LINAC DESIGN FOR THE FERMI PROJECT

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Abstract

FERMI is a fourth generation light source under construction at Sincrotrone Trieste [1]. The project is based upon the conversion of the existing injector linac to a 1.2 GeV machine suitable to drive a seeded FEL. The linac will require significant improvements and the addition of several new accelerating modules. Important parameters are pulse to pulse energy stability and the jitter of the e-bunch time of arrival. This paper covers the baseline design of the machine, as well as experimental results and the proposed technical solutions for the more critical sub-systems.

INTRODUCTION

The FERMI project will convert the existing 1.0 GeV linac, which has been running since the early nineties at the ELETTRA lightsource as the injector to the storage ring [2]. In order to raise the operating energy to 1.2 GeV, necessary to satisfy the requirements of the FERMI project, seven additional sections will be installed. These sections have been obtained from CERN after the decommissioning of the LEP Injector Linac (LIL). These sections will also allow to maintain an adequate margin over the maximum operating energy, providing a more flexible and reliable operation, which is particularly important in a user facility such as FERMI.

The FERMI project will be completed in two phases, starting from the production of radiation in the 100-40 nm range in phase I, up to the 10 nm with phase II. Table 1 summarizes FERMI's main bunch parameters.

Table1: 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, $\|d^2E/dt^2\|$, MeV/ps^2	< 0.8	< 0.2

EXISTING LINAC AND ACCELERATING STRUCTURES

The existing linac has been serving as the main injector for the ELETTRA storage ring since it's inception in the early nineties. It is based upon seven 6.1 m S-band backward travelling wave structures, equipped with a SLED RF pulse compression system, and two 3.2 m forward wave structures, placed in the lower energy part of the machine. With the addition of the CERN structures the final configuration the FERMI linac will consist of three different kinds of accelerating structures:

a) two 3.2 m long, SLAC-type, constant impedance structures (S0A and S0B);
b) seven 4.5 m long, SLAC-type, constant gradient structures (C1-C7);
c) seven 6.1 m long, unconventional backward TW structures (S1-S7).

The first two geometries (a and b) will be operated at a relatively modest gradient (up to 18 MV/m for S0A-S0B and 12 MV/m for C1-C7). The third structure type has a nose-cone geometry, with magnetic coupling and a small beam aperture, 10 mm in iris diameter. These sections (S1-S7) are also equipped with a SLED pulse compression scheme and have been already tested at gradients up to 23-25 MV/m with a good reliability. Moreover for the FERMI project we plan to maintain an operative margin of roughly 15%.

In addition to the previuos described accelerating structures, FERMI will require the use of a 4th harmonic accelerating system in the X-band region, consisting of a 0.5 m accelerating structure operating at 11.4 GHz, to linearize the longitudinal phase space.

With the exception of the X-band system all the structures will be powered by a 45 MW S-band klystron (model TH 2132A): while S1-S7 have installed one klystron tube per section, the remaining modules (S0A-S0B and C1-C7) are powered in pairs by the same klystron.

Table 2 summarizes the main parameters of each of the three section types.

Table 2: Main parameters of the FERMI accelerating sections

Structure type		S0A-S0B	CERN	BTW
Operating Mode		TW 2/3π	TW 2/3π	BTW 3/4π
Operating Frequency	MHz	2997.924	2998.5	2997.924
Iris radius	mm	9.73 (av.)	10.75 (av.)	5.0
Number of cells	Nº	93	135	162
Total length	mm	3200	4500	6150
Q_0		14100		12500
R_0	MΩ/m	67.1		79
Maximum operating gradient	MV/m	18	12	25
Expected Energy Gain	MeV	45	47	120

NEW LINAC LAYOUT AND ENERGY BUDGET

The new machine layout for the FERMI project is schematically shown in Figure 1. The layout was optimized to provide the necessary flexibility 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.

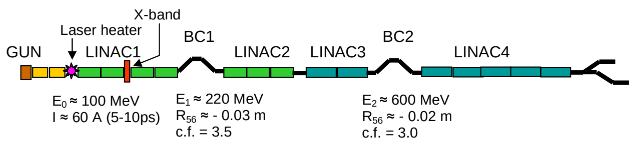

Figure 1: A schematic of the ~150 m long FERMI accelerator.

