



Demonstration of an Automated Assembly Process for Proton Exchange Membrane Fuel Cells Using Robotic Technology

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Dr. Gurau is a full-time tenure track Assistant Professor of Engineering Technology at Kent State University, Tuscarawas campus. Previously he worked for seven years as a Senior Research Associate in the Chemical Engineering Department at Case Western Reserve University where he served as Principal Investigator on several research programs funded by the State of Ohio's Third Frontier Fuel Cells Program, by the U.S. Department of Energy or in collaboration with General Motors. In this quality he performed research on different fuel cell technologies, including numerical modeling and simulations (Computational Fluid Dynamics and systems optimization), experimental research design, fuel cell component characterization, fuel cell stack design etc. Dr. Gurau has more than two years experience in fuel cell industry with Energy Partners, l.c. (now Teledyne Energy Systems, Inc.) as a research specialist, where he modeled fuel cell phenomena in order to predict and optimize cell performance, including developing of analytical and numerical models (heat and mass transfer in multi-phase, multi-component flows with electro-chemical reactions, flows in porous media, etc). He is the author of several patents related to PEM fuel cells and the author of more than twenty publications in peer review journals or conference presentations in the fuel cells area. Dr. Gurau obtained his Ph.D. degree in 1998 from the Mechanical Engineering Department, University of Miami.

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1. Introduction

At the recommendation of the ABET accreditation committee, a new capstone design project class - *Engineering Technology Project* was introduced in the Engineering Technology Department at Kent State University at Tuscarawas in the spring semester of 2011. Students work in groups under direct faculty supervision on creative, challenging, open-ending projects proposed by the professor in the area of renewable energy. Practical, hands-on experience is emphasized and analytical and design skills acquired in companion courses are integrated. These projects align with Ohio's *Third Frontier Fuel Cell Program* commitment to accelerate the growth of fuel cell industry in the state, to investigate manufacturing processes and technologies, to adapt or modify existing components and systems that can reduce the cost of fuel cell systems, to address technical and commercialization barriers and to demonstrate market readiness ^[1].

Projects on which our students worked during the capstone design project class included the design and fabrication of a nine-cell, 50 cm² active area proton exchange membrane fuel cell (PEMFC) stack, a first ever successful demonstration of an automated assembly process of a PEMFC stack using robotic technology, design and fabrication of instrumentation for measuring physical properties for fuel cell components and the investigation of manufacturing processes for polymer/graphite-based bipolar plates for PEMFCs.

As identified by the U.S. Department of Energy, one of the obstacles that remain to be resolved on the road to hydrogen economy is the cost of manufacturing fuel cells. In today's fuel cell industry the fuel cell stacks are assembled manually in a lengthy process involving a repetitive work cycle in which human errors are common. To our best knowledge the demonstration of an automated assembly line for PEMFCs has not been achieved successfully in the past. The reason is the difficulty to perfectly align the fuel cell components in the stack in order to eliminate overboard reactant leaks as well as the variety of fuel cell components that need to be handled by robot arms. Additional obstacles are the general lack of compliance (flexibility) of the robot joints and the inherent limitations in a robot's accuracy and repeatability. These latter two factors reduce a robots capability to tolerate and compensate for misaligned parts. In our opinion, another major barrier in the way to successfully demonstrate in the past the feasibility of automated assembly lines for fuel cells was related to an insufficient integration of the fuel cell design process with the design of the automated assembly line.

We present an innovative, inexpensive end-effector, the robot workcell and the fuel cell components used to demonstrate successfully for the first time the automated assembly process of a PEMFC stack. The end-effector is capable of handling a variety of fuel cell components including membrane electrode assemblies (MEAs), bipolar plates and gaskets. The end-effector and the fuel cell components are designed with features that allow an accurate component alignment during the assembly process. All fuel cell stack components and the end-effector have

been built in house and the automated assembly process has been demonstrated with limited resources and available time by students during the capstone design project class offered in the spring semester of 2011^[2,3].

2. Course Development

The capstone design project class – *Engineering Technology Project* was first offered in the Engineering Technology Department at Kent State University at Tuscarawas in the spring semester of 2011–2012 academic year as a 3 credit hours course. The course was implemented at the recommendation of the ABET accreditation committee and was converted from a previously offered class, *Robotics and Flexible Automation*. The new course introduces the students to automated manufacturing systems, computer numerical control (CNC) programming and industrial robotics through creative, challenging, open-ending engineering design projects in the area of renewable energy. Practical, hands-on experience is emphasized and analytical and design skills acquired in companion courses are integrated. Students work in groups under direct faculty supervision on projects proposed by the professor. Engineering communication such as reports, oral presentations and poster presentations are covered. The course is offered to associate and bachelor's degree students in Engineering Technology Department with a major in mechanical or electrical engineering technology.

The objectives of the Engineering Technology Project class are:

- i. To introduce the students to CNC programming including programming G-code for milling and turning operations;
- ii. To introduce the students to industrial robotics and robot programming;
- iii. To understand the fundamentals of fuel cells, fuel cell components, materials and manufacturing processes used in the fuel cell industry;
- iv. To be knowledgeable with the computer aided design and computer aided manufacturing (CAD/CAM) process;
- v. To acquire experience in project planning, team work, design and creative thinking;
- vi. To learn how to communicate effectively through reports, engineering drawing, oral presentations supported by PowerPoint and through poster presentations.

