This paper presented at the Ninth EPRI Steam Turbine/Generator Workshop, Denver, 2005.

Refurbishment of the KCP&L La Cygne Hydrogen Cooled Brushless Exciter

By

George Yeboah
KCP&L

and

Bill Moore & Tony McConnon
NEC

Abstract

The KCP&L La Cygne brushless exciter was taken off line for an inspection. This exciter is somewhat unique amongst Mark II brushless exciters in that it is one of the largest exciters manufactured, and it is one of only a small population that are hydrogen cooled. Visual inspection of the rotating armature during the inspection showed that several phase leads had developed fatigue cracks at the vertical phase risers. The unit was pulled out of service for additional inspection, evaluation and testing. Further evaluation revealed that a complete rewind was necessary. Due to schedule constraints the rewind would have to be done in a very short period of time.

This paper describes details of the failure mode of this brushless exciter. Some of the challenges of rewinding the unit in a short period of time are also presented. As part of the refurbishment process, a new design of the diode module package was furnished by an alternative source to the OEM.

This paper will be valuable to utility personnel who own brushless exciters, because this failure mode may occur in other units. Additionally, discussion of the diode module components, and of alternative sourcing for these components and major exciter repairs, will be valuable.

Introduction and Background of Unit

The La Cygne Unit 1 Generator is rated at 970 MVA, 22 kV, and 3600 rpm. The brushless exciter is rated at 4500 kW, 525 Volts, 8575 Amperes, and 3600 rpm. There are total of 144 diodes, 24 diodes in parallel per phase per polarity. There are 72 capacitors and 72 fuses. The La Cygne exciter is only one of a handful of hydrogen-cooled exciters.

The exciter had regular inspections and maintenance throughout its life. Several diode wheel components had failed or had high readings, and these were replaced in 1988 and in 1992. In 2004, due to an exciter failure on a nearby, similar unit, KCP&L became concerned about the possibility of the La Cygne unit failing during operation. Plans were underway to consider taking the exciter out of service in 2005 for a major outage, and possibly a rewind. After the failure of the similar exciter, it was noticed that the La Cygne exciter began to demand increasing levels of field current. The table below shows this increasing level of exciter amps from 2004 to 2005, and then again a short time later.

	Exciter Amps	Exciter Volts	MVAR's	MW
Jan 2, 2004	81.25	32.4	53.8	757.6
Jan 2, 2005	90.18	35.85	86.7	760.18
Jan 14, 2005	102.86	41.99	79.54	749.14

Discovery of the Failure

The La Cygne plant had initially budgeted to replace the diodes and rewind or at least refurbish the exciter during the 2005 schedule outage. Plans were to replace the diode modules with those manufactured from an alternative supplier. These diode modules weighed less than the original diode modules.

The increasing levels of exciter field current raised the concern level on the exciter. The 2005 outage also included replacement of the turbine rotors for the HP, IP & LP, and also the generator field. The OEM, responsible for the upgrade, was concerned about an increase in torsional vibration, if the plant replaced the existing modules with new modules that weighed less. Because of this concern, the exciter refurbishment was temporarily put on hold. Torsional vibration testing was done, just prior to the outage, to verify existing natural frequencies and to ensure there would be no torsional vibration resonance problems with the new rotor train. Torsional resonance frequency was tested to be 112 Hz.

Initially, the exciter was planned to be disassembled and tested on site. The exciter was removed from its foundation, out of the way, so work could begin on the generator. An initial inspection inside the generator revealed sections of glass banding laying in the bottom of the generator. The exciter was then opened for inspection, whereupon it was found that the glass band over the phase lead risers was missing. An inspection of the phase leads and attached rotor armature conductors showed cracks in the conductors to the point that the conductors had completely detached from the phase leads.

At this point in time, KCP&L decided to obtain quotes for further inspection, repair and possibly a complete rewind and refurbishment of the exciter. An option to replace the existing hydrogen-cooled exciter with an air-cooled one had been looked at previously, along with the possibility of a conversion to static excitation. The urgency of getting this unit repaired in a timely fashion, however, soon overrode the further consideration of any alternative options.

Due to the high current rating of the exciter, the plant was very limited in the number of vendors that could repair or rewind such a large exciter.

