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BULLETIN

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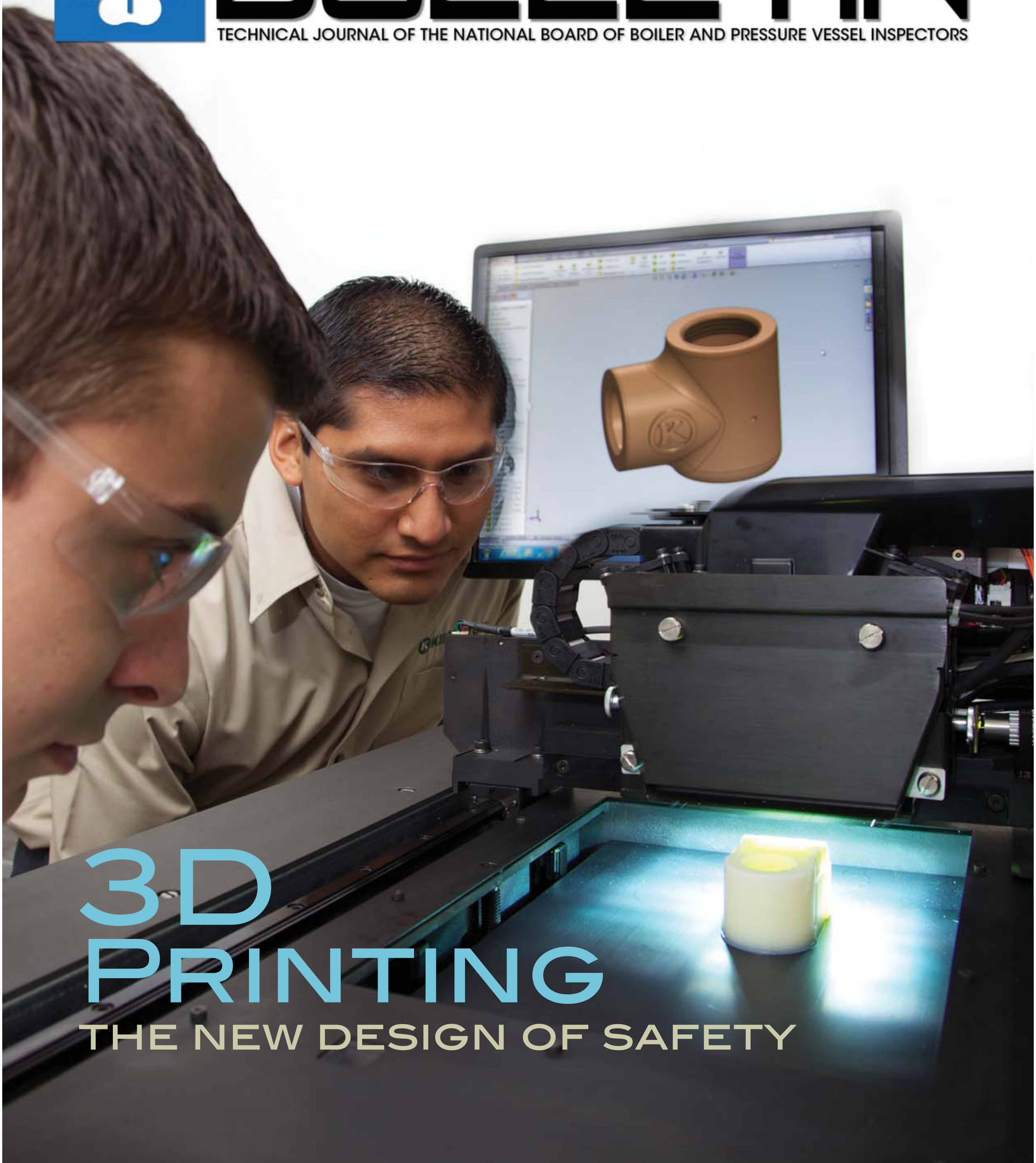


