



SRF cavity surface inspection methods.

Bazyl Dmitry
NRNU MEPhI, Moscow

Supervisors: Aliaksandr Navitski, Yegor Tamashevich

FLA, DESY, Hamburg
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1. Introduction.

The most common application of superconducting RF is in particle accelerators. Accelerators typically use resonant RF cavities formed from or coated with superconducting materials. Electromagnetic fields are excited in the cavity by coupling in an RF source with an antenna. When the RF frequency fed by the antenna is the same as that of a cavity mode, the resonant fields build to high amplitudes. Charged particles passing through apertures in the cavity are then accelerated or decelerated by the electric fields and deflected by the magnetic fields. The resonant frequency driven in SRF cavities typically ranges from 200 MHz to 4 GHz, depending on the particle species to be accelerated.



Fig.1: SRF elliptical cavity.

Superconducting cavities have been in operation in accelerators for 40 years. In the last decade many installations in storage rings and linacs have been completed. Meanwhile, nearly 1 km of active cavity length is in operation in accelerators. Large-scale applications of superconducting radiofrequency systems are planned for future linear colliders and proton linacs.

Superconducting cavities have been proved to operate at higher gradient, lower AC power demand and more favorable beam dynamics conditions than comparable normal conducting resonators. The performance of the best single-cell cavities comes close to the intrinsic limitation of the superconducting material. Complete multicell structures with all auxiliaries (couplers, tuner, etc) lag behind in performance because of their complexity. [1]

The most common fabrication technology for such SRF cavities is to form thin walled (1–3 mm) shell components from high purity niobium sheets by stamping. These shell components are then welded together to form cavities. Several such finished products are pictured below.

When using superconducting RF cavities in particle accelerators, the electrical field level on the cavity axis should generally be as high as possible to most efficiently accelerate the beam passing through it.

One of the most important things about SRF cavities is to keep inner surface clean and smooth (when polished it looks like a mirror). There is some negative affects appears in this kind of cavities, for example quench, which can be caused even by one small piece of dust. That's why it's important to do some diagnostics to control surface condition. Some methods like Second-sound and T-mapping are used to detect position of the quench in the cavity.

2. Second-sound and T-mapping as quench localization systems.

Second sound is a phenomenon in which heat travels as a compressional wave (as sound does), rather than through diffusion.

The understanding of the origin of local thermal breakdown („quench“) in superconducting RF cavities is still a challenge. Such heat spots can be conveniently measured using the second sound in superfluid helium. This detection technique has been examined in several institutes. At DESY there are currently two cryostats for 4 cavities each. At all of the four inserts the second sound setup consisting of eighteen Oscillating Superleak Transducers (OSTs) is mounted. These are connected to amplifier electronics and the measured signals are fed into an ADC to be read. By calculation the location is derived from the measured propagation times. The present system is already in use on a regular basis

There is also another method called temperature-mapping (T-mapping), which is alternative possible way to get information about quench. Basically T-mapping system is a set of resistors connected to the walls, which can rotate around the cavity on 360 degrees. These resistors are sensitive to changes of the temperature of walls of a cavity. Essence of this method consists in the fact that when the quench appears, temperature rises on the wall of the cavity. Changing of resistance of the resistor has being monitored.

We can actually use these two methods to cross check the results and compare to each other. These two methods allow us to find almost exact position of quench. The quench region deduced with the mentioned techniques is then compared with results of optical inspection (which will be described later)

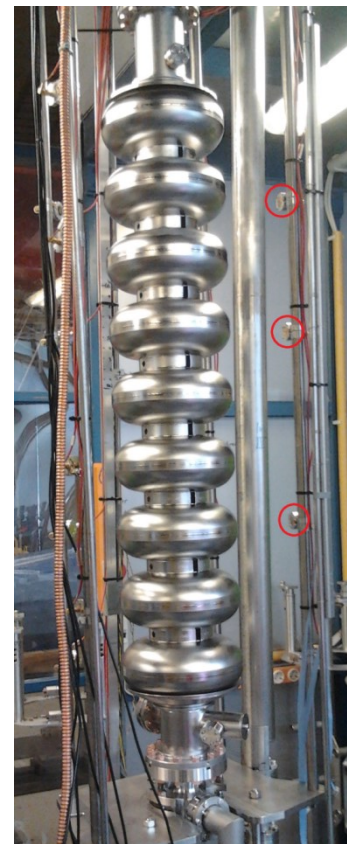


Fig. 2: Assembled second-sound system (OSTs pointed by red color)

3. OBACHT

At HiGrade lab–Optical Bench for Automated Cavity Inspection with High Resolution on Short Time Scales (OBACHT) (Figure 3) setup is used to inspect cavities optically.

