VI.4 Non-Contact Sensor Evaluation for Bipolar Plate Manufacturing Process Control and Smart Assembly of Fuel Cell Stacks

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Fiscal Year (FY) 2012 Objectives

- Expand the capabilities of the measurement system to include measurement of plate thickness and variation-in-thickness.
- Identify and quantify all measurement system error sources in the form of an uncertainty budget.
- Optimize the measurement uncertainty of the system by either physically modifying the system design or application of unique and/or improved calibration methods and physical standards.
- Evaluate the uncertainty of the measurement system as a function of scan speed.

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 R&D Analysis 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 2.2 Develop rapid prototyping and flexible tooling specifically for the manufacture of bipolar plates. (4Q, 2012),
- Milestone 2.3: Develop manufacturing processes for PEM bipolar plates that cost <$3/kW while meeting all technical targets. (1Q, 2018).

FY 2012 Accomplishments

- In FY 2012, we designed and fabricated a fixture to perform opposed point 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’.
  - Studied error sources in the measurement of thickness using opposed point probing.
  - Developed uncertainty budget for such measurements and validated the budget using thickness measurements on gage blocks of known width.

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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 reported the results of this work in the 2011 DOE Hydrogen and Fuel Cells Program Annual Progress Report and in References 2 and 3. In FY 2012, we have modified the fuel cell measurement system by designing and fabricating a fixture so as to measure thickness of fuel cell plates using an opposed probe configuration (Figure 1). Plate thickness information is critical in ensuring that the stack parallelism and thickness uniformity is within stated tolerances. We have studied error sources in the measurement and developed an uncertainty budget for thickness measurements.

Approach

To achieve the objectives of this project we surveyed both the fuel cell plate manufacturing industry and the measurement equipment manufacturing industry. With regards to the fuel cell plate manufacturing industry, we identified the current measurement inspection technologies being employed, the dimensional parameters of interest, and the applicable tolerance levels encountered. Using this information we researched commercially available high-speed non-contact measurement technologies that might be suitable based on published literature. With potentially suitable measurement technologies identified, we evaluated their suitability more rigorously using a set of tests designed to determine their sensitivity to material characteristics (i.e., surface reflectivity) and ability to measure dimensions representing common plate parameters of interest. The bounds of the material sensitivity testing were chosen so that sensors deemed suitable would be able to measure both highly reflective and highly diffuse materials, representative of metallic and carbon based plates currently being manufactured.

The measurement technology most suitable (laser spot triangulation probes) was assembled into a measurement system (test bed) capable of performing detailed single-sided vertical and lateral channel dimensional inspection. This was followed by the expansion of the system to achieve the ultimate goal of dual-sided evaluation enabling thickness and variation-in-thickness measurement capability. To achieve this dual-sided capability we were able adopt the same non-contact probing technology in an alternative configuration versus incorporating another independent non-contact measurement technology. At both design iteration stages, the uncertainty capability of the measurement system developed was rigorously evaluated and optimized, for accuracy and accuracy as a function of speed, through the measurement of reference artifacts and comparison measurements against reference measurements made on sample fuel cell plates using an alternative higher-accuracy method. The sample plates used were representative of plate materials and fabrication methods commonly found in the fuel cell industry. Throughout this process we developed documented testing protocols to enable replication by the industry user in the evaluation of their own systems.

Results

This section describes our results from our opposed-probe thickness measurement.

There are several possible sources of error in our measurement. We consider the following sources of error in thickness measurements:

1. *X, Y, Z* offsets for both top and bottom probes.
2. Tilt angles in *YZ* plane for both top and bottom probes.
3. Tilt angles in *XZ* plane for both top and bottom probes

The offset error occurs when the two probes do not read zero at the same point in space. This separation may be resolved along the X, Y, and Z directions. We compensate the measured data for the X and Z offsets as discussed below. We also present a method to estimate the Y offset; this is later used in the uncertainty budget. While we estimate the tilt angles of the probes, we do not compensate the measured data; we simply used the estimates in the uncertainty budget for thickness.

