

Bearing Damage Resulting from Shaft Voltages and Currents

By: David Kowal, Application Development Engineer

© Computational Systems Incorporated, 1999

With or without the existence of a predictive maintenance (PdM) program, premature bearing failure can result in unscheduled downtime and high maintenance costs. Understanding why the bearing is failing is as important, if not more so, than knowing when it will fail. Once you know why, corrective actions can be taken, increasing bearing life.

EDM: One Cause of Premature Bearing Failure

Bearing damage resulting from Electrical Discharge Machining (EDM) isn't new. This fault has been around many years before any PdM programs were in existence. In some cases, this fault has been either overlooked in the haste to get the equipment back into service, or it has been misdiagnosed and mistaken for another problem. Only in the last few years has this fault begun to be recognized as a major cause of premature bearing failure in certain types of electric motors.

What is EDM?

EDM (or fluting, as it is more commonly known) is the passage of electrical current through the bearing. This fault is also known as frosting, electrical pitting, and electric arc damage.

Even though this paper focuses on bearing damage, please note that other critical motor components can also be damaged.

The following two conditions must exist for current to flow: 1) there must be a voltage potential, and 2) there must be a path to ground. Current takes the path with the least resistance, and in most cases, this is through the motor bearings. However, it also is possible for the path to be through the bearings of a connected component, such as a gearbox or a tachometer (see Figures 1, 2, 3, and 4). On motors with a tachometer directly connected, the tachometer bearings typically are damaged first since the smaller bearings offer the path of least resistance to ground.³

The bearing's lubrication plays an important role in determining the path of current flow. The lubrication acts as an insulator allowing the shaft voltage potential to build until it is greater than the breakdown level of the lubricant film or metal-to-metal contact occurs. As the voltage level exceeds the breakdown voltage level or breakdown threshold of the bearing lubrication, the lubrication begins to oxidize. The oxidation of the bearing lubrication results in the breakdown of the lubrication and creates a pipeline or pathway for the shaft current to flow through.

Current flow through the bearing results in a repetitive electrical arcing phenomenon between the bearing components, which causes localized heating to the extent that metal is removed, damaging the bearings.

The threshold or level at which the breakdown of the lubricant begins is not constant. Changes in bearing lubrication, humidity, temperature, and bearing component clearances will change the breakdown threshold. Bearing component clearances change with the roughness of the component surface. For example, the surface of the ball bearings may appear to be smooth when viewed by the naked eye, but magnified, small peaks and valleys can be seen. The thickness of the lubricant oil film at a peak will be less than it would be at a valley.

All electrically-driven machines have some level of AC and/or DC shaft voltages present. Though typically insignificant, excessive shaft voltages become a problem. Once the electrically-induced damage has started, normal bearing degradation takes over, but electrical arcing may continue.⁶

The rate of failure can vary from a few months to a few years depending on the amount of shaft voltage present, the resistance of the bearing, the distance between the bearing ball and raceway, the type of lubrication, and the type of bearing.

There are three sources of shaft voltages and currents: 1) electromagnetic, 2) electrostatic, and 3) external voltages supplied to rotor windings.

Electromagnetic voltages and currents result

from either rotating a residual magnetic source in a magnetic housing (i.e. an eccentric rotor) or asymmetries in unevenly wound electrical windings, turn-to-turn shorts, open or broken rotor bars, and any other fault that would produce an uneven magnetic flux field.^{1,2}

This magnetic source, generated by transformer action⁶, results in a circulating current flow from the motor shaft, through one bearing, through the motor housing, through the opposite end bearing, and back. There are two possible sources of electromagnetic voltages and currents: 1) axial shaft flux, and 2) axial shaft current. Figures 1 and 2 show the paths

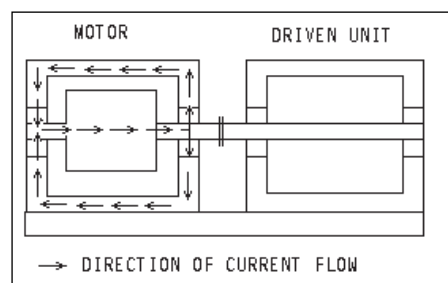


Figure 1. Axial shaft flux flow through motor

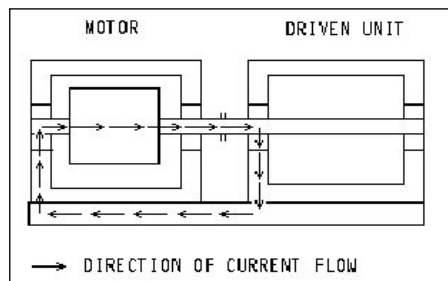


Figure 2. Axial shaft flux flow through driven unit

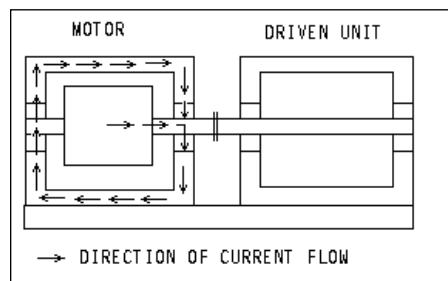


Figure 3. Axial shaft current flow

currents can take in the case of axial shaft flux. Figure 3 shows the path in the case of axial shaft current.

