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T-MAPPING DIAGNOSTIC SYSTEM FOR VERTICAL TEST OF SHINE SUPERCONDUCTING CAVITY*

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Abstract

T-mapping diagnostic system is an indirect method to detect the internal surface of superconducting cavity during vertical testing. When superconducting cavity is powered, T-Mapping can detect the thermal instability and thermal collapse caused by defects. The goal of the project is to develop temperature detection devices that are highly accurate and easy to install. The development of the equipment plays a supporting role in the production of superconducting cavity, and can intuitively feedback the defects in the machining assembly, which is conducive to the improvement of the processing technology.

INTRODUCTION

SHINE project requires the development of 500 superconducting cavities. The target acceleration gradient of the superconducting cavity is 16 MV/m. Due to gradient decay in the process of manufacturing and assembly, the superconducting cavity is required to exhibit a better acceleration gradient during RF vertical testing [1]. The implementation of high acceleration gradient requires good internal surface smoothness and puts forward strict requirements for surface treatment, such as surface treatment mainly includes high purity water cleaning, electric polishing, chemical polishing, etc. [2]. However, the existing detection method is only endoscope scanning to detect the flatness of the internal surface. Because this method consumes a lot of time to scan the superconducting cavity as a whole and reduces the production efficiency, it is necessary to develop a set of equipment for defect detection that is well positioned and easy to install.

One of the main sources of performance constraints in superconducting cavities is tiny imperfections such as scratches, spikes, dust particles, etc., ranging in size from a few μm to a few hundred μm, mostly occurring in equatorial locations. Surface defects cause a sharp impact on the critical magnetic field during RF testing, releasing joule heat and resulting in Quench [2].

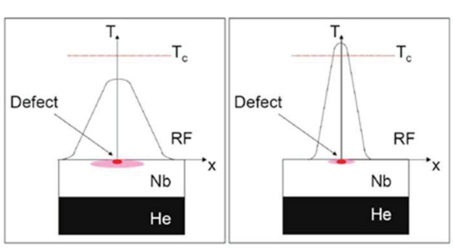

Figure 1: Schematic diagram of quench heat distribution in niobium cavity.

As shown in Fig 1：Quench does not occur when the defect causes Joule heat <Tc value, when Joule heat >Tc value, loss of superconductivity, dissipation of Joule heat stored energy in the superconducting cavity, resulting in thermal collapse.

The T-Mapping diagnostic system is a good test method [3]. During vertical testing of the superconducting cavity, Quench caused by uneven field construction at the flaw location when RF power is fed into the cavity is detected. The detection theory of T-Mapping is to distribute the temperature probe array on the external surface of the superconducting cavity, and make use of the local temperature rise caused by Quench and the change of the resistance of the NTC temperature probe to timely and effectively feedback the temperature change, so as to clear-ly and vividly represent the corresponding position information of the thermal collapse.

T-MAPPING DESIGN

The development of T-Mapping diagnostic system can accurately detect the quality of superconducting cavity. Its main advantages are: high precision (high spatial resolution), time resolution, temperature resolution (temperature probe can be sensitive to temperature changes caused by thermal collapse), low heat leakage rate (reduce the burden on low temperature), less signal cables, easy installation and easy operation.

In order to achieve the above characteristics to ensure that each cm^2 of the outer surface of the superconducting cavity can be distributed to the probe, as well as the matching relationship with the device logic, a Cell requires 1024 temperature probes to achieve high precision spatial resolution (The 1024 probes were distributed across 16 strips, using a cascading model). Because the large number of probes will cause the signal cable to produce heat leakage in Dewar, the extra burden on low temperature, so it is necessary to reduce the number of signal cables, choose to use COMS multiplexing switch to control the working time of the temperature probe, the use of multiple switches to save the number of external flanges, reduce the use of space, At the same time, the COMS multiplex switch can be used well in the low temperature area, and the slight change of electrical characteristics will not affect the test accuracy. The system block diagram is shown in Fig 2.

