Inspecting Upgraded Hydroelectric Generators

Extending the life and increasing the output of older hydroelectric power plants require expanded inspection programs

BY STAN LIGHT

In recent years, power plant operators have had to find new ways to keep up with increasing power demands while at the same time deal with spiraling costs for fuel, meeting tighter emission requirements, and maintaining efficient, safe operations. The hydroelectric sector of the U.S. power industry has always had an edge when it came to the cost of fuel (water), but higher operating and maintenance costs sometimes offset the savings from this cheap, abundant fuel. Most U.S. hydroelectric plants are old — 25 to 50 years or more. More domestic hydroelectric plants have been closed in the past few decades than have been built, mostly due to perceived environmental damage to rivers and fish, but never because of lower demand or higher power costs compared to fossil fuel systems. For a time, plant owners in all sectors of the power industry handled increases in demand by reducing reserves (using existing, previously unused, or underutilitized power equipment). This precluded the need for expensive new equipment, complicated licensing requirements, and dealing with environmental issues. Because of the low cost of hydroelectric power, demand in that sector has always been high; however, reserves were already lower for hydroelectric power than for other sectors. Compounding the problem has been an increasing battle with environmentalists over migrating fish and perceived damage to rivers and their surrounding ecosystems.

Not counting a few scattered examples of new, small hydro plant expansion programs, hydroelectric power operators have, in the past, mostly resorted to upgrading or uprating of existing units. This usually involved minor increases in power output through replacement of the stator windings or, perhaps, the stator core laminations. This meant little change to the mechanical portion of the power equipment. With this small increase in stress on the mechanical system, there was little concern for any possible effect on the quality and safety of these upgraded systems.

More recently, power upgrades on hydroelectric units have gotten seriously complicated. Many times these newer upgrades involve minor changes to nearly all of the mechanical systems and major rework or replacement on some of the larger and more critical systems. The hope is to upgrade the power units as much as possible but to keep downtime and lost revenue as low as possible while accomplishing the job. Further requirements include creation of a robust, more powerful, "new" unit that can, perhaps, have a longer life expectancy than the original machine.

With these more complicated mechanical upgrades comes an increased awareness of the problems that have been historically associated with the poorer controls of implementing field processes vs. the tighter controls of factory-made components. The following are among the potential problems:

- Poor documentation and accountability.
- Greater potential for mechanical failures and resultant rework costs.
- Time and revenue lost because of the need to repair recent, poorly done upgrades.

A typical turbine runner and shaft on a 350-megawatt system. Turbine upgrades can require extensive modification of the water path through the spiral case and past the stay vanes.

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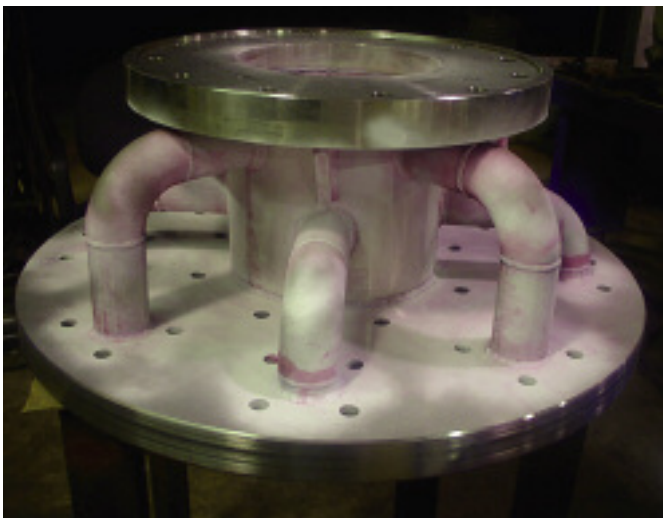

Fig. 1 — A completed penetrant test on a high-pressure rotor water distributor assembly. These are used on the very rare water-cooled hydroelectric generator rotors.