NEC (National Electric Coil) received the contract to repair the exciter. The final workscope would be agreed to after inspection and disassembly. KCP&L also wanted to replace all the existing diode modules with new ones from an alternative source. This was due to the long lead time from the OEM, and the desirability of new modules, which were smaller and lighter.

Incoming Inspection at NEC

The diode modules were tested and 18 were found to be either unacceptable or marginal. About 54 of the 72 fuses tested showed high resistance. Ordering replacement modules at this time would have caused a serious delay in the overall schedule. Fortunately, KCP&L had previously decided to work with another vendor to reverse engineer the existing diode modules. No new modules had been ordered, however, due to concerns raised by the OEM, primarily due to the difference in weight and its potential effect on torsional resonance. The lead time for a set of OEM-manufactured modules was 12 weeks. Due to the previous work with the alternate vendor, an order for new modules manufactured by this vendor would only take three weeks. This fit within the entire rewind and refurbishment schedule of the exciter. In addition, since the pre-outage torsional resonance testing resulted in a test result sufficiently away from 120 Hz, KCP&L felt confident the new, lighter modules would not affect the torsional vibration.

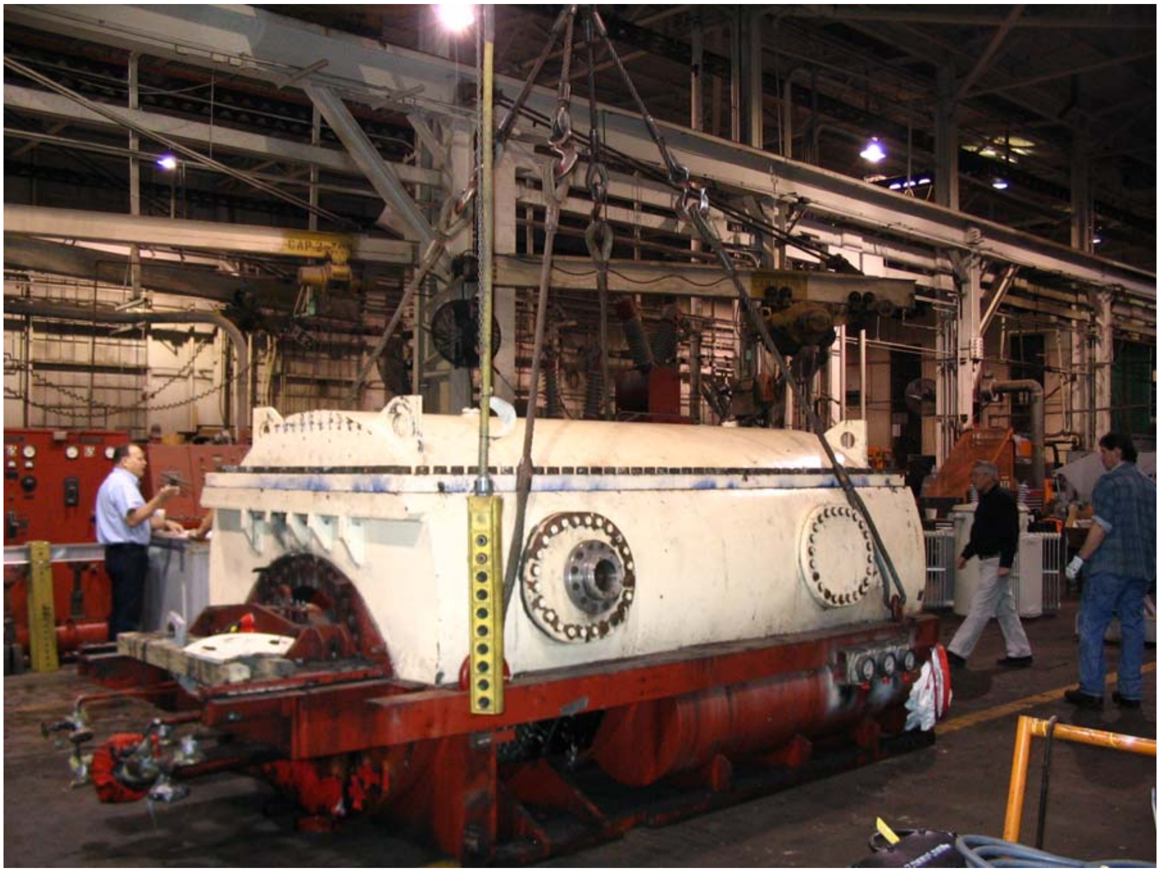

Fig. 1 Large 8000 amp hydrogen cooled brushless exciter upon first arrival at NEC for repair.

