

Workshop on Beam-generated heat deposition and quench levels in LHC magnets

Held at CERN, 3-4 March 2005

Workshop organised in the frame of the CARE-HHH-AMT network Organisers: R. Assmann, L. Rossi, R. Schmidt & A. Siemko

Report from this Workshop

presented by P. Pugnat, Scientific secretary

Thanks to - J. Hadre - Organisers - All Speakers & Participants

Preview

Workshop overview

- 86 participants:
 - 13 External + 73 CERN (28 AB, 38 AT, 4 PH & 3 TS)
- 23 presentations in 2 days:
 1 CEA, 2 FermiLab, 1 HERA, 1 INFN-LASA
 9 AB + 8 AT + 1 PH for CERN
- 4 sessions to better understand:
 - Heat Deposition due to beams
 - Accelerator Operation
 - Quench Levels
 - Modelling nuclear cascade & Quench Levels
- 1 round table discussion
- Outcomes from this Multidisciplinary Workshop
- Summary of the Follow-up

Heat Deposition due to beams

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- Introduction (R. Assmann): The fight against the quench dragon
 - Each quench constitutes downtime for Physic Experiments i.e. reliability issue as the chain end.

Proton beams

- Review of past estimations for LHC dipoles (D. Leroy)
 - Continuous losses: 10 mW/cm³ or 0.4 W/m of cable produces $\Delta T < 0.2$ K with the insulation selected for MBs;
 - Transient losses: Enthalpie margin ~1 mJ/cm³ from insulated conductor & ~35 mJ/cm³ from LHe; LHe contributes if ∆t_{loss} > 8 ms
- Heat Load from beam (V. Baglin)
 - Synchrotron, image currents, electron-cloud, scattering onto residual gases
- Transient and multiturn beam losses (B. Goddard, G. Robert-Demolaize); Losses during normal injection still need to be evaluated.

Heat Deposition due beams Results for protons beams from G. Robert-Demolaize



Simulation with beam Lifetime of 0.2 h

From the "optimistic" side, with beam lifetime of 2 h + tertiary collimators \Rightarrow below the quench limit (J. B. Jeanneret)

Heat Deposition due beams Heavy ion beams

Interaction with matter (G. Smirnov)

 Energy deposition from ions was underestimated, ∃ Boundary Free Pair Production:

Photon flux α Z², e⁺-e⁻ pair production, e⁻ capture by ions^z ⇒ ions^{z-1} ⇒ deflection change ⇒ ions^{z-1} get lost in regions of large dispersion i.e. inside the 1st Dispersion Suppressor down stream from the IP.

Ion operation & beam losses (S. Gilardoni)

Results from calculation for main dipoles in DS:

LHC cannot run ions at nominal L (~ x 2 above the quench limit of 4.5 mW/cm³, *but this limit is not consistent with* $10 \text{ mW/cm}^3 \Rightarrow \Delta T < 0.2 \text{ K}$)

Accelerator Operation

LHC & Magnet Operation (R. Schmidt & S. Fartouk)

- During the ramp, quench margins of MB & MQ decrease significantly;
- During the squeeze the margin of some quadrupoles in experimental insertions could decrease.

Quench Levels and Transient beam Loss at Hera

(K. Wittenburg):

- Empirical approach:
 - adiabatic approximation for quench level: 2.1 mJ/cm³ for
 - $\Delta T_{cs} = 0.8 \text{ K},$
 - cooling & MPZ concept taken as safety margins,
 - x16 the threshold in p/s for continuous loss rate (from Tevatron).
- Experiences & Lessons:
 - Quenches occurred at about a factor 5 below expectation,
 - BLMs cannot protect against instantaneous losses.

Accelerator Operation

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HERA experience with Beam loss induced Quenches 1994 - 2004



Note: A quench in HERA is not a disaster! It takes typ. 1-2 h to recover from cryogenic

Accelerator Operation

Protecting sc magnets from radiation at Tevatron (N. Mokhov)

- Quench levels for
 - fast loss (≤20 μs): 4 mJ/cm³
 - continuous one: 60 mW/cm³
- LHC upgrade scenarios are quite challenging from energy deposition standpoint.
- Experiences & Lessons:
 - 3-stage collimation system is mandatory for sc Hadron colliders;
 - BLMs are useful...
- Why do BLMs need to know the Quench Levels ? (B. Dehning)

For quench prevention, 3700 BLMs need threshold values.

