BEAM TRANSPORT WITH SCATTERING USING SRIM SUPPORTING SOFTWARE ROUTINES CODE*

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Abstract

The paper describes a beam-generation and a beam-transport modules of the S^3M (SRIM Supporting Software Modules) code-package. The modules are used to combine SRIM Monte Carlo simulations of beam passage through matter-containing elements (e.g. stripping foils, beam-scattering devices etc.) with standard beam-transport formalism based on the sigma-matrix beam representation and the transfer-matrix description of the ion-optical elements. Beam transport in complex beam-lines containing scattering elements can be calculated. SRIM simulations with a realistic input-beam model can be performed.

INTRODUCTION

In many situations a particle beam passes through matter-containing elements separated by ion-optical elements. The matter-containing elements scatter the beam and alter (blow-up) its emittance diagram mainly by multiple Coulomb scattering of particles' angles. In order to include accurately the scattering in beam transport, special modules were included in the SRIM Supporting Software Modules package – S^3M [1]. They combine transfer-matrix formalism in ion-optical elements with Monte Carlo particle tracking in matter. At the entry to a scattering element, the beam-generation routine converts the actual sigma-matrix into an ensemble of particles and writes a special SRIM input-file. The beam-transport in the scattering element is then calculated by SRIM. At the exit of the scattering element, the emittance module fits a sigma-matrix to the actual particle distribution in the phase-space, which can be used by other ion-optical programs. Alternatively, the SRIM output data can be used by the S^3M beam-transport module performing transfer-matrix transformations of individual particles' co-ordinates. It means, the beam transport with scattering can either be fully calculated by S^3M or data exchange between S^3M and ion-optical programs is provided. In addition, realistic beam parameters resulting from the beam-transport calculations can be used as an input for simulation of beam-interaction with a final target.

DESCRIPTION OF THE PROGRAM MODULES

In order to combine particle-tracking with beam-envelope transformations, two kinds of conversion-routines must be available: (1) a routine that fills-in the beam contours in the phase by individual particles and (2)

a routine that fits a sigma-matrix to a given ensemble of particles. Both routines are included in the S^3M. The first one is a part of the beam-generation module; the second one is a part of the emittance module.

Beam-Generation Module

The beam-generation module fills-in the beam-contours in the phase-space by individual particles. Elliptical emittance diagrams are assumed in both horizontal and vertical phase-space; no coupling. The emittance diagrams and the emittance can be different in the two transverse planes, which makes it possible to calculate transport of non-symmetric beams. The elliptical beam contours are determined by the maximum beam radius, maximum beam divergence and the total geometrical emittance, from which the Twiss parameters are calculated as shown in Fig. 1. The orientation of the ellipse (i.e. a converging or a diverging beam) is specified by the user.
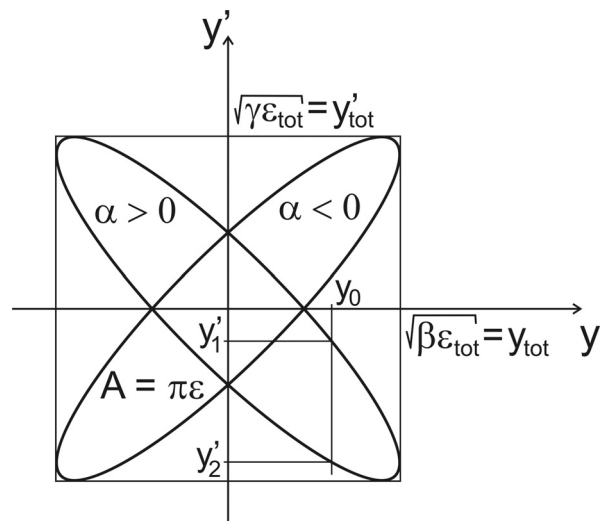

Figure 1: Emittance diagram and Twiss parameters. α, β, γ – Twiss parameters, ε_{tot} – total geometrical beam emittance, y_{tot} – the maximum beam extent (radius), y'_{tot} – the maximum beam divergence.

The particles are generated following certain beam profile and angular distribution (uniform or Gaussian) as well as certain energy distribution (Gaussian) that is characterized by an energy spread. In the case of the Gaussian distributions, the standard deviations must be specified by the user. The distributions are cut-off at the maximum values.

A special feature is provided to take into account the dispersion of the beam line. First, the particle co-ordinates

are generated without the dispersion contribution. However, each particle-record contains particle energy. In the next step, particle co-ordinates are altered according to the dispersion. The D.(dp/p) shift is added to the particles' positions and D'.(dp/p) contribution is added to particles' angles. The relative momentum deviation dp/p is calculated from the actual energy of individual particles. The final particle co-ordinates are stored in a special file that is used as an input file in SRIM.