Static buildup from the accumulation of charged ions on a steam turbine, wet gas compressors, belt-driven equipment, and paper

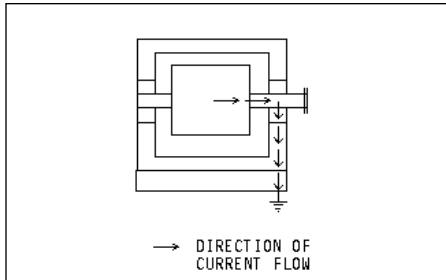


Figure 4. Current flow due to electrostatic source

machine rolls can produce electrostatic voltages and currents. This causes a current flow from the motor shaft through one bearing to ground, as shown in Figure 4.

External voltages are probably the most common reason for fluting and are usually produced by excitation systems of the motor.² This problem is common with variable frequency variable speed drive AC motors that have a high switching frequency³ and DC motors that use Silicon Controlled Rectifiers (SCR), which usually introduce high harmonic distortion into the system. The fundamental design and performance characteristics of the variable speed controllers, as well as excessively long power leads, are primary reasons that cause a current like the one shown in Figure 4. This problem isn't normally seen in constant speed drive AC motors since the supply power is cleaner.

Another external voltage source that could result in bearing damage is welding. If the system isn't grounded properly during welding, additional voltages and currents are introduced, which results in bearing damage.

Visual Identification of Bearing Damage Due to EDM

Visual recognition is one of the key elements in determining whether EDM is the root cause of the bearing failure. Many times this is overlooked or the bearing damage is so severe that the bearing has welded itself together, but the bearing should always be inspected whenever it fails. Even when the bearing is visually inspected, the problem is sometimes misdiagnosed. Damage due to EDM has very distinctive characteristics — frosting, pitting, fluting, and spark tracks.² This damage can occur on the bearing's outer race, inner race, and balls or rollers. It more commonly appears in the

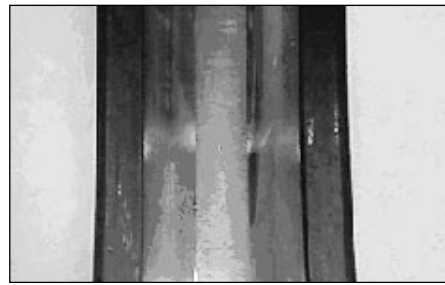


Figure 5. Bearing outer race with frosting

load zone of the outer race, although it does occur on surfaces of all the bearing components.

Frosting has a symmetrically sandblasted or machined appearance. Figure 5 shows a picture of an outer race with frosting. Notice how the center section is shaded differently than on either side of it. When viewed microscopically, the frosted surface is seen as very small individual craters. The bottoms of the craters are round and shiny, indicating melting due to the electrical discharge. Frosting may be mistaken for chemical damage, but its craters are smaller in size and dull in appearance.²

Pitting is similar to frosting, but the craters are fewer, larger, and appear more randomly. Pitting may be mistaken for fretting corrosion.

Fluting, shown in Figure 6, has the appearance

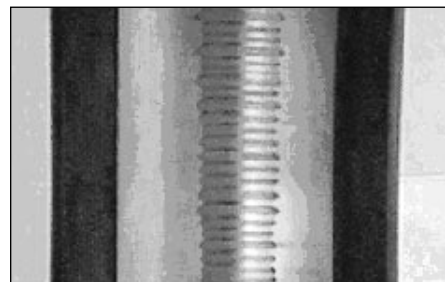


Figure 6. Bearing outer race with fluting

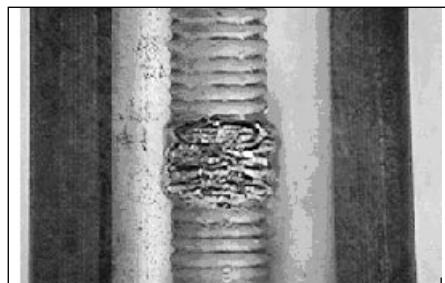


Figure 7. Fluted outer race advancing into spalling

of being machined, thereby making it the easiest to identify as a sign of EDM. The flutes are very narrow and closely spaced.⁹ This is often described as having a washboard appearance. Figure 7 shows a fluted outer race with spalling.

Journal bearings may have spark tracks, which appear as scratches in the bearing surface.

Unlike marks due to particulate or under-lubrication, they are irregular in nature and askew to the direction of rotation. When viewed microscopically, the bottom of the scratch shows indications of melting due to the electrical discharge across it.²

Identification of Fluting Using Vibration Analysis

Bearing damage resulting from shaft voltages and currents (i.e. fluting) can be seen in a high frequency, high resolution vibration spectrum. This type of fault consists of high frequency modulated energy and appears as a mound of energy in the high frequency range between 2000 - 4000 Hz (Figure 8). At this time no reason can be given to explain why it shows up in the vibration spectrum where it does. The location of the mound of energy due to EDM doesn't appear to be related to running speed or any other speed related variable. It has been suggested that the location may be related to the natural frequency of the bearing or encapsulating structure,⁵ but there is no evidence to support this.

