Summary of Session on Beam Losses, Halo Generation and Collimation

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Abstract

The session on beam losses, halo generation and collimation is the first of two sessions of the BEAM07 Workshop, which were devoted to specific CERN-GSI subjects and were meant to be the follow up of last year's CERN-GSI Bilateral Meeting on Collective Effects, which took place on March 30-31, 2006 at the GSI-Darmstadt.

INTRODUCTION

The goal of the session on beam losses, halo generation and collimation was to identify the main loss mechanisms in ion or proton rings and the tools to model them.

During this session, specific beam loss issues in different existing machines (SIS18, PS, SPS, RHIC) were described and explained through simulations. Collimation systems have been proved necessary for future (or upgraded) machines to be able to localize and control the beam losses, which may become intolerable for high intensity/high energy beams, if randomly distributed over the machine. The design of efficient collimation systems strongly relies on the capability of the present simulation techniques to predict with high accuracy the loss distribution around a machine. Therefore, the successful benchmark of the so far developed simulation tools (containing particle tracking, scattering and secondary generation) is a necessary asset to establish their reliability and range of applicability. Most of the presentations of this session (R. Bruce, S. Gilardoni, C. Omet, S. Redaelli, G. Robert-Demolaize, P. Spiller) covered:

- Collimation and studies of loss localization in several machines (PS, SPS, LHC, SIS18, SIS100/300, RHIC)
- Code benchmark against measurements in running machines (PS, SPS, RHIC)

In two presentations (G. Franchetti, S. Sorge), some exotic loss mechanisms were explained in greater detail:

- Resonances induced by the electron cooler
- Trapping and loss induced by electron cloud in a dipole field

Several methods to track scattered and secondary particles and study loss distribution were outlined. The tools were optimized case by case according to specific needs and requirements:

- A combination of Sixtrack for particle tracking and K2 for modeling the interaction with matter is used for specific collimator studies (SPS, LHC, RHIC). It was also modified and adapted to study losses in the PS

- Generation of external distribution through MARS and tracking with MAD-X. It was applied to the PS
- ICOSIM, as a self-consistent package inluding tracking and ion-matter interaction. It uses MAD-X optics and nuclear interaction cross-sections from RELDIS and ABRATION/ABLATION routines. This tool has been widely used for studying ion losses in the SPS and predict those in the LHC
- STRAHLSIM (code developed at GSI) for full ion tracking including capture/recombination phenomena (cross sections available within 30% accuracy at the needed high energies), scattering and desorption. It was used to design the collimator system for the upgraded SIS18 and for the SIS100/300.

All these methods also need to depend on a detailed external aperture model (and detailed collimator geometry, where applicable) to predict the loss locations

The reasons why it is very important to develop powerful and robust tools to predict losses around a circular machine are:

- Assess the required cleaning performance of collimator systems for new superconducting machines with high stored beam energy (e.g. LHC has 360 MJ stored energy to be compared with typical quench limits for superconducting magnets of the order of few mW/m^2)
- Save surroundings from irradiation (CT extraction in the PS). If losses can be predicted, they can be also suppressed or relocated in order not to exceed the allowed irradiation doses in critical areas and to increase the transmission efficiency and performance of the machine
- Determine and steer the design of collimator systems in new machines (LHC, SIS100, PS2) or new collimator systems necessary for the upgrade of existing machines limited by loss induced vacuum instabilities (SIS18)

The reliability of these tools can be only assessed through direct benchmark with known loss patterns in running machines (PS, SPS, SIS18, RHIC) and their predicting power is the base on which the design of collimation systems is founded. In the specific case of LHC, there are at least three reasons why the collimation system is an unprecedented challenge: 1) losses have to be controlled 1000 time better than the present state-of-the-art, 2) collimation is needed at all machine states (injection, ramp, squeeze, store), and 3) the collimation system plays an important role for machine protection.

COLLIMATION SYSTEMS FOR THE LHC AND THE UPGRADED SIS18

S. Redaelli presented the basic scheme of the multi-stage collimation in the LHC. The primary halo of the circulating beam hits the primary collimators, so that the resulting hadronic showers and secondary halo will be intercepted by the secondary collimators. Some shower absorbers are placed further downstream. The tertiary beam halo will be finally intercepted by tertiary collimators which are situated just in front of the superconducting triplet. In addition, some protection devices are placed at intermediate settings in order to shield sensitive machine equipment (including some collimators) from full beam impact possibly induced by missteering. Collimation is needed in LHC from injection to collision, forcing the devices to be movable such that their position may be adjusted according to the beam size. All cleaning and protection devices have to be included in the simulations to assess the efficiency of the system.

