Recovering energy from an existing conduit

The City of Logan, Utah, installed a hydropower system in its water supply system replacing a Pressure Reducing Valve. In addition to the challenges of fitting new equipment into an existing facility, the project required a Francis turbine able to handle an unusually broad range of head pressures. Report by Jeff White

THE City of Logan sits near the base of the Rocky Mountains in northern Utah and draws 70% of its potable water supply from Dewitt Spring, a naturally flowing fountain of pure water located about 11km away in Logan Canyon along US Hwy 89, which is also a beautiful National Scenic Byway (http://www.utah.com/byways/logan_canyon.htm). From the Dewitt collection basin, a pipeline runs down the canyon 8350m to a Flow Control Vault where excess pressure is removed before the water is distributed into several concrete storage reservoirs.

The original steel pipeline was constructed in 1934, with some sections upgraded to reinforced concrete in 1949. Over the decades some sections began to leak, so in 2008 major sections of the old 610mm and 760mm pipes were replaced with 915mm welded steel pipe. The larger diameter increased available water flow to the growing community while significantly reducing pipeline friction.

Less friction resulted in additional head pressure at the Flow Control Vault, creating both a problem and an opportunity. The existing pressure reducing valve (PRV) at the Flow Control Vault was pushed beyond its design limits under the higher pressures, causing severe cavitation and rapid deterioration of the PRV. Remedial action was required to avoid any restrictions on the municipal water supply system.

The excess head pressure, however, also created the opportunity for hydropower. A small turbine would reduce the pressure, much like a PRV, and send electrical power into the municipally-owned power system. The challenge would be to fit the hydro system into the limited floor space of the Flow Control Vault.

Since the project involved the installation of a hydropower unit onto an existing water line, there were no environmental impacts to mitigate. The US Federal Energy Regulatory Commission (FERC) recently streamlined permitting processes for small hydro projects with low environmental impacts, and approval came quickly. Public support was also very positive because the project produced clean, renewable "green power," simply by recovering energy that had been going to waste through the PRV.

Avoiding penstock surges

The remaining section of concrete penstock is the "bottleneck" of the system, creating potential for catastrophic water hammer events, even with minor pressure surges. Although this section is slated for replacement within the next 10 years, special attention was necessarily given to the design of valve closure operations, turbine runner over-speeds, and any other factors that might contribute to water hammer.

It is important to note that power generation is a subordinate function of this asset for the city. The top priority is to provide a reliable, uninterrupted culinary water supply for the community. If an overpressure event destroyed a section of the line, the entire community would suffer with rationed water until repairs could be made. Lance Houser, Assistant City Engineer for Logan, played the critical role in this effort as Project Manager to insure the needs of both the water department and power department were not compromised.

The City of Logan, Utah installed a Francis turbine to replace a pressure reducing valve

Even though the turbine replaces the need for a PRV, if the turbine shut down, the city would still need to ensure culinary water deliv-

The pressure control vault houses the turbine and bypass PRV

ery by using an automatic by-pass system. When the Turbine Inlet Valve (TIV) begins to close, a neighbouring valve at the PRV opens automatically to bypass the turbine and maintain water supply to the storage reservoirs.

Surges can still occur, however. If the generator trips offline for any reason, the Francis turbine can achieve maximum overspeed within seconds, restricting flows by 30%-50%. A heavy flywheel was specified on the system to increase the time required to reach this restricted flow condition and to slow the pressure-rise timing sequence.

The final line of defense for protecting the integrity of the penstock was provided by the installation of a "surge pipe." At our site, a surge pipe was much more economical than a surge tank, but serves the same purpose. In addition, a buried surge line is much less visually intrusive along the beautiful Logan Canyon Scenic Byway. The 610mm diameter surge pipe taps into the penstock immediately upstream above the TIV, and is routed up a steep hillside next to the Flow Control Vault. The surge pipe elevation on the hillside reaches the same static elevation as the Dewitt Spring collection pond up the canyon.

During an over-pressure event, a U-shaped section of piping at the top of the surge pipe redirects the surge water over the "U" and back down the hillside into one of the storage tanks. Under normal operation, the water elevation in the surge pipe remains just below the "U".

This design was an effective surge solution for our project, but created another dilemma. If there were no surge events to circulate and replace the water in the surge pipe from time to time, then the water could eventually become stagnant and a problem for our municipal water supply. To ensure constant and continuous fresh water circulation through the surge pipe, a smaller, 25mm HDPE "bleeder line" was tapped into the surge pipe just below the static water level at the "U". This line is then routed back down the hillside next to the surge pipe and discharges into the low pressure side of the turbine tailrace sump.

Turbine design considerations

Despite the relative simplicity of an in-conduit project, there were a number of technical challenges to overcome. Even though large sections of the pipeline had been replaced, the 3200m length of smaller concrete pipe still remains, effectively choking flow and increasing penstock losses. As a result, net head varies significantly with flow, ranging from 33m to 44.5m.

Consequently, the turbine design must operate smoothly and efficiently across today's wide range of available head, and also across a different range later in the future when the 610mm concrete pipe is replaced with 915mm steel pipe. This upgrade will nearly double the available head pressure and turbine power output.

Site characteristics dictated a Francis-type turbine, a design normally well-suited for varying flows, but less tolerant of wide swings in head pressure. The challenge was to come up with a single turbine designed to handle both current and future head conditions.

We turned to Canyon Hydro in Deming, WA, for the water-to-wire package, including the design and manufacture of a custom Francis turbine able to accommodate vastly different head pressures. During the design phase, Canyon performed extensive Computational Fluid Dynamics (CFD) testing at different heads and flows, making a series of small adjustments to the runner and spiral case parameters. They eventually identified a design with very good efficiency across a broad range of head pressures.

