Working Group D: commissioning and operation

The conveners of Working Group D (**Michael Plum, Yoichi Sato, and Rüdiger Schmidt**) have built a program focussed on answering the following issues:

- observation of beam losses (e.g. time structure, other parameters,...)
- reducing beam losses with operational parameters away from the design set points
- reducing beam losses (or concentrating beam losses at a few locations) using collimators
- minimizing beam losses due to beam transfer from one accelerator to the following accelerator -what parameters are important?

The issue of reducing beam losses with operational parameters away from the design set points - is especially valuable as it is rarely discussed.

Talks in the session

1. Beam losses at **LHC and its injector** Laurette Ponce (CERN, Geneva)
2. Collimation experience at the **LHC** Stefano Redaelli (CERN, Geneva)
3. Performance and Future Plans of the **LHC** RF P.Baudrenghien (CERN, Geneva)
4. High Intensity Operation and Controlling Beam Losses in a **Cyclotron** Based Accelerator Mike Seidel (**PSI**, Villigen)
5. The result of beam commissioning in **J-PARC 3-GeV RCS** Hiroyuki Harada
6. Recent Commissioning of High-Intensity Proton Beams in **J-PARC Main Rin**g Yoichi Sato
7. Beam Loss Control for **FNAL/Booster**: Present and Plans for the Future Fernanda Gallinucci Garcia (Fermilab, Batavia)
8. Characterizing and Controlling Beam Losses at the **LANSCE** Facility Lawrence Rybarcyk (LANL, Los Alamos, New Mexico)
9. Beam Loss Mitigation in the Oak Ridge Spallation Neutron Source **SNS** Michael Plum (ORNL, Oak Ridge, Tennessee)
10. Beam Commissioning Plan for **CSNS** Accelerators Sheng Wang (IHEP, Beijing)
11. Beam Loss Control in the ISIS Accelerator Facility Christopher Warsop (STFC/RAL/**ISIS**, Chilton, Didcot, Oxon)
12. Status and Beam Commissioning Plan of **PEFP 100-MeV Proton Linac** Ji-Ho Jang (KAERI, Daejon)

High Intensity Operation and Controlling Beam Losses in a Cyclotron Based Accelerator Mike Seidel (PSI)

- Two cyclotrons, up to 590 MeV, **1.3 MW (record 1.4 MW),** several targets
- CW acceleration, extraction efficiency of 99.98 %
- **Extraction requires large turn separation between turns, can be achieved by "closed orbit distortions" – gain by a factor of 3, fine Q control required**
- Longitudinal space charge requires high gap voltage
- Tomographic phase reconstruction using wire scanner data – measurement of tails
- **Last 20-50% full current by beam loss fine tuning** (operator dependent)
- **Losses now down to 5*10e-5 (when power increases – no increase of loss)**
- Activation 1 mSv/h, some areas 10 mV/h, accumulated dose for personnel constant over the years
- **Very high operation requires: loss monitoring, interlocks, addressing thermo-mechanical cooling problems, handling of components, …**

Beam Loss Control in the ISIS Accelerator Facility Christopher Warsop (STFC/RAL/ISIS, Chilton, Didcot, Oxon)

- 70 MeV - 800 MeV, 50 Hz synchrotron, **200 kW, loss limited due to activation**
- BLMs (ionization chambers and few scintillators) and BCTs
- Protection systems issues beam dumps or warnings
- For injectors, some beam loss optimised tuning
- H- injection, foil stripping efficiency ~98 %, some losses downstream
- **Trapping loss 5-10 %, acceleration loss <1 %**
- **It is preferred to generate losses at low energy and localise losses in one area on collectors (betatron phases not optimised)**
- New larger acceptance (septum) decreases losses….
- Beam optimisation with 50 Hz (20 points) or experimental (<1.6 Hz)
- Simulations for the ring are very valuable (3 % simulated, 5 % measured) describe observations reasonably well (seems to be state of the art)
- **To reduce beam losses at extraction – might be best to work at injection**