The temperature resistance of T-Mapping uses a low-cost ruthenium oxide negative temperature coefficient resistor. The temperature probe and multiplex switch are welded to an array composed of polyimide FPC soft board by a complex logic combination. The natural bend-able property can be used to efficiently fit with the external surface of the superconducting cavity and more effectively detect temperature anomalies.

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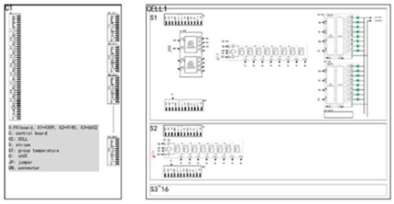

Figure 2: Block diagram of diagnostic system.

FUNCTIONAL TEST

The functional test includes circuit logic verification, low temperature probe test and signal noise accuracy.

Circuit Logic Verification

Each strip uses 64 temperature probes, 8 controlled by each multiplexing switch, and 8 modules per strip. In order to test readability, 1kΩ is used in groups 6 and 8 of the 8 groups, and 10kΩ is used in the others. Clock frequency 10kHz, power supply 5uA. The data acquisition results are shown in Fig 3. The 50mV data is the probe data of 10kΩ, and the 5mV data is the probe data of 1kΩ.

Figure 3: T-Mapping Single strip logical function test diagram.

After the implementation of the single strip test, it is necessary to consider the series of multiple strips. First, the series test of two strips is started. Also for the convenience of reading the test results, the resistance value of the second strip is changed (the resistance value of the probes in the fourth and eighth groups is changed to 15kΩ, and the others are used to 10kΩ), which is conducive to the resolution. There are some probe breaks (effective amplitude equal to 1V) and probe short circuits (effective amplitude equal to 0V) in the data, and the test results are shown in Fig 4.

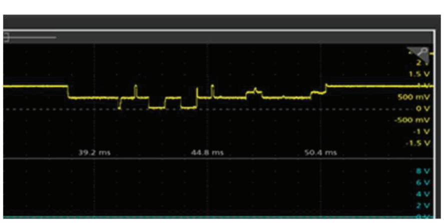

Figure 4: T-Mapping Dual strip series logical function test diagram.

A single cell with 16 strips is connected in series for normal temperature test. Software labview is used to write the operation interface, which contains the filling of clock parameters and current drive parameters. The clock is used at 5kHz, the sampling rate is used at 50kHz, and the test platform is shown in Fig 5.

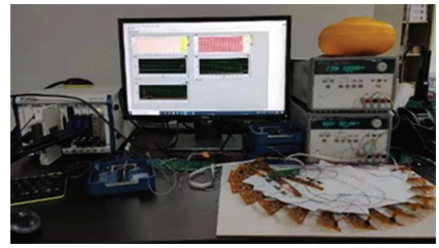

Figure 5: T-Mapping experiment test platform.

Low Temperature Probe Test

The reaction sensitivity of the temperature probe in the 2K temperature zone determines whether the quench of the superconducting cavity can be captured, so it is necessary to measure the resistance change of the temperature probe caused by a small temperature change. As shown in Fig 6, at 2K temperature, the resistance value of the temperature probe increases with the decrease of the power supply current, so the optimal use current is determined to be 5uA.

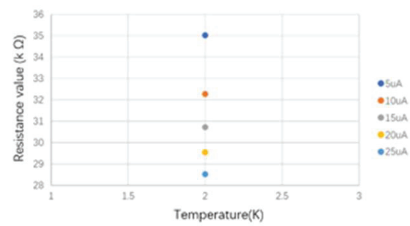

Figure 6: Relation between supply current I and resistance at 2K temperature.

As shown in Fig 7, the resistance value change of the measured temperature resistance from 100K to 2K can clearly show that the resistance value of the temperature probe increases sharply between 10K and 2K, which accords with the TC value change range after Quench of the niobium superconducting cavity.

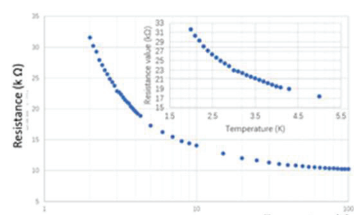

Figure 7: Relationship between resistance and temperature.

