# Inspecting, maintaining air-cooled generators

*It's not often that you find someone at a gas-turbine-based powerplant do more than shrug his or her shoulders when you ask about the facility's experience with air-cooled generators. Provide these workhorses clean lube oil and cooling air and they're a good bet to run forever—in theory, anyway.*

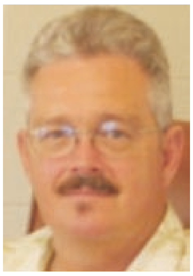
*Generators have performed so reliably over the years that resource-challenged plant O&M staffs are inclined to focus their attention on gas turbines (GTs), heat-recovery steam generators, water treatment, attemperators, etc, where they expect problems. But it's important to give generators the minimal attention they typically require.*

*To help you keep your generators in top condition, the editors of the COMBINED CYCLE Journal approached Derek King and Charles Mallon of Brush Electrical Machines Ltd (a subsidiary of FKI Energy Technology), Houston, and Terry Osman of National Mechanical Services (NMS), National City, Calif. The three men are frequent participants in GT user group conferences and know well the challenges associated with managing profitably combined-cycle, peaking, and cogeneration facilities.*

*By way of background, Brush (www.fki-et.com/bem) is one of the world's preeminent generator manufacturers, with nearly 1500 machines coupled to frame and aeroderivative GTs built by GE Energy, Siemens Westinghouse Power Corp, Mitsubishi Power Systems, ABB, Pratt & Whitney Power Systems, and Rolls Royce. NMS is an independent firm that specializes in inspection, field service, and repair of generators of all types and models.*


King


Mallon


Osman

*King (derek.king@houston.rm.fki-et.com, 281-580-1314) and Mallon (charles.mallon@houston.rm.fki-et.com, 281-639-1375) help reacquaint readers who may be a bit rusty on things electrical with their cutaway drawing of an air-cooled generator and short notes regarding the arrangement, purpose, and general maintenance requirements for key parts. Osman (tosman@natlmech.com, 619-477-1991) provided the material for the second section of this report. His photos and notes reveal where problems might be found during annual, 25,000-hr, and 100,000-hr inspections and overhauls as well as how to identify them.*

*Another valuable reference for planning your inspection and maintenance activities is "Why generators fail," COMBINED CYCLE Journal, 1Q/2005; available at www.psimedia.info/ccjarchives.htm.*

## What's inside the box

**Main stator windings** (1 in the generator cutaway diagram) convert rotor power into volts and amps. Your primary goal, say King and Mallon, is to keep them clean. Visually inspect for dust, oil, foreign object damage, etc, at least annually. Continuous monitoring of winding temperature allows tracking of trends that would indicate the presence of crud and the need for more frequent attention.

Suggested annual electrical tests include measuring (a) the polarization index to determine the extent of moisture and dirt contamination and (b) winding resistance to detect the presence of broken conductors. Also, conduct a reduced hi-pot (short for high-potential) test to ensure insulation integrity.

Heavily contaminated windings are shown in the accompanying photo. Fouling to this degree should never be allowed to happen. When you identify a buildup of crud, use a vacuum, brushes, and lint-free cloth to clean the windings. For stubborn deposits, wipe sparingly with orange oil or equivalent. Take care to avoid forcing contaminants further into the insulation crevices.

**Stator core** is the magnetic heart of the stator (2). Air-inlet and -outlet temperatures are monitored to ensure against damage from an over-temperature condition caused by a blockage of cooling air flow. King advises that you check the manufactur-



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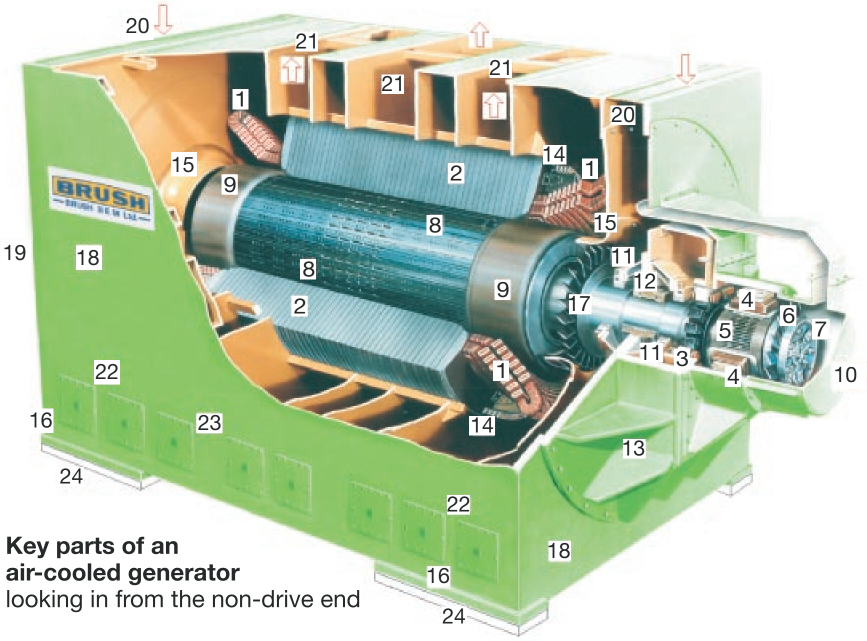


**Key parts of an air-cooled generator**
looking in from the non-drive end

er's instruction book for your machine's temperature limits. Annually, or more frequently, visually inspect for contamination or signs of distress—such as discoloration, foreign object damage, etc. Every 100,000 hours an ELCID (electromagnetic core imperfection detection) test is recommended to identify shorted laminations—if any.

