AUTOMATED CAVITY TEST SUITE FOR CORNELL'S ERL PROGRAM *

Dan Gonnella, Nicholas Valles, and Matthias Liepe,
CLASSE, Cornell University, Ithaca, NY 14853, USA

Abstract

As of 2012, fabrication and testing of main linac 7-cell cavities has begun for Cornell's Energy Recovery Linac prototype project. To standardize the testing process, minimize errors and allow for quick and precise measurements of these cavities, a suite of MatLab programs has been written to automate cavity tests. The programs allow measuring the quality factor versus temperature, and quality factor vs. accelerating gradient, and allow extracting material properties such as RRR and residual resistance. They are compatible with EPICS input/output controllers or standalone computers. Finally, the program can measure continuous Q vs E curves from a single high field decay curve.

INTRODUCTION

Cornell is currently in the prototype phase of designing an Energy Recovery Linac (ERL). This requires the dedication of large amounts of resources and time to the testing of prototype cavities. In order to simplify this task, a cavity testing suite was written to automate many testing functions. It has proved to be very successful in both small and large scale tests.

This paper will serve as an overview of the recently created cavity testing suite used to automate Cornell's tests of superconducting RF cavities. First, we will briefly discuss an overview to the theoretical background to quality factor measurements. Next, we will walk through each function that the testing program performs. The cavity test suite is a graphical user interface (GUI) based MatLab program. It is fully integrated with both EPICS servers and standalone equipment. Notably, it allows the remote control of equipment such as signal generators and power meters. Moreover, monitoring of temperature, radiation, and liquid helium level is streamlined. The program has especially been useful in the recent test of the Horizontal Test Cryostat (HTC) for the Cornell ERL program [1]. The HTC test required remote control of all equipment while running, truly testing the program's capabilities. Overall, the suite has significantly cut down on the length of time required for cavity tests and eliminates much experimenter error from the tests.

QUALITY FACTOR MEASUREMENTS

The theory behind quality factor measurements in RF cavities is well understood [2]. For completeness, we will explain the main points on how the quality factor can be measured from a decay curve. When on resonance, if the RF power to the cavity is turned off, the energy stored in

the cavity decays according to:

$$\frac{dU}{dt} = -\frac{U}{\tau_L(t)}, \qquad (1)$$

where U is the energy stored in the cavity, t is time, and τ_L is the instantaneous decay parameter defined as,

$$\tau_L(t) = \frac{2\pi f_0}{Q_L(t)}, \qquad (2)$$

with resonance frequency f_0 and loaded quality factor Q_L. From a decay curve, the decay constant can be measured. By measuring the forward and reflected powers, the coupling constant β can be calculated in two ways from,

$$\beta_e = \frac{1}{2\sqrt{\frac{P_i}{P_e}} - 1}, \qquad (3)$$

$$\beta_i = \frac{1 \pm \sqrt{P_r/P_i}}{1 \mp \sqrt{P_r/P_i}}, \qquad (4)$$

where P_i is the incident power, P_e is the emitted power, and P_r is the reflected power. Then $\beta = \mathrm{mean}(\beta_e, \beta_i)$ With the measured decay constant and calculated coupling constant, the natural quality factor Q_0 can be calculated from

