STANDARDIZATION OF CEBAF 12 GEV UPGRADE CAVITY TESTING*

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Abstract

CEBAF 12GeV upgrade project includes 80 new 7-cell cavities to form 10 cryomodules. Each cavity underwent RF qualification at 2.07K using a high power accelerating gradient test and an HOM survey in Jefferson Lab's Vertical Testing Area (VTA) before cavity string assembly. In order to ensure consistently high quality data, updated cavity testing procedures and analysis were implemented and used by a group of VTA operators. For high power tests, a cavity testing procedure was developed and used in conjunction with a LabVIEW program to collect the test data. Additionally while the cavity was at 2.07K, an HOM survey was performed using a network analyzer and a combination of Excel and Mathematica programs. Data analysis was standardized and an online logbook, Pansophy, was used for data storage and mining. The Pansophy system allowed test results to be easily summarized and searchable across all cavity tests. In this presentation, the CEBAF 12GeV upgrade cavity testing procedure, method for data analysis, and results reporting results will be discussed.

INTRODUCTION

Jefferson Lab's 12 GeV upgrade requires ten new cryomodules to be added to the accelerator with each cryomodule capable of delivering an average of at least 108 MV and having a heat load less than 300 Watts per cryomodule. Each cryomodule consists of eight superconducting RF cavities in individual helium vessels. Cavity specifications are a Q_0 better than 8E9 at a gradient of 19.2MV/m or greater. Eighty-six Niobium cavities were manufactured by Research Instruments for JLab's 12 GeV upgrade project. At JLab, all cavities underwent a rigorous processing procedure which included chemistry, furnace bake, high-pressure rinse, and individual qualification testing in the Vertical Testing Area (VTA) prior to cryomodule assembly [1, 2].

The VTA is a closed liquid helium cryogenic system consisting of eight dewars [see Fig. 1] ranging in size from 140 to 1200 liters [3]. Four dewars were routinely used for C100 cavity testing: dewars 3 and 4 have an inside diameter of 28 inches, a depth of 108 inches, and a volume of 650 liters; dewars 7 and 8 have an inside diameter of 28 inches, a depth of 132 inches, and a volume of 820 liters.

The VTA also contains a LabVIEW software controlled 1497MHz High-Power RF System that utilizes a Voltage Controlled Oscillator (VCO) with a Phase-Locked-Loop (PLL) capable of delivering continuous wave or pulsed RF power [4, 5]. This software communicates with all of the instrumentation necessary for RF testing. A typical dewar cycle was approximately 24 hours and included insertion of the cavity loaded onto a test stand in to a dewar, cooldown and fill, pump to 2.07 K, low and high power testing, warmup, and removal of test stand from dewar.

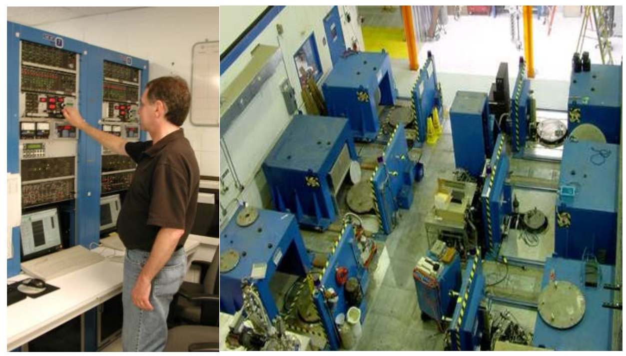

Figure 1: JLab's Vertical Test Area control room and shielded dewars

QUALIFICATION TESTING

Qualification testing involved the Higher Order Mode (HOM) survey, measurement of the passband fundamental frequencies, cable calibration, accelerating mode input coupling, decay time constant, Q_0 as a function of cavity gradient, and Q_0 as a function of temperature at design gradient (20 MV/m). Passband measurements and RF power processing were made as needed due to high radiation levels and/or quenching below the administrative setpoints. By the conclusion of VTA qualification testing for all C100 cavities, there were up to 6 tests per week and sixteen qualified RF testers.

Standardization of cavity testing was necessary in order to ensure consistent testing procedures and interpretation of results. A combination of manuals and software were developed to assist the RF operators in C100 testing. Separate manuals were written for the HOM survey procedure and RF testing procedure. Software packages included LabVIEW, Mathematica, and Excel. Pansophy, an online searchable database, was used to upload and organize all test results through Travelers, a data collection template specific to a cavity [6, 7]. This database was also used for querying test data and documenting cavity process history.