Beam-Emittance Module

The beam-emittance module is mainly foreseen to display emittance plots as well as the beam cross-section in the real space. However, a special numerical routine is included fitting a sigma-matrix to a given ensemble of particles. The statistical meaning of the sigma-matrix terms is used for this purpose [1]. Typically, the sigma-matrix is constructed behind a beam-scattering device, thus converting the ensemble of particles back into the beam-envelope formalism. The sigma-matrix can be used as an input for dedicated ion-optical programs.

Beam-Transport Module

If no special ion-optical functions like matching are required, the individual particle co-ordinates can be transformed according to the transfer matrix representing an ion-optical element. The present version of S^3M has no built-in library of ion-optical elements rather than the transfer matrix terms have to be inserted by the user. The transfer matrix input can also be used to introduce a coupling between the horizontal and vertical planes.

BEAM-TRANSPORT CALCULATIONS

Transport without Scattering

Let us assume a simple demonstrative beam line – a quadrupole doublet focusing an initial diverging 4 mm beam (1σ, diameter) with 1σ geometrical beam-emittance of 4π mm.mrad back to the 4 mm beam spot. The setting for the quadrupole doublet was found with the aid of the matching routine available in WinAGILE [2]. WinAGILE also provides transfer matrices for any sub-system of the beam line. These transfer matrices were used by the S^3M beam transport module to calculate the beam transport along the beam line. The beam cross-section was calculated in several significant positions: (a) entrance to the beam line, (b) entrance to the doublet, (c) exit of the doublet and (d) exit of the beam-line. Results are shown in Fig. 2.

Transport with Scattering

In the next run, a 50 μm Al scattering foil has been placed at the beginning of the beam line. A 20 MeV proton beam as generated by the S^3M beam-generation module passed the foil first. The foil-action is dominated by the multiple Coulomb scattering that alters the particles' angles and blows-up the emittance. A file of transmitted particles is recorded by SRIM. This file was

imported to S^3M and the transfer-matrix transformations were applied again. Results are shown in Fig. 3. The effect of scattering can be observed and evaluated quantitatively by fitting a sigma-matrix to the final particle distribution in the phase-space.
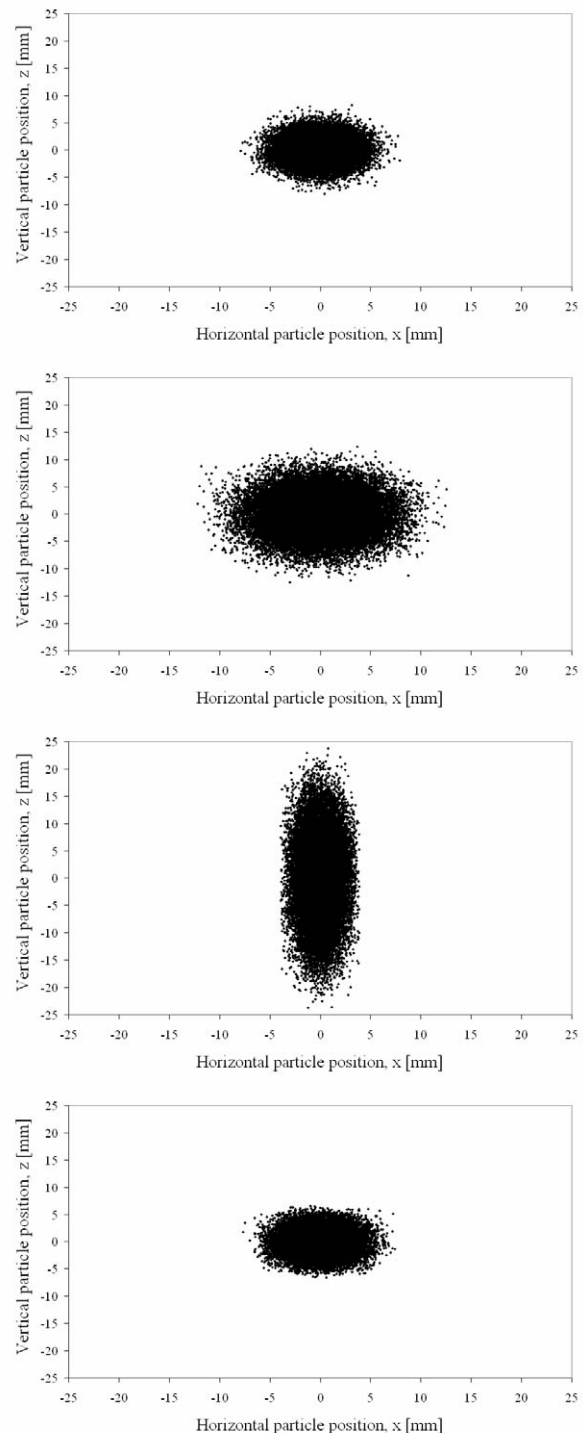

