MEDIUM FIELD Q-SLOPE STUDIES IN HIGH FREQUENCY CAVITIES*

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Abstract

A phenomenon of Medium Field Q-Slope (MFQS) in superconducting RF cavities is of high importance because it occurs in the field range (5-20 MV/m) that includes designed operation fields of future CW accelerators [1]. MFQS impacts resistive losses in the cavity and, consequently, directly affects accelerator operation costs. We present studies of MFQS based on vertical test data for 1.3 GHz nine-cell cavities and make comparisons of vertical test data from different laboratories.

INTRODUCTION

Medium Field Q-Slope (MFQS) feature of superconducting RF cavities can be thought of as a primary factor that determines RF losses in the cavity at typical operating gradients (15-20 MV/m) given cavity performance at low field. Exact unique physics mechanism behind MFQS phenomenon is not understood. The goal of our studies is to form a systematic understanding of MFQS as a function of several factors that affect cavity performance. Such understanding may point towards possible improvements of cavity performance and be of help for understanding the physics mechanism of RF losses in a superconductor.

DATA

We select data from Vertical Test Stand (VTS) Q_0 vs. E_{acc} measurements of 9-cell 1.3 GHz cavities performed at Fermilab at 2 K and 1.8 K and at DESY at 2 K.

Fermilab Data

We use last 2K test of 24 TB9* Fermilab cavities. TB9NR004 TB9ACC014 TB9AC114 TB9AES011 TB9AES014 TB9ACC015 TB9AES012 TB9RI025 TB9NR002 TB9ACC012 TB9AES002 TB9RI022 TB9AES013 TB9RI026 TB9ACC016 TB9RI021 TB9RI024 TB9RI027 TB9RI020 TB9AES003 TB9AES007 TB9ACC007 TB9ACC006 TB9ACC011. Eleven out of these 24 tests include also 1.8K measurements.

DESY Data

We started with all tests of 53 AC* DESY cavities which amounts to nearly 2100 Q_0 vs E_{acc} data sets. Then we selected data sets for MFQS studies according to the following requirements: last test date for a given cavity, fundamental mode measurements at 2 K, at least 10 data points available in the measurement with at least one point below 5 MV/m and at least one point above 20M/m, data were taken before quenching without subsequent warm-up above T_c. These selection criteria give us 38 Q_0 vs E_{acc} data sets from measurements of the following cavities: AC112, AC115-AC125, AC146-AC148, AC150-AC158, AC57-AC60, AC62-AC63, AC70-AC71, AC73, AC75-AC76, AC78, AC80-AC81.

RESULTS

Our observables of interest are: Q_0 value at low field (E_{acc}=5 MV/m is used as a reference point), Q_0 value at a typical operating gradient for near future accelerators (E_{acc}=16 MV/m is used as a reference point), and the rate of change of Q_0 between low field and operating field. We characterize the rate of change of Q_0 with accelerating field by Medium Field Q-Slope (MFQS). We define absolute and relative MFQS. Absolute MFQS is defined as a difference in Q_0 between 5 MV/m and 16 MV/m. Relative MFQS is defined as absolute MFQS divided by Q_0 at 5 MV/m.

In Fig. 1 performance of DESY and Femilab cavities is compared. DESY cavities tend to have higher Q_0 at both 5 MV/m and 16 MV/m. This corresponds to a difference of approximately 4nOhm of residual resistance. Typical accuracy of determining residual resistance is 10%. MFQS plots for DESY cavities (especially absolute MFQS on the lower right of Fig. 1) reveal existence of several populations.

In Fig. 2 we focus on DESY cavities and compare Q_0 value at 5 MV/m and 16 MV/m after splitting DESY data sample into four sub-samples according to chemical treatment (BCP or EP) and according to niobium grain size (large grain or fine grain). Fig. 2 shows that unbaked cavities tend to have lower Q_0 value at 5 MV/m compared to all cavities. Also, in unbaked cavities, there is no large difference in Q_0 between 5 MV/m and 16 MV/m – MFQS tends to be low. We make several observations in Fig. 2 in the context of MFQS studies:

- No significant difference between large grain and fine grain cavities is observed.
- No significant difference between BCP and EP processing prior to Q_0 vs. E_{acc} measurement.
- In both BCP and EP treated cavities, in both large grain and fine grain cases, there are instances in which Q_0 has very similar value at 5 MV/m and at 16 MV/m. In these cases there was no low temperature baking performed in between chemical treatment and Q_0 vs. E_{acc} measurement. The effect of no baking at low