HOM Survey and Passband Measurements

In order to meet CEBAF beam stability requirements, the HOM survey qualification required verifying that the frequency and loaded quality factor (Q_L) of the TE111, TM110, and TM111 modes were within the acceptance criteria specified for each frequency. The HOM survey was divided into several steps, for which detailed instruction were included in manuals and embedded in the software. For each mode, the transmission parameters (S21 and S31 raw data) from a vector network analyzer were saved into an Excel spreadsheet.

An enhanced Mathematica routine package based on a Polfit algorithm [8] was developed and used to extract the Q_L values from the raw data. Any frequency that demonstrated a Q_L value higher than a pre-determined value was flagged for further measurements and corrective actions. The Mathematica Polfit package generated Excel data files containing the frequency and Q_L data for each HOM mode.

An Excel Visual Basic macro was written to import the Excel data files, combine the measurement data for different modes, allow for input of manually measured HOM data, and compare the results with the acceptance criteria [see Fig. 2]. This finalized processed data file, along with any pertinent information gathered during the survey, was uploaded to a Pansophy Traveler.

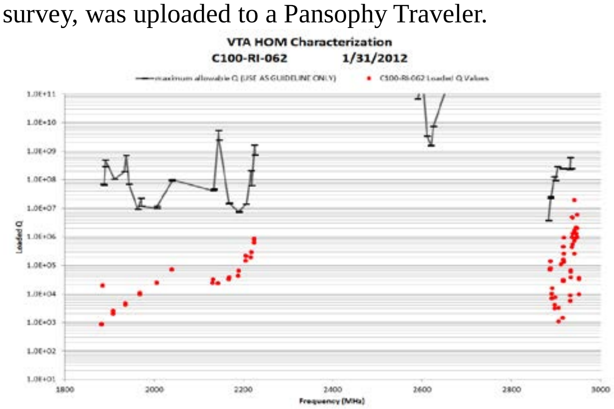

Figure 2: Typical C100 HOM survey results for cavity qualification testing

Manual data recording for HOM survey is possible but is time intensive. Using the enhanced Polfit Mathematica package, the HOM survey was usually completed in less than three hours. The survey was typically performed first in the cavity qualification testing process so that the data could be reviewed while the high-power RF testing was taking place.

RF Testing

The VTA 1497 MHz RF System utilizes a VCO-PLL and 500 Watt amplifier capable of achieving gradients over 40 MV/m in the C100 cavities. A Personnel Safety System (PSS) monitors for any aberrant conditions that may compromise safety to personnel and/or the cavity and will interrupt the delivery of high RF power to the cavity until the condition is corrected and the PSS is manually reset.

The RF testing procedure was detailed in an updated illustrated manual and Pansophy Traveler particular to the C100 cavity qualification requirements. Each tester was trained to follow the procedure as described. Cavity testing constraints were provided based on 12 GeV Upgrade specifications and JLab safety protocols.

A LabVIEW program led the tester in calculating cable calibrations, determining the input coupling and decay time constant, and measuring Q_0 as a function of accelerating gradient [4, 5]. Error trapping was added to the software to detect the most common user input errors.

The RF test began with identifying and measuring the cavity's fundamental frequencies with the network analyzer. These values were logged in the logbook and a Pansophy Traveler. The measured pi mode frequency was used to calculate the CW frequency used for cable calibrations.

Instrumentation needed for cable calibration, such as RF power meter, circulator, and calibrated RF standards, were specified in the procedure and used for all C100 cavities. Upon the completion of the cable calibrations, LabVIEW displayed a summary sheet, allowing the user to verify that no errors were made during the cable calibration before continuing with the testing. Dissipated power measurements were taken while the PLL is open-loop, allowing for additional verification of the cable calibrations.

The cavity lock frequency was found after closing the PLL by using the frequency and phase knobs on the PLL chassis. A LabVIEW subroutine pulsed the RF power to assist the user in determining the cavity coupling. The user was responsible for making the cavity coupling determination and then feeding this information back into the main LabVIEW program.

Multiple decay measurements were performed through a subroutine to find the Q_{ext} values for the field probe, fundamental power coupler, and HOM couplers. The field probe Q_{ext} determined in this manner was used by the main LabVIEW program for gradient and Q_0 calculations.

