TEMPERATURE MAPPING SOFTWARE FOR SINGLE-CELL CAVITIES*

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Abstract

Cornell University routinely manufactures single-cell Niobium cavities on campus. These cavities will be used in the proposed Energy Recovery Linac (ERL). They are tested with a Temperature Mapping system (T-Map) in an effort to understand their heating behavior. In order to expedite this process, a Matlab program has been written that is capable of working with different acquisition hardware, acquiring calibration data, taking temperature maps, and compiling raw data into understandable results.

INTRODUCTION

Niobium cavities are a key component of particle accelerators. They are used primarily because of their high transition temperature to the superconducting state. The Niobium cavities for Cornell University's proposed ERL are manufactured and tested on the university campus. Therefore, much time is dedicated to understanding different properties of the cavities. One such property of interest is the temperature profile of a cavity when it is being driven by a radio-frequency (RF) power source. In order to efficiently measure this quality, a Matlab program was written specifically to expedite data acquisition.

This paper will serve as an overview of the Graphical User Interface (GUI) recently developed for the temperature mapping of single-cell niobium cavities. First, we will give a brief overview of the purpose behind cavity temperature profiling and the implications of surface heating. Then, we will discuss the method of temperature mapping prior to the development of the GUI. Finally, we will discuss the different functions implemented in the GUI and how they are organized.

As of now, one trial run of the new system has been performed. This test proved a great success in both simplifying data collection and shortening test time; it also revealed some possible additional functions that would be useful if implemented in future.

TEMPERATURE MAPPING

Temperature measurement is an important aspect of cavity inspection. Through temperature mapping systems, one can see particular areas on a cavity that are susceptible to excess warming when the cavity is being driven with RF power.

Implications of Surface Heating

Heating on the surface of a superconducting cavity can be caused by several different things. Most commonly, heating is attributed to general defects in the surface of a cavity. For instance, a cavity could have sharp microscopic pits on the surface which could cause magnetic field enhancement. Another common scenario is the existence of dust particles on surface of the cavity. (Fig.1) These dust particles can also cause field enhancement and losses due to radiation.

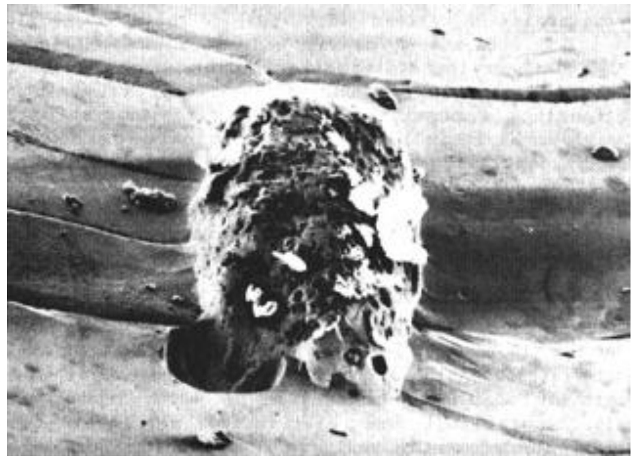

Figure 1: A microscopic dust particle on the surface of a sample cavity.

The reason why physicists are so concerned with surface heating is because specific areas of heating can cause the cavity to transition locally from superconducting to normal conducting. This chain reaction continues to spread throughout the cavity causing the cavity to crash. This undesirable outcome is known as a "Quench". To study and hopefully correct this mode of failure, a temperature mapping system has been developed to measure heating at gradually increasing electrical fields. By studying these T-Maps, one can observe how heating initiates and spreads.

