

May 15, 2007

Controlling shaft voltages

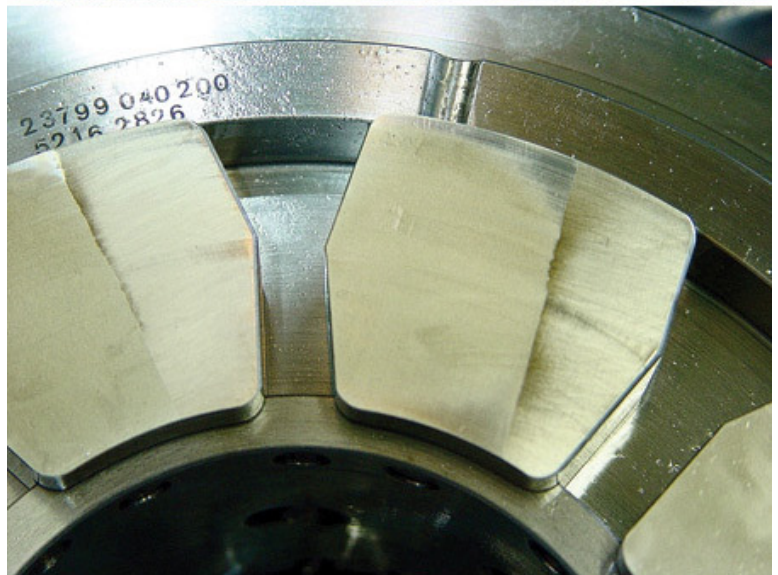
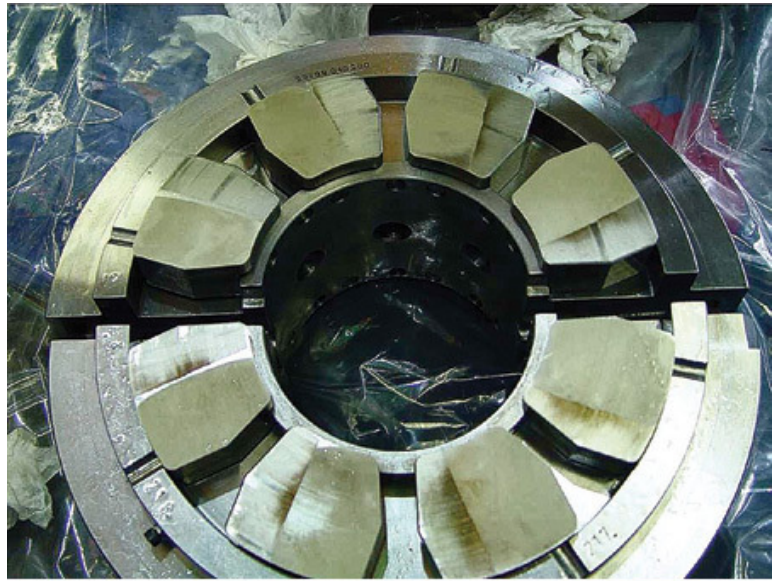
By James S. Bothwell, Jim Bothwell Consulting

The static electrical charges produced by a turbine rotor create an effect akin to the one that results from dragging your feet across a carpet in the winter when the relative humidity is low. Touch a light switch and you usually can draw an arc. Static charges on a turbine rotor are produced primarily by moisture sliding off the last-stage blades. Being lazy, the charges find the easiest path to the turbine case and, under the right conditions, arc to the nearest component, usually the thrust bearing (Figure 1).

1. Walk a straight line. This is what a thrust bearing of a high-speed turbine looked like after six months of operation without a grounding device. Courtesy: Jim Bothwell Consulting

Ideally, the nearest component is the grounding device that was installed to convey the static charge from the turbine rotor to the turbine case. In most cases—but not always—it restricts the voltage to one or two voltages, so there's no arc to the turbine case.

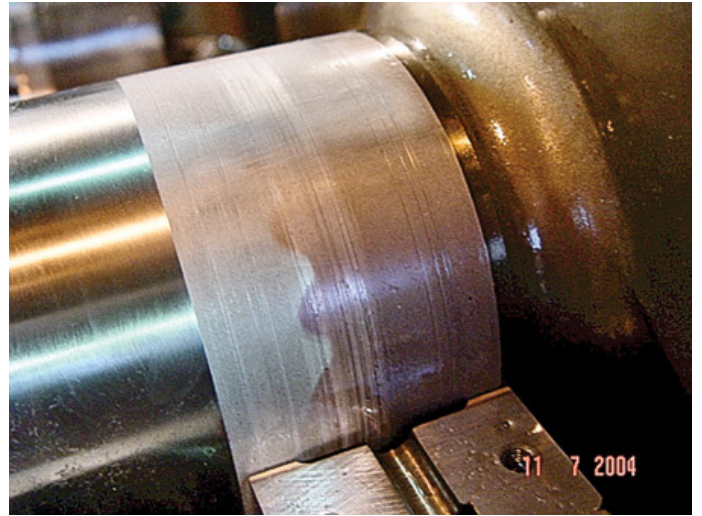
Static voltages produced on turbine shafts range from 1 V to 150 V. In one famous case, the shaft voltage on a high-speed (20,000 to 30,000 rpm) turbine reached about 600 volts. The static discharge from the rotor to the case through the bearings was picked up by the proximity probes on vibration-monitoring equipment in the control room. An inspection found that the turbine and compressor had large clearances filled with lubricating oil that has exceptional insulating properties.



