ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI054

MEDIUM FIELD Q-SLOPE STUDIES IN LOW BETA RESONATORS

O. Melnychuk*, A. Grassellino, A. Sukhanov
Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

Abstract

Studies of the phenomenon of medium field Q-slope (MFQS, 30-80 mT) have been focused predominantly on high beta superconducting cavities. Complementing research on cavity losses with the analysis of low beta cavity data can provide additional insights into the nature of MFQS. We present MFQS measurements of 325MHz β=0.2 single spoke resonators and 650MHz β=0.9 elliptical single cell resonators at vertical test facility at FNAL. We compare our findings with those obtained for high frequency 1.3GHz cavities tested both at the same facility and other laboratories.

INTRODUCTION

We studied performance of 325MHz β=0.2 single spoke resonators and 650MHz β=0.9 TESLA shape resonators at vertical test stand (VTS) facility at Fermilab for different cavity surface treatments. First cavities were characterized by their intrinsic quality factor Q_0 measured as a function of accelerating gradient E_{acc}. Typically Q_0 decreases with E_{acc} in the region between approximately 5MV/m and 18MV/m (20mT – 80mT) which covers operation point of near future accelerators such as LCLS-II and PIP-II. This is known as the medium field Q-slope (MFQS) phenomenon. The goal of our studies was to understand the MFQS power losses in terms of the residual resistance and the BCS resistance of the low frequencies niobium cavities for which only few studies were performed so far [1]. For this purpose cavity Q_0 data were collected also as a function of temperature. Due to different nature of the two types of resistance they, generally, exhibit different dependence on the temperature, which allows to separate them using Q_0 versus T data.

DATA SELECTION

We selected quality factor (Q_0) versus temperature (T) data in bins of accelerating gradient (E_{acc}). We converted Q_0 to surface resistance (R_s) according to $R_s = G_f/Q_0$, where G_f is a geometrical factor. G_f is equal to 78 nΩ and 256 nΩ for 325MHz and 650MHz resonators respectively. Then we performed a fit of R_s versus T data using $f(T) = R_{res} + (A/T) \times e^{-(\frac{g}{T})}$ function where R_{res}, A and g are constants determined from the fit. The function has two terms: temperature independent term that corresponds to residual resistance and temperature dependent Bardeen-Cooper-Schrieffer (BCS) component of surface resistance. Since at 650MHz BCS component is expected to vanish at low temperature leaving only the residual resistance component, we also used alternative way to determine R_{res}, namely $R_{res} = G_f/Q_0$, where Q_0 value was taken at the lowest temperature. We required that lowest temperature was less than 1.625K. Difference between R_{res} at 1.625K and its fit value extrapolated to 0K was within measurement uncertainty. The two estimates were found to be consistent with each other. Typically error on extracted resistance does not exceed 0.3nΩ with the exception of 650MHz EP cavity test, where significantly larger error can be expected due to observed "hysteresis" in the power level measurements, which lead to systematic error in the measurement of Q_0.

* alexmelnitchouk@gmail.com

650MHz ELLIPTICAL CAVITIES

Figure 1 (top) shows Q_0 measured at VTS as a function of electric and magnetic field for 650MHz β_1=0.9 TESLA shape elliptical cavities for different surface treatments. Two cavities were used – with BCP and EP bulk material removal. Note that these cavities did not undergo 800∘0 heat treatment which is a part of a standard procedure for 1.3GHz ILC cavities. Residual and BCS components of total resistance for 650MHz cavities extracted from corresponding Q_0 versus T data are shown in Fig. 1 (bottom).

