STATUS OF AND PLANS FOR THE BEAM DYNAMICS PROGRAM DYNAC*

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Abstract

A short introduction to the beam dynamics code DYNAC [1] will be given. Benchmarking of the Radio Frequency Quadrupole (RFQ) model and the relativistic case of a beam transport line with space charge will be discussed.

Recently implemented features, such as a Graphical User Interface (GUI), will be presented and additional planned features to DYNAC and the GUI will be touched upon.

INTRODUCTION

For beam dynamics, the multi-particle code DYNAC contains a numerical method, capable of simulating single and multi-charge state ion beams in accelerating elements as well as an analytical method, capable of modelling protons, single charge state heavy ions and non-relativistic electrons. The code contains three space charge routines, including a 3D version and has been benchmarked against other codes as well as against measurements [2-4]. It is well suited for online modelling and as an aid in view of commissioning [5], [6] and will work on linux, MAC and Windows.

RFQ

The capability in DYNAC for simulating the RFQ Radial Matching Section (RMS) and Fringe Field (FF) regions based on electrical fields directly obtained in using the electrode shape has been added (see Fig. 1).

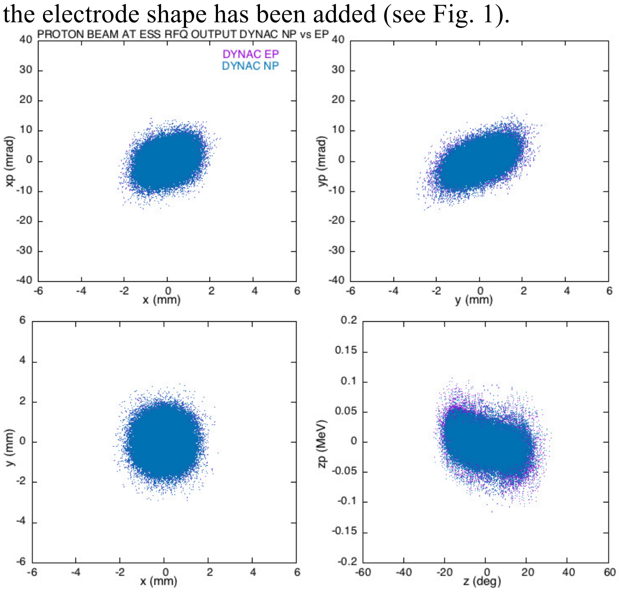

Figure 1: Phase space plots after a fringe field with electric fields directly derived from the electrode profile (EP) and the case where coefficients were used (NP).

For the benchmark of the RFQ, DYNAC results were compared to those obtained from Toutatis [7]. For this purpose, the ~ 4.6 m long 70 mA European Spallation Source (ESS) proton RFQ [8] was taken as test case. This RFQ has a Radial Matching Section (RMS) at the input, followed by a transition cell, 412 accelerating cells, another transition cell and finally a fringe field. The intervane voltage varies from 80 to 120 kV along the RFQ length. The beam is accelerated from 0.075 to 3.62 MeV.

Benchmark Results

The phase space plots at the ESS RFQ output for both DYNAC and Toutatis are shown in Fig. 2. The energy gain differs by ~ 0.1%.

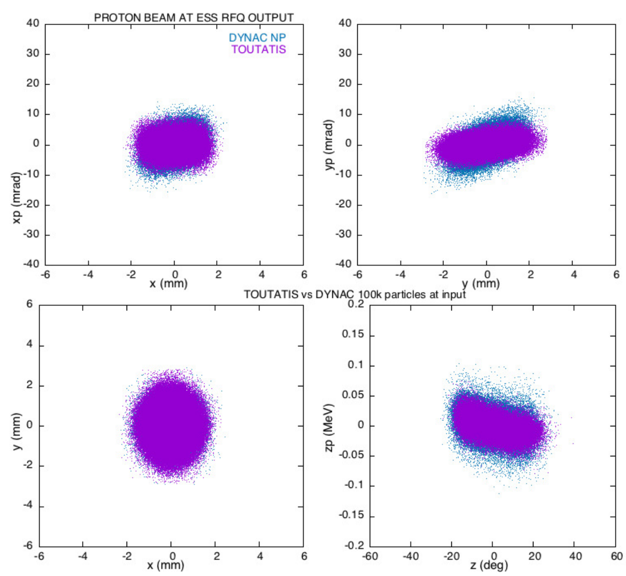

Figure 2: Phase space plots of the proton beam at the output of the ESS RFQ.

