ANALYSIS OF THE QUALIFICATION-TESTS PERFORMANCE OF THE SUPERCONDUCTING CAVITIES FOR THE SNS LINAC*

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Abstract

Thomas Jefferson National Accelerating Facility (Jefferson Lab) is producing superconducting radio frequency (SRF) cryomodules for the Spallation Neutron Source (SNS) cold linac. This consists of 11 medium-beta (0.61) cryomodules of 3 cavities each, and 12 high-beta (0.81) cryomodules of 4 cavities each. Before assembly into cavity strings the cavities undergo individual qualification tests in a vertical cryostat (VTA). In this paper we analyze the performance of the cavities during these qualification tests, and attempt to correlate this performance with cleaning, assembly, and testing procedures. We also compare VTA performance with performance in completed cryomodules.

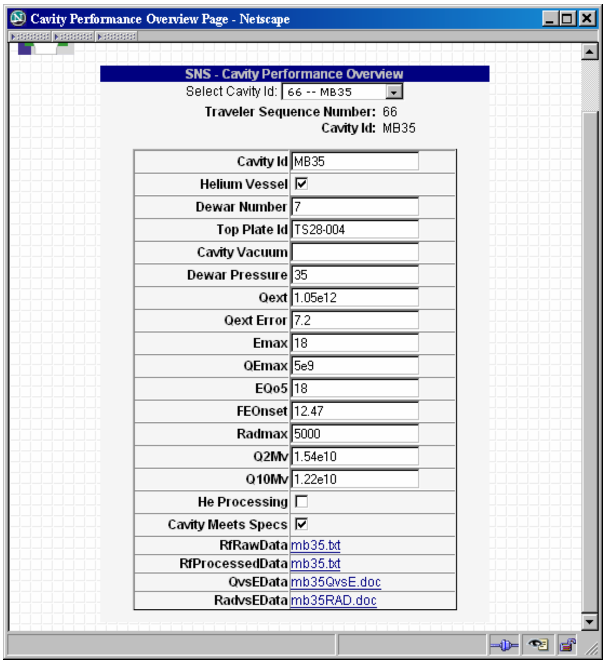
CAVITY AND CRYOMODULE PERFORMANCE ANALYSIS TOOLS

Jefferson Lab has developed a web-based system that integrates commercial database, data analysis, document archiving and retrieval, and user interface software into a coherent knowledge management product called *Pansophy*. *Pansophy* provides key tools for the successful pursuit of major projects such as accelerator system development and construction by offering elements of process and procedure control, data capture and review, and data mining and analysis. *Pansophy* is being used in Jefferson Lab's SNS superconducting linac construction effort as a means for structuring and implementing the QA program, for process control and tracking, and for cavity and cryomodule test data capture and analysis.

Using *Pansophy*, critical process and performance parameters for individual cavities and cryomodules can be entered in the underlying database, in a systematic fashion, by using a set of "travelers" that provide process control and data input. Typical examples of these data include cavity dimensional data, cavity rinse time, rinse water particulate count, BCP etch rate, cavity performance (gradient, Q_o, radiation onset), and cryomodule performance (gradient, Q_o, radiation onset, tuner performance, thermal behavior, probe couplings, etc.).

These data can be analyzed and mined using various standard and user-defined queries. These query tools allow for straightforward investigation of correlations and dependencies between cavity performance parameters and cavity processing variables. For example, the onset of field emission during vertical cavity tests can be investigated with respect to High Pressure Rinse (HPR) water particulate level, with the hope that any observed correlations can be utilized as predictors of cavity performance or water system integrity. Likewise, comparisons between cavity performance in vertical tests and in completed cryomodules can be compared and assessed. The results of such queries can be downloaded to a spreadsheet, or saved as a text file to be used with other analysis programs.

