SUMMARY OF THE COMMISSIONING, OPERATIONS AND PERFORMANCE WORKING GROUP OF THE HB-2010 WORKSHOP

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Abstract

As hadron machines approach higher beam intensity and operational power levels, issues such as machine activation caused by beam loss, machine protection and machine availability become more critical concerns. The operational experience of the high power, high intensity facilities in these areas is compared.

INTRODUCTION

This working group covered commissioning and operational developments of high intensity hadron devices. On the commissioning front, the primary development was the initial operation of the Large Hadron Collider (LHC), with unprecedented beam energy and stored energy concerns. On the operational front, high power operation is a common theme, with mega-Watt beam operation at the PSI and SNS facilities, and operation at the 100's kW level at LANSCE, ISIS, J-PARC and FNAL. The high energy frontier at LHC faces unique challenges in machine protection issues, with the complex collimation schemes working well over the course of the commissioning. The high power facilities also have concerns with machine protection, as well as residual activation from uncontrolled beam loss, and machine reliability. The experience of the major facilities in these areas is summarized below. Details of each of the session contributions are presented in the individual papers. In this summary, we concentrate rather on the common themes.

COMMISSIONING

The Large Hadron Collider at CERN commissioned beam over the past year. Preparations have provided a smooth start for commissioning and initial operation. Beams were circulating within 6 hours, initial collisions within three days, and stable collisions in about two weeks. The initial commissioning was done with low intensity beam, to accommodate setup of the machine protection and collimation systems, with no beam crossing. At the time of the workshop 150 bunches (10 MJ) had been accumulated, and 400 bunches (30 MJ) are expected by year's end. This is to be compared to a design of 360 MJ stored energy. To date the protective measures are working well and no magnet quenches from beam loss have occurred. The average store time is 8 hrs. An unexpected observation is occasional unexpected fast local beam loss events, possibly caused by from beam scattering. These events are not well understood yet.

LHC Collimation

A key component of LHC operation at unprecedented stored energy levels is a complex collimation system designed to protect the beamline devices (e.g. prevent superconducting magnet system from quenching). The collimation configuration process is empirically determined for a given beam setup, with complex pre-programmed algorithms following the beam through the ramp stages. Many interlocks are required to assure the machine protection (order 10^4). The collimation setup time requires about one week, but this is not expected to hinder LHC progress. The present setup was used for about three months. Repeatability of the collimation position control is critical, with tolerances on the order of only 10 μm. Of interest is certainly the fact that the measured collimation efficiency is close to the calculated predictions.

HIGH POWER FACILITIES

In contrast to the LHC colliding stored beam facility, high power accelerator facilities have much lower instantaneous stored beam energy. However the high power facilities continuously accelerate beam and have higher peak and average beam powers. Concerns for high power facilities include protecting equipment from sudden damage caused by errant conditions in which beam hits equipment, protection against excessive build-up of residual activation, and protection of the environment (e.g. ground-water contamination). Also many high power facilities are user facilities, with high reliability expectations. Machine availability and operational aspects are discussed.

Machine Protection Systems

There are many commonalities amongst the protection systems that have evolved in the high power accelerator community. All facilities have some sort of "tune-up" machine protection system. This sort of configuration allows beam operation with higher fractional beam loss than would be permitted in full power mode, yet restricts the beam operation to a lower power mode (such as reduced current, pulse length and/or repetition rate). This mode of operation is useful for beam studies, and critical for initial beam commissioning. Also, all facilities employ redundant beam shut-off mechanisms to ensure shutting of the beam even in the case of a failure of one of the mechanisms. Another commonality of machine protection systems is some sort of by-pass control mechanism. Systems are never perfect, and sometimes inputs to the system produce false signals (e.g. faulty beam loss detection, failing coolant flow signal). Often when there are redundant inputs for a given fault conditions it is possible to temporarily bypass one signal and continue running. The degree of formality in these bypass systems varies greatly from facility to facility. The LHC system has a quite strong level of control, with a data-base system, and signatures are required before bypass can be permitted.

The inputs to the machine protection systems are typically fast inputs (beam loss monitors, collimator currents and in some facilities power supplies, transmission monitors, and acceleration devices) and slow inputs (magnet currents, equipment and coolant temperatures, and flow rates). Quantities of inputs vary from hundreds of inputs to ~10^4 inputs for LHC, and careful management and display software is required to monitor the status of inputs, bypasses, etc. Also, at SNS, the importance of overall periodic system testing was noted, to measure unexpected over-all performance degradations (e.g. beam turn-off times) from incremental changes in sub-system components (e.g. noise suppression in communication networks).

The beam shut-off response time critera vary from ~ 1-10 ms for the CW machines (PSI) to ~ 10 μs for the pulsed machines (e.g. LANSCE, J-PARC and SNS). This separation of time-scales can be understood by examining the timescales for material damage, for a given average beam current. Figure 1 shows the time for a 100 degree C temperature rise in Aluminium exposed to a proton beam with different energy and current (ignoring all heat dissipation). The situation is most critical at low beam energy (< 10 MeV). For beam currents typical for high power pulsed machines (e.g. 10-100 mA), the time-scale is ~ 10-100 μs. For beam currents more typical of high power CW devices (e.g. 1 mA) the time-scale is closer to 1-10 ms.

