A NEW INTERNAL OPTICAL PROFILOMETRY SYSTEM FOR CHARACTERIZATION OF RF CAVITY SURFACES – CYCLOPS*

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Abstract

Jefferson Lab has received and is commissioning a new interferometric optical profilometer specifically designed to provide internal surface mapping of elliptical rf cavities. The CavitY CaLibrated Optical Profilometry System – CYCLOPS – provides better than 2 µm lateral resolution and 0.1 µm surface height resolution of programmatically selected locations on the interior surface of multi-cell cavities. The system is being used to provide detailed characterization of surface topographic evolution as a function of applied surface treatments and to investigate particular localized defects. We also intend to use the system for 3D mapping of actual interior rf surface geometry for feedback to structure design model and fabrication tooling. First uses will be illustrated. CYCLOPS was developed and fabricated by MicroDynamics Inc., Woodstock, GA, USA.

INTRODUCTION

The performance of superconducting resonant rf structures used for particle acceleration is quite often limited by localized surface defects. Developing an understanding of the nature of such defects and their origin is critical to confidently avoiding their occurrence. The surface of interest is the interior of a complex three-dimensional object, which presents a major impediment to the development of such an understanding.

External thermometry during cryogenic rf testing provides confident localization of anomalous heating to within ~1 cm. Use of such thermometric mapping has been followed up with visual inspection by careful non-contacting insertion of a camera and illumination system such as that developed at Kyoto University [1], and by use of long-range microscopes with mirror and lighting inserted into the cavity [2]. Such visual inspection provides valuable information about the morphology of the defect region, but is very difficult to interpret quantitatively. In addition to characterization of defects, quantitative topographical information is needed to refine the understanding of cavity surface topography evolution as a function of applied processing steps, whether mechanical or chemical, to optimize those processes for both effectiveness and economy.

One route to obtain quantitative topographic information from a location of interest is by forming a replica mold of the region which may then be examined with external profilometry tools. This has been successfully accomplished for a few defect spots in multi-cell cavities [3, 4], and even accomplished without affecting the performance of the cavity. Such technique, however, can hardly be envisioned for extensive use.

A more attractive solution would be provided by optical interferometric profilometry accomplished on the interior of the finished cavity. Though perhaps conceptually straightforward, the realization of such a system presents significant motion control challenges.

MicroDynamics Inc. [5] has developed such a system, called CavitY CaLibrated Optical Profilometry System (CYCLOPS) and delivered it to Jefferson Lab. Commissioning of the CYCLOPS is underway.

SYSTEM DESCRIPTION

This unique system provides optical inspection and quantitative profilometry of the interior surface of cylindrically symmetric structures that have axial clearance of at least 48 mm diameter. The system can accommodate structures up to 1.5 m in length and diameter up to 34 cm. See Figure 1.

Figure 1: CYCLOPS setup at Jefferson Lab.

The system is oriented vertically with the non-contacting optical probe traveling down the cylindrical axis. The probe consists of two concentric hollow cylinders, an outer probe which positions a lower mirror,

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and an inner probe which moves vertically with the balance of the optical system, including the reference leg of the interferometer. The displacement between the inner and outer probes establishes the distance of the focal plane away from the bottom mirror. The bottom mirror has a precision tilt control. The range of motion of the mirror provides a view 80º up to 30º down from horizontal.

Because the system is optimized for a very narrow depth of field for interferometric measurements, the cavity interior surface is best observed with the height of the bottom mirror and its tilt angle set to provide normal incidence on the surface of interest. A cavity to be inspected is mounted from below on a fixed-height rotary stage.

The four position control parameters of CYCLOPS are accessed via a computer interface and together establish a unique location in the 3D coordinate frame of the system to a precision of typically about 1 µm.

Reflections from the cavity surface return to a CCD camera. Surface profile data is derived by tracking the interference fringes from a blue LED through a series of acquired digital (1600 × 1200) optical images from an area approximately 2.6 × 2.0 mm. The focal plane is incremented through the surface during this series. Optical element position resolution is 78 nm, roughly 1/6th of the optical wavelength. A non-interferometric, lower magnification mode provides a ~ 5 × 4 mm field of view for manual scanning operations.

OPERATION

A cavity to be examined may either be flange-mounted directly to the rotary headstock or aligned in a standard JLab cavity handling frame, which in turn is mounted to a spider fixture attached to the rotary table as in Figure 2.

Because best results are obtained when the surface is viewed with near-normal incidence, a CAD file of the cylindrically-symmetric design contour of the cavity is loaded as an input to CYCLOPS. Registration of the system's vertical coordinate, $z = 0$, to the design is accomplished by manual control and observation. Subsequently, the operator may specify the elevation of interest and request an auto setup of the system parameters so as to view that location in space with normal incidence to the design surface. Such setup is available except when the slope of the cavity wall is too steep to obtain normal incidence.

The operator then adjusts the position of the focal plane to the real surface and adjusts the field of view to the region of interest. The focus is then further refined to observe interference fringes. A series of digital images is acquired as the focal plane is scanned through the surface. Image processing then tracks the fringes between images and infers topographic information, finishing with a profilometry array for graphical display and further analysis, such as cross-section display, statistical characterization, etc.