**Exciter permanent magnet generator** (3, PMG) provides power to the voltage regulator that controls excitation for the main exciter. Check for cleanliness each time the generator is open for inspection.

**Exciter field** (4). A voltage regulator controls the excitation of the main exciter field. Check for cleanliness annually and use a 500-V megger to verify insulation integrity. During the 25,000-hr overhaul, remove any accumulated dirt from the rotating rectifiers and the main exciter. Also, check to be sure electrical connections are secure.

**Exciter armature** (5) makes the ac power supplied to the 3-phase rectifier (7). Check for cleanliness annually and use a 500-V megger to verify insulation integrity.

**Exciter fan** (6) cools the exciter. Clean annually.

**Diode wheel** (7). The 3-phase rotating rectifier diode wheel should be thoroughly cleaned during the 25,000-hr overhaul. Use a diode tester—usually part of the multimeter function—to verify the condition of individual diodes.

**Rotor body and wedges** (8) hold the rotor windings in place. Recall that the rotor typically is manufactured from an integral forging of nickel/chromium/molybdenum alloy steel with excellent tensile properties. Axial grooves are milled along the top of both winding and ventilation slots to hold the slot-closing wedges. At the exciter end, a hole is bored along the axis of the shaft to take the leads from the main exciter to the rotor winding. The rotor winding conductor is made of a copper/silver alloy. Preformed coils are inserted into the slots, each turn insulated from the next.

The rotor is cooled by air flowing under the end caps (9) past the winding and through axial slots—called interslots—between the winding slots. Exhaust ducts in the closing wedges of the interslots allow the air to escape at the center of the rotor as shown in the cutaway.

Maintain the rotor in clean condition and use a borescope every 40,000 to 50,000 hours to check for winding distortion and movement, which can cause shorted turns or an electrical ground.

**Excessive fouling** of stator windings requires immediate attention

**Retaining end caps** (9) also hold rotor windings in place as they are acted on by centrifugal force. Clean annually. Inspect with a borescope during each major overhaul (25,000 hours). Nondestructively examine for cracks at 100,000-hr overhaul. Mallon, the service manager for Brush's US operation, reminds that if your generator is 20 or more years old, verify original material specs. If 18-4 steel is present, check carefully for stress corrosion cracking. Replace with the modern material 18-18 if damage is present.

**Exciter end of machine** (10).

**Oil seals** (11) prevent the escape of lube oil from the bearing housing into the generator. Note that the construction of some generators—particularly end-frame bearing machines—requires that part of the bearing housing be located in the cooling-air stream. Pressurized seals are fitted at each end of the bearing to prevent the fans from drawing oil mist from the bearings into the generator. Pressurized air is taken from the discharge side of the fan and delivered to the seals via flexible piping.

During planned semiannual outages, check that bearing seals are not leaking. Annually verify that the pressure of the sealing air is within recommended limits.

**Main bearing** (exciter end) supports the shaft (12). Monitor vibration and temperature (bearing metal and oil drain) continuously and check lube-oil quantity and quality (water, acidity, particulates, etc), as well as bearing oil seals, at least twice annually. High temperature is indicative of a problem and the bearing should be inspected. King and Mallon recommend that if vibration and temperature remain within specification limits, there's probably no reason to roll out bearings more frequently than every five years to inspect for scoring or drag marks. Minor scoring usually can be corrected in the field; however, be sure to hire pros for this work so



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the bearing profile is not changed. After reinstallation, check bearing top clearance at each end of the bush using lead strips; side clearances with feeler gages.

**End frame** (13) supports the bearings.

**Winding supports** (14) support the main stator windings. Check with borescope for abnormalities—such as cracking—during major overhauls.

**Fan shroud** (15) is important for efficient cooling. Manufacturer's clearance must be maintained between the fan blades and the shroud; check the OEM settings provided in the O&M/quality data book. Check for cracks and rubbing annually. A borescope can be of help for this work.

**Mounting feet/hold-down bolts** (16) generally require checking only if casing vibration is detected.

**Fans** (17) are located on both ends of the generator. They are machined from cast aluminum disks. Periodically inspect for blade cracking and, as noted earlier, the clearance between blade tips and shroud.

**Stator casing and frame** (18).

**Drive end/coupling** (19).

**Air inlet and outlet** (20, 21). Monitor temperatures continuously; check inlet-air cleanliness regularly. Any crud buildup on components in the inlet-air flow path should be removed with lint-free rags and a citrus-based solvent.

**Access doors** (22). Check that doors are secure and gaskets are in place.

**Access to heater and back of stator** (23). Electric heater prevents moisture buildup when the generator is shut down. Verify its operation whenever the generator is out of service.

**Sole plates** (24).

# Generator inspection, problem identification

Terry Osman spends the better part of his professional life in powerplants inspecting generators and correcting problems. He knows first-hand the pressures on plant and asset managers to defer maintenance for as long as possible to minimize expenses. Osman says that the first question he's usually asked after finding a problem that requires attention: "How much will it cost to fix?"

His reply generally is something along the lines of this: "Think of yourself as a risk manager. What is the risk associated with not doing this work? If your plant is forced out of service, how much revenue will you lose, how much will it cost to purchase replacement power, and how much more will the repairs cost if the damage increases in severity because of the reluctance to be proactive in decision-making?"

