CONCEPTUAL DESIGN OF AN X-FEL FACILITY USING CLIC X-BAND ACCELERATING STRUCTURE

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Abstract

Within last decade a linear accelerating structure with an average loaded gradient of 100 MV/m at 12 GHz has been demonstrated in the CLIC study. Recently, it has been proposed to use the CLIC structure to drive an FEL linac. In contrast to CLIC the linac would be powered by klystrons not by a drive beam. The main advantage of this proposal is achieving the required energies in a very short distance, thus the facility would be rather compact. In this study, we present the conceptual design parameters of a facility which could generate laser photon pulses covering the range of 1-75 Angstrom. Shorter wavelengths could also be reached with slightly increasing the energy.

INTRODUCTION

X-band accelerator development has gained improvement within last ten years, motivated by the need for high-gradient accelerators for the future linear colliders in high-energy physics research [1]. Design of accelerator cells [2], manufacturing [3], and characterization technique [4] have been developed. Due to limited RF power source availability for X-band frequencies, the accelerating principle at X-band frequencies were based on two beam accelerating (TBA) scheme. Simply the TBA scheme can be described as following; The RF power is generated by a high current electron beam (drive beam) running parallel to the x-band accelerator. This drive beam is decelerated in special power extraction structures and the generated RF power is transferred to the x-band accelerator. In other words the drive beam power extraction structures acts as any active RF components (i.e. klystrons) as it is at Compact Linear Collider (CLIC) project [5]. The development of power sources for x-band structures [6] gives opportunity this technology to be used as traditional accelerators especially in FEL designs.

MACHINE DESCRIPTION

The proposed facility is a 6 GeV linac, consisting of an S-Band injector and high-gradient X-band main accelerator which can deliver a high-repetition rate low-emittance beam, one or several undulator sections and photon beam lines with a user facility. The proposed layout is given with Fig. 1. Expected facility length is about 550 m and basic parameters of facility is given in Table 1.

Table 1: Basic Parameters of an X-FEL Facility Based on X-Band linac

	Parameter	Unit	Value
Main Linac	Energy	GeV	6
	Bunch Charge	pC	250
	Normalized emittance	mm mrad	<0.5
	Bunch length	μm	<8
	Linac frequency	GHz	12
	Structure Length (inc. couplers)	m	0.75
	Structure gradient	MV/m	65
	No of structures per RF module	#	10
	Total (effective) module length	m	10 (7.5)
	Number of RF modules needed	#	12
	No of klystrons per RF module	#	2
	Klystron output power	MW	50
	Klystron output pulse length	μs	1.5
	RF pulse length at structure	ns	150
	Pulse repetition rate	Hz	50-100
	Number of bunches per pulse	#	1-3
Injector	Energy	MeV	300
	Linac frequency	GHz	3
	Linac gradient	MV/m	20
	Number of klystrons	#	5
	Klystron output Power	MW	50
	Total (effective) injector length	m	50 (25)

Injector

The injector is proposed to be similar to the injector at SwissFEL [7] . It is based on S-band RF gun operating at about 100 MV/m gradient and standard S-band structures operating at about 20 MV/ gradient. However if the beam pulse repetition rate is required to increase up to 500 Hz one should also design the S-band structures of injector for such repetition.

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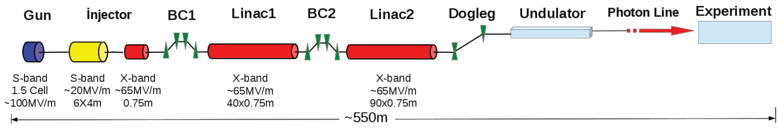

Figure 1: Layout of proposed facility.

Main Accelerator

X-band accelerating structures developed for CLIC project [8] are planned to be used in main accelerating section. In order to define structure parameters such as gradient, structure length, aperture etc., we initially have checked the effect of single bunch wake field along the main linac. If the beam is injected with an offset, e.g. from beam jitter, the transverse wake fields in the linac will induce an additional oscillation of the centroid of the bunch, which is 90° out of phase with the initial oscillation [9]. We require that the ratio $\frac{A}{A_0}$ of this induced oscillation to the original (in normalised coordinates) remains small $\frac{A}{A_0} << 1$.

