

## BEAM DYNAMICS ON-LINE SIMULATIONS FOR THE S-DALINAC INJECTOR

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### Abstract

V-Code is the first beam dynamics simulation tool based on the Model of Ensembles. It was successfully applied to the TESLA Test Facility (TTF) injector.

V-Code has now been modified in order to fit the requirements of S-DALINAC. One of the new features of the present version of V-Code is the model of a bunched beam. To simulate the S-DALINAC chopper system, the tracking code ChopSim has been developed, yielding the initial ensemble parameters for the main V-Code solver. The S-DALINAC layout, including a set of steerers, RF-cavities, lenses and quadrupoles has been implemented. Also, a data acquisition procedure compatible with the S-DALINAC control system has been elaborated, providing on-line functionality for the beam dynamics simulation. The obtained results underline V-Code's potential of becoming an all-purpose simulation tool for linear accelerators.

## 1 INTRODUCTION

### 1.1 The Model of Ensembles

The Model of Ensembles [1] is a new approach to the description of beam dynamics in particle accelerators. Instead of describing a bunch by a large number of macroparticles, simulating their trajectory through the accelerator and calculating mean values afterwards, bunches are represented by a set of 27 already averaged parameters making up an ensemble. The ensemble parameters consist of 6 first order moments  $\langle \xi \rangle$  and 21 second order moments  $\langle \Delta\mu\Delta\nu \rangle$  that can be summarized in a beam matrix  $M$ :

$$M_{\mu\nu} = \int \Delta\mu \Delta\nu f(\tau, \vec{r}, \vec{p}) d\vec{r} d\vec{p}$$

Under some simplifying conditions, the dynamics of the ensemble parameters can be described by a set of ordinary differential equations, enabling a very fast computation. As an extension, a bunch can be described by several ensembles, which lowers the computation speed but allows the description of sliced beams and head tail instabilities, which was not used here. A key issue in applying the model of ensembles for simulation is the determination of the initial ensemble.

### 1.2 V-Code

As the first simulation programme, V-Code [2] has proven the feasibility of fast beam dynamics computation based upon the model of ensembles. As a first application,

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<sup>†</sup> Work partially supported by DESY, Hamburg, Germany

V-Code has been adapted to the Tesla Test Facility TTF at DESY in Hamburg, Germany. The results obtained were encouraging [3], so that we decided to apply V-Code to the injector of the S-DALINAC [4] at Darmstadt University of Technology, Germany in a second step.

## 2 DETERMINATION OF THE INITIAL ENSEMBLE OF THE S-DALINAC

### 2.1 The S-DALINAC

The S-DALINAC is a double-recirculating S-band linear accelerator, serving various experiments in nuclear and radiation physics since 1990. It provides a continuous wave electron beam with a maximum energy of 130 MeV. Since the determination of ensemble parameters is not possible at the gun, another starting point for the V-Code simulations had to be found. The S-DALINAC chopper turned out to be a suitable starting point.

The electrons are emitted by a thermo cathode and preaccelerated electrostatically to an energy of 250 keV. Before entering the first superconducting accelerator cavity, the continuous beam is truncated by a chopper and the bunches are compressed by a prebuncher. The chopper section basically consists of a normal conducting chopper cavity, followed by a collimator. The cylindrical copper cavity inflects the beam on a cone surface, while the entire cone is bent down by a pair of coils, so that the upper tangent to the cone is aligned to the beam axis. On the collimator, the beam describes a circle (fig. 1), passing through every time the beam sweeps over the collimator hole.

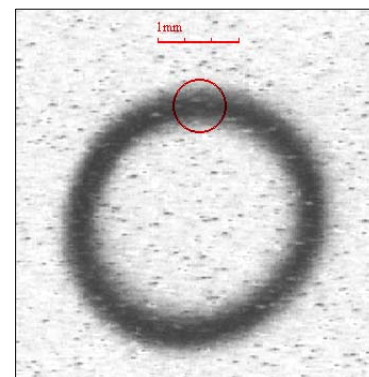


Figure 1: Circle described by the beam on the collimator

### 2.2 Simulation of the chopper section

A study of the control system log files revealed that the insertion device settings of the elements before the collimator have remained constant over the past years.

Provided the chopper section be the predominant emittance and correlation producer, the beam properties downstream will not depend on the settings of the insertion devices before. Hence, the chopper collimator could be taken as the starting point of the V-Code simulation. Since the device settings before that mark are marginally changed, an on-line simulation of the starting part of the accelerator is not of interest anyway.