The velocity spectrum in Figure 8 was

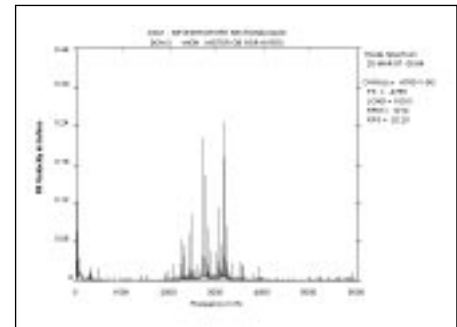


Figure 8. High frequency spectrum showing fluting

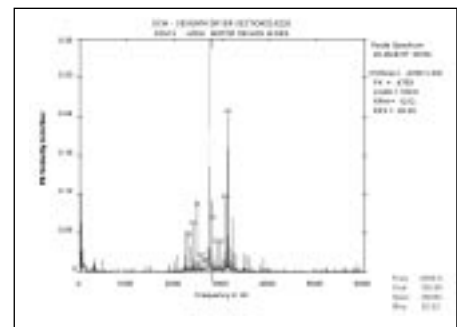


Figure 9. High frequency spectrum showing fluting with BPF0 sidebands

acquired on the outboard bearing of a 400 HP / 500 volt DC motor using a 6000 Hz Fmax and 3200 lines of resolution. Some PdM programs only acquire data out to 2000 Hz or less and miss the high frequency energy resulting from fluted bearings. This mound of energy

will have sidebands of either BPFO, BPFI, or a combination of both. The most common sidebands are BPFO, as in Figure 9.

When setting up an analyzer to acquire a spectrum for this type of problem, it is recommended that you use an Fmax of at least 4000 Hz and a minimum resolution of 800 lines. Acquire data using an accelerometer and mounting techniques appropriate for the high frequency range and take the readings in the horizontal direction of both the inboard and outboard bearings. At one papermill, they acquire one high frequency spectrum in the axial direction only to look for this fault.

As shown in Figures 8 and 9, this type of fault in its early stages doesn't show regular bearing fault frequencies in the lower frequency ranges. As the bearing fault worsens due to normal bearing degradation, the regular bearing fault frequencies will show up in the lower frequency range.

Spectrum analysis can confirm bearing damage from electrical current discharging through the bearing. It cannot be used to predict if the voltage and current levels could potentially result in bearing damage. Vibration can show other electromagnetically-induced phenomenon, such as off magnetic center and SCR control problems that could contribute to the problem.

Signs of Bearing Damage From EDM Using Noise and Temperature Checks

While the machine is in operation and as the vibration levels increase due to fluting, the noise level of the machine during operation can also increase as it would with any bearing fault. In this case the machine's operator, if there is one, becomes an important asset since the operator would probably know more about how the machine should sound during its operation than anyone.

In addition to the noise level, an increase in temperature level can also be an indicator of a bearing problem.

Increased noise and temperature levels only indicate the possibility of a problem; they don't tell you if shaft voltages and currents are present or what kind of bearing damage has occurred.

Depending on lubrication, air flow, load, speed, etc., noise and temperature levels may or may not increase to noticeable levels with the presence of bearing damage due to fluting.

Identification of EDM Using Shaft to Ground Voltage and Current Analysis

An additional analysis technique used to check for the likelihood of damage occurring due to EDM is to measure the actual shaft voltages and currents present on the shaft. This is done by placing a shaft riding brush, wire whisker, or other conductive pickup directly on the rotating shaft and measuring the actual voltage and current levels to ground. Measurements should be made on either the inboard or outboard section of shaft as close to the motor bearing as possible. Making measurements on the other side of a coupling or other connecting device can add additional resistance to the measurements. However, if the electrical source is from the process and not the driver, then this might not be true.

WARNING!!! Extreme caution should be used when placing anything near or against a rotating shaft. Exercise extreme care to keep all body parts, clothing, cables, etc. away from the shaft. It is recommended that before you place anything near or against the rotating shaft that you use a strobe light and look at the shaft surface to check for any possible obstructions or hazards, such as a key or key way.

The shaft should be cleaned with a wire brush before making any direct shaft measurements. Make sure that any locations used for ground connections are clean of paint and rust.

The following voltages and currents need to be measured to properly identify the potential for a fluting problem: 1) AC RMS voltage, 2) DC voltage, 3) peak voltage or voltage spiking, 4) AC RMS current, and 5) DC current. Each of the measurements acquired are a snapshot of what is going on with the system at a certain moment in time.

Each of the AC RMS and DC measurements could be made using an RMS multimeter. While a multimeter can be easy to use and inexpensive, the voltages and currents being measured often aren't sinusoidal in nature. Therefore, a digital oscilloscope is a better device to make these measurements. A digital oscilloscope is required to make the peak volt-



Figure 10. CSI Model 348SP Shaft Voltage/Currents Probe

age reading since limitations in the RMS multimeters can prevent it from correctly reading spike voltages. The disadvantage of using a digital oscilloscope is that it can be difficult to use and relatively expensive.

For most of my field measurements, I used a CSI Model 348SP shaft probe (Figure 10), which is simple to use and can acquire all of the required measurements when used with either a CSI Model 2115, Model 2120, or UltraSpec® 8000 analyzer.

There may be other devices on the market capable of making the required measurements, but I am not aware of them.

A clean wire brush is the recommended means of directly contacting the rotating shaft. The brush material should be resistant to carbon buildup (this eliminates carbon brushes). To make repeatable measurements, replace the brush when worn or it displays carbon buildup. It should also have a very low resistance to provide a good path to ground for current to flow.

Voltage measurements should be made from the shaft to ground (e.g., the motor frame, a bolt head, a threaded rod, or a grounding strap). Make sure the ground connection is free of rust and paint. Record the AC RMS reading, the DC reading, and the peak voltage spiking amplitude.

