VI.10 Non-Contact Sensor Evaluation for Bipolar Plate Manufacturing Process Control and Smart Assembly of Fuel Cell Stacks

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Fiscal Year (FY) 2011 Objectives

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

Technical Barriers

This project addresses the following technical barriers from the Manufacturing R&D 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 R&D 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)

FY 2011 Accomplishments

- Completed the design, fabrication and testing of a dedicated fuel cell metrology station using Aerotech translation stages (stages procured in August 2010) and Keyence laser spot triangulation probes.
- There are several interesting features to note in this design:
  - We integrated two laser spot triangulation probes that are titled in opposing directions. The use of two tilted probes allows collection of data from the side walls of the channels; a single probe looking straight down cannot acquire any side wall information.
  - The data from the laser triangulation probes is synchronized with the position from the translation stage and therefore velocity fluctuations are no longer a concern.
  - The stage has a maximum travel speed of 2,000 mm/sec. We have evaluated channel depth and height on fuel cell plates from speeds of 30 mm/sec to 500 mm/sec without noticing any significant degradation in accuracies at higher speeds.
- Performed numerous tests on the fuel cell station using calibrated gage blocks. The details are recorded in our project update submitted on January 21st, 2011 [1] and in a paper currently under review.
- Measured channel width and height on carbon bipolar plates using this non-contact system. Width and height results were within ±2 µm of the values obtained using a contact coordinate measuring machine (CMM).
- Performed detailed uncertainty budgets for channel width and height for carbon bipolar plates which showed expanded uncertainty of 6 µm (k=2) for width and 3.8 µm (k=2) for height. The details are recorded in [2].
- Completed design of fixtures required to perform thickness measurements on fuel cell plates (one probe looking down on the plate while the second probe is positioned below the plate looking up). Thickness

and parallelism measurements on plates are critical for 'smart assembly'.

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Introduction

The objective of this project is to enable cost reduction in the manufacture of fuel cell plates by providing a rapid non-contact measurement system that can be used for in-line process control. Manufacturers currently either visually inspect plates or use machine vision systems for verifying tolerances. Such methods do not provide the sub-10 µm accuracy that manufacturers are targeting. In this context, we have studied available non-contact sensors in the market for their suitability to be used for fuel cell plate metrology. From our studies, we have short listed laser spot triangulation probes as one of the promising candidates for further exploration. We have since incorporated these probes in a unique two-probe system to develop a rapid yet high accuracy non-contact system that manufacturers can adopt towards process control and metrology. We plan on further extending our design to perform thickness measurements using opposed probe configuration that will enable 'smart assembly'. 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.

Approach

We studied numerous sensors to assess their suitability as a rapid non-contact dimensional measurement tool for bipolar fuel cell plates. We selected laser spot triangulation probes for further investigation because they offered large range (±5 mm) and micrometer level resolution. Our approach then is to build a dedicated fuel cell metrology station with Aerotech translation stages and laser triangulation probes as the non-contact probe of choice. We then intend to test the performance of our system using calibrated gage blocks and subsequently measure numerous bipolar fuel cell plates that have also been previously measured with a contact CMM. Such measurements will enable us to place bounds on errors; a detailed uncertainty budget will also be created to understand dominant error sources. Finally, we also plan on performing thickness and parallelism measurements using two laser triangulation probes (one probe looking down on the plate while the second probe is positioned below the plate looking up). Tagging each plate with thickness and parallelism data will enable the selection of those plates that reduce the combined total parallelism of the stack, a process we describe as 'smart assembly'.

Results

During the last year, we have made significant progress in developing and testing our non-contact fuel cell metrology station. We describe major results next.

Characterizing Triangulation Probe Errors

Our investigations on laser triangulation probes revealed numerous error sources that impact dimensional measurements. Many of these are error sources have been described in the literature before [3]; our studies have attempted to place bounds on errors for linear dimensional measurements and also serve to caution users that laser triangulation probes are not plug-and-play devices as they are often described to be in manufacturer's literature. Despite their limitations, we believe these probes are superior to other non-contact options available currently, if carefully employed.