- **No single quench with circulating beam with 140 MJ in each beam (design 362 MJ)**

  500 kW of losses were achieved during a test – no quench
- Complex system with 100 collimators around LHC required during all phases of operation (for cleaning and protection,..) - jaws moving during cycle
- Loss maps for validation are done, losses concentrated in cleaning section (cleaning better than 99.99%)

  Ion cleaning more difficult (physics is different, 2 orders of magnitude is lost)
- **Gaps of +- 1.05 mm with 140 MJ are used in operation (some collimators)**
- **Stability of the system is remarkable (due to collimators and orbit control), one alignment per year in case of standard configuration, better than 50 um**
- **In 2012, tight setting defining the luminosity reach of LHC (low beta), but larger losses and instabilities**
- Areas for improvement: operational flexibility, low beta reach, challenging handling, time consuming (collimators with BPM buttons are in preparation and address some issues)

- **BLM system with 3600 monitors, more than 1 Mega_thresholds (11 integration windows, thresholds changing during acceleration)**

  single BLM can dump beam

- Losses at injection

  Routine injections with 144 bunches, 288 bunches nominal bunches works

  Un-captured beam makes losses, from SPS and LHC: extra shielding, mimimisation of capture losses, injection and abort gap cleaning

  Stability problem of transfer line can also create losses (to some extent solved, bunch by bunch and shot by shot variation) – septum power supply ripple and kicker magnet ripple

  Losses already in SPS, capture losses at start ramp and from scraping (about 3%)

  Transfer line collimators very important

  Injection failures: several types of kicker failures (no kick or partial kick)

  Failures at injection very critical due to physics experiments and superconducting magnets

  TDI (injection absorber in LHC is critical) – preventing LHC becoming a Swiss cheese

- **Losses during the ramp**
  - Un-captured beam at the start of the ramp momentum cleaning insertion
  - Losses at the end of the ramp with tight collimator settings
- **Losses during squeeze**
  - Due to orbit excursions, 50 um starts to be critical (5% of collimator half gaps)
  - Orbit control very important
  - Tail formation in the injector complex is important, can increase losses by a large amount (not fully understood why…)
- **Losses when going in collisions**
  - Mainly this year, not yet 2011, when intensity was pushed
  - Instabilities at the end of the squeeze and when bringing beams into collisions
  - Sometimes only part of the bunches are lost
  - Losses can be large
  - **UFOs: dust particles fall into the beam, can lead to a beam dump, today mostly below thresholds**

Performance and Future Plans of the LHC RF P.Baudrenghien (CERN, Geneva)

- **Separate RF systems for two rings, max 2 MV/cavity (8 sc cavities / beam)**
- **Excellent performance**
  - Transient during filling leads to phase modulation, minimised with sc cavities and high voltage plus strong feedback, near perfect
  - Coupled bunch instability with high beam current addressed with feedback systems
  - Uncompensated beam loading is very small ……
- **Bunch length evolution over 9 h from 1.2 ns to 1.35 ns, RF noise very little contribution**
  - RF noise minimised to avoid emittance growth by three LLRF loops (per Klystron, per cavity and per beam) – essential for operation
- **Ramp with nominal bunch length – longitudinal instability: blow-up of the beam, stabilises bunch length to 1.17 ns**
- **Optimistic for future beam parameters (7 TeV 2.2e11 – 3e11, 25 ns bunch spacing)**

Status and Beam Commissioning Plan of PEFP 100-MeV Proton Linac Ji-Ho Jang (KAERI, Daejon)

- **Proton Engineering Frontier Project – 100 MeV proton linac started in 2002**
- **DTL linac at 350 MHz, 20 MeV – design 96 kW, 100 MeV – design 160 kW**
- **20 MeV linac operated from 2005 to 2011 (lot of experience with test operation) – demonstrated 20 MeV**