Cavity performance measurements began at approximately 2 MV/m and increased in 0.5 MV/m steps. At each gradient, LabVIEW logged all of the inputs and calculated values to a data file and graphed the loaded Q as a function of gradient. Administrative limits were placed on maximum cavity gradient and radiation allowed during testing to avoid unnecessary risks to the production cavities and schedule.

At the conclusion of the RF qualification test, the raw data from LabVIEW program was imported into a macro-enabled Excel program designed to process the data by the specific criteria needed for reporting in Pansophy such as Q_0 at low gradient, radiation onset, maximum gradient achieved, maximum radiation observed, temperature dependent Q_0 measurements, and the Lorentz force coefficient. Additionally, the program generated graphs

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of the Q_0, radiation, and HOM power versus gradient [see example graph in Fig. 3]. Once the qualification test data had been complied and uploaded to Pansophy, it was available for review prior to warming up the cavity.

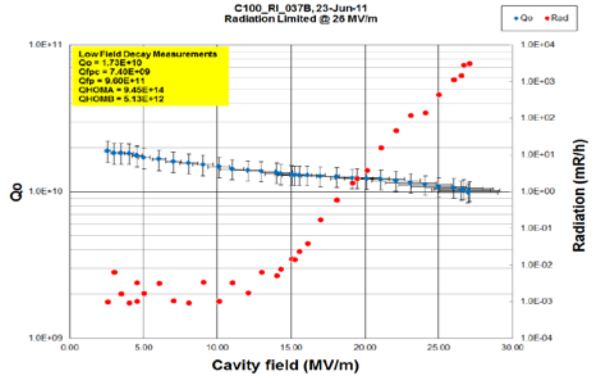

Figure 3: Q_0 and radiation versus gradient, as generated by Excel program on LabVIEW data file

Radiation Onset Determination

In order to specify the cavity gradient in which the field emissions during the high-power RF test exceeded the background radiation levels, a piecewise regression method was built into the Excel program used to process the raw data. The piecewise regression method determines the breakpoint in the radiation versus gradient data where the average radiation level transitions from background noise to a positively sloped trend by searching for the maximum coefficient of determination value from a series of trial breakpoints. The program reported the breakpoint gradient with an accuracy of better than ±0.5 MV/m [see Fig. 4]. Using this breakpoint as the radiation onset gradient allowed a consistent definition to be used across all cavity tests.

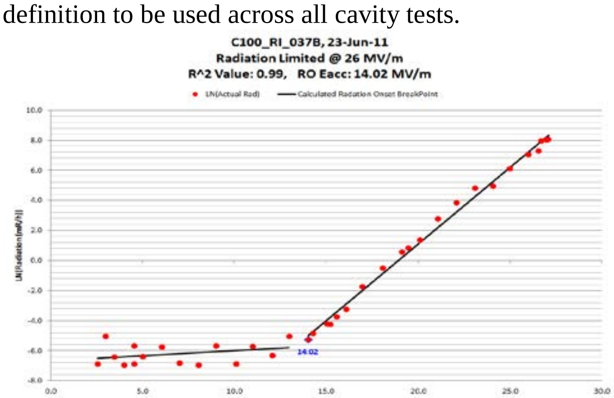

Figure 4: Example of Radiation Onset determination using piecewise regression technique in Excel program

PANSOPHY

Pansophy is instrumental to the JLab SRF group's quality assurance and control goals [6, 7]. The progress of all cavities throughout the production run was tracked by the Pansophy system. Data obtained from each production step was entered into the database through a Traveler, thereby simultaneously creating a log of the cavity's presence at each station as well as providing a platform for reporting process parameters and/or test results. Pansophy provided a screenshot of each cavity's progress, showing which production centers a cavity had visited. Pansophy also enables users to query the database to generate reports and investigate possible correlations. Since the database is archived, it will be possible to continue to study the effectiveness of the C100 process steps when the cryomodules are installed and operating in the accelerator.

SUMMARY

The 86 cavities produced for the 12 GeV upgrade project resulted in approximately 125 VTA qualification tests over a year and a half with all 80 necessary cavities being qualified for use in cryomodule production [1]. The C100 cavity qualification process depended heavily on manuals, interactive software, and tester training to standardize the testing procedure. These guidelines were in place to ensure that each cavity was tested identically and the test data was available for analysis.

ACKNOWLEDGMENTS

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