REVIEW OF RESULTS FROM TEMPERATURE MAPPING AND SUBSEQUENT CAVITY INSPECTION

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Abstract

Temperature mapping systems are used since many years to locate performance limiting defects on superconducting cavities during the RF measurements. In order to investigate the nature of such defects non-destructive optical inspection systems are in use.

Due to better quality control of the niobium material and welds as well as the preparation steps the limitations could be pushed up to gradients higher than 30MV/m. According to the higher gradients and therefore smaller defects new methods of detecting and visual inspection have been developed in the recent past.

This paper gives an overview of the recent developments of such systems and findings on the RF surfaces of superconducting cavities.

INTRODUCTION

Localisation and characterisation of field limiting defects is necessary in order to improve the production and processing of superconducting (SC) cavities. Therefore different T-mapping systems using carbon composition resistors are in use since many years. Recently a new diode based T-mapping was developed. For SC cavities cooled in He II a defect location system with oscillating superleak transducers was developed. Visual inspection systems for identification of the defects are improved for higher resolution and ability to estimate the shape.

The paper will describe the systems now in use at different laboratories. Typical defects at different gradient limitation levels are shown.

DEFECT LOCATION SYSTEMS

Carbon composition resistors such as Allen Bradley are in use at different laboratories in rotating and fix temperature mapping systems (t-map) for localising the thermal breakdown as well as investigating the thermal loss distribution over the superconducting resonator at 4 K [1]. In case the resonator is cooled in a super fluid helium bath additional precaution must be taken in order to isolate the temperature sensor from the HeII bath. Therefore the carbon resistor is housed in an epoxy case as described in [2] and [3] (see Fig. 1). The good thermal contact is provided by Apiezon vacuum grease between the sensor and the cavity surface.

A newer development of a diode based fixed t-map system comes from Fermilab [4]. The advantage of this system is the small size of the diodes (1mmx1mm) and future availability of the wide spread used cryogenic sensors (1N4148 diode).

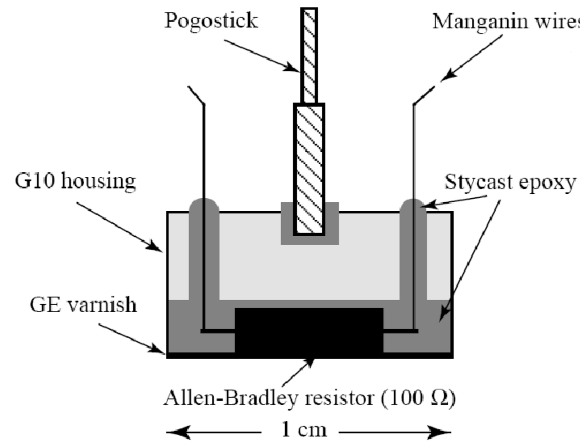

Figure 1: Carbon composite resistor housed in an epoxy case for use in t-maps blow Lambda point

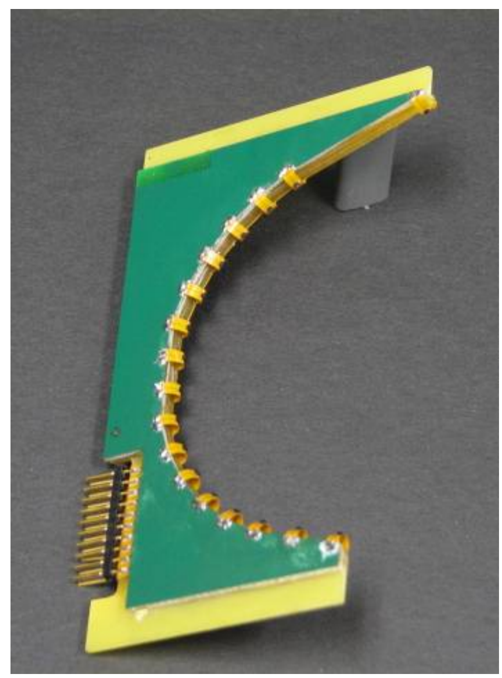

Figure 2: 16 diodes mounted at a flex Kapton foil and assembled to a printed circuit board. 60 boards with 16 diodes each will be assembled around one cell. Consequently the t-map consists of 960 diodes per cell.