It's not easy managing generating plants in competitive markets. Your every move can and will be questioned—most likely by a financial person not quite sure why you need a generator in



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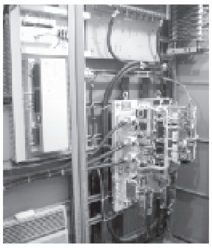

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the first place. But that's no reason to not to do what you know is necessary.

Each OEM (original equipment manufacturer) has established procedures for operating, maintaining, inspecting, and repairing generators—including specific recommendations for conducting annual, 25,000-hr, and 100,000-hr overhauls. Follow them and minimize the potential for serious loss.

## Working with service providers

It's important to work with service providers well in advance of when you might need them, says Osman. The better your preparation and the clearer your proposed scope of work, he continues, the more accurate the cost estimate. At a minimum, recommends Osman, plant managers should put together a work plan for annual and 25,000-hr outages and send them to their preferred service providers for comments and suggestions. Work collaboratively to develop detailed outage plans that just require tweaking on scope, timetable, and price. One benefit to the plant is that realistic numbers are available for budgeting.

At the advance planning stage you should investigate the advantages—if any—of entering into a long-term service agreement. Five years is a typical term. Some plant managers find non-OEM LTSAs beneficial, Osman says, because service providers can be aggressive on price knowing they have your business for an extended period. In addition, costs can be spread out over the contract term, eliminating spikes on your balance sheet.

**Outage preparation** should begin in earnest months before your service provider mobilizes at the plant. Osman suggests that you track generator operating trends diligently for six months prior to the outage. This information should be forwarded to the contractor regularly so experts can keep you informed of machine condition and if any changes will be required to the scope of work.

Vibration and lube-oil monitoring are important because they provide valuable insights into overall machine health. Operating data collected by the plant historian have obvious value, but their primary benefit is to help assess the condition of the generator's electrical components—such as stator, exciters, rotor windings. Information collected during starts and stops is most important.

**Staff preparation.** A month or so before an outage, classroom time should be allocated to communicate plant objectives to the O&M staff and to revisit procedures for disassembly, cleaning, testing, repair, and reassembly. Your staff will be monitoring tasks assigned to the service provider and must have the technical background necessary to report on job progress and test results. This is particularly important for new technicians and others who have no experience in generator overhaul. A valuable resource for your training sessions is the OEM's, technical manual.



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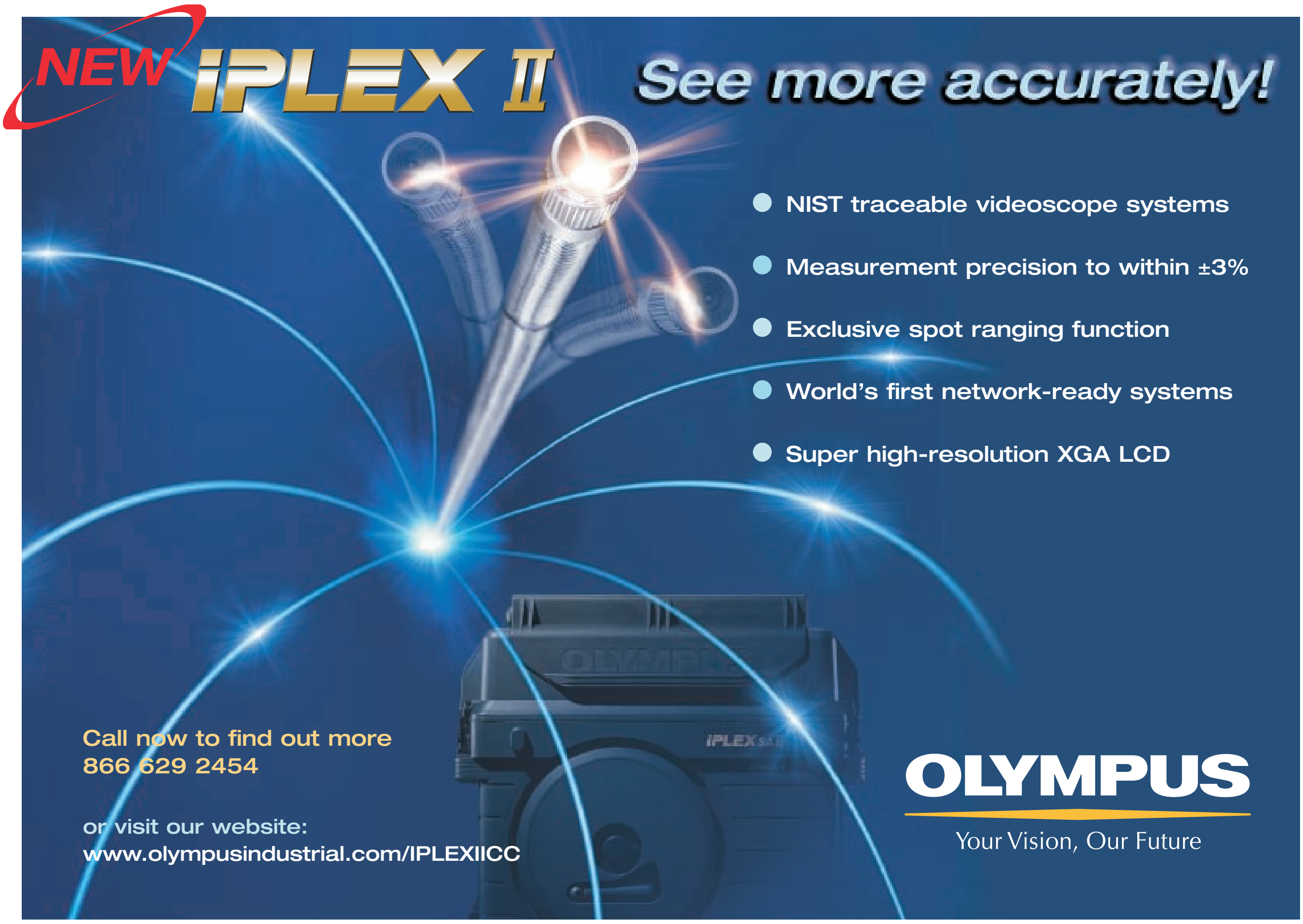