The course is divided into a lecture session and a laboratory session. In the spring semester of 2011 the lecture session covered an introduction to fuel cells, CNC programming, robotics technology, robot programming and notions of engineering communication including progress reports, oral presentations supported by PowerPoint slides and poster presentations. The class notes which are supported by PowerPoint slides were made available to students on Blackboard Vista. During the laboratory session, students familiarized with PEMFC manufacturing processes, developed G-codes for machining fuel cell components and fabricated them using CNC milling and laser cutting technology. They designed and built an end-effector for assembling the PEMFC stack. Students programmed a robotic arm to assemble the PEMFC stack and demonstrated the assembly process. Students practiced to communicate effectively their engineering ideas through CAD drawings, progress reports, an oral presentation and a final poster presentation covering their achievements during the class.

For the engineering technology project class students were graded based on their robot end-effector design, progress report, oral presentation, final poster presentation and class participation. The end-effector design was graded based on concept and on students' knowledge to express technical idea using CAD software such as AutoCAD or Inventor and the ASME Y14.5M-1994 standard rules. The progress report was graded based on the G-code developed and neatness of presentation. The oral presentation and final poster presentation were graded based on student's skills to communicate their achievements. For the progress report, oral presentation and final poster presentation the students were graded individually, while for the designs they were graded as group.

3. Project Details

In order to demonstrate the feasibility of the automated assembly line for PEMFC stacks, the fuel cell components were fabricated in house by students. They contain design features that allow them to be grasped and handled by the robot end-effector and to be perfectly aligned in the stack. The fuel cell stack is a 9-cell high-temperature (HT) PEMFC with an active area of 45 cm². It contains CELTEC[®]-P 1000 phosphoric acid (PA) - doped polybenzimidazole (PBI) - based MEAs purchased from BASF Fuel Cell Inc. The MEAs were purchased without the final cut for inlet and outlet manifolds along the peripheral area. The inlet and outlet manifold cuts and two positioning holes for alignment pins were cut using laser cutting (Universal Laser Systems, M300). The gaskets were cut using the same cutting system out of Perfluoroalkoxy (PFA) sheets purchased from BASF Fuel Cell Inc. The bipolar plates were machined using a Sherline CNC milling machine from 100 mm x 100 mm x 4mm graphite plates purchased from InnoVentures LLC. The bipolar plates were designed and machined with 5-channel serpentine flow field at anode and interdigitated flow field at cathode. The endplates were machined in house using the Sherline CNC milling machine from .5 inch thick Ultem plates (McMaster-Carr) and are provided with recessed pockets where copper current collector plates were flush-mounted. One of the endplates is provided with two threaded holes for alignment pins and the other has two positioning holes. The alignment pins are made of (poly)tetrafluoroethylene (PTFE) rods (McMaster-Carr) and were cut .5 inch longer than the length of the assembled fuel cell stack. The alignment pins have one end threaded in order to be mounted to the endplate and the opposite end was sharpened approx. 30° using a pencil sharpener.

The end-effector prototype is made entirely from acrylic components and consists of an upper cylindrical support and a lower cylindrical support. A circular plate is rigidly attached to the upper face of the upper cylindrical support and is provided with holes for attachment to the robot wrist assembly. A plate is rigidly attached to the upper face of the lower cylindrical support to which four level compensators (SLSA-120NR from Anver) with vacuum cups and suspension mechanisms are mounted. The level compensators were used to provide a soft touch and to reduce machine indexing when picking up and releasing components from stacks. A winglet is rigidly attached to the lower face of the lower cylindrical support and is provided with two positioning holes. The winglet is mounted such that its positioning holes align with the positioning holes in the fuel cell components during pick up and release operations. The upper and the lower cylindrical supports are connected to each other through two perpendicularly mounted miniature linear blocks and rails (Anaheim Automation). This system provides relative mobility in the X-Y plane between the lower cylindrical support holding the winglet with

positioning holes and the plate with level compensators and vacuum cups on one side, and the upper cylindrical support that connects to the robot wrist assembly on the other side. It represents a passive compliance system with minimal friction that compensates for misalignments between the positioning holes on the end-effector and on the fuel cell components and the PTFE pins mounted on the endplate during pick up and release operations. This compliance system along with the conical tip of the alignment pins may compensate for misalignments as large as a few millimeters, which are much larger than the usual limitations in a robot's accuracy and repeatability.