325MHz SINGLE SPOKE RESONATORS

Fig. 2 (top) shows Q_0(2K) versus E_{acc} curves for vertical test data at 2K for single spoke 325MHz β=0.2 SSR1 cavities at Fermilab. These cavities underwent BCP bulk removal and 120°C baking. Fig. 2 (bottom) shows G_f/Q_0(2K) versus E_{acc} curve for the same data. G_f/Q_0 ratio can be interpreted as residual surface resistance since at 325MHz BCS component of the total surface resistance is expected to be negligible. Due to non-trivial SSR1 resonator geometry and more complicated field distributions than for elliptical cavities, G_f/Q_0 is an approximation that does not allow precise comparisons with field dependences of 1.3GHz and 650MHz elliptical cavities [2]. This approximation is going to be revised in future work on this subject. Consistent approximate 1.0-1.5nΩ per 50mT slope is observed in the region between 20mT and 90mT. Above 90mT a steeper nonlinear G_f/Q_0 rise with magnetic field is observed. Possible explanation for this change in the slope could be that above 90mT cavity losses through the walls cannot be described in terms of residual resistance and BCS resistance, different heating mechanisms could be involved. In the cases where significant radiation was present change in slope is due to field emission loading.

DISCUSSION

For the 650 MHz cavities we observe that both residual and BCS surface resistance components scale reasonably with frequency compared to 1.3GHz. The field dependence results in terms of surface processing seems so far consistent with the 1.3 GHz studies presented in [3]: EP and BCP

