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Utility of Big Area Additive Manufacturing for Part Production for Low-Head Hydropower

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Energy and Transportation Science Division
Advanced Manufacturing Office

Utility of Big Area Additive Manufacturing for Part Production for Low-Head Hydropower

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ABSTRACT

ORNL worked with Cadens, LLC, to explore the use of additive manufacturing (AM) to produce low-cost parts for low-head hydropower systems. Cadens develops design optimization software that leverages the flexible, low-cost, high-strength benefits of AM and composite materials. Cadens also operates a micro-hydro lab to test AM components in controlled environments. Until now, Cadens' tests have been limited to components of a size that they can cost-effectively manufacture using local commercial systems. This project provided an opportunity for Cadens to scale up their modular AM hydropower parts using the capabilities of Big Area Additive Manufacturing (BAAM). This project was a success and resulted in the design and fabrication of several end-use parts of a hydropower system, using a Big Area Additive Manufacturing (BAAM) system. The fabricated parts include a draft tube, thimble, runner housing mold, PVC end fitting and two PVC pipe supports. In addition, a runner system was fabricated using fused deposition modeling on a 3D Platform Workbench 400 Series System.

1. UTIILITY OF BIG AREA ADDITIVE MANUFACTURING FOR PART PRODUCTION OF LOW-HEAD HYDROPOWER

This phase 1 technical collaboration project (MDF-TC-2018-144) began on July 19, 2018 and was completed on November 2019. The collaboration partner, Cadens, LLC, is a small business. The results of this project include the successful fabrication and testing of several ducting elements, using additive manufacturing.

1.1 BACKGROUND

Cadens' intended products are AM micro-to-small hydropower S-turbine systems, with an intake, guide vanes, turbine runner, shaft, curved conveyance including intake and diffuser, as well as an off-the-shelf generator situated out of the flow path for simplicity in maintenance, assembly, and installation. The system is modular in that several sub-components are manufactured and then assembled to make the final integrated machine: a powertrain plus conveyance (PPC) system.

Cadens' target market is small, low-head hydropower plants. There are currently over 1,700 small hydropower plants in the country providing low-carbon, reliable electricity. A resource assessment conducted by ORNL indicated the presence of an additional 29 GW of new, small hydropower technical potential across 10,000 sites (Kao et al., 2014). However, the Department of Energy modeled the deployment of this potential and predicted 0 GW will be developed by 2050, unless the industry can radically reduce costs. DOE suggested exploring the use of new materials and manufacturing methods as one cost reduction pathway (DOE, 2016). ORNL has also suggested using standardization and modularity as strategies to make small low-head hydropower development affordable (Witt et al., 2017). Cadens' modular design, coupled with their optimization software and AM components, enables a first-of-its-kind validation of small modular hydropower systems. By producing semi-custom modular systems that can deploy with high efficiency across many different sites with few changes to design and manufacturing processes, Cadens believes the system can be a low-cost, high efficiency solution for the hydropower industry.

What is not well understood is the durability and overall performance of an integrated PPC system, made with BAAM methods/materials and operated continuously under normal and off-design conditions in a field demonstration. Thus, the PPC project test plan involves evaluating the durability of an AM PPC by measuring the wear to components under continuous operation as well as the overall performance in both off-design and normal operating conditions. The DOE MDF at ORNL is uniquely positioned to assist Cadens because of its ability to rapidly push the envelope in large-scale AM.

1.2 TECHNICAL RESULTS

This project began with the design of the first part that was to be fabricated using the BAAM system. This part is called the lower draft tube. Cadens provided the computer-aided designed (CAD) model, and then ORNL and Cadens worked together to improve the design and make it printable. Fig. 1 shows the original CAD model of the lower draft tube.

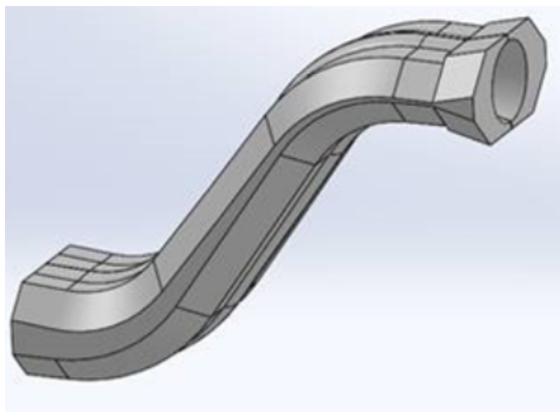

Fig. 1. Lower draft tube original CAD model.