Fabricating the runner

All of this fine-tuning and CFD testing produced a runner design that performed well on computer simulations, but now had to be replicated in stainless steel for the real world. Every complex curve of the runner design had to be precisely matched to the 3-D CAD model, a requirement made even more challenging by the runner's small 480mm diameter. At this size, there was very little room for error, and even minor deviations could introduce performance problems as head pressures moved toward the outer extremes.

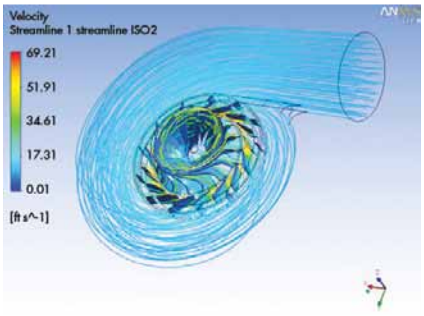
Canyon solved this problem by leveraging technology not often employed in the hydro industry. Using a process called "stereolithography," they first created a polymer version of the runner. Stereolithography uses a process similar to a medical MRI scan, dividing the computer model into very thin digital "slices," each only about 100 microns thick. A laser beam is then used to "print" a three-dimensional runner, literally from the ground up, systematically adding each slice as a microscopic layer of polymer. The end result is a full-size, perfect duplicate of the CAD model design, now in a physical, 3-D plastic form.

Next, the investment casting process begins by dipping the polymer runner into a thin solution of glazing compound, which hardens into a smooth layer around all surfaces. Additional, heavier layers of compound are added, creating a coating around the runner over one centimeter thick.

The thickly coated runner is then oven-fired at extremely high temperatures, which does two things. First, the dense glazing compound is fused into a hard, heat-resistant ceramic jacket around the runner. Secondly, the polymer runner inside melts and is drained away, leaving a perfect negative for the casting process. Molten CA-6NM stain-

The The U-shaped return is installed at the top of the surge pipe

CFD testing of the Francis turbine



less steel is then poured into the cavity and allowed to cool. Finally, the ceramic casing is broken and removed to reveal the stainless steel Francis runner, exactly as modeled in CAD on the computer.

Fitting the turbine into the existing vault

As part of our pipeline replacement a year earlier, the city built a new Flow Control Vault that was larger than needed for the PRV, with hopes of someday installing a turbine. Thanks to a Federal ARRA grant, this opportunity arrived sooner than expected.

Even with this prior planning, space remained a premium. The new PRV and all its plumbing were still necessary to ensure the city's continuous water supply. Water entered and exited the vault at right angles, dictating a horizontal-shaft Francis design. The draft tube needed to climb away from the turbine slightly to match up with existing plumbing, requiring a custom design from Canyon.

The horizontally-mounted generator wouldn't fit within the building's confinement with the surge-damping flywheel added to the end of the rotor shaft. We worked with Canyon on some alternative configurations, but ultimately concrete saws and jackhammers were needed to build an alcove addition onto the building for the flywheel extension.

Despite the many challenges, the final installation looks great, with ample room for the turbine/generator as well as the Hydraulic Power Unit, control cabinets and switchgear. We were able to connect to the grid using the same transformer serving the vault, thereby minimizing interconnection costs.

System startup

No matter how thorough the planning, I think all new turbine owners hold their breath at startup. Richard New was on hand from Canyon Hydro to supervise the process, along with Dan Batdorf from Bat Electric, Canyon's supplier for the controls and switchgear.

As with all Francis owners, we still had some concerns about possible cavitation at certain head pressure regimes. With all due respect to CFD testing and advanced fabrication techniques, it is the real world that tells you how good all of your detailed, digitized, high-tech CAD studies really are! The system started up smoothly with reduced flows. As we increased flow, we all listened intently for that telltale sound of cavitation, not unlike gravel popping and crackling through the turbine runner.

The computer modeling predicted no cavitation, but Canyon took the extra precaution to build in some anti-cavitation measures. The most common fix for cavitation is air injection, where negative pressure in the draft tube is used to draw in atmospheric air to alter the fluid dynamics. Conventional air injection is not an option for our installation, however, since positive pressure must be maintained at the turbine tailrace output to move water into the storage tanks. For our project, Canyon had designed a variable, pressurized water injection system that could be used if needed.

Fortunately, it wasn't necessary. As flows increased, our net head dropped dramatically as expected. Across the entire range, the turbine continued to run smoothly without a hint of cavitation. When the old concrete section of penstock is replaced, the increased head pressure will put the turbine to the test again, but early indications are good that we won't have problems.

A success for the community

Since startup, community interest has been enthusiastic since the project provides the community with a new source of clean and reliable energy. Our system was installed on time and within budget except for the alcove addition onto the Vault. The best part is that the new owners, the citizens of Logan, are now one step closer to securing their own energy independence for many years into the future!

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About Canyon Hydro

Canyon Hydro is a US manufacturer of hydropower turbines and supplier of water-to-wire systems. The company designs and builds custom Pelton, Francis and Crossflow turbines for projects under 50MW. Canyon also provides repair and rebuild services for all types of turbines, including onsite machining.

In business for 35 years, Canyon Hydro established an early reputation for its expertise with high-head systems. The company designed and built a Pelton system for the highest head project in North America, which produces about 10MW from 865m head. In later years, Canyon began producing its own Francis designs.

Canyon Hydro has two manufacturing facilities in Washington State, including a new, large-capacity CNC machining center. ***www.canyonhydro.com***

Below left: The Canyon Hydro Francis runner was first fabricated in polymer using a process called stereolithography; Below Right: Inside the vault with turbine installed