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI054

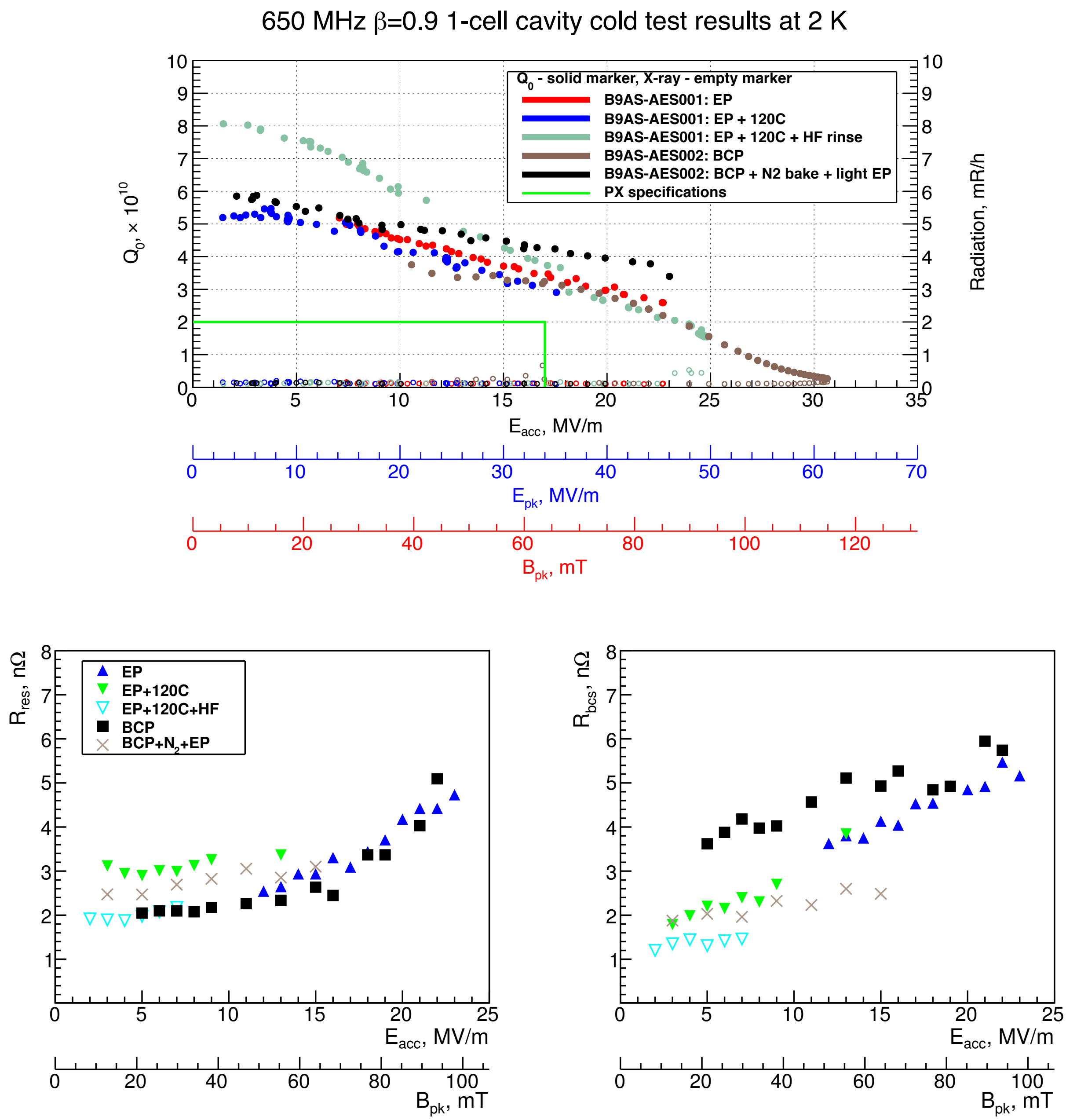

Figure 1: Top: Q_0 and radiation dose rate as a function of E_{acc} for 650MHz β=0.9 elliptical cavities resonators at 2K. Q_0 – solid circles. Radiation dose rate – open circles. Bottom: R_{res} and R_{bcs} as a function of accelerating electric field and magnetic field for the same data.

present the highest BCS surface resistance, and the 120°C bake lowers the BCS component but increases the resid ual component. An additional HF rinse then reverses the increase in residual due to 120°C bake but preserves the low BCS, leading to the best low field quality factors, as described previously in [4]. We have chosen to cut the HF rinse data at relatively lower fields since the cavity had multipacting induced quenches at 12 MV/m level and significant field emission, which would make the field dependence data above 12 MV/m questionable. We plan on repeating these studies after re-HPR of this cavity. Also these studies will be repeated for both EP and BCP degassed surfaces. First attempt in nitrogen doping treatment of a 650 MHz cavity has lead so far to the highest Q at higher fields, due to the lowering of the BCS resistance as a function of field, also consistent with what was observed so far in 1.3 GHz cavities [5]. Notice that the nitrogen treatment is for the first time here implemented on a BCP substrate and that the gas doping recipe used a one step diffusion process, while FNAL has now adopted a more optimized two step diffusion process [6] which should lead to better results. Also we have more recently understood that the strict control of magnetic fields around nitrogen doped cavities is essential for obtaining high Qs, and during the test presented here larger

