SIXTRACK-FLUKA ACTIVE COUPLING FOR THE UPGRADE OF THE SPS SCRAPERS

A. Mereghetti*, CERN, Geneva, Switzerland, and UMAN, Manchester, UK,
F. Cerutti, R. De Maria, B. Goddard, V. Kain, M. Meddahi, O. Mete, Y. Papaphilippou,
D. Sinuela Pastor, V. Vlachoudis, CERN, Geneva, Switzerland
R. B. Appleby, UMAN, Manchester, UK

Abstract

The LHC Injectors Upgrade (LIU) Project aims at upgrading the systems in the LHC injection chain, to reliably deliver the beams required by the High-Luminosity LHC (HL-LHC). Essential for the clean injection into the LHC, the SPS scrapers are one of the important systems under revision. In order to take into account of the effect of betatron and longitudinal beam dynamics on energy deposition patterns, and nuclear and Coulomb scattering in the absorbing medium onto loss patterns, the SixTrack and Fluka codes have been coupled, profiting from the best of the refined physical models they respectively embed. The coupling envisages an active exchange of tracked particles between the two codes at each turn, and an on-line aperture check in SixTrack, in order to estimate the local cleaning inefficiency of the system. Knob-like, time-dependent strengths have been implemented in SixTrack, since the designed scraper system foresees the use of a magnetic bump. The study is intended to assess the robustness of the proposed scraper as well as its effectiveness with respect to the desired performance.

INTRODUCTION

The High Luminosity LHC (HL-LHC) Project [1] aims at increasing the peak LHC luminosity by a factor of 10 beyond its design value. This upgrade is intended to be achieved by improving the machine optics and the beam quality from the injectors. The LHC Injectors Upgrade (LIU) Project [2] is in charge of the latter, upgrading the systems in the LHC injection chain necessary to reliably deliver the required beams. Due to the improved beam parameters and the increased levels of heat load thus expected, a review of the beam-intercepting devices protecting the whole accelerator chain is on-going, especially those in the Super Proton Synchrotron (SPS), in the SPS-to-LHC transfer lines, and in the LHC injection regions [3].

Among the systems under review, the SPS scrapers are a key ingredient for the clean injection into the LHC: they cut off halo particles quite close to the beam core (e.g. 3.5σ) just before extraction, in order to minimise the risk for quenches [4]. The scrapers presently used during operation are installed in the Long Straight Section (LSS) 1 of the SPS: being a single 1 cm long carbon jaws per plane, they are mechanically swept through the beam at a constant transverse position, with a fast movement (see Fig. 1).

* alessio.mereghetti@cern.ch

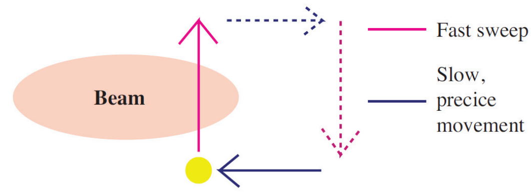

Figure 1: Schematic view [5] of the movement of the SPS scraper jaw during operation: tails outside a desired amplitude are cut off by means of a fast movement through the beam, starting from the parking position (marked by the yellow spot). Only the horizonal scraper is shown.

In the framework of the LIU project, a new design has been proposed as alternative to the present system [6]: the beam is sent against a static absorber block by means of a magnetic bump. Relevant operational assets of this new concept are the better control and sensitivity of the scraping settings with respect to the present system. Moreover, the secondary radiation generated by the interaction of the beam with the absorbing medium can be better shielded, with a consecutive lower pollution of the machine and activation of the tunnel.

Simulations are a relevant tool for the design of the new system, in order to estimate the heat load onto the absorber, the generated losses, both downstream of the scraper and all around the ring, and the induced radioactivity. The studies are technically even more challenging due to the change of the beam impact parameters with time, i.e. revolution by revolution.

THE ACTIVE COUPLING

In order to carry out the simulations, Fluka [7, 8] and SixTrack [9, 10] have been actively coupled: the two codes are compiled independently, run separately at the same time, and exchange particles at run time through a network port. The FlukaIO protocol [11] has been developed on purpose, for managing the communication.

One of the most relevant assets of the coupling is the use of two codes with a long history of development and solid benchmarking: the reliable and refined physics models implemented in one are used for improving the results of the other one, and viceversa. Moreover, the flow of information is direct, with the human intervention being only at the set-up level. In addition, the use of a network port for exchanging particle data drastically reduces the simulation

ISBN 978-3-95450-122-9

time with respect to writing/reading files, and saves space on disk.

Implementation Details

An entry in the sequence describing the accelerator in input to SixTrack is flagged for coupling; at the same time, the corresponding geometry must be implemented in Fluka. Once the simulation has started, every time the tracking in SixTrack reaches the flagged entry, beam particles are sent to Fluka for being tracked in its 3D geometry; once a special surface defined in the Fluka geometry is traversed, they are sent back to SixTrack (see Fig. 2).