Due to an inherent AM limitation of not being able to deposit material if there is nothing below to support it, a tube is not printable without support material. Therefore, the draft tube was divided into two halves. Each half was printed separately and later assembled. The geometry of the draft tube also required the addition of external support structures that run the length of the tube (Fig. 2).

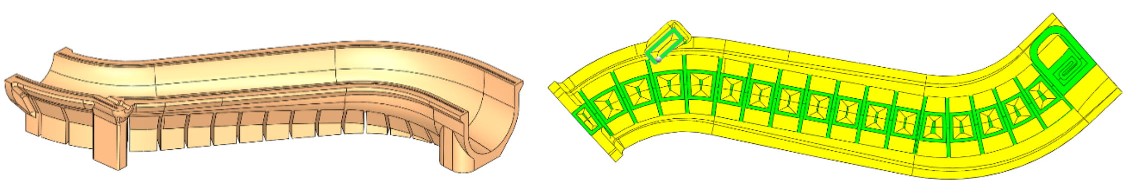

Fig. 2. The CAD model of one half of the draft tube with the external structures (left). The external support structures are shown in green (right).

Although the external support structures were not originally intended to be on the draft tube, the structures were helpful for moving the large tube and did not interfere with the performance of the tube. Therefore, they were incorporated into the final hydropower assembly's CAD drawings (Fig. 3).

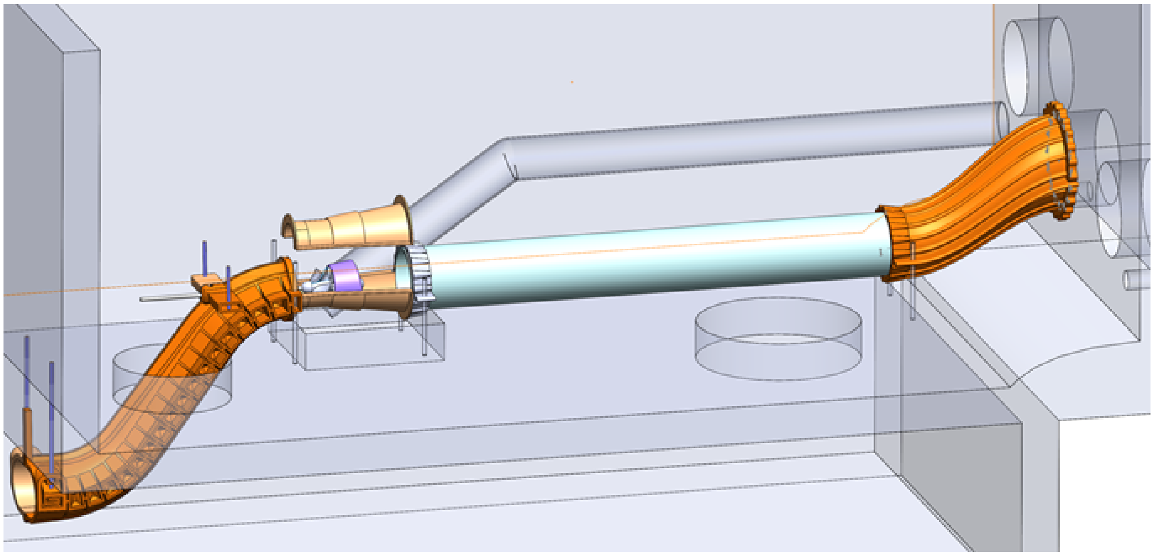

Fig. 3. The CAD model of the hydropower assembly. The draft tube with external support structures is located on far left of the image.

Each half of the final printed draft tube is shown in Figs. 4 and 5. The prints each took approximately 9 hours and 20 minutes. The material used to fabricate the tubes was 20% carbon fiber-reinforced acrylonitrile butadiene styrene (ABS). Each half weighed approximately 344 pounds, for a total of 688 pounds.

