Stewart Ward, PLS setting up scanner in front of access door below turbine blades.

Laser Scanning Interior Vertical-shaft Turbine in a Hydroelectric Power Plant

BY GWEN **INSKEEP, LSI**

Dioptra has been providing land surveying services to the public and government agencies throughout Idaho and beyond for more than 15 years. Diving into 3D scanning in 2012, with the purchase of our first Leica C10 scanner, Dioptra immediately had success. We have since made a continuous effort to implement 3D scanning in a large portion of our surveying services (bridge and highway construction/repair and design, bridge clearances, dam remediation, subsidence, municipal street design, etc.) This project was different and a bit outside of our comfort zone but, at the same time, too unique to walk away from.

This is a story of the collaboration between a municipal power company, Dioptra (a full-service surveying company located in Chubbuck, ID),

Wicket Gates inside Scroll Case

Scan setup between Wicket Gates

and Idaho National Laboratory (INL). As requested by the municipal power company, their name is to be confidential. Therefore, we will refer to them as MPC.

Knowing our company's experience and expertise in 3D scanning, MPC reached out to Dioptra in late 2014 with a proposal. The project proposed was to scan the interior of a vertical-shaft turbine in a hydroelectric power plant. Our first response was "We would love to!" shortly followed with the news that dewatering of the power plant wasn't going as planned and the project would have to be put off all together. Nearly 8 months later we were contacted by MPC once again with the same proposal. This time though, the race was on. They needed us on site within the next 4 days, the scanning to be completed in just 2 days with 0 return visits possible. Time was of the essence due to the short but costly shutdown period which was scheduled with the Federal Energy Regulatory Commission (FERC). The next couple of days were spent touring the site, planning scan layouts and scanning practices in both known and unknown areas, talking with MPC managers about their desired deliverables and expectations and most importantly collaborating with the MPC maintenance crew.

During the limited shutdown period scanning was to take place, planned installations/repairs and maintenance were to be completed, safety practices were to be followed, tours were to be held and vigilant dewatering efforts administered. Shutdowns of MPC's hydroelectric plants are not abnormal due to the quantity of plants they control, so this magnitude of multitasking for them was nothing new. This particular plant produces approximately 120 million kilowatt-hours of electricity annually and is dewatered for routine maintenance only once or twice a decade. This is where the problem arose for MPC. Infrequent individual plant shutdowns were an issue due to seasoned maintenance employees retiring or leaving within those shutdown gaps. "How would training of new maintenance staff take place when the entire project area was under water? How do you effectively train from a 2D schematic?" LiDAR, resulting in a 3D point cloud and in turn a virtual reality environment, was the answer.

Not only was this requested point cloud going to aid in training employees, it was going to be used for engineering/

design purposes due to its accuracies, in planning safety ingress/egress routes, and implemented in MPC tours held at Idaho National Laboratory's Computer Assisted Virtual Environment (CAVE). Allowing viewers to virtually "walk-through" the power plant, this technology provides a whole new perception and understanding of the data to engineers, mechanics and the public.

Our scanning crew consisted of myself, (Dioptra's LiDAR/HDS Manager), Stewart Ward, PLS (Dioptra's Owner) and Darrell Hanners (Survey Technician), along with support from MPC's maintenance crew. If something needed repaired or rigged, those men could do it, and they did! From make shift boardwalks to man-lifts, they were on top of it all. Equipment used for this project included: a Leica C-10 Terrestrial Scanner, a tripod with stabilizer, Canon 60D digital camera w/ Sigma 8mm fisheye lens, external flash and diffuser for camera (for the frequent dark areas), harnesses, headlamps and Leica 6" circular planar targets.

Arrival on day one of scanning was nothing short of an organized night time mud run. The environment was dark, loud, damp, dirty and full of staff on a mission. Slightly confused on where to start and priorities of others, we decided to start on the tightest and most difficult area first, the portion of the turbine known as the scroll case. This area consisted of a very large and vertical spiraling concrete structure which allowed the intake water to funnel around, thereby accelerating and spinning the turbine blades and shaft. As planned in the office, our first connection point from the intake area to the outtake would have to be directly through the turbine blades and down the draft tube. Our second connection point would have to be through a manhole at a lower level. Because a coordinate system was not being applied, connection points were extremely important for registration and unifying the point cloud.