$$Q_0 = 2\pi f_0 \tau_L (1 + \beta). \qquad (5)$$

MAIN GUI FUNCTIONS

All measurement tools and equipment controls are accessible from the main GUI (Fig. 1). The suite allows the experimenter to save new data and load old data, which is displayed at the top of the GUI. The user has the choice between viewing the raw data from measurements (such as forward, transmitted, and reflected powers) or the calculated results (such as E_{acc}, Q, and β). Below the displayed data, on the left hand side, controls for monitoring temperature, radiation, and liquid helium level are in place. Temperature sensor calibration curves are already programmed for use with temperature monitors. On the right hand side of the GUI, below the displayed data, cable attenuation and calibration constants are displayed. These can be manually entered or automatically imported from the cable attenuation wizard, which will be discussed later. Just below the calibration constants is the "Acquire Q Data" button, which, when pressed, will launch a sub-GUI for taking a Q measurement. Finally, recently taken data is plotted in the lower right hand corner. There are four different options for plotting: Q vs E, Q vs T, R_s vs 1/T (surface resistance), or Q vs H. The menus at the top of the GUI allow the user to choose between EPICS control and standalone equipment and also serve as the launching point for the many sub-GUIs that will be discussed in the following sections.
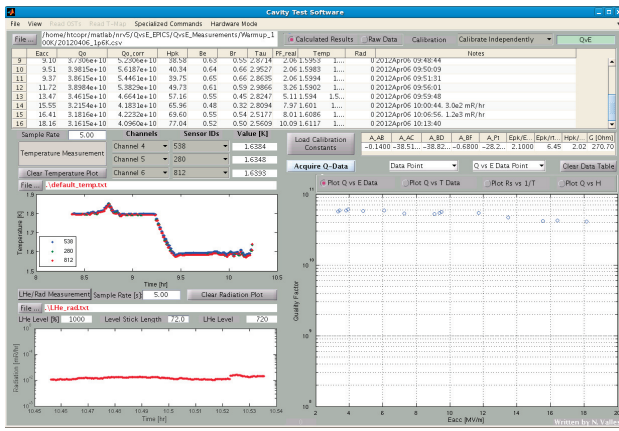
Figure 1: A screenshot of the main GUI. Previously taken data is displayed along with plots of temperature and radiation vs time and Q vs E, Q vs H, R_s vs 1/T, or Q vs T. A series of menus allows access to a variety of other GUIs for more tasks.
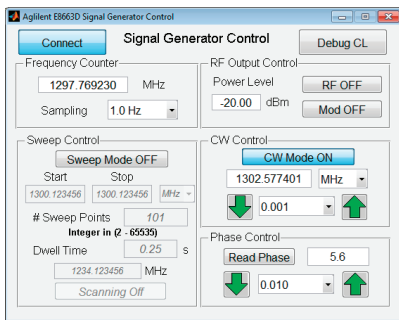

Figure 2: Sub-GUI for control of an Agilent E8663D signal generator. Control of frequency, phase, and amplitude is possible. The signal generator can be operated in CW mode or in "Sweep" mode for sweeping through a frequency range.

EQUIPMENT CONTROL

Signal Generator Control

A sub-GUI was created for control of an Agilent E8663D signal generator. This sub-GUI can control frequency, phase, and amplitude output of the signal generator. A screenshot of this GUI is shown in Fig. 2. The signal generator can be operated in CW mode or in a "sweep" mode. Sweep mode allows for the sweeping of the frequency over a range of values. This is especially useful when searching for resonance in a cavity. This particular GUI was the main control source during the recent Horizontal Test Cryostat (HTC) test for the Cornell ERL. Since it was not possible to manually control the signal generator due to radiation restrictions, this GUI provided a necessary level of control that would have otherwise been unachievable.
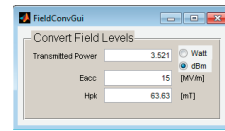

Figure 3: A sub-GUI for easy conversion between transmitted power and electric and magnetic fields.
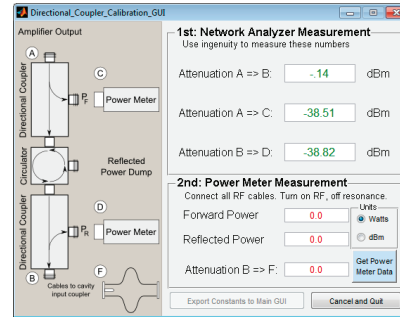

Figure 4: A sub-GUI for the cable calibration wizard. It guides the experimenter through the attenuation measurements that need to be made and exports the attenuation constants to the main GUI.

Field Conversion and Cable Attenuation Wizard

During a cavity test, it is convenient to have an estimate for the strength of the accelerating field without having to measure a decay curve. A sub-GUI was implemented to easily convert between transmitted power (in dBm or W) to electric or magnetic fields using previously obtained calibration. This allows for quick referencing of the field strength. A screenshot of this GUI is shown in Fig. 3.

Prior to a cavity test, the directional couplers and power meters must be calibrated. Directional couplers sample both the forward and reflected power and are diverted to power meters so that measurements can be made. A sub-GUI was created to automate this process through a step by step wizard. Fig. 4 shows this GUI. The left side of the wizard shows a schematic diagram of the circulator and directional coupler set-up for a cavity test. The right side shows the various measurements that need to be made corresponding to locations on the schematic. Usually, these measurements are made by an S_{21} measurement with a network analyzer. Once all attenuation measurements are made, the wizard can export the constants to the main GUI where they are displayed and used during data taking.