The system consists of an injector (a 5 MeV photoinjector gun and two accelerating structures with $E_{Max} \approx$ 100 MeV), followed by four linac segments (L1-L4), interleaved by two bunch compressors. Earlier studies [4] led to the decision to place the S-type cavities, the highest in term of impedance, at the high-energy end of the accelerator, two before and five after the second bunch compressor (BC2) in order to minimize the effect of transverse wakes and to reduce the beam break up instability, while their longitudinal wake fields are used to cancel the energy-position correlation after BC2.

Sections S0A and S0B, that are equipped with focusing solenoids, have been used in the injector section, at low energy, while the C sections are used around the first bunch compressor.

The layout reflects intentional choices for the flexible variations of beam parameters as required by the FEL processes and for the preservation of the beam quality that is high peak current, low emittance and low energy spread. L1 foresees also a laser heater for suppression of the microbunching instability and as already mentioned a high harmonic cavity module. Extensive s2e simulations including jitter studies were performed by means of several tracking codes [5].

Table 3 summarizes the expected performance of each accelerating section, the total contribution to deliver the 1.2 GeV beam required and to identify the available operating margin.

Table 3: Linac energy budget

Linac energy budget					
Type of structure	Quantity	ΔE (MeV)	Maximum energy gain on crest (MeV)	Operating margin (%)	Operating energy gain on crest (MeV)
Gun	1	5	5		5
S0A-S0B	2	50	100	10	90
C1-C7	7	55	382	14	329
S1-S7	7	140	980	14	840
X-band (?)	1	-20	-20	0	-20
With the X-band		**Total**	**1447**		**1244**
FERMI energy 1200 MeV					
For 1200 MeV at the linac exit ΔE_{max}= 44 MeV (-3.5%)					

SENSITIVITY AND TOLERANCE STUDY

The specifications for the new linac were derived from extensive sensitivity and tolerance studies, based upon LiTrack simulations [6]. The results affect in particular the amplitude and phase requirements of the RF system. In turn, this sets the goal for the power modulator upgrade and the new RF control system.

The studies were carried on for three different bunch lengths, a short (200 fs in the flat part), medium (700 fs – identified as M6) and long (1.4 ps – L4). Only the medium and long case are planned for FERMI and reported here. In addition we studied various options for different bunch charge distributions, from flat, to parabolic, to ramped. In the end, we adopted a ramped bunch charge distribution, which allows us to achieve a flat bunch distribution at the end of the linac.

Table 4 shows the results of our modelling and how we allocated the tolerance budget among the various sections of the linac. We report the results for the medium bunch case M6 and for the long bunch case L4, both with a linear ramped charge distribution. In the same table we have also included the jitter of the electron bunch at the cathode as well as the fluctuation of the extracted charge.

The simulations have been carried out to guarantee at the linac exit (at the same time) an energy stability pulse to pulse better than 0.1%, a peak current variation less than 10% and a bunch time of arrival jitter less than 150 fs. All the previous values are rms.

In general we have found values extremely challenging and well beyond the capabilities of the existing RF systems. As shown in table 4, FERMI will require phase stability in the order of 0.1 ^{o}S or better, and amplitude stability even more demanding, 0.05%, in M6. Moreover, if we consider that the X-band is in the 4th harmonic, its tolerance, 0.3 ^{o}X, becomes the most demanding.

While we believe we can reach amplitude and phase stabilities in the order of 0.1% and 0.1 ^{o}S, we have started an R&D program to develop a system capable to reach the required control levels. We are also studying potential noise correlation effects among different stations that could be beneficial to our goals [7].

Table 4: Sensitivity analysis results

Bunch Length/Operating Mode			**M6**	**L4**
Parameter	Symbol	Unit		
L1 RF Ph.	$\phi 1$	^{o}S	0.10	0.10
LX RF Ph.	ϕx	^{o}X	0.30	0.50
L2 RF Ph.	$\phi 2$	^{o}S	0.10	0.15
L3 RF Ph.	$\phi 3$	^{o}S	0.10	0.10
L4 RF Ph.	$\phi 4$	^{o}S	0.10	0.15
L1 RF_Volt.	ΔV1/V1	%	0.10	0.10
LX RF Volt.	ΔVx/Vx	%	0.50	0.60
L2 RF Volt.	ΔV2/V2	%	0.10	0.15
L3 RF Volt.	ΔV3/V3	%	0.10	0.10
L4 RF Volt.	ΔV4/V4	%	0.05	0.08
Gun timing	Δt0	ps	0.25	0.35
Q Initial	ΔQ/Q	%	3.00	4.00

POWER SYSTEMS UPGRADE

The modulators for the existing ELETTRA Linac will need to be upgraded for two reasons: i) several key components of the existing systems are not capable of 50 Hz operation as requested in a second phase; ii) the FEL operation requires a very tight control of amplitude and phase as determined by the tolerances analysis.