The unit was not equipped with a shaft-grounding device. To compensate, engineers installed a ground strap, which eliminated the spikes detected by the vibration monitoring equipment and reduced the amplitude of the static discharge voltage to 0.01 volts. Lost in the annals was how much damage was sustained before the turbine was properly grounded.

Circulating currents

The two primary types of damage to babbitt bearings are "frosting" and "turbine worms." Turbine worms or "worm tracks" are also found on welded teeth of geared couplings and gearboxes. They are most often caused by electromagnetic currents or circulating currents produced by magnetic fields in rotating equipment (Figures 2 and 3). It's current, rather than voltage, that damages a bearing. But because measuring the current through the shaft is impractical, we measure the magnitude of the voltage instead.



2. Decorated shaft. A "frosted" gearbox shaft. Courtesy: Jim Bothwell Consulting

3. Modern art. Frosting on a babbitt bearing section. Courtesy: Jim Bothwell Consulting

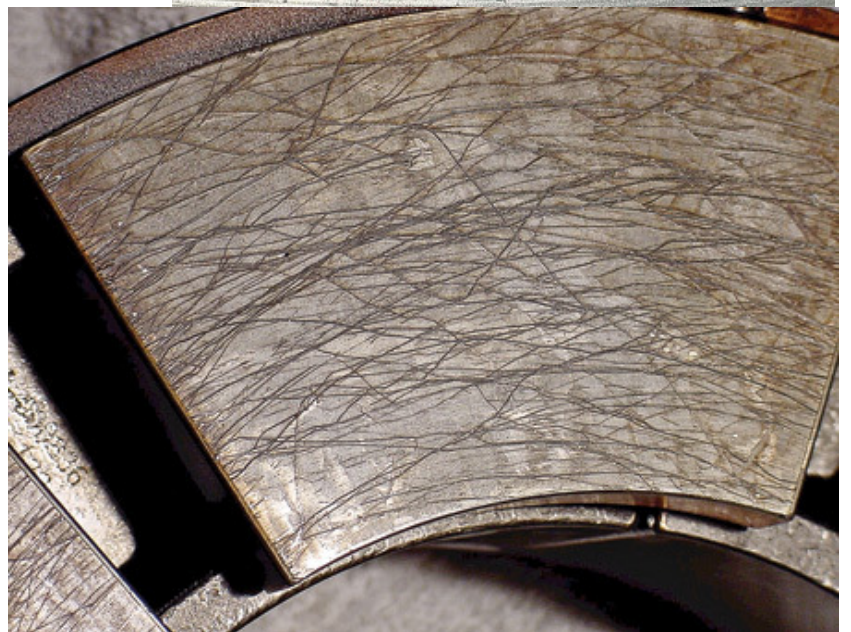
Under a 30X microscope, a turbine worm looks like small weld beads. Damage to roller and ball bearings appears as fluting-like ripples (such as those seen on a poorly maintained gravel road) or spalling of the bearing race. Gears and couplings can experience "welding" or "arc" marks on the teeth, or as pits or frosting (Figure 4).



5. Bad infestation. Here are typical turbine worms created by electromagnetic activity across the shaft-bearing interface. Notice the arc weld bead effect on the bearing. Courtesy: Jim Bothwell Consulting



6. Night crawlers. With these



worm tracks on the thrust bearing of a high-speed compressor, note the change of direction of the electrical tracks. Dirt or contamination would cause straight lines. Courtesy: Jim Bothwell Consulting

Production of an AC voltage requires three elements: a magnet or a magnetic field, a coil of wire, and relative motion. AC current is produced when the AC voltage is given a complete or circular electrical path. In the case of a turbine or compressor, the rotation of the shaft provides the relative motion, and the turbine blades (with their shrouds and/or lashing wires) provide a loop or coil between each blade.

The missing element, a magnet or a magnetic field, is most often supplied by technicians performing magnetic particle testing of turbine blades or compressor components. The technician wraps a few turns of cable around a particular blade group or component and then energizes the cable with a high-amplitude DC current. Once the DC current establishes a magnetic field, the technician sprays Zyglow or some other product on the component and examines it under a black light to see if there are any indications of cracks or imperfections in the surface of the material. Each crack will produce a glow where a north and south pole were formed on the sides of the crack by the strong magnetic field.