The workcell for automated fuel cell assembly (see Figure 1) demonstrated during the capstone design project class consists of a single Fanuc S 420F robot and a workbench on which three stacks containing bipolar plates, gaskets and MEAs and the endplate with alignment pins on which the fuel cell stack is built are securely mounted. The three stacks where the fuel cells components are picked from consist of a polyvinyl chloride (PVC) support plate with two PTFE alignment pins each, similar to the alignment pins on the fuel cell endplate. The robot picks up the fuel cell components and places them on the fuel cell endplate in the following order: bipolar plate, gasket, MEA, gasket, bipolar plate, etc. During pick up operations the positioning holes on the end-effector engage with the alignment pins on the pickup stack even if the misalignment is as large as a few millimeters, while the compliance system allows the positioning holes to realign with the pins when the end-effector approaches the stack. When the fuel cell components are released on the fuel cell stack, the positioning holes on the fuel cell components and on the end-effector align with the alignment pins on the endplate and the components are released always in the same position. To demonstrate the automated assembly process, the Fanuc S 420F robot was programmed by leadthrough programming using a teach pendant.

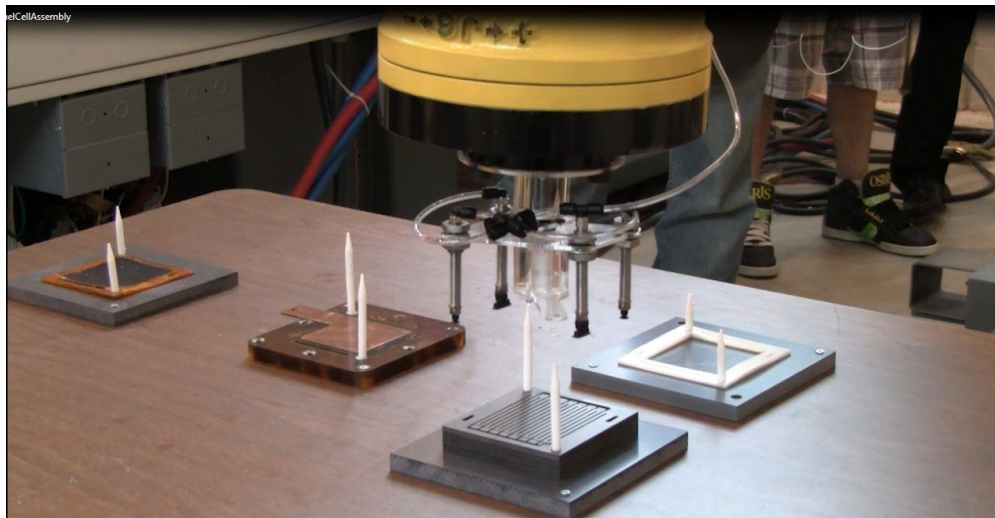


Figure 1

The workbench used to demonstrate the robotic assembly of a fuel cell. The figure shows the end-effector attached to a Fanuc robot and the fuel cell components fabricated by students during the Engineering Technology Project class

The *Engineering Technology Project* class described here was for most of the 23 enrolled students their first opportunity to integrate skills acquired in companion courses and to apply them in a class in which hands-on experience was emphasized. For the design and manufacturing tasks students worked in groups of three or four and all groups performed all the necessary tasks for the successful completion of the project. We learned that while this approach ensures that all the students acquire the necessary experience for the completion of such a complex project, some students could rely on their colleagues' efforts. We decided that for some of the *Engineering Technology Project* classes offered in the future students will be assigned specific tasks within a group and will have to collaborate for the integration of the final design. While initially some students appeared uncertain in meeting class expectations in terms of time organization and planning, through the course of the semester most of the students appreciated the value of this course and added it to their portfolios.

Some of the student comments in their unedited form are presented below:

- Professor relied a lot on students with experience in programming Fanuc robots.
- Want to learn more about robots and programming.
- I enjoyed this class.

Since the capstone design project class - *Engineering Technology Project* was first offered at Kent State University at Tuscarawas in 2011, a number of projects in the area of renewable energy were successfully completed by students which supports the conclusion that the course met the expectations in terms of quality, team work and project management. For the spring semester of 2014, students will work on similar creative, challenging projects which will include the fabrication of a methanol reformer for fueling fuel cells with hydrogen and a fuel cell-operated, underwater, remotely operated vehicle (ROV).

4. Conclusions

This paper describes the development of a capstone design project class – Engineering Technology Project offered to associate's and bachelor's degree students in the Engineering Technology Department at Kent State University at Tuscarawas. We present the course objectives and details on students achievements during the project class offered in the spring semester of 2011. During this class, students fabricated the components of a high-temperature proton exchange membrane fuel cell using CNC machining and laser cutting, designed and build the prototype of a robot end-effector and demonstrated the feasibility of the fuel cell robotic assembly using the fabricated end-effector.

References

- [1] www.ohiothirdfrontier.com/FuelCellProgram.htm
- [2] Tignor K., Newton W., Milarcik A., Williamson G., Bales G., Swick A., Fox K., Sigler L, Sayre C., Williams M., Rajagopal G. and Gurau V., 2011, "Robotic Arm for PEM Fuel Cell Assembly" *2011 Ohio Fuel Cell Symposium*, April 18, 2011, North Canton, OH

[3] Williams M., Tignor K., Sigler L., Rajagopal C. and Gurau V., 2014, “Robotic Arm for Automated Assembly of Proton Exchange Membrane Fuel Cell Stacks”, accepted for publication, Journal of Fuel Cells Science and Technology