It is recommended that current measurements be acquired, first by measuring the voltage drop across a one ohm resistor, and then using a second larger resistor (e.g. 10 ohm) placed in series with the brush and ground.¹² Calculate the current for the AC RMS reading and DC reading for both resistor values and record.

Since all motors have some level of voltage and current, the question is, "At what voltage and current level do I have a problem?" A literature search indicates several views on what

RELATIVE SEVERITY GUIDELINES			
Measurement	Amplitudes		
	Low	Questionable	High
RMS or DC Voltage (volts)	<1	1 - 3	>3
RMS or DC Current (mAmps)	TBD	TBD	TBD
Peak V voltage (volts)	<3	3 - 10	>10

Table 1. Amplitude severity guidelines for shaft voltages and currents

voltage and current levels are acceptable. Differences in acquisition methods, equipment, bearing lubrication, bearing clearances, bearing types, running speeds, and humidity could account for these differences.

Until acceptable voltage and current levels are determined, the following general guidelines listed in Table 1 are recommended:

TBD: These values are to be determined once a larger body of field data has been acquired. Experience has thus far shown less than 1 mAmp to be typical in single speed non-synchronous AC motors.

The values listed in Table 1 are judgments made from a general survey of literature and limited field experience. The criteria are as follows:

- Low - Little likelihood of damage sustained.
- Questionable - If levels are measured and the machine has a history of chronic problems that could be related, then corrective action should be considered.
- High - These levels should be considered unusual and that ongoing damage due to EDM between the shaft and ground is probable. On new machines, if either the "Questionable" or "High" range is detected, check with the vendor for safety levels or for warranty assurances against damage related to EDM.

Note: We have seen bearing damage on machines where voltages never measured in excess of the "Low" levels. The levels in Table 1 may be overly conservative.

Look for elevated current levels accompanying voltage for AC RMS and DC voltage measurements. For peak voltage spiking, higher amplitudes are required to cross the dielectric threshold of the lubricant.⁸ Voltage spiking is suspected to be the major cause of fluting bearing damage.

Trending this data can be beneficial. Changes deviating from the mean value more than 3 or more standard deviations should be considered excessive,¹ and the situation investigated to determine why the change occurred. Increases and decreases of this magnitude can indicate the start or worsening of a problem that can introduce shaft voltages and currents in the system. Changes can also indicate failure of a shaft grounding system used to prevent damage from EDM. The higher the levels, the greater the potential for bearing damage due to EDM.⁸ One theory is that after the bearing degrades to a certain point, the voltage level starts to decrease, thus lowering the current level.

It should be noted that the shaft probe current readings will not be the total current flowing through the shaft if there is a second path through one of the bearings. As the bearing lubrication breakdown increases due to the EDM, the bearing's resistance decreases. Current takes the path of least resistance. In theory with a typical lubrication film, the resistance of the bearing should never be less than the 1 ohm resistor circuit. As the bearing resistance decreases, more current should flow through it. Less current should flow through

the resistor circuits; therefore, the acquired current levels will be lower.

A difference between the two different resistor circuit current readings greater than a 10-to-1 ratio (if 1 ohm and 10 ohm resistors are used) should be an indication of either a change in the system, which could result from a change in speed, load, etc., or it could be an indication that bad data was acquired. The difference can also indicate the resistance of the mechanical system is approaching the resistance of the shaft probe circuit. The resistance of the mechanical system could be a current path through one of the bearings.

No matter what the recommended acceptable levels of shaft voltage and current are, the voltage breakdown threshold of the bearing lubricant is the controlling factor. The voltage discharge threshold and lubricant film thickness is affected by mechanical and environment conditions such as misalignment, vibration, temperature, and contamination. When in doubt, check similar machines to see what their levels are as a comparison.

Recommended Data Acquisition Intervals for EDM

Remember, all motors have some level of shaft voltage and current, but not all need to be monitored on a regular basis. The following motors constitute the highest risk group and should be checked:

- Variable frequency variable speed AC and DC motors
- Large frame motors (over 1000 HP)
- Motors with a history of unexplained chronic bearing failure or failure due to EDM
- Newly installed and rebuilt motors placed into service
- Motors with shaft grounding systems installed
- Vertical motors

It is recommended that other motors, not listed above, be checked occasionally to establish baseline levels and for comparison to the data typical of the higher risk units.⁸

Prevention of Bearing Damage Due to EDM

Corrective action should be taken when shaft voltages and currents exist at levels that could result in EDM. For example, elevated levels of AC RMS or DC voltage of 1-to-2 volts and current levels or peak voltages of 1.4 times the RMS reading can indicate induced voltages due to residual magnetism and asymmetries. Peak voltage spiking levels greater than 3-to-10 volts would point to electrostatic or capacitive discharges. Elevated voltage levels from

fundamental line frequency to multiples of the pulse width modulation frequency would show external power supply problems with the variable speed drives. On pulse width modulated drives, decreasing the pulse frequency may decrease the voltage levels.⁸

Sometimes it might not be possible or feasible to correct the source of the problem. In this case either the shaft current can be rerouted to ground by installing a shaft grounding system, or the current flow can be blocked by insulating the bearings and coupling. With problems due to magnetic fields and asymmetries, the non-drive bearing can be insulated. Insulating the bearing consists of surrounding its outer surface with a non-conductive ring or collar, preventing the current flow through the bearing. Problems like this result in a circulatory current flow from the motor shaft, through one bearing, through the motor housing, through the opposite end bearing, and back. Insulating a bearing other than the non-drive end bearing still allows the current flow path to be completed through another bearing, such as one on the driven unit (Figure 2).

