

# INTEGRATION OF ELEGANT TRACKING CODE INTO THE TANGO SERVER-BASED HIGH LEVEL SOFTWARE OF FERMI@Elettra FOR OPTICS MEASUREMENTS AND MODELING

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## Abstract

The electron beam transverse emittance and Twiss parameters have been measured during the commissioning of FERMI@Elettra. Matching of the beam optics to the lattice transverse acceptance and beam transport was performed by means of the ELEGANT particle tracking code; this was integrated with the Tango-server based high level software of FERMI@Elettra. Matlab scripts were used as an intermediate layer between the code and the server to automate the matching procedure. The software environment, the experimental results and the comparison with the model are described in this paper.

## FERMI@ELETTRA

FERMI@Elettra is the new linac driven seeded free electron laser under commissioning in Trieste, Italy. The linac provides a 1.2 GeV electron beam which drives two seeded free electron lasers in the wavelength range of 100-4 nm. At a second stage of development (FEL2) it is foreseen to rise the beam energy to 1.5 GeV. Wavelength tunability, variable photon polarization will also be available to the end users of this new light source. A description of the project and further references are given in [1].

## PUTTING ELEGANT ON-LINE

The ELEGANT [2] code has been extensively used during the design of the FERMI@Elettra linac. We gained a lot of experience and confidence with ELEGANT and decided to use it also for performing the optics matching on the live machine. In order to use it as an on-line machine model we had to develop a set of utilities for interfacing the simulator with the accelerator. We exploited ELEGANT capability to read and write a set of element parameters from a file in SDDS [4] format via the `load_parameters` and `write_parameters` commands. The SDDS file is filled-in with the actual parameters of the running accelerator by means of a dedicated utility which examines the SDDS file and maps the requested parameters to the appropriate control system variables by means of database tables. The requested variables are then acquired from the control system and scaled if necessary (e.g. converting BPM readings from millimeters to metres). The reverse path is followed for setting parameters: ELEGANT writes the new values to the SDDS files, another dedicated utility reads the new parameters from the SDDS file, maps them to control variables and set the values via standard control system calls. Since ELEGANT works with normalized machine physics

quantities (e.g. quadrupole strength in [1/m]) we developed a set of specialized control system servers (i.e. Tango devices [3]) which perform the conversion from engineering quantities (e.g. current) to machine physics quantities by means of calibration tables. These devices are also directly accessible to operators by means of graphical control panels (see Fig. 1). All these tools are described in [5]. A similar solution for LHC, but larger in scope and based on the MAD-X code, is described in [6].

## BEAM MATCHING

### Overview

The goal of matching is to impose the design optics function at a certain point of the lattice. For this purpose a set of quadrupoles is used. In the case of FERMI, during this commissioning phase [7] matching is routinely performed at the entrance of the laser heater (LH) section.

From the cathode up to the end of the injector (at about 100 MeV), the beam optics is hardly predictable since it is fully in a space-charge dominated regime. For this reason it is very important to measure the beam optics at the end of the injector and match it with the designed linac optics. To do it a beam diagnostic station is installed at 100 MeV [8], mainly consisting in four quadrupoles and three screens. Two additional quadrupoles are added in between the first two accelerating sections. By using the method of the quadrupole scan (see Fig. 2), The beam Twiss parameters have been measured at 100MeV and then back propagated to the first quadrupole by running ELEGANT with a reverse ordered lattice file and element parameters (e.g. quadrupole strengths) acquired from the running accelerator. The initial conditions for the Twiss parameters

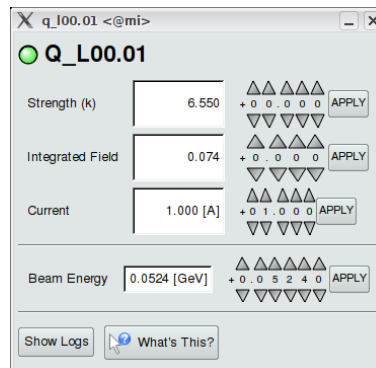


Figure 1: Magnet control panel.

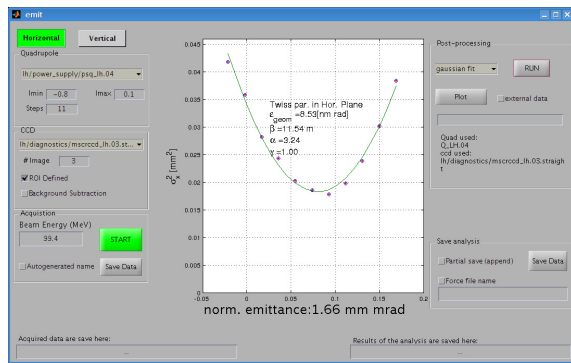


Figure 2: Emittance and optics measurement GUI.

are so available for estimating the optical functions along the whole accelerator and performing the desired matching with ELEGANT. The user can compare the matching results with the requests before actually setting the calculated quadrupole strengths, and eventually iterate the procedure starting with the obtained results or measuring again the beam optics with these setting. All the intermediate data and results are exchanged via SDDS format files and can be plotted also with standard SDDS based tools (see Fig. 3).