In order to obtain the beam parameters at the chopper collimator, a conventional tracking code *ChopSim* has been written, simulating the section of chopper cavity, chopper collimator and enclosed devices. The chopper cavity is a cylindrical copper resonator, excited in both of the  $TM_{110}$  modes, providing a circulating magnetic field in the plane perpendicular to the beam axis that deflects the beam on a cone. However, the  $TM_{110}$  mode includes an accelerating electric field off the axis, which leads to emittance production and correlations within the following lens and steerers. The simulation of the chopper section by means of the tracking code *ChopSim* revealed that the chopper section contributes predominantly to the emittance production and is the main reason for correlations.

This way, an initial ensemble, represented by the matrix  $M$ , has been found, based on the invariant standard settings of the insertion devices before the chopper. The beam parameters delivered by *ChopSim* were well conforming to previous measurements of transverse phase space emittance and energy spread. Also some stronger correlations due to the special construction of the chopper could be demonstrated.

### 3 INTEGRATION INTO V-CODE

The S-DALINAC injector contains various types of insertion devices, including magnetostatic lenses, steerers, dipole and quadrupole magnets, a normal conducting prebuncher cavity and superconducting accelerator cavities. Due to the modularity of V-Code, the devices of the S-DALINAC lattice could be integrated easily. Firstly, the positions of all insertion devices of the injector were measured precisely. Secondly, their field distributions were measured, calculated or taken from previous MAFIA [5] calculations, respectively. Finally, the field strength was gauged to the control system settings in view of the desired on-line connectivity. Due to the high modularity of V-Code, all guidance elements could be integrated easily into the code.

### 4 SIMULATION OF THE INJECTOR

#### 4.1 Simulation with V-Code

Starting with the initial ensemble yield by *ChopSim*, the S-DALINAC injector could be simulated using V-Code. Depending on the time increment, the calculation time on an ordinary single CPU computer is in the range of a few seconds. A screenshot of the simulation is shown in fig. 2. Leaving the chopper collimator at the left edge of the

screen, one bunch travels its way through the S-DALINAC injector to the right. The upper part of the screen shows the trajectory and the emittance. Since the simulated part of the injector is strictly linear, no deviations can be seen at the scale chosen until the entrance to a dipole magnet, where the beam is bent into positive x-direction. Also the emittance remains constant, which is an inherent property of the Model of Ensembles, if only one ensemble is used.

The middle frame of the screen symbolizes the S-DALINAC lattice. Some characteristic devices are highlighted, such as the prebuncher cavity PB, the superconducting cavities #1 to #3, a quadrupole magnet QUAD and a dipole DIP.

In the lower frame, the beam thickness  $\sigma$ , the energy  $E$  and the energy spread  $\Delta E$  are displayed. At the beginning, the thickness corresponds to the diameter of the collimator hole. The energy of 250 keV and the energy spread correspond to the voltage and stability of the electrostatic gun.

The energy curve is shaped as a step function: the first step is taken when the beam undergoes the first boost in the capture cavity #1. After being accelerated twice in the cavities #2 and #3, the injector energy of about 9 MeV is achieved.

The energy spread  $\Delta E$  remains constant until the bunch enters cavity #2, where it grows to about  $\Delta E = \pm 100$  keV. Afterwards, in cavity #3, it is lowered again to some 35 keV, in good accordance with former measurements. A small variation of  $\Delta E$  at the capture cavity #1 is caused by the phase mismatch in that cavity, since the electrons are not yet relativistic at the energy of 250 keV.

The functionality of the prebuncher cavity is highlighted by the curve of the bunch length  $\sigma_z$ : the prebuncher field makes the bunch longitudinally converging, leading to a compressed bunch at the entrance of the capture cavity.

The transversal focusing can be seen in the curves of  $\sigma_x$  and  $\sigma_y$ . Behind the collimator, the beam has the diameter of the collimator hole. Due to the beam divergence, the beam widens afterwards, until it is focused simultaneously in both of the transversal dimensions by the magnetostatic lens LE02.

#### 4.2 Discussion of the simulation results

The adaption of V-Code to the S-DALINAC was successful: all kinds of insertion devices that appear in the accelerator have been successfully integrated into the code. The simulation results are conforming with former measurement data. No further obstacles prevent from extending the simulation to the entire machine.

