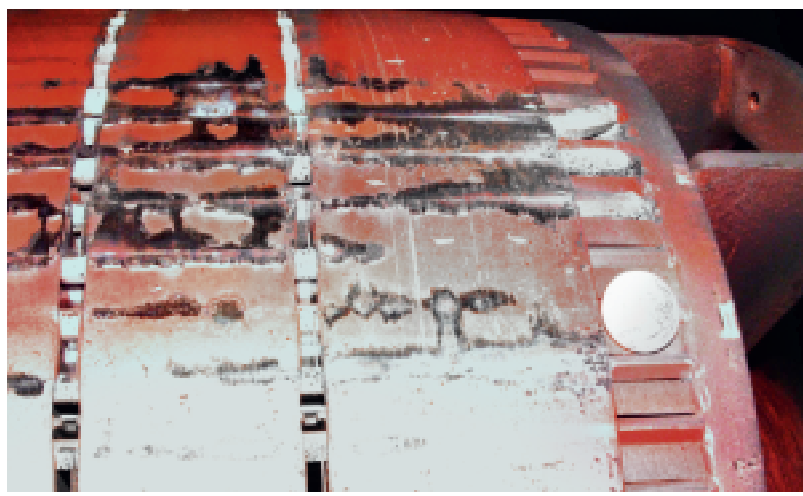
Condition-based monitoring of motors and generators

Prevention of outage major downtime

Sulzer Dowding & Mills uses a range of condition-monitoring methods to assess the status of motors and generators to prevent the customer from major downtime and lost production.

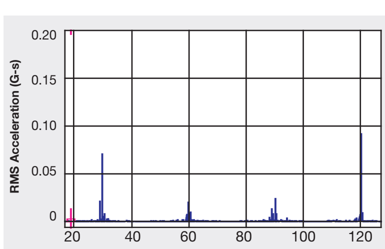


3 Photo of the damaged rotor "called" from the vibration data in figures 1 and 2.

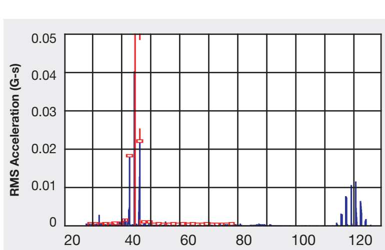
One of the most common root causes of failure of rotating electrical machines is bearing failure; but the failure mode that has the greatest impact, with regards to downtime and lost production, is failure of the stator winding insulation, particularly in high-voltage machines. Premature failure of stator insulation can cause a costly, forced outage. Therefore, prevention of such outages is a major objective. To this end, there has been a lot of effort put toward developing reliable insulation quality assessment techniques.

Sulzer Dowding & Mills uses a range of condition monitoring methods, partial discharge analysis (PD), phase current analysis, insulation resistance (IR), polarization index (PI), tan delta analysis, and, most importantly, close visual inspection to assess the status of the winding insulation and bearing system. Vibration analysis is used to assess the condition of the bearings and rotating parts of the machine, whilst thermographic cameras are used to identify variations in heat that result from bearing problems, bad electrical connections, unbalance in phase loadings, etc.

Parameters routinely monitored—either periodically or online—include vibration, temperature, partial discharge, and, occasionally, shaft voltage. This data together with operating data such as load, running hours, ambient and environmental conditions, system disturbances, etc., are used for condition assessment of the entire machine.



1 Low-frequency high-resolution spectrum showing four rotation speed harmonics.



2 Expanded view of the 1X rotation data.

Analysis of mechanical vibrations

Analysis of the measured mechanical vibration is an excellent method to indicate the current condition of a machine—even where the vibration levels are not necessarily at high levels. They provide an indication of the machine condition because they reflect the dynamic forces acting on the rotating assembly in service, and with good analysis can be used for the early detection of abnormalities and trouble.

High vibration, in addition to causing bearing overheating and, ultimately, bearing failure, can also cause damage to winding insulation systems in rotor and stator. All of these conditions require extensive out-of-service repairs. A modern vibration monitor system provides a database, which, by reviewing vibration trends, is helpful in predicting mechanical problems in rotating machines and estimating future maintenance needs, extending the duration between inspections, and minimizing downtime for maintenance.

Vibration or displacement sensors are mounted on or as close as possible to the bearings at the drive and non-drive ends of the machine. Vibration measurements will be recorded radially—at two points 90° apart at each end—and axially—generally at the drive end. The sensors signals can be reviewed as a waveform or processed using fast Fourier transformations and displayed as a frequency spectrum for detailed analysis. Trend analysis is used to identify change in condition and to predict failure.

