

# Hydroelectric generators: The forgotten mechanical component

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The words 'hydroelectric generators' are often tied to other words such as 'power' and 'electricity' and thought to be the domain of electrical engineers. But for mechanical and generator design engineers who consistently work on these machines, hydroelectric generators and their components are primarily viewed as mechanical. Hydroelectric generators are designed to convert mechanical energy into electricity and generate power, but they are also designed to handle the complicated interconnections of forces between their components, which can sometimes cause issues.

Issues with components not only cause headaches for owners but can sometimes lead to more serious problems. In fact, when inspecting machines, what might seem like a harmless indication of minimal damage that could be cleaned or fixed quickly, could in fact be a symptom and warning of significant issues. Fixing symptoms without understanding the root cause can put an owner on borrowed time and increase the risk of more extensive damage or serious failure.

There have been a number of papers and articles that address known occurrences such as cracks around pole dovetails, rim dovetail slots, and wedge carriers. However, this paper will address the less frequently mentioned components and provide examples of seemingly harmless in various generator components that were found to have serious underlying issues.

## 1. Rotor and spiders

The rotor spider, especially one of large diameter, is arguably the most critical mechanical component in the generator. It is exposed to numerous interacting forces including its own weight, turbine and shaft vibrations, centrifugal forces, thermal forces from heating up, load torque, and rim forces, whether those be radial cyclic forces of a floating rim or compressive hub stresses from a shrunk rim. The spider is normally a large, fabricated component sometimes with bolted parts, so the quality of welding and machining is critical to component life. As the rotor stores a huge amount of kinetic energy, failure of its components during operation can lead to catastrophic damage to the entire unit. Inspection of the critical locations can be difficult and not easily accessible, but any superficial signs of trouble, such as

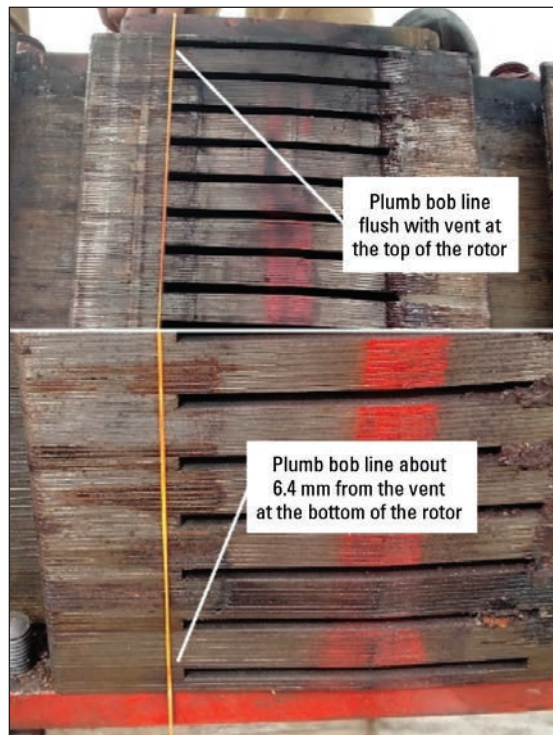


(a) Signs of excessive movement.

excessive signs of movement, an enlarged gap, or small indications of possible cracks, should be taken seriously, and thorough inspections should be undertaken to investigate and understand the situation fully.

### 1.1 Examples

At a multi-unit refurbishment project, what started as finding crushed rim torque keys on one unit during the pre-project planning inspections led to determining that the original rotor rim design had insufficient original shrink and compression. All the rims were found to be 'skewed' to some extent where rim laminations had slipped relative to each other causing rim shape deformations from top to bottom while losing its shrink, which in turn had twisted and deformed the spider arms and imposed additional stress on the welding joints. The stresses and forces induced from this situation manifested themselves among different components. It was first seen as those crushed torque keys on one unit. During unstacking, another unit showed that the rim laminations themselves had twisted and buckled.



(b) Example of a skewed rotor rim.

(c) Looking down on a cracked rotor rim lamination next to the shrink key slot.



The additional tension on the twisted spider arms had also caused systematic cracking at stress-concentrated welds between the arms and the support ledge. On further inspection it was found that the marginal welding quality contributed to the cracking. The skew was found to be tolerable on two other units. On those units, the rim bolts were retorqued to prevent further lamination slippage and then the rim was reshunk to reestablish the original design intent. Understanding the original design intent as well as thorough investigations into the interactions of stresses and forces between components were critical to developing individual refurbishment plans for each unit.

