

Refurbishment Solutions for Various Field Pole Problems

By

Bill Moore, P.E.

National Electric Coil

800 King Ave.

Columbus, OH 43212

614-488-1151

bmoore@national-electric-coil.com

1. Abstract

For many years, NEC (National Electric Coil) has provided hydrogenerator refurbishment services to several U.S. Government agencies and large investor owned utilities. These projects have involved complete rehabilitation and refurbishment of large hydrogenerators. The work-scopes typically involved replacement of the stator cores, new stator windings, and refurbished and reinsulated rotor field windings.

One might assume that refurbishment of field poles would be a simple task, when compared to much more complex stator core and stator winding replacement work scopes. On the contrary, NEC has identified several complex issues in the field pole rehabilitation on older hydrogenerators. Such problems as bowing of the rotor field poles, looseness of the field poles on the rotor, fatigue of field pole connectors, and cracking of field pole damper bars, are examples of problems identified as part of these large refurbishment projects.

In this paper, several of the problems encountered will be fully described, along with the consequences of the problem in terms of operational difficulties. Solutions developed during the project will be presented as well as complete recommendations to prevent recurrence.

This paper will be useful for owners of older hydrogenerator plants, who may be entering into a large refurbishment project. Prior knowledge of these types of problems may save time and money in the refurbishment project and improve reliability over the operational life of the unit.

2. Introduction

As part of large hydrogenerator refurbishment projects, the typical workscope for the generator often involves replacement of the stator core with new, lower loss laminations, replacement of the stator winding with a new, uprated winding, and reinsulation of the existing field coils. National Electric Coil (NEC) regularly performs this scope of work, and has been particularly successful over the last few years in refurbishing many large hydrogenerator projects for the U.S. Government and various Investor Owned Utilities (I.O.U.'s). Contracts with the Army Corps of Engineers, United States Bureau of Reclamation, and the LCRA (Lower Colorado River Authority), as well as Union Electric (Ameren Energy) and many other investor owned utilities, have been successfully completed. On U.S. projects that involve both hydroturbine and hydrogenerator upgrades, NEC teams with VA Tech to cover the mechanical portion of the turbine work.

The typical workscope for field coil refurbishment is shown below. This workscope is abbreviated to cover only the salient points.

- Remove field poles from rotor
- Remove field coil from field pole
- Remove all insulation and resin from coil and pole
- Apply ground insulation to pole
- Apply turn insulation to coil
- Install newly insulated coil on pole
- Install refurbished pole on rotor

Since the field winding copper is typically reused, as well as the iron field pole, significant design alterations in this workscope are not very common. The space "envelope" is relatively fixed, restricting flexibility in design options. This simplifies the field pole refurbishment engineering process.

Over the many years that NEC has been refurbishing field poles, however, certain specific “problems” have been identified repeatedly. From a larger perspective, it is clear that these problems reveal a trend or pattern that can ultimately affect the performance of the generating unit. NEC’s opinion is that the refurbishment process is more complex than one would initially observe or be led to believe, and that certain “subtleties” exist that require careful planning, design, manufacturing and installation processes to assure success in the field pole refurbishment area.

The paper below, first describes some basics of hydrogenerators and field poles, in particular, to orient the reader and provide a fundamental background of the design, configuration, function and purpose, of this key hydrogenerator component. Specific experiences are then discussed to illustrate the issues involved with refurbishment of this component of the hydrogenerator. Finally, root cause and resolution discussions are presented to adequately sum up common trends with this issue.

3. Design Background

Hydrogenerators consist of a rotating spider and field pole assembly mounted to a shaft. The shaft is connected to the turbine, which is driven by flowing water. The generator rotor shaft, spider and field pole assemblies rotate within a stationary assembly called the stator. The stator primarily consists of the frame, which provides support, core iron laminations which provides the path for the magnetic flux, and the stator winding which carries the induced voltage and current out the generator terminals to the bus.

One major component of the field pole assembly consists of a laminated steel pole which is mounted to the rotating rim of the spider. The field coil assembly, which consists of a number of copper turns, is wound onto the laminated steel field pole. Appropriate ground insulation isolates the field winding turns from the ground potential of the field pole. Also, appropriate turn insulation isolates each field turn of the copper from each adjacent turn, preventing shorted turns between copper turns. Direct Current is fed into the field winding, typically through slip rings and carbon brushes. The rotating field winding creates a magnetic field that induces voltage and current into the stationary stator winding. . The field winding consists of individual field coil assemblies, connected to an adjacent field coil by a copper lead connector.

Lead connectors come in a variety of designs and attachment methods. Copper is invariably used, and can be solid, comprised of multiple leafs, flexible or braided. Attachments are typically brazed, copper to copper, or bolted and soldered. Bolting is for strength and soldering is to maintain the electrical contact.

