The Diagnostic Line for the Acceptance Tests of the Elettra 100 MeV Pre-Injector

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Abstract

The 100 MeV pre-injector of the 1.5 GeV Elettra linac is currently undergoing tests. The diagnostic line for the commissioning and acceptance tests for the pre-injector is presented. The line is flexible and is able to characterize the linac during diverse operating conditions.

1. INTRODUCTION

The injection system of ELETTRA will be a 1.5 GeV linac made up of two distinct sections [1]. The first part, termed the pre-injector, is a 100 MeV linac composed of an electron gun, a chopper, various bunching systems and two disc loaded travelling wave sections. The second part (phase II) consists of seven sections powered by a system of SLED type cavities. The pre-injector has various modes of operation, namely, single bunch and multibunch at 100 MeV and variable energy (30 to 75 MeV) FEL modes. For each mode the energy, energy spread, current/charge and emittance has to be measured. Figure 1 shows the layout of the diagnostic line built for the commissioning and acceptance tests of the 100 MeV part. The tests have to be made on electron beams with large relative differences in both energy and optical parameters, and so it is important to have a flexible beam line for the measurements. The principal components of the line are two quadrupole triplets, a bending magnet, three fluorescent screens [2], two Faraday cups, and an electrically isolated collimator. The two quadrupole triplets at the exit of the linac, separated by 0.51 m give sufficient flexibility to account for the various beam exit conditions. The last two fluorescent screens are in air and the vacuum chamber terminates with a titanium window. All magnetic elements are individually powered allowing for maximum versatility. The collimator and Faraday cups are simply slabs of tungsten yielding d.c. readings. The dimensions chosen for the capture up to 90% of the impinging and generated electrons were calculated using the EGS4 code. For more accurate measurements of the current/charge, toroid, gap and beam position monitors are available along the linac [2].

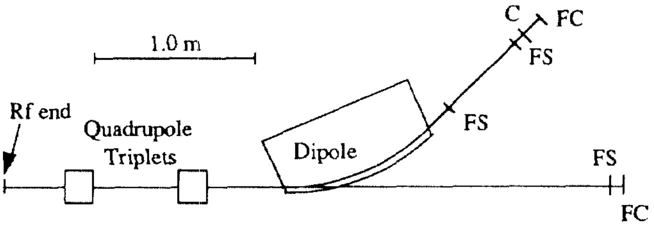

Figure 1: Layout of diagnostic line. FS: fluorescent screen, FC: Faraday cup and C: Collimator.

Modified transfer line fluorescent screens [2] are used to measure both the energy spread and emittance. The use of fluorescent screens in association with a frame grabber and distributed computing power makes the diagnostic line a versatile tool. The frame grabber digitizes the image of the beam seen on the screen. This image is then used by a local process computer which computes the beam width and position [3]. For the width calculation several algorithms are available. This information is then used by high level software programs residing on a workstation. Such a program measures the emittance, which is automatic once the operator has chosen appropriate parameters. A high level program [4] which models the beam line lessens commissioning time, especially when beam conditions are unknown, and can be used to iterate the measurements to obtain higher accuracy.

2. BEAMLINE DESIGN CONSIDERATIONS

The optical arrangement has to take into account the differing operating conditions of the pre-injector. This has been accomplished using the set up shown in figure 1. For the energy spread measurement the natural beam size has to be suppressed at the measurement point where the dispersion is large, i.e., at the second fluorescent screen after the bending magnet. In conjunction with the Faraday cup, the digitized beam image obtained from this screen yields the charge distribution.

For the emittance measurement, knowledge is required of the symmetric 2x2 sigma matrix σ, which fully characterizes the beam at any given position in the transport line [5]. Propagation of the beam from one point to another is given by, $\sigma^*=\mathbf{R}\sigma\mathbf{R}^T$, where $\mathbf{R}$ is the transport matrix between two points in the beamline. In the absence of coupling, which is supposed to be the case here, the square of the beam size at a given location is:

$$\sigma^*_{11} = R_{11}^2\sigma_{11} + 2R_{11}R_{12}\sigma_{12} + R_{12}^2\sigma_{22} \qquad (1)$$

Thus by varying $\mathbf{R}$ (which may be done by varying one or more quadrupoles) and subsequently measuring the beam width all three elements of the sigma matrix can be obtained [6].