Based on a 100k macro particle distribution at the input, a transmission of 99.2% was obtained with Toutatis, whereby only particles that hit the electrodes were eliminated. Optionally one can use radial limits that are defined by a square with an edge equal to two times the minimum aperture. In this case, 98.3% transmission was obtained, but in either case particles that were not or poorly accelerated are still counted. By applying a filter to the output beam such as to eliminate the errant beam, 97.6% was obtained.

For the DYNAC case, the same input distribution was used. Here particles are removed radially when they go beyond an ellipse with the horizontal and vertical apertures as major axis. In addition, particles that are not accelerated are ultimately eliminated as the beam progresses along the structure. This different approach may explain the lower transmission obtained with DYNAC (96.7%).

Discussion

In Fig. 2 one can observe that the transverse and longitudinal beam sizes obtained with the two codes are very similar. The transverse emittances obtained with DYNAC are however larger than those obtained with Toutatis by less than 8% for the horizontal and less than 1% for the vertical plane. In Toutatis one has the option to change the mesh refinement level, which sets the number of nodes per direction. In changing this refinement level from 2 to 1, the horizontal, vertical and longitudinal emittances changed by 3.4%, 4% and 7% respectively.

Further investigation would be useful in order to better understand the difference in the Twiss alpha for the transverse phase space planes between the two codes. Also, the results from Toutatis inside and at the output of the fringe field region are not yet well understood. Finally, it is worthwhile to explore the effect of parameters such as the mesh refinement level in more detail.

RELATIVISTIC BEAM TRANSPORT

The ~ 240 m long ESS High Energy Beam Transport (HEBT) and Accelerator to Target (A2T) proton beam line [9] has been used to benchmark the relativistic beam transport case with space charge (62.5 mA).

The ESS HEBT contains 16 Linac Warm Units (LWU) and a dipole, which can bend the beam 4 degrees up and is the start of an achromatic dogleg. In the path to the target, the HEBT is followed by the A2T, which begins with 6 periods of longer doublet focused sections and a second 4 degree dipole. This dipole bends the beam back into the horizontal plane and forms the end of the achromatic dogleg. The final beam transport to the target uses three sets of quadrupole pairs. It also contains 8 raster magnets that can paint the target surface. For this benchmark, a comparison with TRACEWIN [7] results was made for a non-rastered beam.

Benchmark Results

In the simulations, identical 100k particle distributions were used at the input. In DYNAC, the r-z Particle In Cell (PIC) space charge model SCHEFF was used, whereas in TRACEWIN the 3D PICNIC space charge model was used. In both cases, the beam transport was without loss. The results for the beam on target are shown in Table 1.

Table 1: Parameters for the ESS Beam on Target

ESS HEBT-A2T output beam	α	β (mm/mrad) or (deg/keV)	ε_{rms} (mm.mrad) or (keV.deg)
DYNAC xx’	-76.4	1611	0.1223
TRACEWIN xx'	-75.2	1585	0.1213
DYNAC yy’	-11.2	237.4	0.1235
TRACEWIN yy’	-11.2	236.8	0.1220
DYNAC w-ϕ	41.5	0.1445	1102
TRACEWIN w-ϕ	40.9	0.1432	1081

The largest of the differences is for the longitudinal emittance (< 2%); without space charge the largest difference is ~ 0.3%. Figure 3 shows the phase space portraits for the beam on target.

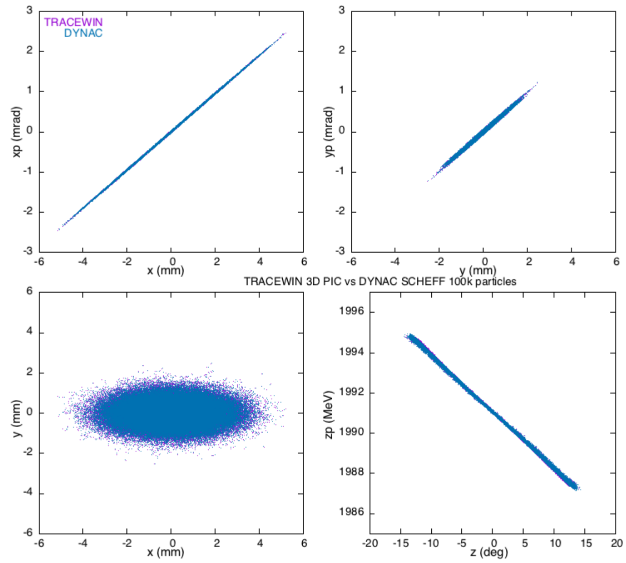

Figure 3: Proton beam on ESS target.

