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# UPDATES ON THE INSPECTION SYSTEM FOR SRF CAVITIES

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*Abstract*

Optical inspections on superconducting cavities have been used by those who are involved in the cavity fabrications. Further improvements on the Kyoto Camera have been carried out these years together with further processing technique developments, such as removing found defects by local grinding techniques. Improvements of Kyoto Camera include implementation of color LEDs for illumination system, which improves the inspection efficiency. These advances are reported.

## INTRODUCTION

Optical inspections have been taking an important role for superconducting cavity fabrications. The first Kyoto camera was developed in 2008 and found good correlations between found defects on the cavity interior surface and a thermometry during a vertical test at FNAL/JLAB [1,2]. It was found to be a good tool to raise the fabrication yields of the cavities. After the proof of the usefulness, we have been improving the system. It includes the local grinding system to repair the found defects for better recovery procedure and better yield in the cavity preparation [3]. We delivered the systems to six institutes over the world since then. Recent developments on the system are reported in the following sections.

## KYOTO CAMERA

The illumination system is the key device in the Kyoto camera to observe the interior surface of the Nb cavity. In order to illuminate the mirror-like shiny metal surface, surface light emitting devices have been used. The first device was an inorganic Electro-Luminescence (IEL) device, which was split into several strips to measure the slope distributions of the local surface of the observed area (see Fig. 1a). Because of the low light emission and the short lifetime, the IEL device was replaced by white LEDs, which had become widely available. Each stripe was realized by a light emitting guide strip with one small white LED at each edge end (see Fig. 1b). This improvement enhanced the amount of the light and the lifetime. When a request for a larger cavity of 750 MHz came, more light to illuminate the far cavity surface and the longer working distance from the camera lens to the cavity surface were needed. Then the Armadillo type LED system was adopted (see Fig. 1c), where the brightness was controlled line by line. This scheme was applied to an inspection system for L-band cavities with brightness control by pixels (see Fig. 1d). For a refurbishment of the old IEL illumination system, the line-by-line-control type Armadillo type system with red and blue LEDs at both

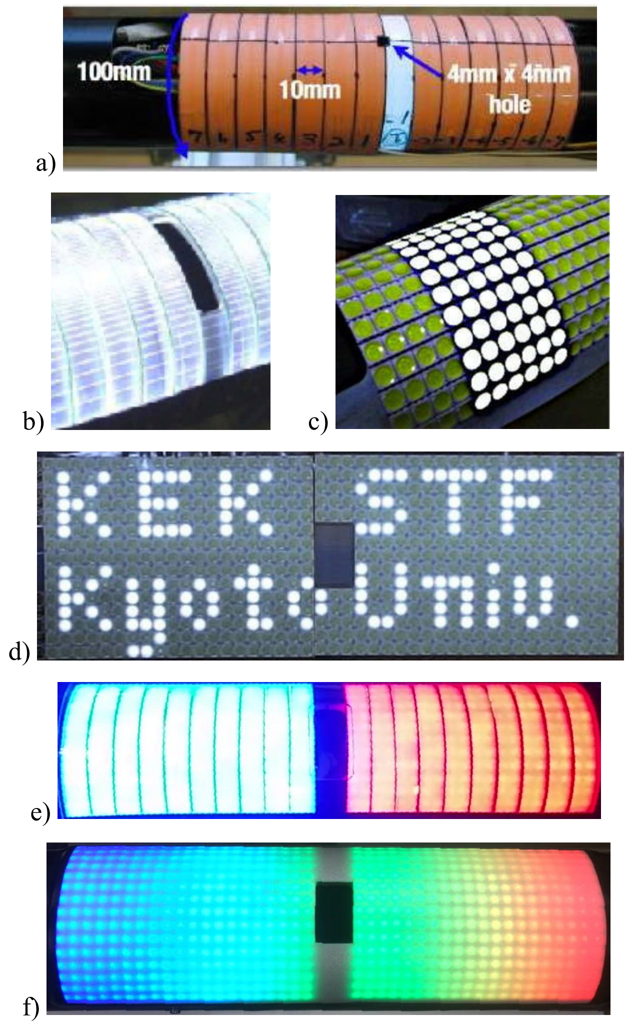


Figure 1: Changes of the illumination system. a) The first inorganic Electro-Luminescence (IEL) device (one strip lighted). b) Light emitting guide strip type using white LEDs. c) Armadillo type illumination with more LEDs (line by line). d) Pixel controlled Armadillo illumination. e) Blue and red stripes for refurbishment of old version. f) Colored pixel controlled Armadillo illumination. The camera holes are located at the centers.

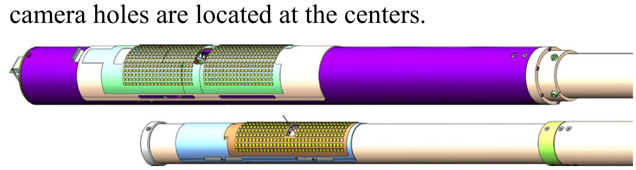

Figure 2: The modular design of the camera system allows adaptability to multiple cavity sizes. A larger cavity with working distance larger than an L-band cavity requires a larger lens system with larger diameter. It also allows easy maintenance by sending the short head part back to the manufacturer instead of the long cylinder.