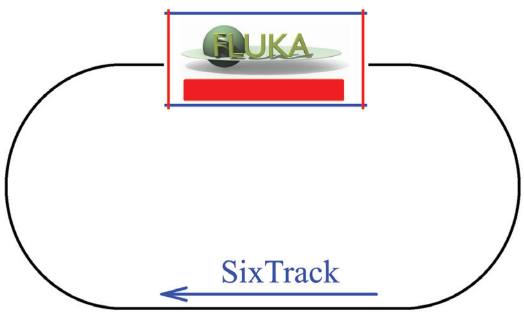

Figure 2: Schematic view of the Fluka-SixTrack coupling.

The coupling is enabled in SixTrack by means of a dedicated `ASTUCE` flag, and it is actually activated by the `FLUK` input block in the SixTrack configuration file (`fort.3`), created on purpose.

At present, the global reference system in Fluka must coincide with the local curvilinear reference system in SixTrack at the flagged element, but for a longitudinal transformation: this can be easily achieved if the concerned element is a drift-like element, e.g. a collimator. Moreover, it is extremely important that only one entry in the whole accelerator structure is flagged, in order to preserve normalisation of data in Fluka.

It should be noted that the interface plane at the "end" of the Fluka geometry of the concerned element is relevant only for sending beam particles back to SixTrack: secondary particles can be anyhow further tracked if the Fluka geometry is extended, so that quantities relevant for downstream locations can be computed at run time.

In order not to overestimate scored quantities, particles that have interacted in Fluka must be removed from the beam as they are lost, either without sending them back to SixTrack (e.g. by means of a filter, preventing SixTrack from handling too off-momentum particles), or naturally loosing them in the accelerator because they don't have a suitable magnetic rigidity. Thus, the online aperture check plays an important role, and it has been re-established in SixTrack. Furthermore, thanks to slicing, it can be performed in multiple locations inside the same magnet.

The coupling can be enabled also for a sequence of adjacent elements: two delimiting markers must be labelled as entry and exit points, and the corresponding Fluka geometry defined. It is the user's responsibility to assure the correspondence between the extension of the Fluka geometry and the length of the flagged portion of accelerator.

Recent developments involve read-out of a map of particles at SixTrack initialisation, and dumping the 6D coordinates of the full beam population, or related statistical data (i.e. averages and standard deviations) at locations selected by the user at simulation set-up. All these features are triggered by the user by means of dedicated input blocks in the SixTrack configuration file.

Extensions: 6D Tracking and Dynamic Kicks

Given the current design proposed for the LIU SPS scrapers, the coupling has been improved to deal with the 6D tracking in SixTrack. Moreover, dynamic kicks were implemented in SixTrack, so that strengths of selected magnets can be varied revolution by revolution.

While the momentum was already part of the set of information exchanged by the two codes in the original implementation of the coupling, the extension to 6D tracking required to add to the communication interface the path travelled by a particle in the Fluka geometry. The `ATRACK` variable in Fluka internally stores the time since a primary particle is started: this variable is passed through the interface when a particle is sent back to SixTrack, and it is converted into the respective travelled path. The user must provide SixTrack with the path-length of the synchronous particle at simulation set-up, in order to properly compute the phase delay: thus, the user has to provide the correct value (it can be easily taken from the twiss file), and assure the consistency of the Fluka geometry.

Dynamic kicks are implemented in SixTrack following the strategy adopted for ripples, and they can be applied to all the SixTrack non-linear elements (i.e. indexes between `-10` and `11`, with zero length). At simulation set-up, the user declares in the SixTrack configuration file the single elements that should be affected, along with the profile to be used, and a multiplication factor. Each profile is read from its file and stored in memory: it must specify the intensity (in arbitrary units) as a function of the revolution number. At the beginning of each turn, the kick of each concerned element is updated; if its value at a given turn is not explicitely stated in the profile, a linear interpolation is performed, using the two closest values. The optics the user should provide SixTrack with must contain the nominal values of the kicks, used for their modulation.

FIRST RESULTS

Results of full beam scraping with a 1 m long block, made of CfC carbon-fibers with a density of 1.7 g cm^{-3}, were presented at the recent review of the LIU-SPS scraping system [12]: energy deposition values were estimated varying the beam impact angle, scraping speed, and absorber length. The simulations were carried out actually moving the scraper towards the beam (by means of geometry directives in Fluka), starting from a distance of $\sim 5\sigma$ from the beam centre. A 4D tracking was performed, with a thin lens model of the accelerator (with 5 slices in the main dipoles, and 3 in all other elements), and aperture checks at each slice. The black, magenta and green curves in Fig. 3 show the longitudinal pattern of the peak energy deposition in the scraper, for three different impact angles, displacing the absorber block by $\sim 0.002\sigma$ per turn.