Figure 2 shows the curves of maximum amplifications of $\max[\frac{A_x}{A_{x0}}] = 0.1$ and 0.4 versus gradient of two different CLIC structure (CLIC-502 [8], CLIC-G [10]). As it can be seen on the figure in order to get $\max[\frac{A_x}{A_{x0}}] = 0.4$ the gradient of CLIC-G structure must be more than 110 MV/m while the gradient above 35 MV/m is acceptable for CLIC-502 type of structure. Both structure do not allow to get $\max[\frac{A_x}{A_{x0}}] = 0.1$ amplification.

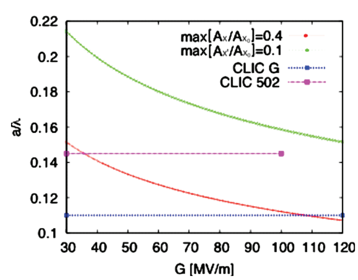

Figure 2: Amplification curves of a single bunch versus gradient and a/λ of structures. a/λ line above curves is acceptable.

Cost estimation has been done using the structure database of CLIC taking into account wake field effect, gradient, length, input power of structures, also considered cost of module consisting the pulse compressor. The summary of cost estimation is given with Table 2.

Pulse compressor and RF module layout: Using the results given in Table 2, 10 structures will be installed on one RF module and fed by one RF station which is essentially is combination two klystrons. Schematic view of the module and power combination/distribution system is given with Fig. 3.

Two klystron that each has power of 50 MW and pulse length of 1.5μs will be driven by two individual modulator. The RF pulses will be combined with hybrids combiners. Single RF pulse that has 100 MW power and 1.5μs length

Table 2: Summary of Basic Parameters of Cost Optimization

Parameter	CLIC-502		Optimum
Structures per RF unit	12	16	10
Klystrons per RF unit	2	2	2
Structure length (m)	0.23	0.23	0.75
a/λ	0.145	0.145	0.125
Operating gradient (MV/m)	77	67.5	65
Energy gain per RF unit (MeV)	213	248	488
RF units needed	27	23	12
Total klystrons	54	46	24
Linac active length (m)	74	84	88
Cost estimate (a.u.)	76.2	71.5	51.7

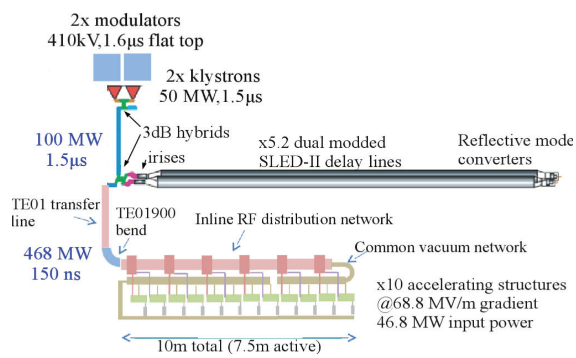

Figure 3: Schematic view of proposed RF unit (module).

will be compressed to 150 ns by SLED-II delay lines [11]. After compression expected RF power is 468 MW. The compressed power will be distributed by an RF network to each structure evenly which means each structure will be fed by 46.8 MW power yielding 68.8 MV/m gradient.

SIMULATIONS

Preliminary simulations has been performed for the injector, main accelerating section and FEL generation.

Injector: Similar to LCLS [12] a 1.5 cell photo cathode RF gun operating 100 MV/m gradient at 3 GHz is proposed for the electron source. The cathode of the gun is assumed to deliver 250 pC bunch charge and 9 ps full width half maximum bunch length. Travelling wave accelerating structures that are operating with 20 MV/m gradient at 3 GHz are fallowed the RF gun similar to SwissFEL. Astra code [13] has been used for simulations and optimization injector section. The beam size and emittance along the injector is given with Fig. 4. As it can be seen the projected normalized emittance ε_x is below 0.5 mm.mrad.

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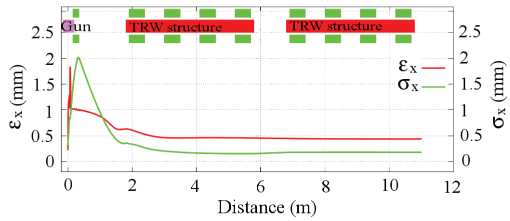


Figure 4: Horizontal emittance and beam size through the injector.

