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Experience in Design, Construction and Application of A Rotating T-R Mapping System in Superfluid He for TESLA 9-Cell Cavities

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ABSTRACT

The rotating temperature and radiation (T-R) mapping system has been developed and successfully identified & diagnosed serious quenches and field emissions in several TESLA superconducting 9-cell cavities in superfluid LHe. More than 10,000 spots on a cavity surface can be analysed in one turn with 5^{o} stepping. The T-R Mapping has played a significant role in understading cavity processing. We introduce briefly the experience in design and construction of the T-R Mapping, and also discussed how to effectively apply the system in the cavity diognostic tests.

INTRODUCTION

1. Main Obstacles of High Gradient Cavities

Thermal breakdown (TB or quench) and field emission (FE) are still the main obstacles preventing SRF cavities from confidently reaching Eacc = 25 MV/m (TESLA's goal) from existing operating levels of 5-10 MV/m[1,2,3,4]. Most of the FE sources and TB defects on the inner RF surfaces of cavities were found to be submicro-sizes and activated or detected only at high RF fields while cavities are in a superconducting state. It is impossible to directly observe the quench and FE on the inner surface of cavities during RF operation. Therefore, the main approach to understanding the quench and FE of cavities is to study the hot spots and X-rays (induced by impacting FE electrons) generated on cavity surfaces.

2. Rotating T-R Mapping System

The Rotating T-R mapping system developed at DESY for TESLA 9-cell cavities combines measurements of temperature (T) & radiation (R) and employs specially invented surface scanning thermometers in He II. It gives information on both heating and x-rays for understanding the dynamic progress of cavity processing. There are several technical challenges that we have faced in developing the instrument.

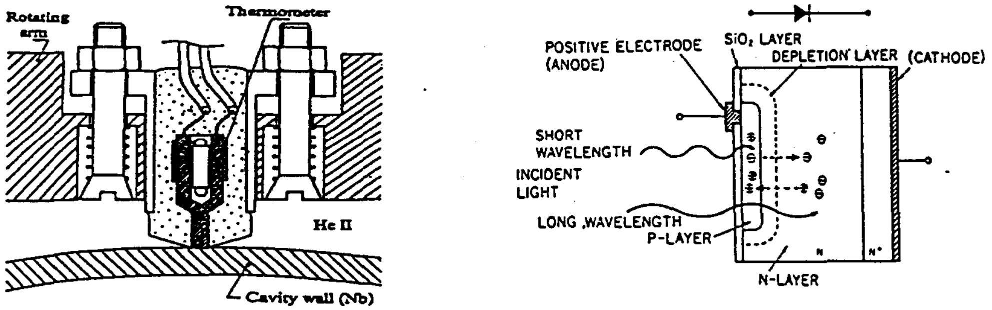

Figure 1. (A) Cross section of a HeII surface scanning thermometer. (B) cross section of a photodiode.

(1) Fixed contacts and use of grease as bounding agent to enhance thermal contact between thermometer and surface being measured are essential to reach a high efficiency (particularly, in He II). In a rotating system, neither fixed contact nor grease can be applied.

(2) Due to TESLA cavity structure, thermometers can not reach the high risk areas of FE at cavity irises. A combined measurement of T & R was required.

(3) Assuring satisfaction of 3-dimension tolerances at all moving contact points is a challenge due to the large cell number of TESLA cavity and thight space of testing cryostat.

(4) To rotate a large number of measuring cables in He II while the mapping turns.

(5) A fast data acquisition system was also needed to trace the dynamic progress.

TECHNOLOGY DEVELOPMENT

1. Surface Scanning Thermometer and Photodiode

The surface thermometer is shown in Fig. 1(A). The sensitive part is an Allen-Bradley carbon resistor (100 Ohm, 1/8 W) housed in a silver block with a sensor tip of 1 mm diameter for the thermal contact to the cavity surface. This housing is thermally insulated from the surrounding He II by an epoxy envelope (Stycast) moulded into a bronze piece which allows the sensor to be mounted in the rotating thermometric arm. The thermometer's tip must present a good contact with the cavity wall when scanning.

The complementary calibration test was performed at different spring pressures and heat fluxes in He II and subcooled He (2.3K and one bar). In the case of He II, the thermal efficiency is heater power dependant. Its thermal coefficient can be only 5 % at low heat flux and as high as 50-70 % at high heat flux in comparison with thermometers using grease as bounding agent. The detailed results are presented in another paper [5].