Man-lift below turbine blades

After scanning around the scroll case and near the 30' high intake gates, our next area would be on top of the scroll case and between what are called the wicket gates. Already being a challenge due to limited line of sight, we had to factor in the narrow and slick setup areas on top of the scroll case. This meant wearing safety harnesses secured to a safety line. The wicket gates are approximately 7' high, 4' wide and 4" thick and are skewed from the center of the shaft to allow maximum funneling. The area between each gate was too narrow to set a tripod so we instead mounted our scanner's tribrach to a 2x4 board, screwed to a piece of plywood. After carefully sliding each setup close to the edge of the draft tube and leveling, we crawled around the next gate to get out of the scan. Having the scan setup close to the edge was necessary to acquire all pivoting turbine blades and data as far down as possible. Our worries weren't so much for our own safety but in fear of losing the C10 to the 40-foot drop down the draft tube. After successful completion of the 20 wicket gate scans and 6 scroll case scans we

Gwen Inskeep, LSI inside Turbine Shaft

Turbine shaft casing with access hatches

immediately downloaded and reviewed scans as there wasn't room for errors or time for return trips.

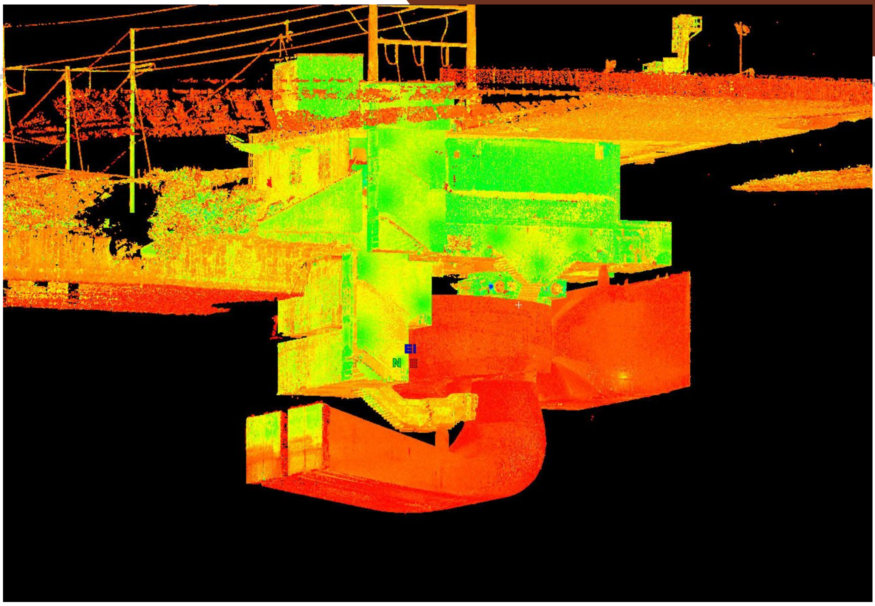
Day two consisted of our next planned route through the gallery room, down the stairs into the lower gallery room, then through a manhole leading to the bottom of the draft tube. The 2 gallery rooms were well lit and mostly free of debris and slick surfaces. Once we were ready to move down the manhole, MPC's crew directed us on the man-lift operation and safety. Snug in the man-lift, one at a time with equipment in tow, we were lowered down to the loud roar of rushing water, complete darkness, and smell of stranded fish. The most challenging parts of scanning in the draft tube was the rushing over-head water obscuring scans, running water down the walls that diminished returns and obtaining well enough lit images using only 2 headlamps and a diffuser for our external camera.

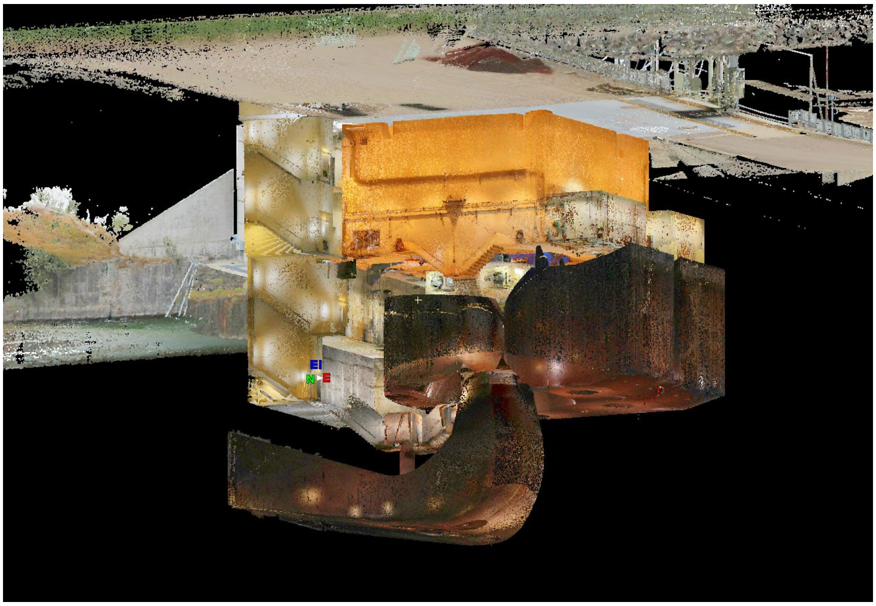
During scanning on day two, MPC requested we look at another area they wanted scanned for future training and design purposes. The additional area was inside of the turbine casing, which surrounded the shaft, and was directly above the blades. This area housed a wear-ring that needed replaced. After a few measurements, I shimmied across the blades and squeezed through a small round hatch into the casing. Inside, we could scan in 5 different locations collecting all crucial parts. The issue that arose in the casing was the scanner's compensator falling out of range. Because of the uneven surface inside of the casing, leveling was a challenge and took several minutes to accomplish between each setup (rolls of duck-tape and scraps of wood wedged beneath the scanner seemed to be the best alternative).