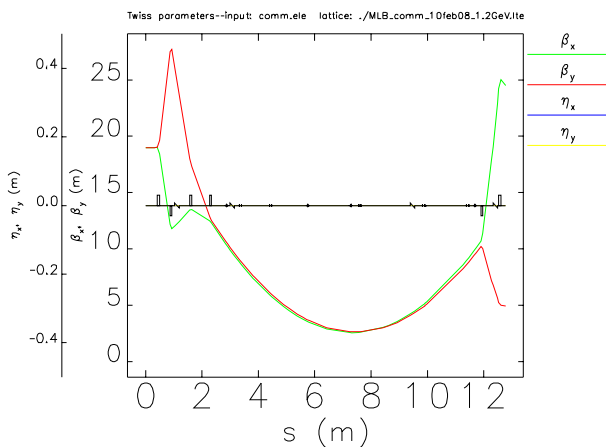


Figure 3: Matched optics in LH section.

### Matlab Scripts

In order to iterate the matching procedure several times and in a short time, it has been coded in Matlab, exploiting the possibility to invoke system commands. The choice of Matlab is mainly determined by the fact that it is well-known by a large part of the physicists and technicians, allowing to build macros and GUIs in short time and performing data processing in a fast and user-friendly way. Moreover, since Matlab is an interpreted language, it was fast and straightforward to test and modify the procedure during commissioning shifts. At this stage of development, we use traditional SDDS toolkit plot utilities since we are quite acquainted to them and we can directly compare the

live data with results and plots from off-line simulations.

### Matlab Based Graphical User Interface

Once the matlab Matching scripts have been thoroughly tested and debugged, they have been incorporated into a graphical user interface (GUI) developed in Matlab. This interface (see Fig. 4) is generally available as a standard control room application.

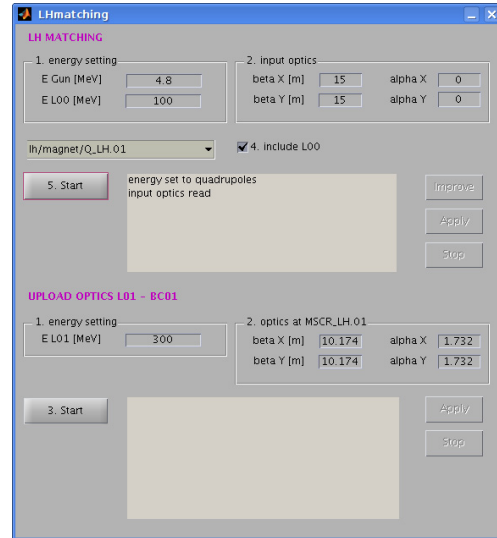


Figure 4: Laser heater matching GUI.

## OPERATIONAL RESULTS

The matching procedure is quite reliable, usually converging in a couple of iterations. Table 1 shows the theoretical Twiss parameters calculated by ELEGANT at the fourth quadrupole and the measured Twiss parameters. The quality of the matching is defined by the  $B_{mag}$  parameter:

$$B_{mag} = \frac{1}{2} [\gamma_0 \beta - 2\alpha_0 \alpha + \gamma \beta_0] \quad (1)$$

where the index 0 refers to the nominal optics: the closer the  $B_{mag}$  to 1 the better the matching. In the last two rows of Table 1 the  $B_{mag}$  calculated with ELEGANT outputs and measured on the beam are reported: the measured mismatch parameter for both planes are very close to the target value of 1. The measurements errors of Twiss parameters yield an error of few percents in the mismatching parameters.

The quality of the matching matching get worst when the measured beam present strong asymmetries between the horizontal and the vertical plane. Moreover noisy or odd-shaped beams make the matching more difficult.

The speed of the matching procedure is acceptable and is in the order of 10 to 20 seconds. It is mainly affected by the speed of the actual matching algorithm performed by ELEGANT. After having matched the beam, we loaded

Table 1: Twiss and Mismatch Parameters for ELEGANT Outputs and Measurements Results

	ELEGANT	Measurements
$\beta_x$	12.2 m	11.9 m
$\alpha_x$	6.1	6.0
$\beta_y$	11.7	10.7
$\alpha_y$	-2.1	-2.0
$B_{mag,x}$	1.00	1.01
$B_{mag,y}$	1.00	1.00

the theoretical optics on the machine downstream of the LH section. After implementing some small trajectory adjustments with the correctors, the beam was transported up to the BC1 section very efficiently.

Figure 5 shows the ELEGANT output concerning the optics propagated after the matching procedure and the nominal optics defined by the requirements: the agreement between them is very good.

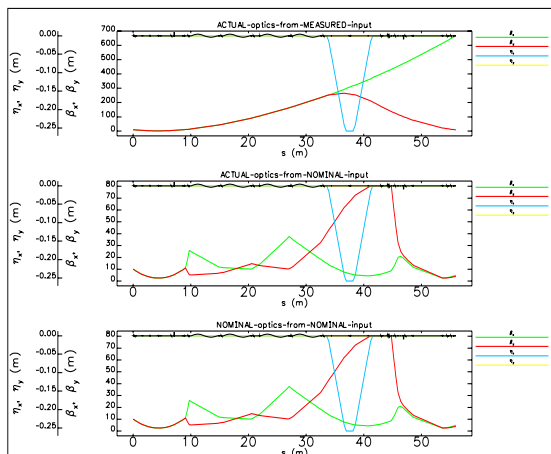


Figure 5: Optics up to BC1 spectrometer.

### CONCLUSION

ELEGANT code has been integrated in the TANGO server-based high level software of FERMI@Elettra and it has been intensively used during the commissioning for machine modeling, optics matching and beam transport. In the next phases we are going to extend the ELEGANT capability in the TANGO server in order to manage the machine optics, the bunch compression and the trajectory control.

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