

**Jason DuBose, Mitsubishi Heavy Industries Compressor International, USA,** discusses types of corrosion in steam turbine rotors and the best methods of prevention.

LETTING

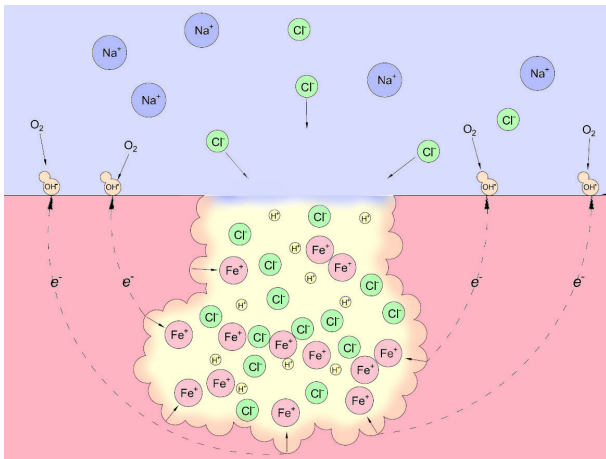
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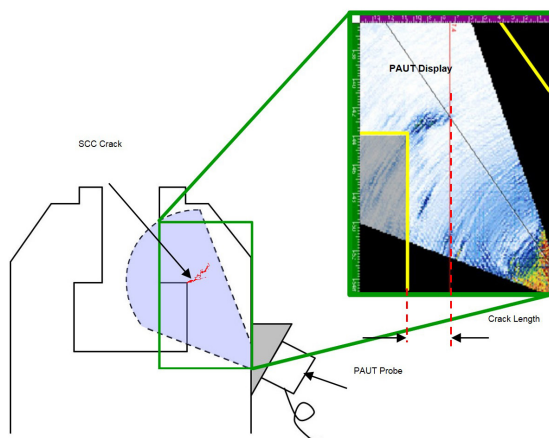
**S**tream turbines are used throughout the petrochemical industry for mechanical drive and power generation purposes because they offer extremely reliable and efficient performance. When properly maintained, steam turbines can operate for 10 years or more and exhibit very little damage. However, corrosion continues to plague steam turbines due to a variety of problems associated with boiler water contaminants as well as maintenance handling. In a 2001 report, the Electrical Power Research Institute (EPRI) estimated that corrosion issues account for almost 5% of the cost of electricity for fossil fuel-fired plants.<sup>1</sup> Additionally, the report stated nearly 22% of corrosion-related costs were avoidable with practical prevention practices and maintenance. Industrial turbines suffer from similar corrosion mechanisms and at similar cost fractions. This article will describe some of the most common corrosion mechanisms associated with steam turbines and approaches to mitigating those mechanisms.

### **Corrosion in steam turbines**

Mechanical work in a steam turbine, in the simplest terms, is generated when steam under high pressure (>2000 psi) and temperature (>1000°F) is fed through the inlet where expansion and acceleration of the steam occurs at each stage – either at the nozzle or blades – and converted to mechanical work by the blades. Consequently, heat energy is extracted from the steam, which results in cooling between the first and last stages.



**Figure 1.** Illustration of pitting corrosion.



**Figure 2.** PAUT detection of SCC cracks.

Of particular significance to steam turbine corrosion is the phase transition zone, commonly known as the Wilson Zone, which is a region where steam spontaneously condenses. Upstream of the Wilson Zone, the steam is almost entirely in the gaseous phase under normal conditions. Downstream of the Wilson Zone, dual-phase flow occurs. Within the Wilson Zone itself, transient conditions of wet and dry steam may exist at any given time. Aside from high temperature oxidation, water is a requirement for corrosion to occur. Therefore, in-service damage mechanisms usually occur near or after the Wilson Zone.

Steam contamination is the root cause of steam turbine corrosion. Although steam is distilled and very little of the contaminants from the boiler should carry over into the steam turbine itself, corrosive materials can be transported by steam in several ways, including carryover through dry steam dissolution and carryover of liquid droplets. Steam chemistry control, therefore, is of paramount importance in preventing pitting corrosion, stress corrosion cracking (SCC) and flow-assisted corrosion.