  Has been disassembled and rebuilt on final site after transportation
- Linac tests 500 us at 15 Hz, temporary limited by radiation in target system
- **100 MeV linac being installed in tunnel, including klystrons, modulators etc.**
- **Commissioning plan, starting this winter with HW tests, and then continuing with beam tests, beam service in Spring 2013**
- **Future possibly 2 MW SRF linac at 1 GeV**

  R&D being done, with 700 MHz cavities (possibly changing to H- operation)

The result of beam commissioning in J-PARC 3-GeV RCS Hiroyuki Harada (JAEA/J-PARC)

- **RCS accelerates from 181 MeV to 3 GeV**
- Start commissioning end 2007, **now 280 kW during user operation (maximum power of up to 420 kW was achieved), design 1 MW**

  For spallation target and as injector for Main Ring
- Imperfections by injection bump changes beta function by 14% and leakage field from extraction elements – corrected
- Beam loss from foil scattering, resulting into two hot points (3-6 mrad/h)

  Movable copper absorber installed to shield aperture, reduces losses by factor of 6
- **High beam losses during extraction**
- **Main cause of emittance growth is part of beam reaches integer resonance 1 ms after injection**

  Improvement of bunching factor by 2nd harmonic cavity, reducing the halo

  Reduced beam loss during extraction

- 3 GeV to 30 GeV, 1.6 km with 3 extraction lines (neutrinos, beam dump, slow extraction), accelerating in 1.4 s, **power today about 200 kW, design 750 kW**
- Linear and nonlinear optics well understood
- **Present limitation is related to collimator cooling capacity (450 W, 2 kW after summer 2012, more in 2013)**
- Some troubles: **degradation of injection kicker (poor electrical contact)** and radioactivity in exhaust gas, limit 180 kW (new damper etc.)
- Bunch by bunch transverse feedback is vital during acceleration
- Beam loading suppression using fast feed forward on RF system
- Beam loss observation: BLMs, DCCT, air-ion chambers
- **2.5D simulation and measurement agree (e.g. survival ratio of beam at injection, other parameters)**
- Effects of 2nd harmonic RF increasing bunching factor, should reduce emittance growth, but needs other upgrades for operational use

Beam Loss Control for FNAL/Booster: Present and Plans for the Future Fernanda Gallinucci Garcia (Fermilab)

- **Synchrotron 400 MeV starting with H- multi turn injection, 15 Hz, fast single turn extraction, to 8 GeV, beams for neutrinos and other clients, >10e17 p/hour**
- Since its design, Continued demand for high proton flux, required many upgrades
  - Factor of more than 10 since 1992, factor of 2 for the next 4 years
- Beam losses for hands-on maintenance is a continuous issue…
  - e.g. extraction in 40 ns particle free gap (notches)
- **Reducing beam losses: working in many different areas: orbit, collimators (2-stage system), cogging system + notches, …**
- **PIP proton improvement plan**
  - Increase frequency
  - Replace components
  - Study beam dynamics
  - New RFQ, alignment, measure aperture, relocation of notcher (fast kickers to create particle free gap at low energy), RF improvement, other

Characterizing and Controlling Beam Losses at the LANSCE Facility
Lawrence Rybarcyk (LANL, Los Alamos, New Mexico)

- **100 MeV DTL, 800 MeV CCL, 60 Hz, many users, H+ and H- beams, …**
  Many different pulse patterns, complex users
- Lujan center: **beam power for H- beams 100 kW,** many users **(design 80 kW)**
- Dedicated collimators only in 750 keV LEBT, no steering magnets in linacs…
- Beam loss detection with BCTs with 10e-5, scintillators, ion chambers
- **Beam losses along the linac arise from a number of sources.**
  DTL capture losses arise from injected beam not fully bunched .
  Losses are observed near all transitions in the quadrupole lattice of the linac.
  H^- stripping losses are observed in the transition region and CCL.
- **Very clear demonstration of IBSt (Intra Beam Stripping)**
- **RF field settings with reduced amplitude away from design values help to reduce beam losses (agree with recent simulations)**
- Much better control requires better understanding
  Online analysis with multi particle dynamics simulations using GPUs, in development