In problems due to electrostatic or capacitive discharges and external power supplies, the current flows from the motor shaft, through one bearing, to ground, as shown in Figure 4.

Insulating only one of the bearings would still allow the current to flow through another bearing. In this case install a shaft grounding system or insulate both the drive and non-drive bearings along with installing an insulated coupling. A shaft grounding system consists of connecting a brush directly to the rotating shaft and redirecting the current flow to ground. When using this method, care needs to be taken to ensure that the system is maintained so that it operates correctly.⁷

Ensure that any attached sensors or piping that can complete a path to ground are also insulated.

Case Histories

Case 1: At a papermill with a history of motor bearing failures due to EDM, the PdM group noticed a fluting problem during normal vibration route collection on a 400 HP DC motor. This reel drum motor had operated since 1989 and used to wind the finished paper onto the spool. To monitor for this problem, they acquire axial data with an Fmax of around 3000 Hz.

This motor was monitored closely by the papermill's PdM group until a decision was made to replace it. This papermill, like many others, replaced the entire motor with a spare, sent the bad one out for repair, and when repaired placed it into inventory until needed.

Since other motors on this paper machine had chronic bearing EDM problems, they decided to install a shaft grounding system on this motor when it is replaced.

Regrettably, we lack complete data since the last change out, but the following data was acquired over a nine-month period starting in October 1996. The CSI Model 2120, with a 100 mV/g accelerometer, was used to acquire vibration data, and the CSI UltraSpec 8000 and Model 348SP shaft probe were used to

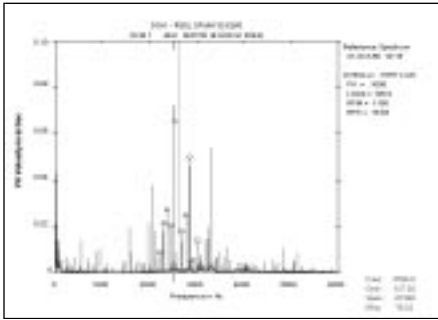


Figure 11. Vibration data acquired 31-OCT-96

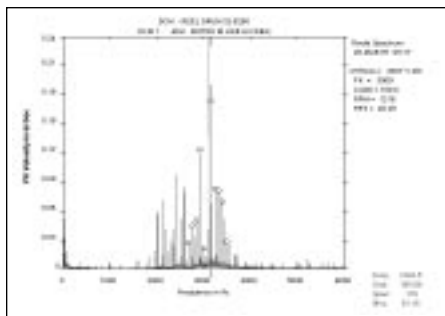


Figure 12. Vibration data acquired 20-MAR-97

acquire the shaft voltage and current data. The motor was run approximately 1200 RPM during all data acquisitions.

Figures 11, 12, and 15 show the mound of energy between 2000 and 4000 Hz with BPFO sidebands, which is characteristic of fluting. Figures 11 and 12 were acquired in the horizontal direction on the inboard bearing. As the problem worsens, Figure 12 shows an

SHAFT AMPS/VOLTS		
Station: (SEP) REEL DRUM		
Machine ID: REEL DRUM		
JOB ID: Reel Drum Date/Time: 31-OCT-96 10:20:46		
PROBE MEASUREMENT	AC	DC
millivolts	391.83	-26.76
Volts Peak	3.20	
milliamps #1	25.02	-.43

Figure 13. Shaft voltage & current data acquired 31-OCT-96

SHAFT AMPS/VOLTS		
Station: (SEP) REEL DRUM		
Machine ID: REEL DRUM		
JOB ID: REEL DRUM Date/Time: 20-MAR-97 09:19:16		
PROBE MEASUREMENT	AC	DC
millivolts	566.14	-38.57
Volts Peak	5.43	
milliamps #1	19.57	-.05

Figure 14. Shaft voltage & current data acquired 20-MAR-97

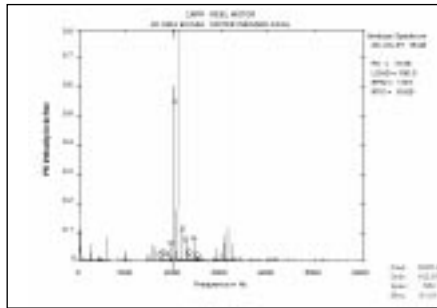


Figure 15. Vibration data acquired 29-JUL-97 (last measurement before shutdown). Notice the amplitude scale is twice that of Figure 12.

SHAFT AMPS/VOLTS		
Station: (SEP) REEL DRUM		
Machine ID: REEL DRUM		
JOB ID: RD ShutDown Date/Time: 31-JUL-97 08:24:25		
PROBE MEASUREMENT	AC	DC
millivolts	432.29	21.62
Volts Peak	2.14	
milliamps #1	21.16	.80

Figure 16. Shaft voltage & current data acquired 29-JUL-97 (last measurement before shutdown)

increase in the vibration level in the upper frequency range since the data was acquired in Figure 11. Also as the problem worsens, Figure 14 shows an increase in the AC RMS voltage and peak voltage levels since the data

