DESIGN CONCEPTS FOR THE NGLS LINAC*

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Abstract

The Next Generation Light Source (NGLS) is a design concept for a multi beamline soft x-ray FEL array powered by a ~2.4 GeV CW superconducting linear accelerator, operating with a 1 MHz evenly spaced bunch repetition rate. This paper describes the concepts under development for a linac operating at 1.3 GHz and based on minimal modifications to the design of ILC cryomodules in order to leverage the extensive R&D and infrastructure development that resulted from ILC community investments. Due to the different nature of the two applications, particular emphasis is given here to high loaded Q operation and microphonics control, as well as high reliability and operational up time.

NGLS LINAC OVERVIEW

The NGLS linac is a single-pass, continuous-wave (CW), superconducting, high-brightness electron linac, to provide high repetition-rate beam to up to 9 separate FELs. The NGLS main parameters are listed in Table 1.

Table 1: Main NGLS Parameters

Electron Beam Parameters	symbol	nom. value	units
Final electron energy	E_f	2.4	GeV
Electron bunch charge	Q_b	0.30	nC
Bunch max. rep. rate (CW)	f_b	1	MHz
Average electron current	I_{av}	0.3	mA
Average electron beam power	P_{av}	0.72	MW
Norm. rms transverse slice emittance	$\gamma\varepsilon_{\perp\text{-}s}$	0.6	µm
Norm. max. rms transverse proj. emittance	$\gamma\varepsilon_{\perp}$	1.0	µm
Peak current	I_{pk}	500	A
Final rms bunch length	σ_{zf}	50	µm
Final useable bunch duration FWHM	$\Delta\tau_f$	300	fs
Final slice energy spread (rms)	σ_{Es}	150	keV

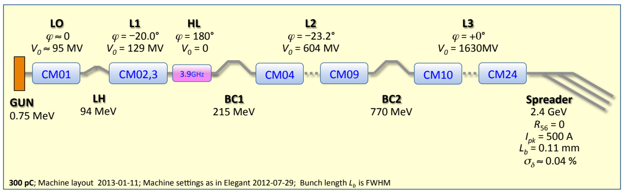

Figure 1: NGLS Linac schematic layout.

The linac is composed of four sections of accelerating cryomodules: a laser heater, a 3rd harmonic linearizer system, and two bunch compressors as described below. Figure 1 shows the schematic layout of the linac, while Table 2 summarizes the main parameters of each section.

Table 2: Main Linac Sections Parameters

Section	V (MV)	f (deg)	Acc. Gradient (MV/m)	No. Cryo-Modules
L0	95	~0	15.9	1
L1	129	-20.0	8.2	2
L2	604	-23.2	12.9	6
L3	1630	0	14.0	15

RF Parameters

The choice of SCRF cavity frequency for NGLS is ultimately driven by the need to minimize development cost by taking advantage of existing proven technology that meets the needs for the NGLS. Arguments for higher frequency include reduced cost of niobium for the smaller cavities, and resulting impact on associated component and cryomodule size and cost. Arguments for lower frequency include reduced transverse wakefields, which scale and f^3, longitudinal wakefields and BCS losses, which both scale as f^2. The plan to take advantage of the investments in TESLA/ILC/XFEL technology that have been made worldwide sets most of the RF parameters for the linac, when combined with the desire to run at a high loaded Q to minimize RF source costs. Table 3 summarizes the main RF parameters.

Table 3: Main RF Parameters

Parameter	Value	Unit
RF frequency	1300	MHz
Operating temperature	1.8	K
Average operating grad.	14	MV/m
Average Q_0 per CM	$2\text{x}10^{10}$	
Cavity length	1.038	m
R/Q	1036	Ohm
Coarse tuner range	600	kHz
Fine tuner range	2	kHz
Lorentz detuning	1.5	Hz/(MV/m)^2
Number of Cav. per CM	8	
Peak detune allowance	15	Hz
Q_{ext}	$3.2\text{x}10^7$	
Min. RF power per cavity	5.4	kW
Total cavity dynamic load	12.5	W
Total CM dynamic load	100	W

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CAVITY AND CRYOMODULE SELECTION

Cavity Considerations

The differences in operating ILC-like cavities in CW mode go beyond the need for increased heat rejection: the emphasis on resonance control moves from coping with the hammer-like effect of pulsed Lorentz forces, to minimizing the impact of microphonic induced frequency shifts due to mechanical vibrations. For the NGLS cavities the most important factor is to operate at a high loaded Q, which results in reduced power consumption, and this is realized by a successful control of microphonics. We have chosen to allow for a 15 Hz peak detuning from microphonic effects without having to derate the cavity field due to limited RF source power. This leads to a loaded Q of approximately $3x10^7$.