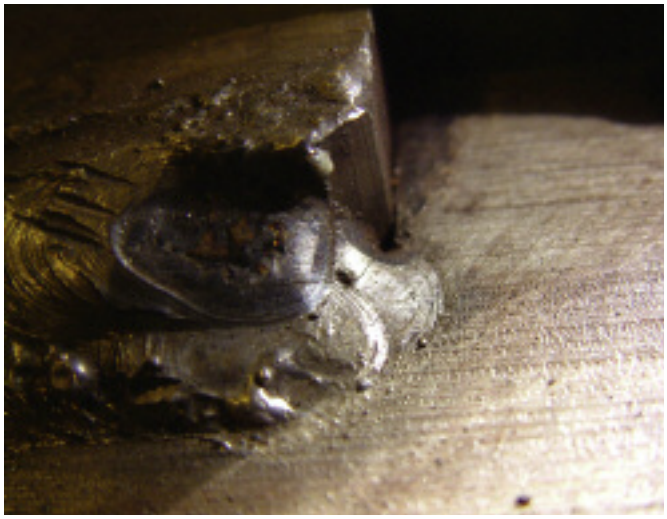

Fig. 2 — Newer repair weld pass over vintage weld passes that contained large cracks that were not ground out. The result was propagation of the old weld cracks into the new repair weld.

These issues have caused hydroelectric plant owners to write expanded specifications requiring adherence to national or international standards, to implement field quality programs, and to demonstrate competence through documentation, training, testing, and certification. This has resulted in an expansion of the need for visual inspection and other nondestructive examination methods in this industry during large aggressive upgrades.

A New Era

To ensure safe, productive, and long-lasting equipment for today's more robust upgrades, plant owners and OEM suppliers realized that it was necessary for extensive inspections to be a major part of the upgrade program.

Inspection programs for earlier upgrades — those resulting only in a small power increase — seldom included more than the following:

- Cursory visual inspection of the unmodified parts, which included the stator frame, complete rotor, head cover, stay vanes/spiral case, and most of the turbine control parts.
- Penetrant testing (PT) of the turbine cavitation repair (cladding on the runner blades).

Most older upgrades on hydroelectric generators essentially involved only the stator winding replacement and perhaps the stator core iron. There may have been some major components replaced on the turbine, but extensive modification requiring welding (other than cavitation repair) was not common. Therefore, there was little need for visual inspection or other forms of NDE. Many older upgrade specifications clearly stated the need for addressing "quality issues" but typically what actually happened was a person who was already assigned several other tasks (expediting, receiving, or even cleanup) was also designated the "quality representative" and assigned the task of "keeping an eye" on things. To an extent this worked fine because most of the changes were to the electrical components. Usually the mechanical systems were still working well or at least had shown only minor signs of wear. There was really no significant need to inspect components that weren't broken or breaking, or that would not see their original design limit tested or exceeded in the future.

Many recent upgrades, however, have involved major component replacement in both the generator and turbine. In addition, the parts not replaced have usually required major modifications. Even the parts that are not replaced or modified because their size or design parameters should withstand the higher stresses of the upgrade are visually or otherwise inspected to ensure they are still structurally sound.

The Inspections Required on Modern Upgrades

Generator

Stator Frame. These days, the stator frame not only has to withstand new, higher stress loads of operation, but it may also need to be strengthened and/or stiffened to allow it to be lifted from its sole plates and placed in a work area away from the turbine pit.

