

# INSPECTION AND REPAIR TECHNIQUES FOR THE EXFEL SUPERCONDUCTING 1.3 GHz CAVITIES AT ETTORE ZANON S.P.A: METHODS AND RESULTS

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## Abstract

The quality control of the inner surface of superconducting RF cavities is essential in order to assure high accelerating gradient and quality factor.

Ettore Zanon S.p.A. (EZ) has implemented in the serial production an optical system that use an high-resolution camera, in order to detect various types of defects. This system is added to a grinding machine, that was specifically designed and built to repair imperfections of the cavities inner surface.

This inspection and repair system is applied to recover performance limited cavities of the 1.3 GHz European EXFEL project, where surface irregularities are detected, either by the Obacht inspection system at Desy or the optical system at EZ.

The optical system and the grinding procedure are qualified using two series cavities limited in gradient and showing different types of surface defects. The performances of these cavities have been recovered to reach the specifications of the project. Until now, all the series EXFEL cavities built by EZ, repaired with this technique, have shown an accelerating gradient well above the EXFEL goal.

The paper describes the equipment installed in the grinding machine and it analyzes the performance of the cavities that have been repaired using this system.

Optical inspections and possibilities to remove defects on the inner surface play an important role in the improving of the production-yield of high performance cavities. For this purpose, EZ has developed a system consisting of an optical tool and a grinding machine to investigate the quality of inner surface of cavities and to remove defects, which can cause of performance-limitations of the cavities. Systems for this purpose have already present in the literature [1-4].

To qualify the technical inspection and repair procedure, EZ has used two series cavities; for both cavities the method has been successfully implemented.

Details of the system and the obtained results will be presented and discussed.

## OPTICAL SYSTEM AND GRINDING MACHINE

### Optical Inspection

Two types of cameras are used for optical inspections, one with fast response time and one with high resolution.

For inspections during the grinding operations, a video boroscope Exttech HDV600 is used. This inspection device consists of a camera mounted on a rotating probe and connected to a monitor. Despite of a limited resolution of 640x480 pixels, it has a quick response and makes easy monitoring during the grinding operation thanks to the rotating probe.

The other camera is See3CAM\_80 (8 megapixels) from e-con System. It allows obtaining a higher-resolution image of 3264 x 2448 pixels. However, the response time is slower due to the large amount of data to be transmitted to the PC. The camera is mounted at the end of rod for inspection tools (see Fig. 1) and connected to the PC. This camera is mainly used to verify a complete removal of the defect.

For both cameras described, the lighting is provided by two LED strips, mounted on the sides of the camera.

### Grinding Machine

The system of grinding machine, consists of the following components (see Fig. 1):

## INTRODUCTION

The Ettore Zanon S.p.A. (EZ) company was founded far in 1919. It is located in the northeastern area of Italy 90 km from Venice.

The company works on two different fronts:

- "Standard" production for chemical industry (reactors, heat exchangers, etc.),
- "Special" production of components for research institutes and laboratories (ultra-high vacuum, cryogenics, fusion, superconductivity, etc.).

Since 2011, EZ company is involved in the European X-ray Free-electron Laser (EXFEL) project, constructed at the Deutsches Elektronen-Synchrotron (DESY), for the production of 420 1.3 GHz superconducting cavities, and it is expected to complete the entire production later this year.