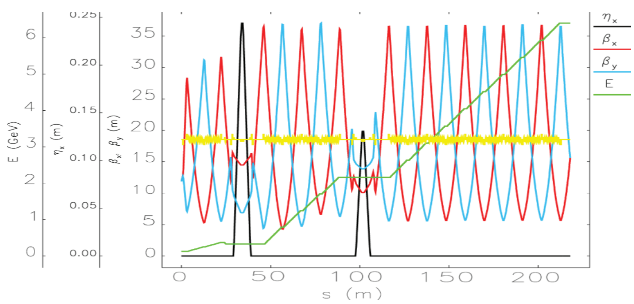
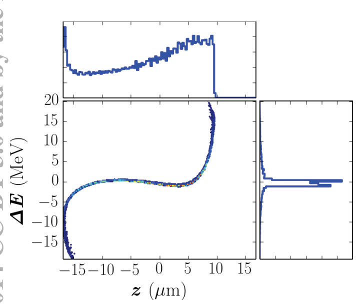


Figure 5: Beam energy, and Twiss functions along the linac.

Main accelerating section: The injector is followed by an X-Band structure as a chirp linearizer in order to perform better bunch compression. A bunch compressor is located after the linearizer structure afterward two stage main accelerating section separated with bunch compressor is proposed for the main accelerating section (see Fig.1). FODO type of lattice is proposed for beam transport and Elegant code [14] has been used for tracking.

Figures 5 and 6 show the beam energy and Twiss functions along the linac and final longitudinal phase space of the bunch. In order to compress bunches down to σ_z = 8μm, we have used two bunch compressor with $R_{56,BC1}$ = 0.0267 m and $R_{56,BC1}$ = 0.0092 m, and summary of structure's settings are



Parameter	Unit	Value
E	MeV	6.364
$\varepsilon_{n,x}$	μmμrad	463.922
$\varepsilon_{n,y}$	μmμrad	468.179
ε_z	MeV.μm	21.602
σ_x	μm	22.503
σ_y	μm	24.048
σ_z	μm	7.860
σ_E	MeV	3.518
$\Delta E/E$	%	0.055

Figure 6: Longitudinal phase space and beam parameters of bunch at the end of linac.

Name of section	No. of struc.	G (MV/m)	ϕ_{RF} (deg)
Gun S-band	1	100	26
Injector S-band	4	16	20
Injector X-band	1	62.2	151.5
Linac1 X-band	40	65	20
Linac2 X-band	90	65	-15

After such compression RMS peak current is $I \approx 9$ kA and RMS energy spread is $\sigma_E/E \approx 0.06\%$.

Lasing Section: We have also performed simulations for the lasing section using GENESIS [15] code. We have used planar type of undulators located on FODO type of lattice. We assumed each undulator have about 4.2 m length, 15 mm period length and 1 undulator strength. Using the longitudinal bunch distribution given with Fig. 6 we have found that the power of laser at 0.9 Å resonant wavelength saturates at around 75 m and power reaches to several GWs which is typical number for X-FELs.

CONCLUSION

Applications of X-band technology in linacs is rapidly expanding due to its great potential already shown and the possibility to operate it at gradients up to 100 MV/m. This will also benefit the interest for very compact high energy linacs for hard X-ray FELs. A committee consist of several institutions which are interested X-FEL has been studying on usage of CLIC X-Band structure for driving an FEL facility in order to write a common conceptual design report (CDR) for such an X-FEL facility. It is planned that the CDR will be completed by the end of 2014 and several projects are going to be started in next years.

In this paper we focused on feasibility of usage of CLIC X-Band structures driving an FEL facility. We described preliminary simulations. It is shown that the bunches can be compressed down to σ_z = 8μm and the radiation below 1 Å can be produced in SASE mode. However energy options of 3 GeV and 12 GeV will be studied as well as the tolerance requirements of such machine. High repetition rate up to 500 Hz, seeding FEL generation and tapered type undulator options will also be studied in future.

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