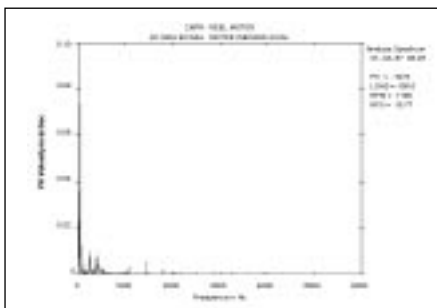


Figure 17. Vibration data acquired 31-JUL-97 (first measurement after shutdown)

SHAFT AMPS/VOLTS		
Station: (SEP) REEL DRUM		
Machine ID: REEL DRUM		
JOB ID: RD ShutDown Date/Time: 31-JUL-97 08:24:25		
PROBE MEASUREMENT	AC	DC
millivolts	53.86	-9.95
Volts Peak	.02	
milliamps #1	13.09	-.84

Figure 18. Shaft voltage & current data acquired 31-JUL-97 (first measurement after shutdown)

was last acquired in Figure 13. Notice how the peak voltage level is greater than 3 volts. As recommended by Table 1, this level indicates a high likelihood of damage due to EDM. Current levels didn't appear to change much.

Figure 15, acquired in the axial direction on the inboard bearing, shows the vibration level of the motor just before it was replaced. Figure 16 shows the shaft voltage and current levels. Note the AC RMS voltage and peak voltage levels have dropped slightly since the last measurement. The current levels still appear to be unchanged.

When the inboard bearing was pulled, the outer race showed signs of fluting in its load zone, and the inner race and balls showed signs of frosting. The motor was replaced with an identical motor with a shaft grounding system. Figure 17 and 18 show the vibration and shaft voltage/current data acquired on it after it was installed. Notice the lower levels. Even though this is a different motor, the vibration data shows no evidence of EDM, and the AC RMS voltage and peak voltage levels have dropped off considerably.

Replacing just the motor only might have solved their problem, but since replacement motors without shaft grounding systems didn't solve EDM problems in the past, installing a shaft grounding system was probably the correct alternative action to take. The replacement motor will continue to be monitored to determine how effective the shaft grounding system is in reducing the damage due to EDM.

Case 2: At a plant that manufactures rubber door and window seals, the PdM group noticed an increase in noise and temperature levels on an 800HP DC motor. Vibration data indicated a bearing problem. Considering the motor's past history they suspected fluting as the cause of the bearing failure. The first failure occurred two weeks after being placed into service. The bearing showed signs of fluting. The ball bearings were replaced with spherical roller bearings. The second failure occurred three weeks after being put back into service.

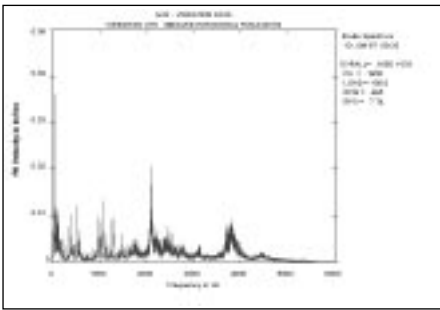


Figure 19. Vibration data acquired while process ran at 457 RPM

SHAFT AMPS/VOLTS		
Station: (DC) GE DC MTR/Mixer (Frame 422)		
Machine ID: DC Mtr/Mix		
JOB ID: 457 RPM Date/Time: 13-JUN-97 10:25:58		
PROBE MEASUREMENT	AC	DC
millivolts	523.70	-41.95
Volts Peak	.95	
milliamps #1	408.08	-5.80

Figure 20. Shaft voltage/current data acquired while process ran at 457 RPM

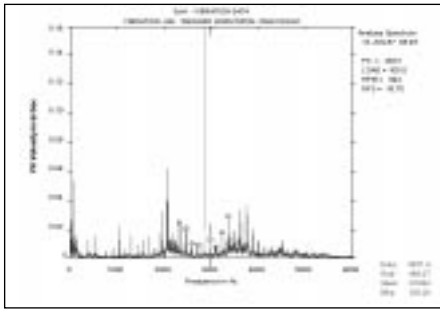


Figure 21. Vibration data acquired while process ran at 944 RPM

The bearings couldn't be examined since they had welded together. After this last failure, spherical roller bearings were put back in, but the outboard bearing was insulated, and the bearing lubrication type was changed.

This plant, like the one mentioned in Case 1, replaces the entire motor with one from spares inventory, repairs the bad motor, and places it into inventory. The replacement motor is identical to the problem motor, but runs about a year before it fails. It doesn't have bearing problems when it fails; it has electrical problems.

SHAFT AMPS/VOLTS		
Station: (DC) GE DC MTR/Mixer (Frame 422)		
Machine ID: DC Mtr/Mix		
JOB ID: 944 RPM Date/Time: 13-JUN-97 10:25:41		
PROBE MEASUREMENT	AC	DC
millivolts	355.85	-44.55
Volts Peak	2.35	
milliamps #1	523.94	-16.81

Figure 22. Shaft voltage/current data acquired while process ran at 944 RPM

The CSI Model 2120, with a 100 mV/g accelerometer, was used to acquire vibration data and the CSI UltraSpec 8000 and Model 348SP shaft probe was used to acquire the shaft voltage and current data. Vibration data was acquired on both the inboard and outboard bearings in the horizontal direction, as the motor ran at 457 RPM. Figure 19, taken on the inboard bearing, doesn't show the mound

of data taken. The vibration data acquired on the inboard bearing, shown in Figure 21, shows the mound of energy in the upper frequency range with BPFO sidebands. The outboard vibration data acquired on the outboard bearing still showed nothing.

