Stefano Redaelli, 17-07-2006

74^{th} Meeting of the LHC Collimation Working Group, July 17, 2006

Present: Ralph Assmann (chairman), Roger Bailey, Giulia Bellodi, Dariusz Bocian, Chiara Bracco, Markus Brugger, Oliver Bruening, Francesco Cerutti, Alexeij Grudiev, Daniel Kramer, Elias Metral, Andres Gomez Alonso, John Jowett, Laurette Ponce, Stefano Redaelli (scientific secretary), Stefen Roesler, Federico Roncarolo, Lucia Sarchiapone, Mario Santana-Leitner, George Smirnov, Rüdiger Schmidt, Thomas Weiler.

1 Quench limits of LHC superconducting magnets(D. Bocian)

1.1 Simulation setup and predicted quench limits

Dariusz Bocian discussed the latest simulation and measurement results on quench limits for various LHC superconducting magnet types. Dariusz first reviewed the LHC magnet and cable designs and then described the thermodynamic model that he uses to calculate the temperature margin before quench. Dariusz studies are mainly focused on the LHC quadrupoles. Depending on the operating temperature (1.9 K or 4.5 K) different paths have to be considered for the heat flow when energy is deposited in the coil. Detailed tables with the cable characteristics are then used to calculate the free volume available for Helium within the coil volume. However, this is not the only parameter that matters for the quench performance. Depending on the operating temperature, having a larger free volume can be better (1.9 K operation) or worse (4.5 K) for dissipating the energy and hence a more detailed model must be used.

The analysis of the heat flow is carried out with a "network model" that uses an electrical equivalent circuit to describe the heat transverse in the coil. Each thermo-mechanical property (temperature, heat, thermal conductivity, ...) has an equivalent electrical property (voltage, charge, electrical conductivity, ...) and this allows modelling stand, cables and whole coil with a complex electrical circuit, which is than solved with a dedicated commercial program (`PSpice`). As boundary conditions, the "electrical ground" is put at the surfaces with zero entalphy. This model allows D. Bocian to predict the measured current on the quench heater as a function of the magnet current for different magnet cables.

Simulation results could be benchmarked with dedicated tests carried out at the SM-18. The model validation for the steady state case, which is of interest for the slow proton losses induced by the collimation system, are performed by keeping the quench heater current constant for 200 s and then by ramping the magnet until it quenches. D. Bocian showed that, with this experimental conditions, there is a very good agreement between simulations and measurement results. For the MQM's, the differences are below **7 %** and for the MQY's up to **15 %** (3 MQM's and 2 MQY's were tested at 4.5 K). This difference is explained by the fact that the MQY's had a larger temperature margin at 4.5 K. It was noted that measurements at 1.9 K could not be carried out for the steady state case due to the limited power of the quench heaters.

Having seen the good accuracy of the model, D. Bocian used it to estimate the temperature margin in case of beam losses, for various loss locations. The expected quench limit for the MQM's at nominal current is **6 mW/cm^3** and for the MQY's is **10 mW/cm^3** for Gaussian beam loss profiles. For a homogeneous heat distribution (simplified assumption) the quench limits are typically three time lower. Dariusz underlined the important of using realistic beam loss distributions as input.

D. Bocian concluded that these preliminary results are very promising. He also stressed that the model should be validated at 1.9 K and should be upgraded to take into account non linear effect, which could explain the small difference with respect to the experimental results. Work is now ongoing to review the quench limits of the MQTL quadrupoles. New results will be ready in a couple of months.

1.2 Discussion

R. Schmidt commented that I had in mind that the available free volume for Helium should be of the order of 8 % to 10 % whereas the latest estimates by D. Bocian show that at most one expects 5 % to 6 %.

O. Brüning asked if the Helium can pass through the cable insulation tapes. D. Bocian replied that this is indeed the case. However, by doing that the Helium can change phase to HeII and hence the insulation effectively becomes a barrier for the heat extraction. R. Schmidt does not agree with this statement.

R. Assmann asked if the comparison between model and experiments is done by using some fitting parameters. D. Bocian replied that this is not the case. The model allows calculating values that are directly comparable with the measurements.

The assumption for the location of proton losses were based on the loss profiles downstream of the TCDQ elements. R. Assmann suggested that new estimates should be carried out by using the loss distributions expected in the cold magnets downstream of downstream of IR7 (**Action**).

J. Jowett asked about the status of the simulations for the main dipoles. This issue is of major relevance for the ion project. D. Bocian replied that the model exist but for the time being the highest priority is given to the MQTL magnets.

O. Brüning asked how the new results compare with old ones J.B. Jeanneret *et al.* of 1994. R. Assmann replied that old studies were only done for the main bending and not for quadrupole magnets and hence it is not easy to compare them.

D. Bocian stated that the MTM group supported more measurements at the SM18. In a couple of weeks, he expects that he will be able to give another update on his studies. The collimation working group strongly supports these activities. Ideally, we should try to have quench limit estimates for each LHC magnet type.

2 Collimator impedance (E. Métral)

2.1 Simulation results

Elias Métral reviewed the benchmarking of collimator impedance studies with the experimental data from the SPS and presented his recent results on collimation impedance studies. His presentation was focused on the latest results. A more complete introduction on impedance theory and tools applied to the LHC collimators can be found, for example, in earlier presentations by Elias at the collimator working group (May 25th, 2005).