The laminated steel field pole is typically keyed to the rotor rim to hold it tight during operation. Tapered keys are often driven tight between the field pole dovetail and the rotor rim dovetail groove. Rotor rims may be solid or segmented steel castings, or as is often the case, circumferentially overlapped segments of sheet steel held in compression by axial core bolts as a single assembly.

4. Experience

4.1 Case History #1

LCRA, Buchanan Dam, has three hydroelectric units manufactured in the late 1930’s. Each of the three generators was originally rated at 12.5 MVA, 0.9 pf @ 6.9 kV. Two of these three units (Unit #1 and Unit #2) were uprated to 18.3 MVA, unity pf @ 6.9 kV.

Competitive bids were taken for the generator rewind work and National Electric Coil (NEC) of Columbus, Ohio was awarded the contract for that work. As part of the contract, new stator coils were provided, and as part of that upgrade, the rotor field winding was removed and reinsulated with a higher temperature rated insulation. These units are designed with a total of 42 poles on each rotor, resulting in a rated speed of 171.4 RPM for 60 Hz operation. The original copper used in these winding was reused and reinsulated with Class F epoxy based insulation. The original field winding lead connector design used a solid piece of copper, bolted and soldered to the next lead connector. Figure 1 illustrates the lead connector design.



Fig. 1. Configuration of Field Winding Lead Connector

Failure of one of the lead connections is shown in Figure 2.



Fig. 2. Failed Lead Connector

Investigations into the failure revealed looseness of the pole pieces where they are secured to the rotor spider. Tangential vibration of the pole pieces during operation placed stress on the solid copper leads and resulted in fatigue crack initiation. The vibration was believed to be the cause of this problem and a multifaceted approach was taken to address the root cause.

Closer inspection of the geometry of the dovetail design for mounting of the poles revealed that a radius in the rotor spider dovetail section was too small to allow the pole piece to be pulled up tight to the spider mounting surface. Also, the rotor spider pole mounting surface was inspected and found to be concave over the entire circumference as a result of distortion during many years of operation. Additionally, it was thought that unevenness of the laminations where the keys are located would limit how tightly the keys could be driven.

LCRA and NEC agreed to make modifications to the rotor design to address these issues and the following three changes were incorporated.¹ First, the rotor spider dovetail slot section was carefully ground down to increase the radius of the edge. This would prevent the pole piece dovetail from bottoming out when the keys are driven, allowing better seating of the pole. Second, the pole body was modified by milling out a 0.010 inch deep area on both sides of the pole piece back iron next to the dovetail area. The machined area extended to within 1 inch of

the outer edge of the back iron surface. This machined area would allow better seating of the pole against the rotor rim, and increase pole stability by providing a land area on the outer edge of the pole. Lastly, a three-piece key design, consisting of a flat shim against the uneven dovetail groove, and two tapered keys. The tapered drive key was now allowed to drive against a smooth, machined surface, rather than the uneven laminations. This helped remove any possibility of the leading edge of the key snagging on a lamination edge and giving a false sense that the key has been securely driven in place.

As an added measure, to accommodate any possible movement of the pole pieces during operation, flexible copper leads replaced the original solid copper design and would allow for some flexing of the poles without inducing sufficient stress on the leads to cause cracking and eventual failure. A drawing of the added flexible leads is shown in Figure 3 below:

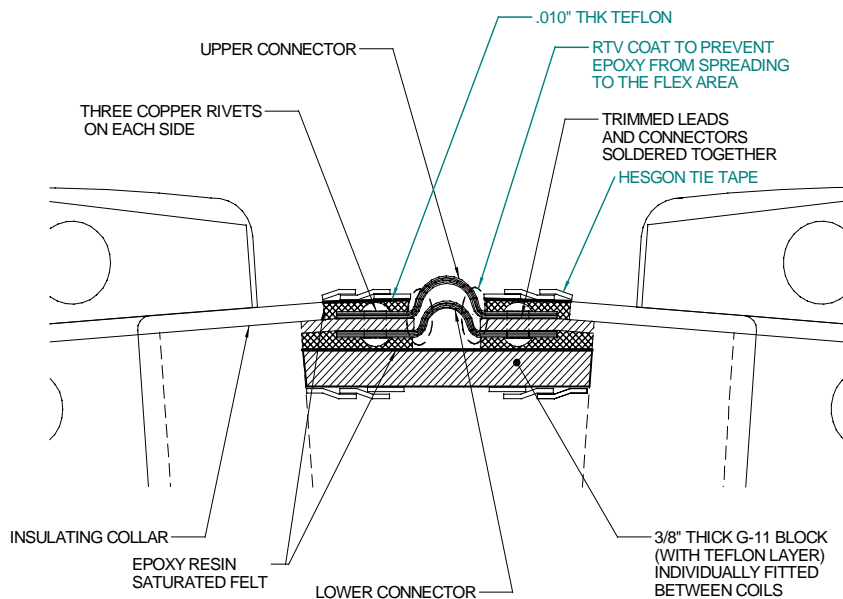


Fig. 3. New Field Coil Lead Connector Design

Both rotors of Buchanan Unit #1 and Unit #2 have been modified to incorporate these changes and been in service for over one year. No failures have occurred to date since these changes have been made and it is believed that these modifications will provide many years of service.