Our experiments studied the following factors: repeatability and noise levels, linearity errors, influence of material/optical properties on height and width measurements, effect of spot size on width measurements, side wall reflections, secondary reflections, and measurements at grazing angle. Figure 1 shows the linearity error over the 10 mm range of the probe for a ceramic and graphite test object. The manufacturer's specification of ±5 µm is only valid for the ceramic case; it is clear from Figure 1 that it does not hold for the graphite case. While these and other such results are summarized in [1] and also in a paper currently under review, we highlight one particular source of error that has significant implications for fuel cell plate measurements under our dual-probe design (discussed next), namely, the influence of part material and optical properties on dimensional measurements. It is well known that triangulation probe suffers from volumetric scattering and surface penetration. We have used ceramic gage blocks and demonstrated experimentally that width and height errors of the order of 10 µm are possible when material/optical properties are not identical for the different

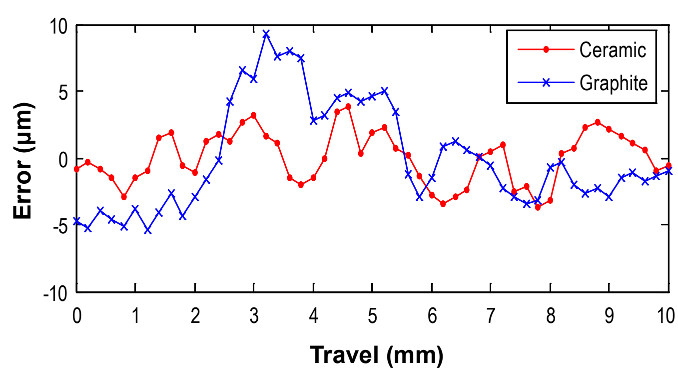

FIGURE 1. Linearity Error when the Probe's Laser is Incident at 25° with the Surface

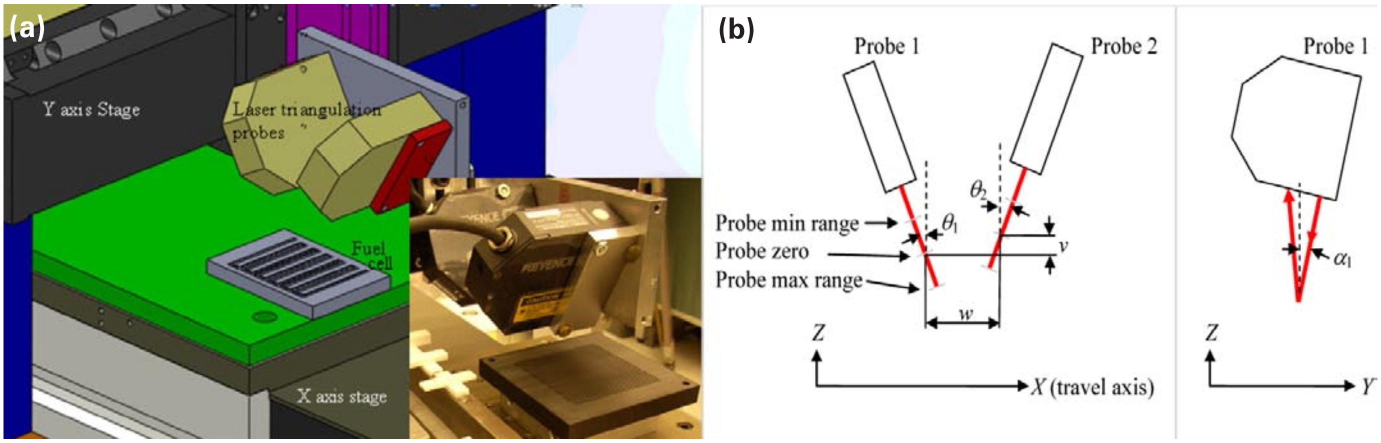

FIGURE 2. (a) The fuel cell metrology station showing two laser triangulation probes, each tilted in opposing directions to obtain side wall information. (b) Six system parameters to be determined by calibration.

surfaces that comprise a height or width feature, although these surfaces may appear to be visually similar. This implies that care must be taken in calibrating the dual-probe system with an artifact made of identical material as the part.

