# RF DESIGN APPROACH FOR AN 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 superconducting linear accelerator, operating in CW mode with evenly spaced bunches at approximately a 1 MHz repetition rate. This paper describes the concepts under development for a linac based on minimal modifications to the design and technology of the International Linear Collider technology in order to leverage the ILC community's extensive investment in R&D and infrastructure development. 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 uses a single-pass, continuous-wave (CW), superconducting, high-brightness electron linac to provide high-repetition-rate beam to multiple FELs. The NGLS main parameters are presented elsewhere in this Proceedings [1].

The linac has four sections of accelerating cryomodules, separated by other elements: a laser heater, a 3rd harmonic linearizer system (also a series of cryomodules operating at a higher harmonic frequency) and two bunch compressors. The linac is shown in Fig. 1.

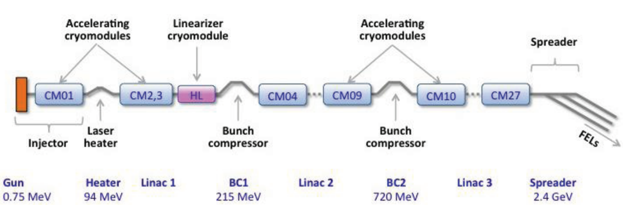


Figure 1: NGLS linac schematic layout.

## LINAC RF DESIGN

### *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 of the NGLS. We plan to take advantage of the extensive worldwide investments in TESLA/ILC/XFEL technology; this 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 1 summarizes the main RF parameters.

Table 1: Main RF Parameters

| | | |
|---|---|---|
| RF frequency | 1300 | MHz |
| Operating temperature | 1.8 | K |
| Average operating grad. | 12-20 | MV/m |
| Average $Q_0$ per CM | $2x10^{10}$ | |
| 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 |
| $Q_{ext}$ | $3.2x10^7$ | |
| Min. RF power per cavity | 5.4 | kW |
| Total cavity dynamic load | 12.5 | W |
| Total CM dynamic load | 100 | W |

## CAVITY AND CRYOMODULE DESIGN

### *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 microphonics-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. This goal is realized by successful control of microphonics. We have chosen to allow for a 15 Hz peak detuning from microphonic effects without having to de-rate the cavity field due to limited RF source power. This choice corresponds to a loaded Q of ~3.2 $x10^7$ and has a direct impact on the requirements for the RF plant. A smaller allowance for microphonics would result in significant cost savings but could compromise reliability. We are therefore monitoring progress in the community to identify the most reasonable compromise.

### *Tuners, Couplers and HOM Dampers*

Resonance control is particularly important because we want to operate at high loaded Q and therefore we

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need tuners able to quickly compensate for microphonics effects. 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.

There are several existing power coupler designs that could be adopted for a power coupler to operate the envisioned CW power 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.

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 cryosystem.

### *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, as well as U-tube cryogenic connections. In addition to magnetic shields that keep the field around the cavities below tens of milligauss, 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, along with careful selection of flow direction and routing of the cold gas circuit. The expected intrinsic $Q_0$ of the cavities (important for reasons mentioned earlier) is significantly higher at 1.8-1.9 K than at the ILC design temperature of 2.0 K.

## RF SYSTEM AND DISTRIBUTION

### *RF Technology Options*

There are two basic technologies capable of delivering the high power RF needed to energize the cavities in the NGLS linac: 1) vacuum tubes, specifically inductive output tubes and klystrons; and 2) solid state power amplifiers, in which the outputs of a number of low power (few hundred watts) transistors are summed. Klystrons have been the traditional power source for particle accelerators in these frequencies because they produce high power RF and offer high gain (~50 dB) with efficiencies around 50%. The recently completed 12 GeV upgrade of CEBAF adopted klystrons as the source of RF power [2].

Recent improvements in transistor technology have led to an increased power capability of solid state power amplifiers (SSPAs). Individual transistors can reach power levels on the order of a couple of hundreds of watts, and by combining many in a single power source, several to tens of kilowatts can be achieved with tolerable efficiency degradation. Several facilities are adopting this technology for its modularity, ease of maintenance and potential for incremental upgrades. The system operating efficiency for such L-band SSPAs does not much exceed 40%.

The solid state technology is still emerging, and further advances, including better efficiency, can be expected. However, for the same reason—the lack of maturity—the reliability of these systems at present is less well established. We plan to keep monitoring progress in this technology and defer a decision on a baseline design.

### *System Topology*

Providing an individual RF power source for each cavity offers many advantages. In particular, it allows the beam energy gain in each cavity to be precisely regulated, independently of the other cavities to better optimize the operating gradients to the most reliable performance of each cavity. It also simplifies the high-power RF distribution system and minimizes the effect of source failures. Of the 192 linac cavities, only a small fraction would need be held in reserve to compensate for such failed units, likely with only a brief (or no) interruption of beam operation.

We have therefore chosen to power each cavity with an independent power source. 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.

