Standing Wave Probes for Micrometer-Scale Metrology

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In this project we are developing a low-force, high-aspect-ratio, mechanical probe for the nondestructive characterization of manufactured components and assemblies. The key concept for the probe is the correlation between the dynamic response of an oscillating cantilever rod (probe) and the interaction of its tip with a surface (Fig. 1). The applications for this probe begin with surface location, but may encompass the characterization of the material properties of the surface, and perhaps branch into the modification of the surface. This project is a collaborative effort between LLNL, the University of North Carolina at Charlotte (UNC-Charlotte) and an industrial partner, InsituTec Inc.

Project Goals

The project has provided the scientific understanding of a low-force, contact probe capable of being applied on a number of machine tools and metrology platforms with a characterized uncertainty based on the fundamental understanding of the probing process. The exit strategy includes continued collaboration with UNC-Charlotte, rigorous calibration efforts with NIST, engaging a commercial source of probing instruments, and the probe's practical application at LLNL and its vendors for target fabrication. Measurements have been made on geometries and materials relevant to LLNL target manufacture.

Relevance to LLNL Mission

Currently, Inertial Confinement Fusion (ICF) and high-energy-density physics (HEDP) targets comprise components with dimensions in the millimeter range, while having micrometer-scale, high-aspect-ratio functional features, including fill-tube holes and counterbores, hohlraum starburst patterns, and step-joint geometry on hemispherical targets. Future target designs will likely have additional challenging features. Variations in geometry from part to part can lead to functional limitations, such as limited flow rates during target filling, unpredictable instabilities during an ICF experiment, and the inability to assemble a target from poorly matched subcomponents. Adding to the complexity are the large number and variety of materials, components, and shapes that render any single metrology technique difficult to use with low uncertainty.

The near-term impact of this project is the expansion of LLNL's ability to accurately perform dimensional measurements of micrometer-scale features using a low-force, high-aspect-ratio probe system. The final goal of this work is to enhance LLNL's precision engineering capabilities, which encompass key core technologies supporting NIF, DNT and nanofabrication.

FY2009 Accomplishments and Results

A prototype standing wave probe system including upgraded electronics

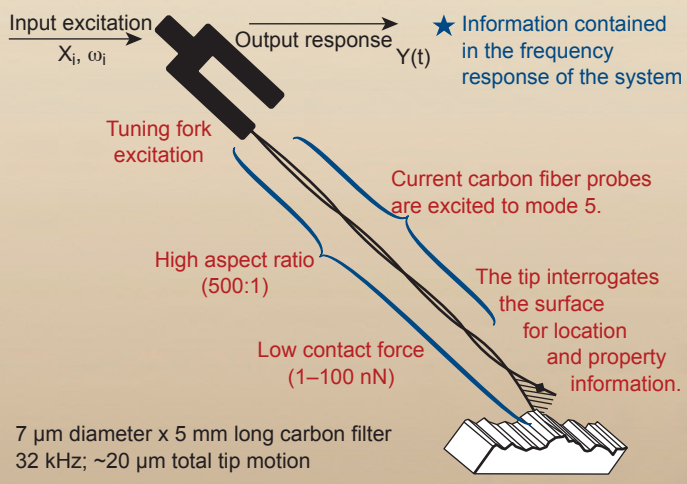

Figure 1. Schematic of probe system including tuning fork excitation and high-aspect-ratio rod. An input amplitude (X_i) at a frequency (ω_i) is applied to the tuning fork while the output amplitude (Y) is monitored as the probe comes into contact with the surface.

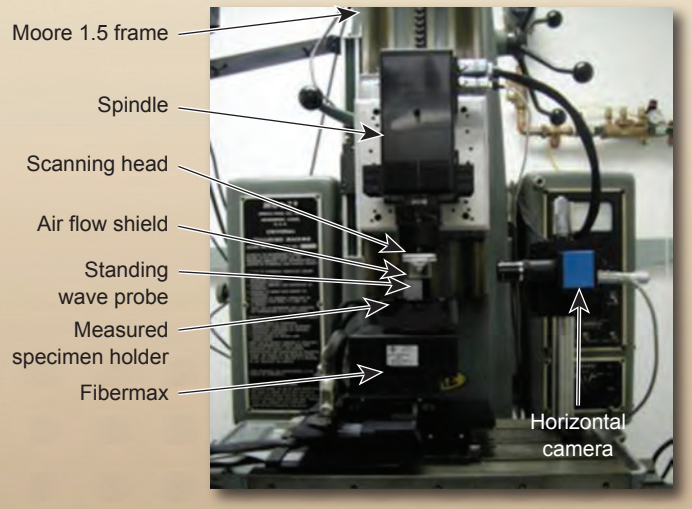

Figure 2. Standing wave probe incorporated into measurement system. Closed-loop controlled scanning stage is integrated with rotation axis onto a Moore machine.

for increased sensitivity has been built and is operational at LLNL. The system has been integrated with a precision motion stage station with subnanometer-level positioning capability and data acquisition. Probe sensitivity/repeatability to contact has been measured on a hardened steel gage block and has been shown to be at the ±10-nm level for experimental systems at both UNC-Charlotte and LLNL.