Commercial PIN silicon/S 1223-01 photodiodes are used as x-ray detectors in the mapping because of their small size (3mm x ϕ10 mm) and fast response. A simplified photodiode cross-section is shown in Fig. 1(B).

2. Rotating T-R Arms

As shown in Fig. 2, 14 thermometers and 4 photodiodes are mounted in each arm which is precisely machined to have the same curved surface as the cavity cell. Due to the reinforced structure of TESLA cavity, the thermometers can not directly touch the surfaces

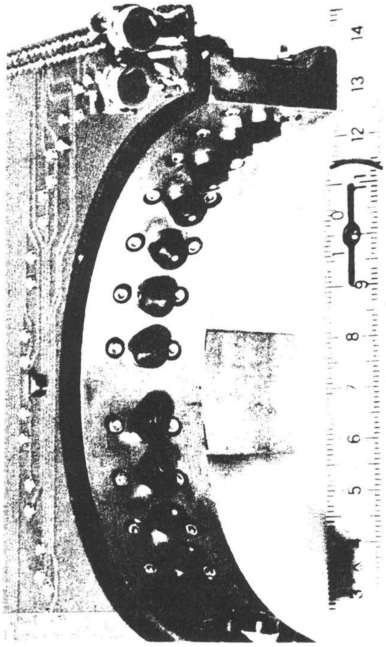

Figure 2. A picture of the rotating arm.

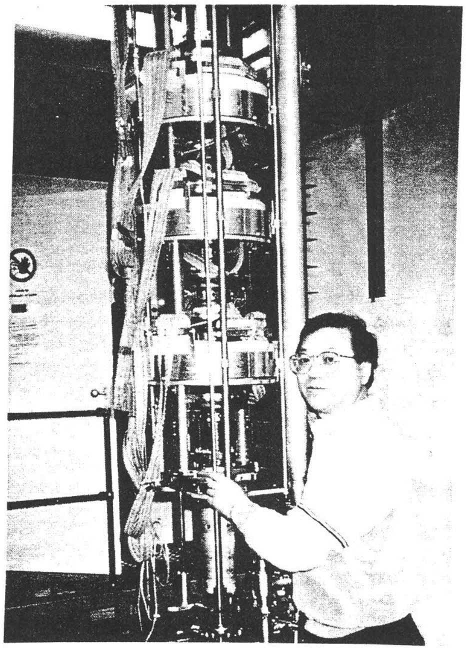

Figure 3. A picture of the T-R mapping system.

of the cavity iris. Considering that the electrical fields reach maximum at the iris, 4 photodiodes are located in the end of each arm to monitor FE induced X-rays while 14 thermometers are used to monitor the temperatures in the entire region between the irises of each cell. Two springs located inside two holes in the body of the rotating arm are used to adjust the contact pressure. A printed circuit board is mounted on the side of the arm. All cables for the sensors are fed through a device, called moving adapter device or "pancakes", and then connected to a feedthrough on the cryostat. Fig. 3 is the T-R mapping system.

3. Driving and Suspension Frame (DSF)

A total of 116 surface scanning thermometers (14x7 + 9x2) and 32 photodiodes are assembled into 9 rotating arms which are mounted in the DSF as shown in Fig. 4 (A). The most important consideration in the mechanical design is to assure the three dimension tolerance between the cavity surface and the tips of the 116 thermometers over the entire cavity surface (i.e. more than 10,000 points) are within ±1mm. The DSF has two centering rings. The centre of each centering ring is adjustable to allow the axis of DSF as close to the axis of the cavity cells as possible. The rotating frame is suspended on two disks made of low friction materials. These structures enable the DSF in superfluid He to gently turn the arms around the cavity and uniformly press the thermometers (through the spring-holder structure, force=100 g per thermometer) against the cavity surfaces. Driven by a computer-controlled stepping motor, the T-R arms can be automatically turned to any position on the cavity surface with a accuracy of ±3 degree.

4. Moving Adapter Device (MAD)

A large number of electronic measuring cables have to move with the rotating arms when the T-R mapping rotates. These cables become very rigid in LHe. A moving adapter device was successfully designed to overcome the problem as shown in Fig. 4 (B). Each pancake has two rings. The inner ring is mounted in the moving DSF and turns with the DSF around the cavity. Its outer ring is fixed with cavity supports. One end of each 64-wire-cable is connected to the inner moving ring and the cables make 9 turns around the inner ring of the MAD while the other end of the cables connects to the outer fixed ring.