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the half stirps was fabricated in 2018 (see Fig.1e). Recent LED technology allows us to control the color of each pixel with RGB information, which is applied to an inspection system for 650 MHz cavities (see Fig. 1f). In this version, the camera cylinder head is separated for a better maintainability and adaptability to the smaller cavity (see Fig. 2). Figure 3 shows a picture taken with the color illumination system. By using the unique color information, the slope information can be obtained from just one picture, instead of the former multiple pictures taken with different active illumination strips. This allows an efficient inspection procedure. Figure 4 shows a picture with a defect found in the vicinity of the EBW seam, which is marked by a red circle. As shown in the close up picture, typical cat's eye shape appears (see Fig. 5).

## GRAPHICAL USER INTERFACE

As to the control system, a Graphical User Interface (GUI) was prepared for better operation of the camera system (see Fig. 6). In the GUI panel, controls of the cavity table (longitudinal motion and rotation), the illumination pattern, the camera cylinder rotation, camera focusing and the mirror angle can be performed. After a manual calibration of the cavity coordinates, automatic image capture can be started by setting parameters such as the number of pictures to be taken.

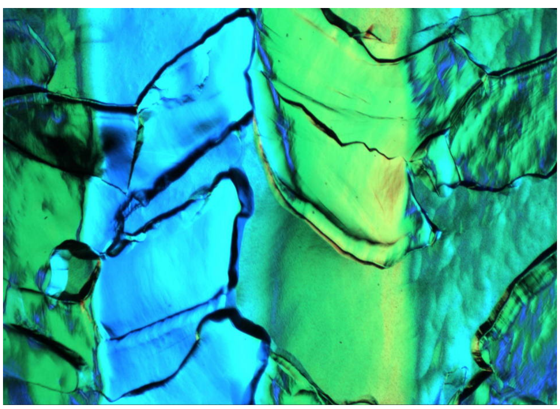

Figure 3: Picture taken with the color illumination. The color information has the slope of the surface.

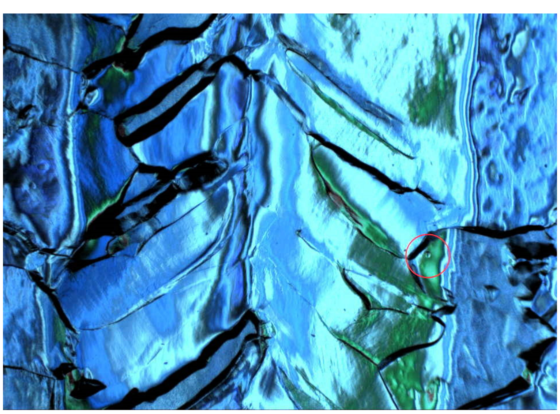

Figure 4: Picture with a cat's eye type defect in the vicinity of the EBW seam. The defect is marked by red circle.

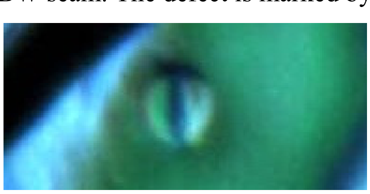

Figure 5: Close up of the defect with Cat's eye shape.

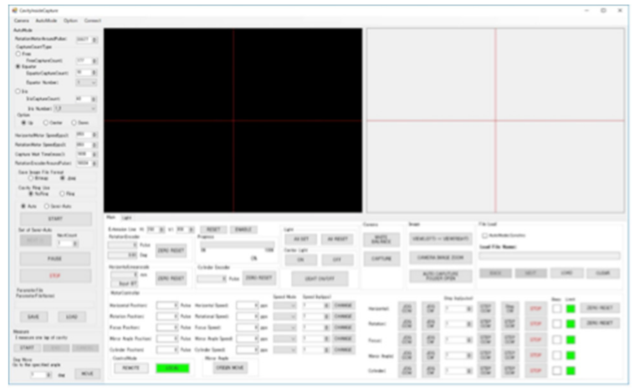

Figure 6: Graphical User Interface for the camera system.

## LOCAL REPAIR TECHNIQUE

Once a defect was found by the camera, conventional technique to recover the cavity was to electro-polish (EP) the whole cavity surface. Because the removal depth is the order of that of the defect depth and the total volume tends to be large, this might spoil the cavity. The local repair technique is an efficient way to save such cavities with deep defects and to improve the production yield of cavities. The local grinder was developed for that purpose. It has a pantograph mechanism to carry the small grinding head to the cavity surfaces, while the grinding head should be retracted to be inserted to a specific cavity cell. The defects are usually found in the vicinity of the EBW seam (heat affected zone) [2]. Then the surface is fairly perpendicular to the radial direction. Thus the pantograph configuration is good for almost all cases.