Beam Loss Mitigation in the Oak Ridge Spallation Neutron Source
Michael Plum (ORNL, Oak Ridge)

- **Design 1.4 MW, typical operation with 1 MW**
- About 365 BLMs, ionisation chambers, scintillation detectors, neutron detectors
- Maximum radiation levels: 0.5…3 mSv/h general ring injection after 2 days, hot spots up to 4.5 mSv/h
- Mitigation: scraping, increase beam size (IBSt), empirically change settings of magnets
  - Tails are reforming after scraping
- **LINAC: design values not the best values for minimum beam loss**
  - Changing magnet setting empirically, very different results from simulation
  - Changes up to some 10% for magnet strengths, phase difference up to 10 degrees for cavities
  - Small changes can make a large difference (1 degree RF phase doubles beam loss)
- **Hypothesis for linac: Low loss set-points are best to transport halo particles, might results in unusual beam core parameters**
  - Tail population from 0.01 %-30 %
- Ring parameters close to the design

- **Recent project, to be ready in 2018 and reaching design in 2021**
- **DTL to 80 MeV then RCS to 1.6 GeV, 100 kW can be upgraded to 200 MeV and 500 kW**
- First stage 2013-1017 ion source low intensity beam on target
- Second stage 10 kW, 2018
- Third stage 100 kW, 2021
- Starting with 1 Hz, to finally 25 Hz
- MEBT and DTL with a large amount of instruments
- **Commissioning plans were defined, profiting from experience of JPARC and SNS**

Discussion session

- UFOs in other machines than LHC?

  Probably yes, only LHC is sensitive to UFOs, but not demonstrated

- Online models in control room, what can they provide?

  Several machines (LANSCE, FNAL, LHC and injectors, SNS, J-PARC) have machine models. This is very useful, e.g., for beam loss & collimation simulations.

  A very interesting approach… close collaboration between accelerator physics and operation is required

  Could be one of the topics to be discussed for the next workshop….

- Scraping? How, where?
- Concentrating beam losses? On few dedicated areas? Multistage collimation schemes?
- Beam loss calculations + hadron shower calculations, status?

  Codes (MARS, STRUCT, FLUKA, …) are very useful in design and commissioning of the collimator systems (FNAL Main Injector, LHC, …)

  Closer coupling between tracking programs - shower calculations make life simpler

  Scraping at different betatron phases required for optimum efficiency, otherwise less efficient (e.g. done in transfer lines CERN-SPS to LHC and FERMILAB)

Discussion session: Beam Halo

- Calculate and match optics for tails? And not for core?
- Better instrumentation? Or better modeling?
- Instrumentation: wish list to our colleagues from BI…

No-Gaussian tails are seen in many machines. Get much better agreement between simulation and experiment when use these tails in simulations.

Optimising the machine assuming parameters for the core might not be optimum to minimise beam losses (e.g. SNS).

1/r distribution of tails seen at many ring (comment N. Mokhov).

BI needs: **Halo monitoring during normal operation** is considered to be very useful, needs **large dynamic range measurements**, ideally non-intercepting.

Correct initial beam distribution is a key to simulate halo and loss growth.

PS-SPS got good results by tomographic reconstruction of non-Gaussian tails, and then using this distribution to understand beam losses.

IFMIF interesting case: assume simulations cannot accurately predict beam loss, so **plan to use computer control with many degrees of freedom search algorithm to empirically reduce beam loss**. Might end up in local minimum because losses required to find a better minimum may be excessive. Waiting for their experience….

Few remarks

- The performance of several machine is limited by beam losses (activation etc.)
- Collimators are essential for beam loss control

  SNS scrapes 3%, SPS similar
- Beam loss reduction after many decades of operation (new techniques are developed)
- Simulation of beam losses codes do a nice job in rings, less convincing for linacs

Thanks a lot for all speakers and the participants to our sessions

And thanks a lot to Michael Plum and Yoichi Sato for the very pleasant working in a team, from preparation[1)] to preparation[2)]

1) …of the sessions
2) …of the summary