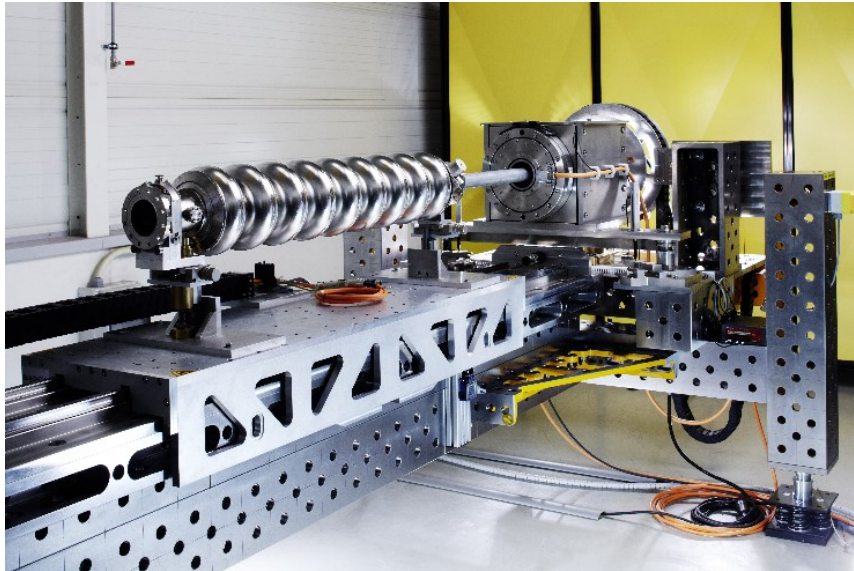


Fig. 3: OBACHT.

Schematic version of OBACHT system is shown on the picture below:

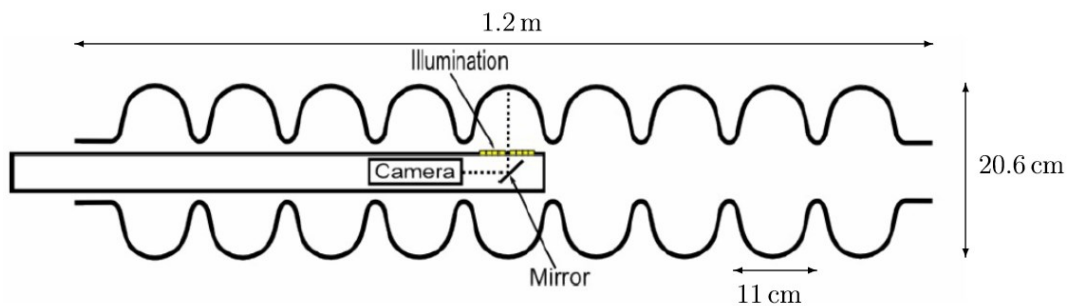


Fig. 4: The principle of the OBACHT system: The high-resolution camera is mounted in a tube which can be introduced into the 9-cell cavity. The focus is adjusted by longitudinal movements of the camera inside the tube. [3]

OBACHT basically gives us opportunity to get pictures of inside surface of the cavity. An example of what kind of pictures we have from this system is shown below:

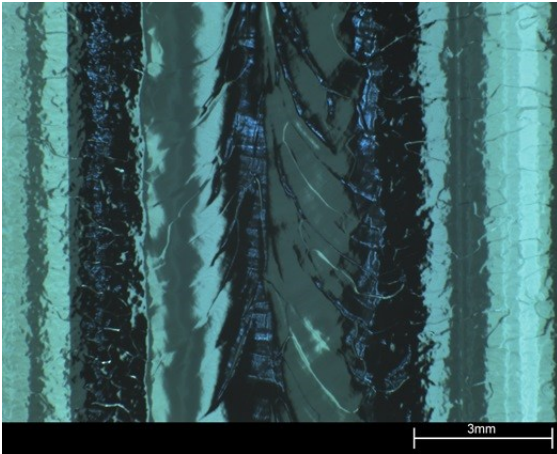


Fig. 5: Welding seam.

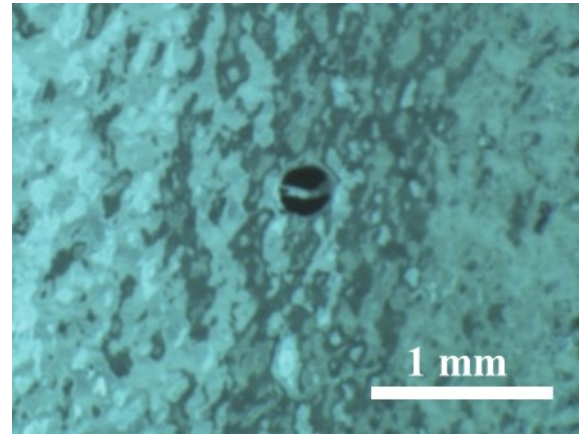


Fig. 6: Defect on the surface inside of the cavity.