All scans, 41 total, were completed in a total of about 12 hours on-site. The extent of vertical and unique objects helped tremendously when it came to post processing the data. Registration of the point cloud was done using the "visual alignment method" in Leica's Cyclone Software and colorization was accomplished by using images from our external camera. The biggest delay was stitching images in the dark and tight spaces, especially when stitching a concrete wall with minimal visible constraints. Dioptra has always chosen to colorize the point cloud using external images because of two main reasons: one, the colorization seems to be of higher and clearer quality and two, one of our deliverables is digital movie files at all setup locations. Deliverables to MPC consisted of these .mov files and colorized .pts files (registered and unified point cloud). The .pts files were to be used in the CAVE for public viewing and in Bentley's Pointools Viewer for MPC's viewing.

Upon completion of our scope of work and MPC's review of the registered point cloud, again, MPC came to us with another proposal. They wanted us to scan the remainder of the power plant. This consisted of a portion of the exterior of the power plant, all interior rooms and all stairwells. These areas were accessible during normal plant operation and scanning did not need to be completed in a certain timeframe. The additional areas took 2 days to scan and consisted of 76 scan setups. And, yes, challenges did arise. MPC wanted the turbine generator scanned as part of the scope. At this point the plant was fully operational and therefore had moving parts. This is typically a problem for us, as moving parts don't allow for a tight point cloud registration. Luckily, the only moving parts in the generator room were pivoting arms that automatically moved, adjusting blade angles based on flow rates to get optimal efficiency. After explaining the problem to MPC's staff, a phone call was made and control over the generator was switched to manual, but urgency was requested on our part. Again, tight spaces where inevitable. With nowhere to hide to get out of the scanner's line of sight, hiding under the tripod ended up being a great solution in several situations. All in all, scanning went smooth and registration even more so. Registration was performed, once again using the "visual alignment method" resulting in 3 different unified point clouds. Final deliverables to MPC consisted of additional digital movie files at all setup locations, colorized .pts files (registered and unified point cloud) and a review day with MPC employees at INL's CAVE.

Review day at the CAVE was very exciting for us, this was the first time any of Dioptra's staff had seen the CAVE, let alone with our own collected data being projected. The CAVE projects the 3D scan's point cloud on 3 large walls and the floor. Wearing 3D glasses, you can step into the CAVE and experience depth perception while using a wand to move and rotate images to create a virtual world or "walk-through" of the point cloud. We had the opportunity to show our results on a whole new scale and to a crowd who had never been exposed to such technology. They would be using this data for years to come and to them, it was also very exciting. With additional power plant shutdowns scheduled in the next couple of years, we are in high hopes that MPC will ask us to scan an additional plant for the same purpose.





Intensity View of registered point cloud

This project was Dioptra's first plant scanning project of this magnitude and couldn't have been accomplished without the help of MPC and co-workers at Dioptra. The benefits of scanning, since first introduction, has proven itself but not without trials. The more we learn through experience, it is ever more clear that anyone's end-result is dependent on collaboration. Collaboration, between staff, management, the public, software, wherever it might come from, is essential for success.

Gwen Inskeep received her Associate's Degree in Civil Engineering Technology (2011) and her Bachelor's Degree in Geomatics Technology (2013). She has worked for Dioptra since 2013, is currently their HDS/LiDAR Manager, and plans to take her Professional Licensing Exam this year. Gwen can be reached by e-mail at gwen@dioptrageomatics.com