This paper presented at the 2016 International Conference of Doble Clients

Field Pole Attachment Cracking on Hydrogenerators

Bill Moore, P.E.
Director, Technical Services
National Electric Coil
bmoore@national-electric-coil.com

Introduction

Rotor field poles on hydrogenerators use dovetail, Tee head or radial bolt attachments to attach to the rotor spider. Dovetail and Tee head attachments are more common and can consist of single or double attachment arrangements. Tapered keys are driven in place between the attachment and the rotor rim to tighten and secure the field pole to the rotor spider. A dovetail arrangement is shown below in Figure 1, and a Tee head arrangement in Figure 2.

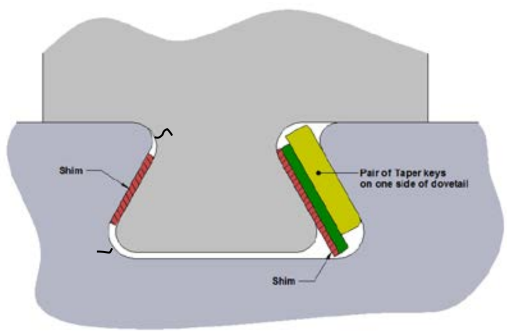

Figure 1 above showing dovetail attachment to the rotor rim.

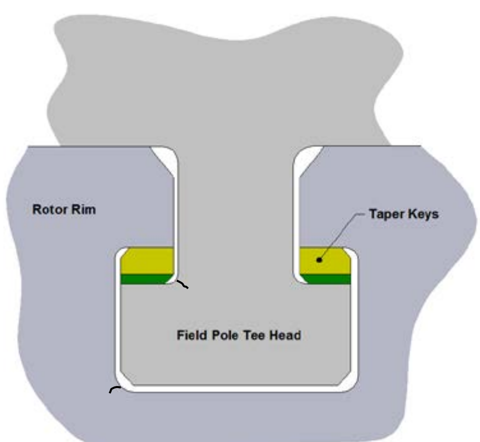

Figure 2 above shows a Tee head attachment of the rotor pole to the rotor rim.

Background

Due to rotational forces during operation, attachments can be highly stressed. Rotational force is by far the most predominant force that occurs in operation. Runaway speed is by far the highest force experienced during operation. It can be as high as nine times greater than the forces at rated speed. It is common in the industry for pole attachments to be designed and sized based upon runaway speed loading. However, frequent start/stop operation, from standstill to rated speed and back to standstill, severely stresses the field pole attachments. In comparison, the magnetic forces are a small percentage of the inertia loading at rated speed and zero at runaway, and hence do not play a significant role, typically, in field pole attachment cracking.

Fatigue cracking of the rotor field pole attachment can lead to catastrophic failure. One such failure occurred in Austria in 2009 at the Rodund Power Station. In this case, a field pole attachment failed, allowing the field pole to enter the air gap and engage with the stator core inner diameter during operation, causing massive damage.

Other incidents of field pole attachment cracking have been discovered. A list of known units with identified field pole attachment cracking includes the following:

- Yards Creek
- Turlogh Hill
- Bath County
- Helms
- Raccoon Mountain
- Juktan

The ultimate remedy has been to completely replace the rotors, or in some cases just the rim. For some units, a new attachment design has been incorporated and has changed from dovetail to Tee head and in other units, just the opposite (i.e. Tee head to dovetail).

Temporary repairs have been made and evaluated, to assess the available remaining cycles of safe operation of the units such that new rotors could be manufactured, delivered and installed prior to the damaged rotors being retired. Temporary repairs typically include the following:

- Machining a larger radius to remove the cracks
- Hand grinding to remove cracks and then polish the surfaces
- Replacing cracked and damaged field poles or sections of field poles

One common thread is that all units discovered with cracking are pumped storage units, operating as motor/generators. These units speed cycle two, sometimes four times a day, and build up huge numbers of cumulative speed cycles over their lifetime. Pumped storage units certainly should be the fleet priority for any inspection/investigation program.