This quick turnaround, in addition to the fast schedule by NEC on the exciter armature rewind, negated the requirement to rent a high-cost mobile exciter.

The unit was received February 18, 2005 to inspect and provide a report on the potential repair options. Numerous phase leads were either cracked or partially cracked at the electrical connection to the vertical phase lead riser. The phase lead riser retention band which had also failed, had been previously located by the Customer during generator disassembly.

During the initial visual inspection at NEC, the damage to the phase lead connections was confirmed. Visual inspection, likewise, discovered armature coil damage at both the inboard and outboard coil connections.

Figure 2. - Damaged Phase Leads

Figure 3 – Damaged Outboard Coil Connection

The most likely failure scenario involved crack initiation by failure of the phase lead riser band. This band covers the phase lead risers, and also the phase lead coil extensions as they come out to the risers. Loss of support in this area, quickly led to a failure in shear of the coil extensions. Arcing damage was also noted in this area.

Based upon the extent of the damage found, NEC's recommendation to KCP&L was to rewind the AC exciter armature. KCP&L accepted this recommendation and NEC initiated an armature rewind on February 21, 2005.

During disassembly of the diode wheel components, it was discovered that 34 of the 36 phase lead connectors had "deformed." These connectors are aluminum and provide the electrical connection between the phase leads and the diode wheel modules (see figure below).

Figure 4 – Normal Connector Depicted in Center; Two Deformed Connectors Shown to the Right

Figure 5 – Deformed Connectors Depicted on Top

These connectors were replaced with a modified design that provided a stiffer connector consisting of a cross section 1" by 1" instead of the original 7/8" diameter (see picture below).

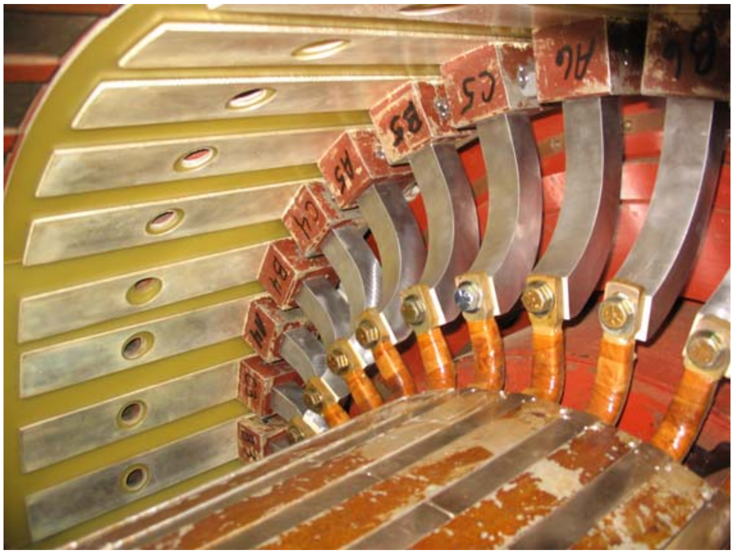

Figure 6 – New Phase Lead Connectors

Prior to disassembly of the diode wheel components, insulation resistance tests were performed. The phase leads and wheel-to-wheel connectors were removed, reformed and reinsulated. The phase lead risers and phase lead steel wedges were NDE tested and qualified for reuse. All electrical connectors (diode module plates, wheel to wheel connectors, etc.) were thoroughly cleaned and silver-plated.

The fuses were removed and their element resistances tested. The fuses were a combination of the original “straight’ element design and the latter “folded” element style. There are 36 fuses in each diode wheel. Of the 72 fuses, 51 exhibited resistance values higher than desired maximum resistance.

