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KEY EVALUATION FACTORS FOR UPGRADING AND REFURBISHING ELECTRICAL GENERATORS

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ABSTRACT

As power plants age, failures due to component “wear out” occur at increasing frequency. Owners of these aging plants desire to improve or at least maintain, past performance levels of reliability. There often comes a point in time, however, where continued regular maintenance, is not enough to maintain the same level of reliability. Failures occur at an increasing rate, and the cost of multiple repairs can eventually exceed the cost of a major upgrade and refurbishment.

This paper will present key evaluation factors for upgrading and refurbishing electrical generators. These factors, can be applied to one’s own electrical generator, using them to assess and evaluate the most timely upgrade or repair. First, information will be provided on the requalification of generator metal or forging components, including the generator rotor forging, rotor slot wedges, retaining rings, fans, and the generator frame. The ability of these components to withstand the increased stresses resulting from the upgrade will be discussed. Other failure mechanisms, commonly found in the industry will be presented. Awareness of these will prevent the owner from a costly premature refurbishment.

Next, evaluation of the electrical windings, both rotor and stator, and their part in a major generator upgrade are discussed. Factors, which can be used to identify the pro’s and con’s of re-using rotor copper will be presented. Factors influencing the ability to achieve the greatest uprate possible by designing additional copper into the stator coils are also touched upon.

Also included is a discussion on the insulating components, both rotor and stator. For older machines, significant technological advances have occurred in this area, and they are really the driving force behind large generator uprates. Different types of insulation systems (epoxy and polyester versus asphalt), including their long-term reliability will be presented. Tests to determine insulation quality will be discussed, as this is important to the timeliness of the upgrade or refurbishment.

Overall, this paper should be useful for those individuals making decisions about generator maintenance activities, stator and rotor rewinds, and other generator component upgrades and refurbishments.

INTRODUCTION

Electrical generators are usually upgraded and refurbished for one of several reasons:

1. Major component failure
2. End of life
3. Conversion/Repowering (i.e., steam unit to combined cycle)
4. Increased power delivery

It is important that all factors affecting future machine reliability be evaluated and considered when the unit goes through one of the above-mentioned processes, whether on a rush basis (typical with item 1 and, possibly, item 2) or on a more planned, deliberate basis (as with items 3 and 4). It would be unacceptable, for example, to repower a generating station, rewind the existing steam turbine generator for longer life and forget to inspect and resolve a key concern with the rotor forging. With that possible scenario in mind, the next section describes the most common generator components that should be evaluated during an upgrade and refurbishment.

GENERATOR COMPONENT EVALUATIONS - GENERATOR ROTOR

ROTOR COMPONENTS

Evaluation of the rotor forging is one of the most important activities when an upgrade or refurbisment is planned for a generator. Procurement of a new forging might take over a full year, causing substantial delays in the overall project schedule. If a severe and serious problem were found, a new forging would be necessary, and the cost of a new forging, if unexpectedly required, could also throw the entire project in jeopardy. However, a thorough examination for the common problems, which include cracking in the bore (if one exists), tooth tops, snap ring grooves or blower hub shrink fits, should be part of the evaluation process.

Rotor Bore

Cracks in the bore are generally low cycle fatigue cracks, caused by rotational stresses during start/stop operation. These cracks can start spontaneously, or they can initiate from inherent inclusions in the rotor forging, which were not removed during the bore machining process. These cracks, if ignored, can propagate to the point of causing rupture of the rotor and catastrophic damage to the unit. A complete bore examination and test should be done to requalify an older rotor forging for continued long-term duty. Most bore exams consist of a complete visual examination, a magnetic particle test, and an ultrasonic test (UT). Surface indications can be removed by honing the bore. Deeper indications, identified by UT, can be removed, if necessary, by bottle boring.

Tooth Tops

Alternating radial and compressive loading, during start/stop cycles of the generator, causes cracks in the rotor tooth top areas.[i] These cracks most often occur in the tooth top fillet radii, and they can be detected by visual inspections, eddy current, dye penetrant or wet magnetic particle exams. Tooth top cracks, according to industry literature, have not caused a forced outage. Even in the worst case, with cracks all the way through, the tooth tops were constrained by the retaining ring surrounding them. Small cracks can be removed by enlarging the fillet radius. Larger cracks require removal of the tooth tops, with retrofit of a longer retaining ring.