## Cleaning fundamentals

Cleaning is one task that may be part of the plant's work-scope, both as a cost-saving measure and hands-on training for O&M staff. Most plant managers agree that one of the best ways to learn about equipment is to help disassemble and clean it. Procedures for both cleaning and testing are well defined in standards published by the Institute of Electrical and Electronic Engineers Inc (IEEE; visit www.ieee.org). Cleaning procedures are in Section 8.4, testing in Section 8.5.

Regarding cleaning, frequency depends on the machine environment. Generators should be cleaned as often as operating conditions dictate and certainly during an overhaul. A vacuum cleaner is recommended as a first step. Low-pressure compressed air is a viable alternative, but only if the air is dry.

After top dirt is removed, a cleaning fluid may be necessary to remove oily deposits from windings. Consult the OEM's technical manual for a suitable solvent. A mistake here could lead to varnish and insulation damage. Caution: When working with solvents, be sure the work space is well ventilated; prohibit smoking.

## Important diagnostic tests

Plant managers generally have greatest interest in conducting diagnostic tests that accomplish the following:

■ Provide a basis for determining the serviceability of a generator, or the corrective action necessary, following severe duty or a suspected or actual failure.

■ Indicate long-term trends in behavior.

■ Anticipate potential service failures.

Tests that have proved useful in accomplishing these objectives are listed below. The methods for conducting them, and guidelines for interpreting test results, are in IEEE Standard 43-1961 (Reaff 1971)—also known as ANSI C50.22-1972. The tests are:

**Insulation resistance at low-voltage** direct current (dc)—used primarily to detect grounds and wet or dirty insulation.

**Insulation resistance at high-voltage** dc—to reveal problems that may not be evident from tests at low voltage.

**Dielectric absorption**—to assess insulation condition.

**Dielectric over-voltage**—to establish at the time of the procedure that the winding is capable of withstanding the applied voltage. Both ac and dc tests are available. The dc high-potential (hi-pot) test, says Osman, has these advantages over the ac method: (1) It causes less deterioration of the insulation (up to within a few percent of the breakdown point); (2) The small leakage current drawn can be easily measured and tendencies to increase or decrease noted; (3) It minimizes damage in the event insulation breakdown occurs; (4) Test equipment is relatively small and lightweight because it only is required to supply the insulation leakage current. When using the dc method, keep



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in mind that it takes a relatively long time to drain off the charge after completing the test.

