QUASI-CW NORMAL CONDUCTING LINAC FOR SOFT XFEL*

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Abstract

The Next Generation Light Source (NGLS) envisions using a 2.5 GeV, CW, L-band (1.3 GHz) drive linac with a 1 MHz bunch rate to produce soft X-rays. While superconducting linac technology is the obvious choice for such a linac, it requires significant development and entails using a large cryo-plant. In this paper, we explore an alternate design based on a room temperature, L-band linac. Long pulse (1.6 ms) L-band sources that have already been developed for E-XFEL and ILC would be used to power travelling wave(TW) structures with a several microseconds fill time. While the lower structure shunt impedance relative to SC cavities will require more rf power, it allows for higher current operation, for example, a 3.2 MHz average bunch rate with 250 pC bunches spaced by 5 ns.

INTRODUCTION

Future X-ray sources will be able to explore the atomic and nano-worlds on time scales from seconds to atto-seconds. However, the scientific promise of X-ray Raman and inelastic X-ray scattering is limited by the available flux from existing hard and soft X-ray sources. The scientific impact of present short-pulse X-ray sources is also limited by the average flux and brightness. Furthermore, time-resolved experiments and nonlinear X-ray science with short-pulse sources require the ability to trade-off peak and average brightness for specific applications, including correlation spectroscopy.

A high bunch rate X-ray source with short bunch spacing would provide a solution to achieving high average flux, and could be operated with a variety of bunch patterns. One major component for such a linac, a long pulse (1.6 ms), high power (10 MW), efficient (65%) klystron has been developed for ILC and E-XFEL [1]. Also, transformer-less Marx modulators are being developed to drive these tubes [1]. In this paper, we present an L-band TW accelerator structure design, a calculation of its long range transverse wakefield, and the parameters for a 2.5 GeV linac using this structure.

TW L-BAND ACCELERATOR

Based on a structure optimization study for low beam loaded linacs [3], the optimum field attenuation constant, τ, for a TW accelerator far exceeds unity for rf pulse lengths as long 1.6 ms, which are achievable with high power L-band klystrons. For this study, τ = 0.95 was chosen as a compromise between maximizing the energy gain and minimizing the fill time. For this field attenuation constant, Fig. 1 shows the length of a constant gradient structure as a function of average iris radius assuming the cells have essentially square edges, and the iris thickness is 7.4 mm. To obtain high shunt impendence while keeping the wakefields reasonably small, a structure length of 5 m with an average iris radius of 16.2 mm was chosen. The power attenuation in the structure in this case is 85%. The long structure also helps reduce the linac cost as the rf distribution system is simplified. Details of the structure design are listed in Table 1.

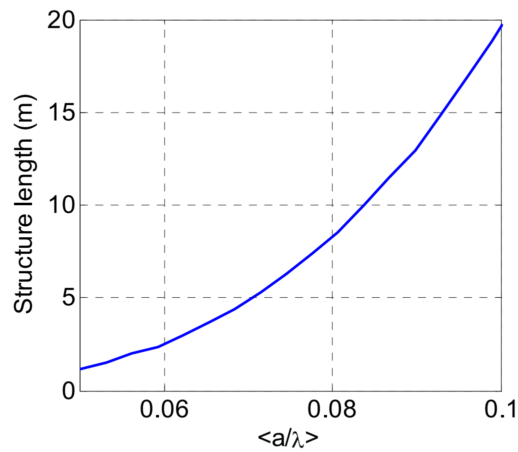

Figure 1: Constant-gradient structure length as a function of average iris radius, normalized to the rf wavelength.

Table 1: L-Band Structure Parameters

	Symbol		Unit
Length	L_a	5	m
Number of cells	N_c	65	
Filling time	t_f	4.9	μs
Phase advance / cell	ψ	120	Deg
Fundamental Q	Q_0	2.1×10^4	
Field attenuation constant	τ	0.95	
Cell radius	b	88.3	mm
Average iris radius	$\langle a/\lambda \rangle$	0.07	
Iris radius	a	19.6 ~ 12.5	mm
Iris thickness	t	7.4	mm
Shunt impedance	r_s	52.8	MΩ/m
Unloaded gradient	G_a	9.5	MV/m
Input power	P	10	MW

LONG RANGE WAKEFIELD

The long-range transverse wakefields of this structure were computed using the program Cascade [2, 3]. The most troublesome transverse modes are those in the first dipole passband, and only these modes will be considered

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in this study. Including attenuation, the dipole wakefield of the structure can be written as [4]

$$\vec{W}_{\perp}(s) = \sum_{n=1}^{N} 2K_n \sin\left(\frac{\omega_n s}{c}\right) e^{-\frac{s\omega_n}{2cQ_n}}, \quad (1)$$

where K_n and Q_n are, respectively, the kick factor in V/C/m^2 and the quality factor for nth mode. The calculated first dipole band Q and kick factors are plotted in Fig. 2, where it can be seen that the first few lowest frequency modes contribute the most. Due to the dense mode spacing, only about two-thirds of the modes were identified with the Cascade program (work is continuing to improve on this). Fig. 3 shows the resulting long range transverse wakefield (in blue) computed using Eq. 1. for these modes, and for comparison (in red), the wakefield computed with an uncoupled model (i.e., for each cell geometry, the synchronous dipole mode is computed for a periodic structure made from such cells [4]). As expected, the two wakefields agree well at short distances behind the bunch.