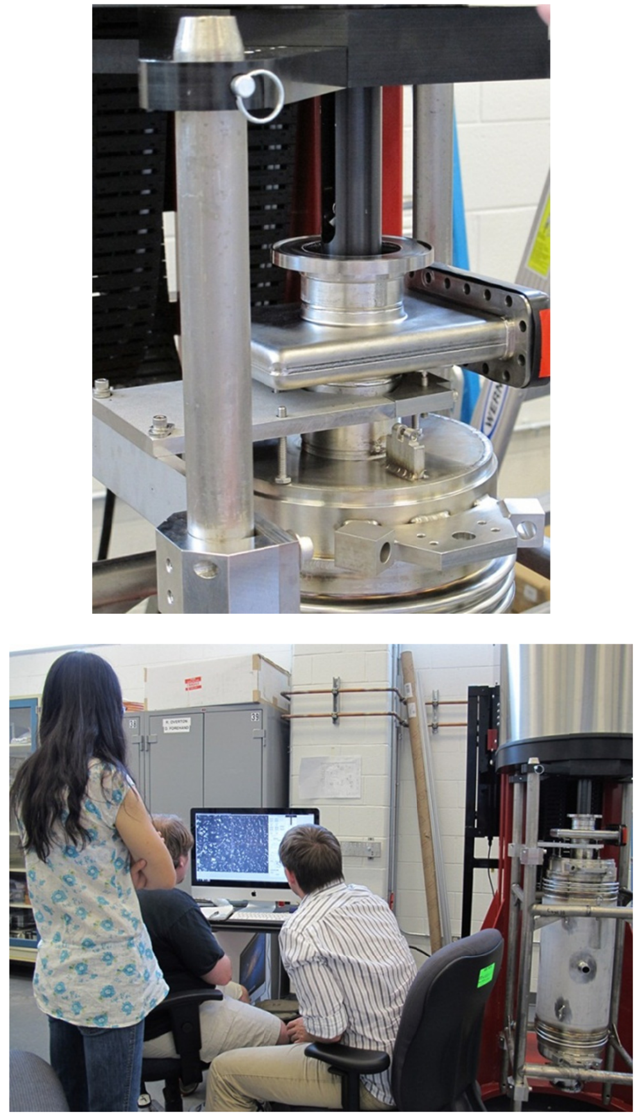

Figure 2: CEBAF upgrade cavity mounted on CYCLOPS for inspection.

Figure 3 shows the user interface while inspecting an intentionally drilled hole in a single cell test cavity. The right-most panel gives the operator graphical feedback on the location being viewed. The left panel is the live digital image. In between is the motion control panel for use by the operator.

Figure 4 is a rendering of the resulting profilometry scan for this defect. Due to the extreme depth of the hole, no interference fringes were observed there, so this region remains unresolved.

At present, operation is limited to user driven analysis of specific locations. Our intent is to continue to develop the user interface and to gradually increase the degree of automation in surface characterization and defect recognition.

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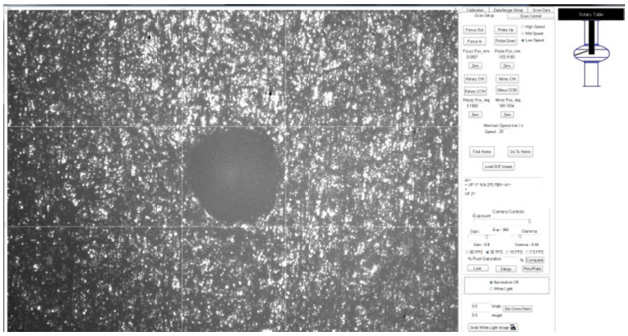

Figure 3: CYCLOPS user interface inspecting a 680 µm diameter drilled blind hole.

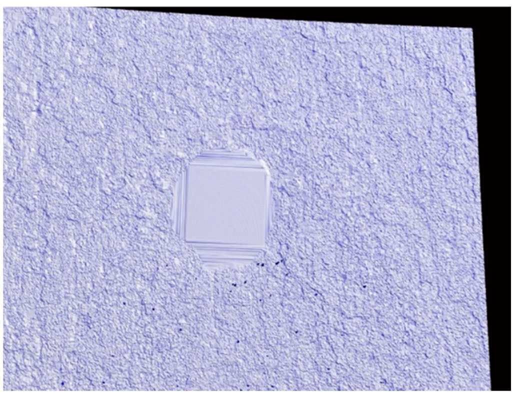

Figure 4. Interferometrically reconstructed surface profile from the surface imaged above.

Another intended use for CYCLOPS is as a tool for mapping the actual internal surface of multicell cavities for comparison with the theoretical design surface. Creating a 3D point cloud mapping of the actual surface will be valuable feedback to both the cavity sheet metal and welding fabrication processes. The feedback is also valuable for RF modelling, which is increasingly called upon to anticipate the field configurations of multiple higher-order modes as well as the fundamental accelerating mode. Subtle shape deviations from designs can have significant effects on the field configuration of such modes in multi-cell cavities. The CYCLOPS software to accomplish this mapping mission has not yet been commissioned.

SUMMARY

A new system for inspecting and characterizing the interior surface topography of cylindrically symmetric RF accelerating cavities has been developed. The system provides a helpful bridge between *ex situ* material studies and *in situ* visual inspections of "normal" and "defect" surfaces. Further automation of CYCLOPS is planned for the near future.

REFERENCES

[1] Y. Iwashita, *et al.*, Phys. Rev. ST Accel. Beams, 2008. **11**(9): p. 093501.

[2] R.L. Geng, *et al.* in *Proc. 15th Int. Conf. on RF Superconductivity*. 2011. Chicago, IL USA: p. 798-800.

[3] M. Ge, *et al.*, Supercond. Sci. Technol. , 2011. **24**(3): p. 035002 (8 pp).

[4] S. Berry, *et al.* in *Proc. 11th Int. Workshop on RF Superconductivity*. 2003. Travemunde, Germany: p. 591-595.

[5] MicroDynamics Inc., Woodstock, GA 30189, USA.