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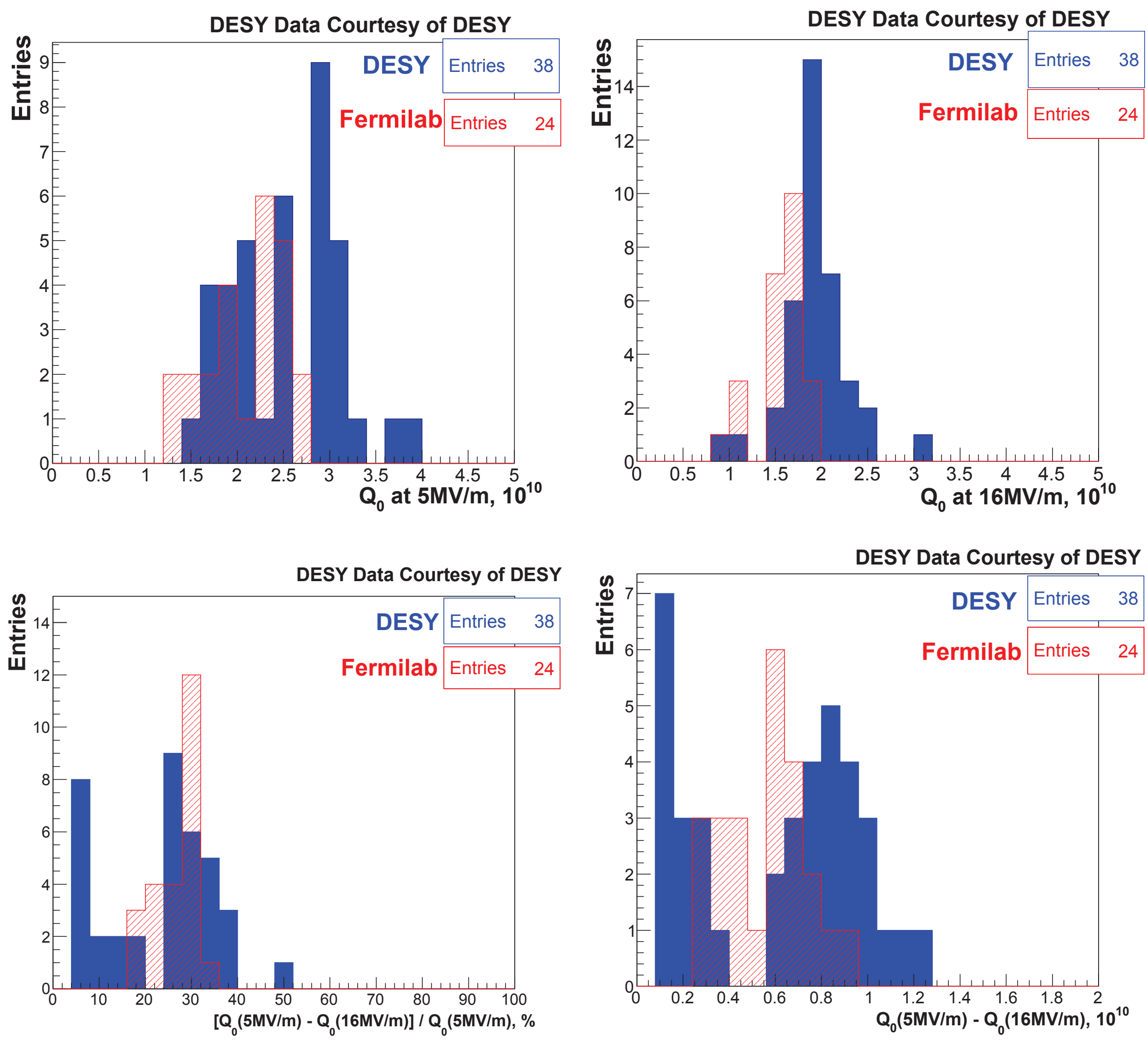

Figure 1: Comparison between DESY (solid blue) and Fermilab (hatched red) cavities. Top left: Q_0 at 5 MV/m. Top right: Q_0 at 16 MV/m. Bottom left: relative MFQS. Bottom right: and absolute MFQS

temperature is studied in more detail in Fig. 3. The difference in Q_0 between low temperature baked and unbaked cavities appears to be noticeably larger at 5 MV/m than at 16MV/m (top plots in Fig. 3).