Testing Setup

The mechanical setup consists of a series of 38 boards stationed around a cavity with each board having 17 Allen & Bradley resistors. These resistors are in contact with the cavity at all times throughout the test. (See Fig. 2)

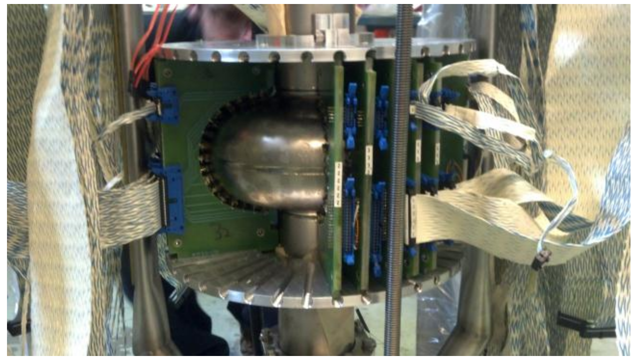

Figure 2: A picture of the Allen & Bradley resistor boards stationed around a sample cavity.

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These particular resistors are extremely sensitive to temperature. Therefore, as the temperature changes at a particular point on the surface of the cavity, the associated resistor's resistivity changes as well. This change in resistivity, in turn, causes a change in the voltage drop registered across the resistor. Using this information, a detailed map of the surface temperature can be made.

When all the boards are in place, the setup is inserted into a test pit. Then, the temperature in the pit is brought down to around 2 K. The cavity, now in the superconducting state, is then driven by an RF power source at increasing electrical field values. At each field, a T-Map is taken to observe the behavior of the cavity. Analysis of these maps will show where a cavity quench originates. (Fig. 3) When the setup is dismantled, the quench spot is examined in an attempt to determine the source of the heating.

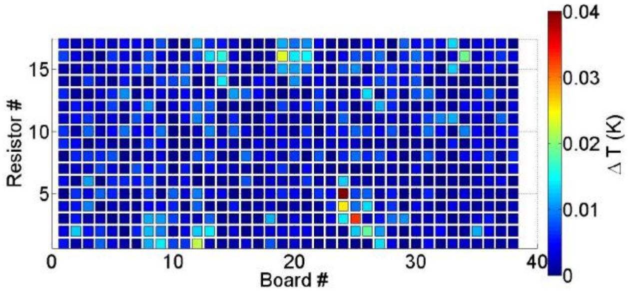

Figure 3: A T-Map showing a quench location; the quench location is the hottest spot, board 24, resistor 5. [1]

THE OLD SYSTEM

Prior to the development of the GUI, there were individual Matlab scripts written to perform the various testing functions. These functions were such that one had to call each function individually by typing the function callback in a command window. This proved to be a cumbersome and time consuming form of data acquisition. In order to explain the necessity for a GUI, we will go through the three main functions that are needed to run a successful T-Map test.

First, before any temperature measurement can be performed, the temperature sensors have to be calibrated in order to accurately represent the temperature change. Since voltage needs to be associated with temperature, a function was written to take calibration points as the temperature of the cavity is brought down to 2 K. To check the validity of our calibration, a plot is made and fitted with a logarithmic function. This function is meant to model the behavior of the resistors as they are subjected to different temperatures. Therefore, the more closely our calibration points fit the function, the more we can trust our data. (Fig. 4) The process of taking calibration points is a tedious one with this system. One has to type each individual command while at the same time making slight alterations to the code. These alterations are to make sure that the calibrations are saved to different variables. This ensures that no point are overwritten and lost.

Once the calibration is complete, a separate function takes temperature maps while the cavity is not being driven by RF power. This gives us a zeroing factor which we can subtract from the actual data to give us reduced background noise in the temperature measurements. This particular T-Map is called an "RF Off" measurement. This measurement is also slightly difficult to take simply because it needs to be taken several times. Then, an average reading of all the maps is calculated to ensure accuracy in the zeroing factor.