This system can be used at one cell and 9 cell SC cavities. The diode is mounted on a flex Kapton foil and assembled to a G10 printed circuit board (Fig. 2). The diodes are configured as a multiplexed system without a separate multiplexer. For a 9 cell cavity as much as 8640 diodes are installed. The resolution is about 1cmx1cm.

A new acoustic defect location system was developed at Cornell, Newman Lab [5]. When operating the cavities below the lambda point the second sound wave originated from the quench location is used to triangulate on the quench-spot. Only a few (e.g. 8 at a 9 cell cavity) oscillating superleak transducers (OST) have to be placed around the cavity. The advantages are the simple fabrication (Fig. 3) and easy assembly of the OSTs near the cavity. Also there is no reduction of the active cooling surface of the cavity.

Figure 3: The oscillating superleak transducer components are shown: in the middle the isolated electrode with the sensor body, lower right the filter membrane and lower left the assembly ring.

INSPECTION SYSTEMS

In addition to the traditionally used optical systems like borecopes and long distance microscopes now a new camera based system was developed at KEK and Kyoto University [6]. It consists of a CCD camera with a resolution of 3.7 µm per pixel. A variable illumination system allows measuring the height or depth of a defect (Fig. 4).

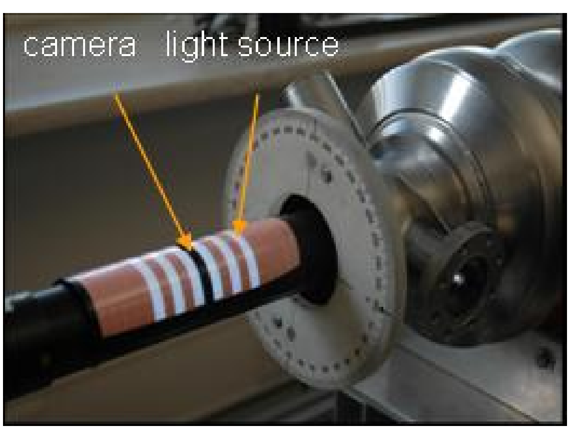

Figure 4: The head of the inspection system developed at KEK and Kyoto University houses a camera and the variable illumination system.

For further investigation of the defects samples can be cut out of the cavity. The shape of the defect can be investigated by optical microscope (resolution: >1 µm), 3D microscope and SEM (resolution: a few nm). At many labs replications are taken from the defect in case of pits. On these replications the shape can be measured by a profilometer.

There are several methods to investigate the composition of the defects like e.g. EDX and Auger.

MEASUREMENT RESULTS

Results from DESY

With the use of a rotating t-map system at a low performing 9 cell cavity many defect locations measured in the different modes of the fundamental mode passband were found. Hence samples at the suspicious locations were cut out and investigated. Many defects could be identified [7]:

In the area of a hot spot at a 16MV/m quench several particles were found (Fig. 5). The size range is from 5 to 100µm. EDX analysis showed iron and carbon as the main elements.

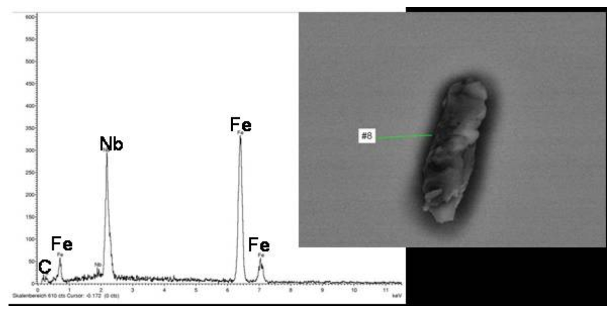

Figure 5: A particle of the size l = 10µm was analysed by EDX and found out of iron. It was limiting the cavity gradient at 16 MV/m.

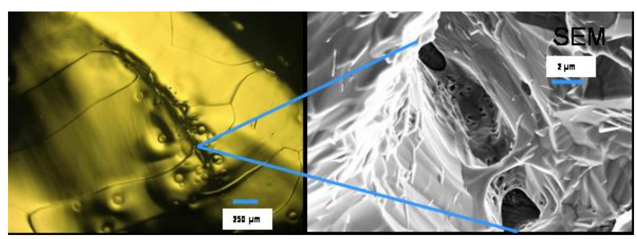

Figure 6: Along the grain boundaries in the equator weld many holes and pits were found limiting the cavity gradient to 16 MV/m. At right the SEM picture shows a hole of 10 µm length.

