VI.7 Non-Contact Sensor Evaluation for Bipolar Plate Manufacturing Process Control

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Contract Number: DE-EE0001047

Project Start Date: October 1, 2007 Revised Interagency Agreement (October 1, 2009)
Project End Date: October 1, 2009 Revised Interagency Agreement (October 1, 2011)

Objectives

- Identify and evaluate the capability and uncertainty of commercially available non-contact, high-speed scanning technologies for applicability to bi-polar plate manufacturing process control.
- Using capabilities identified in the first objective, demonstrate smart assembly concept (new under revised interagency agreement).

Technical Barriers

This project will address the following technical barriers from the Manufacturing R&D – Fuel Cells section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(B) Lack of High-Speed Bipolar Plate Manufacturing Processes

(F) Low Levels of Quality Control and Inflexible Processes

Contribution to Achievement of DOE Manufacturing Milestones

This project will contribute to achievement of the following DOE milestones from the Manufacturing R&D section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 7.** Develop manufacturing [quality control measurement] processes for graphite resin, natural flake graphite, and metal plates. (4Q, 2010)
- **Milestone 12.** Demonstrate pilot scale processes for assembling stacks. (4Q, 2013)
- **Milestone 13.** Complete development of standards for metrology of PEM fuel cells. (4Q, 2010)

Accomplishments

- Evaluated and concluded that photogrammetry is not a potential measurement solution for this application (9/2009).
- Assessed the capabilities and performance of several in-house instruments for use as a test bed for Phase II Sensor Testing (Accuracy as a Function of Scan Rate) and found only one that was marginally acceptable and most likely not the ultimate setup (12/2009).
- Discovered through initial Phase II testing, using our intermediate test bed with the laser spot triangulation probe, promising performance for some parameters but approach/sensor combined performance limitations for others (1/2010).
- Designed and procured (awaiting delivery) the necessary components to facilitate the fabrication/assembly of a dedicated sensor evaluation platform meeting all desired performance specifications. This dedicated platform is necessary to overcome the limitations identified in the previous two bullets and it will ultimately provide us the translation mechanism to evaluate these sensors over the desired range of scan rates (3/2010).

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Introduction

Based on input from numerous bipolar plate manufacturers, we initiated an internally funded project in the summer of 2007 to develop, integrate, and evaluate non-contact, high-speed sensors or system of sensors for application in the dimensional process control of bipolar plates. This effort initially focused on determining the measurement needs of plate manufactures; this included learning what the common plate materials were and the current methods of fabrication and inspection. Using this information, we attempted to identify what, if any, alternative commercially available measurement technologies existed that would be suitable for in-line high-speed inspection or if a solution needed to be developed. Since 2008, DOE has provided funding support for this project and in 2009 the project scope was modified to include demonstrating the concept of "Smart Assembly." This additional objective, the concept of "Smart Assembly" is that if plate parallelism is measured and tagged to each plate, then assembly can be done in an automated fashion where plates are configured ideally to minimize the overall stack parallelism. This will allow lower tolerances on individual plate parallelism.

To date, an informal survey of plate manufacturers indicates that they are using vision-based ex situ systems for inspection of plate dimension. With the nature of the plate materials used and features of interest this approach is subjective, potentially not fully automatable, and does not have the accuracy required for evaluating the tighter tolerance demands. Furthermore, plate manufacturers have not yet looked for potential high-speed in-line solutions as high production volumes have not yet been demanded. In regards to measurement technology, numerous well qualified solutions for topography characterization exist but accuracy of lateral dimensions seem questionable for this application as these systems were not originally intended for those types of measurements.

Ultimately this project aims to enable cost reduction and rapid commercialization by providing plate manufacturers with a traceable, high-speed, fully automated solution for process control and intelligent stack assembly along with the information needed to optimize inspection scan rates as a function of the accuracy requirements.