3D PRINTING

THE NEW DESIGN OF SAFETY

COVER STORY

3D PRINTING

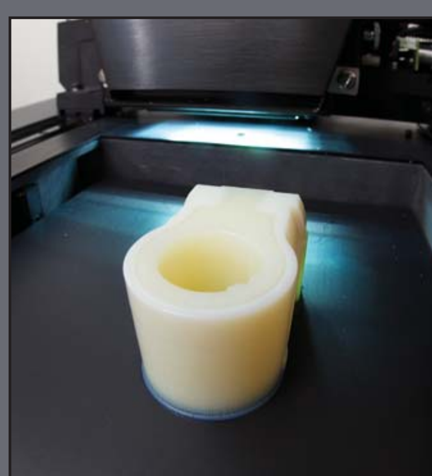
THE NEW DESIGN OF SAFETY

PHOTOS BY TONY ALOI PHOTOGRAPHY AND BRANDON SOFSKY

Additive manufacturing, also known as 3D printing, has been making headlines: from the controversial first fully 3D-printable handgun; medical pursuits to print human tissue, organs, and body parts on demand; research toward printing edible, artificial meat for consumption; to a myriad of dust-collecting hobbyist knickknacks and other common household items.

And now, pressure relief device parts.

The use of additive manufacturing is on the rise in virtually every industry. It helps that the cost of 3D printers has come down from many thousands of dollars to often less than $1,000, making it an accessible apparatus for virtually anyone who wants to print on demand. But those observing the manufacturing community see something more, and some predict 3D printing will pioneer the next industrial revolution – just as steam was a major technological development of the Industrial Revolution of the 1800s.



Top: A variety of 3D-printed valve body parts engineered by F.C. Kingston.
Above: A 3D printer produces a valve part.

Why?

3D printing is an advanced, digital-manufacturing process that reduces costs and production time, and gives manufacturers significant latitude when it comes to designing and prototyping new products. And the technology has made its way to the National Board.

A NEW PROPOSAL

The National Board Pressure Relief Department (PRD) recently had the opportunity to look at pressure relief valve parts produced with a 3D printing process. After considering issues related to the safety of the parts, the PRD accepted the new configuration for testing.

