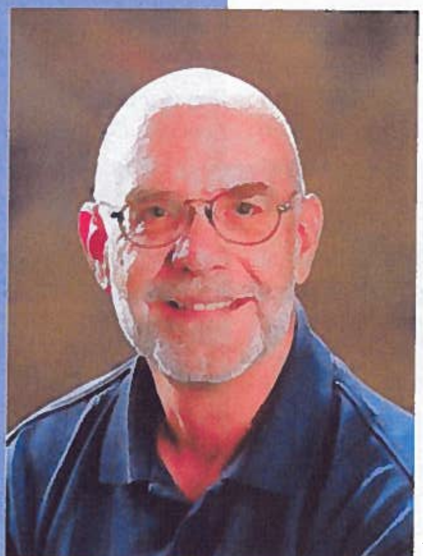
Machine Vision Technology

By Chris Hebel, Ron DiSabatino, and Kate Gresh, Exelon Nuclear.

Chris Hebel

Chris Hebel started at Quad Cities Station in 1982. Chris has worked in Systems Engineering, Operations, On-Line Work Control, and Outage Work Control, over the past 30 years, before returning to Engineering as the Quad Cities BWR Reactor Internal Components Engineer. Chris graduated from Southern Illinois University Carbondale with a B.S. in Engineering.



Ron DiSabatino

Ron DiSabatino joined Exelon Nuclear, LLC in 2006. DiSabatino is an engineer in the Asset Management group at Exelon's corporate office in Kennett Square, PA and has responsibility for BWR Reactor Internal Components. He has experience with engineering programs at both the corporate office and at Exelon's Peach Bottom Atomic Power Station and holds a B.S. and M.S. in Mechanical Engineering from the University of Maryland.

Recently developed underwater laser scanning technology, specifically designed for in-vessel use, was used to precisely measure a weld and surrounding components on the Jet Pump 13/14 Riser Elbow-to-Pipe weld location (RS-2) in the Quad Cities Unit 1 reactor. The scanner has an accuracy of +/-.004 in. (0.10mm) at a 12 in. (300mm) distance and the point cloud output is designed to be processed by 3-Dimensional software into fully-measurable Computer Assisted Design (CAD) files. Pre-deployment testing and training was carried out by Westinghouse Electric Company engineers at their BWR mock-up. The subsequently successful Quad Cities scans resulted in significantly better results than could be obtained by traditional methods and scanner deployment took only 12 hours, followed by CAD file rendering.

When first-time, in-vessel modifications need to be planned, it is critical to have sufficient as-built details available to design the correct tooling and hardware. When these details are not available, measurements must be taken during a refueling outage.

In mid-May 2011, Thomas Wojcik, the Quad Cities Manager for Engineering Programs, emailed that an indication was identified on the jet pump 13/14 Riser Elbow-to-Pipe weld location (RS-2) in Quad Cities Unit 1. This was the first time in the U.S. nuclear industry experience that an indication had been observed at this specific location on a jet pump riser. What makes this RS-2 degradation so challenging is that installation of a first-of-a-kind modification would need to be accomplished in a future outage. Further, this issue is compounded by a lack of sufficient as-built details. These requirements meant that the measurements had to be scheduled during the recent 2011 refueling outage and, to complicate matters, be taken in one of the more difficult-to-reach areas of the BWR annulus.

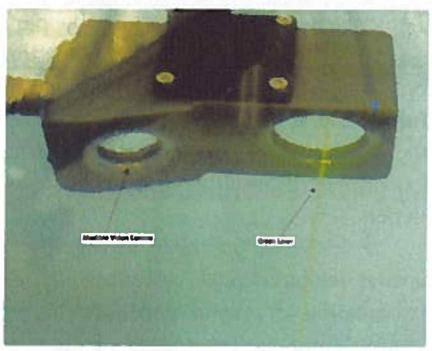
Previous similar experiences involved simply taping a ruler onto a pole, lowering it into the reactor annulus and, using underwater cameras, attempting to measure the critical dimensions needed by the design engineers. This method requires physical contact and not as accurate as one would wish. Normally it would have been the only method available to measure the Quad Cities jet pump weld. But this time it was different.

At Exelon, we have experienced numerous challenges correctly fabricating and installing modifications to reactor internals the first time using measurement data from a T-square ruler, or a mechanical profiling tool. In the recent past we have needed to add more than 11 days of critical path time to rework tooling and hardware in order to get modifications to reactor internals to fit properly. It all comes down to not being able to obtain sufficiently accurate measurements in-vessel using the traditional methods. What was needed was an accurate, non-contact, underwater measuring process.

Unfortunately, the environment within BWR reactor internals presents five challenging problems that usually defeat non-contact measurement devices. The first is that water refracts and distorts light, so a process that works in air will not usually work underwater; second is the very high radiation field; third is the tightly constrained working area; fourth is the heat thermals produced by the fuel in the core; and the fifth is the turbulence of the core cooling water circulation that buffets measuring devices during data acquisition. Keith Moser, Exelon Innovations Manager, searched for a better non-contact underwater measuring process literally taking him to three continents, numerous vendors and several research facilities in order to evaluate promising technologies. On one of his visits, a nuclear service provider recommended that Moser visit Newton Research Labs near Seattle, Washington.