## Pitting corrosion

Pitting corrosion is a localised form of corrosion in which damage may occur in one location, while adjacent areas

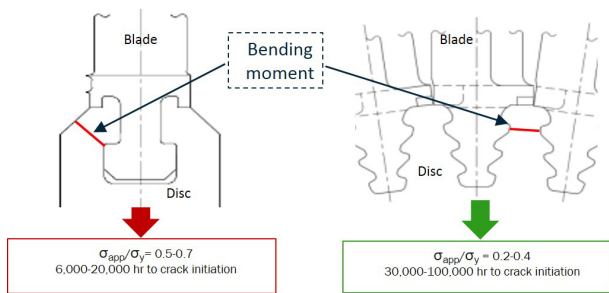
remain unaffected. Pitting is initiated when mechanical damage, embedded contaminants, or localised concentrations of corrosive elements cause the passivation layer of a metal to be breached. Once initiated, two reactions occur, which result in an autocatalytic feedback loop: first, the anodic dissolution of iron inside the pit results in a surplus of electrons, and second, there is a cathodic reaction outside of the pit involving dissolved oxygen, water, and the surplus electrons from the iron dissolution. The positively charged pit attracts negatively charged ions, such as chlorine, and the pH of the solution within the pit is drastically reduced. An illustration of pitting corrosion is given in Figure 1.

In addition to water and ions, oxygen is necessary to initiating and sustaining pitting corrosion, which is not present in-service. Often mistaken as a result of in-service corrosion, pitting on external surfaces of steam turbines actually occurs at maintenance intervals when oxygen is present and corrosive substances remain on the surface. Condensation or humidity levels over 60% can be enough to initiate pitting. Therefore, pitting may occur on stages that are normally dry during service. Condensing stages of the turbine, however, typically exhibit less pitting corrosion than their dry counterparts because corrosives are washed away and do not accumulate. The primary cause of pitting corrosion is steam containing excessive sulfur and especially chlorine, which can lead to pitting with concentrations of 100 ppb in the steam. Pitting corrosion is often a precursor to more insidious forms of corrosion such as SCC and corrosion fatigue.

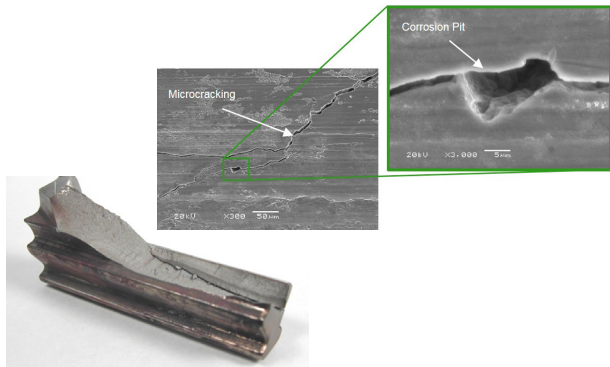
## Stress corrosion cracking

By far the most expensive corrosion mechanism to affect steam turbines is SCC on discs, which can result in catastrophic failure of the unit and result in costs of US\$100 million or more in repair and lost production. SCC is a form of environmentally induced cracking which requires a conducive environment, a susceptible material, and stresses. SCC occurs near the Wilson Zone, where fluctuation of wet and dry conditions can result in the accumulation of corrosive materials. Within this region, SCC is most likely to occur in the high stress areas, and especially within side-entry blade roots where corrosive elements cannot effectively be washed out by steam. When examined, cracks may traverse between grains (intergranularly) or through individual grains (transgranularly), but SCC cracks typically have crack branching that may propagate in directions other than perpendicular to the applied stress.

While SCC can result in catastrophic failure, it will often progress slowly enough that residual life may be calculated based on the current crack length. The EPRI has several analytical approaches to predicting the life of the steam turbine, the simplest and most conservative of which is based on the existing crack length, stress concentration, and steady state crack growth rate. However, to determine the existing crack length, special phased-array ultrasonic testing (PAUT) inspection procedures are required (Figure 2).