Many holes and pits were found along the grain boundaries in the equator weld at a different quench location (limit 16MV/m). The SEM pictures show sharp edges (Fig. 6). No foreign material could be identified by EDX and Auger. Some increased content of carbon was seen, but the suspicion is that this was introduced by the cutting procedure.

At a quench value of 23 MV/m a hole and a bump was identified at the equator weld (Fig. 7). Pictures taken by the Kyoto camera as well as the 3D microscope show a hole with a deepness of about 200µm. No foreign material was found.

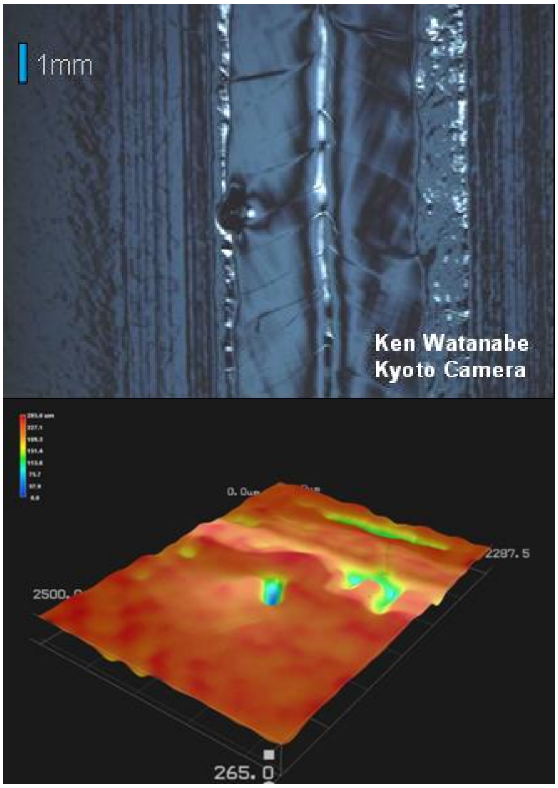

Figure 7: A hole as the identified defect at the equator limiting the cavity at 23 MV/m. The upper picture is taken by the Kyoto camera whereas the lower picture shows the same defect with a 3D microscope. The defect size is about 1 mm.

In all quench locations identified by the t-map system we were able to find conspicuous defects at this level of limitations below 25MV/m.

Results from Cornell University

At 1 cell measurements the quench was localized with a t-map system, but with the optical inspection no suspicious spot could be identified.

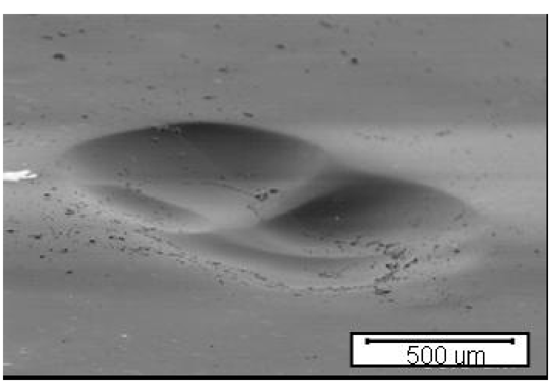

Figure 8: Quench causing defect only seen with the SEM, but not with the camera inspection system.

After cutting the cell (at Cornell with a pipe cutter, a very clean and efficient method) and investigating the location under the SEM many interesting details were found. Fig. 8 shows a pit only seen by SEM [8].

The quenches at the 9 cell cavities are localized by 8 OSTs arranged around the cavity. With the help of the long distance microscope many defects could be identified (Fig. 9). These defects cause quenches at magnetic fields ranging from 700 Oe to 1250 Oe.