Each diode module consists of two diodes and a capacitor in parallel. There are 36 diode modules in each diode wheel. Each module was electrically tested to check the forward and reverse resistance of the diodes and the charging capacity of each capacitor. Three diodes were found to be either open circuit or low reverse resistance and 13 capacitors failed the electrical charge test.

The AC exciter stator was split at the horizontal joints, thoroughly cleaned and inspected. Damage was noted to the leads connecting the split halves and was replaced. The two halves were re-assembled and electrically tested. Tests included a pole balance and an insulation resistance to ground.

The PMG assembly was removed from exciter rotor. Both the stationary PMG armature and rotating magnet assembly were cleaned and inspected for signs of damage. Each magnet was checked for cracks and all mounting hardware was thoroughly inspected. The insulation resistance of the armature was measured at 500 VDC. The DC resistance of each phase was measured, also.

AC Exciter Armature Rewind

After the coils were stripped, a core loop test was performed to re-qualify the armature core for continued operation. After the core was energized for one hour, the maximum temperature deviation recorded was 2ºC.

The armature was wound with coils utilizing the same conductor geometry and arrangement as the OEM design. The coil ground wall system consisted of fully-pressed and-cured straight sections with 3-staged, flexible involutes and knuckles. After winding, the coil basket was supported and packed with Scotchply®. Upon completion of the winding and connection process, the entire coil assembly, together with the support structure was pressed and cured at 135˚C for 12 hours to consolidate the winding assembly. Glass banding was subsequently applied to the inboard and outboard coil involutes and extended on the inboard side to support the neutral ring and phase lead assembly. Each band was applied and cured separately to assure full process control. Temporary bands were first installed and removed to pack the coil assembly into their final locations prior to the application of the final bands. All insulation materials used on the armature assembly were rated for operation at Class F temperatures or greater.

Insulation resistance and high potential electrical tests were performed throughout the winding process.

The armature has seventy two slots and, thus, 72 coils. Each phase group consists of two coils; one end brazed to the neutral ring and the other to the phase lead riser. After the phase lead and neutral ring braze joints were completed, phase resistance measurements were taken to verify the integrity of the phase, neutral and series connections. Using a DLRO, resistance readings were measured between each phase lead riser to the neutral ring. Once all of final bands were applied and cured, the armature winding was subjected to final insulation resistance tests and hi-potential tests.

The neutral ring was no longer accessible due to the neutral ring glass band, so resistance measurements were taken phase to phase rather than phase to neutral.