Cavity and Cryomodule *Performance Overview* pages have been added to *Pansophy*. They provide "Single-click" performance summary of cavities tested in the VTA (along with downloadable data and plots), and cryomodules tested in CMTF. An example for such a page for a cavity is shown in Fig.1.



SNS - Cavity Performance Overview

Select Cavity Id: 66 -- MB35

Traveler Sequence Number: 66

Cavity Id: MB35

Cavity Id	MB35
Helium Vessel	☑
Dewar Number	7
Top Plate Id	TS28-004
Cavity Vacuum	
Dewar Pressure	35
Qext	1.05e12
Qext Error	7.2
Emax	18
QEmax	5e9
EQo5	18
FEOnset	12.47
Radmax	5000
Q2Mv	1.54e10
Q10Mv	1.22e10
He Processing	☐
Cavity Meets Specs	☑
RfRawData	mb35.txt
RfProcessedData	mb35.txt
QvsEData	mb35QvsE.doc
RadvsEData	mb35RAD.doc

Figure 1: *Performance Overview* page provided by *Pansophy* summarizing processing, testing, and performance data on a cavity.

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ANALYSIS OF TEST RESULTS

The following figures show a summary of the experimental results obtained to-date during the qualification tests of the medium-β and high-β cavities for SNS.

Figure 2 shows, chronologically, the accelerating gradient at the specification Q of 5 x 10^9. The red triangles are for the medium-β and the blue squares are for the high-β cavities. The red and blue dashed lines are the specification gradients corresponding to peak surface fields of 27.5 MV/m for the medium-β and 35 MV/m for the high-β. Figure 3 shows the Q_0 at the design gradients of 10.1 MV/m for the medium-β and 15.6 MV/m for the high-β. The dashed line is the specification of 5 10^9.

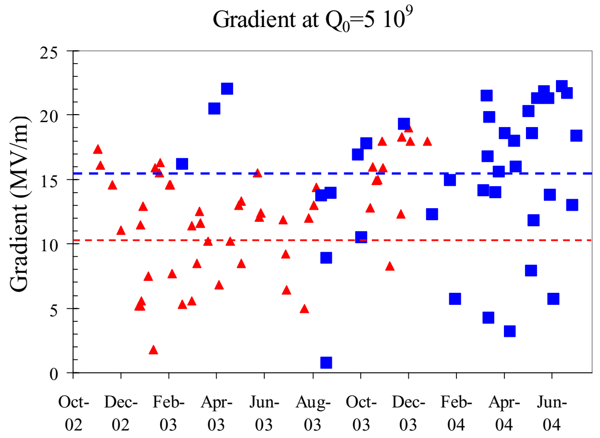

Figure 2: Gradient of SNS medium (triangles) and high (squares) β cavities measured at the Q_o specification of 5 x 10^9 during all vertical cavity tests at 2.1 K. The lower (upper) curve represents the gradient specifications for the medium (high) β cavities, respectively.

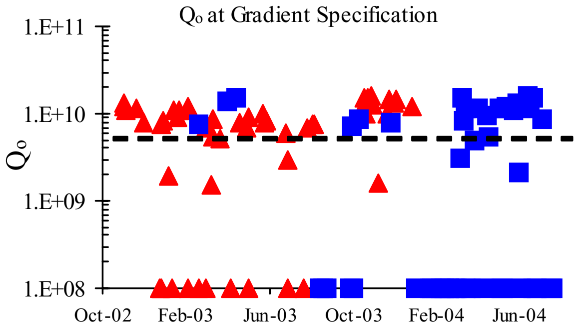

Figure 3: Cavity Q_o measured at the respective gradient specification for SNS medium- (triangles) and high- (squares) β cavities. Cavities that did not meet the required gradient specification are shown with a Q_o of 1 x 10^8.

Figure 4 and 5 show for the medium-β and high-β, respectively, the number of tests in the vertical dewar required to qualify a particular cavity, ordered chronologically by date of the first test. The effect of process improvements initiated during the medium β cavity production cycle can be seen in Figure 4, by the decline in number of tests required. These process improvements were maintained for the high β cavity production cycle.