Approach

Our approach includes the identification and/or development, integration, and evaluation of high-speed non-contact sensors or system of sensors for application in process control of bipolar plates. The evaluation will include: suitability based on typical plate materials and methods of fabrication, ability to quantify the dimensional parameters of interest to the accuracy required to evaluate those parameters against the tightest tolerance demands, and the flexibility to vary the scan rate (velocity). This variability in scan rate will enable fabrication rate flexibility that can be selected in relation to accuracy required. During this process we intend to develop measurement evaluation protocols for both sensors and plates to support and substantiate our efforts and to support future evaluation efforts as new sensors become available. Inclusive in these measurement protocols will be approaches for achieving contractual traceability requirements to support international product acceptance. Lastly, assuming a suitable measurement solution is obtained; demonstrate the concept of "Smart Assembly."

Results

Although an ongoing effort, we have conducted research to determine the scope of potential measurement solutions, common plate materials, typical high-speed plate fabrication methods, and the plate dimensional parameters of interest along with the associated range of tolerances encountered. In general, the measurement solution must be able to perform lateral and topographical (vertical) measurements on both graphite (diffuse) and metallic (shiny) plates, at high incident angles commonly encounter due to tapered sidewalls (a product of many high-speed fabrication techniques or by design), capable of scan rates of up to minimally 100 linear mm/s (300 mm/s desired), and to an accuracy suitable for evaluating these parameters against tolerances ranging from 0.05 mm down to 0.012 mm.

Our initial efforts resulted in the procurement of two potentially promising structured-light non-contact sensors, both of which were evaluated based on ability to measure both graphite and metallic plates, as well as, their sensitivity or lack of as a function of incident angle (Phase 1). From this testing, one of the sensors, a 30 um diameter laser spot triangulation probe showing the best promise from the initial testing was mounted to the spindle of a 3-axis machine tool where it was tested in a scanning configuration to evaluate its sensitivity to measurements of feature height and to demonstrate the feasibility of lateral measurement by tying profile data to velocity of the translation mechanism.

Over the past year, the testing of this sensor moved to another test bed that provided us with a platform for evaluating the sensor accuracy as a function of scan speed (Phase 2). As part of this process numerous in-house measurement instruments were evaluated for velocity stability and velocity range capability. Unfortunately, none of these instruments satisfied the needed stability of 0.01 mm/s and minimum selectable and stable velocity of 100 mm/s. The coordinate measuring machine (CMM) chosen as an intermediate test bed has a maximum velocity of 70 mm/s and stability of 0.03 mm/s at 30 mm/s as measured using a the velocity output of a laser interferometer. Although this test bed did not meet the desired requirements it did allow us to discover numerous performance limitations and determine their cause based on the sensor and/or the approach used to quantify lateral dimensions.

Using this intermediate test bed for the laser spot triangulation probe we assessed the performance using "gage blocks" for absolute testing and sample fuel cell plates characterized using a more accurate reference system for repeatability and correlation testing at 30 mm/s (Figure 1).

The laser spot triangulation probe demonstrated a repeatability of 1.5 um and errors on the order of 2 um or less on the width of flow field channels with “sharp” edges such as those produced by machining. Figure 2 shows flow field channel width comparison data between the non-contact laser triangulation spot probe and reference measurements performed on our dual-probe micro-feature CMM. The plate used is a carbon composite plate with machined flow field channels. The flow field consists of three individual channels in a serpentine configuration. This particular plate was a reject from an initial machining process employed to make experimental plates for our other plate manufacturing project. In this instance, as you scan across the plate with the channels oriented perpendicular, each individual channel is measured several times and the data shows each channel has a different average width. For this project this is the perfect plate in that the data shows excellent agreement between the non-contact probe and the reference data and it shows the non-contact probe has the sensitivity to see these subtle differences (approximately 10 to 20 µm) between the channels.

Unfortunately, the reality is that bipolar plates manufactured by typical high-speed fabrication techniques, such as, injection molding compression molding, and stamping have chamfered edges and tapered sidewalls (Figure 3). The effect of this was apparent for the gage block and injection molded bipolar plate measurements where width errors of 10 um or more were common.

