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

Outcome presented by P. Pugnat, Scientific secretary

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

Preview

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

Heat Deposition due to beams

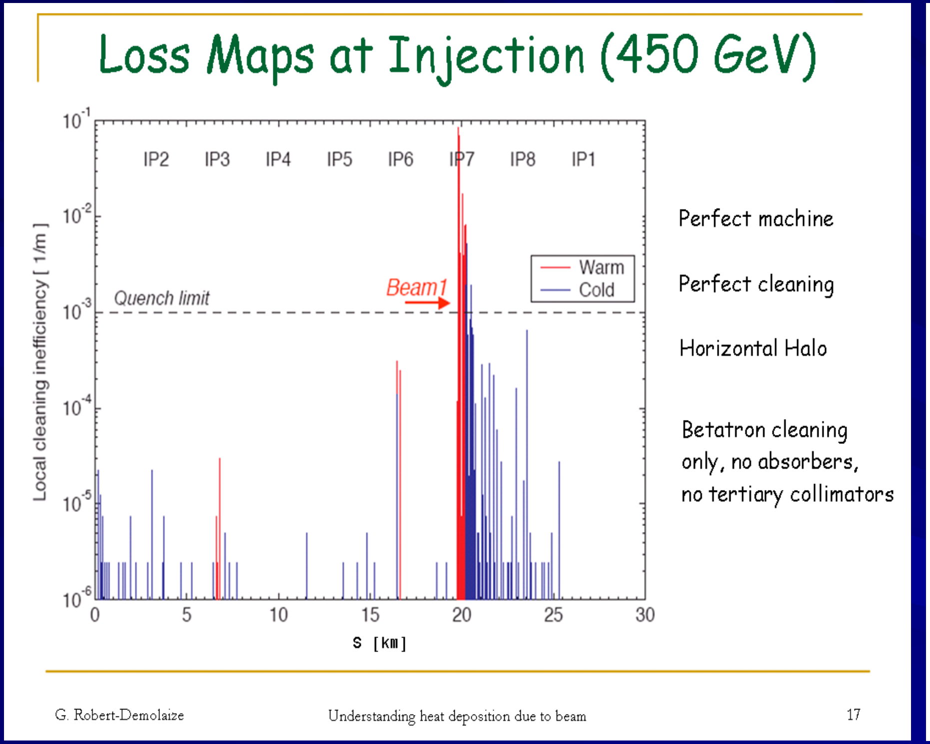
- Introduction (R. Assmann) : The fight against the quench dragon
  - Each quench constitute downtime for Physic Experiments i.e. reliability issue as the chain end.

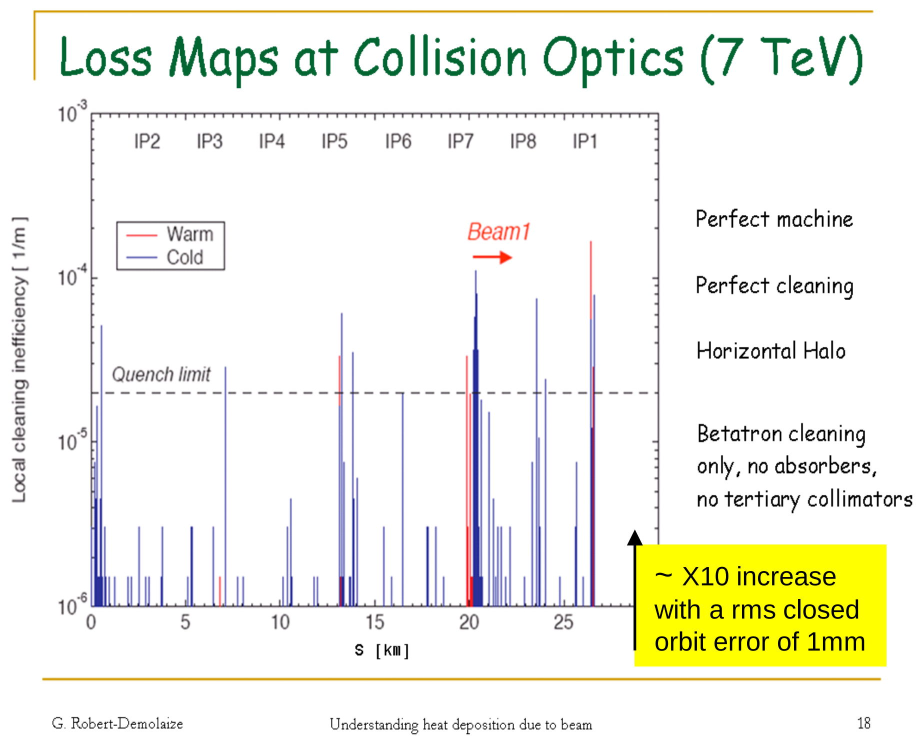
- Proton beams
  - Review of past estimations for LHC dipoles (D. Leroy)
    - 10 mW/cm^3 produces $\Delta T \approx 0.2$ K with the insulation selected for MBs.
  - Transient and multiturn beam losses (B. Goddard, G. Robert-Demolaize); *Losses during normal injection still need to be evaluated.*
  - Heat Load from beam (V. Baglin)

