ASSUMPTIONS FOR THE RF LOSSES IN THE 650 MHz CAVITIES OF THE PROJECT X LINAC

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Abstract

The requirements for the FNAL Project X cryogenic system depend on the dynamic heat loads of 650 MHz cavities. The heat load is in turn determined by quality factors of the cavities at the operating gradient. In this contribution we use the available experimental data to analyze quality factors achievable in 650 MHz linac cavities taking into account different RF losses contributions such as BCS resistance, residual resistance and a medium field Q-slope.

INTRODUCTION

Current Project X design parameters imply CW operation for the acceleration of high intensity proton beams up to 3 GeV. Other parameters considered for the Project X are reported in [2].The choice of superconducting RF technology for cavity design requires optimization of quality factor and operating gradients to minimize the dynamic heat load. Dynamic heat load at the operating temperature determines the refrigeration power needed to sustain the operating gradient in the cavities. Major part of the linac will be populated by two sections of 650 MHz SRF niobium cavities with $\beta = 0.61$ and $\beta = 0.9$, operated at the accelerating gradients of about 17 MV/m. Hence, the maximization of the quality factor Q_0 at this E_{acc} becomes a primary task for Project X SRF R&D. If all currently understood limitations such as field emission, multipacting and hydrogen Q-disease are removed, the remaining losses around $E_{acc} = 17MV/m$ (corresponding to $H_{peak} = 70\ mT$) in elliptical TESLA-shape cavities are determined by the so-called *medium field Q-slope* (MFQS). Uniformly accepted and proven model for the MFQS has not been developed yet, although possible mechanisms have been suggested [3]. We rely on the available experimental data from literature as well as on recent FNAL experiments to estimate possible Q_0 values in 650 MHz cavities. Since it is not clear at this stage if magnetic or electric field is a dominant factor for the MFQS, we will only use data for the same elliptical TESLA cavity geometry (same field distribution) as prospective 650 MHz cavities. In addition, the baseline process to be used for cavity processing has not been selected yet, and treatments, which are necessary to achieve highest gradients for example for ILC, might not be the best ones for maximizing Q_0 at 17 MV/m. Preliminary investigations of optimal chemical and heat treatments are also included in this contribution.

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BCS SURFACE RESISTANCE

Surface resistance of superconducting niobium at 650 MHz considered in this analysis consists of the temperature-dependent BCS part, and a temperature-independent residual resistance. To calculate the BCS part numerical algorithms are typically applied. We used SRIMP program by J. Halbritter [5] to estimate the expected BCS component at different temperatures in the range 1.6-2K. The calculated values for typical cavity niobium parameters are shown in Table 1.

Table 1: BCS Surface Resistance Values for 650 MHz at Different Temperatures Calculated Using SRIMP [5] Program

T, K	1.6	1.7	1.8	1.9	2.0
R_{BCS}, nOhm	0.3	0.5	0.9	1.4	2.2

RESIDUAL RESISTANCE

Although several contributions to the residual resistance are known (trapped flux, hydrides, adsorbed gases - see [1]), the spread in their values is not yet controlled. Typical residual resistance values observed at FNAL in state of the art niobium cavities are consistenly around 5-6 nOhm for both 1.3 GHz TESLA shape elliptical cavities and 325 MHz single spoke resonators [6]. 650 MHz cavities have not been manufactured and tested yet, but there is no reason to suspect different values of residual resistance in these elliptical structures, since the residual resistance is believed to be determined by the processing quality. Thus, for target Q_0 estimate for Project X the assumption of the residual resistance of about 6 nOhm with no frequency dependence is reasonable.

MEDIUM FIELD Q-SLOPE

Medium field Q-slope is a degradation of the cavity quality factor in the medium (20-80 mT) field range in niobium cavities. The effect of different surface treatments and frequency on the MFQS has not been completely understood yet, hence we performed a series of RF cavity tests to study general trends and compare with the literature if available. We avoid the widely used parametrization based on the linear and quadratic in field components in the surface resistance, and look at the normalized Q_0 values instead to determine a range of Q-degradation at 70 mT. The RF test results at different temperatures from 1.6-2 K and different surface treatments are shown in Fig. 1.