Signal Noise Accuracy

During the test, the sampling rate is 10 times of the operating frequency of the temperature probe (50kHz), 100 times of storage and collection, and the average value of each data point is taken. The difference between the current collected value and the average value (Delta value) is drawn with the accuracy of less than 6mV as shown in Fig 8. The change of delta value reflects the local temperature change of each temperature test point by T-Mapping.

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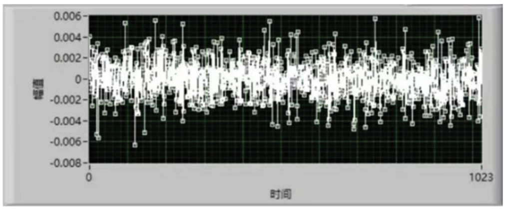

Figure 8: Signal and noise accuracy of T-Mapping diagnostic system.

RF TEST AND T-MAPPING TEST RESULTS

The mounting bracket is designed for single cell cavity T-Mapping. This design uses the elastic force of Z-shaped copper profile to make the temperature probe have good contact with the outer surface of the superconducting cavity. The maximum contact with the outer surface of the superconducting cavity is conducive to the temperature probe to make the best response to temperature changes. To ensure that the test was successfully completed, multiple signal checks were carried out from the installation stage until the superconducting cavity was placed in the vertical Dewar. The installation is shown in Fig 9.

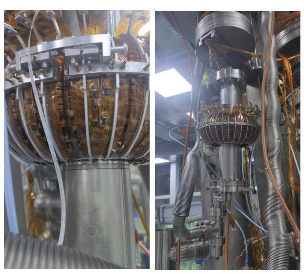

Figure 9: A T-Mapping diagnostic system is installed in a single cell superconducting cavity.

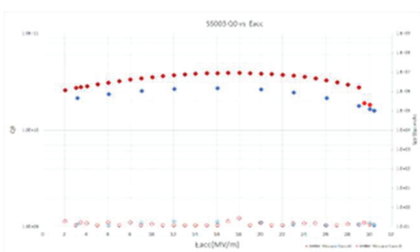

Figure 10: Single cell superconducting cavity RF test quality factor Q_0 and E_{acc} diagram.

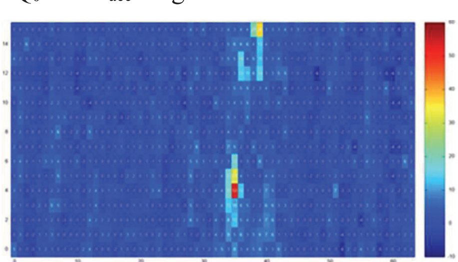

Figure 11: The T-Mapping diagnostic system detects the Quench of the superconducting cavity.

In the RF test of the single cell superconducting cavity in this test, the first Quench occurs at 29MV/m, as shown in Fig 10. At the same time, the T-Mapping diagnostic system detects two quench locations, where the temperature rises by 1.5K and 0.8K respectively, as shown in Fig 11. After the test is completed, the superconducting cavity is removed from the vertical Dewar and corresponding positions are marked, as shown in Fig 12. Endoscopic scanning is performed, and the scanning results are shown in Fig 13. The scanning results show that the two defects have obvious burrs and grain boundary textures, so it can be proved that the T-Mapping diagnostic equipment meets the ability of detecting Quench of the superconducting cavity.

Figure 12: Endoscope scanning of superconducting cavity defect location.

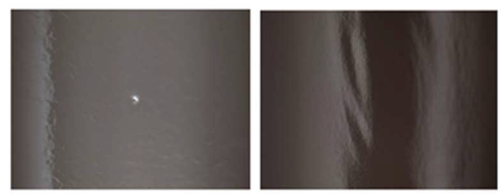

Figure 13: Results of endoscope scanning of defect location in superconducting cavity.

CONCLUSION

Through the design introduction and logical function verification of T-mapping diagnosis system, the Quench location detection is realized by T-mapping in RF test of single cell superconducting cavity.

The next step is to carry out T-Mapping integral fabrication, which can accurately locate local temperature changes caused by surface defects in the 9cell superconducting cavity during RF testing.

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