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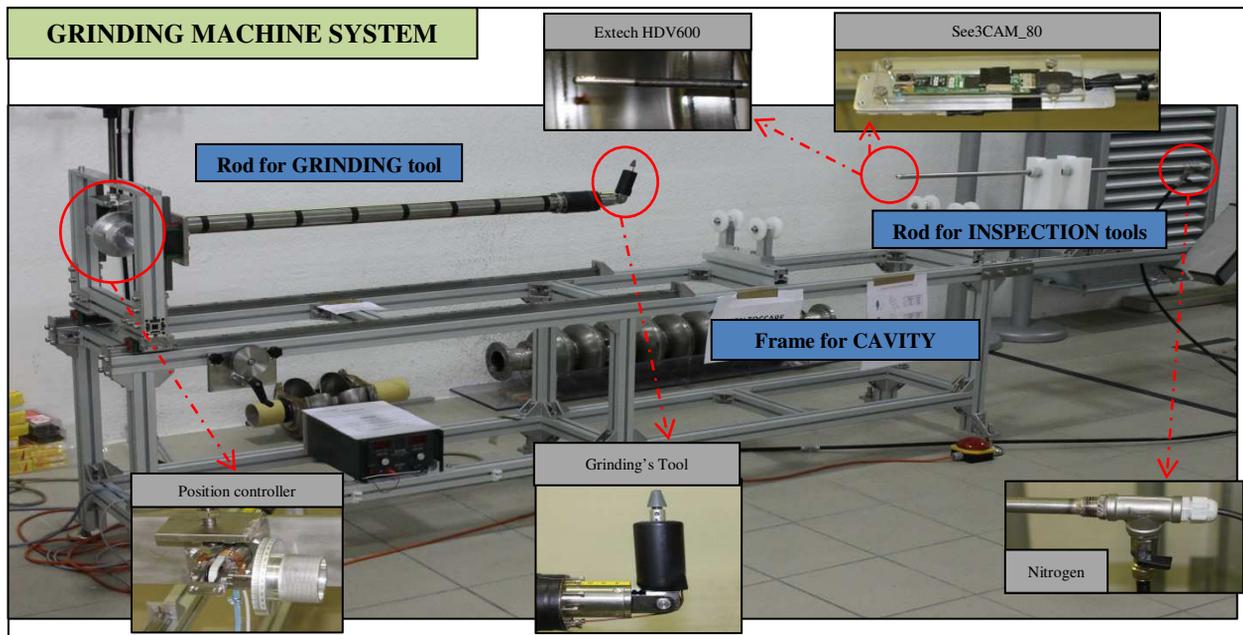


Figure 1: Overview of the grinding machine with the optical system.

- support frame for cavities,
- grinding tool on a support rod,
- optical inspection tool on a support rod.

The Cratex<sup>®</sup> cones are mounted on the head of the grinding tool (see Fig. 2). A "position controller", located on the opposite side of the rod defines the angular position of the grinding head, and the longitudinal positioning is performed by displacement of the whole grinding tool on the table guides.

**Repair Method**

The removal of the defects, found during the optical inspection of the inner surface is performed using the grinding tool with Cratex<sup>®</sup> abrasive cones of different grid texture from coarse, medium, fine and extra fine.

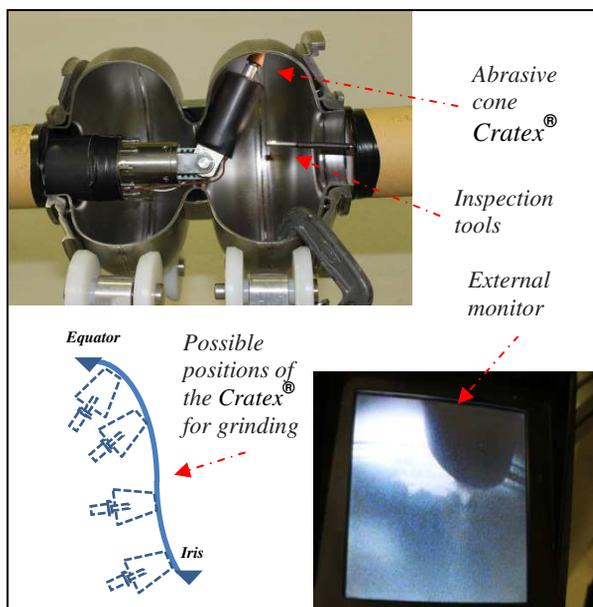


Figure 2: Grinding tool and possible grinding area.