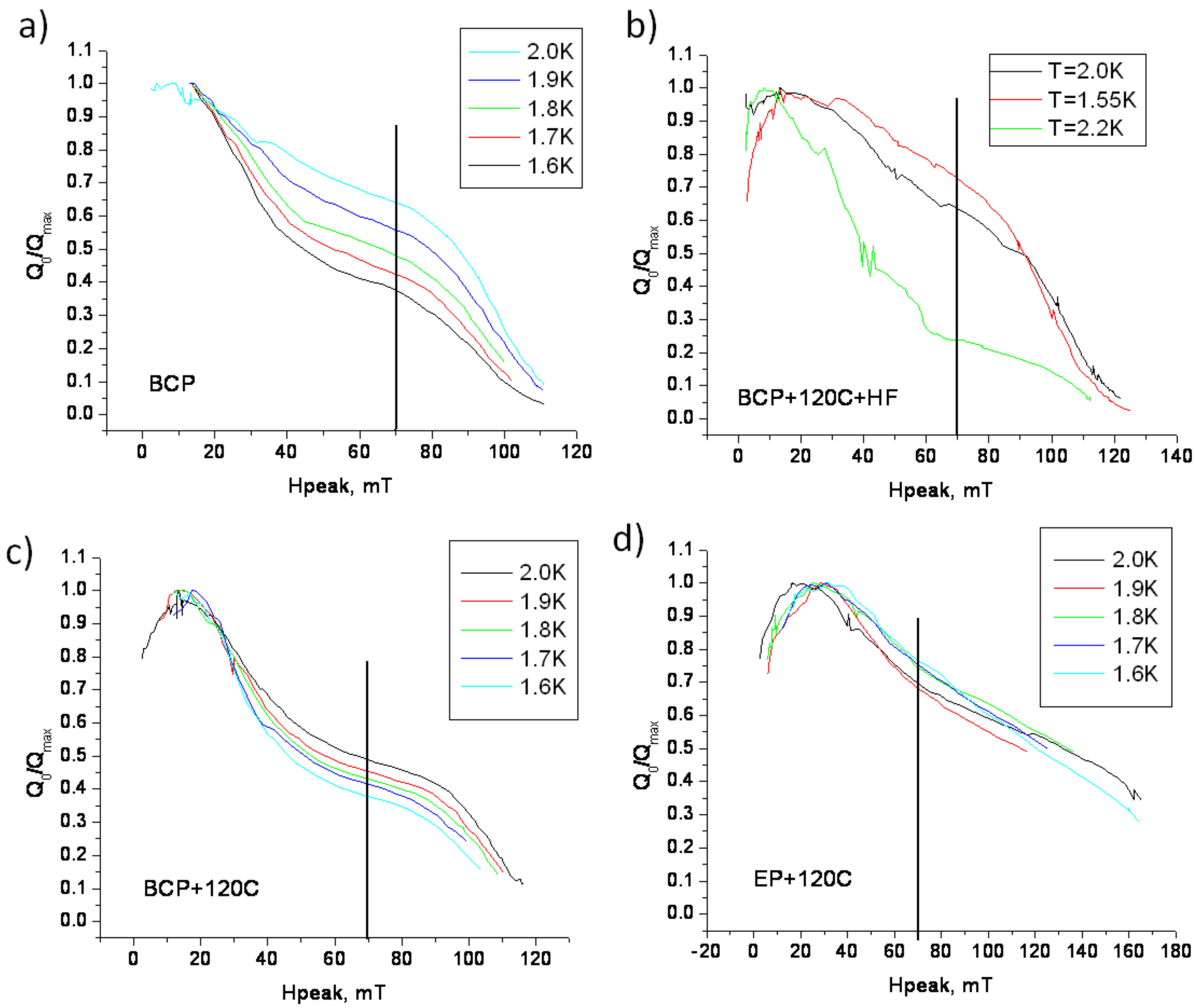

Figure 1: RF test results in the temperature range of 1.6-2 K for different surface treatments: a) BCP; b) BCP + 120°C baking + HF rinsing; c) BCP + 120°C baking; d) EP + 120°C baking. Presented are the ratios of the quality factor to a maximum quality factor at each temperature to elucidate the range of Q degradation. Vertical black lines markthe location of the gradient of interest (70 mT).

The extracted Q_0 values and the ratio of the Q_0/Q_{max} are shown in Fig. 2.