This usually means a complete visual inspection of the old frame before modification. Repairs, if any, need to be done at this point because the modification design assumes that the rest of the original frame is in good shape. Then the frame is stiffened and/or strengthened and perhaps modified to add crane lifting points. An example of this is a project that was completed in the mid to late 1990s. The project required modification of three stator frames that were each originally installed bare (no core or windings) in six segmented pieces weighing more than 18 tons. With the core and windings added, the completed frame weighed in excess of 800 tons. For this project, the completely assembled stator frame had to be lifted and moved several hundred feet. The modifications to the assembly required a two-shift crew of four welders almost a month to complete. Visual and other NDE inspections took the inspector another month to complete. After the old frame was strengthened and stiffened, lifted, moved, and stripped, a new core support system and stator core and windings were installed. These were followed by welding nearly a thousand core attachment straps. These core attachment points required 100% visual and 10% fluorescent penetrant (FPT) inspections.

Rotors. Although rotors experience a lot of mechanical stresses, they are usually well designed, and little needs to be done to them to support the upgrade effort. Therefore, major

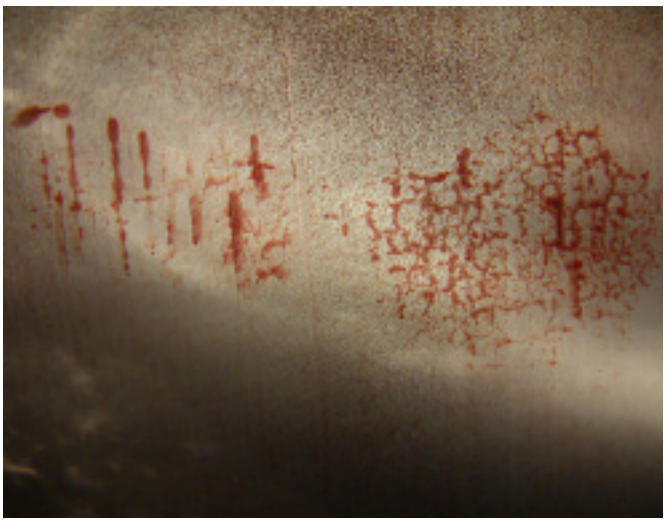

Fig. 3 — Penetrant test brings out small stress cracks and heat checking on the rotor brake ring surface.

changes to the rotor are not needed. Experience has shown, however, that parts of the rotor, particularly the rotor poles (field windings), can be pushed to their limit, especially on an upgrade where the air gap changes significantly. Given that situation, there is usually a serious effort made to inspect the entire rotor to ensure that it is at least up to the original specifications — Fig. 1. The areas that usually require inspection include the rotor's center hub/spider arm assembly, stacked rotor rim, and pole/field winding assemblies and the welded locking keys that hold them together.

The spider/hub assembly is a large, partially machined weldment. Stresses can be significant here as this component holds together a rather large, centrifugally loaded mass (the rotor rim). Usually a 100% visual inspection is done. Of most concern are the highly stressed spider arm-to-hub welds and balance weight welds. If there are suspicious areas, the paint can be removed and NDE performed (usually just PT).

There are three areas of concern on the rim assembly: the rim-to-spider attachment key welds (Fig. 2), the brake ring, and the tack welds on the rim-clamping studs. Other areas include welded fan blade assemblies and other welded/bolted attachments and supports. The rim-clamping studs are prevented from backing off by large tack welds between the nut/washer and washer/rim top or bottom plate. These single-pass welds are several inches long and require only 100% visual inspection. The rim-to-spider tack welds can have several passes and are highly stressed both centrifugally and thermally. At rest, the welds are usually under transfer compression so if cracks develop in operation, many times they are squeezed shut. Often, these cracks can barely be seen visually, if they are not totally invisible. In fact, there are times when even PT cannot present these cracks strongly. Fluorescent penetrant testing might add a slight level of additional sensitivity here but usually isn't warranted, and due to access limitations, ultrasonic testing (UT) is not usually possible.

The brake ring (a large, flat, donut-shaped ring at the bottom of the rim) presents several inspection opportunities — Fig. 3. First, the attachment points (weld-locked bolts) to the spider require a visual inspection. Then the surface of the brake ring gets 100% visual and PT inspections looking for heat checking and cracks. There are numerous other small nonmetallic components attached including electrical insulating components that also require visual investigation as part of a comprehensive rotor inspection program.