**Figure 3.** Blade root stress reduction by axial entry design.



**Figure 4.** Blade root failure by corrosion fatigue.

Prevention of SCC damage is difficult as cracking has been reported even in very pure steam.<sup>2</sup> Therefore, reducing stress and accumulation of corrodents is the most effective means of extending the life of discs. A common approach is to reconfigure blade slots through weld repair (Figure 3). Converting from side-entry to axial entry can effectively delay crack initiation by five times in severe conditions by reducing stresses. One additional benefit of axial entry roots is increased steam flushing, which prevents the buildup of corrodents.

## Corrosion fatigue

Corrosion fatigue is not a discrete corrosion mechanism but is simply a significant reduction of a material's fatigue life through the presence of a corrosive environment during cyclic loading. For example, steels, which have definite fatigue limits when tested in air, will show no fatigue limit in corrosive environments. Corrosion fatigue, like SCC, often initiates at corrosion pits or other stress concentrations, but unlike SCC will have a transgranular progression through the material. Within the crack itself, passivation films are continually ruptured which accelerates the attack. Furthermore, corrosion products can accumulate within the fracture and wedge open the crack, increasing localised stresses at the crack tip. Figure 3 shows a typical fracture in a blade root associated with corrosion fatigue. Figure 4 shows microcracking adjacent to the fracture and the presence of corrosion pits which served as stress risers.

Steam turbine blades are loaded both cyclically and statically. Cyclic loading can result in nozzle excitation (the

pulse of steam flow) or self-excitation (harmonic resonance). To reduce these stresses, blades are typically coupled with shroud bands, tie wires, or with integral shrouds. Static stresses are due almost entirely to centrifugal loading and can be reduced through root redesign or by changing the blade material. Corrosion fatigue manifests when coupling between blades is lost, allowing undamped movement of the blade.

As well as reducing overall stresses, corrosion fatigue can be mitigated by making the surface more resistant to corrosion or fatigue. Methods of achieving this in turbomachinery include shot-peening the blade roots or introducing finer surface finish requirements on the blade root.


## Flow-accelerated corrosion

Flow-accelerated corrosion (FAC), otherwise known as flow-assisted corrosion and often incorrectly called erosion corrosion, is the exacerbation of general corrosion due to fluid flow over a metal surface. The corrosion rate depends on fluid velocity, turbulence, and chemistry. Below a certain fluid velocity, FAC does not occur because the passivation layer either is unaffected by fluid flow or can be restored much quicker than it breaks down. FAC results in smooth, scalloped or undercut recesses which are often free of corrosion product.

Low alloy and carbon steels are susceptible to FAC because of the thick, weakly adherent passivation layer. Stainless steels are virtually immune to FAC because of the relatively thin and tightly adherent chrome-oxide scale formed. Within a steam turbine, the blades and nozzles rarely exhibit FAC. Liquid droplet erosion may be observed on the leading edges of the blades in later stages, but this damage is not a type of corrosion mechanism. FAC often occurs in diaphragms in areas that are exposed to flow or improperly sealed, such as split lines.

FAC can be effectively mitigated by steam control, namely the removal of CO<sub>2</sub> which forms a weak acid, bicarbonate, at the pressure and temperature conditions observed downstream of the Wilson Zone. Additionally, a material change from mild steel to stainless alloys is a very effective measure of FAC control.

## Conclusion

With the proper care, steam turbines are unsurpassed in terms of reliability. However, corrosion continues to plague turbine end users. Steam chemistry control is paramount in the life of a steam turbine, as the root cause of most steam turbine corrosion issues is steam contamination. However, some corrosion mechanisms can occur in very pure environments, so additional measures for mitigation must be considered. The four most common corrosion mechanisms – pitting corrosion, SCC, corrosion fatigue, and FAC – can be effectively controlled through proper maintenance handling, life monitoring, proper operation, and material selection. 

## References

1. 'Cost of Corrosion in the Electric Power Industry', EPRI, (2001).
2. 'Guidelines for Predicting the Life of Steam Turbine Disks Exhibiting Stress Corrosion Vol. 1', EPRI, (1989).