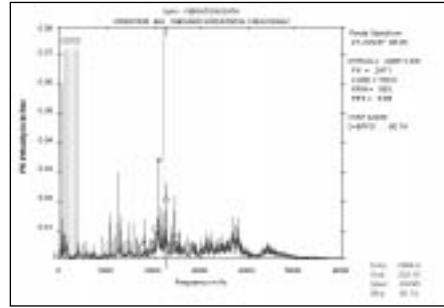


Figure 23. Vibration data acquired on inboard bearing while process ran under no load at 592 RPM

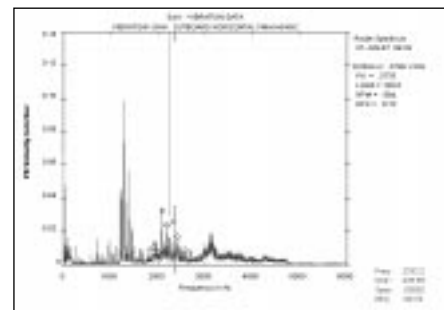


Figure 24. Vibration data acquired on outboard bearing while process ran under no load at 592 RPM

SHAFT AMPS/VOLTS		
Station: (DC) GE DC MTR/Mixer (Frame 422)		
Machine ID: DC Mtr/Mix		
JOB ID: 592 RPM Date/Time: 27-JUN-97 11:32:31		
PROBE MEASUREMENT	AC	DC
millivolts	617.97	-14.12
Volts Peak	.92	
milliamps #1	504.48	-2.25

Figure 25. Shaft voltage/current data acquired while process ran under no load at 592 RPM

of energy characteristic to fluting. The shaft voltage and current data shown in Figure 20 shows low voltage levels and a significantly higher current level than what has typically been seen on other motors, up to this point.

The process speed and load changed after the first set of data was acquired, so a second set

of data was taken. The vibration data acquired on the inboard bearing, shown in Figure 21, shows the mound of energy in the upper frequency range with BPFO sidebands. The outboard vibration data acquired on the outboard bearing still showed nothing.

The shaft voltage and current data shown in Figure 22 shows an increase in the peak voltage level. This reading increased to approximately a "Questionable" level. The current level remained "High".

Concern over the repeatability of the data between the two speed and load processes prompted another set of data to be acquired about two weeks later. This time the motor was run at a speed a little above the first process speed, but had to be run under no load. This time the vibration data acquired on both the inboard and outboard bearings show indications of fluting, as shown in Figures 23 and 24.

Figure 25 shows that the shaft voltage and current readings, except for the peak voltage level, which dropped to below 1.0 volt, remained about the same. An RMS multimeter was used to verify the AC RMS and DC voltage and current readings, and a digital oscilloscope to verify the peak voltage reading.

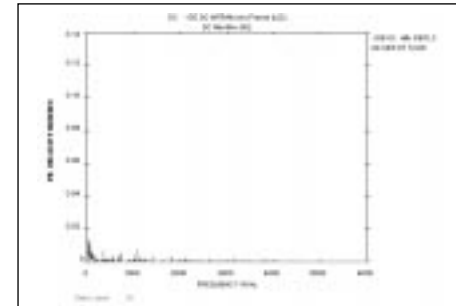


Figure 26. Vibration data after motor replacement

SHAFT AMPS/VOLTS		
Station: (DC) GE DC MTR/Mixer (Frame 422)		
Machine ID: DC Mtr/Mix		
JOB ID: Mtr REPLC Date/Time: 02-SEP-97 12:35:23		
PROBE MEASUREMENT	AC	DC
millivolts	121.95	20.88
Volts Peak	1.53	
milliamps #1	107.76	-34.79

Figure 27. Shaft voltage and current data after motor replacement

ing. All the voltage readings matched, but the AC RMS current reading was 1.0 Amp. This is the highest current reading we have seen on any motor to date. The difference in the AC RMS current readings between the CSI shaft probe and the multimeter was determined to be due to the CSI shaft probe being designed

to read accurately only to 200 mAmps. The electrical circuit maxed out at about 500 mAmps.

Up to this point the following conclusions can be made from the data shown:

- The presence of fluting in the vibration data and the peak voltage level appear to be speed and/or load dependent.
- The RMS and peak voltage levels are less than the "Questionable" levels given in Table 1, indicating that either the voltage levels may have been higher when fluting first began and decreased as the bearing problem worsened (lack of prior data prevent this from being proven), or higher voltage levels may be randomly occurring at different process speeds and/or loads.
- The potential damage due to excessive current levels is very high compared to what has been seen on other motors.

More data will have to be acquired before these conclusions can be confirmed.

This motor was replaced with one that has a shaft grounding system installed on it. Figure 26 shows no EDM present since the mound of energy present in the 2000 - 4000 Hz range doesn't have BPFO or BPF1 sidebands.

Figure 27 shows that the shaft voltage and current levels have been reduced, but the levels aren't as low as I would have hoped to see. I question if the shaft grounding system is working as well as it should be. This motor will be monitored regularly to check the effectiveness of the shaft grounding system.

The operator says this motor sounds a lot better than the one it replaced, and upon visual inspection, both the inboard and outboard bearings showed signs of fluting. Remember, the outboard bearing was insulated; therefore, it either was not insulated properly or something occurred that caused the bearing to become shorted to ground. One possible answer for this motor's problems could be a carbon buildup inside of the motor. Further investigation found that the motor's air intake is next to the plant's carbon dust exhaust and was sucking up carbon dust. They are currently working on a solution for this.