**Power factor tip-up**—to detect moisture and voids in the insulation and to indicate the amount of ionization.

Air for exciter cooling and oil-seal pressurization

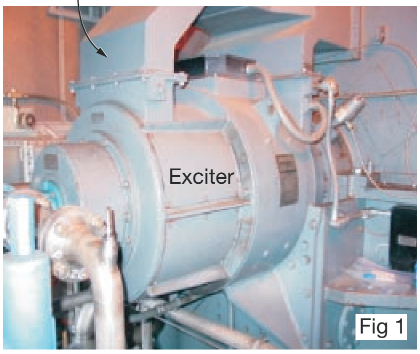


Fig 1

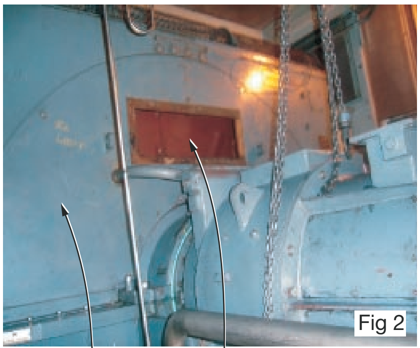

Fig 2

Remove exciter air duct . . .
. . . then outer quad cover to access fan

Clearance between fan tip and shroud a critical dimension

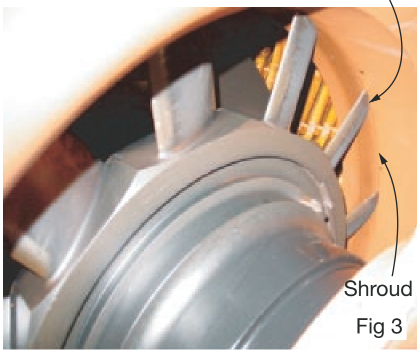


Fig 3

End-turn coil and overhang

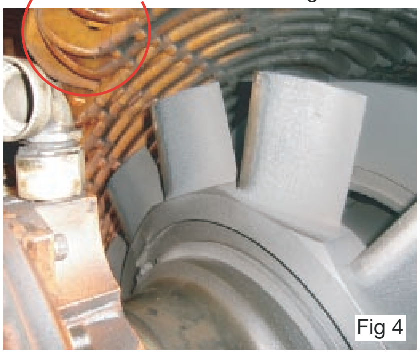

Fig 4

**Slot discharge**—to detect potentially injurious surface discharge.

**Surge comparison**—to check turn-to-turn insulation.

**Corona probe**—to indicate and locate unusual ionization about the insulation structure.

**Winding resistance** (dc)—to detect loose connections and open-circuited windings.

**Field-winding impedance and pole drop**—to detect and help locate turn-to-turn faults.

**Ducter** (low-range voltmeter)—to check inter-polar connections of the field windings.

**Interlaminar insulation**—to detect and locate damaged portions of the stator core.

## Inspecting generators

Photos taken during several outages—annual, 25,000-hr, and 100,000-hr—illustrate key steps in the inspection/overhaul process, some of the as-found conditions you may encounter, and how to correct and restore an air-cooled generator to optimum running condition.

Fig 1 shows the exciter end of a machine scheduled for overhaul. After shutdown, the outer quad cover identified in (2) is removed and a visual inspection conducted. Use of a borescope improves your ability to identify fouling of coils and rotor as well as any oil present. Note that the duct removed to access the machine supplies high-pressure air to both the exciter and the oil seals. Air is used to help prevent bearing oil from entering the generator.

**Removal of the outer quad cover** offers access to the fan assembly and shroud. Check the clearance between blade tips and the shroud. It must be tight to ensure proper cooling but not so tight as to cause rubbing (3). Also examine the fan for a buildup of crud. Any accumulation can impact fan balance and must be removed. Suggestion: Remove the supply air fitting to the inner seal assembly before dismantling the inner quads and/or shrouds. This nylon/plastic insulated part is easily broken if hit while doing this work (4).

With the shroud removed, it is easy to access the end-turn coils and overhang and to assess the extent of stator contamination. Fig 5 shows what to expect after 25,000 hours of operation. Borescope examination (6) allows a thorough assessment of cleanliness during each inspection. If excessive fouling is identified during an annual inspection, careful consideration should be given to extending the out-

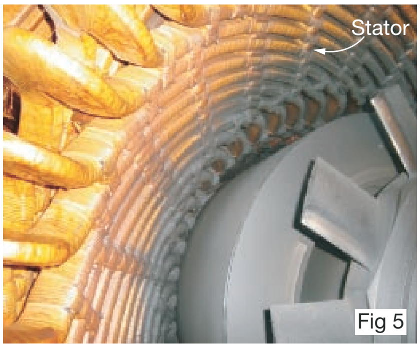


Fig 5

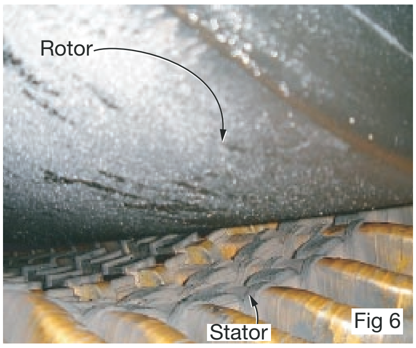


Fig 6

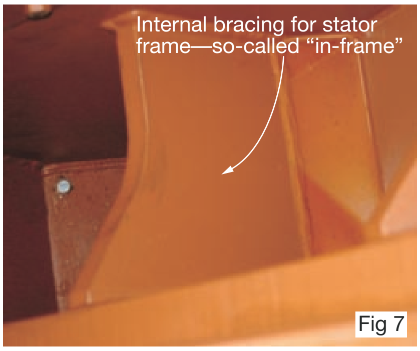


Fig 7

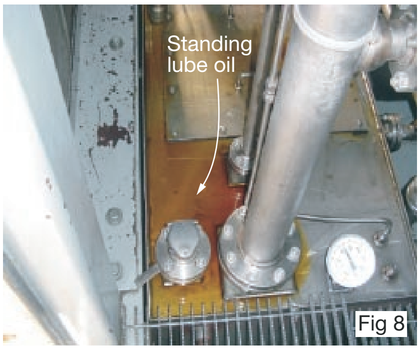


Fig 8



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Fig 9

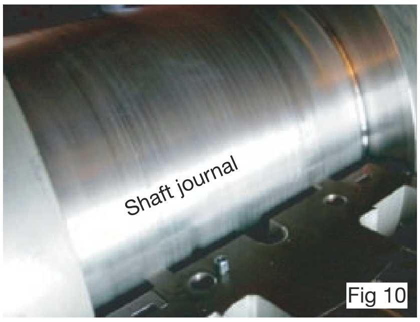

Fig 10


Fig 11

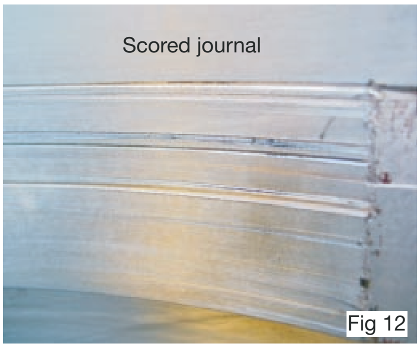

Fig 12



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age for proper cleaning—this to avoid possible insulation damage caused by overheating.

**At the other end of the generator,** where the reduction gear and coupling are located, the grounding (sometimes referred to as "earthing") brush must be inspected. The single carbon brush should be replaced if wear has reduced its length to less than about 5/16 in. (check the OEM's technical manual for the actual number for your machine). Also important is to look for crud buildup where the brush rides on the rotating shaft. Peakers are particularly prone to crud buildup, says Osman, and this can distort the control signal, adversely impacting operation.