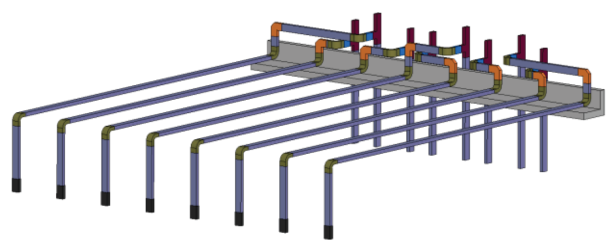

Figure 2: Waveguide distribution system. Each cavity is fed from a dedicated power supply housed in a separate tunnel, located to the right hand side of this diagram.

## CRYOGENIC SYSTEM CONSIDERATIONS

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.

## CAVITY PRODUCTION RUN ASSUMPTIONS

Most of the RF parameters, including the requirements on the RF power system and the expected dynamic load

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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 example Linac 3 in Fig. 1 with 14 cryomodules) and show that the chosen parameter space is well within the limits of today's technology. Figure 3 shows a simulation 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 that no cavity in this run would be rejected.

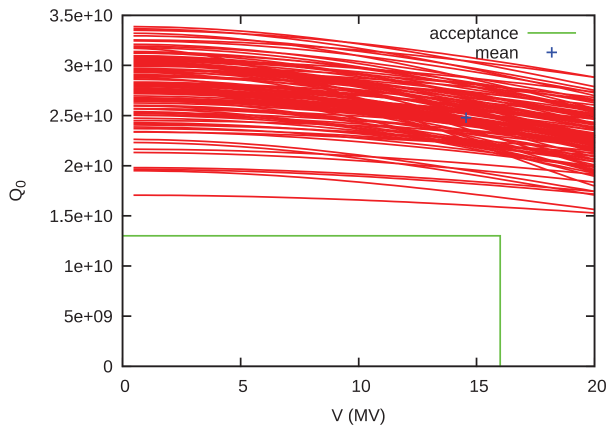


Figure 3: A simulated production run of 112 cavities. The green line shows the assumed acceptance criteria.

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 $3.2x10^7$. 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 950 W. This result is one component of a larger optimization including scaling to the whole linac, and adding other dynamic and static loads.

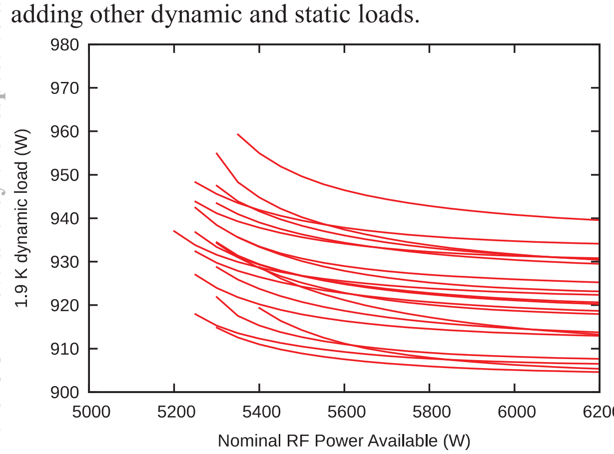


Figure 4: Modeled performance with simulated random production run of 112 cavities.

## COST CONSIDERATIONS

Since the superconducting linac is one of the largest expenses in the construction of the facility, we have developed a parametric cost model that allows us to seek cost optimization. The model includes the cost of the cryogenic system, tunnel construction, cryomodules and RF power amplifiers and distribution. As expected, the cost of the RF amplifier system is relatively independent of the operating gradient because it is mostly driven by the total power delivered to the beam. 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 and 1.9K are shown up to the limit of a single cold box.

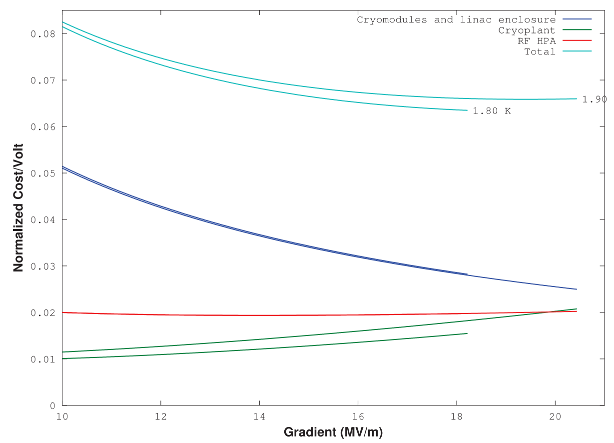


Figure 5: Relative cost of construction plus 15 years operation, as a function of cavity gradient. Operating cost assume 8000 hours per year, and $0.12 per kW-hr.

The higher electrical operating costs further offset the savings of construction of a machine running at a higher gradient. However, when capital cost is the main parameter, construction cost is minimized at the highest gradient, thus a choice is then determined by the desired operating reliability. Figure 5 shows the relative cost scaling with cavity gradient.

## ACKNOWLEDGMENTS

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[2] "RF Power Upgrade at Jefferson Lab", R. Nelson and A. Kimber, Seventh CW and High Average Power RF Workshop, Brookhaven National Laboratory, May 2012.



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