In general, OBACHT allow us to find defects on the surface. We can only determine the size of the defect. In order to get know for example height of defect, silicone replicas are used. This method will be described further in this report.

4. Inspection of the defects inside of the cavities.

Cavities are welded on the equators of cells and irises. Because of that fact the welding seam and surrounding areas is affected by heating and this is the most “popular” place to find defects. Typical defects that can be found shown on the Figure 7 (OBACHT pictures):

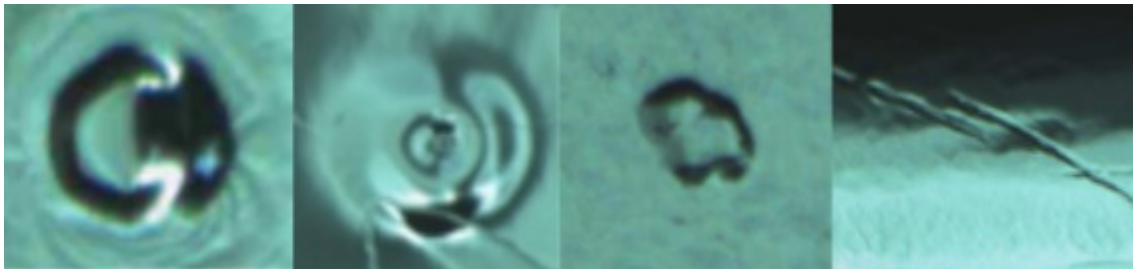


Fig. 7: Defect classification (from left to right): ‘cat eye’, etching pit, welding spatters, and scratch.

As it was mentioned before defects can cause thermal breakdown and field emission. In order to “treat” the surface of the cavity we need to know geometrical parameters of the defect. And as soon as OBACHT is only allows us to get information about the size of it, silicone replica method is used to get more information about defects (such as height/depth). So what we actually do is we put liquid silicone in defined position of the cavity, for example if we want to inspect welding seam and surroundings then we make it like it’s shown (schematically) on the Figure 8:

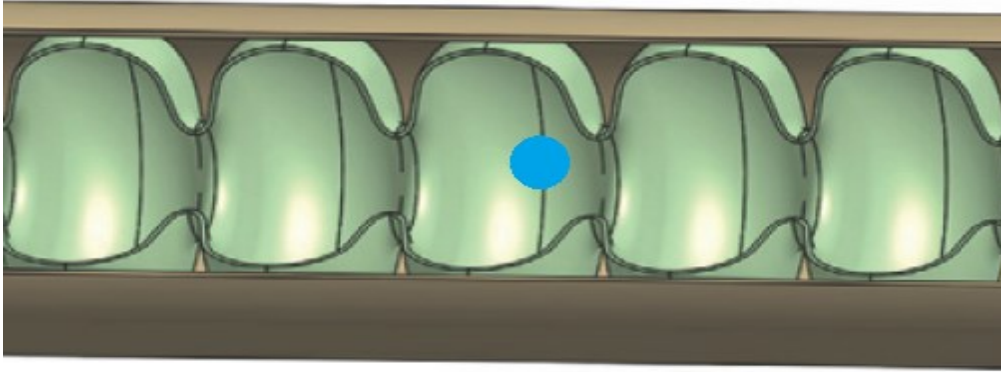


Fig. 8: Schematic version of making replicas.

After one hour, we can get silicone replica in a solid state and inspect it with microscope. An example of replica is shown on the Figure 9:

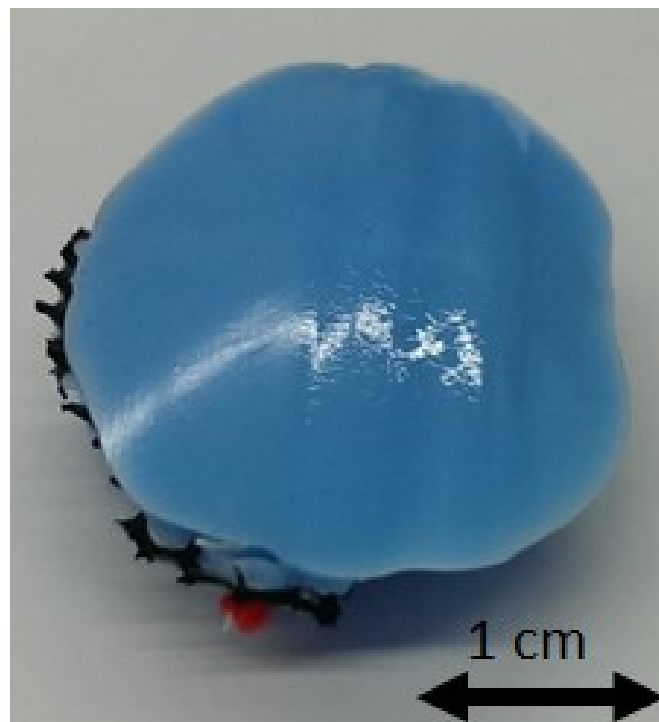


Fig. 9: Silicone replica made on the welding seam.