After the DC supply has been turned off, the turbine or compressor component retains a certain amount of magnetic field or gauss that depends on the strength of the magnetizing DC current, the number of cable turns or wraps, and the permeability of the component material. The residual gauss is produced by the alignment of polar molecules in the material. Removing it requires returning the molecules to the random state in which they existed prior to the testing.

Some magnetic particle inspection technicians believe that they can restore the particles to their prior state (a process known as degaussing) by reversing the polarity of the DC current in the wrapped cables for a duration equal to the time of its energization. That may happen, but I'd bet that the technician has a better chance of hitting the lottery.

Circulating currents are produced in the rotor and stationary components of a piece of turbomachinery when it is operating. They can result from the residual magnetic fields in the components of a turbine, compressor, or pump. In general, circulating currents are of low voltage but of high current amplitude. If there are large gaps between the rotating and stationary components or insulators on the bearings, an arc will not form but the AC voltage will exist on the component, waiting for a chance to complete the electrical circuit.

Turbine, compressor, or pump components also can be magnetized by:

- Placing magnetic base tools on components.
- Allowing coils of "stinger" or ground cable from a DC welder to rest on, or be close to, a component while welding is taking place.
- Holding a component in place with a magnetic field so it can be drilled or machined.

All turbine or compressor or pump components should be degaussed to a level of less than 2 gauss following magnetic particle testing or any other activity that places a magnet or magnetic field on or near the components. Bid specifications for the following activities and equipment purchases should include the requirement that all components be degaussed to less than 2 gauss:

- Magnetic particle testing.
- Nondestructive testing.
- Inspection or repair work that includes welding or the use of magnetic base tools.

That may seem a lot of trouble to go to every time a pump is overhauled, but experience teaches otherwise. Here's an example.

A 5-hp pump failed at a refinery and required repair work on the impeller and case. The pump was sent off-site to the shop for the repair. The pump was returned, installed, and operated for about nine months before the bearings failed. The pump was removed from service a second time, new bearings were installed, and it was returned to service. About six months later, the bearings failed again. This time, the bearings were examined using a 30X microscope, which revealed the telltale worm tracks of a magnetic field. The pump then was sent to the shop to be disassembled, degaussed, and returned to the plant. It later was reinstalled and has been in continuous operation for the past five years.

Controlling shaft voltages

By James S. Bothwell, Jim Bothwell Consulting

Batteries not included

Does your turbine-generator run on batteries? Probably not, but an "AC battery" or AC potential exists on the shaft between the generator and brushless exciter of small units, and on the entire brushless exciter shaft of large units. That's why generators and exciters have insulated bearings.

Consider another case history (more can be found in our May [WEB EXCLUSIVE](#)). The AC potential on the bearing pedestal of one 800-MW generator was measured at about 40 V with a handheld multimeter. The setup used a carbon brush taped to the end of a broom handle and a "capture and hold ammeter"; 18 AWG test lead was used to determine the bearing pedestal to ground current on a "touch and read" basis. When the carbon brush contacted the exciter bearing pedestal, there was an instantaneous flow of 150 amps. Leave this test to the pros; the 18 AWG wire served as an excellent fuse, as it promptly vaporized on contact.

As a practical matter, do not perform ground current measurements on brushless exciters. Also, never attempt to ground the shaft between the generator and exciter or the exciter shaft. Maintaining insulation between bearings and case and insulated couplings is the key to avoiding "AC battery" problems.

VFDs: A special case

The downstream bearings and gears of some types of rotating equipment can become pitted, frosted, or spalled even if they are not part of the drive train. In newer variable-frequency-drive (VFD) units that use solid-state controllers to decrease signal switching, electrical spikes on shafts can find their way to ground through the unit's bearings. Motor manufacturers were the first to recognize the phenomenon, and they responded by insulating

both bearings. Manufacturers of gearboxes were next to notice the problem, but it has taken them longer to address it.

In one recent case, vibration increased on the turbine of a turbine-compressor-generator set that had been in operation for less than six months. The set consisted of a steam turbine, an insulated coupling, a gearbox, an insulated coupling, a multistage compressor, and a generator with a brushless exciter. When the turbine shaft began vibrating, the unit was shut down for inspection and repair. The turbine bearings were reported as having been frosted, and they were replaced during the forced outage. When the unit was restarted, plant personnel reported rapid deterioration of its bristle-brush grounding device, which proved unable to keep the shaft voltage near zero. The installation of an auxiliary ground strap reduced the static charge on the shaft to 0.01 volts.

Apparently, the gearbox manufacturer had either installed, or insisted on the retrofitting of, insulated couplings on both the drive and driven side of the gearbox. In this case, the static discharge from the steam turbine due to inadequate grounding made its way to the turbine case through the turbine bearings, and not through the bearings or gears on the gearbox.

