SUMMARY OF THE WORKING GROUP ON COMMISSIONING AND OPERATION

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INTRODUCTION

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, Philippe Baudrenghien (CERN, Geneva)
4. High Intensity Operation and Controlling Beam Losses in a Cyclotron Based Accelerator, Mike Seidel (PSI, Villigen)
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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)
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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, Daejeon)

High Intensity Operation and Controlling Beam Losses in a Cyclotron Based Accelerator, Mike Seidel

PSI has two cyclotrons accelerating protons up to an energy of 590 MeV. The beam power is with 1.3 MW still the worldwide record. During tests even a beam power of 1.4 MW was achieved. The beam is sent to several targets.

Acceleration is in CW mode with an extraction efficiency of 99.98 %. Clean extraction requires large turn separation between turns, this can be achieved by “closed orbit distortions”. A gain by a factor of 3 can be achieved using this technique. A fine control of the tune is required to minimise losses. Longitudinal space charge requires high gap voltage.

The tomographic phase reconstruction using wire scanner data allows measurement of beam tails.

The last 20-50% of the full current are achieved by minimising beam loss with fine tuning, this process depends to some extent on the operator skills.

Beam losses today are down to $5*10^{-5.}$ An increase of the beam power is only accepted if the losses do not increase.

Activation in general is in the order of 1 mSv/h, some areas 10 mSV/h, the accumulated dose for personnel is constant over the years.

Very high power operation requires loss monitoring, interlocks, addressing thermo-mechanical cooling problems and remote handling of components.

Beam Loss Control in the ISIS Accelerator Facility, Christopher Warsop

The ISIS synchrotron accelerates protons from 70 MeV to 800 MeV at 50 Hz. The total beam power is 200 kW, the power is limited by beam losses leading to activation.

Monitoring is with BLMs (ionization chambers and few scintillators) and BCTs. The protection systems issue beam dumps or warnings in case of too high losses.

For the injector, beam losses are minimised by careful tuning. Injection into the synchrotron is with H- beams, the foil stripping efficiency ~98 %, leading to some losses downstream of the foil. Trapping loss are 5-10 %, and losses during acceleration <1 %.

It is favoured to generate losses at low energy and localise losses in one area on collectors, even if the betatron phase for the collector is not optimised.

A new septum with larger acceptance decreased the losses at extraction. However, to reduce beam losses during the entire cycle (in particular at extraction) the

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preferred strategy is to improve the beam quality at injection.

The optimisation of the transmission in the 50 Hz cycle is possible by adjusting the parameters with 20 points during the ramp, or experimental (<1.6 Hz). Simulations of the beam losses for the ring describe observations reasonably well (3 % simulated, 5 % measured), which is considered to be state of the art.

Collimation Experience at the LHC, Stefano Redaelli (CERN, Geneva)

A complex system with 100 collimators around LHC is required during all phases of operation, both, for beam cleaning and for protection. The collimator jaws move during the cycle close to the beams. Gaps of +- 1.05 mm with 140 MJ beam energy are used in operation for some of the collimators.

The optimum cleaning efficiency with a multistage cleaning system is achieved when the hierarchy is respected: jaws of primary collimator closest to the beam, jaws of secondary collimator slightly further out etc. Loss maps for validation of this hierarchy are performed. Losses are concentrated in the cleaning section (cleaning better than 99.99%).

It is remarkable that there was no single beam induced quench despite operation with circulating beams with 140 MJ stored energy in each beam (design 362 MJ). Beam losses of 500 kW were achieved during a test without quenching the magnets.

Ion cleaning is more difficult since the physics of ion-material interaction is different from protons, two orders of magnitude in efficiency are lost.

The stability of the system is remarkable, due to control of the collimator position as well as the control of the orbit. One alignment per year in case of standard configuration is sufficient and tolerances are less than 50 um.

The settings of the collimators define the luminosity reach of LHC. With collimators close to the beam, operation with a reduced beta function in the collision points is possible. During 2012 the collimators are closer to the beam but beam losses are larger and instabilities are observed due to the increased impedance with the tight collimator settings.

Areas for improvement: operational flexibility, low beta reach, challenging handling, time consuming adjustment of the collimator jaw positions. Collimators with BPM buttons are in preparation and will address some of these issues.