By using a thin lens approximation of (1) one sees that σ^*_{11} varies quadratically with a quadruples strength k:

$$x^2 = R_{12}^2 x_0^2 (k - k_0)^2 l^2 + \frac{\varepsilon^2 R_{12}^2}{x_0^2} \qquad (2)$$

where x_0 is the beam size at the position of the quadrupole with effective length l, k_0 is the strength of the quadrupole at the minimum beam width and R_{12} is the (1,2) transfer matrix element from the end of the quadrupole to the fluorescent screen. Equation (2) also shows that the emittance is directly related to the minimum beam size.

In order to minimize the error on the measured emittance, the following considerations were made when designing and using the optics of the diagnostic line:

(I). Since the emittance is obtained by the formula $\varepsilon^2 = \sigma_{11}\sigma_{22}-\sigma_{12}^2$, and the sigmas are measured values with implied errors, the error on the emittance is smallest if the value of σ_{12} is zero. Recalling $\sigma_{12} = -\alpha\varepsilon$, we get that the slope of the beam envelope at the entrance of the measuring quadrupole should be small.

(II). Due to errors in the measuring system the measured beam width in formula (2) is systematically larger. In the present case the main contributor to this error is multiple scattering through the titanium window which separates the vacuum from the fluorescent screen. Assuming x_s is the rms beam broadening (i.e. $x_{measured}^2 = x_{beam}^2 + x_s^2$) and neglecting the terms with $(\Delta\varepsilon)^2$ one gets from (2):

$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{1}{2}\frac{x_0^2\,x_s^2}{R_{12}^2\,\varepsilon^2} \qquad (3)$$

Therefore the beam size in the varied quadrupole must be kept small and optics chosen which give a large (1,2) transfer matrix element. If, however, x_0 is too small then the beam width becomes larger than the fluorescent screen, as can be seen from the last term in equation (2).

(III). It is preferable to have a double minimum, so that the emittance in both planes can be measured in one magnet sweep. If this is not possible, then the beam size in the measured plane should be much larger than the beam size in the other plane, to minimize effects due to possible coupling between the planes.

(IV). The measurement should be performed with as few magnetic elements as possible to minimize errors arising from incomplete knowledge of the magnets.

With the exception of the lower energy FEL mode, it is difficult to satisfy all of the above requirements when searching for a double minimum with small alphas in both planes. Given the fairly symmetrical nature of the beam exit parameters [7], however, optical arrangements are easily found whereby these conditions are satisfied in the one plane. Then, by a simple inversion of the quadrupole polarities, similar configurations are found for the other plane.

The optics have been determined by using the model program "knobby"[4]. This program has been used to check that for reasonable changes (up to 50%) of the initial conditions [7], an acceptable measurement can still be performed for all operational modes.

2.1. The Estimation of the Measuring Error

The effect of measuring errors have been thoroughly estimated analytically and by simulations. The total error, which principally affects the emittance measurement, is a result of the following contributions:.

(I). The systematic error on the beam width: If the foil thickness is known to better than 10% and the effect due to scattering is subtracted, the residual error will not influence the emittance measurement to more than a few percent.

(II). The statistical error on the beam width measurement: This error may come from pulse to pulse variations of the linac or from fluctuations in the measuring system. This error is minimized by a sufficient number of repeated measurements at the same quadrupole current.

(III). The systematic error on the value of the magnetic fields: If R_{12} is purely a drift space then an error in the estimate of $(k - k_0)$ results in a proportional error in the calculation of x_0, which in turn is proportional to the error in the emittance, thus $\Delta k/k = - \Delta\varepsilon/\varepsilon$.

(IV). The statistical error of the values of magnetic fields: This does not create a problem as long as the last magnet is used for measurements. In such a case the errors on the emittance are equivalent to the errors in the case of systematic field errors.

(V). The error on the effective length of the magnets: Simulation have shown, that a 20% change in the effective length has practically no effect on the emittance.

Other sources of errors turn out to be negligible. The total error will not surpass 5% under normal measuring conditions.