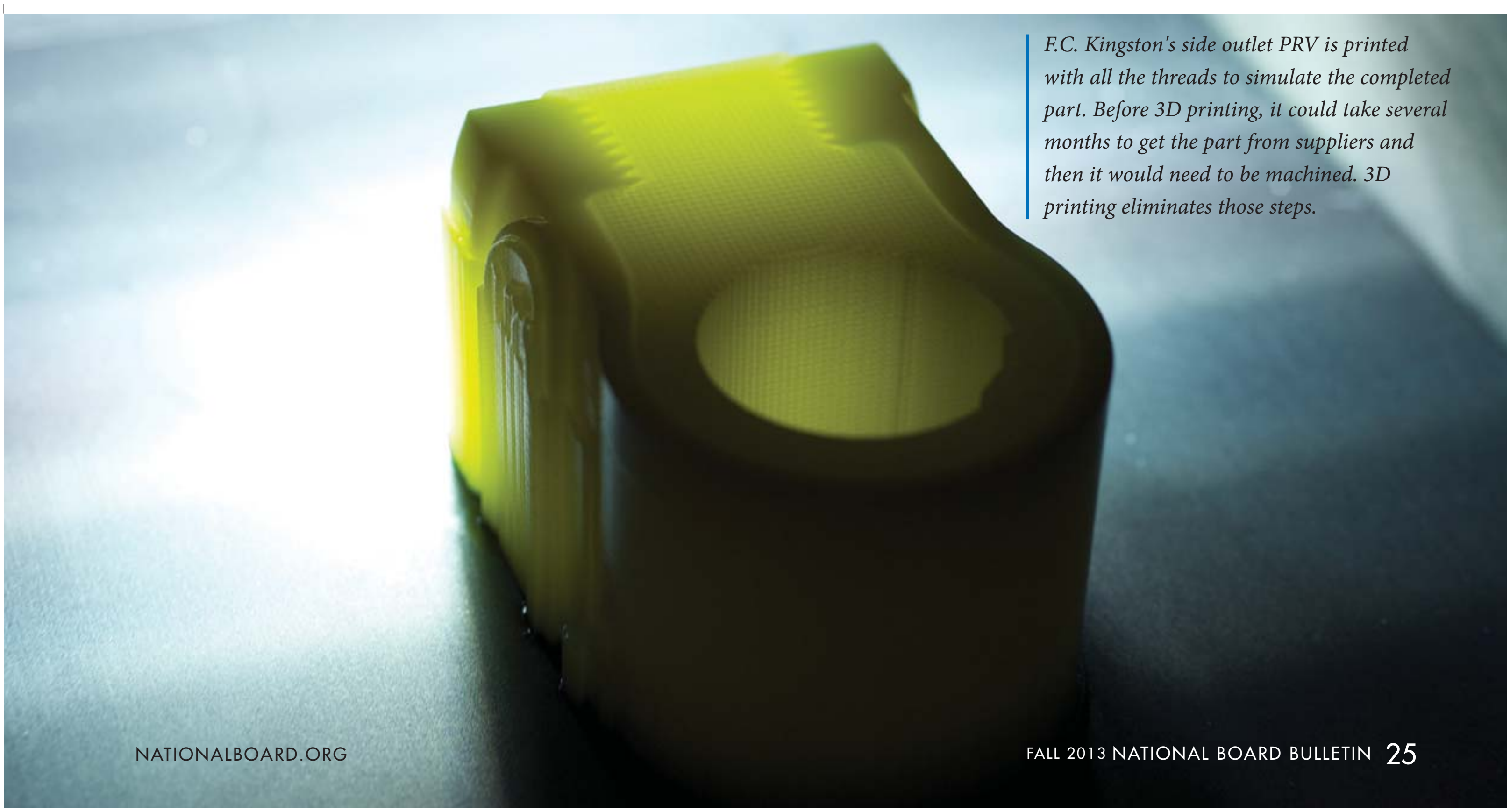
The capacity certification test process for a new pressure relief valve design involves two steps. First is a test program where the capacity rating factor for the design is determined. The valves being tested at this stage are prototypes, since the ASME certification mark and **NB** mark cannot be applied until the rating value has been determined. If they will not be sold later, the valves are often manufactured with different materials than will be used in the final, finished design. The second step requires that samples using standard production procedures and materials be inspected and submitted for test, validating the capacity rating factor determined when the prototype valves were tested.

The F.C. Kingston Company (part of Storm Manufacturing Group, Inc.), a pressure relief valve manufacturer in Torrance, California, presented the National Board with a new valve type for capacity certification. The valve body would be produced as a brass casting when the design was finalized. The production of castings is an involved process where the part design is determined and a casting pattern produced. Sample castings are made and dimensionally checked; machining is done; and finally, a part is ready. The casting patterns can be quite involved and expensive, and if subsequent flow testing reveals that the cast part does not flow properly, a new pattern would be required and the process repeated. This cycle can take several months each time it is determined that a design change is necessary.

The manufacturer's engineer came to the National Board with a proposal that the cast body for the valve would be produced using the 3D printing process. The prototype part would be "printed" directly from their CAD software. The valve would be tested, and if a problem was found, the design could be easily modified; a new part printed; and additional testing performed. By using the 3D printing process, expenses associated with revising casting patterns would be eliminated, and the lead time needed to produce a new casting pattern would be avoided.

PROOF TEST

"While the National Board embraces new technology, it first considers the safety of any item accepted into the test laboratory," stated Joe Ball, director of the National Board Pressure Relief Department. "The National Board's experience within the realm of the *ASME Boiler & Pressure Vessel Code* is mostly with parts produced from metal where the engineering properties of the materials used are well understood," he added.



F.C. Kingston's side outlet PRV is printed with all the threads to simulate the completed part. Before 3D printing, it could take several months to get the part from suppliers and then it would need to be machined. 3D printing eliminates those steps.

