) until the LHC becomes operational. An important question raised in the presentation concerns the definition of the Golden value. One alternative consists in deriving the Golden values directly from measurements over a number of cycles.

The current measurement is performed by a 14 bit ADC, the signals of 8 power converters being multiplexed to one ADC. Due to ripple and noise, the accuracy of the current measurement requires an increase of measuring time. More information on noise and signal stability is required before one can decide if the delays mentioned by **B. Goddard** in his presentation can be reduced.

AOB

R. Schmidt summarized the present compromise that had been found on aperture kickers at a recent BI instrumentation specification meeting. During that meeting it was agreed that:

- The Q kicker would be upgraded to provide **kick amplitudes of 8σ at 450 GeV**.
- As a consequence **the kick duration increases to ~ 20 μs**, i.e. ¼ of the ring.
- Development of the aperture kicker will be stopped for the moment, but it will be possible to add an aperture kicker for 7 TeV in the future if it is required within a delay of about one year.

R. Assmann and **B. Jeanneret** expressed their concerns on this option, since the same power supply is used for tune and aperture kicks. **R. Schmidt** insisted that very strict interlocking (energy and intensity) is mandatory. It must be excluded that a beam with full intensity can be kicked to amplitudes of 8σ (at SIL 3 or SIL 4). **R. Assmann** and **B. Jeanneret** remained worried that such interlock could not provide enough safety. It was proposed to discuss interlocking of this device in a future meeting of the MPWG.

Appended document :

Summary of the BISpeC WG meeting of the 18th June 2003

Present: O. Bruning, C. Fischer, R. Schmidt, J.P. Koutchouk,
Invited for topic 1: H. Schmickler, W. Herr, F. Schmidt, A. Burns, W. Hofle, L. Ducimetiere, S. Fartoukh
Excused: J.J. Gras, J. Wenninger.

1. **Beam excitors**

The two classes of beam excitors, kickers and shakers were considered separately:

a. Kickers

Q-kickers: The Q-kickers foreseen allow kicking the beam to 2.6 sigma at 450 GeV and 0.7 sigma at 7 TeV. This is fine for Q-measurement but insufficient for non-linear studies.
Aperture Kickers for 450 GeV: The aperture kicker (8 sigma) is felt mandatory at injection. Indeed the machine performance limit at 450 GeV is a single particle issue. Furthermore the non-linearity is distributed. In thiese conditions, the kick-methods are most appropriate. This functionality is presently provided by the aperture kicker (8 sigma at 7 TeV, 32 sigma at 450 GeV).
Aperture Kickers for 7 TeV: At 7 TeV on the contrary, the non-linearity is localized in the triplets and IR's. It can be reduced to an insignificant level by optics detuning and the choice of the beam current (long-range beam-beam effect) at the expense of a lower performance. The localized non-linearity can be studied by several methods (e.g. bump method demonstrated in RHIC). The kick method involves kicking the pilot beam to about 8 sigma. This should be safe with collimators withdrawn but limiting the aperture (R. Assmann). The safety margin is however only 2 sigma beyond which the damage limit is approached or reached.
Discussion: The consensus is that aperture kicking at 450 GeV is mandatory while it should be an open option at 7 TeV, to be decided soon after the LHC commissioning. A one year notice (Laurent) is required to build and install the required power generator. This is felt acceptable. If the option was abandoned today, the savings in kicker hardware would be insignificant.
It is therefore ***agreed to cancel*** the request for a 7TeV aperture kicker power generator and to keep the kicker hardware compatible with an upgrade.
The aperture kicker at injection remains a requirement which can no longer be fulfilled using the former option. The use of the dump kicker is totally excluded for safety reasons. The use of the injection kicker could be contemplated, but it would requiredan increased complexity in interlocks and kick in only the vertical plane.
It is ***agreed to boost*** the power generator of the Q-kicker to produce 8 sigma oscillations at 450 GeV (2 sigma at 7 TeV). This can be done technically with a very small cost increase. The drawbacks were discussed and accepted:

1. ¼ (instead of 1/12) of the bunches will be kicked simultaneously: this does not change the situation when debugging the machine with one or a few bunches.

Furthermore, a factor of 2 or more in bunch selectivity may be gained by shifting properly the timing (Stephane) at the expense of a larger emittance blow-up for the bunches kicked several times. At injection, the damper may be used in few turns to kick only few bunches at about 1 sigma (2 urad per turn at 450 GeV, Wolfgang). Finally, the kick method is to be used only until the PLL is operational (Hermann).

2. Repetition rate: to be clarified (Alan looking into it)
3. The hazards to the machine are increased but the oscillation amplitude at 7 TeV remains small (2 sigma). Interlocks based on beam current should be provided to limit the kicker charge. Rudiger will investigate the situation which looks, a priori, OK.

The cost saving should be invested in R&D on an AC dipole (frequency outside beam eigen-frequencies) which would be the ideal safe excitation means in LHC if it can produce large enough amplitudes.
A new specification for the Q-kicker summarizing the above-mentioned changes will be written by Alan and sent to Rudiger for MP analysis. The goal is to finalize by Email within 3 weeks to present the conclusion to LTC on the 9th July.

b) Shakers

Interpretation of the table: The oscillation amplitudes quoted are that needed at equilibrium. Stephane questions the tickler in bunch-by-bunch mode for the measurement of the beam-beam transfer function: the beam-beam coupling is weak and an excitation to only 0.1 sigma might be insufficient in bunch-by-bunch mode. This of course depends very much on the PU sensitivity. The issue is to be resolved but not for the baseline programme. Werner will investigate whether bunch-by-bunch excitation is useful for other purposes, e.g. study of coupling between bunches.
Wolfgang says that the damper can easily produce a 0.1 sigma oscillation within its bandwidth at any energy.
For the low amplitude envisaged, Wolfgang proposes the damper to be used as `tickler' with a bunch-by-bunch selectivity. Hermann underlines that the advantage of the dedicated tickler is the ability to increase the frequency bandwidth beyond the 20 MHz of the damper.

c) Other diagnostics of the Non-linearity

Hermann suggest considering as well other means in measuring the non-linearity.
Transverse profile monitors with a high dynamic range (10^5) could be used to study the tails. There is interest in such a device if it can be built. Stephane recalls that the bump method is best suited for the low-beta sections at 7 TeV.
The method of blowing up the beam emittance gradually is well adapted to LHC as well (loss control). It was fully operational in the SPS.