In order to prove validity of this method, small experiment has being made. Piece of inside surface in the region of welding seam were inspected with microscope to get a profile of welding seam. Results are presented below:

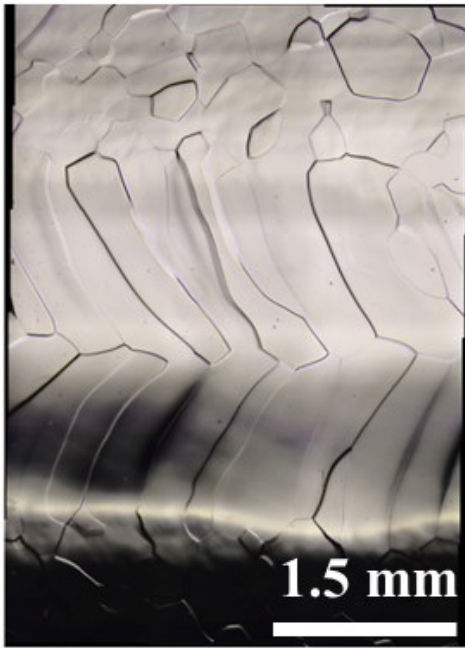


Fig. 10: Picture of Nb from microscope.

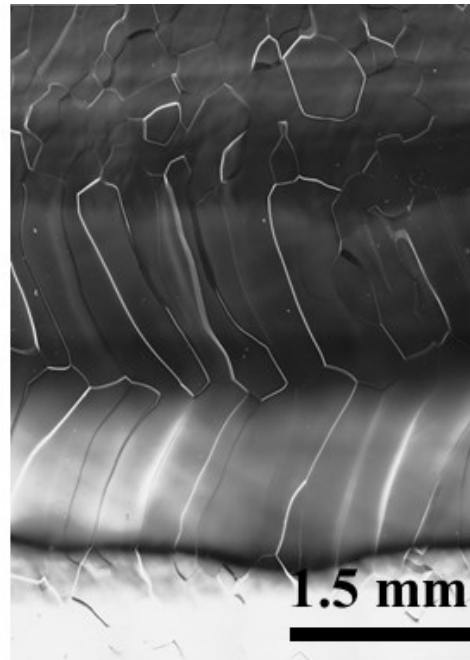


Fig. 11: Picture of replica from microscope.

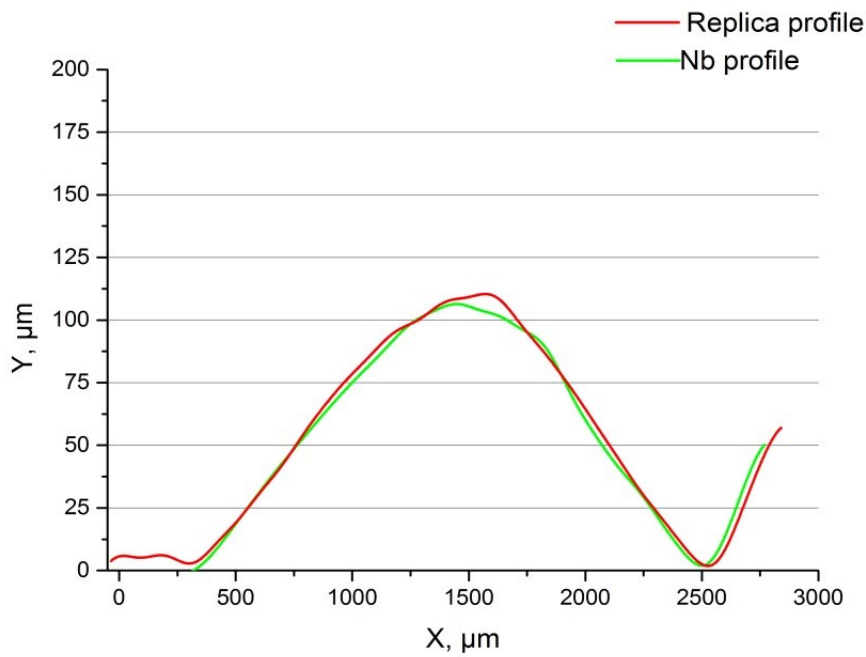


Fig. 12: comparison of profiles taken from the original part of the cavity and replica

Profiles are almost looking like the same.