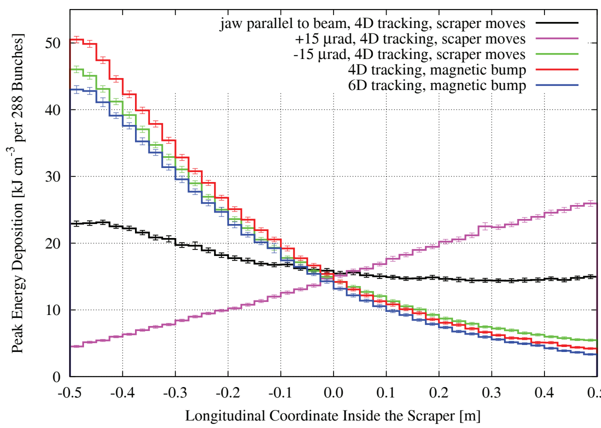

Figure 3: Longitudinal pattern of the peak energy deposition in the LIU SPS scraper, for different simulation settings. Error bars indicate to statistical errors.

The dynamic kicks just implemented allowed to obtain first results actually simulating the rising of the magnetic bump in SixTrack. The red curve in Fig. 3 shows the case of 4D tracking, whereas the blue one shows the case of 6D tracking, made available by the recent upgrade of the coupling. The position and angle of the scraping edge of the block in these two cases have been set to the natural values of the bump at full nominal amplitude. The red curve is similar to the green one, featured by a little, constant impact angle: the natural angle of the bump at the scraper increases with amplitude by $\sim 15\mu$rad per each σ on the transverse position. The blue curve shows lower values, since the longitudinal motion helps in spreading the impact parameter of beam protons.

Figure 4 shows the evolution in the number of beam particles with time. As expected, the red curve reproduces the black one, but for a small delay, mainly due to a tiny offset in the average position of the beam at the scraper, induced by the sextupoles in the bump region. The curve for the 6D tracking faithfully follows the one for the 4D tracking at the beginning, but is then featured by an enhanced cleaning speed: indeed, the longitudinal dynamics slowly moves particle ellipses in the phase space, bringing them on the side of the scraper from the opposite one.

CONCLUSIONS

The active coupling between Fluka and SixTrack has been set up: the two codes exchange particles at run time through a network port, while running separately. It has been systematically used for estimating values of energy deposition in the SPS scrapers in the framework of the LIU project [12].

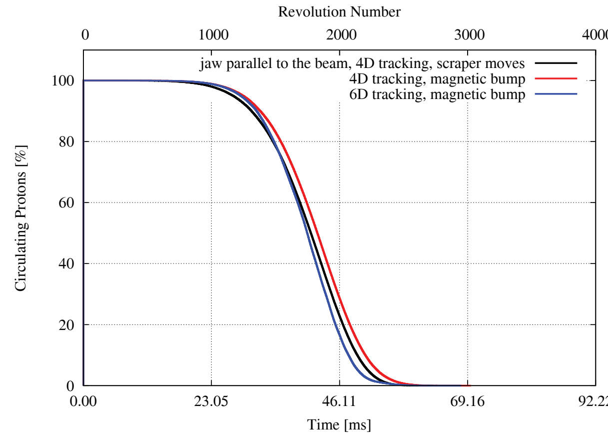

Figure 4: Evolution in the number of beam particles with time, from the beginning of the simulation. The equivalent turn numbers are indicated as well.

The handling of dynamic kicks has been recently added to SixTrack, and the coupling improved to deal with full 6D tracking. First results from the studies about the LIU-SPS scrapers give good indications for a sound implementation. These major upgrades, together with other smaller features, have been added in a general way, so that they can be re-used in other cases.

REFERENCES

[1] hilumilhc.web.cern.ch

[2] espace.cern.ch/liu-project

[3] O. Mete et al., "Upgrades of the SPS, Transfer Line and LHC Injection Protection Devices for the HL-LHC Era", MOPFI053, these proceedings.

[4] G. Arduini, H. Burkhardt, "Transverse Tail Scraping in the SPS for Clean LHC Injection", CERN EDMS Doc. 772782, 2006.

[5] P. A. Letnes et al.,"Beam Scraping to Detect and Remove Halo in LHC Injection", EPAC'08, Genoa, June 2008, THCP149, p. 3339.

[6] O. Mete et al., "Design of a Magnetic Bump Tail Scraping System for the CERN SPS", THPEA040, these proceedings.

[7] A. Fassò et al., "FLUKA: a Multi-Particle Transport Code", CERN-2005-10, INFN/TC-05/11, SLAC-R-773.

[8] G. Battistoni et al., "The FLUKA code: Description and Benchmarking", Proc. of the Hadronic Shower Simulation Workshop 2006, Fermilab 6^{th}–8^{th} September 2006, M. Albrow, R. Raja eds., AIP Conf. Proc. 896, p. 31, 2007.

[9] F. Schmidt, "SixTrack Version 4.2.16 Single Particle Tracking Code Treating Transverse Motion with Synchrotron Oscillations in a Symplectic Manner", CERN/SL/9456, 2012.

[10] G. Ripken, F. Schmidt, "A Symplectic Six-Dimensional Thin-Lens Formalism for Tracking", DESY 95-63 and CERN/SL/95-12(AP), 1995.

[11] twiki.cern.ch/twiki/bin/view/FlukaTeam/FlukaIO

[12] LIU-SPS Beam Scraping System Review, January 2013, indico.cern.ch/conferenceDisplay.py?confId=221617

ISBN 978-3-95450-122-9