Insulated couplings should be considered or installed between any motor driven by a VFD unit and downstream components, as well as between any static charge-producing drive unit and downstream components. That's especially true for any specialty gearboxes or for any equipment that uses roller or ball bearings.

Some end users have installed grounding devices on the shafts of motors driven by VFD units in an attempt to prevent damage to downstream bearings. In each case, the device did not prevent damage to downstream bearings. It is not known if the grounding devices were not functioning correctly, or if any shaft voltage measurements were obtained to verify their performance.

Other mechanisms have been known to produce an increase in shaft voltage or shaft-to-ground current. They include unbalanced electrical circuits in motors or generators (caused by turn-to-turn shorts in the stator), unbalanced magnetic fields in a generator rotor (caused by turn-to-turn shorts in it), and the failures of diodes on brushless exciters or static excitation systems. You'll need to research those on your own.

Staying well-grounded

Although they are in common use, the terms "grounding brushes" and "grounding devices" are actually misnomers. Each has the same purpose: to convey static charge from the turbine shaft to the turbine case and not convey static charge from the shaft to station ground.

There have been cases in which plant personnel installed wires to connect the grounding brush on their steam turbine to the station ground two floors below. They had the best of intentions but the wrong solution. Because arcing or sparking occurs between the rotor and the bearings or seals within the turbine's case, the circuit must run directly from the shaft to the case. The grounding device in contact with the rotor must first make contact with the case. The next step is to provide a connection from this connection point to station ground.

Several types of grounding devices are commercially available. They include:

- Carbon brushes
- Copper-impregnated carbon brushes
- Braided copper straps
- Braided copper straps with spring assists
- Braided copper straps with weights on one end
- Bristle brushes
- Braided welding cables
- Copper ground straps

Each has strengths and weaknesses and a price that ranges from a few dollars to a few thousand dollars. All grounding devices, regardless of the type or manufacturer, require the maintenance and monitoring of shaft voltage to ensure that the rotor and case remain at the same electrical potential. There does not appear to be a single grounding device that works for all equipment or all environments. Personnel at each plant should evaluate and select the grounding device based on the performance of the device at their location. For this reason, a high price is not necessarily an indicator of high performance in your application.

The maintenance requirements for shaft grounding and shaft voltage sensing are likewise site- and application-specific. At one plant, where technicians remove and clean one of the four bristle brushes on one unit every single day for cleaning, shaft voltages remain below 1 volt, as verified by a handheld meter reading. At another plant, technicians began by checking ground straps every week but then backed off to once every two weeks and, later, to once a month and then once every six months. Although they later installed shaft voltage-monitoring equipment that sends signals to the control room, the techs at this plant still routinely check shaft voltages with a handheld device.

I carry ground straps with me when checking shaft voltages on rotating equipment. In most cases, I find elevated shaft voltages, indicating that the existing rotor grounding device is either missing or not functioning correctly. If that is the case, I fabricate a ground strap and bracket and throw it over the shaft. This almost always reduces the shaft voltage to 0.001 volts, buying time to identify the problem and its solution. In every case, the customer leaves my ground straps in place to maintain the shaft voltage at or near 0.01 volts.

Locating grounding devices

The grounding devices on most turbine-generator sets are located on the bearing cover of the turbine closest to the generator. Some units have grounding devices in the governor pedestal. Because the turbine-generator shaft consists of solidly bolted couplings between each of the train components, one, two or more grounding devices can be located at a single point on the turbine shaft from the governor pedestal to the coupling between the turbine and the generator. The same can be said for turbine-compressor sets with solidly bolted couplings. I advise locating the grounding device(s) near the low-pressure turbines on turbine-generator sets and near the turbines on turbine-compressor and turbine-pump sets.

The same situation applies to trains containing gearboxes. In some cases, a turbine that drives a generator through a gearbox has a grounding device that is installed between the gearbox and the generator, or attached to the generator end shield. Any static charge on the turbine shaft must pass across the teeth of gears in the gearbox to get to the grounding device and hence to the turbine case. These arrangements, which were part of the unit's design package,

clearly did not consider the electrical path. Moving the grounding device to the turbine shaft would allow static charge from the turbine shaft to pass to the turbine case without passing across the teeth of the gearbox.

There have been instances where braided ground straps have been used on gears located in the governor pedestal of a turbine-generator unit to remove static charge from the rotor. The static charge passed through the gear teeth to get to the turbine case. The resulting pitting made the gears unusable. To correct the situation, the braided straps had to be moved so they contacted the rotor.

Controlling shaft voltages

By James S. Bothwell, Jim Bothwell Consulting

Taking shaft readings

In the U.S. market, instruments are available to simplify measurement of shaft voltage and shaft-to-case current. All such instruments rely on the contact between a grounding device and the rotor, or the contact between a sensing device and the rotor, for their input. Because all grounding devices and sensing devices currently available require some degree of maintenance, there is always the need to verify readings of an installed instrument by a handheld instrument capable of measuring shaft voltage or shaft-to-ground current.