Many defects were found and inspected during this work, three of them shown on the picture below:

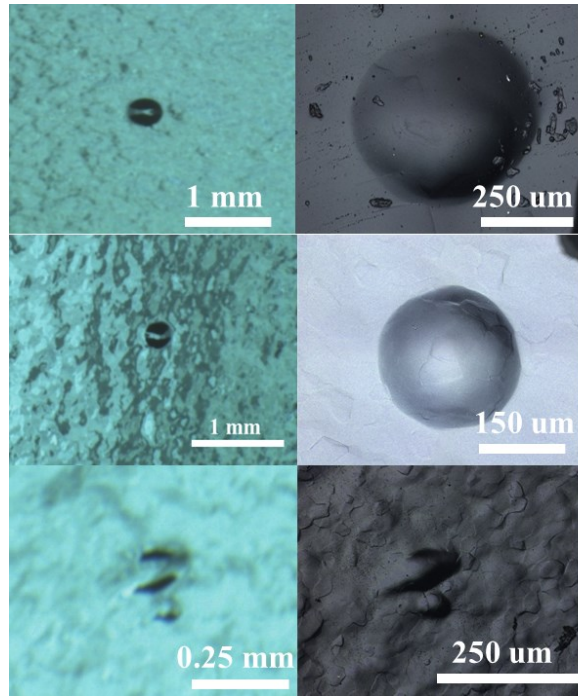


Fig. 13: Defect on the surface inside of the cavity (on the left side pictures from OBACHT and on the right side corresponding to them pictures from microscope)

The results from the inspection of one particular defect are represented on the Figure 14:

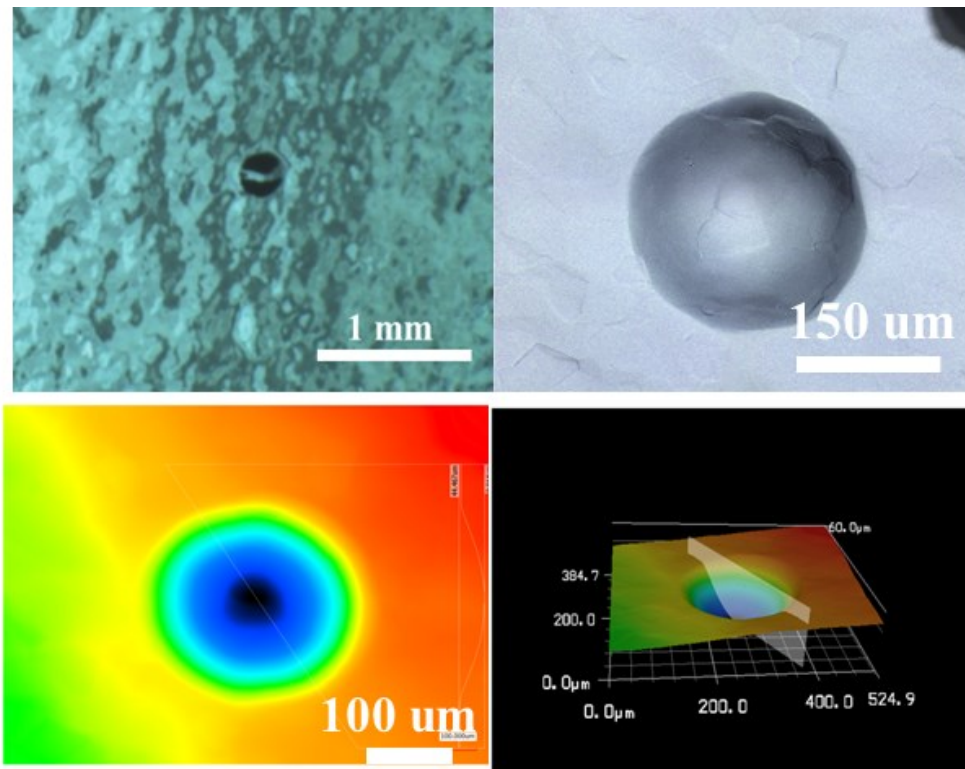


Fig. 14: Defect, which was found with OBACHT, and then the silica replica was made and inspected with microscope.

One of the possible ways to get rid of these defects described in Paragraph 5 of this report.

5. Polishing of the cavities.

After niobium superconducting radio frequency (SRF) cavities are made there is a 80-120 micron damage layer on the inside of the cavities which must be removed. This material has typically been removed in the past by buffered chemical polishing (BCP) or electro polishing (EP), if higher accelerating gradients are required. Much interest was generated in the mid to late 1990s in an alternative cavity surface processing technique called centrifugal barrel polishing (CBP), that mechanically polishes the inside of SRF cavities by rotating them at high speeds while filled with abrasive media. Part of the original motivating factor of this work was to remove the hazards associated with the toxic hydrofluoric acid used in electro polishing (EP) and buffered chemical polishing .[2] Centrifugal installation is shown on the Figure 13:



Fig 15: Centrifuge used to polish cavities at HiGrade HiGrade laboratory.