However, the tedious effort for the adjustment of the RF phases of the superconducting cavities appears both for the simulation as in reality. Even though simulation results are credible, it must be stated that a detailed verification has not yet been performed.

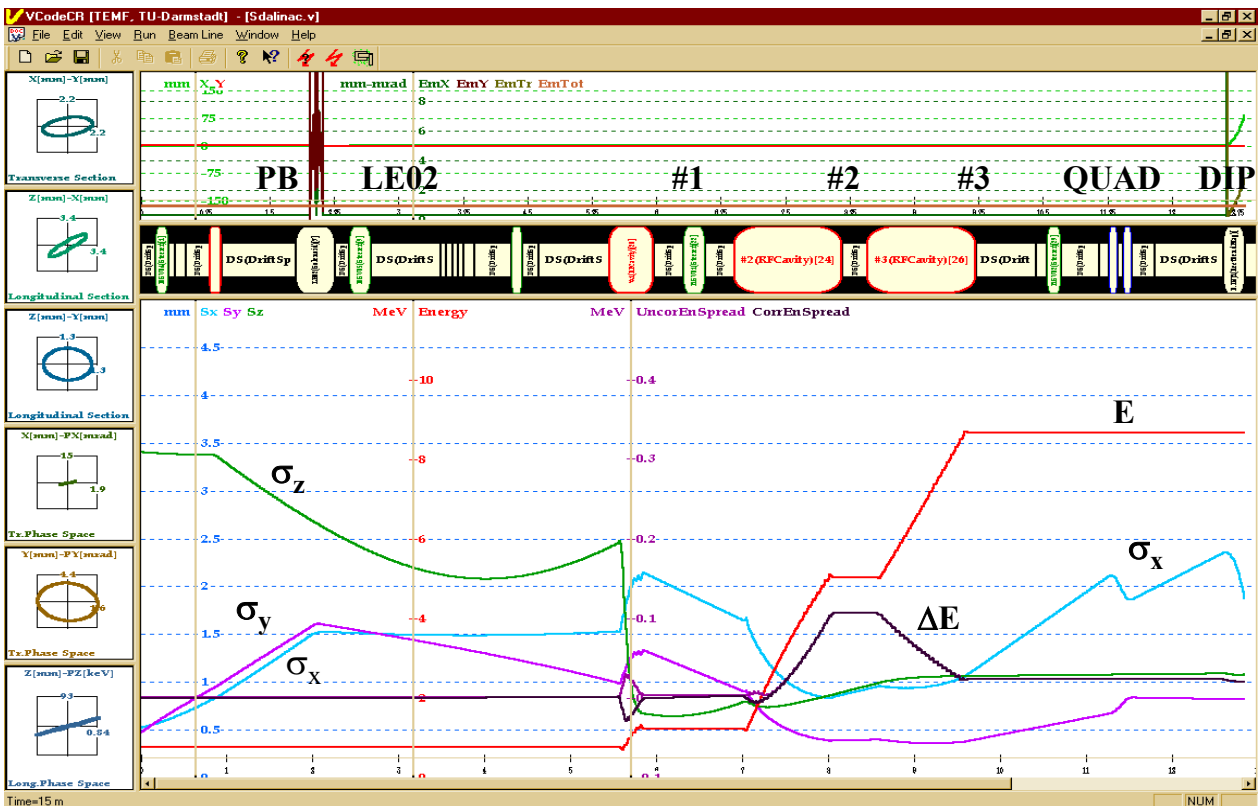


Figure 2: Screenshot of V-Code simulation of the S-DALINAC injector

## 5 ON-LINE CONNECTIVITY

The extraordinary velocity of V-Code invokes the desire for connecting the simulation code directly to the accelerator control system. This way, the current device settings could be seamlessly taken over into V-Code or could be written back.

The major challenge at this is to build a bridge between the world of the OpenVMS-based accelerator control system and Windows-driven V-Code. Therefore, the functionality of the control system has been encapsulated in a kind of web service, offered by a http-server on OpenVMS. This server can be accessed by a Windows-based web client. Reversely, appropriate device settings according to V-Code can be pushed to the server and made on-line immediately.

## 6 SUMMARY AND CONCLUSION

The aim, to apply V-Code to the S-DALINAC was successfully achieved. However, the full verification of the simulation results is still outstanding. Therefore, a set of additional beam position monitors will be installed. The obtained results underline V-Code's potential of becoming an all-purpose simulation tool for linear accelerators.

## 7 REFERENCES

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