The key to installing instruments is to first establish a baseline and then choose the setpoint or alarm to trigger upon deviation from that level. Establishing the baseline includes verifying the performance of the grounding device or shaft-sensing device.

The amplitude and frequency of static shaft voltages are too great for most standard handheld multimeters to handle. Such instruments require real RMS output indications. Because they read the average of the signals within the instrument's sampling period, they do not capture the high voltage spikes or peaks of static voltage produced on rotors of rotating equipment. Voltage meters must be able to measure voltage at over 400 Hz. Although the voltages produced by electromagnetic effects inside equipment are only a few volts in amplitude, they are usually at a high frequency that a standard multimeter cannot deal with.

You can use a handheld device to measure the shaft voltages on a piece of rotating equipment, but doing so requires probing the shaft directly. Accordingly, use extreme caution when using a handheld instrument that contacts the shaft.

Shaft voltage case studies

Case study #1: Gas turbine-generator

Florida, 1983 - The site had 24 such units.

Situation: Circulating currents were detected in pods containing four jet engine-expander-generator sets. In each set, two Pratt and Whitney jet engines exhausted into an expander whose squirrel-cage fan was connected to a generator. Arced and welded teeth on the Waldron couplings between the expander and generator had locked the couplings and caused high vibration. Plant personnel had been replacing couplings on a fairly routine basis.

One day, three of the four units in one pod were delivering power to the grid. A clamp-on ammeter installed on the ground cable of the out-of-service generator indicated that there were 50 amperes of current in the ground cable and the unit, which was on turning gear. The current was coming up from the ground grid and passing through the grounding brush, which was mounted on the generator, and through the coupling to the expander.

Solution: All couplings were insulated as soon as possible.

Case study #2: Refinery

Aruba, 2003 - The site had seven small steam-turbine generators, six compressors, and four pumps.

Situation: During scheduled outages, electrical activity was found to have damaged or caused the failure of the thrust bearings of Turbine-generator #4 (TG-4). Magnetic Products and Services (MPS) was called in to survey shaft voltages. Later, the survey was extended to the site's six other turbine-generators, four compressors, and three pumps. During the survey, technicians noticed that the carbon grounding brushes on TG-4 were bouncing on the turbine shaft and creating visible sparks. The measured shaft voltage was approximately 42 V.

Solution: The shaft was cleaned with the unit running at 3,600 rpm. Then, technicians installed a bristle-type grounding brush and a combination voltage/current monitoring (VCM) instrument from MPS. The condition of the shaft caused rapid deterioration of the bristle brush, so the shaft was polished some more and a second bristle brush was installed in the governor pedestal. The shaft voltage was never lowered below about 2 V.

The carbon grounding brushes on the other six turbine-generators were in better condition than those on TG-4. But each unit showed elevated shaft voltages, which suggested that the brushes were not functioning correctly. An inspection revealed that the brushes had been subjected to leaks of steam and oil, which reduced their effectiveness.

MPS developed and installed a grounding strap for use in harsh environments like this one. Later, plant personnel on Aruba fabricated their own grounding straps following installation by MPS. All static electrical activity was eliminated and the unit no longer suffered bearing damage due to electrical activity.

Case study #3: Phosphate plant

Louisiana, 2003 - The site had three turbine-compressor trains.

Situation: The bristle grounding brushes on one of the three turbine-compressor trains had begun to deteriorate rapidly. Their inserts had to be replaced frequently. The wear rates and insert replacement intervals of the three units had been fairly uniform until the compressor drive bearing of one unit failed.

After the bearing was reassembled, the new bristle brush deteriorated just as rapidly as the old one and required frequent insert replacement. Magnetic Products and Services' voltage/current monitoring instrument read about 2 V on the shaft and 0.5 A of current from shaft to ground. The voltage readings on the failed bearing correlated with readings from proximity vibration probes as the shaft moved downward due to wear of its bearing pads. After the compressor shaft was removed, engineers observed static discharge pitting on its journal over about half of its circumference.

No magnetic fields were detected on the removed compressor shaft, and no magnetic fields were detected on the exposed shaft of the operating turbine-compressor unit.

Resolution: Engineers were unable to determine why the bristle brush inserts deteriorated rapidly.

Case study #4: Polychromate plant

Iowa, 2004 - The site had four turbine-compressor trains with one, three, or four bristle-type grounding brushes.

Situation: Plant personnel reported elevated shaft voltages on J-104, which had three grounding brushes. Personnel at a sister plant were asked to check their trains, and they reported similar, but not identical levels. At the polychromate plant, readings on ungrounded shafts were between 14 V and 45 V. Only one turbine-compressor train showed a shaft voltage reading of 2V when its bristle brushes were in contact with the shaft.