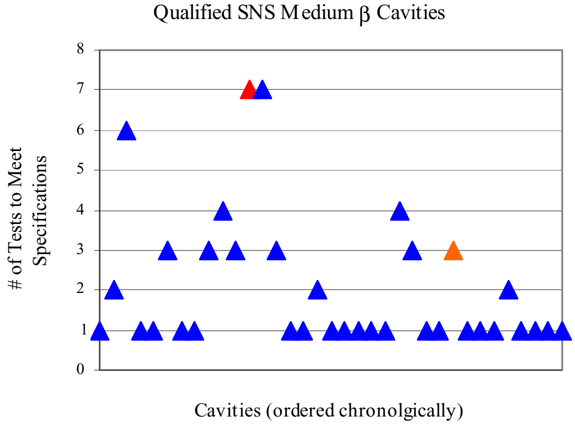

Figure 4: Number of vertical dewar tests required to reach acceptable cavity performance levels for each SNS medium-β cavity, ordered chronologically by date of 1st test.

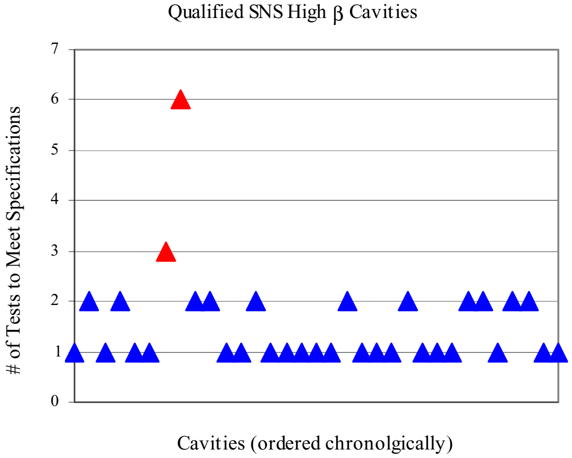

Figure 5: Number of vertical dewar tests required to reach acceptable cavity performance levels for each SNS high-β cavity, ordered chronologically by date of 1st test. The cavities denoted in red were used for additional procedure tests.

Figure 6 compares the performance of the medium-β cavities in the VTA and in the cryomodules. No performance degradation was observed between the former and the latter.

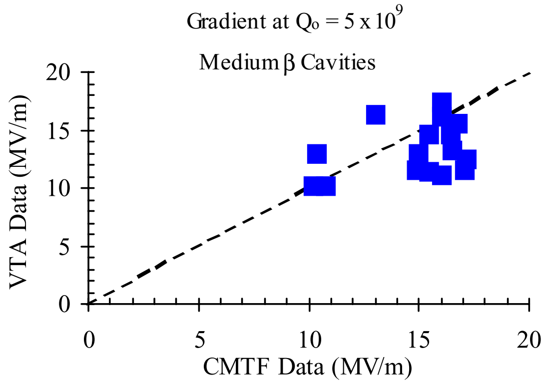

Figure 6: Comparison of measured cavity gradient at the Q_o specification of 5 x 10^9 for the SNS medium-β cavities, as measured in CW mode during vertical dewar tests and in pulsed mode in the completed cryomodule.

Figure 7 shows an attempt at finding a correlation between the performance of a cavity and the number of particulate in the water used during the high-pressure rinsing. While performance still varies significantly between tests, to-date no obvious correlation has been found between performance and any of the measured processing parameters.

