BASELINE DESIGN OF THE LINAC UPGRADE FOR FERMI

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Abstract

The FERMI FEL requires a major upgrade of the existing Linac, which needs to be transformed from being the injector for the ELETTRA light source, to becoming the source for the FERMI FEL. In this work, we present the baseline design, including the integration of the 7 additional systems from the LIL Linac, and one X-band station as a linearizer. We will present the new layout with the required modifications and additions to the existing infrastructure to meet the more demanding needs of the system. Such modifications include a new RF controller, improvements in the modulator stability and an upgrade to the average power capabilities of the system to operate up to 50 Hz.

INTRODUCTION

The FERMI@ELETTRA project design is based upon the conversion of the existing Linac from working as the injector to the ELETTRA synchrotron light source, to the driver for a seeded FEL [1]. The existing Linac will be upgraded in energy with the addition of 7 sections made available by CERN after the decommissioning of the LEP Injector Linac (LIL). With this addition, the planned Linac energy will be 1.2 GeV. The FERMI project will evolve in two separate phases, starting from the production of radiation in the 100-40 nm range, and eventually reaching 10 nm at a later second phase. In both cases the Linac energy remains 1.2 GeV.

We describe here the modelling studies performed to optimize the design of the FERMI Linac, and the tolerances, in terms of amplitude and phase, required on the RF stations to obtain the expected beam. We also briefly cover the most important sub-systems that will be upgraded in order to meet the new, more stringent requirements of the system.

LAYOUT AND DESIGN PARAMETERS

The 1.2 GeV FERMI accelerator is schematically shown in Figure 1. Its main components are an injector and four Linac segments(L1-L4), interleaved by two bunch compressors. The four Linacs are made of two different types of accelerating sections, one that operates at lower gradient, (SLAC-type, S0A, S0B, C1-C7), the other running a high gradient and equipped with a SLED system (S1-S7). Both systems have been studied in terms of impedance and wake fields [2].

The layout reflects our design choices for the flexible variations of beam parameters as required by the FEL processes and for the preservation of the beam quality [3] that is high peak current, low emittance and low energy spread. L1 foresees a laser heater for suppression of the micro-bunching instability [4] and a high harmonic cavity for the linearization of the longitudinal phase space . High impedance accelerating structures (L3 and L4) [5] are located where the bunch is shorter in order to reduce the beam break up instability [6], while their longitudinal wake fields are used to cancel the energy-position correlation after BC2. We performed, by means of several tracking codes, extensive S2E simulations including jitters [7] and photoinjector optimization [8].

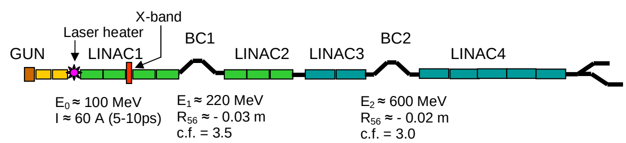

Figure 1: A schematic of the ~150 m long FERMI accelerator.

Table 1 summarizes the main beam parameters at the Linac exit for two pulse length options i.e. 700 fs and 1.4 ps.

Table 1: Main electron beam parameters for FEL process

	Medium	Long
Average energy	1.2 GeV	
Bunch length, ps (flat part)	0.7	1.4
Peak current, A	500	800
Emittance (slice), μm	<1.5	<1.5
Energy spread (slice), keV	<150	<150
Flatness, $\lvert d^2E/dt^2 \rvert$, MeV/ps^2	<0.8	<0.2

SENSITIVITY AND TOLERANCE STUDY

To understand and optimize the layout of the Linac and its expected performance, including the requirements on the new RF modulators and controllers, we completed a series of studies using the LiTrack code. In these studies, we considered three options of using a short (200 fs in the flat part), medium (700 fs) and a long bunch (1.4 ps), but only the medium and long bunch cases will be used for FERMI.

For all configurations we did sensitivity studies to determine the tolerance budgets for each segment of the Linac. We have also studied the effects of different charge distributions generated at the electron source, from flat, to parabolic, to ramped.

The results indicate that the most stringent phase requirements are on the first Linac segment (L1), while the tightest amplitude control is required on L4.