On another project, uneven gaps between the rim-mounted brake ring segments and spider arms were found during the initial generator inspection. Further investigations revealed that some of the spider arm support ledges had actually cracked or broken off completely, leaving the rim to sag under its own weight. The damage was so severe that an immediate 'do not operate' order was given with only one unit allowed to return to service under restricted operations and regular inspection. Only after replacing the damaged support ledges with an improved design, and prolonged forced outages, were the other two units allowed to return to service.

Another example of superficial signs that can be indicative of something more serious was a rotor that kept having cover plate bolts break. After replacing bolts for some time, the rotor was finally inspected in detail. Because of the rotor rim losing its shrink and causing excessive movement between the arms and cover plates, deformation was found in the spider arms which led to the broken cover bolts. The welds on the top of the spider were also under additional tension and further found to be developing cracks. The cracks were so severe that an 'do not operate' order was given, as well as a one-year forced outage.

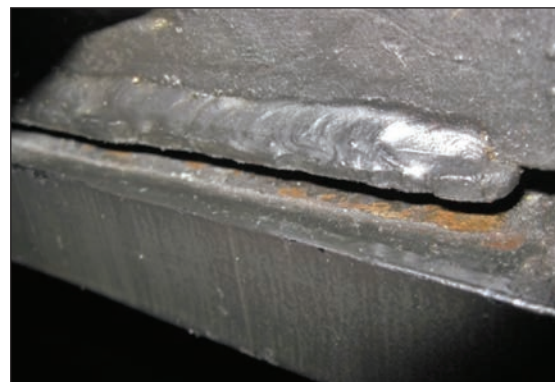
The thrust bearing bracket typically supports the total weight of the rotating mass and the hydraulic thrust of

the turbine runner. On most machines, it is considered part of the generator. The bracket also normally houses the generator guide bearing, which imposes radial forces on it, especially when the guide bearing centre-line and bracket sole plate elevations are different.

A rotor with unbalanced magnetic pull was found to be imposing large forces on its bearing bracket. Deviations in guide bearing shoe temperatures were seen in the monitoring system. A detailed inspection inside the bearing revealed cracks in the guide bearing structural components. Without sufficient inspection, these cracks would not have been found and structural components could have overloaded and prematurely fatigued other parts of the bearing. The guide bearing stiffeners were reinforced to increase the bracket loading capacity.

The causes of the unbalanced pull, primarily the excessive rotor eccentricity, were also investigated and addressed. In this example, tolerances were very small and machines became sensitive deviations in dynamic conditions, demonstrating that the interactions between mechanical and electromagnetic forces are important.

Furthermore, a rotor vibration issue that is only mitigated by mechanical balancing can still cause overloading of the generator components when the mechanical and electromagnetic forces are working against each other. Stresses and forces can travel and manifest themselves in different locations. The situation can become critical when an extreme event happens, such as a runaway condition, where the electromagnetic forces are not present anymore, but the mechanical unbalance effect is amplified by high rotor speed. In general, good quality of assembly prevents unnecessary forces and high-cycle fatigue of generator mechanical components and helps to extend the useful life of the machine.



(d) Gap between spider arm and brake ring due to rim sagging.



(e) Hair-line crack on a spider arm support ledge.

## 2. Stators

The stator is very important in the successful operation of a generator. The potential for stator movement must be understood and included in the design. Stantec has come across numerous projects where the stator core connections to the frame (which are typically welded) have broken loose from the frame, and many instances where a split joint in the stator, placed there for transportation limits, has mechanically opened up. Both events have led to premature and catastrophic failures of the stator windings as a result of additional mechanical and consequently electrical stress on the winding insulation systems. In most of these instances, but not all, the problems can be traced back to the design of the sole plates and their connection to stator frame that are not suitable to allow proper thermal expansion. Typical thermal expansion of a stator on a large generator is around 3 to 4 mm on a machine with an 80°C rise and if the stator cannot expand, that stress will eventually break the foundation, structural parts or cause excessive core buckling. In one instance, the concrete around the sole plate broke. It was found that the entire sole plate block was moving freely as one piece in and out towards the shaft.

These routine expansion-contraction issues for a stator and the air gap can be aggravated in situations where powerhouses have large contact surfaces with water, such as run-of-river dams, and are susceptible to seasonal foundation deformations because of the annual river water temperature cycle as well as sun exposure in the summer.