Case 3: This data was acquired in a lab environment on a variable frequency 1/4 HP DC motor running at 1822 RPM to show how installing a shaft grounding system can be effective in reducing the problems or potential problems due to excessive shaft voltage levels. The data in Figure 28 shows the AC RMS voltage readings dropped from 6,439 v to 22 mV, the DC voltage level from 873.25 mV to 4.21 mV, and the peak voltage level from

33.19 v (pk) to 0.01 v (pk). Since this small test motor didn't have any appreciable current levels to begin with, these readings were not affected.

SHAFT VOLTAGE/CURRENT SUMMARY				
Job ID:	DC mVolts	Volts	AC mAmps	DC mAmps
	rms	peak	rms	rms
Job ID: UNGRNDED 26-AUG-97 09:57:54	6439.00	33.19	.30	.01
Job ID: GRNDED 26-AUG-97 10:00:13	22.40	.01	.29	.00

Figure 28. Summary comparison of shaft voltage & current on motor with and without shaft grounding system

Conclusion

Chronic bearing failures due to excessive levels of shaft voltages and currents can increase maintenance and downtime costs unless the problem is correctly identified and the appropriate corrective action is taken. Implementing the following strategy for early detection of problematic machines can help reduce problems due to EDM:

- Test all new and rebuilt motors for potentially damaging levels of shaft to ground voltage or current. Seek early remedy to prevent premature bearing failure.
- Recognize variable speed and large frame electric motors (> 1000 HP) are the higher risk group. Establish a baseline value for shaft to ground voltage and current for these if not all electric motors at your site.
- Learn to recognize signs of fluting damage in vibration and by visual inspection. Take appropriate preventive and corrective action when replacing these bearings to prevent repeat occurrences.
- Monitor those machines with shaft grounding systems on a periodic basis to determine the effectiveness of the shaft ground.

Vibration data can be a good indicator of EDM if it exists, but shaft voltage and current readings are required to identify the actual levels present that are resulting in, or could potentially result in, an EDM problem. With all that is known about bearing damage due to EDM, there is that much more that is not yet known. Understanding bearing damage due to EDM is still relatively immature as it once was for other faults that result in bearing damage. Greater knowledge and understanding of this type of fault is coming, as further studies and regular monitoring of this problem are being done. Until then, consider the recommenda-

tions given by this and other papers, while at the same time gaining a greater understanding of it through routine monitoring and trending.

References

1. Bowers, S.V. and K.R. Piety, "Proactive Motor Monitoring Through Temperature, Shaft Current, and Magnetic Flux Measurements," CSI 1994 Users Conference, Nashville, TN October 10-14, 1994.
2. Costello, Michael J., "Shaft Voltages & Rotating Machinery," Magnetic Products and Services, Inc., Holmdel, NJ, IEEE Paper No. PCIC-91-13, July 1991.
3. EPRI Power Electronics Applications Center, "Preventing Premature Failure of Bearings in Motors Driven by PWM ASDs," PEAC Application Note No. 8, May 1996, Knoxville, TN.
4. Boyanton, Hugh, "Bearing Damage Due To Electric Discharge (ED)," Shaft Grounding Systems, Inc., Albany, Oregon, July 23, 1995.
5. Simoncic, David A., "DC Motor and Control Problem Detection Using Vibration Analysis," pp. 21-21, Technical Associates of Charlotte, Inc., Charlotte, NC, 1994.
6. Walter, Peters, "Preventing Motor Shaft-Current Bearing Failures," pp. 90-93, *Plant Engineering*, October 4, 1990.
7. Skibinski, G.L., "Installation Considerations for IGBT AC Drives," pp. 660-662, *Energy Business & Technology Sourcebook*, November 6-8, 1996.
8. Bowers, Stewart, and Richard Piety, "Shaft Voltages and Currents Application Information," Computational Systems, Inc., August 21, 1997.



*Changing the way
the world performs
maintenance.®*

World Headquarters

835 Innovation Drive
Knoxville, TN 37932
Phone: (865) 675-2110
Fax: (865) 675-3100

Houston Training Facility

15425 North Freeway
Suite 160
Houston, TX 77090
Phone: (281) 873-6000
Fax: (281) 873-6633

San Diego Training Facility

4180 Ruffin Road
Suite 115
San Diego, CA 92123
Phone: (619) 571-8882
Fax: (619) 571-8887

CSI European Headquarters

Interleuvenlaan 64
Research Park Interleuven
B-3001 Leuven
Belgium
Phone: 32-1640-2211
Fax: 32-1640-0457

World Wide Web Site

<http://www.compsys.com>

Reliability-Based Maintenance (RBM) is a comprehensive strategy that is changing the way the world performs maintenance. Through the careful balancing of preventive, proactive and predictive maintenance, RBM can help businesses reduce costs while increasing profit. Serving customers worldwide, CSI integrates multiple technologies into its maintenance systems: vibration analysis, oil analysis, infrared thermography, motor diagnostics, and alignment and balancing.

Through its RBM programs, CSI offers not only the instrumentation and software, but also the support services, training and consulting needed for an easily implemented, profitable maintenance program.

RBM is a trademark of Computational Systems Incorporated. MotorView, Reliability-Based Maintenance, and the CSI logo with changing the way the world performs maintenance are registered trademarks of Computational Systems Incorporated.