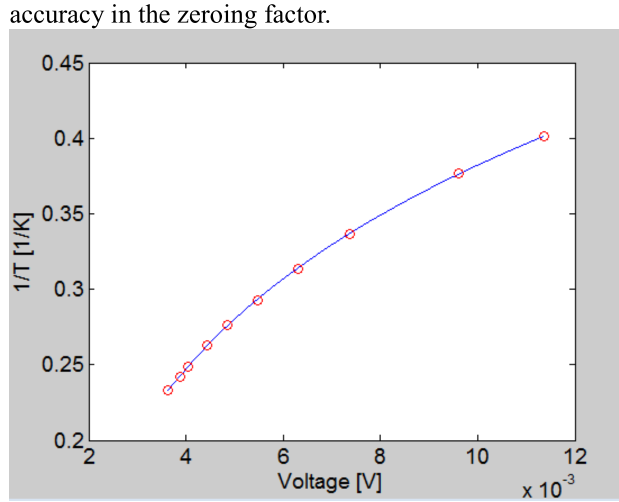

Figure 4: A calibration plot showing the relationship between voltage and temperature. The circles are the experimental plot points taken as the temperature is brought down to 2 K and the line is the logarithmic fit.

Finally, after the RF Off T-Map is taken, it is time to measure the temperature profile at different increasing electric field values. This function is similar to the RF Off function. The only difference is that it has inputs for the name of the field value. However, the naming scheme used here is not sufficient. For instance, for a T-Map taken at a field value of 1.5 MV/m, the name of that map would be "1p5m" where "p" is the decimal point and "m" is "MV/m". Obviously, this naming scheme is confusing and not particularly scientific. Additionally, it depends on all program users adopting the same convention which is currently not the case. Therefore, another criterion for making a GUI was to improve the way in which T-Map data is named, saved, and recalled.

Each of these functions works decently well independent of the others. However, when they are used in conjunction for testing, they tend to be confusing in purpose and meticulous in execution. Therefore, it was deemed necessary to devise a new and more useful Matlab program to bring all the necessary temperature mapping functions together in one place in order to increase the efficiency of testing time. To that end, we have developed a graphical user interface which holds all the important functions as well as makes them easy to understand and implement. The next section will describe the details of the GUI.