- Heavy ion beams
  - Interaction with matter (G. Smirnov)
    - Energy deposition from ions was underestimated: photon flux α Z^2, e^+-e^- pair production, e^- capture by ions^z $\Rightarrow$ ions^{z-1} deflection change…
  - Ion operation & beam losses (S. Gilardoni)
    - results from calculation for main dipoles in DS: LHC cannot run ions at nominal L (x2 above the quench limit)

Heat Deposition due to p^+ beam

Results from G. Robert-Demolaize





- “Pessimistic” 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)

Accelerator Operation 1/3

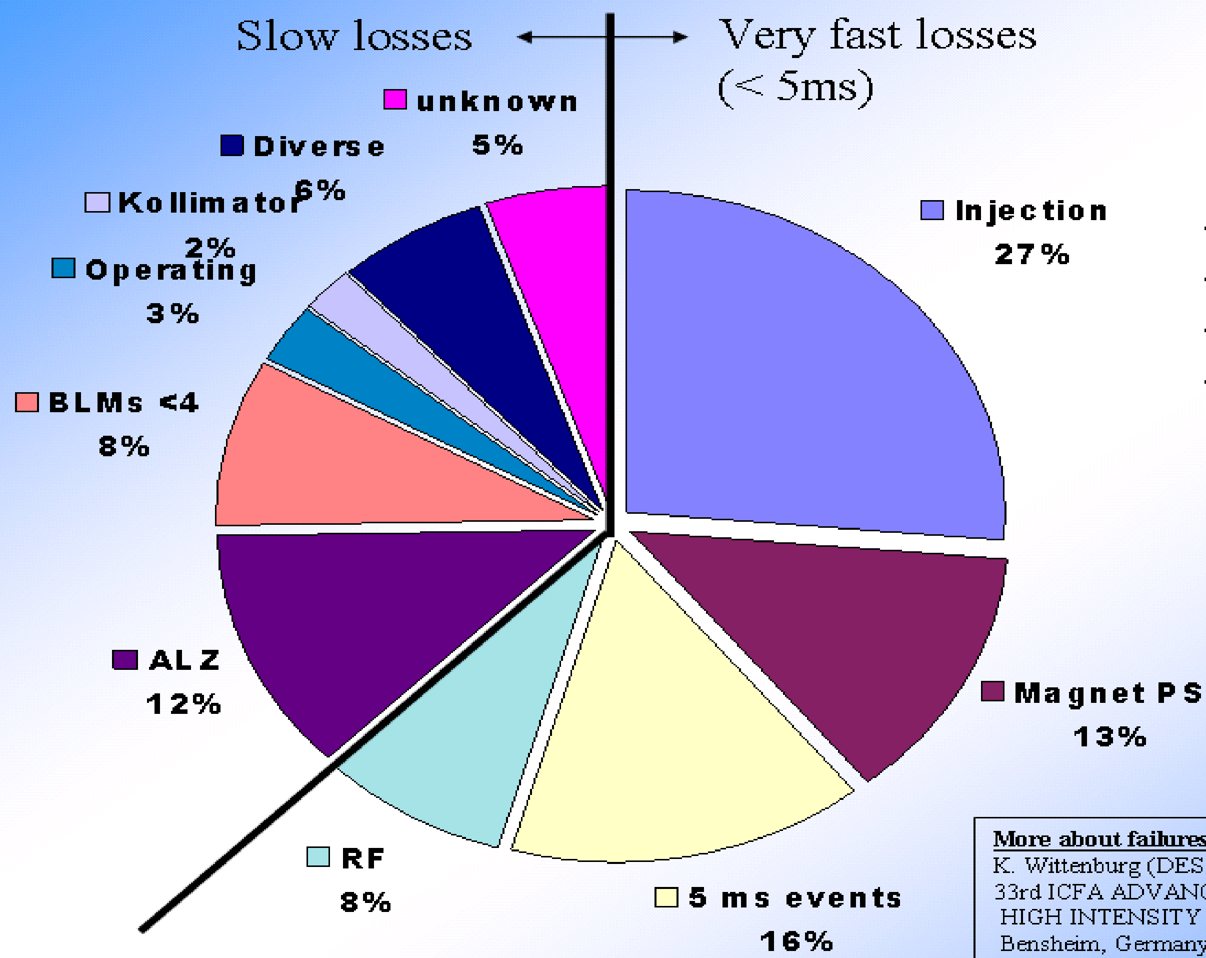
- LHC & Magnet Operation (R. Schmidt & S. Fartouk)
  - During the ramp, quench margins of MB & MQ decrease significantly;
  - During the squeeze the margin of some quadrupoles in experimental insertions could decrease.