Beam Losses at LHC and its Injector, Laurette Ponce

The BLM system has 3600 monitors, and more than 10^6 thresholds are defined (11 integration windows, thresholds changing with increasing energy during acceleration). If the losses at a single BLM exceed the threshold, the beams are dumped.

Losses at injection: routine injection with 144 bunches works well, injection with 288 bunches (nominal) has also been successfully tested. Un-captured beam increases beam losses, both coming from SPS and LHC. Extra shielding was installed, capture losses were minimised and cleaning of the injection and abort gaps is applied using the transverse feedback system.

Stability problems of the transfer line can also create losses, such as bunch by bunch and shot by shot variations. Some sources for the instabilities were corrected (e.g. septum power supply ripple and kicker magnet ripple).

Losses are also present in the SPS, such as capture losses at the start of the ramp and losses from beam scraping before extraction to LHC (about 3%). Transfer line collimators are very important to avoid losses in LHC in case of ill steered beams.

Injection failures: there are several types of kicker failures, e.g. no kick or partial kick of the injected beam, and wrong kick on the circulating beam. Failures at injection are very critical due to physics experiments and superconducting magnets downstream of the injection points. In case of a failure at injection, a 4 m long injection absorber (TDI) in LHC is very critical, preventing LHC to be damaged.

Losses during the ramp: un-captured beam at the start of the ramp is taken out in the momentum cleaning insertion. Losses at the end of the ramp appeared with tight collimator settings during 2012.

Losses during the squeeze: due to orbit excursions, in 50 um change of the orbit starts to be critical. This corresponds to about 5% of collimator half gaps.

Beam tail formation in the injector complex is important and can increase losses in the LHC at the top energy by a large amount. The mechanisms are not fully understood.

Losses when going in collisions: mainly in 2012 when the beam intensity was pushed, much less in 2011. Instabilities at the end of the squeeze and when bringing beams into collisions can lead to large losses. Sometimes only part of the bunches are affected by losses.

Another mechanism for losses are UFOs: dust particles fall into the beam and can generated losses leading to a beam dump since the BLM thresholds are exceeded. Today, mostly UFOs generate losses below thresholds.

Performance and Future Plans of the LHC RF, Philippe Baudrenghien

The LHC has separate RF systems for two rings, with max. 2 MV / cavity and 8 superconducting cavities / beam. The performance of the RF system is excellent. During filling, the field in the empty buckets is perturbed by the beam in the filled buckets. This causes an injection phase error and then capture losses, if injection phase is kept constant. The effect is minimized by using superconducting cavities with low R/Q and high voltage. Coupled bunch instability with high beam currents are addressed with feedback systems. The uncompensated beam loading is very small.

The RF noise is minimised to avoid emittance growth by three LLRF loops (per Klystron, per cavity and per beam) – this is essential for operation. The increase of the

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bunch length during a fill is very low (for 9 h from 1.2 ns to 1.35 ns). RF noise contributes very little to bunch lengthening.

For a ramp with nominal bunch length longitudinal instabilities were observed, cured by blow-up of the beam increasing the bunch length to 1.17 ns through the energy ramp.

Future beam parameters (7 TeV, $2.2*10^{11}$ – $3*10^{11}$, 25 ns bunch spacing) should be possible, but this needs still to be demonstrated.

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

The PEFP (Proton Engineering Frontier Project) plans the construction of a 100 MeV proton linac. The discussion for the machine started in 2002.

The first stage is a DTL linac at 350 MHz accelerating protons to 20 MeV with a design beam power of 96 kW, for the 100 MeV the design beam power is 160 kW.

The first part, a 20 MeV linac, was already built and operated from 2005 to 2011. Lots of experience with test operation was gained and 20 MeV were reached. The linac tests were performed with 500 us long bunch trains at 15 Hz, the power was temporarily limited by radiation in target system. This linac has been disassembled and rebuilt at the final site after transportation.

The 100 MeV linac is now being installed in the tunnel, including klystrons, modulators etc. Commissioning starts this winter with hardware tests and then continuing with beam tests, beam service is expected for Spring 2013. A future option of an upgrade to a linac with a beam power of 2 MW using a SRF linac at 1 GeV is being discussed. R&D is being done, concentrating on 700 MHz cavities (and possibly changing to H- operation).