For the F.C. Kingston test program, the PRD would be receiving a liquid service pressure relief valve (PRV) whose body was made of plastic. "Our initial response was to request that the manufacturer validate the design based upon the material properties of the plastic," said Ball. "But it turns out that the material properties are not extensively documented because parts made by this process are not often used as production pieces where a detailed design analysis is needed."

And so a second proposal was made: validate the printed parts via proof testing. The PRD staff requested that the manufacturer follow the principles in ASME Section VIII, Paragraph UG-101, for guidance. "We recognized that since material properties were not known, they would not be following those rules exactly; however, the rules would serve as a reference for the process and procedures to be used," said Ball.

The pressure required for a proof test was agreed upon as four times the maximum pressure that the part would be expected to see during the test. The highest set pressure of the valves to be tested was 250 psig with an overpressure of 275 psig. However, the valve body is part of the secondary pressure zone of the valve (discharge pressure region), and from previous experience, the pressure in this part was estimated to be 10% to 20% of the valve set pressure, with 20% being used for conservatism. It was also requested that operational stresses be considered, which included stresses on the threads where other parts are attached to the casting, and thrust forces. The valve spring exerts force on the adjusting screw, which in turn exerts force on the valve body as well.

For final conservatism, the manufacturer used a proof test pressure of four times the overpressure of the valve, which would cover the case where the valve outlet was actually pressurized to the inlet overpressure. (Since the valve outlet should never be blocked, this pressure is much higher than would actually be seen during the test, but this would also give some margin for operational stresses.)

The company produced several samples and went through the proof test procedure. Valves were assembled with the various holes plugged and water pressure was slowly applied with a hydraulic hand pump. The pressure was recorded with a data acquisition system, with the pressure sensor calibrated against a dead-weight tester. The first two tests resulted in burst pressures of 460 and 580 psi. One of the advantages of the 3D printing process is the ability to quickly modify the design in the CAD software, and then make a revised part. The wall thickness was increased and the radii on fillets at discontinuities were increased to reduce stress risers. New parts were printed, and the test repeated.

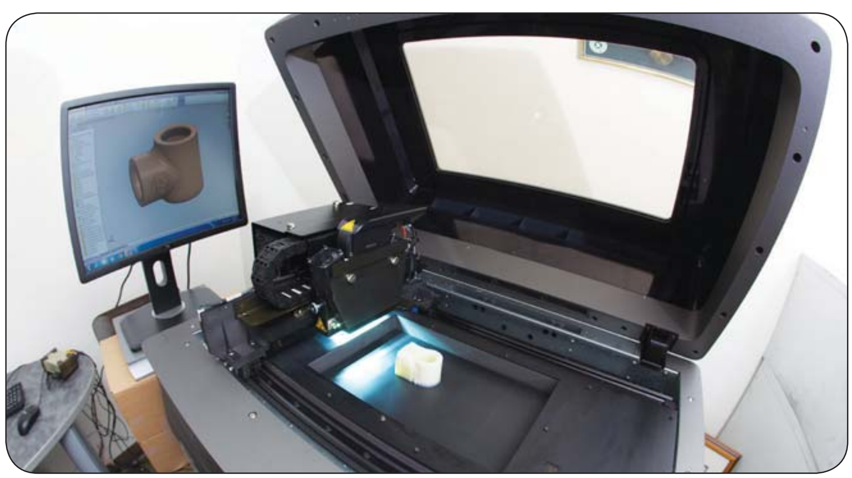
THE RESULTS

While it had been agreed that the proof test pressure only needed to go to the pressure necessary to verify the test pressure, the part was tested to burst. On the retest, a burst pressure of 1,150 psi was measured. This met the goal of having the burst pressure

How 3D Printing Works

Fans of the old *Star Trek: The Next Generation* television show may recall a device called the "replicator," which magically created food or other objects seemingly from nothing. The future is present and fiction one step closer to reality with advances in 3D printing technology.