Similar Issue on Turbogenerators

There are similarities between this problem occurring on hydrogenerators, and "Tooth Top Cracking" first observed in turbogenerators in the early 1980s. With turbos, cracks similarly initiate in the fillet radius of the tooth top, advancing in depth based on the number of start/stop cycles. The tooth tops of turbogenerator rotors perform a similar function to the dovetail and Tee head in hydrogenerators – namely resisting rotational forces and keeping the field winding flying away during operation. In addition to the tensile stresses trying to pull the tooth top off, at standstill, tooth tops have large compressive stresses due to the shrink fit of the retaining ring. Therefore, they undergo an even greater stress range, and coupled with higher rotational forces at higher speeds, can see crack initiation much, much sooner. On some designs, rotor tooth top cracking can initiate in as few as 300 start/stops.

The very first identified case of tooth top cracking occurred at the Manatee Plant. It was unusual because no operational issues were reported prior to shut down. When the retaining rings were removed, broken tooth top sections fell out of the rotor. Figure 3 below shows a few of the broken tooth tops, some with cracks all the way through the tooth top and the section fallen away, and another with the section still in place.

Figure 3 showing Manatee rotor with cracked and separated rotor tooth tops.

This unit was a large 800 MW unit that was known to cycle frequently – almost daily. This frequent cycling not only initiated the cracks, but led to their full propagation and failure when they reached their critical length. What is quite unusual in this instance is that no operational issues were noted prior to shut down and disassembly. In fact, this failure mode occurring on many, many, rotors, has never been known to cause a forced outage during operation. The reason is that the tooth tops are constrained and contained by the shrunk on retaining ring.

Unfortunately this is not the case with hydrogenerators. A crack that reaches critical crack size in a field pole attachment can lead complete destruction of the generator.

Case History Discussion

Findings

The author's company may have identified the first case of field pole attachment cracking on hydrogenerators in the industry. The Yards Creek unit is an original GE manufactured pump storage unit, rated at 125,430 kVA. It has 30 field poles and rotates at 240 rpm. The inner diameter of the stator core is 222 inches, and the length of the core is approximately 88 inches.

This unit has a double Tee head field pole attachment arrangement. There is a steel endplate on each end of field pole body. Four, 1.5 inch diameter bolts are used to clamp the pole assembly together. The pole is secured to the rotor with twin "T" shaped dovetails running the length of the poles. Amortisseur bars pass through clearance holes in the pole end plates. Figure 4 is a photo of the these field poles.

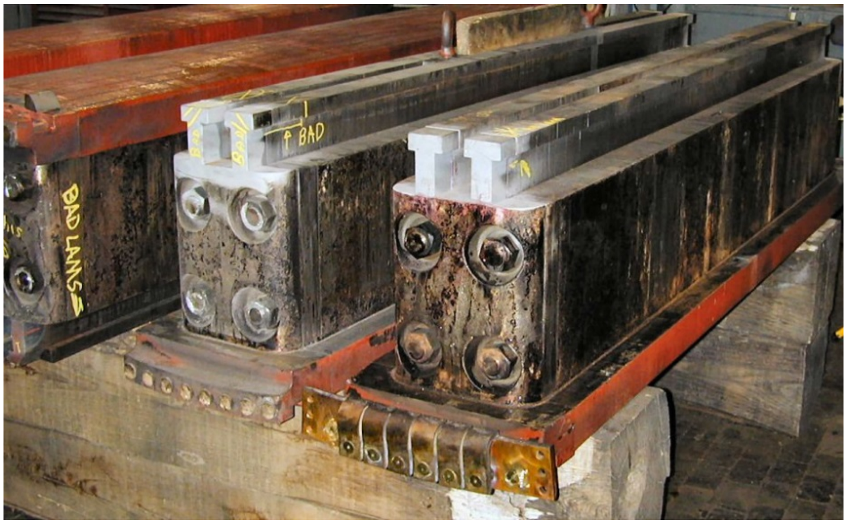

Figure 4 above shows the Yards Creek unit field pole attachment arrangement.

The field poles for this unit were refurbished in 2007. During the inspection that typically occurs during the refurbishment process, cracks were identified in the Tee head fillet radius. A summary of the inspection findings are as follows:

- T-heads on field pole endplates were observed to have radii as sharp as a right angle up to 1/32 inch – no larger than 0.030 inches.
- Lamination radius was measured at 1/16 inch.
- 16 rotor field pole endplates were cracked.
- 14 poles out of 30 poles had one endplate that was cracked.
- 1 pole out of 30 poles had both endplates cracked.
- 4 poles had cracks extending into pole body laminations – in one instance up to 3 inches.
- All cracks were located at the Tee head corner away from pole centerline.