Fig. 4. The first half of the draft tube as printed. It is flipped upside down, so the support structures are seen on top.

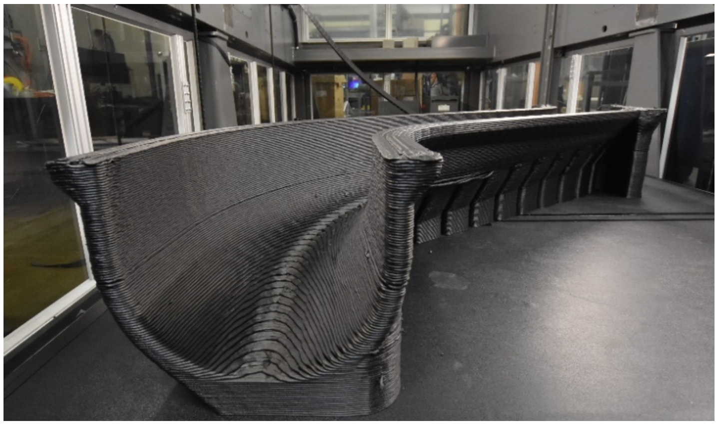
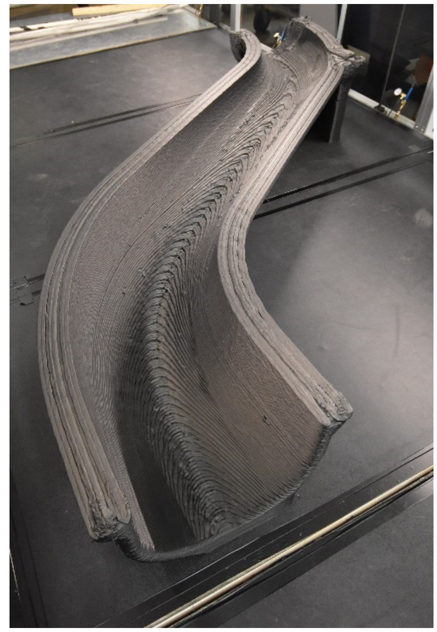

Fig. 5. The second half of the draft tube, as printed.

The second aspect of the hydropower system, the thimble, also went through design iterations between ORNL and Cadens and was printed using the BAAM system. The CAD model of the piece and the final as-printed part are shown in Fig. 6. The long thru-channels house 1/8th – 3/16th rods that hold the stack in compression during use.

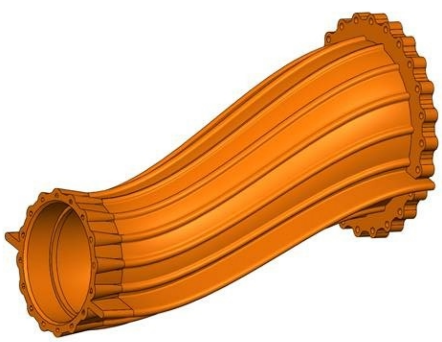


Fig. 6. The CAD model of the thimble (left) and the final printed version (right).

The final piece to be printed using BAAM was a layup mold for the runner housing. It was printed with BAAM, spray coated to fill any voids and even out the surface, CNC machined to get the exact tolerances, and then spray-coat sealed to protect the surface. The print took approximately six hours and weighed 81lbs.