Discussion

Parameters used for the space charge models can affect the results [10]. For the results shown above this consideration was taken into account.

The differences observed earlier [3] for the ESS Super-Conducting Linac (SCL) were largely reduced (see Fig. 4) by choosing more appropriate space charge model parameters in both beam dynamics programs.

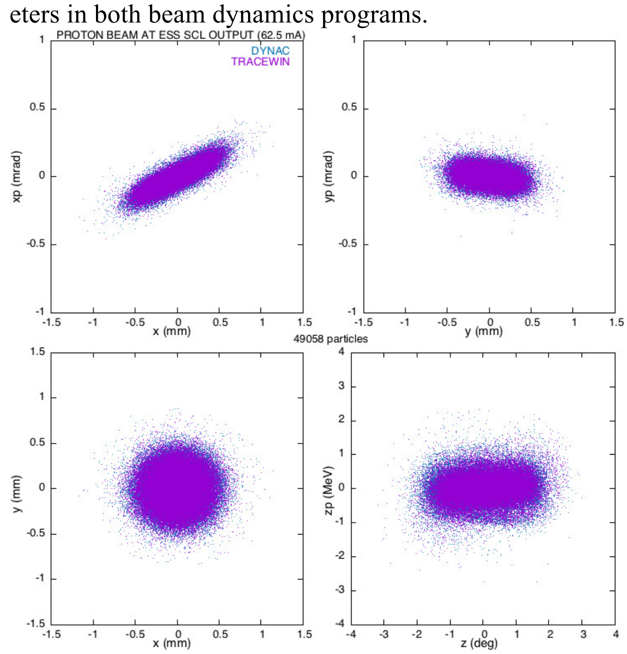

Figure 4: Phase space portraits for TRACEWIN and DYNAC at the ESS SCL output.

Also the difference between the envelopes was largely reduced. These new results also include a correction of an error related to one of the field descriptor files as used by

DYNAC. For the parameters shown in Table 1 related to the transverse phase spaces, the largest difference was for the horizontal emittance (<5%). The longitudinal emittances differed by ~6.5%. It should be noted that there is some dependency of the results on the number of steps in TRACEWIN, although it uses a cubic spline interpolation between field points for the transport of the particles in a field map.

GRAPHICAL USER INTERFACE

DGUI is a graphical user interface that has been developed for DYNAC (see Fig. 5) and has been successfully tested on linux, MAC and Windows. With the first release of DGUI the user can select and plot particle distributions and select a DYNAC input file and start program execution. In addition, one can obtain various plots as a function of the longitudinal coordinate, such as emittances, beam and reference energy and beam size. Functionality will be added over time to DGUI, in particular based on user needs and requests.

Like for the DYNAC code itself, the DGUI code is available as a free and open source, and includes a User Guide.

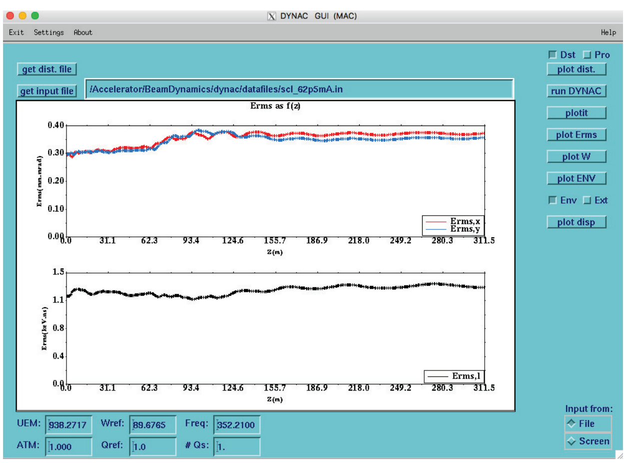

Figure 5: The DGUI window allows for more ease of use of the DYNAC code and its associated files.

CONCLUSION AND OUTLOOK

The RFQ model in DYNAC has been benchmarked against Toutatis using the ESS RFQ as a test case, and although there is basic agreement between the codes, further investigation is needed to understand the differences observed.

For the relativistic case of a beam transport with space charge, good agreement between TRACEWIN and DYNAC was obtained for the ESS HEBT-A2T transport line. In addition, better agreement between the two codes was found for the ESS SCL in using more appropriate space charge model settings.

A basic Graphical User Interface to DYNAC has been made available, that will work on linux, MAC and Windows. It is planned to add more features and functionality to this GUI.

Work is currently on going to add a Multi-Harmonic Buncher (MHB) to DYNAC as a thick lens element (as a thin lens, the MHB can already be simulated).

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