# CST SIMULATION AND RF POWER
# FOR AN EQUIVALENT SCL CAVITY AT LANSCE

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## Abstract

Superconducting LINAC (SCL) technology has been a mature option for several years. The SCL option has been studied in the past. This option has the potential to improve beam availability to the LANSCE facility users by allowing the RF system to partially migrate to a modern RF power solution such as the Spallation Neutron Source (SNS) or the European Spallation Source (ESS) klystron modulators. Due to the higher RF efficiency of the SC cavity, the use of recent advances in Solid-State Power Amplifiers (SSPA) becomes a possibility as an adequate substitute for the RF power plant. Another important aspect of the SCL option is that the partial removal of the Coupled Cavity LINAC (CCL) at $\beta$=0.78 and implementing high-gradient SC cavities provides a technically sound solution to reach beam energy of more than 1 GeV within the already existing beam tunnel, making this available for the users at LANSCE. In addition, the current capability of 800 MeV beam can be maintained by choosing a dynamic mode of operation where only the needed SC RF structures are operated. This would allow continued use of the Proton Storage Ring (PSR) without requiring an upgrade, while providing the >1 GeV option for other users on demand.

## THE HIGH BETTA SECTION

The 805 MHz LANSCE CCL cavity LINAC is composed of 44 modules. The CCL has been in operation for over 50 years. The extended life is due to the robustness of the original CCL design. The last cavity in the chain of modules can be used under normal operation for fine tune of the proton beam. That is, the last cavity can be utilized to either accelerate or decelerate the beam for optimal operation. This last module is powered by a full-sized klystron tube rated at 1.25 MW of RF power.

For the high-beta sections, the length of the LANSCE CCL is comparable to that of the SNS SCL [1, 2], with approximately 15.3 meters for the CCL module, and 7.7 meters for the SCL cryomodule, respectively. Thus, replacing a CCL module at LANSCE with an SNS SCL would consume only half the linear length of the existing linac section, leaving space open for future needs [3].

The CCL at LANSCE averages 1 MV/m of acceleration, and according to initial design reports the SNS cavities were qualified at the Tesla Test Facility (TTF) at a gradient of 11.9 MV/m. The design energy gain of the last module in CCL 16.9 MeV. The high beta cryomodule in contrast has four, six-cell cavities, with each SCL cavity averaging 8 MeV of design energy gain. This results in 24 MeV energy gain per SCL cryomodule at the design gradient.

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## SC CAVITY SIMULATION

A CST simulation was run to verify cavity parameters and required performance of the RF power amplifier. The unloaded Q of the cavity simulation is 1.12E6, which can be considered low by modern standards. A parametrized tunning check was done for field flatness. Although further geometry tunning needs to be performed for optimal cavity design (insert quote here), this was used for a first order calculation of the expected RF power and beam energy gain through the cavity. The length of the model is of 0.84 meters. The cavity from Fig. 1 parameters of Table 1 from the simulation are found in Table 1.
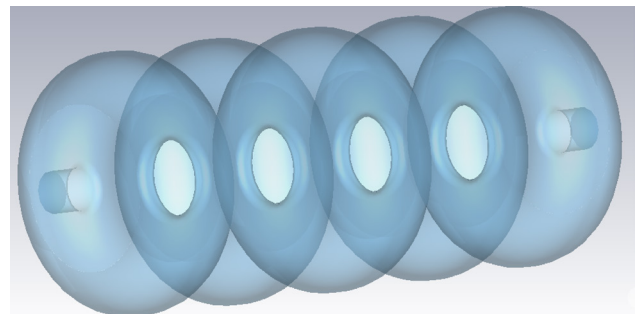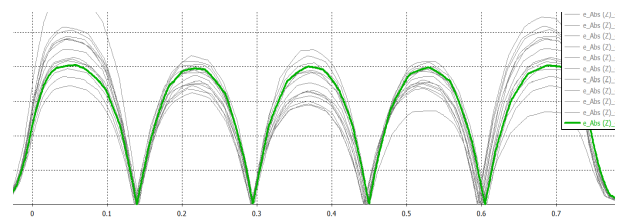


Figure 1: CST model cavity model.



Figure 2: Tunning iterations for field flatness.