In the SIS18 the main reason for vacuum runaway leading to beam loss is the charge exchange process. U^{28+} can be further ionized by collisions against the rest gas, so that the U^{29+} ions are lost in the bends because of the higher charge and start a vacuum instability process due to the high desorption yield values. Therefore collimators have to be inserted downstream from the dipoles to catch all the ions with the wrong charge and localize the loss. P. Spiller and C. Omet pointed out that losses should be peaked at location of the collimators (designed such as not to reduce the machine aperture), where the main beam and the products from charge exchange are well separated. The performance of SIS18 is expected to increase dramatically (and meet the requirements to become injector for SIS100) with the use of adequately placed absorbers along with NEG coating and pumping ports in the vicinity.

BENCHMARK OF SIMULATION PACKAGES WITH EXPERIMENTAL DATA

S. Redaelli showed the results of the comparison between the predicted loss maps (using a combination of Sixtrack for particle tracking, K2 for modeling the interaction with matter and BeamLossPattern for the detailed aperture model) and the measured ones. Measurements were taken at the SPS using the signals of the Beam Loss Monitors, when the circulating beam in the machine was scraped by an LHC collimator prototype. The agreement is remarkably good, because it can successfully reproduce not only the high peak at the collimator location, but also the other small peaks present in other locations of the machine (where the scattered or secondary particles hit some aperture limitation).

The same sets of data were used in the study presented by R. Bruce to benchmark the ICOSIM code against experimental data. The ICOSIM code is oriented to the ion collimation, which needs to be studied separately because, due to large probability of fragmentation in primary collimators, there is a high production of isotopes having Z/A which would not be intercepted by the secondary collimators as designed for protons.

The same tool as used for the SPS was also used by J. Barranco and S. Gilardoni to benchmark loss data in the PS machine. However, this required some modifications, in particular the halo had to be identified with the scattered particle distribution and the event cross sections had to adapted to the lower energy of the PS. The resulting loss pattern turned out to be in very good agreement with the measured one. Still based on this simulation tool, G. Robert-Demolaize presented a satisfactory comparison between simulated loss locations and live measurements from the RHIC BLMs, when the collimator jaws were moved in different positions.

GSI simulations are all based on the internally developed code, called STRAHLSIM, which can apparently well reproduce the loss patterns as presently observed in the SIS18.

MORE CONSIDERATIONS ON SOME LOSS MECHANISMS

Particle loss occurs at different stages due to several mechanisms. For example, there are usually injection and rf-capture losses in all machines, and particles can get lost on the accelerating ramp if they were not correctly captured in the buckets. The result of a GSI study presented by P. Spiller was that fast ramping can help to reduce the losses on the ramp, and an optimum can be found before the rf-capture losses take off. In the frame of the FAIR project, an SIS18 uppgrade program has been approved to improve all the known loss mechanisms. The most important points (some of which will be financed by the EU) are:

- New RF-System, h=2 acceleration cavity and bunch compression system (2009)
- Upgrade of the UHV System, with new, NEG coated dipole and quadrupole chambers (2006-2008). Next year the SIS18 will run with 30% of the chambers coated and a significant improvement in the storage and acceleration of U^{28+} is foreseen.
- Set-up of a of the previously described desorption collimation system (2007-2008)
- Upgrade of the Injection/Extraction Systems, with a new injection septum, power supply and large acceptance extraction channel (2007)
- Replacement of Main Dipole Power Supplies, to allow operation with 10 T/s up to 18 Tm (2010)

On top of that, to push the SIS18 performance and fight instabilities and halo formation, a crash program for the development of high current operation has been started in 2007, including studies on compensation of resonances and impedance reduction. Furthermore, longitudinal and transverse feedback systems are being designed for damping of

coherent oscillations, coupled bunch modes and for phase stabilization.

Beam losses also occur because particles move to large amplitudes in the transverse plane due to resonance crossing and eventually hit some aperture limitations. G. Franchetti developed an analytical model which explains why the stripe structure of the electron cloud inside a dipole field during the pinch can cause single particle detuning depending on the longitudinal position of the particle within a bunch. Trapping in the islands and growth to the large amplitude is therefore possible due to the synchrotron motion, which moves the particles in the longitudinal direction and causes them to see different detunings in a periodic fashion. This may result in emittance growth in rings like the SPS and the SIS100, if there is an electorn cloud and its density is high enough. S. Sorge studied the effect of the electron cooler on detuning and resonance crossing, which is relevant both for the SIS18 and for some of the future GSI storage rings that are planned to be equipped with an electron cooler. The resonances that can be excited by the electron cooler have been identified using MAD-X with a nonlinear kick, which models the electromagnetic interaction of the beam with the electron cooler. When the machine working point is such as to cross any of these resonance lines, emittance growth sets in.

CONCLUSIONS

Many tools have been developed to predict beam loss locations in rings and they have been successfully benchmarked against measurements. Based on these tools, collimation systems have been designed for new or upgraded rings. Furthermore, understanding the location of the losses gives a powerful tool to suppress or relocate them conveniently.

Electrons in a proton or ion machine (from an electron cooler or an electron cloud) may cause losses The odd distribution of a uniform electron cloud pinched in a dipole field can give rise to trapping and hence, to emittance growth. The electron cooler was found to excite resonances up to 6th order.

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