Finally, we compare Q_0 values at 5 MV/m and 16 MV/m between 2 K and 1.8 K measurements. The comparison is done using Fermilab cavities. Figure 4 shows Q_0 measured at 2 K and 1.8 K in the top and middle row respectively. Not all 2 K measurements have their 1.8 K counterparts, only 11 out of 24 measurements. Since the comparison could not be done with identical set of cavities we check that the subset of 11 cavities on which 1.8 K data is available is not biased with respect to the full 2 K sample. 2 K distributions for the subset of 11 cavities is shown in the bottom row of Fig. 4. There is no significant difference compared with the full 2 K sample of 24 cavities.

SUMMARY

Fermilab and DESY VTS Q_0 vs. E_{acc} data for 9-cell 1.3GHz cavities were studied with the focus on low field, operating field, and MFQS. In summary:

- for Fermilab cavities average Q_0 at 2 K(1.8 K) is $2.1(2.6)\times10^{10}$ and $1.6(2.1)\times10^{10}$ at 5 MV/m and 16 MV/m respectively;
- DESY cavities tend to have somewhat higher values of Q_0, difference in performance between Fermilab and DESY cavities can be attributed to difference in residual resistance of about 4nOhm;
- no significant difference between large grain and fine grain cavities is observed;
- no significant difference between cavities treated with BCP or EP is observed;

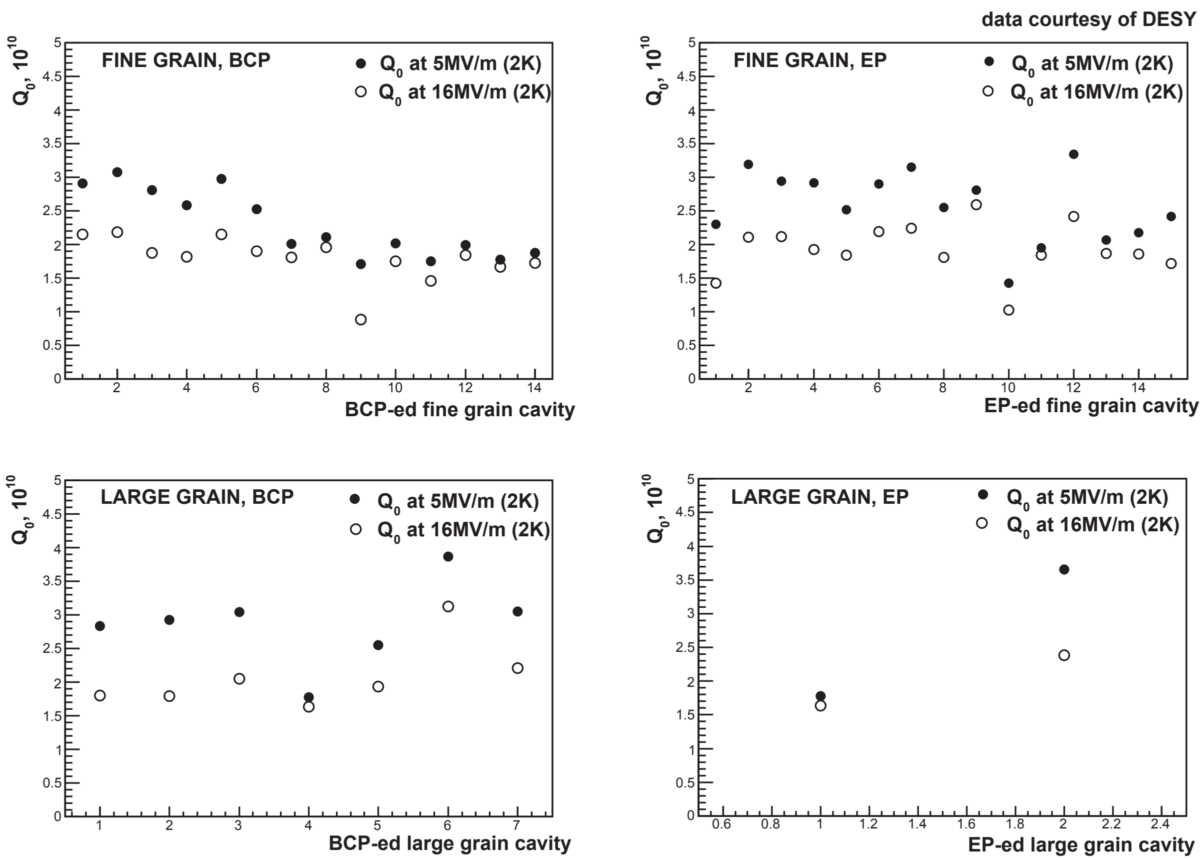

Figure 2: Q_0 at 5 MV/m and 16 MV/m for large grain DESY cavities

- cavities without lower temperature bake have significantly lower Q_0 at 5 MV/m (this observation applies for both large grain and fine grain cavities and for both types of chemical treatment, BCP and EP).