Solution: Plant personnel were trained how to measure shaft voltages properly and reminded to take appropriate steps—such as cleaning bristle brushes—any time elevated shaft voltages were detected.

Case study #5: Gas-to-petroleum products plant

Malaysia, 2004 - The site had four turbine-compressor trains, each with a different grounding brush arrangement:

- KT-1405 had two bristle brushes—one for grounding and one for shaft voltage measurements. It also had been retrofit with a VCM instrument for measuring shaft voltage and current to ground.
- KT-1401 had been commissioned with one bristle brush on the nondrive end of the turbine. Later, two sets of carbon grounding brushes were installed on the drive end of the compressor.
- KT-1804 had been commissioned without grounding brushes, and that oversight had caused bearing failures. In 2004 it had been retrofitted with two pairs of carbon grounding brushes on the nondrive end of the turbine, two pairs of carbon brushes on

- the drive end, two plunger-type bristle brushes between the turbine and the compressor, and one vertical bristle brush on the nondrive end of the compressor.
- TG-7601 was commissioned with, and retained, its original braided ground strap.

Situation: The newest unit, KT-1405, had been operating for less than one year when temperatures on its thrust bearing began increasing steadily. The unit's VCM instrument had not been functioning correctly, so engineers ordered and installed a replacement printed circuit board, to no avail. Next, plant personnel bypassed the VCM and grounded both the grounding and shaft-voltage monitoring bristle brushes. This stopped the increases in thrust bearing temperatures of KT-1405.

Over the years, the thrust bearings of KT-1401 and KT-1804 had failed repeatedly. After KT-1405 was shut down and had its thrust bearings removed, they revealed extensive pitting, characteristic of static discharge.

Solution: On KT-1405, the grounding bristle brush was found to have been wired to the VCM instrument, instead of being grounded through a 0.05-ohm shunt. This presented an open circuit to the brush. High shaft voltage had destroyed the PC board in the VCM instrument. The wiring was corrected, the thrust bearings replaced, and the unit restarted. Shaft voltage indicated about 2 V. After technicians installed a 12-gauge wire between the turbine case and the ground point on the turbine skid, the shaft voltage fell to about 1 V. After lifting the lead on the ground brush, it was determined that the open-circuit shaft voltage was about 118 V.

On KT-1401, the voltage on the shaft was found to be 130 V, high enough to warrant immediate attention. Upon inspection, the bristle brush insert was found to have been worn away, and the carbon brushes were not in contact with the shaft. The carbon brushes were cleaned and freed in their holders. The bristle brush got a new insert. Because no replacement carbon brushes were on hand, technicians fabricated a grounding strap from welding cable and installed it.

When technicians removed the ground strap 48 hours later and lifted the lead on the bristle brush, it was clear that the carbon grounding brushes still were not contacting the shaft. Later, plant personnel reported that, although the fabricated ground strap showed wear, deterioration of the bristle brush had ceased. A grounding strap that MPS developed and installed on KT-1401 then became a model for use on the site's other turbine-compressor trains.

On KT-1804, plant personnel determined that both sets of carbon grounding brushes on the nondrive end of the turbine were not contacting the shaft. They also found that the sets of brushes on the turbine's drive end were responsible for about 30 V of the overall, measured 40–60 V on the shaft. Individual bristle brushes were maintaining different voltage levels: 0.01 V at the plunger-type bristle brushes between the turbine and the compressor, 1.191 V at the right-side bristle brush, and 0.445 V at the left-side bristle brush. After the brushes and shaft were cleaned, any one of the carbon or bristle brushes could maintain a shaft voltage of 0.01 V. MPS advised plant personnel to install on the turbine of KT-1804 a ground strap similar to the one installed on KT-1401.

On TG-7601, the measured shaft voltage was 2.5 V. Plant personnel took pictures of the braided grounding strap inside the generator. Based on readings from the hand-held VCM

instrument, engineers determined that the instrument provided a better shaft ground than did the original-equipment braided ground strap.

Plant and company personnel in Malaysia decided that all four turbine-compressor trains needed a more-robust grounding device. Subsequent experiences at other plants suggested that improving existing ground brushes would provide adequate protection for the trains' bearings. New grounding straps of a new material were fabricated and installed.

Case study #6: Refinery

Singapore, 2004 - The site had three turbine-compressor trains and one turbine-generator set.

Situation: Plant personnel had begun to detect elevated shaft voltages on all four units. Plant management wished to reduce or eliminate them, so the plant could continue running until its next scheduled outage the following year.

Solution: On 2CT-300, which was equipped with carbon grounding brushes, the shaft voltage was 2.5 V. With the installation of a new grounding strap, the voltage fell to 0.01 V.

On 2CT-600, which also had two carbon brushes, the shaft voltage was 10 V. Again, the installation of a new grounding strap reduced it to 0.01 V.