It is NEC's opinion that the effects of pole looseness cannot be remedied by the installation of flexible connectors. However, in some cases, with severely distorted rim and pole components, some settling may occur as newly reinstalled poles are once again subjected to high centrifugal loading and thermal cycling. The installation of flexible connectors provide unit reliability until the pole keys can be rechecked for tightness after reseating of the pole assembly occurs.

4. 2 Case History #2

Another hydrogenerator refurbishment involved a frequency change from 25 Hz to 60 Hz.ⁱⁱ These 1913 vintage, 11,000 kVA machines were uprated with a stator rewind and in this particular case, new field poles. The number of field poles was increased from 52 to 124 to accommodate the frequency change. Other design

changes included the throw of the stator winding, and modifications to the rim to accommodate the new field poles and their added weight.

The additional poles, although smaller, increased the total weight and loading on the rotor spider and rim. The rim is somewhat unusual in that it consists of four, quarter segments, keyed together by a “dog-bone” shaped joint. Due to the extra forces from the additional new pole, new, higher strength, dog-bone keys were required. To assure that contact between the rim and spider remained at runaway speed, the spider arms were also shimmed. A depiction of the dogbone key and segment parting joint is shown in Figure 4 below.

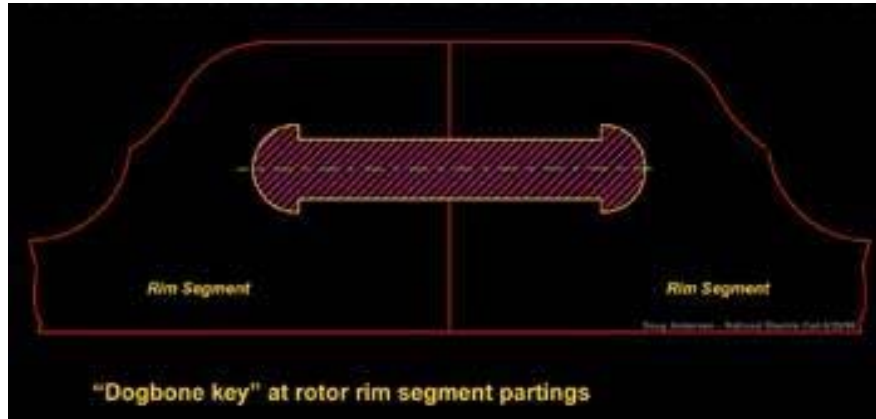


Fig. 4. Depiction of “dogbone” key between rotor rim segments.

In this case, the field poles were fastened on the rotor by bolts, rather than dovetails and keys, as described in the previous design. Some poles were located directly over the rotor rim segment splits.

Soon after the machine was reassembled with the new stator winding and new field poles, a field lead connector failed. Upon inspection and root cause analysis, it was discovered that the rim segments were slightly offset at the parting line between segments. The segments had become warped and distorted over years of operation, and did not perfectly mate back up during final re-assembly.

Allowing the unit to return to service, and experience several mechanical and thermal stress cycles, enabled the parting segments to properly realign. The original offset disappeared. The field poles that were once tightly bolted over the offset at the parting line, were now loose, as the parting segments aligned back into place. The mating back to their original position created “slop” in the assembly. Accordingly, the pre-tensioned field pole bolts on the pole piece bridging the rim split, suddenly lost much of their tension. This event had the effect of allowing the field pole bolts to loosen, and hence allow the field pole to loosen on the rotor. The loose field pole then vibrated until a failure of one of the field lead connectors occurred.

The resulting looseness on the pole created an audible hum during operation and resulting fatigue on the pole to pole connectors. Once the problem was identified, the pole bolts at the rim split were retorqued, and the associated field lead connectors renewed. These pole to rim assemblies have given many years of service and reliable service since this point in time.

5. Solutions

In both of these cases, root cause was determined, and the appropriate corrective action was put into place to prevent reoccurrence of these failures. All problems were satisfactorily resolved with each customer.

The common thread between them that is apparent, however, is that each field coil connector lead failed due to vibration, stemming from a loose pole. Vibration of the field pole during operation led to fatigue cracking of the lead connector. As cracking progressed, arcing between the small gap initiated as the field current was maintained during operation.