A model of the probe dynamics including contact has been derived as a stand-alone model in FORTRAN. The current scale system has a restoring force of ~100 mN due to the strain energy in the distorted beam during oscillation, while the theoretical and experimentally measured combined contact force is less than 10 mN. Scaling the system by an order of magnitude and using the same analysis, the restoring force in the oscillating beam is approximately 2 mN, while the combined surface forces are nearly 0.5 mN. Clearly, the influences of the surface forces are much more dominant at the smaller scale, as expected.

Using our modeling techniques, we have designed a system that can overcome the surface effects by either increasing the drive frequency at constant amplitude and/or shortening the fiber length to produce a larger restoring force.

A measurement system has been built at UNC-Charlotte by InsituTec Inc as a development platform for qualifying performance of the probe system measuring features and materials of interest to LLNL. The probe has been incorporated into a closed-loop controlled motion system to allow for scanning of sample features (Fig. 2).

One of the primary goals of this work was to investigate this probe technology on low-density materials used in HEDS targets. Two low-density foam artifacts were manufactured with 100-µm steps turned into the face of the structure (Fig. 3). These materials represent some of the most difficult to measure due to their combined optical and mechanical properties. Multiple measurements of each sample were made to evaluate repeatability and to investigate influence of material properties on probe performance. Based on increased probe sensitivity developed over the initial part of this effort, measurements of the foam features were done in a "non-contact" mode where the probe traces the surface without directly contacting the material.

Figure 4 shows results of the measurements for a 6% full-density (893 mg/cc) copper foam.

Related References

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FY2010 Proposed Work

We are building a 2-D probe system to be tested in FY2010. In addition, designs for a scaled 1-D probe and expanded 2-D probe have been modeled. Prototyping and testing are ongoing.

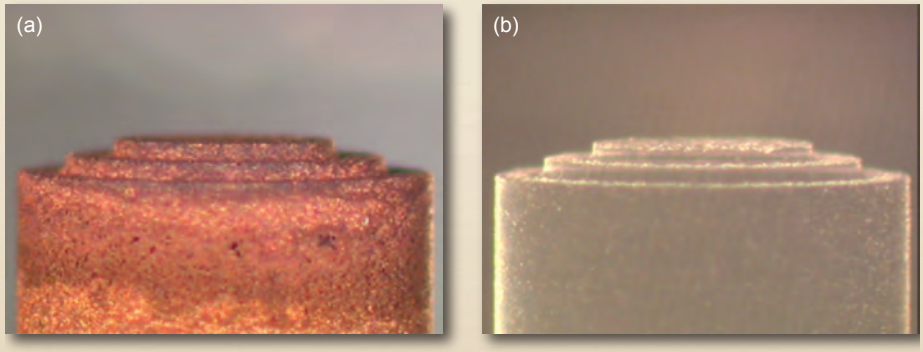

Figure 3. Two low-density foam artifacts with 100-mm steps: (a) 6% full-density (893 mg/cc) copper foam stepped sample; (b) 50-mg/cc SiO_2 foam stepped sample.

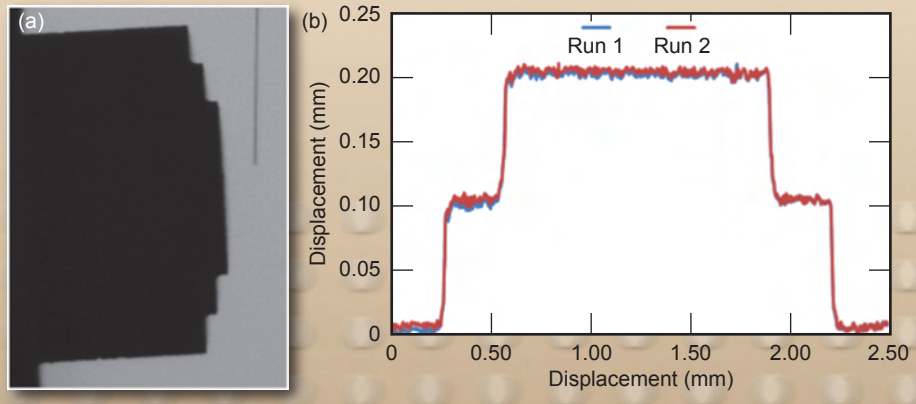

Figure 4. (a) Standing wave probe coming into contact with copper foam artifact; (b) step height measurement of 10% dense copper foam after removing tilt.