So-called in-frames in (7), which support the stator, are extremely clean in this unit. There is no sign of oil contamination or particulate accumulation. Fig 8 shows standing lube oil (on top of the sump) found during the inspection of a similar machine. It must be removed and the source of the oil leak identified and corrected to prevent damage to the generator. In-frame inspection in (9) shows fouling resulting from a minor oil leak. Oil entrained in cooling air blowing at about 50 mph is deposited on the supports creating an ideal collection medium for particulate matter present.

**Bearings** warrant close inspection. The shaft journal in (10) is in excellent condition: even wear and no grooving or pitting. Bearing set in (11), also showing no evidence of scoring, sits on bench prior to dimensional check to verify tolerances and determine if repair is necessary.



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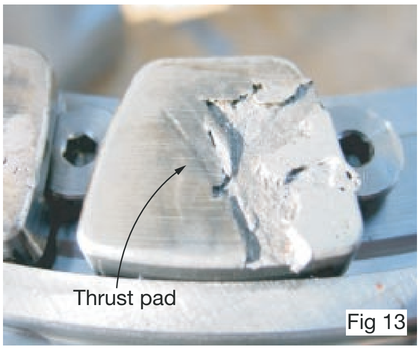


Fig 13

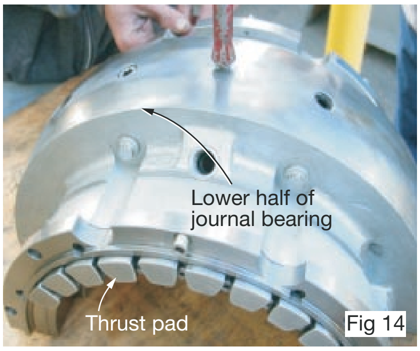


Fig 14

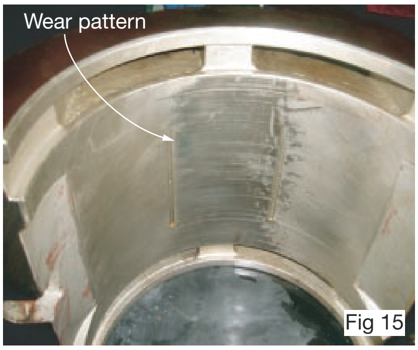


Fig 15

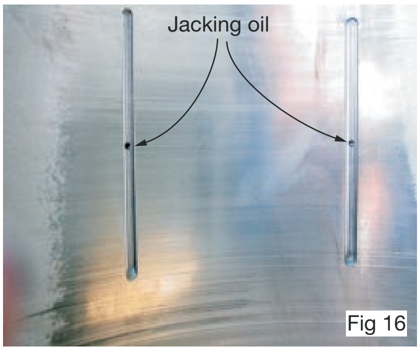


Fig 16

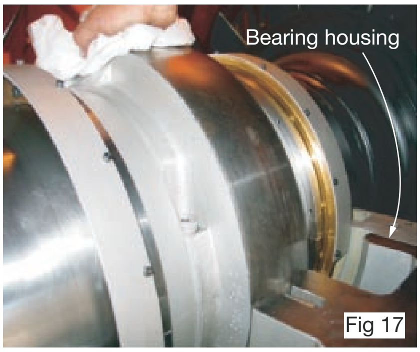


Fig 17

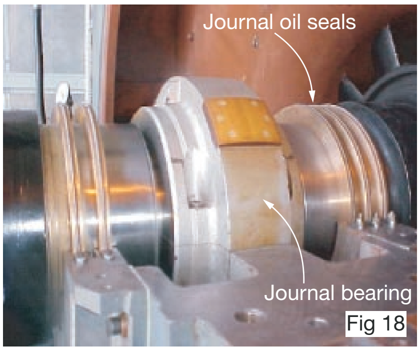


Fig 18

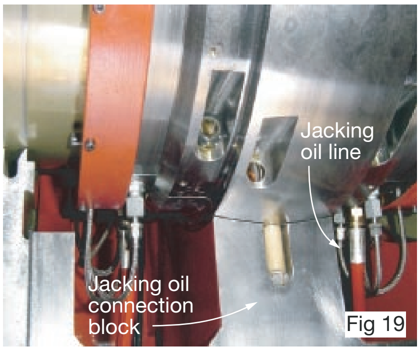


Fig 19

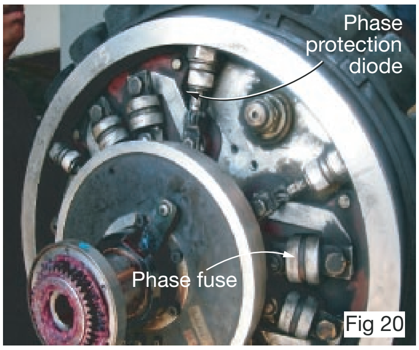
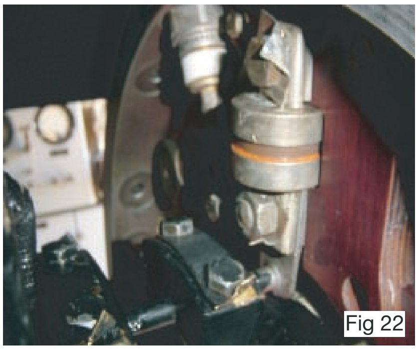