There are a number of different forces that act on the field pole during operation. One is the centrifugal force of the pole due to its own weight under rotation. By far the largest force, this is a steady state force that imposes a constant load on the field pole dovetail.

Another force acting on each pole is a magnetic force due to the flux across the air gap. This force is generally on the order of about 10% of the steady state rotational force, but varies with time, creating an alternating stress condition on the field lead. This force variation causes field pole relative displacement on a loose pole. This displacement adds additional cyclic stress to the field lead connector, eventually initiating fatigue cracking and then failure.

Field pole looseness can readily occur after an overhaul or anytime a field pole is removed. Over time, field rotor rims and field poles themselves warp and distort due to the accumulation of many years of stress and strain during operation. In both cases described above, either the rotor rim, or field pole itself, had significantly warped or bowed out of alignment. Once the pole is separated from the rim, refurbished and reinstalled, it is improbable that the pole will be installed back into the rim in exactly the same manner and position, so that the pole is perfectly aligned and is seated the same as it was originally. As a result, it is highly probable that the pole is not pulled tight to the rim, to the point that it cannot loosen again, when re-alignment occurs.

Soon after startup as the unit heats up, the poles seat better, and the pre-loading force and pressure that was once on the keys is eliminated. The poles become loose and vibrate due to the varying magnetic forces. Loose, vibrating poles, then lead to lead displacement, additional fatigue stresses and crack initiation.

6. Recommendations

Poles must be assembled fully tight. This is often attempted by driving the keys as far as they go. In some cases, however, a "tight" key is not really tight. Such things as dovetail geometry, irregular rotor rim laminations, sharp radii, burrs, and cover plates can all interfere with rotor key driving and sufficient tightness.

Over long periods of time, stacked rotor rims can distort, so they are no longer true cylinders. Depending upon the construction of the rim assemblies, they can distort into concave or convex shapes, and no longer have flat mounting surfaces. Irregular mounting surfaces inhibit the tight mounting of rehabilitated field pole assemblies.

Pole mounting procedures must incorporate checks to ensure the pole mounting surface on the rim makes intimate contact with the pole assembly so that proper key preload can be achieved.

Careful inspection of the rotor rim and pole piece is essential before the first pole is removed for refurbishment and then again after. Visual observation of the existing key condition and position is essential. Signs of key interferences should be documented. Feeler gages can be used to determine if the pole is seated fully against the rotor rim. This can be done prior to pole removal, and then again after the refurbished pole is reinserted back onto the rotor rim. Bottom cover plates should be removed before the poles are removed to allow visual inspection of the driven key position. Bottom cover plates should be left off until new keys are driven home to fully seat the refurbished poles. Three piece key designs, if space permits, should be strongly considered. The use of the third key (flat shim), eliminates problems that may occur due to rotor rim or pole dovetail lamination irregularity.

A pole jacking test (see Fig. 5 below) done after pole assembly can verify that the poles are tight. A hydraulic button jack can be placed between two poles, and with an appropriate fixture, pressure can be exerted on the poles to verify tightness. Dial indicators are used to verify pole movement. Movement of a pole more than 0.001 inch warrants extra attempts to drive keys even tighter.

When complete assurance that the pole assembly cannot be held perfectly tight against the rim, flexible connectors can be designed and installed to provide interim reliability until the pole pieces can be retightened at a later date.



Fig. 5. Pole jacking assembly with dial indicators used to measure pole movement.

Careful attention to these concerns prior to field pole refurbishment and then again after repairs are done, will eliminate pole looseness, and remove a leading cause of field lead connector failure. Implementation of these recommendations during your next hydrogenerator refurbishment project will ensure long, trouble – free operation of the field poles.

References

ⁱ **Gunter, L., Moore, W., Witkowski, D.**, “Hydroelectric Generator Rewinds, Problems and Solutions,” Water Power XIV, Austin, Texas, HCI Publications, 2005.

ⁱⁱ **Weiman, L. and Andersen, D.**, “Changing the Frequency of an Existing Generator,” Hydro Review – Machine Dynamics Notebook, Volume 18, Number 7, December 1999.

The Author

Bill Moore, P. E., is Director of Product Development for National Electric Coil (NEC) in Columbus, Ohio. Prior to this, he was Engineering Manager at NEC, responsible for all aspects of generator engineering. Bill has published and presented over 50 papers in the power generation field. He received the 2005 “First Place Paper Award” at the IEEE Pulp and Paper Conference, and the “Author’s Award” from Hydro Review Magazine in 2001. He has a Master’s and Bachelor’s of Science degrees from the University of Pittsburgh, and Notre Dame University