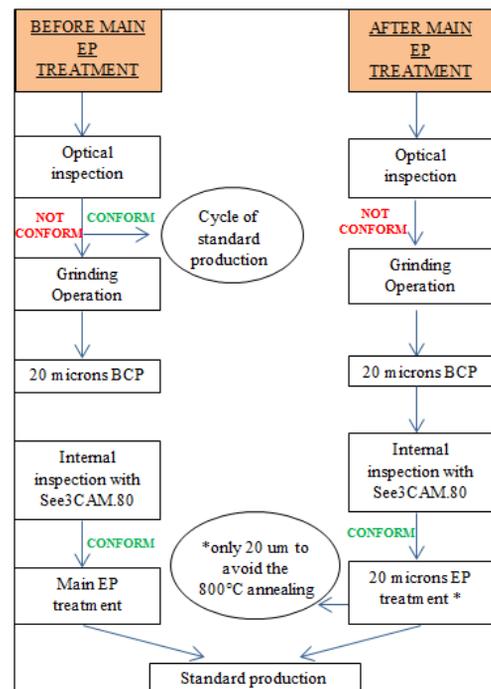


Figure 3: Production cycles after grinding operation.

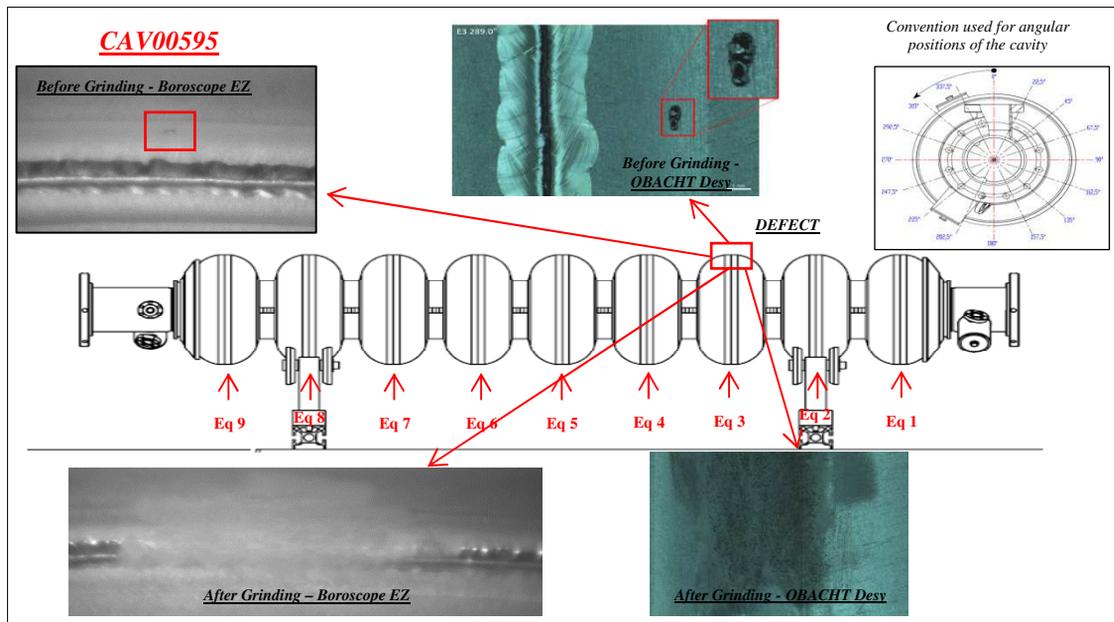


Figure 4: Defect found after the EBW final welding on the equator 3 of CAV00595: OBACHT and boroscope images before and after the grinding procedure used for qualification of the repair techniques.

Rotation of the grinding tool is motor-driven and controlled by a foot pedal, and it can be interrupted at any time by the operator.

The grinding operation starts with the coarse-grained abrasive cones and is monitored by means of the Extech HDV600, boroscope connected to an external monitor (see Fig. 2).

As shown in Fig. 2, the grinding system is able to remove the defects on the equator and iris welds and on the tapered area of the cells.

During the grinding operation, the cavity is rotated manually by an operator to avoid a local overheating of the material and to obtain a finally a regular and smooth surface.

In order to ensure the removal of the defects, the inner surface is finally inspected by the See3CAM\_80 camera.