As a result of the study we adopted a ramped bunch charge distribution: our modeling showed that fluctuations in amplitude and phase had nearly identical effects on different longitudinal bunch profiles, with the only noticeable, but still minimum difference, in medium sized bunches. Such a distribution at the gun allowed us to obtain a flat charge profile at the end of the Linac.

In this process, we also allocated the tolerance budget among the various elements of the Linac, trading off amplitude and time jitter in the RF gun with those of each of the accelerating sections. The corresponding requirements in amplitude and phase result in the tightest phase control in L1 (0.09 ^{o}S) and amplitude control in L4 (0.05%). While our RF systems have not achieved these extremely demanding goals, we have done preliminary measurements on the existing systems. So far, we believe we can achieve stability in the order of 0.1% amplitude and 0.1 ^{o}S, not including potential benefits from noise correlation among different stations in the Linac [9].

With the above conditions, our error tracking analysis verified a satisfactory result in the final slice energy and peak current as a function of the time defined by the master clock.

RF GUN AND INJECTOR SYSTEM

We have started the procurement of a commercial S-band photocathode, which we plan to have installed by the end of 2007. The whole injector system is in the stage of technical design: we are presently defining the mechanical details of the RF cavity and Solenoid, which will also include the vacuum components connecting the Gun to the first accelerating section. We are allowing a distance of 1.65 m from the cathode plate and the centre of the first cell of the booster Linac (S0A + S0B) to accommodate the diagnostics and beam optics.

An extensive simulation program of the full injector has been completed to define the working points suitable for the FERMI operation considering a peak field in the RF cavity of 110 MV/m.

POWER SYSTEMS UPGRADE

The modulators for the existing ELETTRA Linac will need to be upgraded, for two reasons. On one side, several key components of the existing systems are not capable of high rep rate operation, i.e. 50Hz. On the other the FEL operation requires a very tight control of amplitude and phase as determined by the sensitivity analysis. This challenging task starts from the optimization of the performance of the modulators.

We are therefore planning to design and build new modulators for all of the stations in the system. We plan to compare two prototypes: one based upon conventional technology, Thyratron and an extremely low ripple PFN, in combination with a HV pulse transformer. A second based on a hybrid technology combining a solid state switch (an inductive adder) with a HV pulse transformer.

This R&D plan is intended to verify system performance expecially in terms of reliability, extremely important for an user facility like FERMI. This will lead the final design for the upgrade of the whole system.

DIAGNOSTICS

The upgraded Linac requires a newly designed diagnostic system in order to be properly configured and operated as the injector to a FEL [10].

In particular, we will use RF deflecting cavities for the measurement of the slice emittance in the dispersion free regions and cavity BPMs for accurate measurements of beam position. We will also instrument the injector with an optically triggered streak camera, capable of 200fs time resolution, which is well suited for measuring accurately bunches of a few ps as expected from the injector. The laser heater at the end of the injector is very rich of information for beam measurements (based on the optical replica concept). We also plan to measure bunch length using CSR from the last bending of the bunch compressors.

The measurement setup for the bunch arrival information for machine tuning will make use of an electro optical method based on Mach Zenhder modulator already tested at DESY. Resolution better than 100 fs should be easily achieved with this method.

A proper set-up of RF deflecting cavity combined with the horizontal bend of the spreader foreseen at the end of the Linac, provides a powerful tool for multiple beam measurements. Slice measurements of parameters like the emittance and the energy spread are required to provide details insight the portions of the bunch participating to the FEL process.

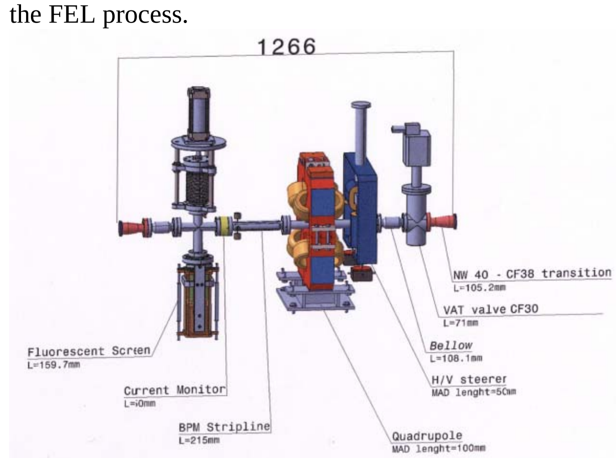

Figure 2: A schematic of intra-sections layout.