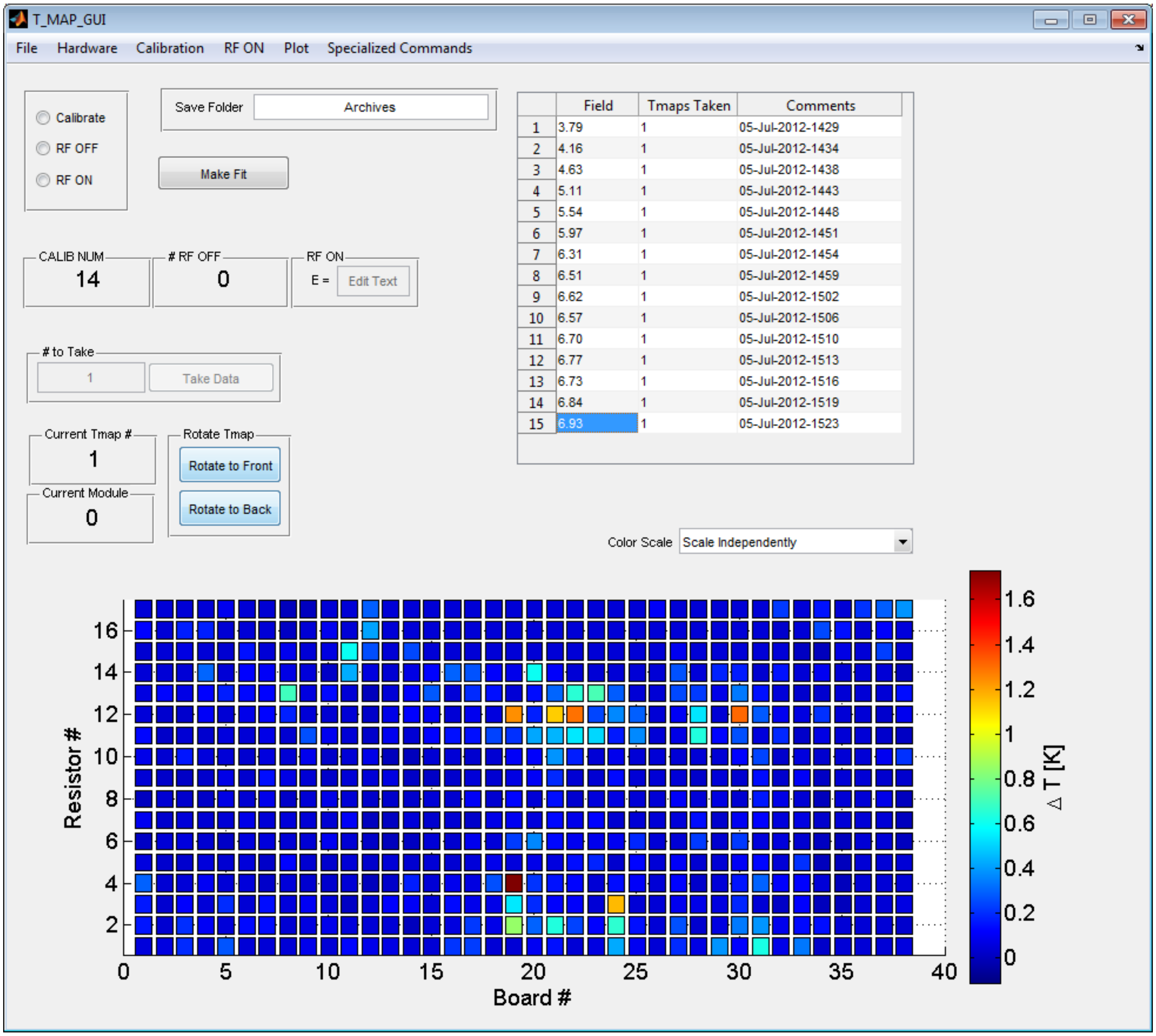

Figure 5: A screen shot of the new GUI as it looks currently. There are sections for data acquisition, temperature map plotting, previous temperature T-map selection, and various menus of editing GUI content.

THE NEW SYSTEM

Here we shall give an in-depth discussion on the layout and functionality of the GUI. We will go over the different sections of the GUI and the functions they include as well as illustrate the success of the GUI and suggest additional functionality to be added in the future.

Taking Data

The GUI has a single "Take Data" button for data acquisition. This button performs three different functions depending on which what part of the test you are performing. Notice the radio buttons in the top left corner of the GUI in Figure 5 labeled "Calibrate", "RF OFF", and "RF ON". These radio buttons switch the functionality of the "Take Data" button between taking calibration points, RF Off temperature maps, and RF On temperature maps respectively.

When the "Calibration" radio button is selected, the "Take Data" button will take a calibration point and store it in the background of the program. The "CALIB NUM" box keeps track of the number of calibration points that are stored in the program memory and displays that number in the GUI. After several calibration points have been taken, the user can press the "Make Fit" button next to the radio buttons to bring up a sub-GUI having the calibration plot shown in Fig. 4.

Pushing the "Take Data" button when "RF OFF" is selected takes the T-Map used to subtract from the RF On data for the purpose reducing background noise. The"# RF OFF" box keeps track of the number of RF off T-Maps stored in the program memory and displays that number in the GUI. This information is stored in a background file to be used later in the program.

Finally, when "RF ON" is selected and the "Take Data" button is selected, the GUI takes a T-Map of the entire cavity. Once the program finishes taking the map, it automatically plots the map to the axes located at the bottom of the GUI. These axes are rotatable which enables the user to move the axes all around to get a clearer picture of individual spot heating and to see how the heating compares with the areas surrounding the hot spot.