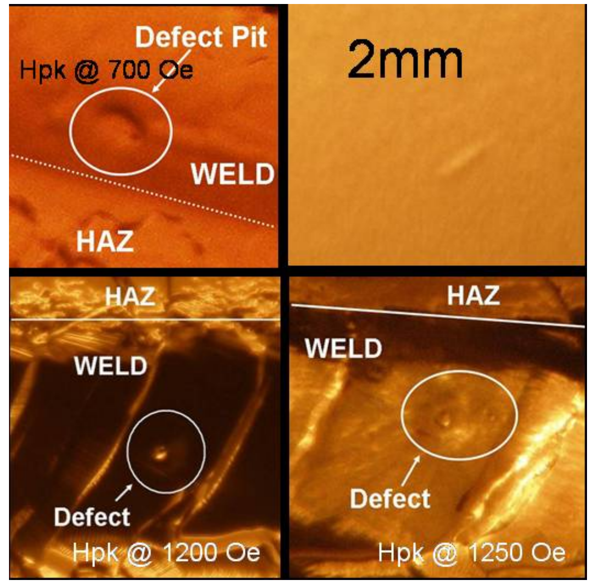

Figure 9: Defects localized by the OSTs and pictures taken by the long distant microscope. Limitation magnetic field ranges from 700 Oe to 1250 Oe.

Results from KEK

In order to find the cause of the limiting defects an extensive inspection during the whole fabricating process together with consequent RF measurements and quench localization was done [10]. Two cavities have been inspected near (±15 mm) and on the equator weld with the help of the Kyoto camera:

- before dumbbell welding
- cavity as received
- after pre EP
- after 100 m EP
- after annealing
- after final EP
- after vert. test + T-map

Many suspicious spots were found before second EP:

- typical pits:
  - diameter: 200 - 500 µm
  - depth: 10 - 30 µm
- typical bumps:
  - diameter: 800 µm
  - height: 50 µm

During this inspection many suspicious spots were observed on the surface even in the dumbbells stage. The subsequent cold RF measurements did not show heating and field limitations at these previously identified spots.

Fig. 10 shows the equator weld area where the heating was localized at 33 MV/m [11]. On the upper picture a non uniformity of the weld can be seen.

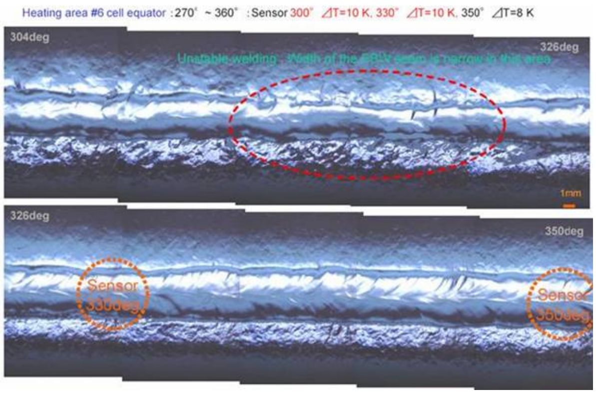

Figure 10: The area of a quench at 33 MV/m at the equator weld is shown. On the lower picture the location of the temperature sensors is indicated. On the upper part the only suspicious spot in this area is shown: a non uniformity of the weld.

DISCUSSION

Doe to the very advanced fabrication and processing techniques we are able to regularly reach accelerating gradients above 25MV/m [12]. Simulations have shown that the breakdown field scales with the defect size. At gradients of E = 30MV/m respectively H_{pk} = 130 mT (for a TESLA shape cavity) the calculated defect size is in the range of 30 µm (when the niobium has a RRR of 300 and the particle is Tantalum like) [13]. The tools to identify defects of this size are available. The KEK surface investigation during fabrication and after the 2K RF test has shown that many defect like irregularities can be found. Most of them are pits and bumps. But up to now it is difficult to classify these defects and draw predictions on the limiting gradient and effect.

CONCLUSION

Over the last years a big improvement in the cavity fabrication and treatment could be made. Foreign material as cause of limitations at gradients < 20 MV/m is the exception.

The systems like t-map and new acoustic defect location system are still of a high importance to find the quench location and abnormal heating zones.

New visual inspection systems are available and allow a resolution down to 3.7 µm per pixel. Many irregularities in the cavity RF surface are found with these systems during and after fabrication and treatment like pits, bumps and weld irregularities.

Some correlations are found with quench limitations at higher fields > 20 MV/m.

But often there is no correlation between suspicious pits and bumps and the quench location.

At gradient limitations in the range >30 MV/m defects are often not identified.

Both, the defect location systems during RF test as well as the visual inspection systems are essential to understand the limiting effects and to give the necessary feedback to the manufacturer of the cavities and also improve the processing.

Investigations have to be done on order to understand the limitation mechanism of the different defects at higher fields.

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