Newton Research Labs was a different company from what Moser had been used to working with in the nuclear industry. They are a small, but very high-tech company, beginning as a start-up at MIT where the founders had focused on the combination of machine vision technology with robotics. In the early days of the company, they had even applied their machine vision expertise to compete in international robotic soccer tournaments and, due to their superior technology, won most of them. Building from this playfully-serious beginning, Newton Labs adapted and grew this technology into advanced manufacturing and industrial processes which included the machine vision guidance system for Zetec, Inc.'s robotic inspection devices for steam generators.

What was most impressive about Newton Labs was that they were ready and able to quickly come up with a technical solution to accurate, non-contact measurement within the challenging environment of reactor internals: that solution was an underwater laser scanner. The first Newton prototype scanner projected a line-scan laser coupled with a high-resolution machine vision camera. Both units were packaged within a compact, radiation-resistant housing that allowed access into the tight areas of the reactor internals. But the most evolutionary feature was not the hardware, but the software algorithm that canceled the refractive characteristics of water and enabled the recording of a dense and accurate point cloud. Even the first prototype delivered underwater measurements of impressive speed and accuracy. To resolve the issues of thermals from the core's heat, a second-generation Newton scanner was deployed in the Byron fuel pool and after collecting thousands of views, an updated algorithm was developed to remove the blurriness from the thermal-influenced images.



Newton's underwater Machine Vision Camera.

The Newton scanner's performance showed that this technology was ready to be tested by a service provider that could ensure that the measuring device would be able to perform in core flow conditions during refueling. This task originally proved to be more difficult than anticipated, as all but one service provider passed on the new technology.

The one exception that did accept the challenge was Westinghouse, whose efforts were led by James DuBay. James' background in large part influenced his decision to road-test the Newton Labs underwater laser scanning technology. He already had extensive experience with hands-on reactor modifications, engineering, and project management work on BWR reactor internals. James pursued an MBA degree from the University of Colorado in their entrepreneurship program, and after achieving his MBA, connected with Westinghouse BWR Services.

At Westinghouse, the laser scanning technology was a natural fit since DuBay had first-hand knowledge of the challenges inherent in as-built modifications of reactor internals, and his entrepreneurial mind saw the potential of the underwater laser measuring technology as a business opportunity. Its ability to provide far more accurate as-built dimensions than the original design drawings in-vessel meant that modifications could be accomplished faster and with greater precision. The other benefit with his position at Westinghouse was access to BWR reactor internals mock-up at its state-of-the-art BWR training center in Chattanooga, Tenn., where he could put the technology and its hardware through their paces and find out where any potential pitfalls might lie.

When the opportunity presented itself to obtain measurements at the Quad Cities plant, the hard development work and several beta tests had already been done and the scanner was ready for actual in-vessel use. The next step was to prepare a reproduction of the specific RS-2 jet pump location at the Westinghouse Chattanooga mock-up facility. This step proved to be invaluable and enabled the equipment and contingencies to be thoroughly and specifically tested before actually going on site and as a result, considerably shortened the required critical path time.

At the Quad Cities site, Thomas Wojcik, Chris Hebel, Ron DiSabatino and Kate Gresh provided the team site coordination and support. The Westinghouse team was given a 12-hour window on the refueling floor to deploy and complete the scans. They met the time frame and the results were impressive: the scans in the high radiation belt line region, as anticipated, resulted in considerable noise in the point cloud data, but post-processing with Geomagic software provided very clear 3-D images that were readily dimension-able.

In all, more than 20 scans were taken; scans which captured critical dimensions requested by the design engineers. After capturing the raw data, the 3-D point clouds were stitched together using Geomagic post-processing software. The accuracy of the detailed images was outstanding and significantly better than previous measurement methods; to the extent that weld profile dimensions, which in the past required the use of a $1 million mechanical profiling tool and additional days of critical path, were measured to within a few mils of accuracy within a single 12-hour shift.

For their efforts the Quad Cities team was awarded the North American Young Generation in Nuclear (NA-YGN) Innovation Award at Exelon's June 2011 CNO Staff Meeting, and Quad Cities engineers are anticipating a much smoother procedure during the next outage when they make their first-of-a-kind jet pump modifications, greatly aided by the precise, in-vessel measurements now possible with the new underwater laser technology.

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Kate Gresh

Kate Gresh joined Exelon Nuclear, LLC in 2009 as a Corporate Programs Engineer. Gresh worked in the areas of finite element analysis, flaw evaluation, and composite pipe wrap, before working in materials management for BWR Reactor Internal Components. Gresh holds a B.S. in Civil Engineering from the University of Illinois.