The original grinder system had a small grinding motor on the grinding stage (see Fig. 7). The recent local grinding system has a powerful motor located at the end of the local grinding cylinder, which enables a powerful grinding capability (see Fig. 8). In order not to hit the cavity wall, the head stage has two magnetic proximity sensors for the interlock system to the longitudinal movement action of cavities instead of the original optical sensors. The camera to look at the target surface was also updated to replace an obsolete product. This local grinding system is combined with the camera system for better mutual operation and smaller footprint of the system (see Fig. 9). The pantograph height for a larger cavity should be higher, so a customized local grinding head assembly for each cavity size is required. The recent modular design gives a better expandability and maintainability similar to the camera system (see Fig. 10). There is interlock system against the dangerous actions such as elevation movement while either of cylinders is inserted in a cavity or cavity table movement while the pantograph is not retracted enough.

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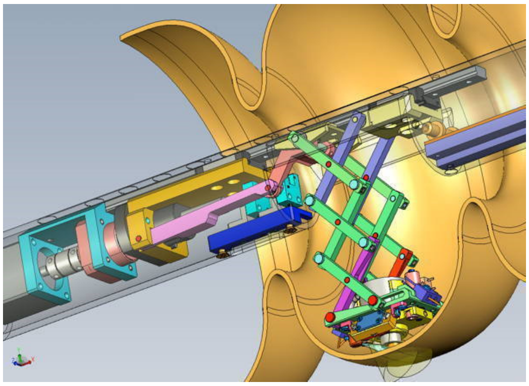

Figure 7: The original structure of the local grinding system, where the local grinding motor is located at the retractable grinding stage.

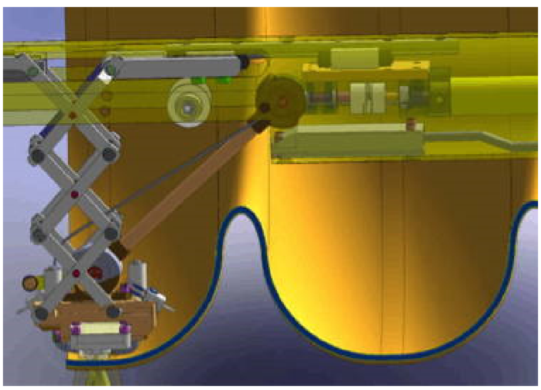

Figure 8: The improved structure of the local grinding system, where the local grinding motor is located at the end of the cylinder.

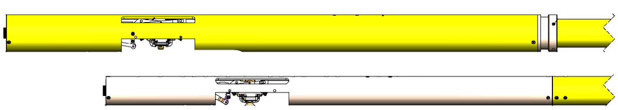

Figure 9: The modular design of the grinder system allows adaptability to multiple cavity sizes. A larger cavity requires a longer pantograph system. The head part can be exchanged when one needs to treat a cavity with different size. It also allows easy maintenance by sending the short head part back to the manufacturer instead of the long grinding cylinder.

Figure 10: The combined Kyoto camera (top cylinder) and the local grinding system (bottom cylinder).

## R&D ON IMAGE PROCESSING

Because of the large magnification of the camera system, the depth of focus is rather narrow and objects with bumpy or large slope are difficult to observe. Focus stacking, which has been used as a digital image processing technique, combines multiple images taken at different focus positions to give a single well-focused picture (see Fig. 11). While this needs more pictures and takes some time, it will give more information such as rough height information of the object surface. The auto-focus function may not be needed because of this function. Other image processing technique such as High Dynamic Range may also be combined with the focus stacking.

The pattern recognition to detect defects automatically among thousands of pictures is also under investigation.

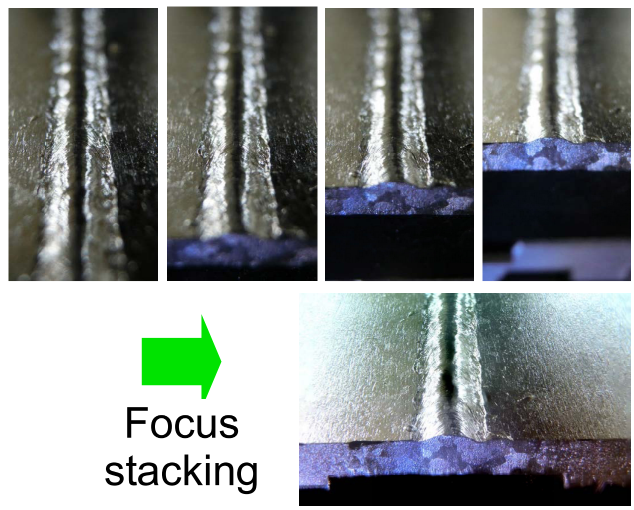


Figure 11: Focus stacking from pictures with different focus positions will eliminate the autofocus function.

## CONCLUDING REMARKS

As is included in the ILC-TDR, the Kyoto camera and combined local grinding system have been important tools to improve high gradient cavity performance. It has been developed since 2008 and helps to improve the performance of the superconducting cavities. Further developments based on the image processing are on going. It will enable to get more information such as surface roughness with the same device. An automatic defect pickup will also be a target for future developments.

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