Snap Ring Groove Cracking

Snap ring groove cracking occurs in a similar area as tooth top cracking, but for different reasons. The alternating axial forces of a tapered retaining ring pulling on the tooth tops causes these cracks, typically located as shown in ***Figure 1***. Cracking occurs in the very sharp machined radius in the snap ring groove. These cracks can be detected most easily by wet magnetic fluorescent penetrant exam. An enlarged radius can be employed to remove the existing cracking, and extend future crack initiation beyond planned cycles. Other techniques, such as inclusion of slip planes and modification of the retaining ring taper, can be incorporated to reduce the axial forces involved.

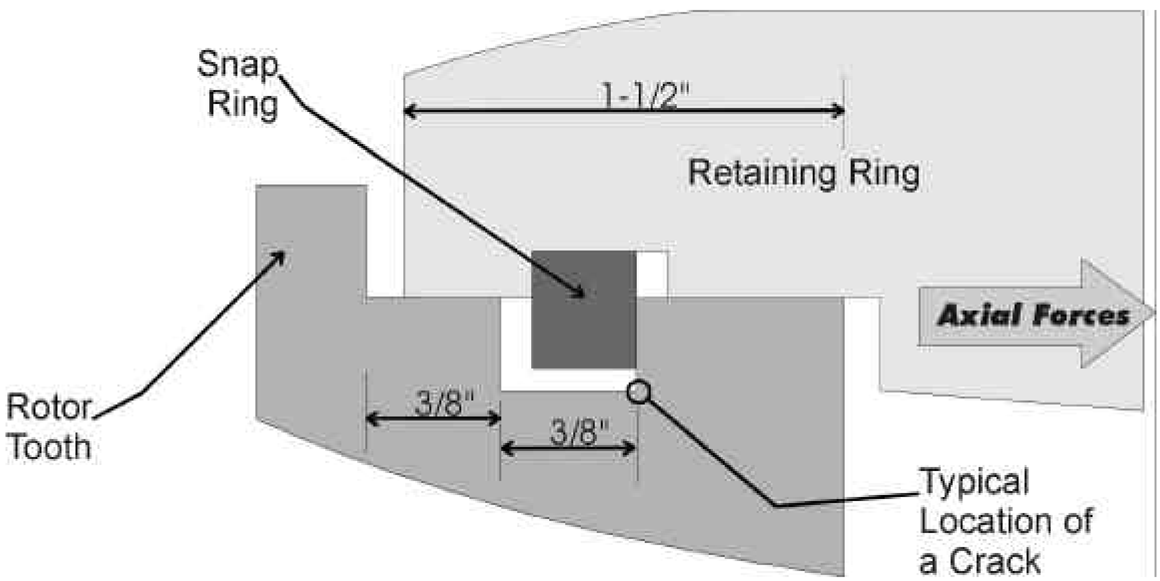

Figure 1: Typical location of snap ring groove cracks.

Shaft Fluted Areas

Cracks commonly occur on fluted sections of rotor shafts, as shown in ***Figure* 2.** This rotor, in the author's factory for a rewind, had a large (approximately 4 inch long) crack across one of the flutes. These cracks usually occur on the shaft fluted portion, underneath a heavy shrink fit of a blower hub or fan. The heavy shrink in the radial direction tends to resist the axial thermal expansion and contraction of the rotor shaft. Over time and many cycles, these resisting forces eventually lead to crack initiation. The rotor in question was weld repaired, rewound and returned for long-term service.