Fig. 4 — A UT technician checks a generator thrust bearing for unbonding.

Bearings. Generator and turbine bearings — both guide and thrust bearings — are high wear, high maintenance items. They have always been prime candidates for inspection (visual, PT, and UT) during any outage whether the outage was for simple maintenance checks or for a major upgrade. Older, obviously worn bearings or bearings that visually show the early stages of failure are usually re-babbitted after only a visual inspection before going out for rework. However, since most upgrades, including major ones, do not change the rotational speed or weight load on the bearings, if the bearings are good there is usually no need to upgrade them. An inspection to determine their continued serviceability may include a general visual inspection, followed by a 100% PT inspection of the edges at the steel/babbitt interface, and a UT thickness inspection of the entire surface to look for unbonded areas — Fig. 4.

Turbine

Modern, aggressive turbine upgrades require extensive modification of the water path through the spiral case and past the stay vanes (see lead photo). These modifications can include lengthening of the stay vane on the inlet or outlet end and/or reducing the area of the water path, essentially changing velocity, pressure, and general flow characteristics as the water passes the wicket gates and enters the turbine runner.

Shaft. The shaft(s) are usually only checked at the radius of the flanges. Depending on shaft material, surface condition, and the engineering concerns, any combination of PT, magnetic particle, or UT can be required. Since volumetric inspection (UT) was usually part of the factory test program, in-service cracks are the primary concern and not casting voids.

Head Cover. The head cover is a large weldment that retains the wicket gates. This component sometimes requires modification and subsequent weld inspection but always needs a complete visual inspection.

Spiral Case and Stay Vanes. The spiral case is a very large statically poured steel casting that resembles a nautilus shell. It is assembled at site and embedded in concrete. The large end is the water inlet and as the water makes one complete circle, the cross section reduces to zero. The water must pass through the openings between the stay vanes (blades) and head toward the center and the runner.

Sometimes the cast spiral case will have shrinkage cracks (surface and subsurface) near the welding modifications. When this occurs, the surface cracks may expand or the subsurface cracks enlarge. These cracks can actually propagate into the new modification welds. This is unacceptable and requires some NDE investigation prior to modification. Some stay vanes are integrally cast into the spiral case and some are welded in, which can affect the amount and type of inspection needed. Once the modifications are completed, the added vane extensions require PT of the welds attaching the extensions to the vane and/or case.

Wicket Gates, Gate Arms, and Related Fabrications. Whether modified or not, these components can get visual and PT and/or MT inspection.

Runner. The runner is replaced in most aggressive upgrades; however, if replacement is not necessary to meet efficiency or output requirements and only cavitation repair (weld cladding) is done, the inspection can be done visually and with PT.

Conclusion

It is obvious that new aggressive upgrades at hydroelectric job sites take quality programs, including inspection and NDE, to new levels. Plant owners now clearly specify the need and requirements for effective quality programs at the request for quote stage. Usually these specs include identification of dedicated, qualified, quality personnel. This requirement can be met as simply as using a qualified, part-time inspector who can do some other assigned work if it doesn't interfere with his or her prime quality responsibility (and not the other way around), or full-time staff or outsourced inspection personnel brought in as needed. Documentation and reporting are also expanded to include the certifications and experience of the inspector, and reports include weld maps, sketches, photos, and detailed narratives of the relevant findings — not just a quick handwritten paragraph simply stating, "everything looks okay."

Upgrades have gotten complicated and inspections more detailed, extensive, and far-reaching to now include nearly all the system upgrade components. The qualifications and experience of visual and NDE personnel are verified. Inspection documentation is reviewed on several levels. Repairs based on relevant inspection findings are acted upon. These "reincarnated' hydro turbine generators now squeeze more power out of less water, operate safer, need less maintenance, and last longer than they did in their previous lives.❖