Fig 20


Fig 21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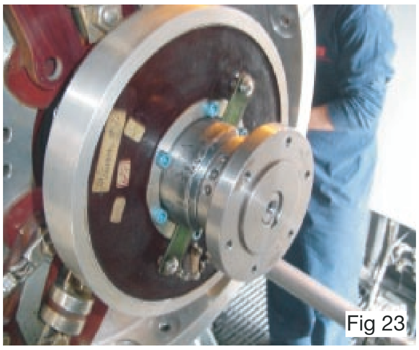
Fig 23

By contrast, note scoring of the journal bearing in (12) that resulted from material liberated from the thrust pad in (13). Electrolysis caused this damage. Improper alignment and overload are other causes of thrust-pad damage. After repair, thrust pads should look like they do in (14) which shows the lower half of a journal bearing ready for reinstallation.

Fig 15 shows polishing between the jacking-oil slots in the non-drive-end bearing that enable lube oil to lift the shaft prior to rolling the generator (16). This is exactly where you want the wear pattern. Housing cleaned and ready for bearing installation is shown in (17); journal oil seals and the split journal bearing have been reinstalled in (18) prior to bolting the bearing cap in position. Bearing series ends with (19), showing the jacking-oil lines installed alongside the connection block. There are six hoses on this machine that must be inspected. Osman says that about three-quarters of generator bearing-damage incidents are caused by the failure of the jacking oil system to do its job.

**Exciter assembly.** Exciter diode wheel on the non-drive end is shown in (20) after removal of the lube-oil pump. This unit has minor lube-oil leakage and high particulate contamination. Dual diode assembly requires hand cleaning. Phase protection diode after cleaning and testing is in (21); phase protection fuse in (22). A coaxial cable carries ground-fault protection signal (23) to the control system. Take care not to damage PMG magnets (24) during the overhaul. And do not put them on or near iron after removal; permanent damage can result.

**Drive-end coupling bolts** (25) are a matched set. Mark the bolts carefully prior to breaking the coupling and reinstall them in



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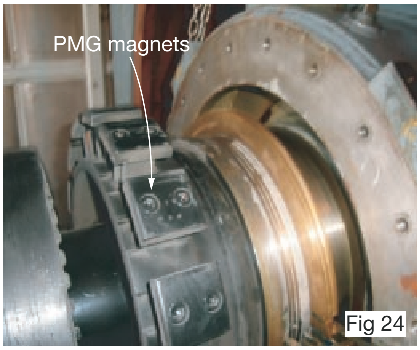

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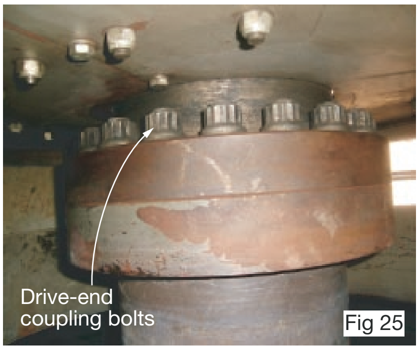


Fig 25

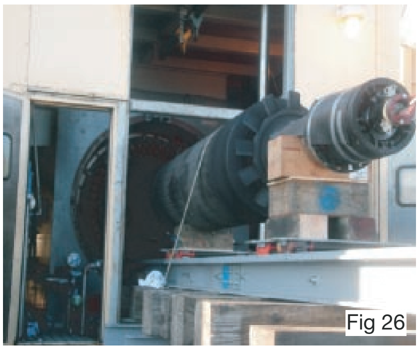
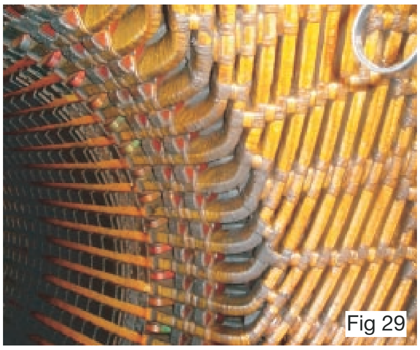


Fig 26


Fig 27


Fig 28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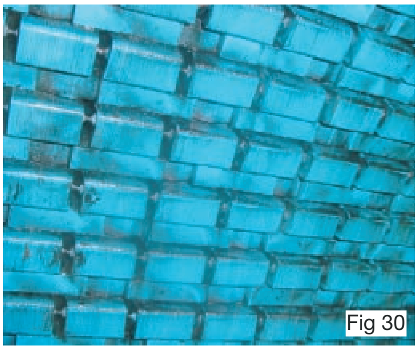
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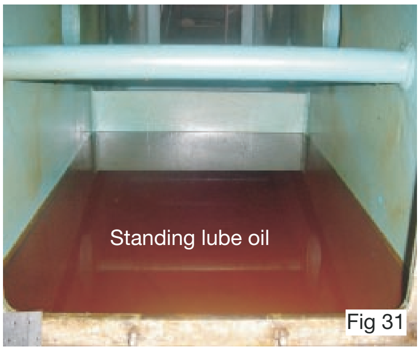

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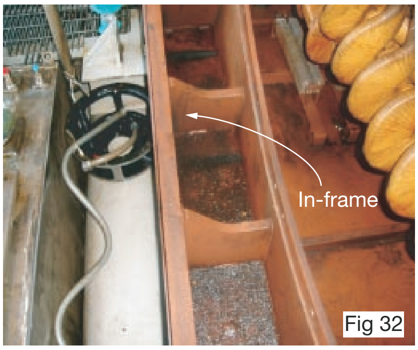