We are therefore planning to design and build new modulators for all of the stations in the system. For this purpose an R&D program to assembly and compare the performance and the reliability of two different units has already started. The first unit will be based upon a conventional technology, thyratron, an extremely low ripple PFN and a HV pulse transformer, the second will be based on a hybrid technology combining a solid state switch, an inductive adder, followed by a HV pulse transformer, Figure 2.

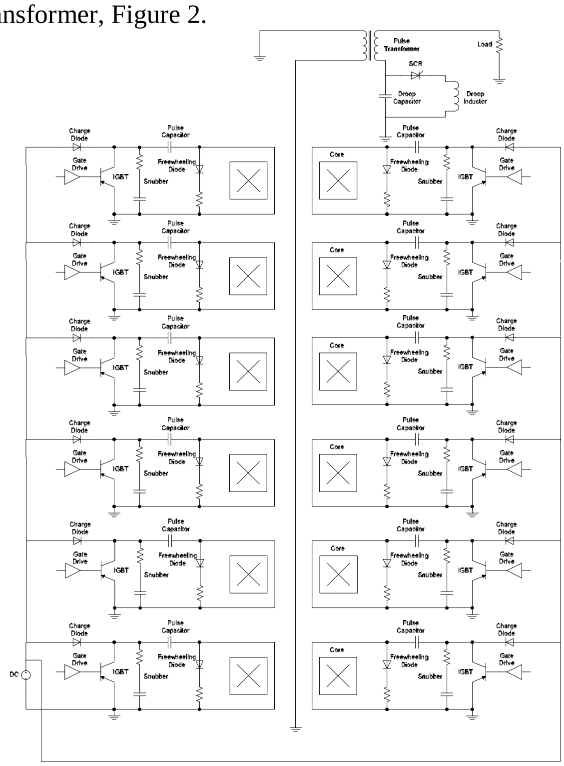

Figure 2: Solid state modulator layout.

FREQUENCY CONTROL, TIMING AND DISTRIBUTION

The requirements on the RF control and timing systems are extremely demanding. For this reason, we have adopted state of the art technologies to accomplish both RF station control and system timing synchronization. One additional complication it the use of the X-band linearizer, which is likely to be at an integer harmonic of the USA S-band frequency (2856 MHz) and therefore not an exact multiple of the existing linac at European S-band (2998 MHz). The RF controller will make use of an FPGA-based digital processor [8] which takes advantage of the high dynamic range available in modern ADCs and DACs by downconverting the S and X bands to 48.2 and 47.6 MHz respectively. The RF and timing system distributes an RF reference signal at 49.164 MHz to all stations in the system. This frequency is then processed by the digital controllers, that synthesize the IF locally and lock each station to a phase reference provided by the synchronization system. This provides frequency references across the facility and eliminated asynchronous events. This is achieved by using a common frequency of 15.779 MHz, which generates the S-band frequency when multiplied by 190, and the X-band when multiplied by 724. Such frequency can also be used to create a 61.455 MS/s clock for the FPGAs, and a 48.167 MHz IF for the S-band system (multiplying it by 190-74/19*8*6). The X-band system would use an IF of 47.614 MHz (multiply by 172/57). Each station is individually controlled by a single FPGA system, that works of the 491 MHz reference frequency and the laser distributed timing pulses, as shown in Figure 3.

The synchronization system will distribute phase references to each station [9]. The requirements correspond to maintaining a sub 100 fs synchronicity across the 300m of the facility. Integration of the synchronization system with the local RF controllers will be essential.

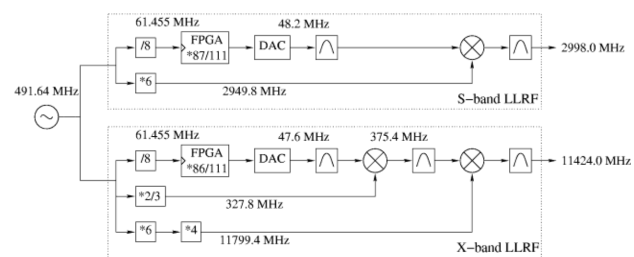

Fig 3: Single station RF controller block diagram.

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