Representative photos of the attachment cracks are shown in Figures 5, 6 and 7, below.

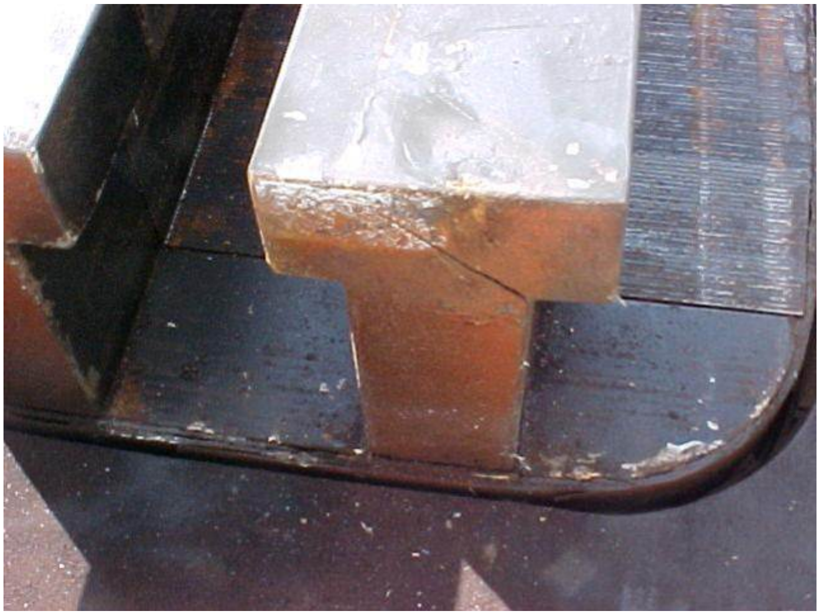

Figure 5 above shows attachment crack almost completely through the Tee head section.

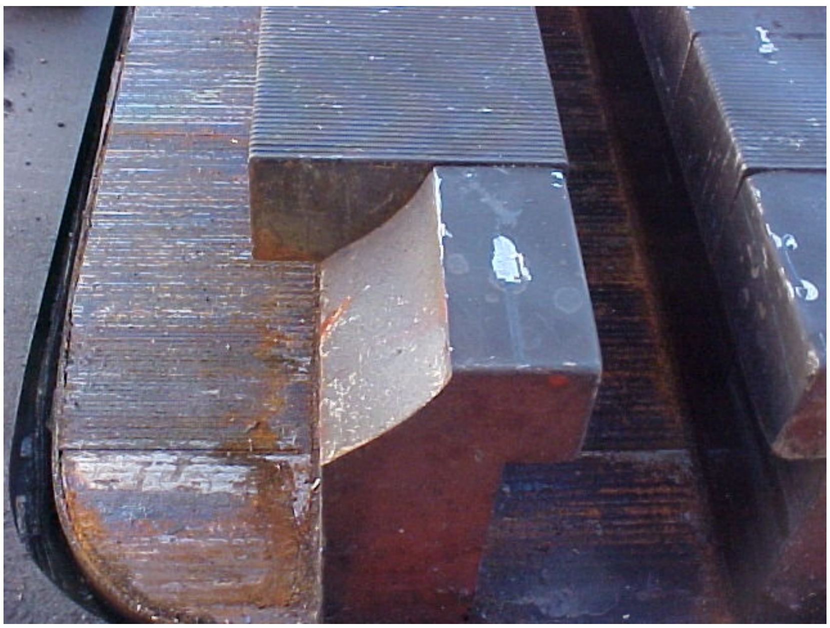

Figure 6 above shows crack completely through Tee head section. Note the similarity in the failed tooth top shown previously in Figure 3.

Figure 7 above shows crack progression through end plate well into pole laminations.

Evaluation

The cracks on these field pole attachments were fully evaluated metallurgically. They were determined to be fatigue, with very little tearing and shearing at the end of the crack. This implies that the mean stresses are low.

SEM (Scanning Electron Microscope) photos showed fatigue striations across the entire length of the fracture surface. The fatigue striation density indicated that on the three cracks examined, the number of starts would be estimated to be in the 100,000 to 140,000 cycle range. This is considerably more than the estimated actual number of starts of 40,000 reported to be on the unit. This finding may indicate that an additional stress component may be in play during the cycling mode. Figure 8 below shows the fracture surface magnified at 4000 times.