REFERENCES

[1] Padamsee H., 2009 RF Superconductivity: Volume II, Science, Technology and Applications (New York: Wiley) chapter 3

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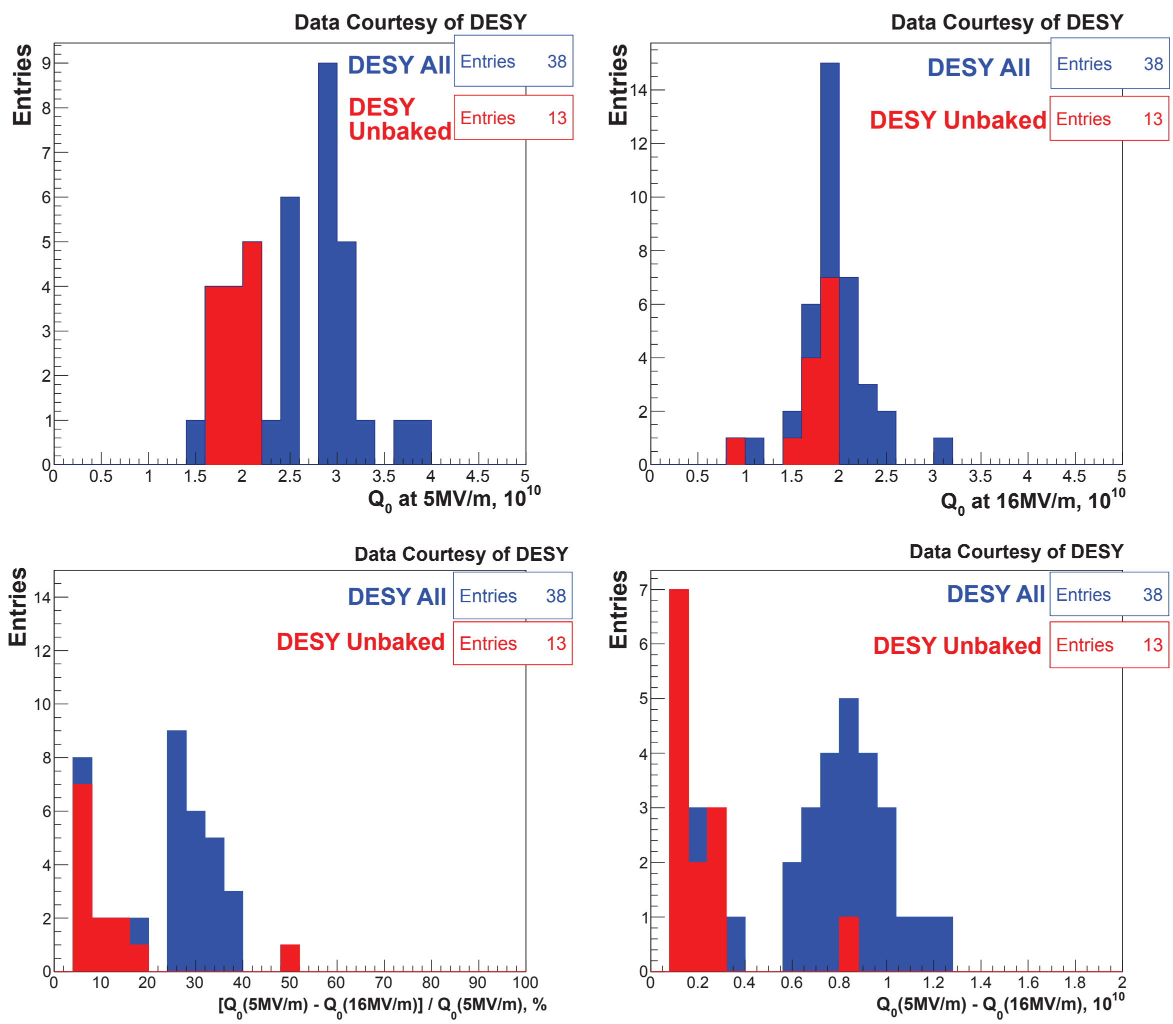