- Quench Levels and Transient beam Loss at Hera

(K. Wittenburg):
  - Empirical approach:
    - adiabatic approximation for quench level: 2.1 mJ/cm^3 for
    ΔTcs = 0.8 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 2/3

HERA experience with Beam loss induced Quenches 1994 - 2004



Hera:
Ring of 6.3 km
- 422 sc main dipoles
- 224 sc main quads
- 400 sc correction quads
- 200 sc correction dipoles

$\Sigma = 200$ Quenches

From K. Wittenburg

More about failures:
K. Wittenburg (DESY): Beam loss & machine protection
33rd ICFA ADVANCED BEAM DYNAMICS WORKSHOP on
HIGH INTENSITY & HIGH BRIGHTNESS HADRON BEAMS
Bensheim, Germany

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

Accelerator Operation 3/3

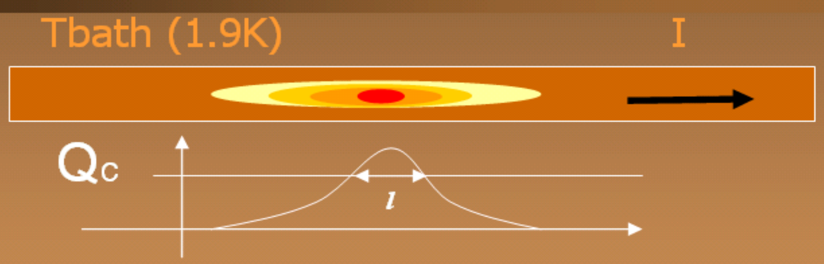
- Protecting sc magnets from radiation at Tevatron (N. Mokhov)
  - Quench levels for
    - fast loss ($\leq$20 μs): 4 mJ/cm^3
    - continuous one: 60 mW/cm^3
  - LHC upgrade scenarios are quite challenging from energy deposition standpoint.
  - Experiences & Lessons:
    - 3-stage collimation system is mandatory for sc Hadron colliders;
    - BLMs are useful…

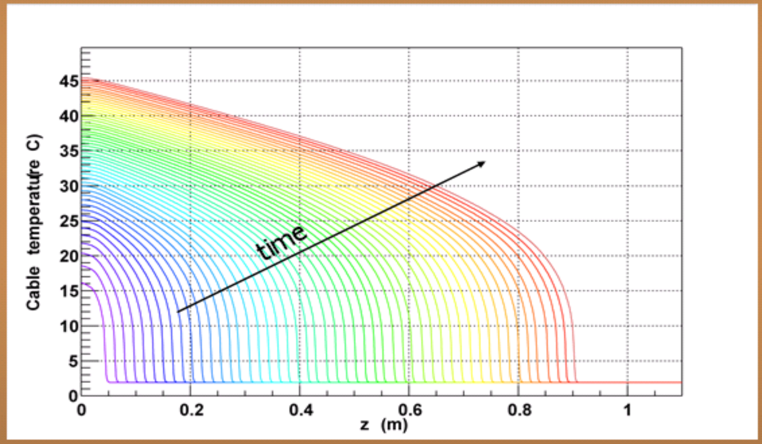
- Why do BLMs need to know the Quench Levels ? (B. Dehning)
  - For quench prevention, 3700 BLMs need threshold values.

Quench Levels 1/2

Transient losses

MQE and MPZ





$$Ac_p \frac{d\theta}{dt} = A\frac{d}{dz}\left(k(\theta)\frac{d\theta}{dz}\right) + G(\theta, I, B) - \Phi_t$$

- 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

Slide 11

AMT Workshop, CERN March 2005

Quench Levels 2/2

- Experience from magnet tests at CERN (A. Siemko)
  - New calculations, Quench Limit estimate presently available for ~25% of superconducting magnet types with transient losses;
- 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/cm^3.
- 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)

- 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;
    - 2^{nd} Halo with low lifetime (few per day) to prevent quenches: Q4/MQY loading may limit beam intensity (24-120 mW/cm^3 at 7 TeV & 450 GeV respectively, factor 10 & 100 of reduction required)
  - IR7: Betatron cleaning (V. Vlachoudis)
    - 1-5 mW/cm^3 with tertiary collimators (absorbers)

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

- Thermal modelling of IR quadrupoles (F. Broggi, INFN-LASA)
  - Study of a design of Nb_3Sn 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, Saclay)
  - Experimental results & heat transfer analysis
    - Electrical insulation is the largest thermal barrier against cooling.

First Outcomes from this Multidisciplinary Workshop

- Time profitable for many lively discussions, clarifications and self-training;

  → a written summary report and a proceeding will be 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 some R&D needs.

First Outcomes - Point out the 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 Limit, 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 ?

First Outcomes - Point out the 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/*

First Outcomes - R&D needs for the LHC Luminosity Upgrade.

- How to extract 50-80 mW/cm^3 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 Nb_3Sn IR triplets
  - INFN-LASA contribution with Fluka + Ansys calculation;
  - FermiLab estimate: 36 mW/cm^3 at 1.9 K & I/Ic = 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.

Conclusions

- Feedback from all participants was very positive;
- The weather was cold but beam losses are also good heaters for discussions;
- It was proposed to organise a similar workshop in 1 Year.