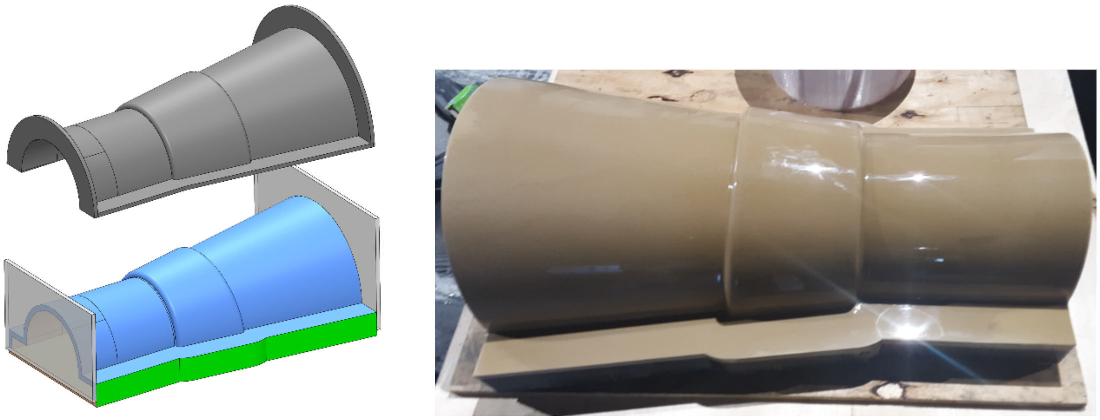

Fig. 7. The CAD model of the runner housing layup mold (left) and the final printed version (right).

Following the large prints on BAAM, there were smaller parts that needed to be printed - the runner and stator. These were both printed at ORNL on the 3D Platform Workbench 400 Series printer using Polyethylene terephthalate (PETG). Cadens provided the spacer plates needed for final assembly.

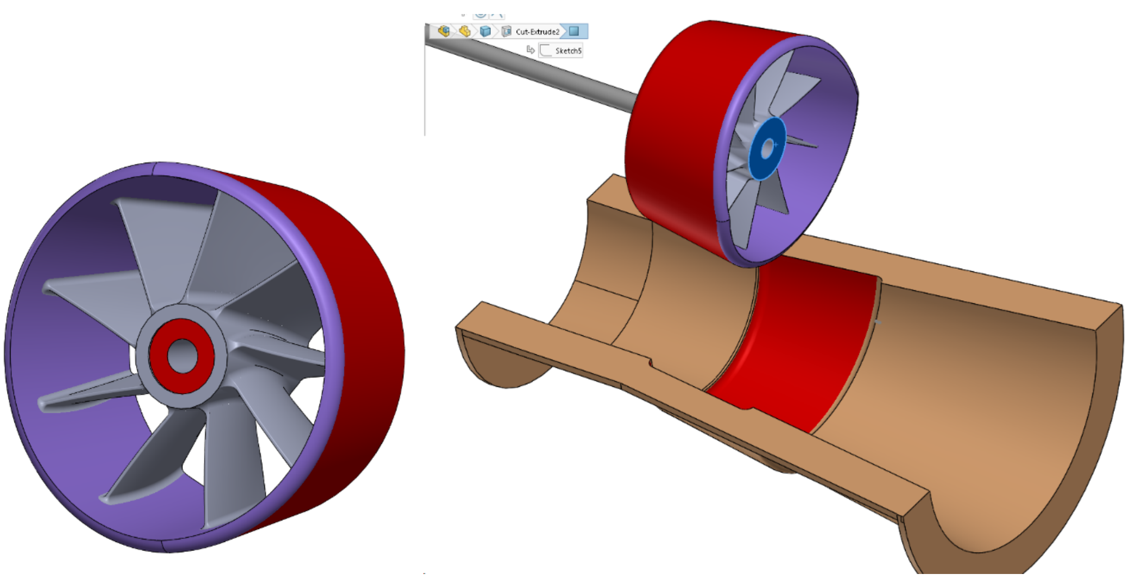

Fig. 8. CAD models to show the runner and stator as they fit into the housing.

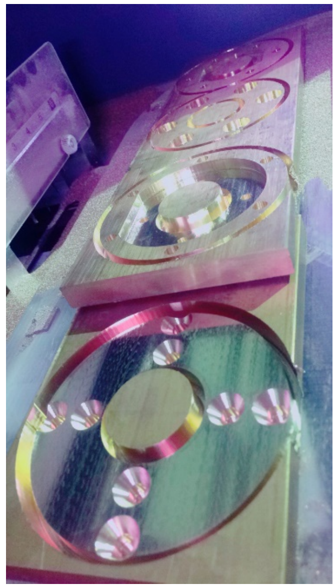

Fig. 9. Runner spacer plates provided by Cadens

With all the parts printed, ORNL shipped them to Cadens for preparation, assembly, and testing. The draft tube required minor repairs and sanding to perfect the fit. The thimble needed to be drilled out to thread the rods through; it also required sanding and epoxying to fit the PVC pipe into it.