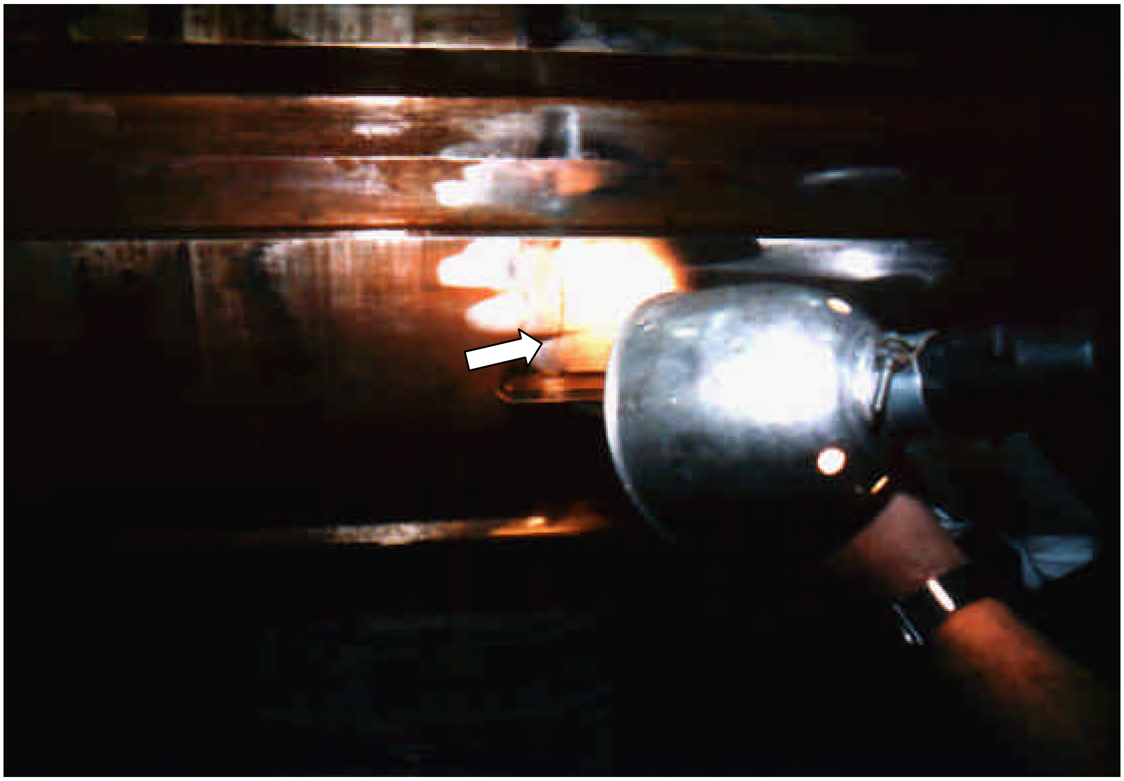

Figure 2: A faint four-inch vertical crack across the rotor shaft flute is shown to the right of arrow point.

Retaining Rings

Careful consideration should be given to replacement of the generator retaining rings during a major upgrade or refurbishment project. If the rings are non-magnetic and made of a material other than 18Mn18Cr, they should be replaced. Other non-magnetic ring materials, such as 18Mn5Cr, are susceptible to stress corrosion cracking in the presence of moisture. Replacement of the rings during a major project is recommended to reduce the risk of an in service cracking and rupture.

Magnetic retaining rings most often can be re-qualified for future long-term use. These rings do have their problems, including vent hole cracking, hydrogen embrittlement, arcing damage, and corrosion.[ii] Dye penetrant, wet magnetic fluorescent penetrant and ultrasonic testing should all be done to detect any pitting or crack like indications. Generally, a great enough margin of thickness exists in the ring that skim cuts can be taken in its body area to remove surface pitting.

ROTOR WINDING & INSULATION

Rotor Copper Windings

"Should I buy all new rotor winding copper, or reuse the old?" This is a common question that surfaces during a generator refurbishment and upgrade project. The answer, of course, is *"It depends!"* There are advantages and disadvantages on both sides. Rotor copper windings can last forever, if they remain in good condition. Problems that can occur include, softness due to overheating, top turn cracking, coil foreshortening, top turn elongation, and copper turn deformation between wedges. (Due to space constraints, reference to another of this author's

writings must be made for a discussion in greater detail on each these problems.[iii]) A good visual inspection of the winding will identify any excessive distortion. In most cases, distorted copper coils can be straightened, or new turns can replace the distorted sections. Dye penetrant testing can identify cracks in rotor copper turns, common on rotors with spindle-mounted retaining rings. Hardness testing can determine if the copper is soft, either from overheating or due to its initial, annealed state. Some older machines were wound with low strength annealed copper. These windings should be replaced with higher strength silver-bearing copper, resistant to deformation. A new copper rewind will generally cost more than reusing the old copper.