Figure 8 above shows SEM photo of fracture surface at 4000X.

Repairs

A detailed finite element stress analysis (FEA) was done on the field pole attachment geometry. A model was created as shown in Figure 9. The model was adjusted to reach good agreement with analytical stress concentration factors.

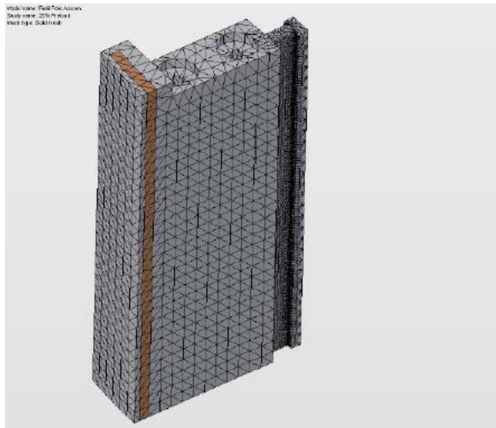

Figure 9 above shows FEA model of the field pole.

Stress concentration factors in the original geometry were estimated at 9.38, with a maximum stress level at 46,000 psi. As with the case of Tooth Top cracking on turbogenerators, the fillet radii size is crucial in determining whether cracks initiate or not. A very small fillet radius, or none at all, cause crack initiation much, much sooner, as would be expected. Large, generous radii in the high stress fillet area can significantly extend life and future start/stop cyclic capability. Multiple radii were analyzed for this specific geometry and loading conditions with one FEA plot of the enlarged fillet radii as shown below.

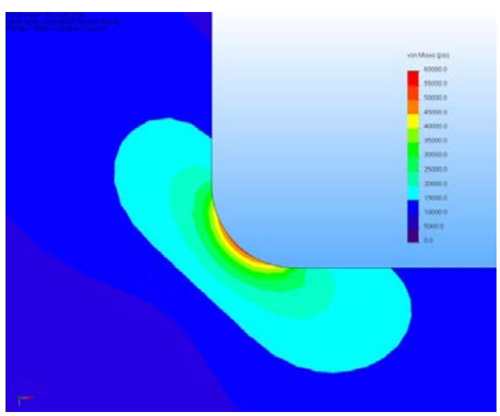

Figure 10 above shows FEA of the fillet radius of the field pole attachment.

For this refurbishment project, all cracked field pole endplates were replaced. For those that were not replaced, the radius was enlarged to 0.064 inches in all cases. All field pole laminations that were cracked were replaced.

Conclusions and Recommendations

The following conclusions can be made:

- This failure mode so far has been found on Pumped Storage Units.
- Units with cracking have thousands of start/stop cycles.
- Cracking in the field pole attachment is from fatigue.
- Tee head designs with sharp fillet radii are prone to cracking – these designs are likely to have high stress concentration factors.
- Failure mode is comparable to Tooth Top Cracking on Turbogenerator Rotors.

The following recommendations can be made:

- Identify the number of starts on each unit and document radius fillet size, and dovetail/Tee head design.
- Inspect field pole attachments for cracking on large pumped storage units that cycle frequently.
- If cracks are found, implement appropriate repair/replacement plan..

References

"The Effects of Cycling on Hydrogenerators," William G. Moore, Doble 2014, Boston, MA.

"Fatigue assessment in the pole fixation of hydro-generators," M. Hagmeyer, et. al., Hydrovision 2015, Portland, Oregon.

"Speed Cycling and Premature Failure of Generator Components," Bill Moore, P.E., Power-Gen Europe, Cologne, Germany, 2014.

"Bath County – the successful replacement of 6x530MVA motor generator rotors," S. Allgeyer, et. al., Hydrovision 2015, Portland, Oregon.

"The Effects of Cycling on Generator Rotors," Bill Moore, ASME Power 2012, Anaheim, CA.

"Crack initiation in hydro power plant rotor rim sheets," Oskar Altzar, KTH Materials Science and Engineering, 2014.

About the Author

Bill Moore, P. E., is Director of Technical Services for National Electric Coil. His department provides high level technical support in the areas of advanced engineering design, R&D, and product development. Prior to joining NEC, Bill held utility power plant management positions with Florida Power & Light, working at three different power plants. He started his 38 year power industry career as a generator design engineer with Westinghouse. Bill is a Fellow Member of the ASME and was past chairman of the ASME Power Division.