Using the machined plates in Figure 1 and the injection molded plates shown in Figure 3 along with reference values obtained using a more accurate dual-probe micro-feature CMM, height errors where found to be within the range of 1 to 7 um.

In addition, we demonstrated feasibility for plate parallelism measurement by conducting a simple test using the machined graphite plates where data was collected as the laser spot triangulation probe was translated across the plate overlapping the edges of the plate to collect data from the reference surface upon which the plate was fixtured. The reference plate for

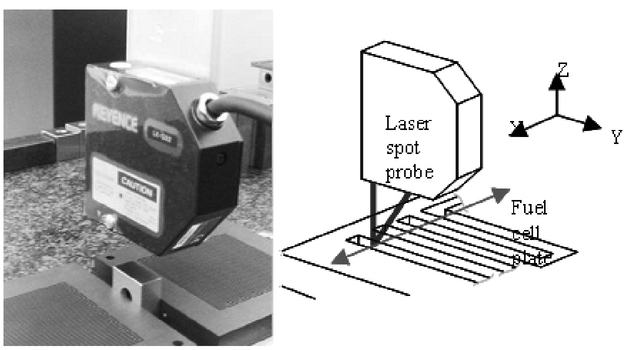

FIGURE 1. Laser Spot Triangulation Probe Mounted to Z-Axis of CMM. Setup Shows Reference Gage Block, Machined Flow Field Plates from NIST Project 1, and Scanning Pictorial.

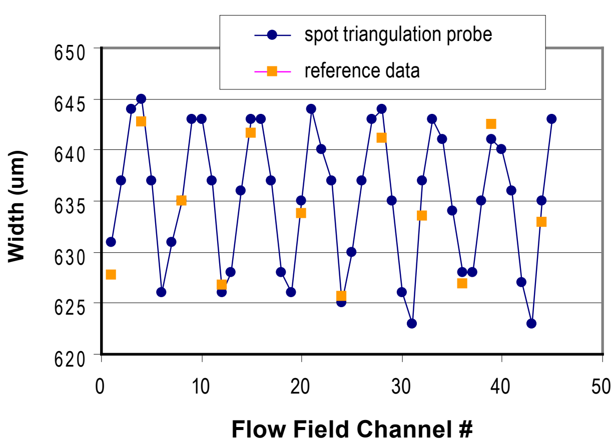

FIGURE 2. Laser Spot Triangulation Probe Comparison Data Using a Machined Flow Field Plate with Real Channel-to-Channel Differences in Width

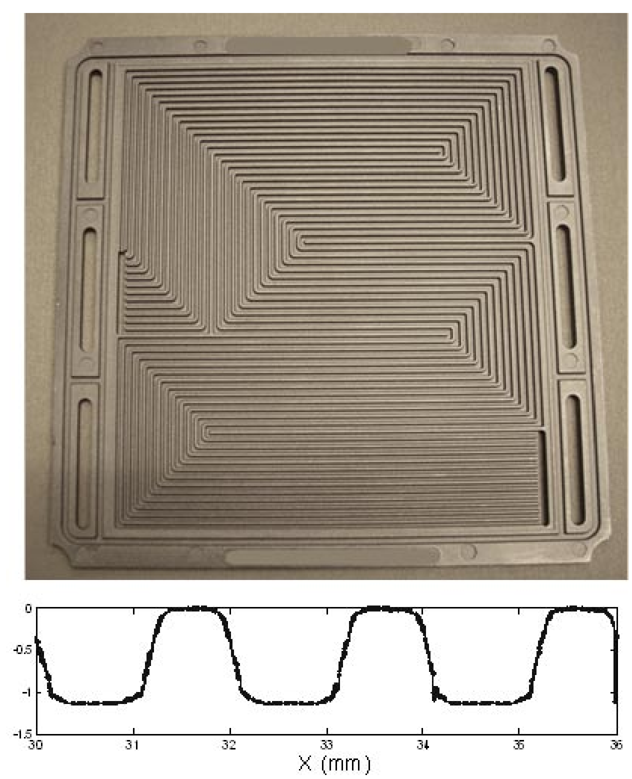

FIGURE 3. Example Output from Laser Spot Triangulation Probe of a Injection Molded Plate