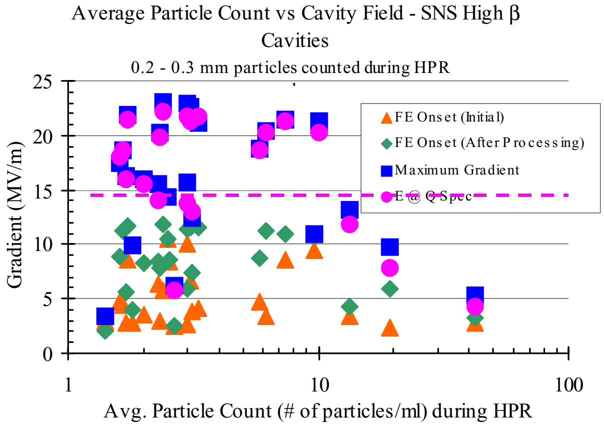

Figure 7: Effect of particulate density in the water during high-pressure rinsing on various cavity fields for the SNS high-β cavities.

MULTIPACTING IN HIGH-β CAVITIES

To date, thirty four of the production high beta cavities were RF tested at 2.1 K. Analysis of the RF test data for these cavities shows that thirty one of them exhibited multipacting (MP) during testing and only four of these showed that the barrier was completely processed away during the test. Two cavities did not show any multipacting while one cavity failed to reach the gradient typical for MP onset. One of the two cavities that did not show multipacting was electropolished.

There originally was a concern that lower-frequency, intermediate-velocity elliptical structures might be more prone to multipacting than the higher-frequency, high-velocity ones. For this reason, simulations were performed and prototypes were tested. No obvious MP behavior was observed in the prototype cavities and in the production medium-β cavities.

Simulations were performed on various cavity shapes including the SNS high-β by W. Hartung [3] which showed that MP in these cavity structures could occur at gradients of 10 to 13.7 MV/m with electron impact energies up to 31 eV. The analysis of vertical test data on high-β cavities shows that the onset occurred from 9.5 to 18.6 MV/m with a mean of 11.7 MV/m, and a standard deviation of 1.8 MV/m. Onset of multipacting was defined as the gradient at which a sudden drop in Q-value was first observed. Typical results are shown in Fig. 8.

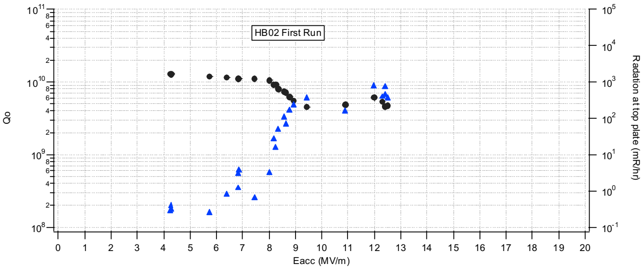

Figure 8: Experimental results on a high-β cavity showing typical multipacting behavior. Black circles show the Q and the blue triangles shown the radiation level measured outside the dewar.

One possible mechanism contributing to the spread in the onset of the MP could be the condition of the niobium surface after processing and evacuation. It is known that cleanliness and level of absorbates present during testing can influence secondary electron yield of the surface.

Simulations of the medium beta cavity shape also showed the potential for multipacting between 10 and 13.7 MV/m with impact energies up to 28 eV. Multipacting was not observed during any of the medium-β production RF tests. The fact that the impact energy in the high-β structures was higher than in the medium-β structures could explain why MP was frequently observed in the former but never in the latter.

REFERENCES

[1] C. Reece, V. Bookwalter, and B. Madre, “A System for Managing Critical Knowledge for Accelerator Subsystems: Pansophy,” *Proc. 2001 Part. Acc. Conf.*, Chicago, June 2001.

[2] V. Bookwalter, B. Madre, J. P. Ozelis, C. Reece, “Utilization of Integrated Process Control, Data Capture, and Data Analysis in Construction of Accelerator Systems,” *Proc. 2003 Part. Acc. Conf.*, Portland, OR (USA) May 2003.

[3] W. Hartung *et al.*, Studies of Multipacting in Medium Axisymmetric Cavities for Medium-Velocity Beams”, *Proc. 2001 SRF Workshop*, Tsukuba, Japan, September 2001