Figure 3: Comparison between all DESY cavities (blue) and low temperature unbaked DESY cavities (red). Top left: Q_0 at 5MV/m. Top right: Q_0 at 16MV/m. Bottom left: relative MFQS. Bottom right: and absolute MFQS

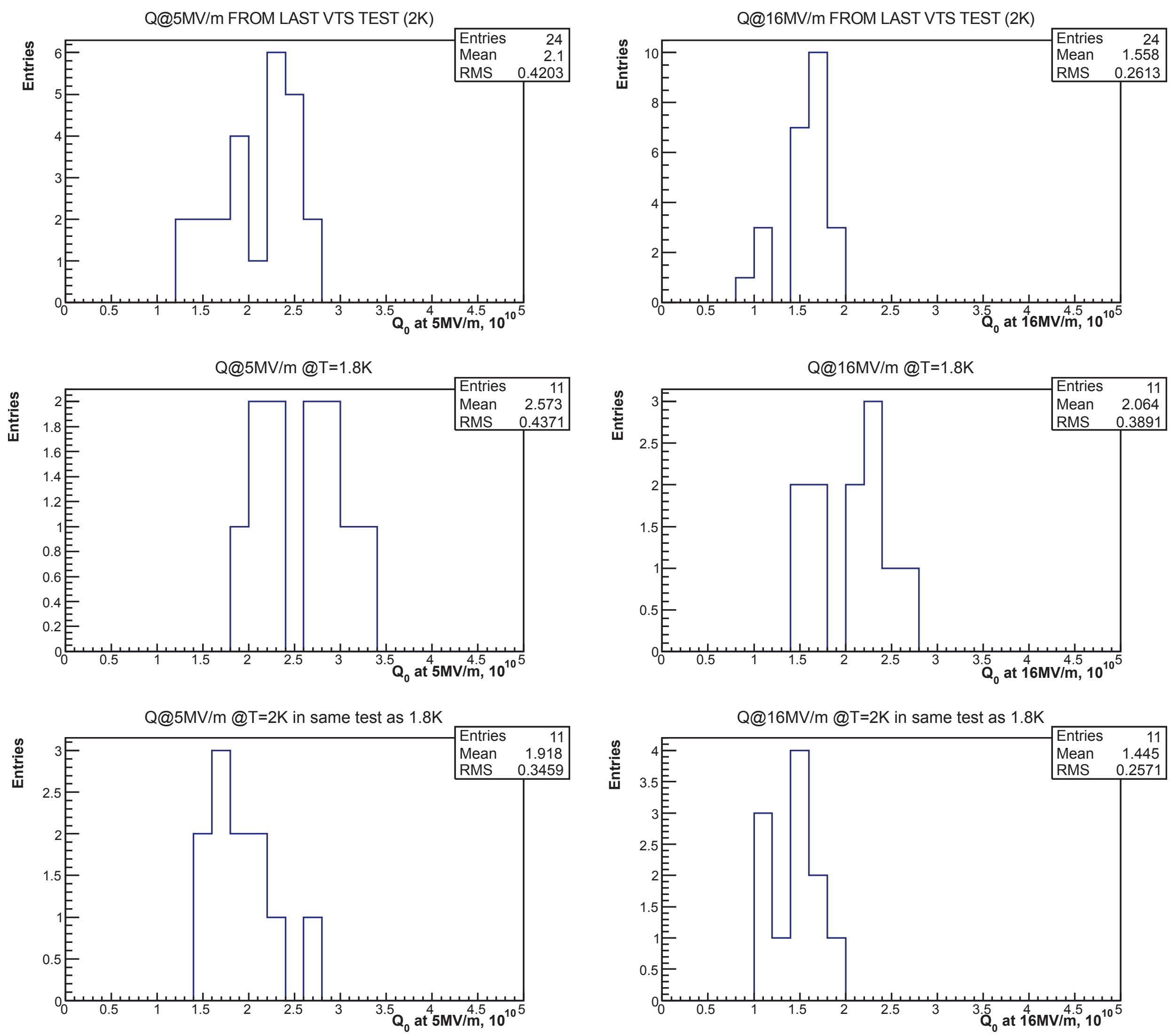

Figure 4: Q_0 at 5MV/m and 16MV/m for Fermilab cavities at 2K. Left: Q_0 at 5MV/m. Right: Q_0 at 16MV/m. Top: 2K measurements. Middle: 1.8K measurements. Bottom: 2K measurements for the sub-sample that corresponds to 2K measurements.

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