CBP is an alternative processing technique that polishes the inside of superconducting RF cavities by rotating the cavities at high speeds while filled with an abrasive media. In the CBP process the cavity is filled approximately 50% by volume with a mixture of different media. The media is typically used with water and a surfactant to cool the cavity and remove material from the surface to allow for further polishing. [2]

There are many different types of media that can be used in the CBP process. These media have a vast number of different shapes, sizes and compositions. However, commercially available media are typically designed for tumbling parts in slurry of media, water and soap. This is quite different than CBP applied to SRF cavities as the media is held within the part being polished. This difference coupled with the unique properties of niobium (soft and work hardens easily) means that industry has no experience with this process and can offer little help in media selection. [2] Media that was used in our experiments is shown below (from left to right: first two mixed with ultrapure water, third one is mixed with alumina mesh, fourth mixed with silica :

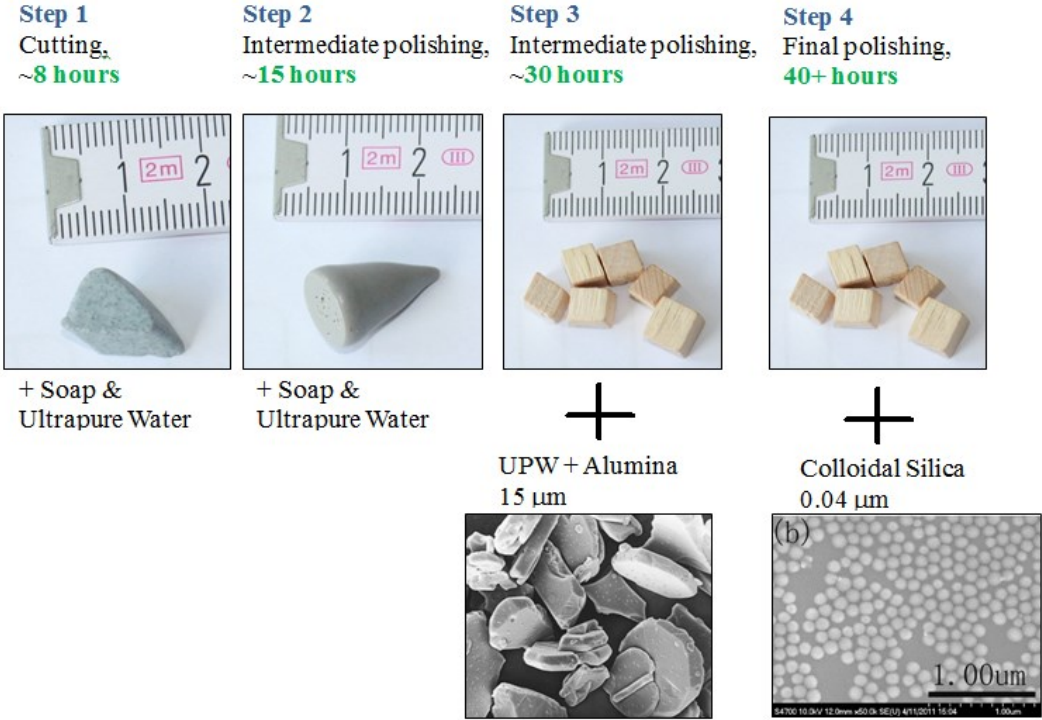


Fig. 16: Pictures of some media used for CBP of cavities at DESY FLA/ILC group to polish cavities.

6. Speed of polishing.

Many equators of the SRF cavities were inspected with replica method, in order to get information about the speed of polishing after each step. Two examples of the inspection shown on the Figure 15 and 16:

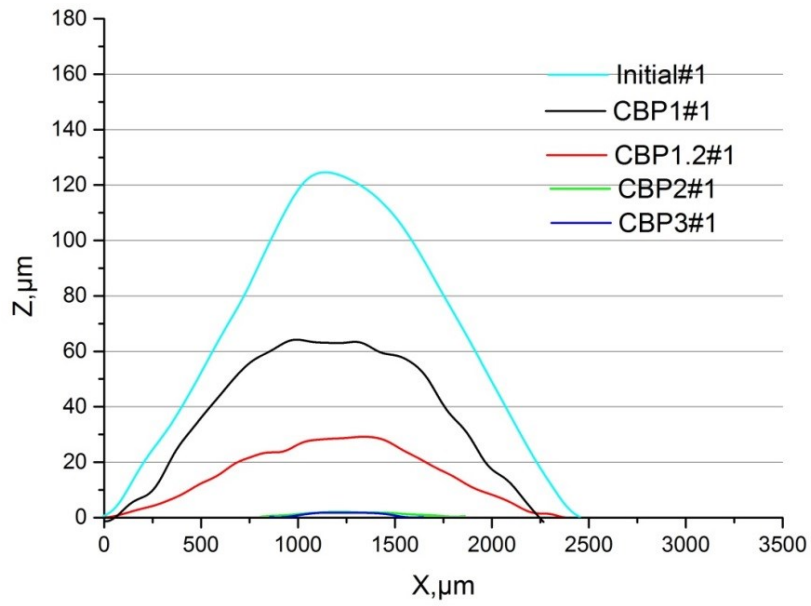


Fig. 17: Results for Equator #1.

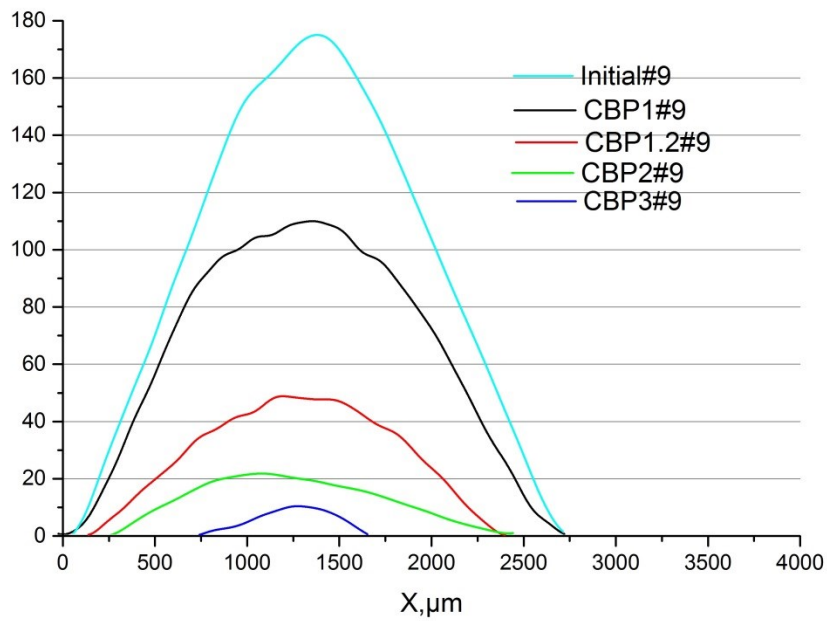


Fig. 18: Results for Equator #2

Easy to see that after each step of polishing the “gap” of the equator is getting lower and lower. Tables 1 and 2 representing the difference between each step:

Table 1. Difference between each step of polishing for equator 1.

| Difference between: | $\Delta z, \mu\text{m}$ |
|---------------------|-------------------------|
| Initial and CBP#1 | 58.03 |
| CBP#1 and CBP#1.2 | 37.32 |
| CBP#1.2 and CBP#2 | 27.38 |
| CBP#2 and CBP#3 | 0.03 |

Table 2. Difference between each step of polishing for equator 9.

| Difference between: | $\Delta z, \mu\text{m}$ |
|---------------------|-------------------------|
| Initial and CBP#1 | 64.87 |
| CBP#1 and CBP#1.2 | 59.92 |
| CBP#1.2 and CBP#2 | 28.22 |
| CBP#2 and CBP#3 | 9.36 |

We also checked the speed of polishing by using coupons. The graph below represents the profile of the coupon surface before and after polishing:

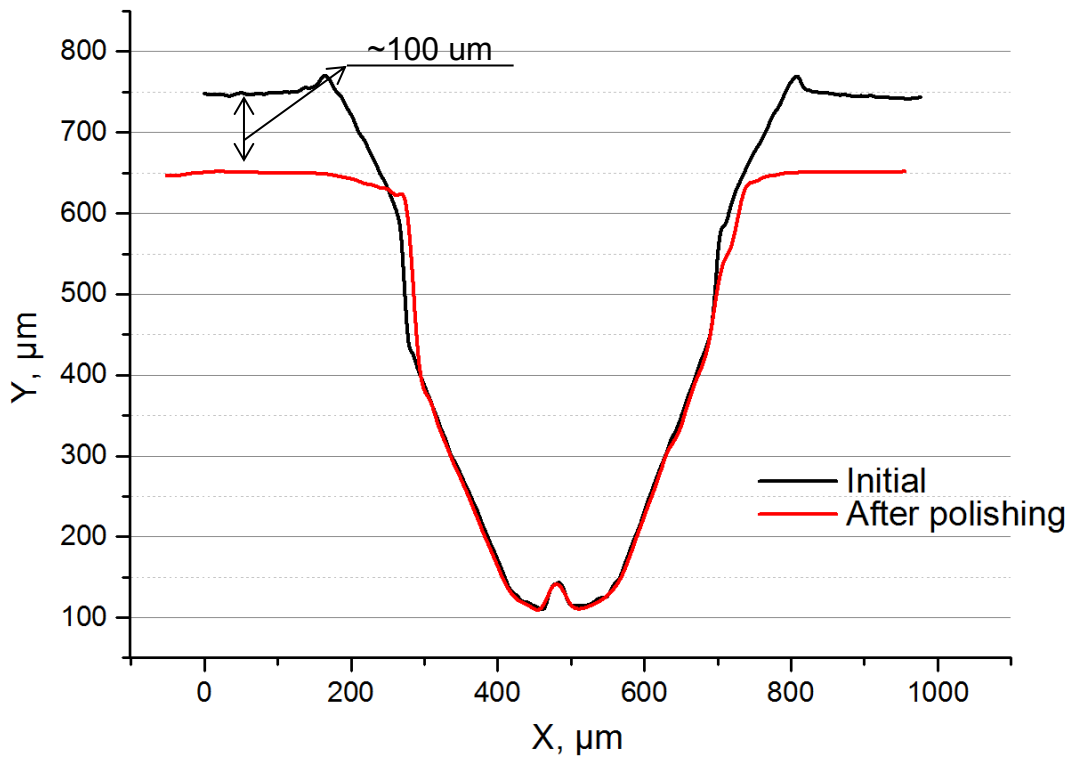


Fig. 19: Surface of the coupon before and after polishing

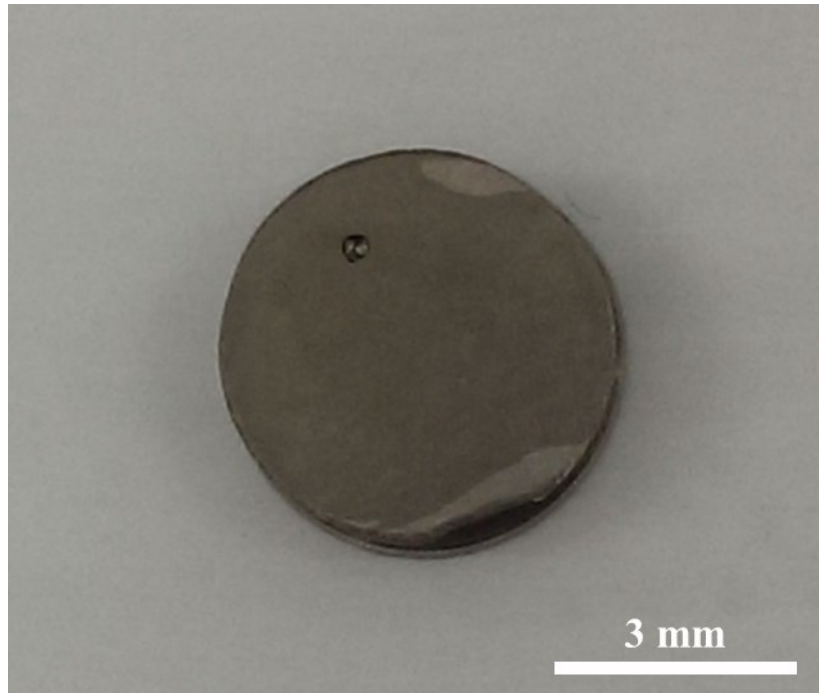


Fig. 20: Nb Coupon. (Small hole in the left corner, is the place where the profile was taken)

7. Summary

Some of the aspects of the RND of SRF cavities were studied during this internship. Replica method to inspect surfaces of the cavities was learned.

Few cavities were assembled with T- mapping and Second-sound for vertical test during this work. Results of these measurements are still processed. Further experiments with second sound and T-mapping required to be done in future. Several cavities were inspected by OBACHT. Few cavities were polished and then the speed of polishing was checked by using silicone replica.

Defects were found with OBACHT and successfully inspected with use of replicas and microscope. OBACHT and replicas method shown to be a reliable way for the inspection of cavities surfaces.

[1] Superconducting cavities for accelerators // Dieter Proch DESY 1997

[2] CENTRIFUGAL BARREL POLISHING OF CAVITIES WORLDWIDE // C. Cooper, Kenji Saito et. Al Fermi National Accelerator Laboratory, Batavia, IL, U.S.A; High Energy Accelerator Research Organization, Tsukuba, Japan

[3] Camera Control for the OBACHT system // Y. Ulrich, A. Navitski L. Steder, M. Wenskat