Quench Levels Transient losses

MQE and MPZ

Simulation Program for Quench Research



In typical SC accelerator magnet extremely small energy density disturbance is sufficient to initiate a quench MQE (op) = several µJ

Also the absolute size of the minimum energy release area is extremely small

♦ MPZ (op) ~ 1mm

A. Siemko and M. Calvi, CERN/AT-MTM



Quench Levels



- Experience from magnet tests at CERN (A. Siemko)
 - New calculations; at that time, quench limit estimates for transient losses available for ~25% of superconducting magnet types;
- Quench-based magnet sorting at MEB ? (L. Bottura)
 - Answer from A. Siemko: No as such; but the proper question would have been: with constraints easily manageable, is it advantageous to put unstable magnets in quiet regions? → present MEB baseline
- LHC Insertion Magnets and Beam Heat Loads (R. Ostojic)
 - For both types of low- β quadrupoles, safety factor of 2.5-3 for quench limit at nominal luminosity;
 - Results for MQM and MQY have not been experimentally verified.
- Thermal Anlysis and experimental results in IR triplets (A. Zlobin, FermiLab)
 - NbTi MQXB-IR quads: Quench vs. RR & calculation give 10 mW/cm³.
- AC Losses for LHC magnets (D. Richter)
- Heat transfer in superconducting magnets (R. Van Weelderen)
 - Heat transfer paths and the limits of the present IT-HX design.

Modelling nuclear cascade, Quench Level & future work 1/2

- Experiment for energy deposition in a target (V. Kain)
 Damage Levels: Comparison of Experiment & Simulation
- Case study of energy deposition in sc magnets for:
 - IR6: Beam dump (B. Goddard, A. Presland)
 - Asynchronous dump (few per year) to prevent damage of Q4;
 - Normal dump (few per day) to prevent quenches from abort gap population during regular beam abort;
 - ^{2nd} Halo with low lifetime (few per day) to prevent quenches: Q4/MQY loading may limit beam intensity (24-120 mW/cm³ at 7 TeV & 450 GeV respectively, factor 10 & 100 of reduction required)
 - IR7: Betatron cleaning (V. Vlachoudis)
 1-5 mW/cm³ with tertiary collimators (absorbers)

Modelling nuclear cascade, Quench Level & future work

Thermal modelling of IR quadrupoles (F. Broggi, INFN-LASA)
 Study of a design of Nb₃Sn low-β insertion quadrupoles.

Modelling, R&D on stability at FRESCA (A. Verweij)

- Accurate determination of some modelling parameters require dedicated experiments;
- Poorly known phenomena: transient cooling, current redistribution,...
- LHe heat transfer through superconducting cable insulation (B. Baudouy, CEA-Saclay)
 - Experimental results & heat transfer analysis
 - Electrical insulation is the largest thermal barrier against cooling.

Outcomes (1/4) from this Multidisciplinary Workshop

- Time profitable for many lively discussions, clarifications and self-training;
 - \rightarrow a written summary report and a proceeding were issued;

→ transparencies are available at the website http://amt.web.cern.ch/amt/

- Point out the information needed to optimize the starting & running of the LHC ⇒ Impact on the LHC operation;
- Prepare the LHC upgrades from discussions to identify the R&D needs.

Outcomes (2/4) - Point out information needed to optimize the starting & running of the LHC

From AB (R. Asseman):

- Perturbation Spectrum (space & time distribution) of the beam heat load around the LHC;
- List of all magnets sitting in the hottest zones from beam loss point of view.

From AT:

- Uniformisation of physical terms and units (L. Rossi);
- Condensed table containing for each magnet type, the Quench Limits, its uncertainty & the safety factor to apply (A. Siemko).

Needs for R&D on superconductor stability issues

- Study of the heat deposition by a beam in a superconducting magnet is the most relevant experiment \Rightarrow sector test ?
- Study at SM18: Quenches at Minimum Energy, vs. RR & Losses;
- More "flexible" studies can be performed at the FRESCA Test facility for superconductor stability issues; relevance of the results for magnets ? for beam loss inside magnets ?