On 2CM-450, which lacked a grounding brush, the measured shaft voltage was 0.7 V. Once again, the installation of a new grounding strap reduced the shaft voltage to 0.01 V.

On 2GT-51, the gas turbine-generator, which was equipped with carbon-impregnated grounding brushes, the measured shaft voltage was 17.5 V. The brushes were cleaned and paint was removed from their point of connection to the grounding cable. This lowered the shaft voltage to 1.6 V. With the installation of a new grounding strap, the voltage fell further, to 0.01 V.

The shaft voltage on each of the four units now is transmitted to the control room. The voltage on all four units has remained at 0.01 V since the retrofits. Plant personnel experimented with different materials to prove that the ground straps they fabricated provide the best ground.

Case study #7: Power plant

New Jersey, 2004 - The site had one 10-MW steam turbine-generator.

Situation: The turbine-generator did not include a grounding brush as part of its original design. Although the unit's bearings had no history of damage by static discharge, its collector rings brush assembly had recently failed.

Solution: A new grounding strap and VCM modules were installed on the unit. The strap was placed between the low-pressure turbine sector and the generator and grounded to the turbine case at the point where the plant's ground cable was attached.

Case study #8: Steel mill

East Chicago, 2004 - The site had four turbine-generators and two turbine-driven fan units with a variety of carbon grounding brush configurations.

Situation: During a scheduled outage of Turbine-generator #5, mechanics had replaced its one grounding brush with a copper grounding strap they had fabricated by braiding three welding cable wires. The braided strap, which appeared to have become brittle due to heat from the turbine, failed, creating an open circuit. The loss of shaft grounding caused the failure of both turbine bearings.

Situation: Turbine-generator #5 received a new ground strap, which reduced the shaft voltage to 0.05 V during start-up.

The one carbon grounding brush on Turbine-generator #6 was found to have been installed backward. As a result, the measured shaft voltage was 7.49 V. The correct installation of a new ground strap reduced it to 0.05 V.

Turbine-generator #7, which also had one grounding brush, was out of service for an overhaul. A new ground strap was fabricated and left with plant personnel to install when they reassembled the unit.

The measured shaft voltage on Turbine-blower #3 was 0.61 V, suggesting that its one carbon grounding brush was functioning correctly. No modifications were made.

The measured shaft voltage on Turbine-blower #6, a De Laval unit with two bristle-type grounding brushes, was 11.5 V. Technicians removed one of the brushes, straightened its bristles, and cleaned their ends with a Scotch-Brite pad. This reduced the unit's shaft voltage to 0.05 V. They then did the same to the second bristle brush. After the techs reinstalled it, they lifted the wire on the first brush to verify that the second brush was contributing to a further reduction of shaft voltage, to 0.05 V. A new ground strap was fabricated and left with a supervisor for later installation, if needed.

The fourth turbine-generator, a Siemens unit with one bristle grounding brush, showed a shaft voltage of 1.25 V. When the lead was lifted from the bristle brush, the voltage rose to 20.5 V. Again, a new ground strap was fabricated and left with plant personnel for possible installation later.

Case study #9: Ethylene plant

Illinois, 2004 - The site had two turbine-compressors, one with four bristle brushes and the other with five.

Situation: Both turbine-compressor trains had similar histories: long periods of unvarying shaft voltage levels followed by rapid deterioration of one bristle brush element. After the element was replaced, the new element deteriorated very quickly. More recently, swings in shaft voltage had been detected on one of the units.

The measured shaft voltage on Turbine-compressor #201, the one with four brushes, was about 20 V. Turbine-compressor #501, with five brushes, had approximately 0.5 volts on the shaft.

Solution: As soon as the shaft voltage on Turbine-compressor #201 was detected at 20 V, technicians fabricated a new ground strap and installed it. This reduced the voltage to 0.01 V. The techs also removed one of the unit's four bristle brushes, cleaned its bristles with a pocket knife, and reinstalled it.

But when the new ground strap was lifted later, the shaft voltage rose to 2.5 V, suggesting that the bristle brushes were not in full contact with the shaft. Technicians then removed a second brush, cleaned its bristles as before, and reinstalled it. This lowered the shaft voltage to an acceptable 0.02 V.

The exercise demonstrated that all four bristle brushes had to be cleaned to maintain shaft voltage at or near 0.01 V. The technicians and their supervisor repaired to the plant's office to discuss the situation away from the noise of the turbine. They agreed that the only way to determine the effectiveness of each bristle brush would be to open-circuit the other three brushes, clean the brush being investigated, lift the newly installed ground strap, and then measure the shaft voltage. After confirming that each brush was contributing to maintaining shaft voltage at 0.01 V, the techs open-circuited that brush and moved on to clean the next brush and verify its operation.