The Result of Beam Commissioning in J-PARC 3-GeV RCS, Hiroyuki Harada

The RCS accelerates beam from 181 MeV to 3 GeV. Start of commissioning was end of 2007, now the beam power is 280 kW during user operation. A maximum power of up to 420 kW was achieved. The machine is designed for a beam power of 1 MW.

The RCS is used for sending beam to a spallation target and as an injector for the Main Ring.

Imperfections in the injection bump changed the beta function by 14%, and leakage fields from extraction elements were corrected. Beam loss from foil scattering result into two hot spots (3-6 mSv/h contact). Movable copper absorbers were installed to shield the aperture and reduce the beam losses by a factor of 6. The beam losses during extraction are high. The main cause is emittance growth when part of the beam reaches an integer resonance 1 ms after injection.

Simulation and measurement of beam dynamics agree (e.g. survival ratio of beam from injection to extraction, other parameters).

Improvement of the bunching factor by 2nd harmonic cavity allows reducing the halo and also the beam losses during extraction.

Recent Commissioning of High-Intensity Proton Beams in J-PARC Main Ring, Yoichi Sato

The main ring accelerates protons from 3 GeV to 30 GeV. It is 1.6 km long and has 3 extraction lines (for producing neutrinos, to a beam dump, and hadron experiments). The beam is accelerated in 1.4 s, and the beam power today is about 200 kW (design is 750 kW).

The linear and nonlinear optics is well understood. The present limitation is related to collimator cooling capacity (earlier only 450 W, now 2 kW since summer 2012, more in 2013).

Some troubles limited the beam power to 100 kW due to a gradual degradation of the injection kicker (poor electrical contacts), and to 160 kW for radioactivity in exhaust gas (new damper etc).

Bunch by bunch transverse feedback is vital during acceleration. Beam loading suppression uses fast feed forward on RF system. Beam loss observations are with BLMs, DCCT and air-ion chambers.

2.5D simulation and measurement of beam dynamics agree (e.g. survival ratio of beam at injection, other parameters).

A 2nd harmonic RF improving the bunching factor should reduce the emittance growth, but needs other upgrades for operational use.

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

The booster accelerates protons from 400 MeV to 8 GeV starting with H- multi turn injection at a rate of 15 Hz. It uses a fast single turn extraction. Beams are for neutrino production and other clients. More than 10^{17} protons are accelerated per hour.

Since its design there has been a continued demand for increased proton flux requiring many upgrades over the years. A factor of more than 10 since 1992 of the proton flux was achieved, a factor of 2 is expected 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 requires working in many different areas: improvement of the orbit, operation with a 2-stage collimators system, improvement of the cogging system + notches.

The proton improvement plan (PIP) includes an increase of the frequency, replacement of components, detailed studies of beam dynamics, a new RFQ, improved alignment of the accelerator components, a measurement of the aperture, relocation of the notcher (fast kickers to create particle free gap at low energy), RF improvement and others.

Characterizing and Controlling Beam Losses at the LANSCE Facility, Lawrence Rybarcyk

LANSCE accelerates H+ and H- beams with a DTL to 100 MeV and with a CCL to 800 MeV. Today it operates with 60 Hz (design is 120 Hz) and has many users. The linac allows for easy switch over from H+ and H- beams.

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Many different pulse patterns and the user requirements are complex.

One target station is called Lujan Center with beam power for H- beams 100 kW and many users (design is 80 kW).

Dedicated collimators are only used in the 750 keV LEBT, no steering magnets are present in the linacs.

Beam instrumentation includes loss detection with BCTs with a resolution of 10^{-5}, scintillators, and 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.

The linac allows a very clear demonstration of IBSt (Intra Beam Stripping) since it can switch between H+ and H- without difficulties.

RF field settings with reduced amplitude away from design values help to reduce beam losses. These observations agree with recent simulations.

An improved control of the beam losses requires better understanding. Online analysis with multi particle dynamics simulations using GPUs is in development, to be used by operation.

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

The design beam power is 1.4 MW, typical operation is with 1 MW.

Beam loss measurements use about 365 BLMs, ionisation chambers, scintillation detectors, and neutron detectors.

The maximum radiation levels are between 0.5 and 3 mSv/h at 30 cm after 2 days of cool down, with hot spots up to 4.5 mSv/h. Mitigation for minimising beam losses includes beam tail scraping, increasing the beam size to reduce Intra Beam Stripping, and empirically changing the magnet settings.