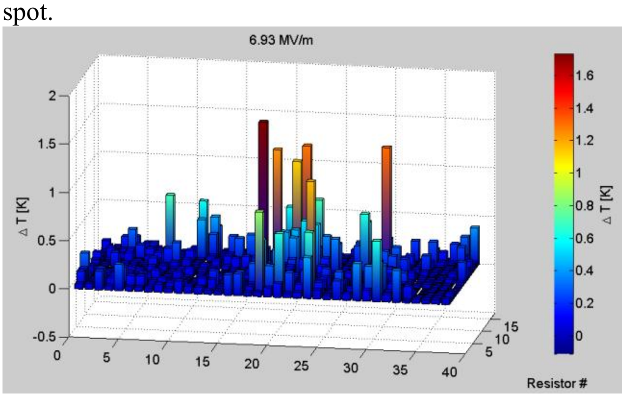

Figure 6: A screenshot of the rotated T-Map axes. Rotating the axes can be beneficial in seeing more clearly the areas that are subject to excess heating.

The GUI has also has two buttons near the plot titled "Rotate to Back" and "Rotate to Front". These buttons automatically rotate the plot to the back and to the front, respectively.

T-Map Table

One criterion for the design of the T-Map GUI was to make it such that past T-Maps could be recalled and view easily. For this purpose, we integrated a table that stores all previous maps for easy access.

	Field	Tmaps Taken	Comments
1	3.79	1	05-Jul-2012-1429
2	4.16	1	05-Jul-2012-1434
3	4.63	1	05-Jul-2012-1438
4	5.11	1	05-Jul-2012-1443
5	5.54	1	05-Jul-2012-1448
6	5.97	1	05-Jul-2012-1451
7	6.31	1	05-Jul-2012-1454
8	6.51	1	05-Jul-2012-1459
9	6.62	1	05-Jul-2012-1502
10	6.57	1	05-Jul-2012-1506
11	6.70	1	05-Jul-2012-1510
12	6.77	1	05-Jul-2012-1513
13	6.73	1	05-Jul-2012-1516
14	6.84	1	05-Jul-2012-1519
15	6.93	1	05-Jul-2012-1523

Figure 7: The T-Map table implemented to store previous temperature maps and make them easily accessible for review.

This table holds three columns. The "Field" column holds the electric field value of the associated T-Map in MV/m. The value of the electric field that appears in the "Field" column comes from user input; that is, whatever value is entered into the "RF ON" box to the left of the table is the number that appears in its respective T-Map row. The "Tmaps Taken" column tells the user how many T-Maps were taken at the specified field value. The "Comments" column holds the date and time that the specific T-Map was taken. The "Field" and "Comments" columns are both editable.

Selecting any part of any Row automatically brings up the plot of the associated T-Map. This quick access feature is extremely useful when looking at the gradual heating of the cavity.

Menu Bar and Sub-Menus

The menu bar of the GUI has several drop-down menus with miscellaneous functions specific to different parts of the test. This section will go through some of the menu items and discuss their uses.

The "File" drop-down menu has several useful selections. They are as follows: "Load Calibration", "Load Tmap Data", and "Save Tmap Data". Selecting "Load Calibration" will open a Windows Explorer window which can be used to select previous calibration data. These calibration plots can be either from the current test or from previous tests. Selecting "Load Tmap" will open a Widows Explorer window which allows the user to select T-Map data from previous tests. This data can be loaded to the GUI for further review at any time. Selecting "Save Tmap Data" will open a Windows Explorer window for saving the current T-Map data to a file.

The "Hardware" dropdown menu has selections for changing the data acquisition hardware. For example, the program can either be run in "Standard" mode or in "Debug" mode. Written in the program code is a case switch that changes the functionality of the GUI depending on which case, "Standard" or "Debug", is selected. "Standard" runs the program as if there was an actual test proceeding. "Debug" is used for grabbing sample data and employing it in program development. There is also a sub-menu for selecting the appropriate Lakeshore temperature measurement bridge to be used for the test.