If the defect is not visible anymore, the grinding operation is considered to be finished. In order to obtain a good surface finish, the grinding operation proceeds by using the Cratex® cones of finer grid size in the following order: medium, fine and extra-fine. When the quality of the surface is satisfactory, the cavity proceeds with the chemical surface treatments foreseen in the standard production cycle [5]. The cycles are different (see Fig. 3) if the grinding operation is performed on cavities that have already received once the main electropolishing (EP) treatment (removal of 140 μm) or not.

### RESULTS

The optical system and the grinding procedure are qualified using two series cavities: CAV00595, where a not acceptable defect has been observed during the optical inspection after the final electron beam welding (EBW); CAV00731, which showed limited performance during the final cold RF test and where OBACHT [6] has discovered some defects on the irises.

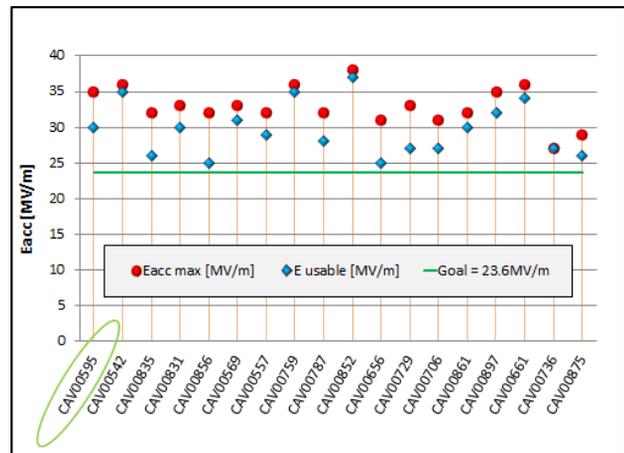


Figure 5: Results of the cold RF test of the cavities grinded after the EBW and before the main EP.

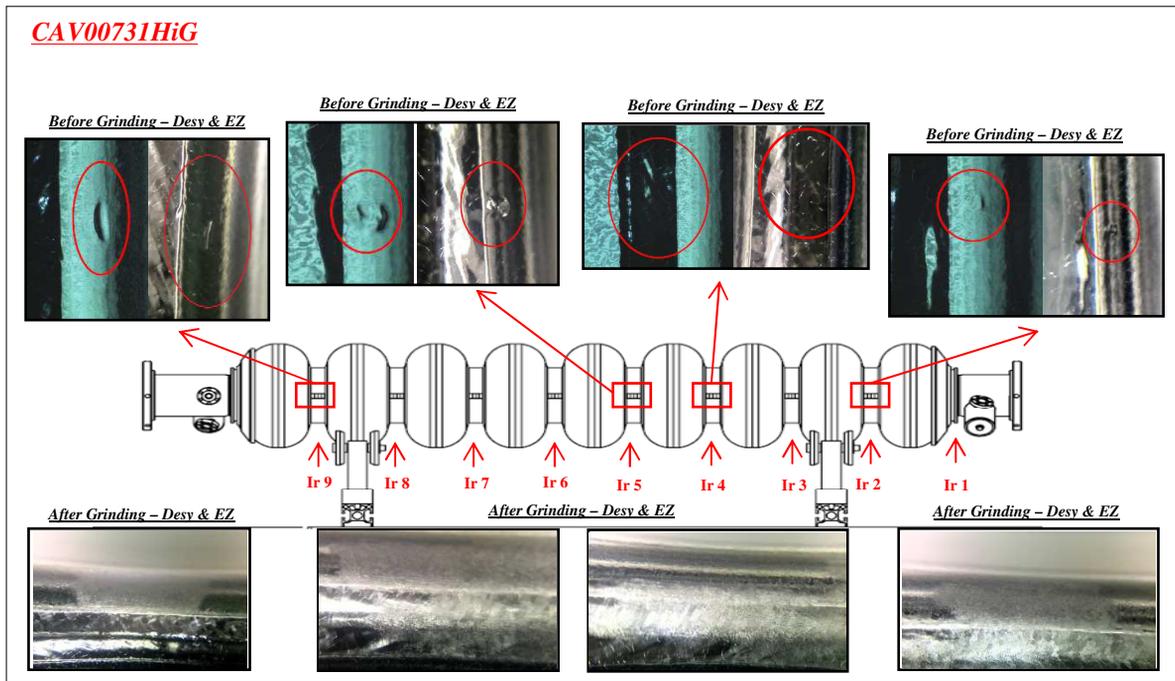


Figure 6: Defects found on the irises of CAV00731 after an unsuccessful cold RF test: OBACHT and boroscope images before and after grinding procedure used for qualification of the repair techniques.