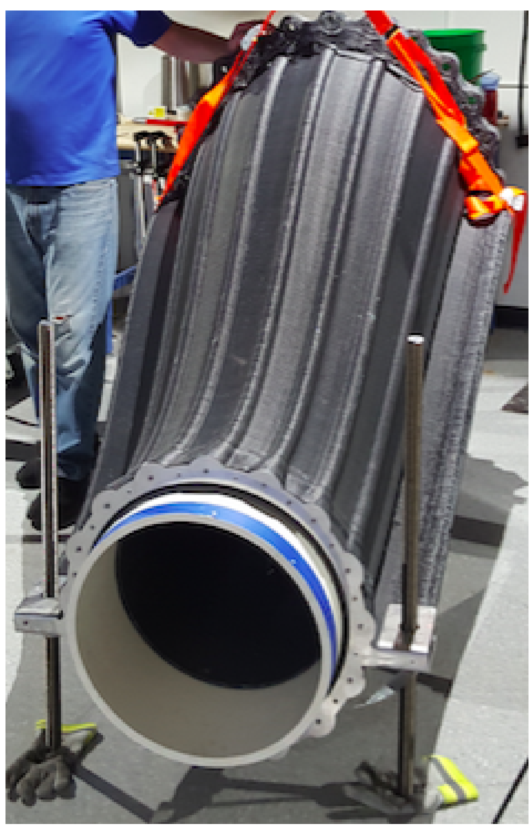

Fig. 10. The thimble after post processing and prep work by Cadens.

1.3 IMPACTS

This project had an impact in several areas of hydropower technology development. They include decreasing costs, entering a new market, and reducing process energy use.

The volume of components needed for the hydropower industry is low, so part production costs are generally high. Site conditions also vary from location to location, which results in custom, site-specific designs. This project report provides other companies, and the public, access to information describing the print process, assembly, and commercial coating/sealing techniques for finishing end-use parts. This information can provide a path forward for cost reduction in the manufacturing of small batch hydropower systems.

The small hydropower market is stagnant – over the past fifteen years, only seven small hydropower plants with 24.4 MW of total capacity (mostly in Alaska) have received a FERC license to operate (Witt et al., 2017). This project helped to revitalize the market for small hydro by demonstrating low-cost, reliable production enabled by rapid design and manufacturing.

The conventional approach to this project would be to use a metal turbine runner and concrete or steel pipes that are overdesigned for low-pressure systems. Using AM, which combines low cost feedstock with quick manufacturing times, significantly reduced the energy used in the manufacturing process. The resulting Micro Hydro Test-bed allows for further advancement in the state-of-the-art of the runner and turbine, as well as energy conversion methods and system/software/model optimization. This test-bed is the first of its kind and supports the industry interest in testing many system components, materials, and energy conversion/storage regimes.

1.3.1 SUBJECT INVENTIONS

No subject inventions resulted from this project.

1.4 CONCLUSIONS

Through this project, ORNL and Cadens have demonstrated how 3D printing can be used to help the hydropower industry. Several parts were able to be made on BAAM both quickly and inexpensively, and parts with finer details were made using a 3D Platform System. Final assembly for testing the printed parts is under way, and phase 2 will explore printing and developing many additional components, as well as thorough testing of all the designs.

2. CADENS, LLC BACKGROUND

Cadens is a clean energy startup located in Sullivan, WI advancing environmentally compatible, low-cost hydropower specifically with additive manufacturing. Cadens plans to lead the way in the development of new hydropower technologies. They are building a team to actively address conversions to produce clean, renewable energy at existing non-power dams and existing powered dams in need of maintenance and upgrades. With an agile combination of off-the-shelf and standardized parts, along with site-specific turbines generated on 3D printers, they envision modular, drop-in hydropower systems that are lightweight, energy dense, and optimized for each specific site. A particular focus are dams with a capacity of <1MW, which represent 98% of the 54,000 suitable NPD's. River communities, private landowners, and businesses that must rebuild vital dam infrastructure can partner with Cadens to retrofit non-hydropower dams with new, lightweight hydro turbine machines.