It was observed that beam tails are reforming after scraping. The tail population varies from 0.01 % to 30 %.

In the linac, design values for the optics and the RF are not optimum for minimum beam loss. Changing magnet setting empirically to minimise losses results in settings very different from simulations. Changes of magnet strengths of up to some 10% is not unusual, as well as phase differences of up to 10 degrees for cavities. Small changes can make a large difference, e.g. one degree RF phase change can double the beam loss.

The hypothesis for linac: the low loss set-points are the ones which best transport the halo particles, even when this might result in parameters for the beam core that are away from the design but still acceptable. The ring parameters are close to the design.

Beam Commissioning Plan for CSNS Accelerators, Sheng Wang

CSNS is a recent project, to be ready in 2018 and reaching design parameters in 2021.

A DTL will accelerate protons to 80 MeV and a RCS to 1.6 GeV. Output beam power is expected to be 100 kW, with an option to upgrade the linac energy to 250 MeV and the output beam power to 500 kW.

The first stage 2013-2017 aims at constructing an ion source with low intensity and sending the beam to a target. In a second stage 10 kW beams should be accelerated in 2018. The third stage with 100 kW is planned for 2021. Operation will start with 1 Hz and go finally up to 25 Hz. MEBT and DTL are designed with a large amount of instruments.

The commissioning plans were already defined, profiting from experience of JPARC and SNS.

DISCUSSION SESSION

1. UFOs are observed in the LHC, are they also present other machines? Probably yes, only the LHC is sensitive to UFOs, but is has not been demonstrated that UFOs are present elsewhere.
2. Online models in the control room, what can they provide? Several machines (LANSCE, FNAL, LHC and injectors, SNS, J-PARC) have machine online models. This is considered to be very useful, e.g., for beam loss & collimation simulations. For such models to be used in operation, close collaboration between accelerator physics and operation is required. This is a topic of general interest that could be discussed in the next workshop. LANSCE is working on an on-line particle-tracking model.
3. Scraping? How should it be done, and where? It is felt that concentrating beam losses in dedicated areas makes sense, equipped with specific absorbers. Scraping at different betatron phases is required for optimum efficiency, otherwise it is less efficient (e.g. done in transfer lines CERN-SPS to LHC and FERMILAB). However, this needs space that is not always available. SNS has seen good results in beam loss reduction by scraping at low energy upstream of the DTL.
4. 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, …). A closer coupling between tracking programs and codes for shower calculations would simplify the simulations.
5. Beam Halo: Should the optics be calculated and matched for tails (at least for linacs) and not for core? This is an open question, but deserves some reflections. Non-Gaussian tails are seen in many machines. Instruments to measure the beam distribution in the tails are required, this is a clear wish addressed to the colleagues working on beam instrumentation. Ideal would be non-intercepting halo monitoring during normal operation, and this needs large dynamic range measurements. The agreement between simulation and experiment are much better when using the correct (measured) tails in

simulations. 1/r distribution of tails seen at many ring (comment N. Mokhov). Correct initial beam distribution is a key to accurate simulations of the halo and loss growth.

6. In the PS-SPS good results were achieved by measurements by tomographic reconstruction of non-Gaussian tails, and then using this distribution to understand beam losses.
7. IFMIF follows an interesting idea: they assume that simulations cannot accurately predict beam loss, so they plan to use computer control with a many degrees of freedom search algorithm to empirically reduce beam loss. The question was raised if this might end up in local minimum because losses required to find a better minimum may be excessive. We are looking forward for their experience.

FEW REMARKS

It is interesting to observe that significant beam loss reduction is still possible after many decades of operation, e.g. with new ideas and new techniques.

Some empirical tuning is necessary to minimize the beam loss in high intensity machines. Simulations provide good set points to start from. Beam loss reductions obtained by empirical tuning are about 50% in the SNS and the PSI cyclotron. Both quadrupole and RF phase adjustments may be needed. The LANSCE DTL is a slightly different case, where modern simulations agree with the empirically-derived low-loss set points.

Collimators are essential for beam loss control. At SNS and SPS the amount of the beam scraped is similar (about 3 %).

Beam loss simulations agree with measurements within about a factor of two for rings. However, this is not the case for linacs. In general, for both linacs and rings, loss simulations can be made more accurate by using measured input beam distributions.

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REFERENCES

The presentations in the sessions are written up in the proceedings.