Imagine an ordinary inkjet printer. On demand, the printing device moves the ink cartridge back and forth across the page to print words or images. Additive manufacturing equipment works in similar fashion but with a third dimension. Following a blueprint from a computer-aided design (CAD) program, the 3D printer moves back and forth and deposits layers of material until the desired object is built. The type of material used to make the product depends upon the application, but common materials include powder, paper, sheet metal, and liquids – and scientists are experimenting with human tissue.



Work in progress: The partially-completed body of F.C. Kingston's side outlet pressure relief valve (PRV) emerges on a 3D printer.

The National Board Test Lab's very first 3D printed valve part from F.C. Kingston, a liquid service PRV, undergoes successful water testing.

be equal to or greater than four times the valve overpressure. The test was deemed successful.

Based upon the proof test data and supporting analysis work, the PRD accepted several sample valves for testing in its lab, which included the printed bodies. These valves were tested for operation and capacity with test media of both air and water. For the first tests, PRD staff took care to bring the pressure up at a slow rate, but ultimately all of the valves tested worked as they were supposed to and no functional or pressure boundary failures were observed.

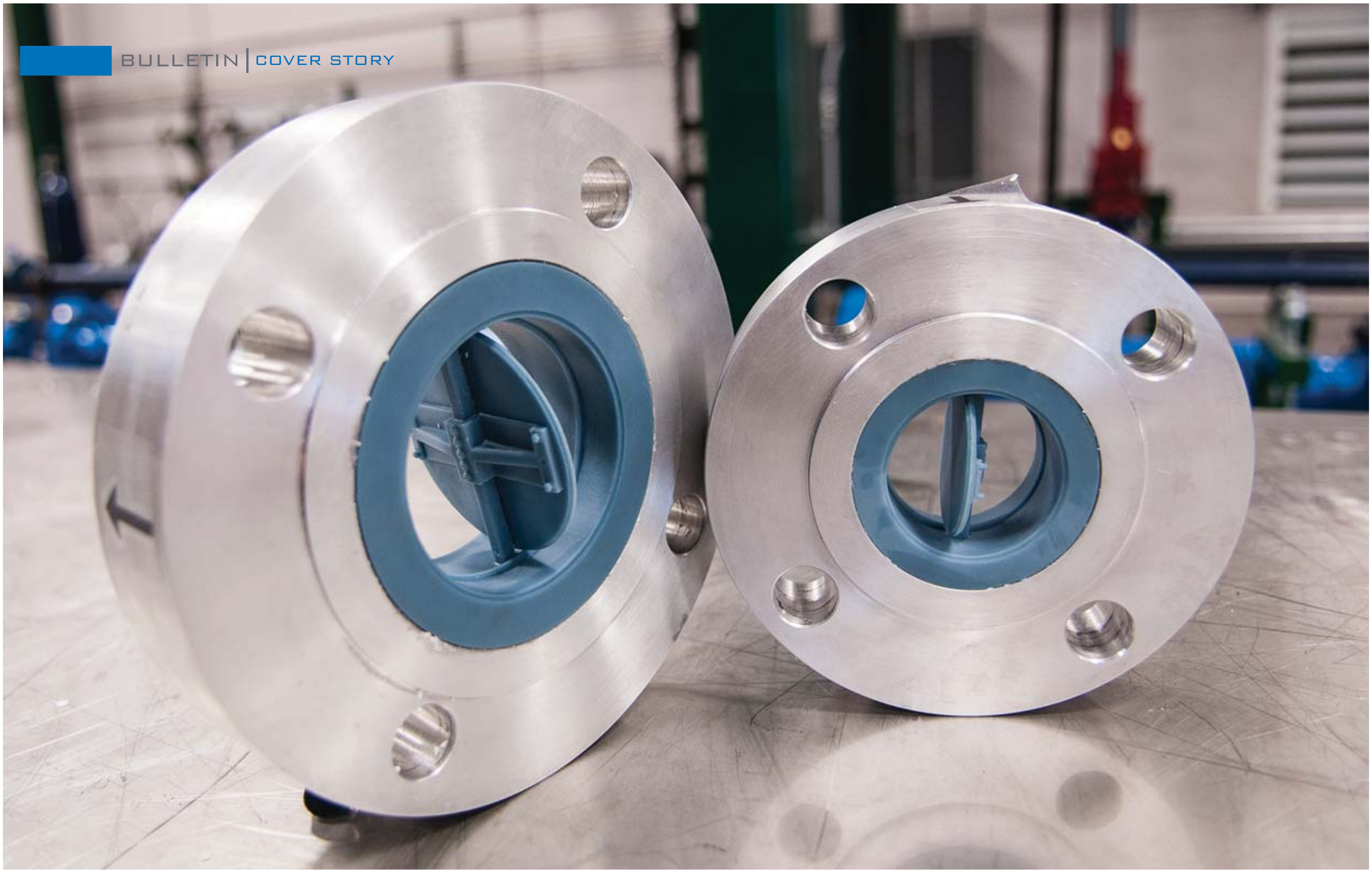
"Being able to complete tests using a plastic body that was printed overnight was a definite milestone for our company," said F.C. Kingston engineer Derek Parnett. "The ability to validate a design without dedicating money to tooling was a huge improvement from traditional design methods. Working with the National Board to develop guidelines enabled us to use printed prototypes for preliminary testing. We applaud the National Board for recognizing this emerging technology and taking on the challenge."