## RF POWER CALCS

Currently, the RF power system at LANSCE feeds the CCL and most of the power is spent in the Copper establishing the required field gradient for acceleration. On average the LANSCE cavities use up to 300 kW for peak beam loading. The CCL can drive up to 15 mA of beam, the remainder of the RF power from the 1.25 MW available from each klystron is spent in the Cu cavity. Since a SCL cavity option has higher efficiency than the CCL, most of the RF power would be available for proton beam acceleration.

The equations from Ref. [4] for steady state conditions, and appropriate scaling were used to find the required

Table 1: Cavity Parameters

| Parameter | Value |
|-----------|-------|
| Qo | 1.12E6 |
| R/Q | 220 |
| Rs | 1.98E10 |

power to drive such a structure. The simulation was used to find the unloaded Q of the cavity and the simulation energy is of 1 Joule. The simulation returns a gradient of 1.3 MV/m.

$$P = \omega U Q_0 = 4.5 \text{ kW}. \quad (1)$$

This results from the CST calculation are scaled to reach the gradient comparable of the SNS cavity design. Thus, we use a gradient of 11.9 MV/m with an un-optimized transit-time-factor of 0.7 to get

$$Vacc = TTF \times E_{acc} = 8.33 \text{ MV}. \quad (2)$$

This results in an updated RF power required to drive the SCL cavity of 41.2 kW.

Since the max current that LANSCE can support is of 15 mA the RF power required by the beam as given in Ref. [1] will be based on this value.

$$P_b = I\Delta U/q = 125 \text{ kW}. \quad (3)$$

## DISTRIBUTION OF THE RF POWER AT LANSCE FOR FEEDING AN SCL CAVITY

Given the power calculated above is for a single structure, and that a typical cryomodule in the high-betta sections at SNS include 4 cavities, the total power required to feed the 4 cavities, or the entirety a similar cryomodule, accounting for driving the cavity, is of 732 kW.

Such a structure can be driven by the standard LANSCE 805 MHz klystrons, which have a peak power rating 1.25 MW. That is for a nominal cryomodule with a gradient of 11.9 MeV/m, a 732 kW of RF provide 24 MeV of acceleration. Since the length of the cryomodule is half that of the CCL module, making use of the entire CCL module for SCL acceleration provides 48 MeV of total gain.

Current efforts to maintain the LANSCE accelerator online involve the replacement of the old-style klystron with 50% efficiency with a modern more reliable power tube. Such an effort will result in increased up-time and performance of the LANSCE accelerator. Such tubes can drive 2 of the said cryomodules worth of accelerating cavities.

Another type of system that is plausible with the SCL option is the use of recent developments in SSPAs in con combination with the SCL cavities. Since each cavity in the SCL needs 125 kW. Recent advancements in GaN based RF power transistors make this within reach. Such a system would capitalize on ongoing efforts to increase the power density available in this frequency band for particle accelerators. Furthermore, the use of multiple 125 kW systems, one per-cavity provides independent phase control over each cavity in the cryomodule, instead of driving all cavities with a single tube.

Although now, it is necessary to improve the CST model from Fig. 1 and Fig. 2 to reach the TTF and SNS cavity parameters [2, 3], the results with lesser cavity performance already show that the required RF power for driving the cavity is negligible with comparison to the already available RF power at LANSCE, and the LANSCE klystrons can drive an entire cryomodule. Scaling of these results to reach 1 GeV of beam energy could be reached by replacing 3 of the existing CCL structure with 6 SCL cryomodules, where the options to drive the structure are varied from using the next generation high efficiency klystrons, to capitalizing in the recent developments in Solid-State technology to achieve higher power efficiency and control over the entire SCL section. In addition, since not all the SCL needs to operate, the current 800 MeV operation can be maintained for those users that prefer this mode of operation. Beam transport structures such as the proton storage ring (PSR) would not require any modification due to the inclusion of the SCL in at the end of the LINAC.

## CONCLUSION

The SCL option has the potential to increase the capability while capitalizing in either the existing RF power infrastructure, or the new and ongoing developments in RF power. Such an investment would not render other facilities such as the PSR as obsolete, since operation modes can be selected as to tune the beam for the current nominal beam energy of 800 MeV. With this the SCL option would not incur a cost significant cost in the RF power plant but rather a reconfiguration while maintaining the existing capability and increasing the beam energy for other users as needed.

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