The Dual-Probe Fuel Cell Metrology Station

One unique aspect of our fuel cell station design is that we have incorporated two laser triangulation probes that are titled in opposing directions as Figure 2(a) shows. The purpose of having two tilted probes is to be able to acquire channel side wall information, which a single probe looking straight down cannot accomplish. But having two probes necessities the determination of six system parameters (tilt angles and offsets) shown in Figure 2(b); we have developed a calibration procedure for this purpose and have described it in detail in [2]. Determining these system parameters accurately is essential in superimposing the data from the two probes into a common frame of reference.

While it may appear that the tilt angle θ of the probes can be determined by measuring a calibrated height block, we show in [2] that such measurements are corrupted by misalignment angle α and are therefore not very accurate. We further demonstrate that vertical profile measurements (measurements on the vertical face of a gage block) can yield much higher accuracies because the misalignment angle α can be separated out. The mathematics and uncertainty in such calculations are described in [2].

Bipolar Plate Measurements and Uncertainty

We have compared measurement results on fuel cell plates from our non-contact system against a contact CMM. Our results for channel height and width on a graphite bipolar plate agree to within ±2 µm as Figure 3 shows. The expanded uncertainties on height and width for the contact CMM are 0.5 µm and 1.7 µm. We have developed detailed

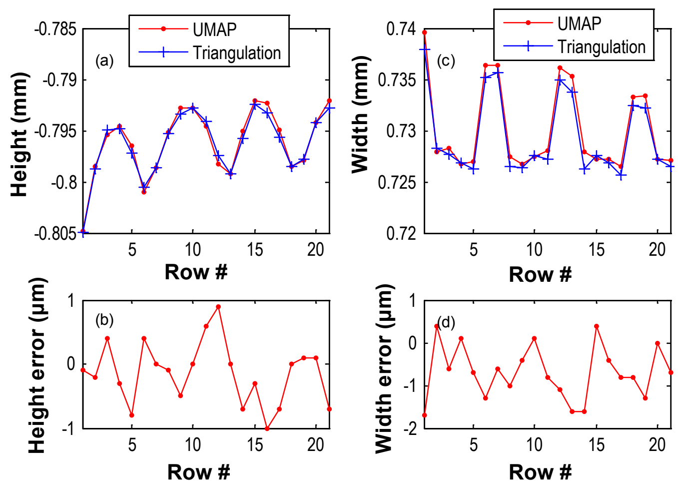

FIGURE 3. (a) Measured height of each row using both the ultrasonic micro and accurate probe (UMAP) and the dual-probe laser triangulation system (b) Height error for each row (c) Measured width of each row using both the UMAP and the dual-probe laser triangulation system (b) Width error for each row.

uncertainty budgets for the graphite bipolar plate channel height and width measurements; they are described in [2]. We estimate expanded uncertainty of 6 µm (k=2) for width and 3.8 µm (k=2) for height using our non-contact system on the graphite part. Major contributors to the uncertainty are the probe linearity errors and pitch motion of the stage.

Speed Tests

We performed width measurements at different speeds on an etched plate. The results from 30 mm/sec to 500 mm/sec are shown in Figure 4. There is no significant degradation in accuracy at 500 mm/sec in comparison to that at 30 mm/sec as Figure 4 shows. We have also verified the same for height measurements; those data are not shown here.