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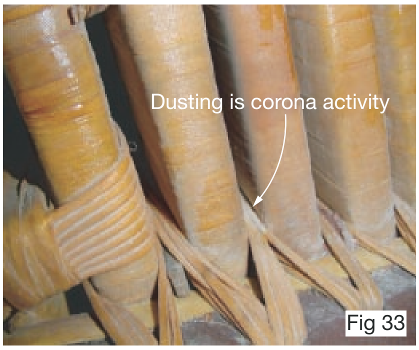

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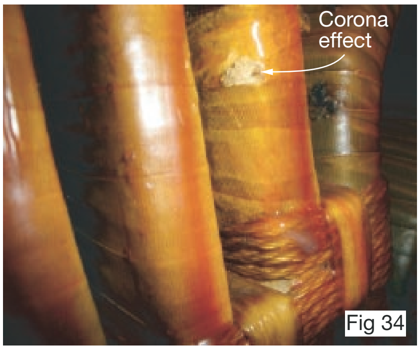

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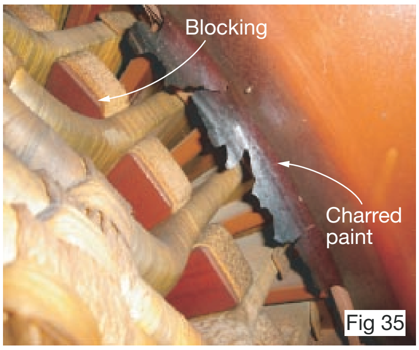

Fig 35

their original holes. Loss of a bolt can add as much as $5000 to the cost of an overhaul.

**Rotor** typically is pulled only after 100,000 hours of operation, unless internal oil contamination is in evidence. Removal is by a track and trolley system (26) or by crane (27). The rotor in (27) was pulled and shipped to a service facility (28) because of a leak so severe that oil pooled underneath the generator. The 18-4 retaining rings on this unit were upgraded to 18-18 during the overhaul.

**Stator** the way you want it to look after 100,000 hours of operation is in (29). Service provider removed dirt on the windings by hand. Highly contaminated stator caused by standing lube oil in the frame base is in (30). Rewedging is required after cleaning because residual oil acts as an agent to loosen wedges. Oil that collected in the frame base is shown in (31). Additional evidence of abnormal lube-oil contamination was found in the in-frames (32). Sleuthing on the part of the service provider identified the source of the leak and it was corrected.

Stator coil inspection includes checking of the strapping, found in excellent condition (33) after 25,000 hours of operation. Corona activity is identified by dusting shown. More corona-related damage is shown in (34). Overheating is indicated by charred paint on



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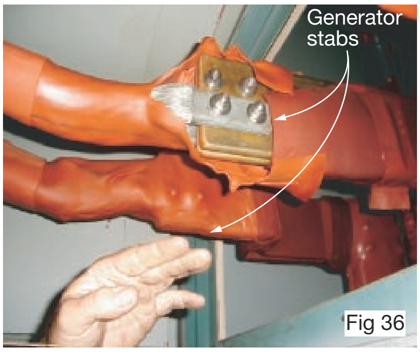

Fig 36

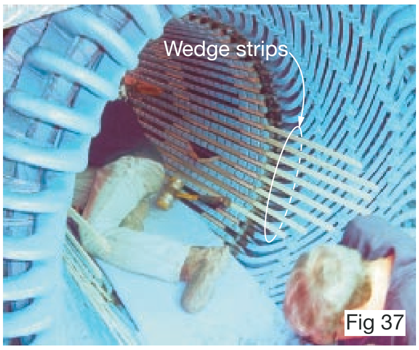

Fig 37

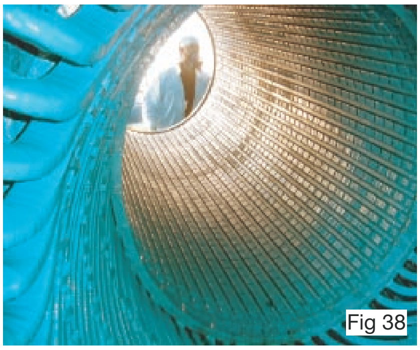
Fig 38


Fig 39

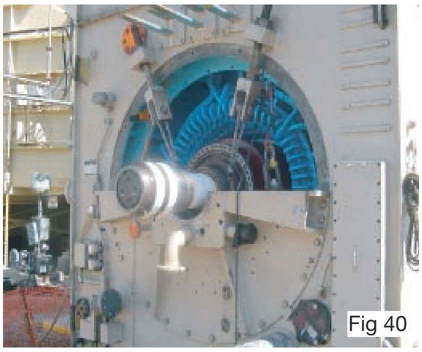
Fig 40


Fig 41

the outer frame of the generator (35). Problem was identified and the frame repainted.

Heat damaged the insulation on this generator's stabs (36). Cause was use of standard-grade bolts, not the stainless steel bolts recommended by the OEM.

**Reassembly.** Rewedging is underway in (37) and the finished job is shown in (38). Next the repaired/cleaned rotor is reinstalled by crane (39) and the lower half of the end frame and bearing housing is replaced (40). Lube-oil piping is reinstalled after reassembly of the non-drive end and lube-oil pump (41). CCJ OH



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