Rotor Winding Insulation

Improvements in rotor winding insulation systems have led to the use of low coefficient of friction slip planes to minimize rotor winding distortion and improve operating performance. Bonded Teflon®, for instance, allows the rotor windings to thermally expand and contract without becoming bound in the slot or end turn area. Slip planes, using these low coefficient of friction materials, should be specified and incorporated into the rotor rewind for all major generator upgrades.

Rotor Slot Wedges

Rotor slot wedges play an important part in radially constraining the copper windings against rotational forces. These wedges should be checked by visual, dye penetrant and/or magnetic particle examination for cracks, pitting or other indications, which could increase overall stress in the wedges and eventually cause a failure. ***Figure 3*** shows the catastrophic results of a wedge failure. In this case, failure of the wedge allowed it to come out of the slot at full rotational speed. This then allowed the rotor coil to come out. The resulting damage was so extensive that new core iron was needed, in addition to a rotor and stator rewind.

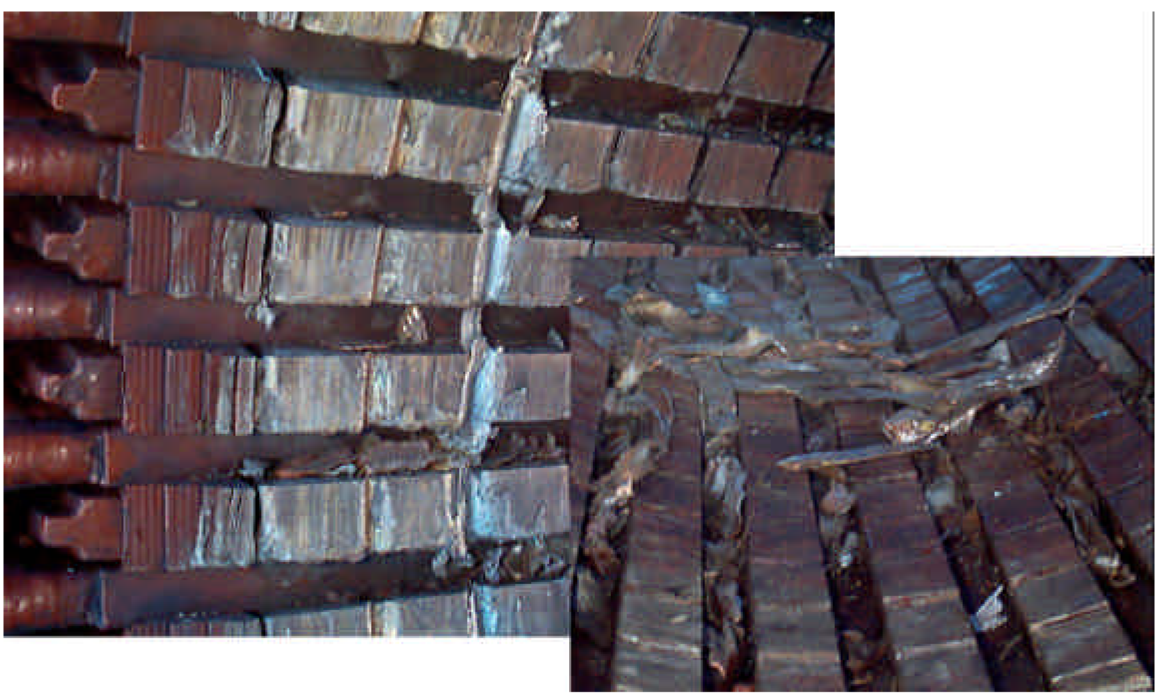

Figure 3: With a rotor wedge displaced at full rotational speed, substantial damage to the stator resulted.

Rotor Journals and Bearings

A close visual and dimensional check of the rotor journal area, including the corresponding bearings should be done as part of a generator refurbishment project. Diametral checks, in conjunction with rotor lathe runout readings, will identify if the journals are egg shaped, undersized or non-concentric with the rotor body. Considerations should be given to returning the journal and bearing diameters to original factory sizes. As a minimum, journals should be undercut, then ground concentric with the rotor body. Bearings should be rebabbitted to the appropriate journal to bearing clearance.