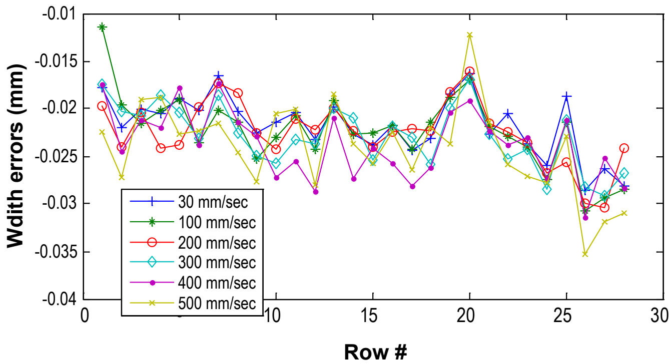

FIGURE 4. Width Errors at Different Speeds as a Function of Row # for an Etched Plate

Conclusions

To date, we have designed, built, and tested a dedicated dual-probe fuel cell station system for dimensional inspection of fuel cell plates. The two probes are oriented in a novel configuration that increases the accuracy of lateral dimensions and simultaneously provides the ability to capture side wall information for form evaluation. With this design we performed numerous experiments to study the different error sources (such as edge effects, linearity errors, spot sizes, etc.) in laser triangulation probes and their impact on dimensional measurements. With a thorough understanding of the error sources the limitations of these probes can be overcome making their application suitable for fuel cell metrology. Following careful evaluation of the sensor errors and approaches to minimizing them we made comparison measurements of channel height and width using sample fuel cell plates fabricated by common methods that were previously measured using a micro-feature CMM. With a high quality fuel cell flow field plate we demonstrated agreement with reference measurements to within ±2 µm. From our error source investigation and intercomparison measurements we developed a detailed uncertainty for both height and width measurements. We then furthered our capability study to evaluate accuracy as a function of scan speed, finding that there was no noticeable degradation of accuracy up to 500 mm/s.

Future Directions

The final phase of this project involves developing a configuration that provides the capability to measure variation in plate thickness. The opposing probe design modification has been developed and the additional mounting fixtures are being fabricated. Upon completion of the new probe fixturing components we will began demonstrating the capability of the system to measure variation in thickness along the development of a detailed measurement uncertainty. From these data we intend to show that parallelism from variation-in-thickness can be derived and used for the concept of "smart assembly."

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

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FY 2011 Publications/Presentations

1. Eric Stanfield, Non-Contact Sensor Evaluation for Bipolar Plate Manufacturing Process Control and Smart Assembly of Fuel Cell Stacks, Project Update, January 21, 2011.

2. B. Muralikrishnan, W. Ren, D. Everett, E. Stanfield, T. Doiron, Dimensional Metrology of Bipolar Fuel Cell Plates Using Laser Spot Triangulation Probes, Measurement Science and Technology, 22(7), July 2011.

3. E. Stanfield, "Non-Contact Sensor Evaluation for Bipolar Plate Manufacturing Process Control," FY 2010 Annual Progress Report, DOE Hydrogen and Fuel Cells Program, February 2011 http://www.hydrogen.energy.gov/pdfs/progress10/vi_7_stanfield.pdf

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1. Eric Stanfield, Non-Contact Sensor Evaluation for Bipolar Plate Manufacturing Process Control and Smart Assembly of Fuel Cell Stacks, Project Update, January 21, 2011.

2. B. Muralikrishnan, W. Ren, D. Everett, E. Stanfield, T. Doiron, Dimensional Metrology of Bipolar Fuel Cell Plates Using Laser Spot Triangulation Probes, Measurement Science and Technology, 22(7), July 2011.

3. A. Garces, D. Huser-Teuchert, T, Pfeifer, P Scharsich, F. Torres-Leza, E Trapet, Performance test procedures for optical coordinate measuring probes, Final project report, part 1, July 1993, European Communities Brussels, Contract No. 3319/1/0/159/89/8-BGR-D (30).