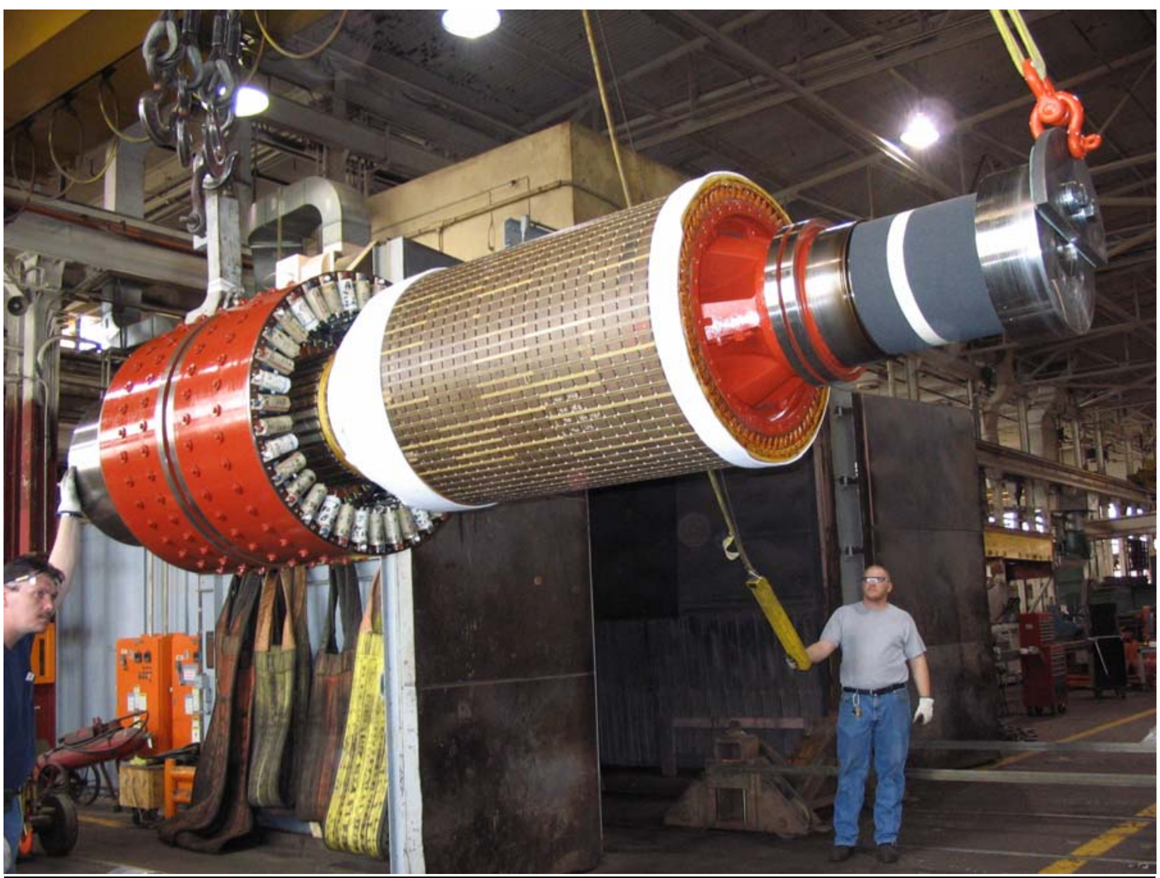

Fig. 7 Photo of rewound exciter coming out of balance pit.

The AC armature winding process was completed March 30, 2005 and released for diode wheel re-assembly.

Figure 8– Completed AC Exciter Armature

Diode Wheel Assembly

The diode wheel components were installed using new G-11 heat sink insulation. All electrical contact surfaces were silver-plated, and all locking hardware replaced with new components.

Kansas City Power & Light elected to replace all the diode modules with new components. The diode modules were electrically tested at NEC prior to installation.

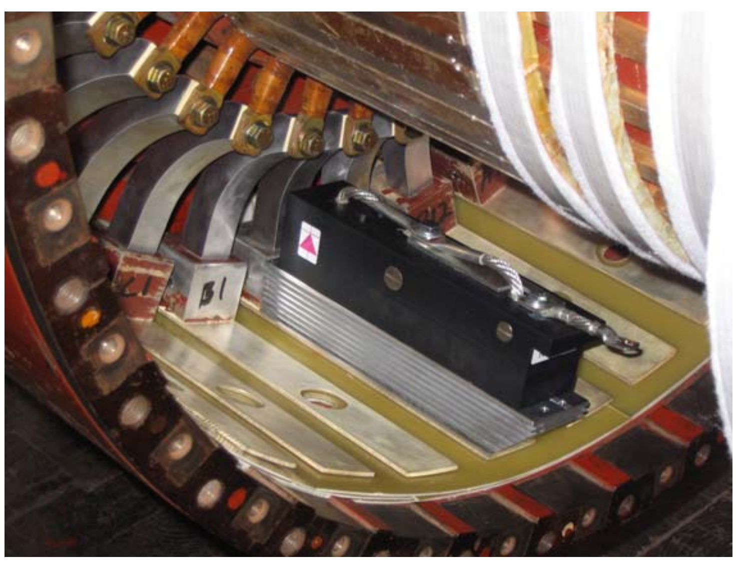

Figure 9– New Diode Modules Supplied by Basler

Kansas City Power & Light supplied NEC with twenty-four new 'folded' element fuses. This left a balance of 27 original fuses that exhibited fuse resistances higher than recommended maximum fuse resistance. KCP&L stated that it had ordered replacement new fuses and would install them during a future mini-outage.

To minimize the effect of the higher resistance fuses, NEC installed the 27 'best' of the original 51 high-resistance fuses and distributed them equally around the six phase groups. To aid in identifying the high-resistance fuses, a red stripe was applied on the side of the fuses.