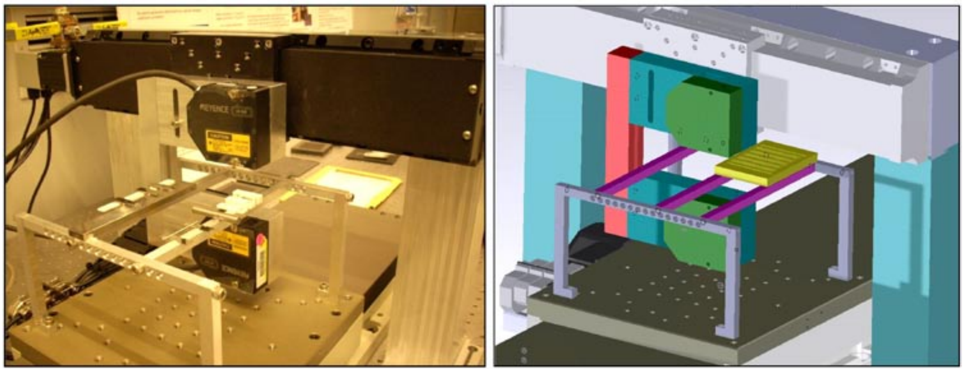


FIGURE 1. Photo and schematic of opposed probe configuration for thickness measurements

Probe Z Offset

Since the thickness measurement is the sum of the readings of the two probes, a Z offset error will directly affect thickness measurements. While measuring the thickness of a single calibrated gage block (and comparing against its known thickness) will provide an estimate of this offset, we measured thicknesses of multiple blocks to determine an average offset.

Probe X and Y Offset

The X offset calibration is performed by mounting a cylinder so that its axis is parallel to the Y axis. The two probes then scan a profile across this cylinder. Best fit circles are constructed on the data and the shift along the X axis is used as the estimate for the X offset. In order to estimate the Y offset, a disk with sharp edges is placed on the table and scans are performed on chords away from the largest diameter (all scans are along X axis). From the measured chord lengths for the two probes (L_1 and L_2), and the known disk radius R, we estimate the Y offset. Refer to Figures 2(a) and 2(b).

Tilt Angles

The probes can be tilted in both the XZ and the YZ planes. We estimate the magnitude of the tilts by measuring the thickness of several gage blocks of known thickness. Tilted probes will produce a larger measured thickness. This produces an upper bound on the tilt angle for the probes. We manually adjust the tilt to obtain an upper bound of ±3° on the probe tilt and use this value in the uncertainty budget for thickness measurements.

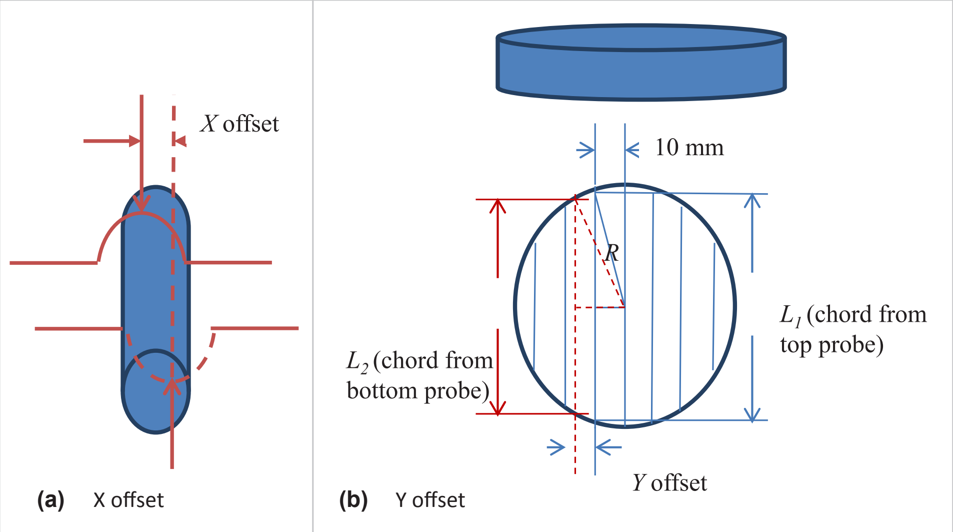
Opposed Probe Thickness Measurement Uncertainty Budget (using 4-mm nominal thickness gage block)