The collimator impedance measurements carried out at the 2004 SPS tests with beam have provided a crucial validation of theory and formalisms developed in the past years, which are now used to predict the collimator impedance at the LHC. Even if not all the effect expected to be relevant for the LHC could be investigated at the SPS, an excellent agreement was found between measured and predicted SPS impedance. This makes us confident that the prediction for the LHC are reliable. The only regime that could not be investigated is the the so-called **inductive by-pass** regime, which may be relevant for the LHC.

More specifically, E. Métral summarized the present understanding of the collimator impedance as it follows (see Elias's slides for more details).

- The non-linear impedance model (F. Zimmermann *et al.*) explains extremely well the SPS measurements of collimator impedance versus collimator gap. Even if this

regime will **not** be relevant **for the LHC machine**, this is a extremely important achievement and we are fully confident that we understood well the collimator effect at the SPS (imaginary part of the impedance).

- Impedance measurements carried out by F. Caspers and T. Kroyer with a displaced wire in the laboratory are in very good agreement with the theoretical predictions, but not in the frequency range of interest.

- None of the measurements in the above items (SPS beam test nor laboratory measurements with a displaced wire) are suitable for a direct experimental verification of the by-pass effect, which takes place at very low frequencies and according to theory will be the dominant contribution for the LHC beam.

As a further development of the previous theories, E. Métral has recently **extended the Zotter formalism of 2005** to (1) take into account the impedance in all frequency ranges and to (2) calculate the impedance with no constraints on the assumptions on the surface resistance. Elias pointed out that this theory has been successfully benchmarked with measurements of the SPS MKE kicker impedance (see page 8 of E. Métral's slides - Comparison with experimental data was only performed up to 1 GHz). Impedance-wise, the MKE kicker is significantly more complicated than the LHC collimator. Hence this good agreement between predictions and theory suggests that the model can accurately predict the collimator-induced impedance at the LHC.

E. Métral noted that at recent international workshops colleagues from GSI (I. Hofmann, O. Boine-Frankenheim *et al.*) have presented impedance estimated that are quantitatively and qualitatively different from the one of the various models developed at CERN. The GSI model do not fit with the experimental results that have been discussed above. Discussions with the GSI colleagues are ongoing to understand the source of these discrepancies.

Then, E. Métral also showed stability diagrams for the coherent tune shift calculated for different chromaticity values. The expected tune shift is compared to the stable regions for the cases with and without Landau octupoles. Elias' results indicate that with the nominal collimator setting, **less that 50 % of the nominal LHC current could be stored in the LHC**. These results show a strong dependence on the chromaticity. This could be an issue in the early commissioning phases, in particular if the chromaticity will not be measured and set precisely. On the other hand, it appears clear that the **chromaticity** control could also be used as a **knob to reduce beam instabilities** from collimator impedance.

Elias also reported that a lot of work has been carried out by A. Grudiev to study the trapped modes in the two-in-one collimators (TCT's and TCLIA's in IP2 and IP8). These studies show that we can expect significant broad band impedance and trapped modes for these special collimators. The calculations by A. Grudiev set a **limit of 12 mm to the minimum gap** of these TCT's and TCLIA's to stay within the agreed impedance budget. The same criterion is also used for the TCLIA's at injection.

In conclusion, E. Métral stated that we can now be confident that the impedance models setup in the last years are very accurate for the low-frequency regime. However, the present experimental results cannot be used to benchmark the theory prediction of the inductive by-pass effect, which is expected to induce the largest contributions for the LHC (low frequency regime). Next studies will be focused on finding experimental evidence of this effect (beam or laboratory tests).

2.2 Discussion

O. Brüning commented that during the commissioning, when the chromaticity will not be precisely known, we should aim at values of the order of $Q' = 8$. It has been shown that this will not cause problems of dynamic aperture and on the other hand could provide a sufficient margin to ensure that we will not reach negative chromaticity values within the measurement accuracy. Oliver also suggested that one should investigate whether with $Q' \approx 10$ one will still be able to use the Landau octupoles to damp instabilities. E. Métral replies that this is the case. He has performed scans with -20¡Q'¡20, as it is shown at page 12 of his slides.

S. Redaelli commented that in any case during the LHC commissioning a much reduced system will be needed and hence we should not be limited by the collimator impedance. Triggered by a question by R. Assmann, E. Métral replied that the contribution of the primary collimators only is of the order of a few percent of the total collimator impedance.

O. Brüning stated that the predicted impedance effect have strong dependence on basic beam parameters such as tune and chromaticity. This should be seen as a strong argument to push to commission as early as possible proper measurements tools such as BBQ and PLL.

R. Assmann reminded that after summer we will have collimator beam tests at the SPS with 270 GeV proton beams. These should be seen as an opportunity to investigate the inductive by-pass effect, if new ideas are proposed to measure this effect. Preparation meeting for the SPS beam tests will start after the summer break.

3 Results of latest IR7 energy deposition studies (M. Santana-Leitner)

See Mario's slides for details. The list of pending actions for FLUKA studies will be discussed at the next meeting.

The next meeting will be announced.

Action Items:

- ▷ Calculation of temperature margins of LHC superconducting magnets for the typical proton loss distribution in the critical magnets downstream of IR7 (D. Bocian, input from ABP collimation team).
- ▷ Can we use the Landau octupoles to damp the collimator impedance instabilities with high chromaticity values? (E. Métral).