DATA TAKING

Quality Factor Measurements

The strongest feature of the cavity testing suite that was implemented was the automation of quality factor measurements. In the past, the experimenter measured the quality factor by manually taking a decay curve and measuring various parameters. With the test suite, an automated routine of the main GUI gives a measurement of Q, E_{acc}, and β, the coupling constant. The decay curve is displayed along
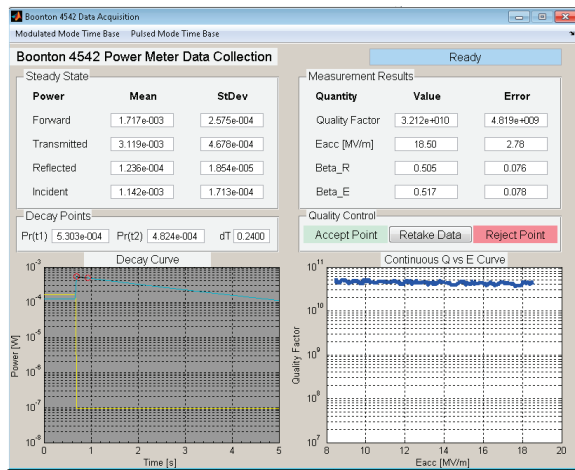
Figure 5: A screenshot of a decay curve measurement. Measured forward, transmitted, reflected, and incident power are displayed. Calculated quality factor, accelerating field, and coupling constants are displayed. The time span over which the power measurements were made can be adjusted on the decay curve. A continuous Q vs E curve is displayed for the length of the decay.

with all of the data used to compute Q including forward, transmitted, reflected, and incident power. Fig. 5 shows a screenshot of a sample data point. When measuring a Q value, the program uses two points on the decay curve that are automatically chosen. If the automatic triggering fails, the experimenter has the option of choosing these two values manually by clicking on the decay curve.

Continuous Q vs. E Curve

When a cavity decays from high field, the field in the cavity drops with the decay curve. This allows a continuous Q vs E curve to be drawn from a single high field measurement. The lower right hand corner of the data acquisition GUI (Fig. 5) shows this plot. A Q measurement was made at 18 MV/m in the Cornell HTC and a continuous curve was calculated. Fig.6 shows the continuous Q vs E plot drawn on the same axis as the Q vs E curve obtained from traditional cavity testing methods. The accuracy of the continuous curve is clearly visible as it completely lies within the error bars of the individually obtained data points. This effectively allows an entire Q vs E curve to be obtained from a single high field measurement, greatly reducing the amount of time for cavity tests.

CONCLUSION

A GUI based MatLab suite was created to automate cavity testing for the Cornell ERL. The suite can fully communicate with either EPICS servers or stand alone equipment. The program possesses complete remote control of the signal generator and power meters and is capable of measuring temperature, radiation, and liquid helium level. Most importantly, quality factor measurements can be made quickly
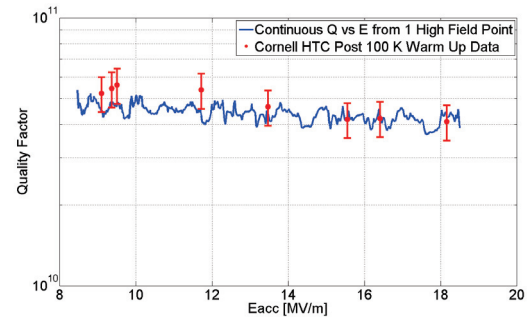

Figure 6: A continuous Q vs E plot obtained from a single 18 MV/m measurement in the Cornell HTC at 1.8 K. For comparison, it is plotted against data taken during the same run using traditional cavity testing methods. Noisy nature of $Q(t)$ is due to numerical differentiation. Future implementations of better derivative algorithms will lead to cleaner continuous Q vs E curves.

and accurately through an automated routine. This has reduced the amount of time it takes to obtain a full Q vs E curve to minutes. In addition, a full, continuous Q vs E curve can be obtained from a single high-field Q measurement. This curve is in good agreement with data taken by traditional means, suggesting that in the future, an entire Q vs E curve can be obtained from one measurement, greatly reducing the amount of time required for cavity tests and in turn saving valuable laboratory resources.

The program was recently tested during the Cornell HTC test. Due to radiation hazards during this test, experimenter access to the testing area was limited. Through EPICS servers and the cavity testing suite, the experiment was completely controlled from a remote location.

The cavity testing suite will continue to be adapted to automate more complicated cavity tests. Temperature mapping equipment will be controlled through an additional sub-GUI accessible from the main cavity testing suite that will allow for quench detection and heating distribution measurements to be made easily. Also, quench detection through the use of oscillating superleak transducers (OSTs) will be integrated into the main GUI. MatLab scripts already exist for these two operations and are being converted into GUI format for use with the test suite. Once this is complete, most cavity tests will be able to be exclusively run from a computer and a single program, increasing efficiency and streamlining the testing process.

ACKNOWLEDGEMENTS

REFERENCES

[1] N. Valles et al., *Testing of the main-linac prototype cavity in a horizontal test cryomodule for the cornell erl*, IPAC 2012.

[2] H. Padamsee, J. Knobloch, and T. Hays, *Rf superconductivity for accelerators*, Wiley, 1998.

07 Accelerator Technology and Main Systems

T07 Superconducting RF