Rotor Collector Rings

Collector rings can wear unevenly over time due to uneven brush pressure, or differences in polarity. Rings can wear to the point where dust removal grooves are almost non-existent. Ground insulation underneath the collector rings can deteriorate. Rings should be visually evaluated and electrically tested to determine the proper course of action. Rings should be ground to the same diameter and concentric with the rotor shaft, if found uneven. Dust grooves should also be restored. If insulation is grounded, rings should be removed and reinsulated. If excessive wear exists, new rings with new insulation should be installed.

GENERATOR COMPONENT EVALUATIONS - GENERATOR STATOR

Stator Core

Verification of the stator core integrity is an essential part of any generator upgrade project. Loss of integrity usually means core hot spots. Hot spots can continue to heat, and if left uncorrected, melt the core iron. Core hot spots can be caused by physical damage to the core iron itself, or by damage to the "interlaminar" insulation, which separates the individual core iron laminations. Physical damage often occurs from a foreign object such as a disconnected rotor balance weight, or thrown wedge. Damage to nterlaminar insulation can result from vibration of the core iron or from the overheating of stator coils. Prudent checks should include evaluation of the existing tightness of the stator core. A knife test and a through bolt tightness check will give a good evaluation of the overall core tightness.

Core hot spots can be detected by a thermal loop test or by an EL CID test.[iv] Both tests involve excitation of the core to induce the flow of eddy currents between shorted laminations. Repairs can be local or global. A local repair to a core hot spot might involve the insertion of mica between the shorted laminations to reestablish the interlaminar separation. A global repair might involve removal and replacement of all core iron laminations.

Stator Winding and Insulation

A stator rewind with a new insulation system is usually part of a generator refurbishment and upgrade project. It is often possible to uprate the generator to a higher KVA output by designing additional copper into the new stator coils. Lower losses and improved efficiency can usually be achieved. Advances in insulation systems allow designs to have less insulation, but maintain higher dielectric strengths. Because of these considerations, stator coils are almost always cut out and sold for the scrap value of copper. The rare exception would involve a strip and reinsulation of a large water cooled bar, to maintain schedule or minimize cost. If the turbine output is limited, it too can be uprated, or the generator with the increased copper and lower losses, can be run at cooler temperatures for a longer life. The generator rewind specification should state the desired KVA output, losses, efficiency gains, and final machine operating parameters.

Increasing the generator rating by adding copper to the stator coil cross section necessitates a balanced trade off between space available in the slot, required insulation thickness, I^2R losses, and finally circulating eddy current and strand losses.[v]

Stator Slot Wedges and Wedging System

Advances in non-conducting materials have led to improved slot wedge and wedging system designs. Slot wedges are typically damaged during removal of the existing coils, and new wedges are supplied as part of nearly all generator refurbishment projects. The opportunity exists, depending on the design of the new stator coils and allotted space, to upgrade the wedge material and wedge design. "Piggyback" style wedges, using a tapered slide, provide one of the best means of assuring radial compression of the coil. Combined with top and side (if possible) ripple springs for radial and tangential follow-up, today's slot wedging system is vastly improved over last generation's machines.

Stator Bracing System

Likewise, improvements in the generator's end winding bracing system will enhance long term reliability. The use of decoupling brackets to separate thermal growth of the end windings from the fixed bracket support, will prolong coil life by minimizing abrasion due to relative movement of the bracket and coil. A typical decoupling bracing system is shown in ***Figure 4.*** It is important to evaluate, before the refurbishment project starts, what is really needed for a bracing system. Smaller machines see less overall thermal expansion/contraction, and a decoupling system may not be cost justifiable. Consolidation and tightness of the end basket in the radial and tangential directions are critical to maintaining low vibration amplitudes. "Detuning" the natural frequency of the end winding away from the double operating frequency (for two pole machines) can be accomplished by radial and tangential clamping and bracing. Modal analysis testing can determine the overall global mode of the end winding basket, or if individual coils are resonating, any desired frequency.[vi]