The ability to quickly produce parts through 3D printing was also used in other ways by the company. A valve body was produced that had three pressure taps in the outlet portion of the valve. Flow tests performed at their facility verified that pressure in the valve body during the flow test was very close to the 20% value previously estimated. They also later reported that tooling for the casting pattern was produced by the same method for the casting supplier. Additionally, four weeks were eliminated from the time needed for the first run castings, and a savings of over $3,000 was recognized in the pattern production process.

"From this project, it appears that a safe test object can be prepared using 3D printed parts," said Ball. "At this time, the lab is not quite ready to use these parts in a production valve because data for the long-term material properties is not available, but for a short duration test, the process appears to be a valuable addition to the development process, and I would not hesitate to accept new products built by this method in the future."

In fact, a second valve company, EnviroValve Inc., submitted 3D production parts to the lab in July for testing. The valves were scale models of a larger valve not compatible with the lab's equipment. Ball explained: "The 3D printing technology made it easy for the manufacturer to scale down the larger valve and produce models that would fit on the lab's equipment. They were also able to produce complicated internal geometries that would be difficult to machine." Ball reported that EnviroValve's tests were also successful.

Ball is optimistic that the use of 3D printing technology in valve manufacturing will expand. "What was initially a unique request by F.C. Kingston to use 3D printed valve



EnviroValve's reduced scale model of a pin-actuated non-reclosing pressure relief valve. The blue pieces are the printed parts.

parts is on its way to becoming a standard procedure. I believe we will see production valves made this way someday," he predicted, and then added: "I'm glad the National Board is able to respond to requests and incorporate new technologies in the testing process. It helps manufacturers improve their time to market and it reflects the ever-increasing pace of industry."

F.C. KINGSTON TALKS RAPID PROTOTYPING

Derek Parnett (application engineer) and Marco Martinez (design engineer) of Storm Manufacturing Group (SMG) provided insight about their use of 3D printing in its pre-production of safety valves (referred to as rapid prototyping) and how the growing technology could change manufacturing as we know it.

BULLETIN: When did you begin using 3D printing and what sparked the company's interest in trying the technology?

Parnett/Martinez: We began implementing rapid prototyping at the end of December 2011. Storm Manufacturing Group continually looks for improved efficiencies in the design and production of safety valves. Some members of our engineering team brought their 3D rapid prototyping experience to SMG. Management recognized the potential benefit immediately and invested in the required equipment.

BULLETIN: Besides valve parts, how else are you utilizing the technology?

Parnett/Martinez: We have also used this technology to reduce casting lead times by printing pattern tooling, to take weight out of assembly fixtures and to design new product concepts.