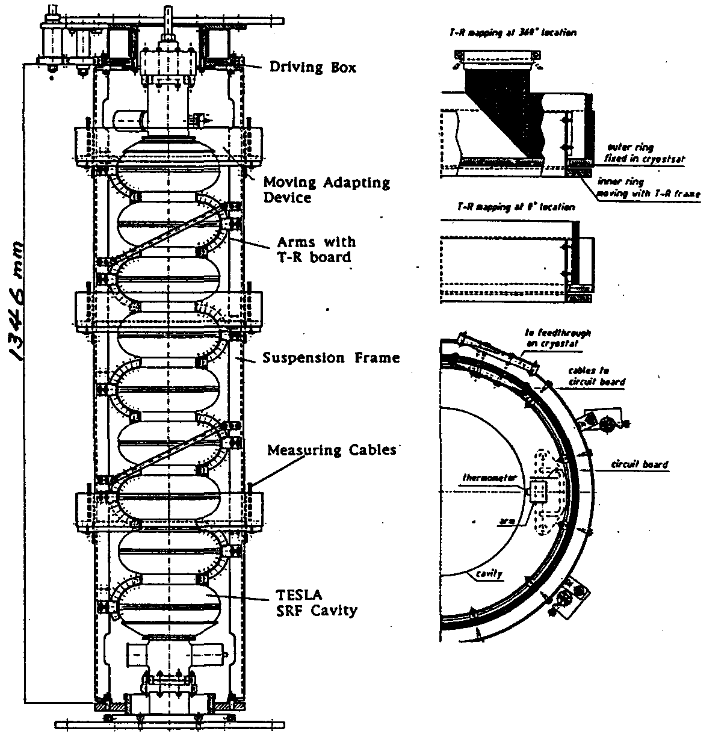

Figure 4. Schematic cross sections of the DSF and MAD.

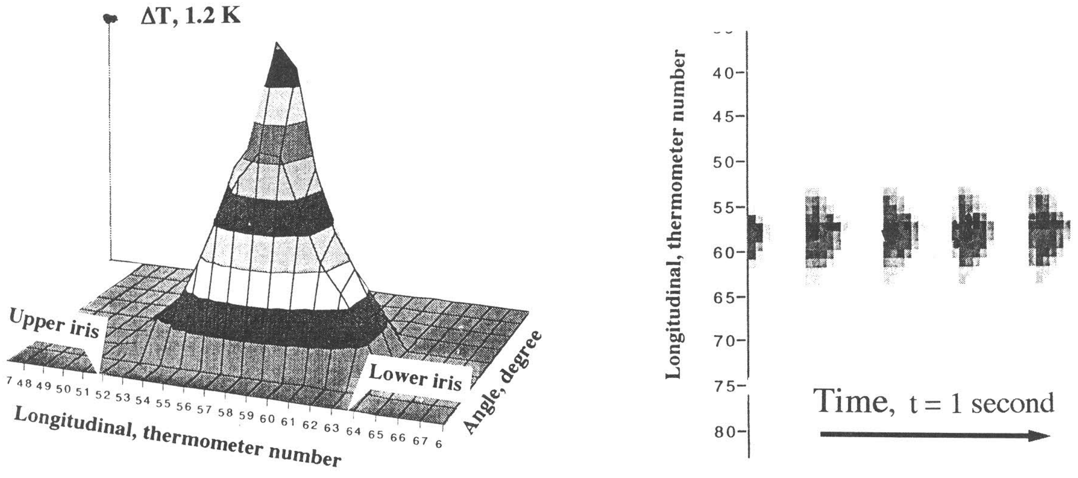

Figure 5. (A) The heated area due to quench. (B) ΔT as a function of time longitudinally through the quench origin during self-pulse quench & recovery.

When the DSF turns 360° around the cavity, the cables only make relatively short movement inside the MAD.

5. Fast Data Acquisition and Test Procedure

Maps can be taken with auto-scanning of entire cavity surface or scanning with time in a fixed position. The temperature change ΔT is made by comparison of measurements of RF power on and off (also, the bath temperature changes are subtracted from the total ΔT). The effective resolution of temperature measurement is less than 5 mK. One longitudinal measurement of all cell in a fixed angular position can be completed in less than 10 ms (less than 1 ms for one cell). All data taken, control and display are performed through a multiplexer by a Sun-station computer with a LabView™ language program[6].