Operation of the cavities above lambda point (about 2.17 K) is not desirable because of the significant heat conductance decrease at the cavity-helium interface. Poor cooling of the walls will result in the thermal feedback and hence the severe quality factor degradation with field as compared to the below lambda point operation. We performed RF measurements at 1.5, 2, and 2.2 K for the same cavity to evaluate the effect as shown in Fig 3. A very strong medium field Q-slope is observed at $T = 2.2\ K$ in agreement with earlier reports [4].

Based on the results of these tests and further analysis of other data obtained at FNAL and other labs we adopt the assumption of the similar medium field Q-slope expected in the 650 MHz cavities, and the level of Q degradation at 70 mT of about *30%* achievable by current processing techniques.

TOTAL RF LOSSES

Summing up all the contributions considered above, we obtain the expected total resistance of about $6 + 2 = 8\ nOhm$ and the medium field Q-slope contribution of about 30%, with the resulting quality factors of about 2×10^{10} at the operating temperature of about 2 K. Using the R/Q factors reported in [2] we obtain for the dynamic heat loads about 22 W/cavity or 176 W/cryomodule in both $\beta = 0.61$ and $\beta = 0.9$ sections of the linac.

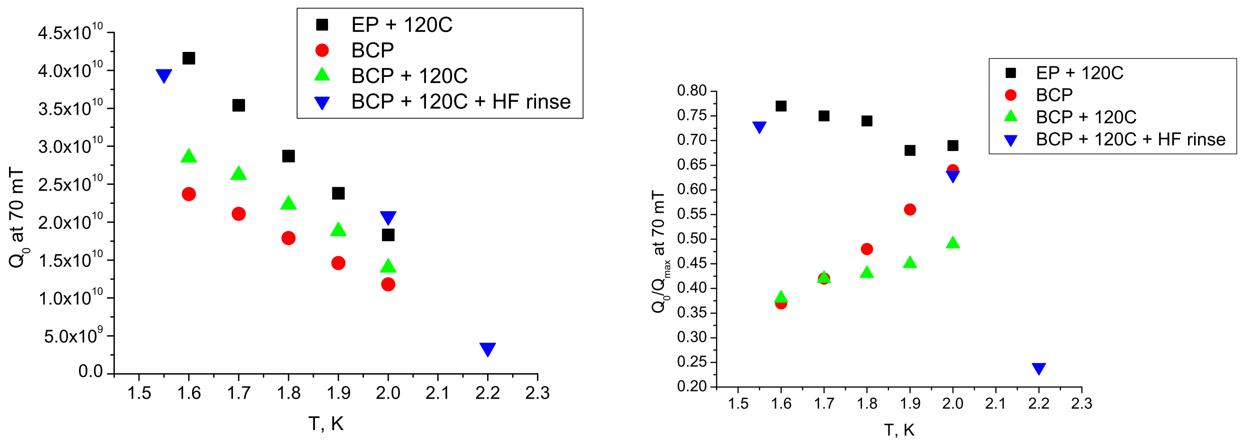

Figure 2: Summary of the measured quality factor values (left) and the MFQS magnitude (right) at $H_{peak} = 70\ mT$ for 1.3 GHz single cell elliptical cavities.

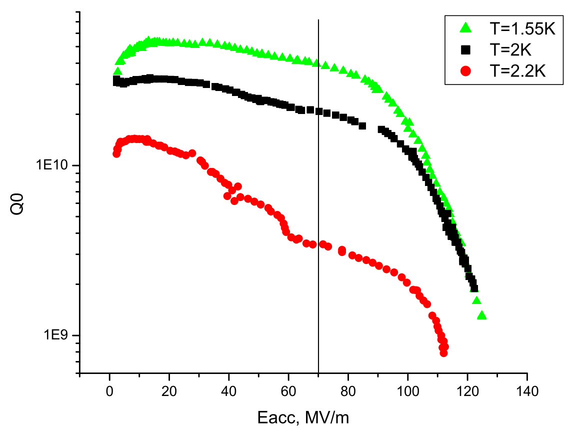

Figure 3: Effect of the temperature increase above lambda point on the Q-slope in the medium field range. The cavity investigated is the fine grain BCP 1.3 GHz one subjected to mild baking and HF rinsing.

CONCLUSION

We presented the assumptions used to estimate the target quality factors for 650 MHz section of the Project X linac. Preliminary optimization suggests possible baseline processing ways at the operating temperature of 2 K, further systematic studies are planned to be performed. The resulting target Q_0 value of about 2×10^{10} at 2 K would translate into losses of about 22 W/cavity or 176 W/cryomodule.

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