Outcomes (3/4) - Point out information needed to optimize the starting & running of the LHC

At present, no guaranty can be given concerning the LHC at nominal conditions for ions:

- Because of heat loads in arc dipoles that can reach quench levels;
- Underestimation of the quench margin ?
- More studies required to improve the situation & many ideas came up for limitation due to quench limit:
 - Other optics ?
 - Local thicker beam screen ?

— ...

- K. H. Mess: If running just below the Quench Limit \Rightarrow few MGray/year
 - \Rightarrow Mean time for magnets survival \approx 5-7 years ?
 - Electrical insulation the weakest part... beam test on Apical & other insulation materials to better estimate the damage threshold & magnet life time...
 - HHH AMT, Topical Meeting on Insulation and Impregnation Techniques for Magnets, 22 - 23 March 2005, see http://amt.web.cern.ch/amt/

Outcomes (4/4) - R&D needs for the LHC Luminosity Upgrade.

- How to extract 50-80 mW/cm³ from a superconducting magnet (NED proposal) ?
 - Required to be "imaginative" such as to develop a new type of electrical insulation with high porosity (B. Baudouy, CEA).
- Results from simulation & modelling for Nb₃Sn IR triplets
 - INFN-LASA contribution with Fluka + Ansys calculation;
 - FermiLab estimate: 36 mW/cm³ at 1.9 K & I/I_c = 0.85.
- Simulation and modelling require a fine tuning of physical parameters (heat load & cooling) with proper boundary conditions.
- Dedicated Experiments:
 - Use of Fresca Test facility for superconductor stability issues; relevance of the results for beam losses inside sc magnets ?
 - Need of real case studies with beam heat load.

Summary of the Follow-up Evaluation of Beam *Losses in the LHC*

- Work done & in progress in the AB department <u>http://lhc-collimation-project.web.cern.ch/lhc-collimation-project/</u>
 - Loss distribution within magnets: Peak Loss in magnet ends;
 - Beam Loss Map over the LHC ring from a new version of Sixtrack with collimation & aperture interface; <u>http://lhc-collimation-project.web.cern.ch/lhc-collimation-project/BeamLossPattern/References/PAC05.pdf</u>
 - New calculations with
 - Fluka for IR7,
 - STRUCT for IR3 (collaboration with IHEP).

Summary of the Follow-up

Estimate of Quench Limits (1/2)

Example of Results for transient losses (Available for all LHC magnet types)

	Cable type	Op-T (K)	Enthalpy (mJoule/cm ³)	
Magnet type			Fast perturbation	Slow perturbation (no insulation)
			< 0.1 ms	> 100 ms
MB	Type-1	1.9	1.54	56.55
MB	Type-2	1.9	1.45	56.41
MQ	Type-3	1.9	4.24	70.53
MQMC	Type-4	1.9	1.51	49.97
MQML	Type-4	1.9	1.51	49.97
MQM	Type-7	1.9	1.51	49.97
MQM	Type-7	4.5	2.41	9.87
MQML	Type-4	4.5	2.41	9.87
MQY	Type-5	4.5	2.89	12.15
MQY	Туре-б	4.5	3.80	15.31

from A. Siemko et al., CERN LTC 19 October 2005

CERN - 23 November 2005

CARE-HHH-AMT Annual Meeting - Report from the workshop on Beam Losses - P. Pugnat

Summary of the Follow-up Estimate of Quench Limits (2/2) Conclusions from A. Siemko, CERN LTC 19 October 2005

- All relevant data on the superconducting cables and magnet design features were collected (32 types to analyze & compute)
 - Free volumes inside the superconducting cables were re-calculated

Transient beam losses were partially simulated with SPQR

- Preliminary results are available for each magnet type
- Further developments for iteration
 - Transition from He II to He I and the formation of a boundary layer

Network Model (linear) for Steady State losses is developed for MB, MQ & MQM magnets

- Further developments
 - Non-linear objects in the model
 - Other magnets
 - Loss scenarios

First experiments to validate the Models have started:

- Stability experiments in FRESCA facility (A. Verwej)
- Heat transfer into He in operating like conditions (SM18)