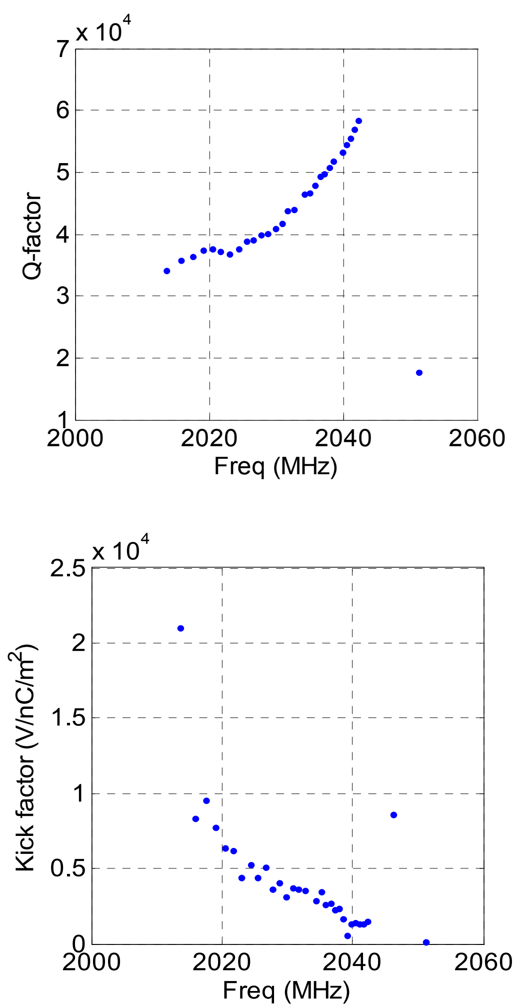

Figure 2: The Q-factors (top) and transverse kick factors (bottom) for the first dipole passband of the structure.

The magnitude of the wakefield near s = 0 is about one thousandth that of the NLC X-band structures [5] and several times larger than that of the 1.3 GHz cavities in the ILC main linacs (due to the smaller iris size in this case) [6]. When including the other relevant factors that determine the transverse wakefield affect on subsequent bunches (i.e., bunch charge, bunch energy, linac length, …), the net kicks to the bunches with a 5 ns spacing would be comparable to that for the 300 ns spacing in ILC.

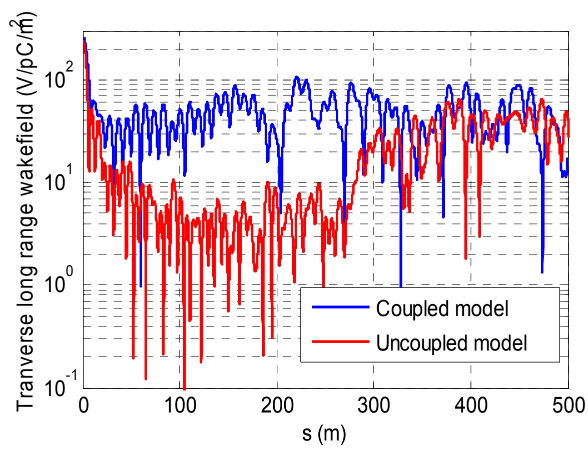

Figure 3: Transverse wakefield envelope as a function of the distance, s, behind the bunch.

LINAC PARAMETERS

For this study, an rf pulse structure similar to that for E-XFEL and ILC is assumed, that is, 1.6 ms rf pulses at 10 Hz. However, the charge per bunch is limited to 250 pC, the same as that at LCLS (but four times smaller than NGLS), and a minimum bunch spacing of 5 ns is assumed, which is likely near the practical limit for a low emittance, long-pulse injector. Thus the maximum beam current is 50 mA, about five times that of ILC and 50 times that of NGLS. With a 10 MW klystron powering each of the proposed 5 m long structures, the loaded gradient would be 8.6 MV/m (about 10% loading). At lower beam currents, the rf power would be reduced to maintain the same gradient.

Assuming an efficiency of 65% for a multi-beam L-band klystron (already achieved), and 85% for a modulator to drive it, the AC power required to generate the rf in a 2.5 GeV linac with 50 mA beams is 17 MW. Table 2 lists the parameters for such a linac for bunch spacings from 5 ns to 300 ns. The pulse repetition rate could be lowered to reduce the AC power requirement, for example to 5 Hz, where the AC power would be within a factor of two of NGLS while the bunch rate would still be larger (by 60%).

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SUMMARY

An L-band, room temperature TW structure is presented that is optimized for low beam loading operation. Using modulators and klystrons developed for E-XEFL and ILC, a 2.5 GeV, 50 mA peak current, L-band linac with such structures could deliver 250 pC bunches at 3.2 MHz and would require 17 MW of AC power. The long range wakefield effects for bunch spacing as short as 5 ns should still be manageable.

Table 2: 2.5 GeV L-band linac parameters

	Value	**Unit**
Bunch repetition rate	53 - 3200	kHz
Max bunch charge	250	pC
Klystron peak power	8.2-10	MW
Klystron pulse width	1.6	ms
Pulse repetition rate	10	Hz
Loaded gradient	8.6	MV/m
Number of structures	58	
Number of klystrons	58	
Max AC power for linac rf generation	17	MW

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