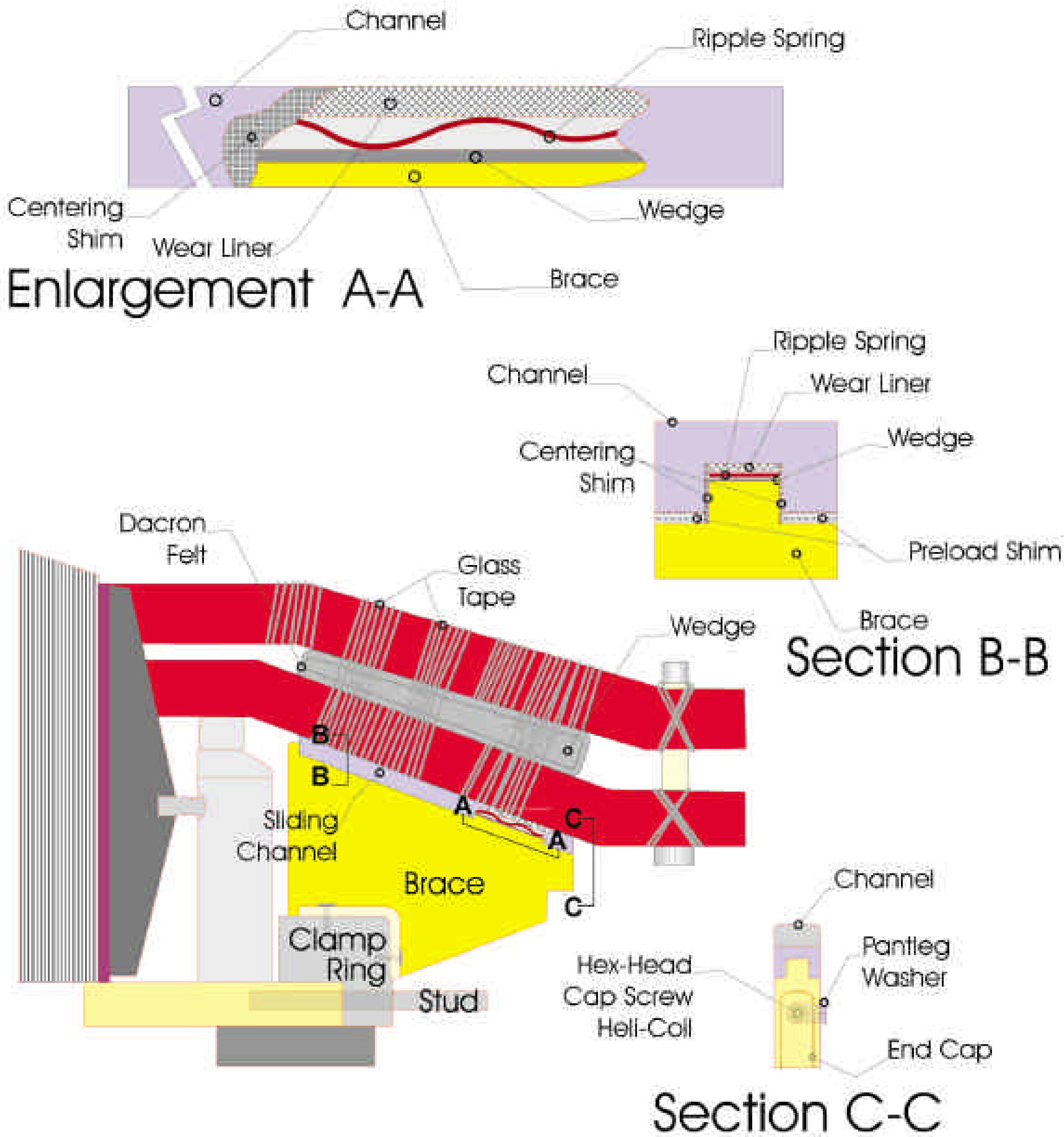

Figure 4: A typical decoupling stator bracing system.

SUMMARY/CONCLUSIONS

A generator upgrade and refurbishment project involves up front and in process evaluation of key generator components. Proper and thorough evaluation of all critical generator components can assure long-term, reliable service after the completion of the refurbishment project. Omitting the examination and evaluation of one key component can jeopardize future reliability of a unit. Choosing a knowledgeable company, experienced with many different manufacturers and various machine-specific design problems, to perform the generator upgrade can assist with project success.

END NOTES AND REFERENCES

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