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI054

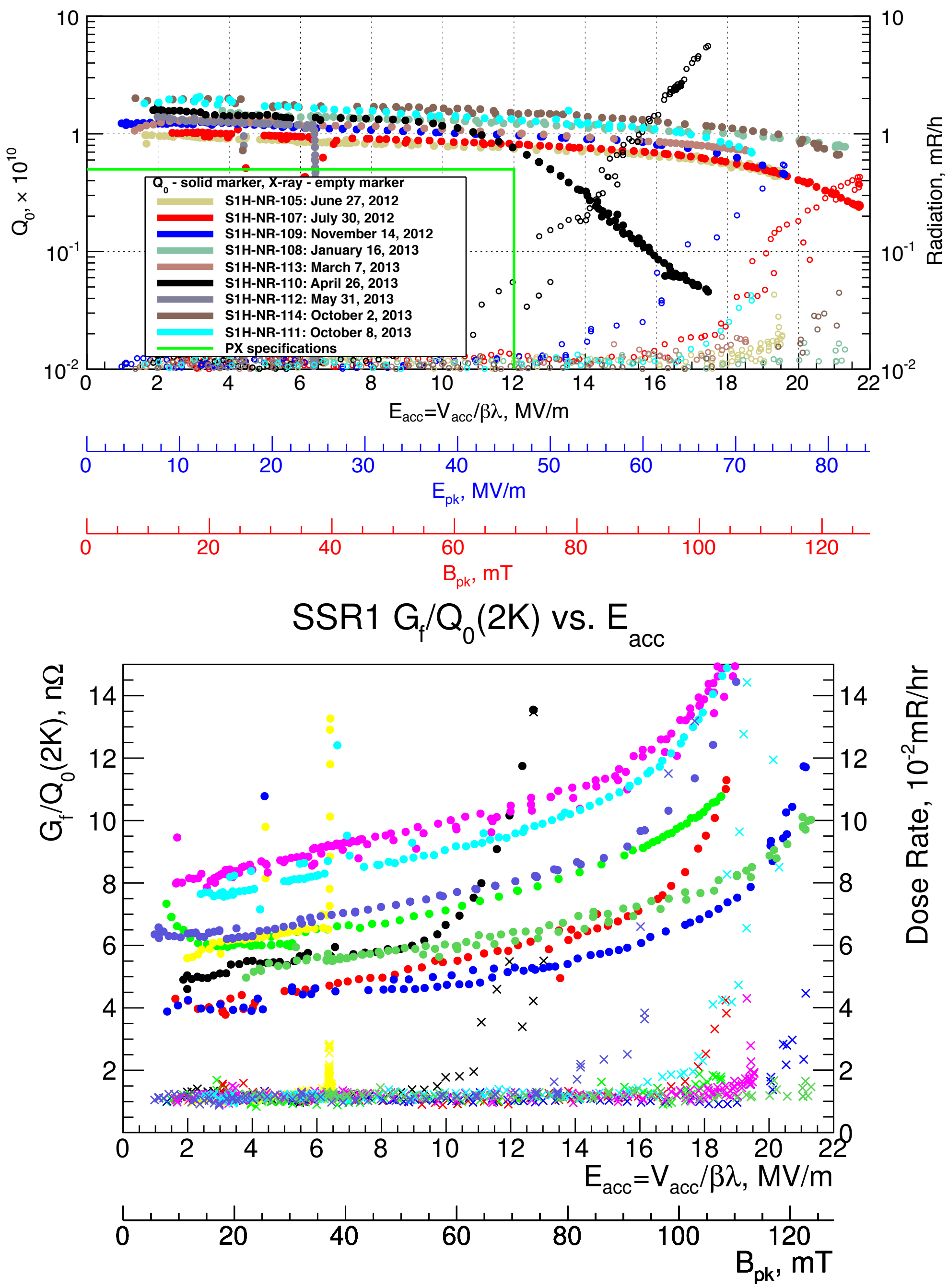

Figure 2: Top: Q_0 and radiation dose rate as a function of E_{acc} for 325MHz β=0.2 single spoke resonators at 2K. Bottom: G_f/Q_0(2K) and radiation dose rate as a function of E_{acc} for 325MHz β=0.2 single spoke resonators. Solid circles – G_f/Q_0(2K). Crosses – radiation dose rate.

remnant fields could have been present due to the proximity to magnetic support frames around the cavity. Further studies are planned with the new and more advanced knowledge of the nitrogen doping treatment for this particular frequency, with the goal of determining a Q maximization processing recipe for PIP-II 650 MHz cavities [7]. For the 325 MHz cavities, the residual resistances are significantly higher than expected from a frequency scaling point of view. This could be partially due to the fact that the 2K data is collected post repeated MP-induced quenching and carries therefore a significant trapped flux component. A strong field dependence in the medium field regime is found at these temperatures where BCS resistance has vanished, indicating that the residual resistance at this frequency and for BCP processing is strongly field dependent.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI054

REFERENCES

[1] A. Grassellino et al, FIRST INTERNATIONAL SYMPOSIUM ON THE SUPERCONDUCTING SCIENCE AND TECHNOLOGY OF INGOT NIOBIUM. AIP Conference Proceedings, Volume 1352, pp. 161-168 (2011).

[2] Anna Grassellino, "Field-dependent losses in superconducting niobium cavities" (January 1, 2011). Dissertations available from ProQuest. Paper AAI3497980. http://repository.upenn.edu/dissertations/AAI3497980

[3] A. Romanenko and A. Grassellino, Appl. Phys. Lett. 102, 252603 (2013).

[4] A. Romanenko et al, Phys. Rev. ST Accel. Beams 16, 012001 (2013).

[5] A. Grassellino, A. Romanenko, D. Sergatskov, O. Melnychuk, Y. Trenikhina, A. Crawford, A. Rowe, M. Wong, T. Khabiboulline, and F. Barkov, Supercond. Sci. Tech., 26, 102001 (2013).

[6] A. Grassellino, "High Q cavities at high gradient", AWLC14, FNAL, Batavia, IL, USA (2014).

[7] S. Holmes et al, http://projectx-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1232