BULLETIN: What are some of the benefits of using this process?

Parnett/Martinez: Time savings is by far the greatest benefit for engineering when it comes to developing new designs. Three-D printing has enabled us to print multiple designs simultaneously, which not only frees up time in the machine shop, but also saves time in the design development process. We can expedite prototyping through our machine shop and reduce time to market.

Printing casting tooling also cuts down lead times by almost half and reduces tooling costs. The ability to print accurate and repeatable components reduces human error in machining, thus saving time. Overall, rapid prototyping has been a great alternative to traditional prototyping and has proved to be a vital asset to our design process.

BULLETIN: Have you encountered any downsides to the technology?

Parnett/Martinez: The biggest downsides are the size constraints (6″ x 8″ X 10″), material costs, material expiration dates, and the inability to print multiple surface finishes on the same design. These constraints may impact testing of different valve designs (surface finish, threading, etc.) because of irregular flow paths which may affect flow.

The limitations of manufacturability are also a downside to this technology. The quality of a rapid prototype component that was printed may not

Marco Martinez uses 3D CAD software to design the side outlet pressure relieve valve component.

Pressure Relief Device Parts: Coming to a Printer Near You

Derek Parnett explains how pressure relief device parts are produced using 3D printing:

1) An engineer begins by creating a 3D model of the desired component in a 3D CAD software program. When the model is complete, the engineer uses the software program to convert the 3D model into a binary ".stl" file.

2) Next, the engineer will use the host computer to access the software program and select the files to be printed, as well as select the desired surface finish and the orientation of the part. The host computer is connected to the 3D printer via network cables similar to the way a standard ink printer is connected.

Parts are created using a rigid and durable material that starts out as a liquid. Complimentary support material (also liquid) is also used to temporarily fill all openings, gaps, and crevices of a part while it is being printed. The materials are loaded into the printer via plastic bottles, each of which contains 1KG of liquid material.

3) The 3D printer then begins making hundreds or thousands of "passes" back and forth over the print area. The nozzle deposits very small amounts of the liquid material on each pass. Each layer that is deposited is only 28 microns (.0011 in.) thick. The printer is equipped with a powerful UV light that instantly cures the liquid material as it is deposited. The complimentary support material is also deposited during the printing process and is also cured via UV light. The printer continues to make passes back and forth until the part is completed. Depending on the complexity of the design, printing a part can take anywhere from 2 to 14 hours. For a standard valve body, the process usually takes 10 to 12 hours.

4) The finished part is cleaned with a high-pressure water jet. This process removes all of the complimentary support material from the model and leaves only the hard plastic material. Once the part is cleaned, it is ready to be assembled to metal parts or other printed parts to create the final product. At this point, if the part will need to be tested at high pressures, hydrostatic tests of the printed part are conducted to ensure it can safely handle the desired pressures.

F.C. Kingston's fully assembled valve on their test equipment. The valve is mounted on a tank inside a sound abatement structure and tested for set pressure, flow, blowdown, and leak tightness.

translate to actual real-world manufacturing because of unrealistic designs. This may increase the cost of manufacturing and delay the product from being introduced into market.

BULLETIN: How would you forecast the use of 3D printing in valve manufacturing?

Parnett/Martinez: Companies looking to deliver increased value with new products or "application specific" valves will eventually gravitate to 3D printing.