Figure 10 – High Resistance Fuses Identified with Red Stripe

After the fuses were installed, final resistance readings were taken on each fuse. The brushless exciter rotor assembly was high-speed balanced upon job completion. A ten percent over-speed test was performed to qualify the winding and band integrity.

Once the rotor was removed from the balance pit, additional insulation resistance tests, armature coil phase to phase resistance tests, and a final Hipotential test was done. The unit was then prepared for shipment.

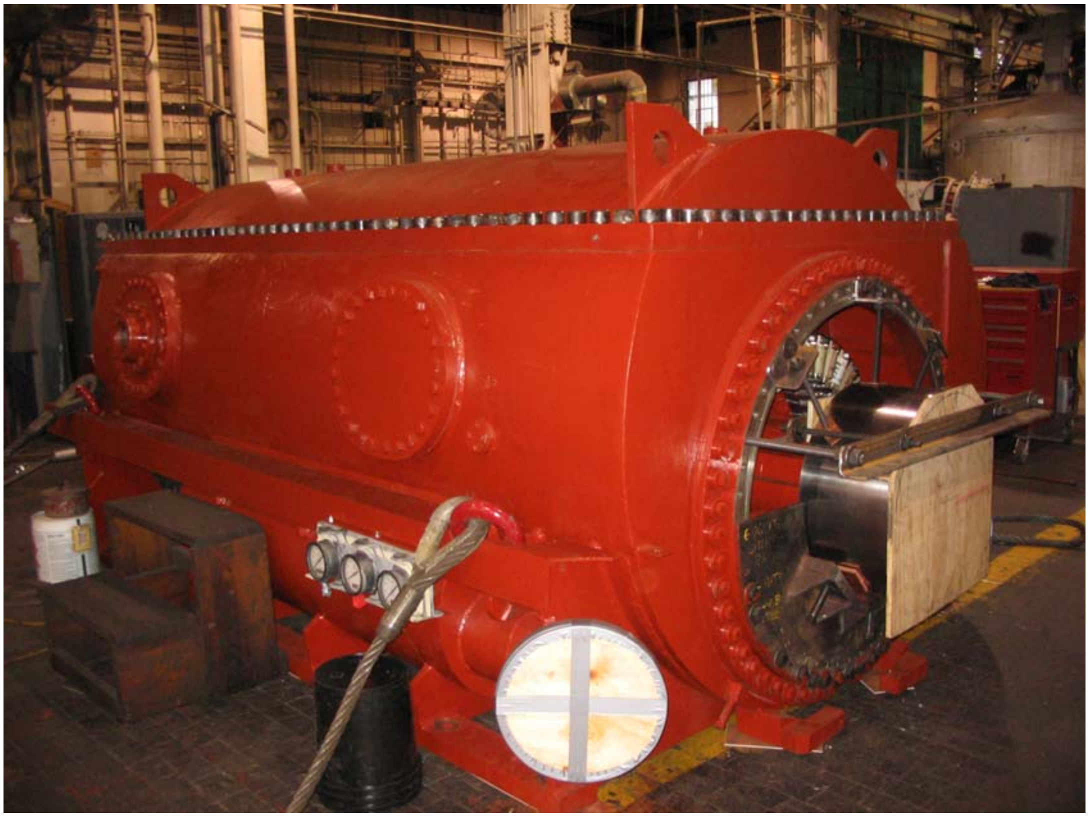

Fig. 11 Exciter after rewind and refurbishment prior to shipping.

The exciter was shipped on February 16, 2005 and was return to the plant on April 6. Start-up began on April 14, 2005 and was completed on April 18, 2005.

During the start-up, initial vibration levels for bearings #10 and #11 were higher than expected. Balance shots were put in to reduce the vibration levels, but that did not help. The plant put shims under the exciter pedestal which corrected the problem. The plant turbine engineer indicated that the source of the vibration was due either to an oil seal rub or that the exciter was not aligned or shimmed properly at installation.

After the start-up was completed and the unit running at full load, the exciter DC currents was measured and the level was lower than the pre-outage level. As shown in the graph below, the exciter field current is approximately 90 amps. Prior to the outage, levels exceeded 100 amps.