APPLICATIONS OF THE T-R MAPPING

The T-R mapping has been successfully employed in the diagnostic testing of TESLA SRF cavities. We will briefly introduce how to detect the quench location, identify the FE heating area & its origin, and carry out the analyses of heat intensity and quench dynamics.

1. Detection & Analysis of Thermal Breakdown

The TESLA 9-cell cavity (D-6) has been heat treated with Ti-purification at 1400° C for 4 hrs and a test sample has a RRR of about 500. It finally reached Eacc = 12.5 MV/m and was limited only by a quench. While scanning the entire surfaces of the 9-cell cavity, the T-mapping located a strong heating area centred at the equator of the cell-5 over 10 thermometers between the 10° to 50° longitude as shown in Fig. 5 (A). To further study the TB event, we relocated the T-R arm to the heating area, moved it by 5° angular steps and found the hottest spot to be near 35°. Finally we moved the arms to 35°, turned on the RF power in CW mode and observed continuing quenches and recoveries of the cavity as shown in Fig 5 (B). Optical observation after test showed a surface irregularity on the inner surface in the area of cell-5. A detailed analysis is presented in another paper [7].

2. Identification of FE Heating Area and Emitter Location

The TESLA prototype 9-cell was initially limited by thermal breakdown at about Eacc = 10 MV/m. After heat treatment at 1400° C with Ti-purification, we then removed 80 μm of material from the inner RF surface and 30 μm from outer side by chemistry, followed by

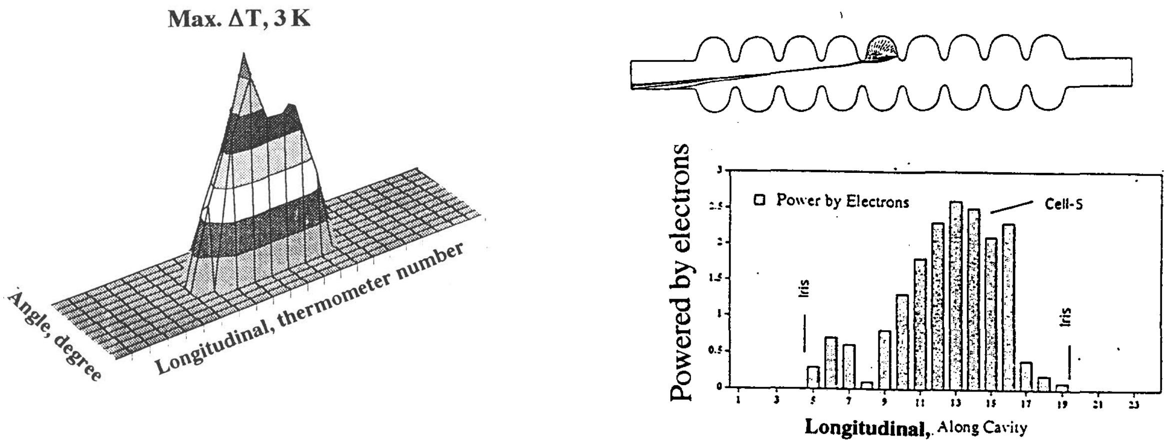

Figure 6. (A) FE heating area responsible for the Q dropping and limit of Eacc

(B) FE electron trajectories of the emitter located at So = 8 cm.

high pressure rinsing. It finally limited by heavy FE at Eacc = 21 MV/m.

The T-map, Fig. 6(A) indicates an important heated region delimited by 12 thermometers (#53 to #64) centred close to the equator of the 5th cell, between the 130^{0} to 180^{0} angles. Outside of this region the heating is very low. The ΔT value in this region is 100mK - 3.3K. The integration of the product of Kapitza conductance and ΔT over the heated region leads to a total heat power going to He bath: Q~100 W. This value is consistent with the RF measurements of the experiment. However, the measured hot spots by FE only indicate the landing of impacting FE electrons, but not the emitter. The simulation of FE electron trajectories indicated that a emiter at location S=8 cm of cell-5 with emiter area $Se=1x10^{-13}$ m^{2} and $\beta = 400$ at the same Eacc will generate a similar heating profile to the measured heating areas, as shown in Fig. 6(B).

3. Information from X-Ray Maps

A large number of radiation maps of X-rays induced by FE electrons were also observed. In general, information from X-ray maps are in consistent with that obtained from T-maps. Futher analysis of these maps will be performed later.

CONCLUSION

The T-R mapping system has been successfully employed to analyse the FE and TB in the TESLA 9-cell SRF cavities. The information learned from T-R maps has played a significant roles in understanding the cavity processing.

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