### CAV00595

The optical inspection on the cavity CAV00595, performed regularly in the production cycle after the EBW final welding, discovered a spatter weld close to the weld bead of the equator No3 at the angular position of 289°. This defect was also analyzed with the OBACHT system, in collaboration with DESY (see Fig. 4).

After the complete removal of the defects, as confirmed by the optical inspections both at EZ and DESY (see Fig. 4), the cavity has followed the production cycle according to the scheme shown in Fig. 3.

At the vertical cold RF test at DESY the cavity has reached finally maximum accelerating gradient  $E_{max}$  of 35 MV/m and usable gradient  $E_{usable}$  [7] of 30MV/m, limited by some field emission.

With this result the repair procedure has been successfully qualified and finally applied on 18 cavities. The results of vertical cold RF tests of these cavities are shown in Fig. 5. All the cavities perform well above the XFEL performance goal.

### CAV00731

At the 1<sup>st</sup> vertical test at DESY, the cavity has reached  $E_{max}$  of 32 MV/m and  $E_{usable}$  of 23 MV/m, limited by quench and strong field emission.

Even after HPR reprocessing at DESY, this result didn't improve. Two optical inspections has been performed.

By the camera at EZ and OBACHT system at DESY, the following defects have been discovered:

- Scratch on iris 2, 4 and 5 at angular position of 120°.
- Incision on iris 9 at angular position of 6°.

The defects have been successfully removed with the grinding techniques, as shown in Fig. 6 and the cavity has followed the production cycle according to the scheme shown in Fig. 3 for the cavities that received already once the main EP treatment.

During the 2<sup>nd</sup> vertical test at DESY the cavity has reached  $E_{max}$  of 39 MV/m and  $E_{usable}$  of 38 MV/m, limited by low field emission. With these results the procedure of the removal of such defects has been successfully qualified as well (see Fig. 7).

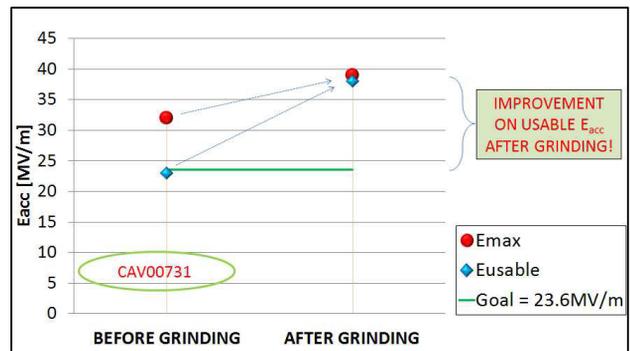


Figure 7: Comparison of the results of cold RF test of CAV00731 before and after the grinding.

## CONCLUSIONS

Ettore Zanon S.p.A. has realized an inspection and repair system, within the European EXFEL project, for the production of 420 superconducting 1.3 GHz cavities.

The end of the production is expected later this year.

The system has been developed to investigate and repair different types of defect (on equators and irises weld) and surface irregularities, in order to ensure high accelerating gradient and high quality factor.

Until now, all the EXFEL series cavities built by EZ and repaired with this technique have shown the accelerating gradients well above the EXFEL goal.

EZ future developments involve increased levels of automation in the system, in order to limit as much as possible the risk of human errors, further improve the inspection quality (using e.g. more higher-resolution camera) and minimize time/cost while keeping the highest quality standard.

## ACKNOWLEDGEMENTS

We would like to thank all participating colleagues.

About 100 people are actually fully involved in the EXFEL task, whose enthusiasm, effort and professionalism has allowed us to approach with good results to the end of the production of the cavities for the European project EXFEL.

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