Cryomodule Approach

For reliability in a relatively small machine and safety in the face of cryogenic fault screening, we will use discrete cryomodules, allowing for ease of removal and replacement, as well as accommodating equipment such as lattice magnets, diagnostics, and travelling-wave absorbers in warm sections between cryomodules. The modifications to ILC cryomodules involve short warm-to-cold transitions at each cryomodule end, and U-tube cryogenic connections.

TUNERS, COUPLERS AND HOM DAMPERS

Tuners

Resonance control is particularly important because we want to operate at high loaded Q. The success of this depends upon the ability of the tuners to quickly compensate for microphonics effects. While the detuning excitation sources and cavity frequency stability goals are very different for a narrow-band CW cavity compared to the ILC pulsed scenario, the technology for achieving usable cavity tuning is equivalent. One of the existing ILC tuners, composed of a fast/fine piezo coupled with a slow/coarse motor drive, is likely to suit the needs of NGLS.

Input Couplers

There are several existing designs that could be adopted for a power coupler to operate the 5-8 kW CW range. Our approach based on obtaining maximum benefit from the ILC cryomodule design is to use a coaxial input RF power coupler derived from the TESLA TTF-III design.

HOM Dampers

Geometric wakefields and higher-order-modes (HOMs) in the cavities affect two aspects of the linac: the beam dynamics and the dynamic load on the subatmospheric helium bath. HOMs are well characterized for the TESLA-type cavities although NGLS bunches excite a very broad spectrum of modes extending into the THz range. For modes propagating outside the cavities, beam-pipe HOM absorbers at room temperature are used to avoid coupling between cryomodules, and may reduce heat load on the cryo system. Beam dynamics studies are under way to determine whether HOM dampers are required for the NGLS cavities

CRYOGENIC SYSTEM CONSIDERATIONS

The function of the cryomodule is to support the rf cavities, maintain them at the operating temperature of about 1.8 K, and shield them from magnetic fields in excess of tens of milliGauss. In addition to magnetic shields, the vessel wall being one of them, a single thermal shield operating over the 40 K to 50 K will be used to limit radiation heat loading on the ~1.8 K structure through careful selection of flow direction and routing of the cold gas circuit. An important decision is that to operate the cavities between 1.8 and 1.9 K, where the expected intrinsic Q_0 is significantly higher than at the ILC design temperature of 2.0 K.

Dynamic heat loads dominate the NGLS requirements due to the CW operating conditions. Heat loads were estimated from a combination of known cavity parameters, extrapolations from the ILC RDR values and measurements made on ILC type cryomodules and couplers.

We assume to implement one modern cryoplant, limited by the size of a single cold box, such as those used in the JLAB upgrade or the LHC. This choice does not appear to be an unwelcome constraint for the desired system.

RF SYSTEM AND DISTRIBUTION

We have chosen to power each cavity with an independent power source. This allows us to operate each cavity in its preferred conditions, optimizing the gradient and therefore energy gain in the linac while minimizing dark current and possible nuisance trips. This configuration is likely to result in the highest possible beam availability and machine reliability. The planned waveguide distribution system is shown in Fig. 2 and has been used to calculate waveguide losses and heat dissipation to the tunnel.

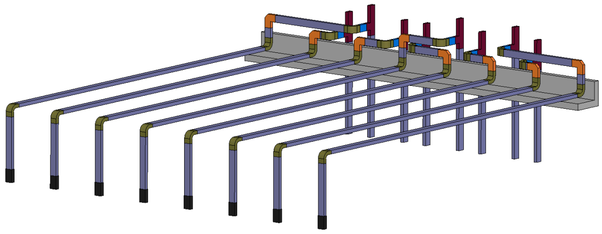

Figure 2: Waveguide distribution system.

CAVITY PRODUCTION RUN ASSUMPTIONS

Most of the RF parameters, including the requirements on the RF power system and the expected dynamic load on the cryogenic system, depend upon the assumed performance of the RF cavities.