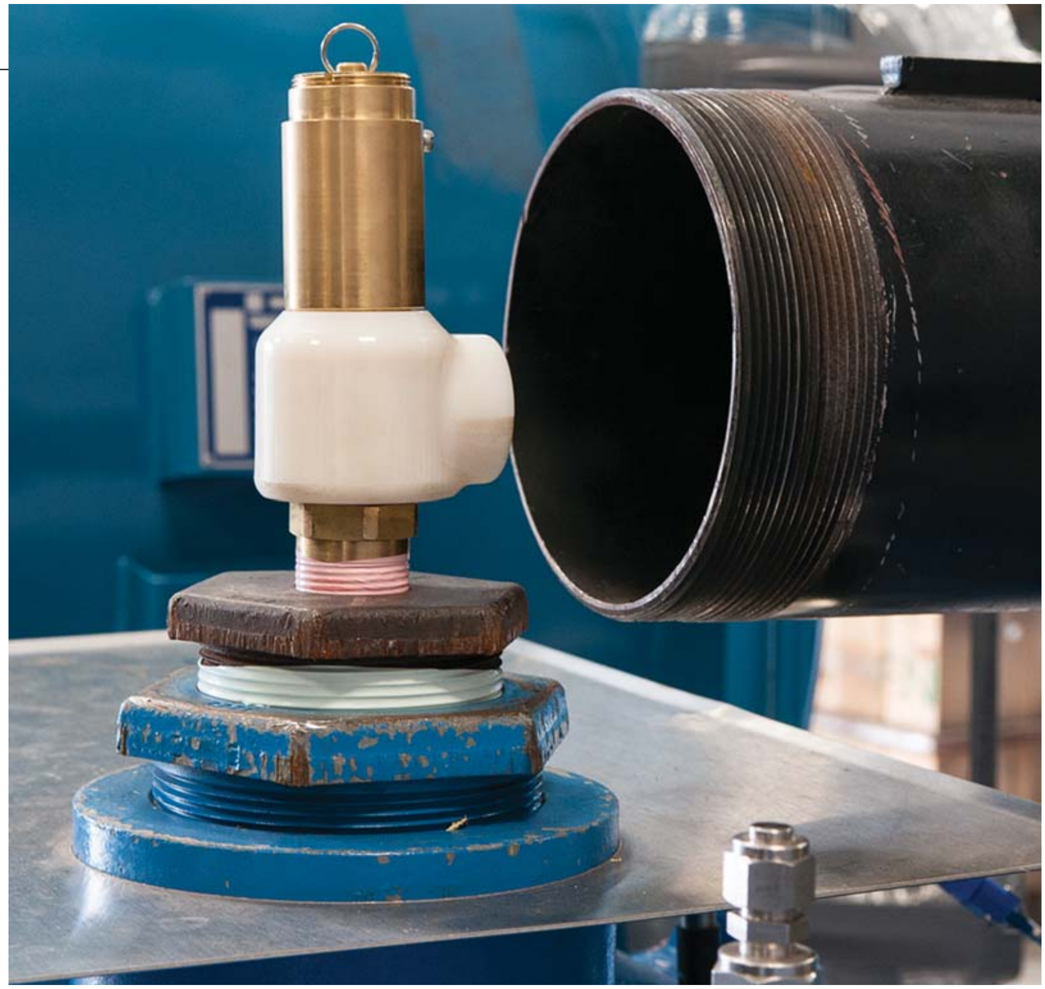
BULLETIN: In current media coverage of 3D printing, some suggest that this technology could become the next industrial revolution akin to the steam engine and the printing press. Your thoughts?

Parnett/Martinez: Three-D printing has already demonstrated its potential across industries: medicine, space exploration, and textile manufacturing currently see the benefits of 3D printing. The use will grow exponentially with advances in technology.

BULLETIN: An article on additivemanufacturing.com says "additive manufacturing is a truly disruptive technology" to traditional manufacturing. How could 3D printing impact or disrupt traditional manufacturing?

Parnett/Martinez: At this point, the technology is aiding traditional manufacturing; however, in the distant future it is possible that it will replace manufacturing as we know it today. As 3D printing becomes readily available, the use will grow because of the attractiveness to reduce waste, improve efficiency, and achieve repeatability. In the near future we can see the use of rapid prototyping for custom products, printing repair parts in remote locations, and design support.

With developing technology in rapid prototyping and the materials used, one can only imagine what the future holds, such as printing valves or replacement parts. ✤



Above: F.C. Kingston's side outlet PRV is successfully air-tested at the National Board lab.
Below: Engineers Derek Parnett (left) and Marco Martinez (right).