our test was a porous ceramic square vacuum chuck encased in a granite frame. The flatness of the entire surface, ceramic area and frame is less than 2 um. By applying a least-squares linear fit to the profile data that corresponds to the reference surface then removing the slope of the best-fit line from both the reference plane data and the plate surface data, the variation in parallelism between the bottom plane and plate, top plane, can be quantified. This was simplified in that we scanned only one profile line rather than numerous lines across the surface and that we used one probe and a reference plane. Application on a real production line would utilize two or more opposing probes where the differences would be analyzed.

Concurrent to this effort, we also explored photogrammetry as a potential measurement solution and we procured a "laser line" triangulation based probe similar to the individual "laser spot" probe that has thus far shown promising results. Photogrammetry was conceived as a possible solution shortly after the 2008 DOE Annual Merit Review Meeting; however our research shows that this is a "no-go" even with the enormous advancements in the resolution of digital single lens reflex cameras due to the aspect ratio between the channel depth and width.

Conclusions

- Photogrammetry is not a potential measurement solution for this application due to aspect ratio between channel depth and height.
- Phase 2 Preliminary Testing Conclusions:
  - On our intermediate probe testing platform, at a translation speed of 30 mm/s, the laser spot triangulation probe has the potential to meet the needs for this high-speed non-contact application, if limitations due to the interaction of the probe with chamfered edges and tapered sidewalls can be overcome.
  - Height errors are acceptable and for the most part sensor based only, but lateral errors are a function of the sensor and our approach that obtains position using the sampling rate of the probe in conjunction with the known velocity of the probe translation mechanism.
- Devised a new approach that synchronizes the probe data collection with the position of a precision stage with an adjustable translation velocity. This approach eliminates the need for a calibrated (known) and stable translation velocity.
- Designed, procured (awaiting delivery), and fabricated all necessary ancillary equipment (two stages and associated controllers, framing, and fixturing mechanisms) to assemble a dedicated sensor test bed to implement our revised approach (Figure 4).

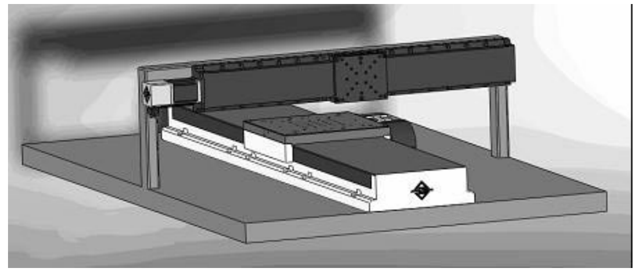

FIGURE 4. Future NIST Non-Contact Sensor Test Bed

Future Directions

- Assemble and test new non-contact sensor test bed.
- Test new approach for measurement of lateral dimensions.
- Investigate edge-effect.
- Using the variable translation speed of the new test bed, perform rigorous characterization of the laser spot triangulation probe accuracy as a function of scan speed up to 300 mm/s.
- Test line-based triangulation probe.
- Extend testing to other probing technologies as appropriate.

Disclaimer

Certain commercial equipment, instruments, or materials are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Acknowledgements

The work detailed in this report would not have been possible without the contributions of the following, all are NIST personnel and guest researchers unless otherwise noted: Dennis Everett, Bala Muralikrishnan, Wei Ren, and Ted Doiron.

FY 2010 Publications/Presentations

1. Precision Engineering 2009 Program Technical Accomplishments, pp 42-45, 2010 http://www.nist.gov/mel/ped/index.cfm.

2. E. Stanfield, "Metrology for Fuel Cell Manufacturing," DOE Annual Merit Review Proceedings, MN006, June 11, 2010, http://www.hydrogen.energy.gov/pdfs/review10/mn006_stanfield_2010_o_web.pdf.