To validate our assumptions, we have analyzed recent test results from cavity production of 17 ILC/XFEL cavities from DESY. The observed parameters have been used as the basis for a Monte Carlo simulation of a potential NGLS production run (for L3 only) and show the chosen parameter space is well within the limits of today's technology. Figure 3 shows a simulation of a linac configuration based on a possible cavity production run using measured cavity parameters; the green line indicates the acceptance criteria set by the NGLS requirements and shows no cavity in this run would be rejected.

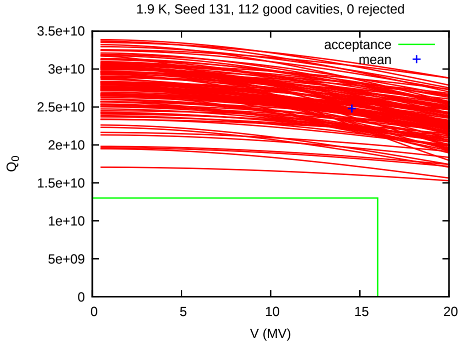

Figure 3: A simulated production run of 112 cavities.

The model also helps calculating the statistics of a practical RF amplifier system and dynamic load to the cryogenic system. As shown in Fig. 4, each trace represents a random cavity behavior within the limits set by the actual production data, when each cavity is operated at the nominal Q of 3.3x10^7. This shows how a power of 5.8 kW at the cavity flange would be sufficient to operate all cavities at the stated Q_L and the corresponding cryogenic heat load would be less than 950W. This result is one component of a larger optimization including scaling to the whole linac, and adding other dynamic and static loads.

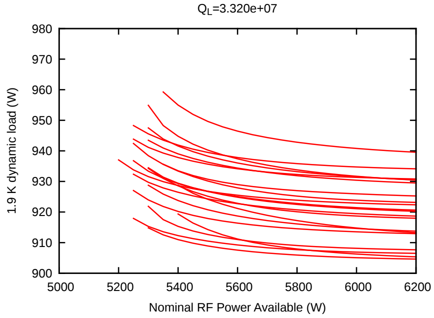

Figure 4: Modeled performance of linac with simulated random production run of 112 cavities.

COST CONSIDERATIONS

Since the superconducting linac is one of the largest expenses in the construction of the NGLS, we have developed a parametric cost estimate that allows us to seek cost optimization. The estimate includes the cost of the cryogenic system, tunnel construction, cryomodules and RF power amplifiers and distribution. The resulting costs (shown in Figure 5 in normalized units) show how the cost of the RF amplifier system is relatively independent of the total cost, as expected. On the other hand, higher gradients result in reduced cryomodule and tunnel capital expenses, but some of these savings are offset by increased costs of the cryogenic system due to the increased heat load at higher gradients. Note that curves for operating at 1.8, 1.9 and 2K are shown up to the limit of a single cold box.

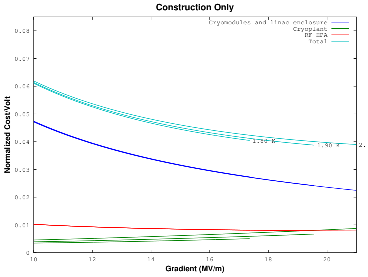

Figure 5: Construction cost as a function of cavity gradient.

Similarly, Figure 6 shows the same analysis when we also include the expected cost of electrical power to operate the facility for 15 years for 91% of the year (8,000 hours). This shows how the higher operating costs further offset the benefits of a higher gradient, although the minimum is shallow and dependent on cavity temperature.

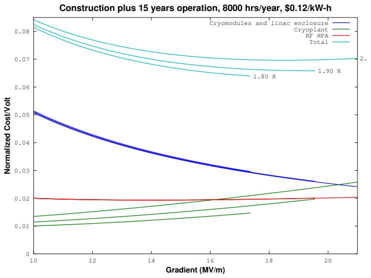

Figure 6: Total construction and operating cost as a function of cavity gradient.

While parts of the work presented here are developed for a 2.4 GeV linac, the concepts and studies have general applicability for any CW SCRF-linac-driven soft X-ray FEL facility. A full optimization study of scope versus cost is underway, including a facility driven by a 1.2 GeV linac.

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REFERENCES

[1] J. Corlett, et al., "A Next Generation Light Source Facility at LBNL", proceedings of the 2011 Particle Accelerator Conference, New York, NY, USA