The "Calibration" dropdown menu has selections for editing the current calibration data. For example, selecting "Remove Last Point" will remove the most recent calibration point taken. This is useful when an unexpected error occurs during data taking. "Remove a Point" brings up crosshairs on the GUI window which are used to select any calibration point on the calibration plot. Selecting any point will remove it from the calibration. "Clear Data" simply removes all calibration data from the GUI memory.

The "RF ON" dropdown menu contains selections relating to the managing of RF On data. Selecting "Remove Last Point" will delete the most recent T-Map from the GUI memory. Selecting "Clear Data" will delete all RF On T-Maps from the GUI memory.

The “Plot” dropdown menu has selections for working with the T-Map plot at the bottom of the GUI. Selecting “Remove Broken Resistor” will bring up crosshairs on the GUI for selecting a point on the T-Map plot. Selecting a point removes it from the current T-Map as well as all future T-Maps taken or viewed during the test. This is useful because sometime resistors fail during a test and will register a false voltage which, in turn, throws off good data. “Plot Externally” enables the program to plot T-Maps in a separate window which contains the T-Map plot alone. This is useful because it is common practice to save screen shots of T-Map data in network notebooks for sharing and review. “Plot Bad Channels” plots the resistors on the T-Map axes that are known to be malfunctioning. This is used mainly in the mechanical maintenance of the system.

The “Specialized Commands” dropdown menu contains special commands such as “Reset Take Data Button” and “Make Movie of Tmaps”. The “Reset Take Data Button” re-enables the “Take Data” button. This is useful because the “Take Data” button sometimes gets stuck inactive in the program. This usually occurs when an error in taking a T-Map makes us have to halt the data acquisition process. “Make Movie of Tmaps” takes a selection of T-Maps with increasing field values and makes a movie showing the progressive heating of different hotspots.

Miscellaneous Functions

The GUI also has some additional functions that have not yet been discussed. These are as follows: “Save Folder”, “# to Take”, “Current Tmap #”, “Current Module”.

The “Save Folder” box enables the user to select the folder that he wants to save all the data taken during the test. This folder must be located in the source folder of the GUI in order for the GUI to find it. This is used for archiving all data taken during a test.

The “# to Take” box allows the user to select how many T-Maps he would like to take at any point. This is useful for ensuring accuracy in measurement of temperature at different electric field values.

“Current Tmap #” tells the user where the program is in the process of taking multiple T-Maps. Taking multiple T-Maps takes more time than a single T-Map. Therefore, knowing at what point the program is in in the process is a useful feature.

“Current Module” informs the user as to the progress of the program through the data acquisition process. The program has to run through 24 modules in order to obtain all the data. When the program completes the process, the module number in the box is replaced with “Finished”.

Possible Functions to Add in the Future

A trial run of this program revealed some possible additional functions that would be useful if incorporated in the future. Here, we will give a brief over view of a few of them.

From the trial run, it was shown that a useful feature would be the ability to select a resistor on the T-Map plot and have the program return the temperature of that single resistor. This would help to more clearly illustrate the temperature difference between adjacent portions of the cavity. Another possibility would be to have a section that would check to see if all the necessary data for taking an RF On T-Map had been acquired. This would eliminate the sole reliance on user memory to remember the previous data collected. In addition, it would be beneficial to incorporate a plot to automatically measure and record the bath temperature throughout the test. This would help in monitoring the Helium level of the test pit as well as provide a visual aid for calibration.

CONCLUSION

A GUI was designed and written for the sole purpose of expediting the data acquisition process by bringing all necessary data taking functions together in one place. This program enables a user to easily acquire calibration, RF Off, and RF On data by selecting GUI buttons rather than calling Matlab functions via command line. This greatly decreases the amount of time needed per test as well makes the testing process more understandable for new users.

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REFERENCES

[1] Dan Gonnella, Sam Posen, and Matthias Liepe, “Quench Studies of a Superconducting RF Cavity”, CLASSE, Cornell University, 2012.