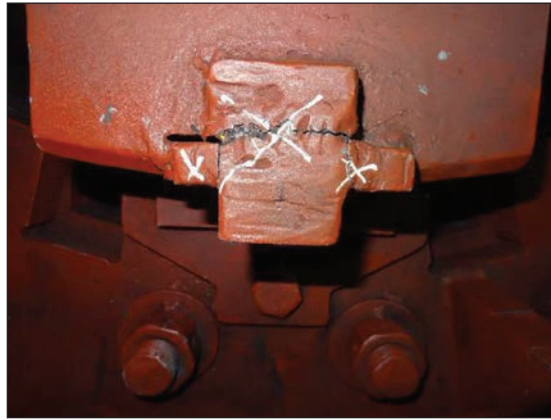
### 2.1 Examples

Stantec has documented this phenomenon over more than 20 years at numerous projects in the western USA. Typically, this issue manifests in an ‘ovaling’ of a unit’s foundation. Depending on the powerhouse stiffness, it varies along different axes or acts in different directions. Seasonal oval deformations have been documented to exceed 7 mm radially (or 14 mm diametrically). Normal expansion and contraction movement means that a stator design (and potentially bearing brackets in the generator housing) must not only account for its own thermal expansion from operation but also its anchorages that are not as stable as one would expect. Thus, the frame and sole plate designs need to allow for the more obvious radial thermal expansion as well as accommodating any relative ovaling of the surrounding structure.

On recent projects, investigations of vibration issues causing air gap variations found the variations could be partially attributed to these seasonal changes in the generator foundation shapes. Once this phenomenon was considered in the stator realignments, the impacts of the seasonal foundation deformations could be minimized. On another project, an out-of-round stator condition caused the generator guide bearing sleeve, which was heat shrunk on to the shaft, to lose its interference fit and the rotor-to-shaft connection was therefore unstable.

## 3. Generator shafts

The generator shaft should also not be overlooked during inspections. The alignment of a thrust runner on a vertical unit can be critical. It is important to inspect the thrust runner flatness and any misalignment at the splits for two-piece runners. Aside from



(f) Tangential crack on rotor radial key.

the potential to cause balance or vibration problems, if further issues are not caught during inspection, they could lead to significant damage later, including wiping the bearing or worse. There is also potential for relative movement between the thrust runner and the shaft, causing fretting damage at the adjoining surfaces which could lead to trouble later. Removing a thrust runner is a commitment for refurbishment. Once disturbed, it usually requires shop machining and reassembly to ensure proper reseating, alignment, and flatness. In addition to the thrust runner, the alignment of the rotor end and turbine shaft end flanges are also critical to the overall machine alignment. Issues here can lead to a dog-legged shaft assembly and vibration problems. For Kaplan units, misalignments could even cause runner oil leakage issues from the shaft joints. Good disassembly inspections and keeping a close watch on shop refurbishment of the shaft will alleviate costly fixes later on.

### 3.1 Examples

The thrust and guide shoes form the remainder of the generator bearings. The quality of shoe rebabbiting is important to the health of the machine. With modern high-pressure lift systems, the old method of scraping is not necessary anymore, and continuing to use scraping could lead to failure. On one project with a lift system, the first sets of thrust shoes were rebabbiting and still scraped per the manufacturer’s typical process. After twice reinstalling and loading the unit up to 70 per cent during commissioning, the bearing oil film collapsed, and two sets of shoes were wiped. It was later determined that the scraping was too deep, leading to a thick, and thus less stiff, oil film that was unable to support the bearing load. Additionally, the scraped pockets were interconnected, leading to oil being squeezed off the shoes and further collapsing the bearing’s support. By now, the importance of inspecting the right parameters during quality control inspections should be clear. Understanding the practice of scraping and its design function was certainly important in this case.

## 4. Conclusion

As demonstrated by just a few examples above, detailed inspection, root cause analysis of anomalies, as well as ‘bigger picture’ understanding of component interactions and involved forces are the key to finding the best solutions and preventing major damage. This approach helps the owner to achieve high unit reliability.



(g) Sole plate grout block protruding from concrete wall towards the shaft.

(h) Above right: Stiffeners were welded to the back of the keybar to address cracks in the keybar, however the stiffener welds cracked from top to bottom.

Mechanical issues typically have a slow progression rate but can be detected by careful visual inspection, precise deformation measurements, or additional non-destructive examinations. Sometimes there are signs of excessive movement or damage on less critical parts, including sole plates. Red fretting dust may be seen or iron filings might be found with a magnet, both of which could be indications of more serious underlying issues on critical components.

It is common during routine maintenance to remove a few covers and check the few areas that are easily accessible or inspect sample locations to save time or effort. However, there is great value in thorough and detailed inspections at least every few years. Findings from inspections and measurements are important to understand what a machine is going through. Likewise, monitoring system data should be viewed from a holistic unit perspective to link potential warning signs and see the bigger picture.

In an era where existing units are often uprated to take advantage of additional capacity and new or replacement designs are optimized to minimize cost, it is essential to take a close look at indications in the generator mechanical components, which are often times forgotten in the heart of the machine. ◇



(i) Wiped thrust bearing shoe.



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