Upon returning to the turbine deck about an hour later, the crew noticed that the shaft voltage on Turbine-compressor #201 had increased from 0.02 V to 1.5 V. This suggested that the two cleaned bristle brushes had deteriorated as quickly as before, compromising their ability to ground the shaft contact. Replacing the ground strap on the turbine shaft finally lowered the shaft voltage to 0.01 V.

On Turbine-compressor #501, the unit with five bristle brushes, measured shaft voltage was 0.5 V. Based on their experience with Turbine-compressor #201, the crew suspected that only one of the five brushes on #501 was working to maintain shaft voltage at 0.5 V. They decided that all of the brushes required regular cleaning.

At this plant, technicians now remove and clean one bristle brush of each turbine-compressor each day. Again, two new ground straps were fabricated and left with plant personnel for possible installation later.

Case study #10: Refinery

Pennsylvania, 2004 - The site had one turbine-compressor train that lacked a grounding brush.

Situation: Proximity-type vibration probes were delivering intermittent readings of 6–8 mils to the control room. Operators believed that the vibration was caused by electrostatic discharge, most likely on the inboard (drive end) turbine bearing.

Solution: When the train's shaft voltage was measured at a shockingly high 600 V, technicians were instructed to fabricate a grounding strap and install it, as a temporary

measure, across the shaft. This immediately reduced the voltage to 0.01 V. But when the grounding strap was lifted, the shaft voltage began to rise. Dropping the strap back on the shaft reduced the voltage to 0.01 V.

The retrofit put a stop to the intermittent vibration readings. Supervisors then called for the temporary grounding strap to be replaced by a permanent strap and ordered a VCM instrument from MPS for installation at the next scheduled outage.

During the next scheduled outage, plant personnel reported that the bearings of the turbine-compressor train showed fewer signs of static discharge pitting than before the retrofit.

Case study #11: Ammonia plant

Trinidad, 2005 - The site had one turbine-compressor train with two bristle brushes. One provided a path to ground for current; the other was used for shaft voltage measurement. Both levels were read by a Magnetic Products and Services VCM instrument.

Situation: The turbine-compressor had been in service for less than seven months when the turbine's bearings began experiencing high vibration. The unit was shut down, and after the bearings were replaced the old bearings exhibited pitting typical of static discharge. Once this was noticed, technicians also replaced the insert on the brush used for grounding.

When the unit was restarted, the new insert deteriorated within 10 days. The shaft voltage monitored by the VCM instrument went into alarm, with values above the 10 V setpoint. Supervisors shut down the unit again, this time to evaluate the grounding brush situation.

Solution: During the restart following the bearing replacement, the unit's shaft voltage was measured at 30 V using a hand-held instrument. The immediate fabrication and installation of a new ground strap reduced the voltage to 0.01 V.

Technicians then performed various tests to verify that the suspect bristle brush was not performing as intended. That was indeed the case. The techs then installed a permanent mounting bracket for the ground strap and wired the ground strap in parallel with the brush. This configuration, they hoped, would allow shaft current to flow to ground through both the strap and the brush.

The technicians also improved the connection of the shaft to ground by adding a wire between the skid ground connection point and the turbine case. The ground strap reduced the static buildup and, in turn, the level of static discharge current below the 10-V setpoint.

During the evaluation, a second grounding strap was temporarily installed on the nondrive end of the turbine with the first grounding strap in place on its drive end. Technicians connected the strap on the nondrive end to the shaft-voltage measuring section of the VCM instrument, and the strap on the drive end to the existing shunt to ground. When they lifted the temporary grounding strap, shaft voltage began to rise steadily. When the strap was dropped back onto the shaft, the voltage began falling and bottomed out at 0.01 V.

The procedure was repeated a number of times to ensure that the VCM instrument and the ground straps were working correctly. It also demonstrated to plant personnel the dynamic nature and effects of static discharge on a steam turbine.

Case study #12: Methanol plant

Trinidad, 2005 - The site had one turbine-compressor that was factory-equipped with carbon grounding brushes and a VCM instrument.

Situation: Plant personnel replaced the factory-installed carbon brushes with bristle-type grounding brushes. Later, they also replaced the original VCM instrument, from MPS with a new one because the old one hadn't worked correctly from day one. The personnel complained to the vendor that voltage readings supplied by the original instrument had always been higher than the 10-V setpoint on the plant's data collection system. The new instrument delivered similar readings, which engineers determined must be erroneous because new bristle grounding brushes had been installed.

Solution: The shaft voltage on the turbine-compressor was measured at about 40 V. As you would expect, after technicians fabricated a new ground strap and installed it on the turbine, the shaft voltage fell to 0.01 V. The installation was temporary and used tie-wraps to hold the insulated shunt-mounting device in place.

Following the installation, the VCM instrument's low-current alarm sounded and plant personnel bypassed it in the control room. A permanent ground strap then was installed during a subsequent scheduled outage of the unit.

—**Jim Bothwell** is the principal of Jim Bothwell Consulting. He can be reached at jsbothwell@aol.com.