FREQUENCY CONTROL, TIMING AND DISTRIBUTION

One of the most critical elements of the upgraded linac is the control of frequency and phase distribution across the machine. RF amplitude and phase control will be provided using a modern FPGA-based controller which will take advantage of the high dynamic range of ADCs and DACs, by down-converting the S-band RF to an IF of up to 70 MHz. The fully digital I/Q modulation is then performed in the gate array [11].

A very advanced synchronization system will provide the timing of time-critical subsystems, with stability of a few tens of femtoseconds. A central clock system generates stable timing signals for the whole facility, sending them to locations up to 300m away over optical fibres in a "star" configuration. Timing information is transmitted using either RF-modulated CW light (mainly for the Fermi RF systems) or pulsed light (mainly for laser systems). The overall design incorporates different synchronization methods, optimized for their particular applications [12].

The synchronization system interfaces with the low-level RF electronics in the accelerator, with lasers in the photoinjector, seeding and end stations, with accelerator and with x-ray diagnostics via precise timing signals. Completing the timing distribution system, we generate and distribute a trigger for coarsely timed, low rep-rate devices throughout the facility, in synch with the precise timing signals. This allows the use of conventional delay generators where needed.

In addition to these systems, the Linac will also take advantage of a series of feedback systems, such as the beam based alignment, that will further ensure adequate performance. Figure 3 shows the machine frequency and phase distribution.

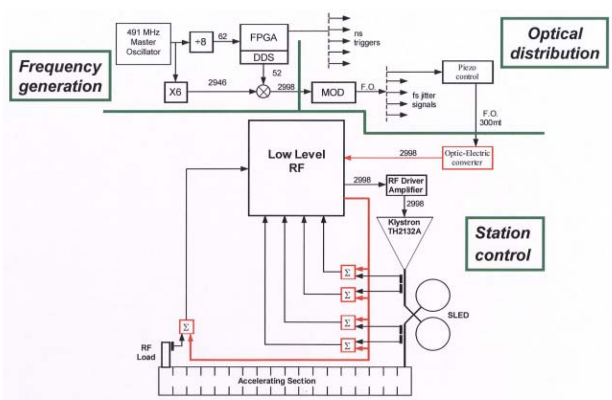

Figure 3: RF Controls system diagram.

STATUS AND PLANNING

The final layout and machine parameters are being defined this summer, as a result of the collaboration with LBNL and MIT, with the completion of the conceptual design report. While the CDR is being finalized, we have started procuring some key elements, such as the laser systems and rf gun. Conventional facilities have started the excavation and construction of the front end extension of the Linac gallery, needed for the final installation of the RF gun and injector system.

As the new booster for ELETTRA will be completed, the Linac will cease to support the storage ring operation as an injector and the main layout changes can take place. Until then, we will be developing and testing new concepts, without altering the performance or layout of the existing Linac. We are also planning a staged path towards 50 Hz operation, with an intermediate step at 10 Hz which will allow for a gradual upgrade of the RF power components that need replacement.

In preparation for the upgrade of all the RF power systems, the first prototype based upon a PFN is under development and will be used to energize the new RF gun, while the second unit, based on a hybrid technology, solid state switch and pulse transformer, is going to be assembled and installed on L0.

CONCLUSIONS

We have defined the new layout and main operating parameters of the FERMI Linac by extensive computer modeling and optimization. We will be finalizing this design into a CDR in the next months. Since the resulting upgraded Linac has very demanding requirements on amplitude and phase control, we have starter an R&D program to determine the final design of the optimal system, both in terms of modulator and of RF controller.

In the meantime we have also starter the procurement of critical components, such as the laser systems and the RF gun.

ACKNOWLEDGMENTS

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