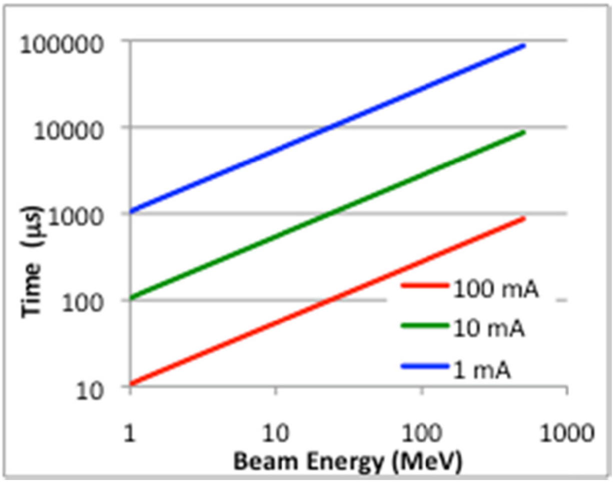

Figure 1. Time for a 100-degree C temperature rise in Al, exposed to a proton beam of various energy and current.

Some facilities employ a dual layer beam loss protection system: a fast layer to prevent sudden equipment damage from errant beam, and a slower layer to prevent excessive residual activation damage. The fast system is hardware based and protects from sudden destructive beam loss situations. The beam loss detection system threshold for this sort of damage can be relatively high, since beam loss monitoring systems are quite effective at detecting quite low fractional losses, which may not cause immediate damage. However, these systems are not optimal for controlling the very small permissible fractional beam loss acceptable at high power operation with respect to residual activation. Lowering the fast hardware trip level to control residual activation build-up can result in excessive noise induced nuisance trips. Slower integration systems (such as software systems or implemented in the electronics firmware) can be used to provide an averaged value more amenable to monitoring very small fractional beam loss levels.

Finally we note that the high power accelerator machine protection systems tend to have faster time responses than commercially available systems, or those used in the nuclear industry. Thus the accelerator machine protection systems are developed in-house and are one-of-a-kind systems.

Residual Activation

A primary element in operation of high power accelerator facilities is control of the equipment residual activation. Excessive residual activation levels complicate the maintenance and repair activities, with measureable effect of reliability and hours of operation. Machines are able to operate with residual activation levels up to 1-10 μSv/hr at 30 cm, at high loss locations (e.g. injection or extraction regions of Rings). Some facilities have higher activation levels in regions of controlled beam loss (e.g. collimation or beam dumps). These higher activation locations require special provisions for repair work such as specialized shielding and tooling. The J-PARC facility has lower activation levels than other high power facilities, but is still in the early stages of it's power ramp-up (i.e. beam power and hours of operation).

Operating a high power facility results in annual work force exposure doses of 10's of mSv. For example, recent annual experience at SNS was 20 mSv, LANSCE 50 mSv, J-PARC-5 mSv, FNAL 30 mSv and PSI 47 mSv.

Models are used successfully to predict expected residual activation levels for a prescribed beam loss (e.g., see papers from working group on Beam-Material Interactions in these proceedings). The models range from simple scalings to complex simulations of beam/material interactions. It is important to model expected activation levels during design stage of high intensity machines, when mitigation action is more easily possible. Mature facilities can accurately predict post-operational residual activation levels based on past experience. Even in initial power-ramp-up stages, the activation levels can be reasonably predicted with modest increments in power levels (10s of percent), based on beam loss measurements.

Availability

Beam availability is defined as the time beam is provided divided by the planned beam-on time. Typically availability is reported for periods of ~ one year, to avoid influences of singular long down time events and to accurately capture a statistically meaningful period. Some recent annual machine availabilities are SNS – 86%, PSI-85 to 90%, ISIS – 88% (average 1998-2008), LANSCE/Lujan centre – 85%, FNAL – 95% (Main Ring only), and J-PARC – 92% (annual average not available for J-PARC, this is for 5 recent runs). It is quite difficult to exceed 90% availability for extended periods with high power machines, and also operate more than 5000 hours/year. PSI and ISIS have approached this level, but no high power facilities have been able to maintain > 90% availability for any extended period of years. All facilities tend to have lower availability at the start of extended run periods and the consensus is that longer runs with fewer scheduled extended maintenance periods are preferable, if possible.

Another operational consideration is the time to restore a well tuned high power beam after an extended outage. Typical start-up periods are SNS: ~ 1 week, LANSCE: ~ 3-4 weeks, PSI: ~ 2 weeks, FNAL: 2-3 days, ISIS: ~ 1 week per month of down-time.

Operational Hours

The number of hours these machines operate in a production mode annually varies widely, and often is funding limited. As examples, the past year PSI operated 5600 hrs (64% of the year), SNS operated 4900 hours (56% of the year) and LANSCE/Lujan operated 3300 hours (funding limited). For the case of SNS, the remaining fraction of the year was spent in maintenance and upgrades (30%), beam studies and monthly maintenance (10%) and start-up (3%).

Loss Tuning

A final mention is needed on the subject of loss tuning. For high power, high intensity machines, beam loss is a primary driver in machine setup, and often a limitation on the attainable power. It is common among the high power facilities to do “loss based tuning”. This is a description of adjusting magnet, and RF settings to empirically reduce the beam loss. Typically, model based methods are initially used to configure the machine setup, at lower power levels. Then loss based empirical tuning is employed to reach levels deemed suitable for high power operations. The reasons these typically slight adjustments help reduce beam loss are not fully understood, but given the very small fractional beam losses being affected (10^{-4} to 10^{-6}), this is perhaps not surprising.

ACKNOWLEDGEMENTS

We would like to thank all the participants of the working group on commissioning, operations, and performance. The summary material presented here is composed from input from all the participants in both presentations and working discussions.