Figure 2: Evolution of the beam cross-section along the beam line as calculated by the S^3M beam-transport module. From the top to the bottom: entrance to the beam-line, entrance to the doublet, exit of the doublet, exit of the beam-line.
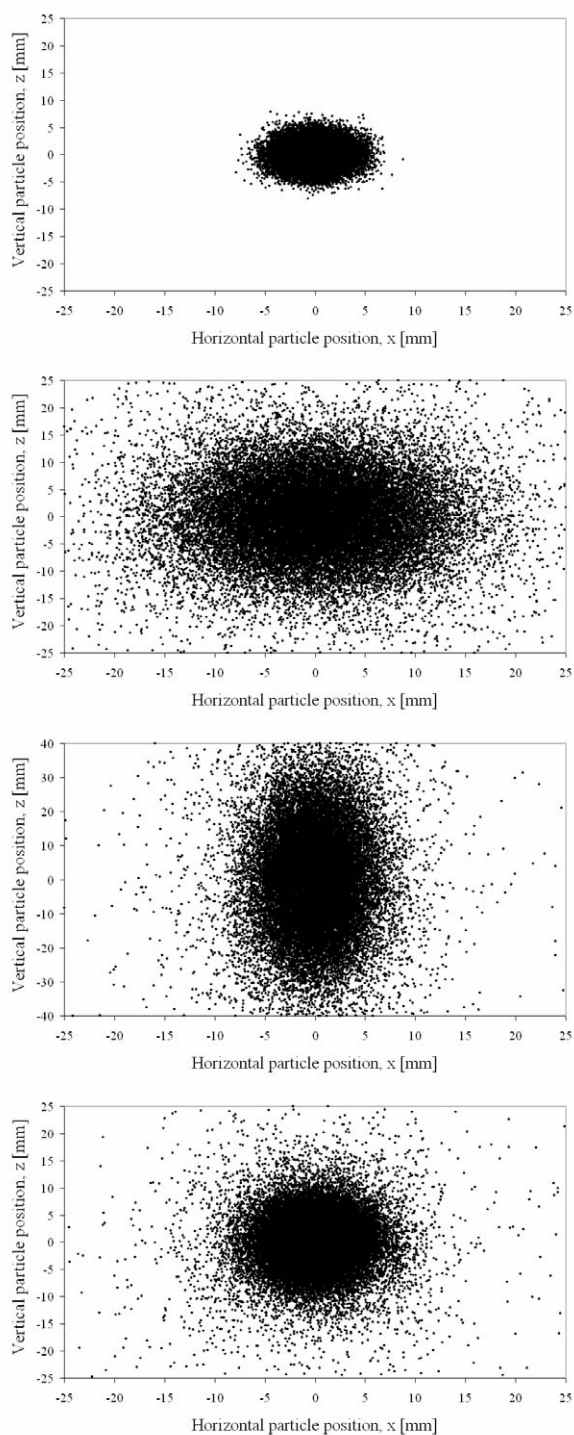
Figure 3: Evolution of the beam cross-section along the beam line with scattering as calculated by the S^3M beam-transport module. From the top to the bottom: behind the foil, entrance to the doublet, exit of the doublet, exit of the beam-line.

OTHER APPLICATIONS

As a preparatory work for the FAIR facility, samples of magnetic alloys foreseen for RF-cavities have been irradiated by different beams. The aim of these experiments was to investigate their radiation hardness, especially the ion-beam induced changes in magnetic properties. Two kinds of alloys, namely Co-based and Fe-based were investigated.

The Co-based alloys were irradiated in ITEP Moscow by high-energy protons. It has been observed that the main limit for application of these materials in accelerator technology comes from their activation. Residual activity caused by high-energy protons was very high and further sample analysis will be possible only after some cooling-down time. It is expected that the magnetic properties of these materials do not deteriorate at the dose-levels acceptable from the activation point of view.

The Fe-based alloys were irradiated at HMI Berlin (593 MeV Au) and Slovak technical university in Bratislava (110 keV N). The samples were analysed by MS (Mössbauer spectroscopy) and CEMS (Conversion electrons MS). The choice of heavier ions and lower energies was motivated by a goal to avoid high sample activation. The low-energy experiments were simulated using S^3M in order to achieve optimal conditions for CEMS. The maximum of radiation damage must be placed in a shallow slice below the surface, because the CEMS signal is restricted to the depth of about 200 nm. The experiment showed that deterioration of magnetic properties of the Fe-based magnetic alloys started at ion fluences of 10^{18} ions/cm^2 for nitrogen beams and 5×10^{11} ions/cm^2 for gold beams. This indicates higher sensitivity of these materials to heavy-ion irradiation. Nevertheless, computer simulations using the SHIELD code [3] showed that heavy ions do not constitute a major part of the spectrum of irradiating particles. The main contribution comes from protons and neutrons.

The investigated samples of magnetic alloys were prepared by rapid quenching of a melt and had a form of ribbons about 23 µm thick. The main effect of ion-irradiation was rotation of the net magnetization out of the ribbon plane.

DISCUSSION AND CONCLUSIONS

The S^3M software has been developed and is now available to beam transport and accelerator communities to calculate beam transport in complex matter-containing beam lines and to run SRIM simulations of different experiments with a realistic input-beam model.

REFERENCES

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