2.2. The Emittance Program

The program is written partly in C and partly in FORTRAN. It accepts the diagnostic line structure as an input file so it can be readily modified to perform the emittance measurement, using the linac to storage ring transfer line, of the 1.5 GeV linac. Variable parameters are the initial and final quadrupole currents (several quadrupoles may be varied at the same time), the number of steps and the number of beam size measurements per step. The program automatically varies the quadrupoles' strengths and reads the corresponding beam width measured in the fluorescent screen via the remote procedure call mechanism and finally performs a least squares fit of the measured values to equation (1), including a complete statistical treatment of the covariant matrix. The resulting sigma matrix is stored in a file which can be input to the modelling program knobby, with which a better optics for the measurement can be found in a new iteration of the optics design.

3. CONTROL SYSTEM CONFIGURATION

In order to efficiently control the diagnostic line equipment, a two level distributed system has been installed. A high performance UNIX workstation serves as operator console and is used for the development of application software at the upper level; the main control and equipment interface functions are integrated within the lower layer Local Process Computers (LPC) running the OS-9 operating system. A thin Ethernet Local Area Network (LAN) with the TCP/IP protocol connects the workstation to the LPCs.

An additional OS-9 based system works as central disk server for the LPCs and provides an OS-9 software development system, in case small "on-line" changes of the LPC programs are needed.

3.1. The Local Process Computers

Two LPCs are dedicated to the control of the bending and quadrupole power supplies [8] respectively and are integrated in the power supply cabinets. A third one is used for the acquisition of the instrumentation data (beam position monitors, fluorescent screens, Faraday cups, etc...). Each LPC consists of a diskless VME crate equipped with a CPU board, which is also connected to the LAN, and input/output boards of different types carrying out the hardware interface with the equipment they control.

Two main logical software levels are combined in the LPC: the process and the equipment access, on the top and bottom respectively. By dealing with the hardware details of the boards (OS-9 drivers and descriptors) and of the input/output points (for example power supply calibration constants, engineering units conversion), the equipment access layer hides them to the upper processes and permits symbolic access to the controlled points, which are identified by the Elettra naming convention.

Some continuously running monitoring programs together with the so called Remote Procedure Call (RPC) servers, which are described below, are installed at the control process level. Moreover, auxiliary tasks performing complex operations are executed under operator or application software demand: for example, a ramp generating process allowing selectable slow or fast setting of the power supply output current is available.

In order to automatically download the software into the diskless LPCs, we take advantage of the OS 9/NET [9] communication software package. OS-9/NET is based on the Network File Manager (NFM) and provides for homogeneous file access among distributed OS-9 nodes. Only the essential OS-9 booting and compact NFM modules are burned into the CPU board ROM; by executing the OS-9 startup procedure after the power-up, all the necessary software modules are loaded into the CPU board RAM from a single shared disk server, and the control tasks are autonomously started.

3.2. The Communication System

In spite of the different operating systems run on the workstation and LPCs, the LAN communication software makes the distributed control system environment homogeneous and supplies powerful tools for the development of the application software.

The communication services of the TCP/IP protocol are installed and allow the workstation user to open remote sessions on the LPCs (TELNET) or to easily transfer files between different nodes (FTP).

The RPC technique is the tool adopted for the development of distributed applications. RPC, which is formally an application protocol working on top of TCP/IP, applies the concepts of the software client-server architecture: a program running on the UNIX workstation (client) can call a subroutine (server) resident on an LPC and execute it in a completely transparent way. The main advantage is that both client and server do not contain any code referred to the LAN node configuration and communication. As an example, the client program "C" language line which remotely sets the power supply output current of the first magnet of the second quadrupole triplet at 4.2 A is:

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rpc_WIR (PSTRL2, 1, CURR, WIR, 4.2)
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3.3. The Power Supply Control Panels

Starting from a simple synoptic which represents the diagnostic line magnets, we have developed a user friendly man-machine interface for the control of the power supplies.

By simply clicking on top of each magnet with the mouse arrow, the corresponding power supply virtual control panel is opened and ready to operate. The control panels consist of a set of graphical objects called "widgets" which reproduce real devices like switches, buttons, scales, dials, etc... and resemble the operation of the apparatus they reflect. The representation of the control panels is based on the X11 and Motif software graphic packages.

The communication between the workstation processes associated with the control panels and the LPCs is built again on top of the client-server model implemented by the RPC protocol.

4. CONCLUSIONS

The system has recently been successfully used in the commissioning and for the first measurements of the pre-injector. The diagnostic line has allowed for fast optimization of beam parameters, and enabled rapid measurement of the emittance under various conditions.

5. ACKNOWLEDGEMENTS

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