Laser triangulation probes are sensitive to material/optical properties of the test artifact and suffer from linearity errors. Assuming the Z offset calibration suffers from a ±5 µm error due to the difference in material properties between the calibration artifact and the test artifact, and assuming a rectangular distribution, the standard uncertainty in the offset calibration will be $5/\sqrt{3} = 3$ µm. The manufacturer's specification for probe linearity is also ±5 µm, and therefore assuming a rectangular distribution, the standard uncertainty in thickness measurements will be $5/\sqrt{3} = 3$ µm.

The X and Y offsets will not introduce an error when measuring perfectly flat/parallel gage blocks if the block is aligned to have no tilt. On the other hand, if the block is tilted (we are assuming a bound of ±3° for the tilt and a rectangular distribution), and assuming a 50-µm error in the calibration of the X and Y offset, we estimate a standard uncertainty of 5 µm in thickness due to these offsets.

Assuming a bound of ±3° for the probe tilt in the XZ and YZ planes, we estimate a standard uncertainty of 3.5 µm for thickness of the 4-mm thick gage block due to probe tilt.

It is not clear yet how the stage motion errors will contribute to thickness measurement errors. Z straightness errors have a negligible effect on the thickness errors since it affects both probes in the same way. The rigidity of the plate fixture will perhaps contribute to thickness measurement errors, but we have not yet determined its precise quantitative influence. We are currently operating the stage at 30 mm/sec. Increasing the speed will deteriorate measurement accuracy unless a more rigid fixture is designed.



(a) X offset **(b)** Y offset

FIGURE 2. Estimating the X and Y offsets

Combining the terms above, we estimate a combined standard uncertainty of 10 µm, or an expanded uncertainty of 20 µm ($k = 2$) on the thickness values.

TABLE 1. Results from measurements on gage blocks

Gage Block Manufacturer	Nominal (mm)	Deviation from Nominal (mm)
Webber	3.302	-0.0067
Webber	6.350	-0.0051
Mitutoyo	4.318	-0.0014
European	4.000	-0.0020

Conclusions and Future Directions

- Designed and fabricated a fixture to measure opposed point thickness of fuel cell plates.
- Studied error sources in the measurement, developed procedures to calibrate the system parameters (offsets and tilts), and developed an uncertainty budget for thickness measurements.
- Validated the system by measuring gage blocks of known width.
- Future work includes measurement of fuel cell plate thickness and comparing the measured values against measurements from other techniques (using a coordinate measuring machine to measure the thickness).
- Refine the uncertainty budget by further studying the error sources.

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.

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FY 2012 Publications/Presentations

1. B. Muralikrishnan, W. Ren, D. Everett, E. Stanfield, T. Doiron, Performance evaluation experiments on a laser spot triangulation probe, Measurement: Journal of the IMEKO, 45(3) 2012, 333-343.

References

1. E. Stanfield, “Non-Contact Sensor Evaluation for Bipolar Plate Manufacturing Process Control and Smart Assembly of Fuel Cell Stacks,” 2011 DOE Hydrogen and Fuel Cells Program Annual Progress Report, November 2011, http://www.hydrogen.energy.gov/pdfs/progress11/vi_10_stanfield_2011.pdf

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. B. Muralikrishnan, W. Ren, D. Everett, E. Stanfield, T. Doiron, Performance evaluation experiments on a laser spot triangulation probe, Measurement: Journal of the IMEKO, 45(3) 2012, 333-343.