Case study Gillette

Vibration analysis was carried out on a four-pole induction motor driving a 48-inch conveyor belt in a surface coalmine preparation plant. Figures 1 and 2 illustrate the correlation of the vibration data to the actual damage on the rotor of a 1000 HP (750 kW) induction motor. The amplitude of the harmonics and amount of side banding at rotor slip frequency are indicators of severity of the problem.

Note: These side bands, with differential frequency of 0.67 Hz from the fundamental, can be used to calculate the rotor slip of this four-pole motor at the rotation speed indicated in the data plot. The height of the side bands, together with an increase of the slip frequency, gives an indication of the severity of damage to the cage rotor winding.

Figure 3 clearly confirms the fault condition identified in the vibration analysis as a failure of the rotor cage winding with several broken rotor bars. Vibration analysis has also been successful at determining bearing defects associated with variable frequency drives (VFDs). VFDs are notorious for causing fluting damage (EDM, electrical discharge machining) in antifriction bearings if the rotor shaft is not grounded properly. These defects have been detected by the reliability groups at several of our customers' plants.

The following example is of a 350 HP (4160 volt) four-pole induction motor driving a conveyor in a surface coal mine prep plant.

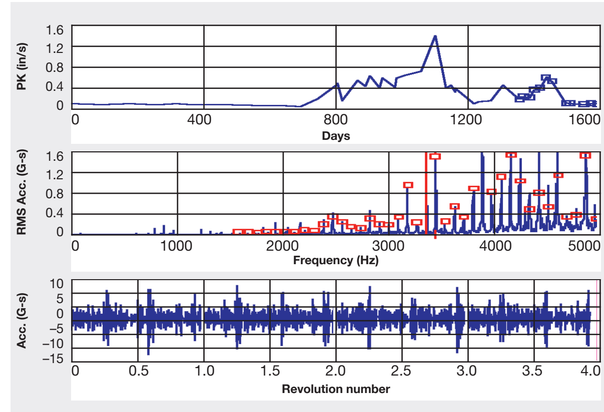
The vibration data in the trend display and high frequency spectrums indicated a defect that had become so significant that corrective action was recommended to the customer 4.

The bearings, which had been removed from the motor, clearly showed evidence of electrical discharge machining 5. They were replaced and a commercially available shaft current diverter ring was installed in the motor to discharge the eddy currents developed on the rotor. These changes should prevent recurrence of this motor failure.

PD analysis and further tests

When high partial discharge (PD) activity is detected during online testing, equipment users usually want to verify the problem by performing a visual inspection and/or doing some off-line testing before taking the machine out of service. The traditional off-line tests are the direct current (DC) insulation resistance (IR), polarization index (PI), and alternating current (AC) tan delta tests (called Tip Up Test in North America), off-line PD test and close visual inspection. All these tests are well understood and have been employed for many years.

The main limitation of off-line insulation tests is the requirement for a machine outage, which, in some cases, may take several days. In addition, during off-line tests, winding insulation is not subjected to operating stresses experienced in service, and, therefore, it does not truly reflect the condition of the insulation system in service. Online testing provides more accurate and more reliable diagnostic information regarding the insulation condition whilst in service. Online PD monitors can detect PD activity, a significant increase of which is an indication of potential insulation degradation; this increase can, over time, lead to insulation failure for large machines above 5000 V.

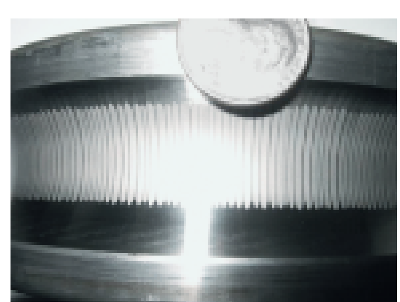


4 Conveyor drive motor trend display, frequency spectrum, and waveform.

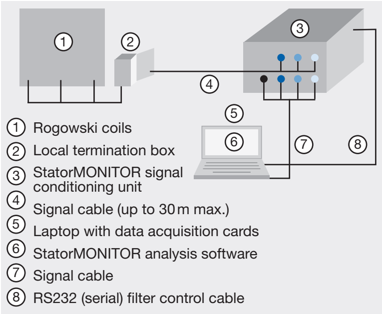
Measurement principle

Partial discharge (PD) activity, in rotating electrical machines, is the physical breakdown of a gas, usually air, within a void, in a gap, or adjacent to solid insulation within an insulation system in the presence of high electrical stress. This discharge can cause chemical and thermal degradation in the materials adjacent to the discharge. As Pd activity continues, highly conductive materials are formed from the epoxy resin binders or other materials. As the carbon atoms contained in the insulating materials become free molecules, they join together and form carbon tracks. If this Pd activity continues, it will cause permanent damage to the insulation system and eventually will cause a complete breakdown or failure of the insulation system.

This breakdown of the gas results in an electrical spark, which generates a high-frequency signal that can be monitored by a variety of methods: though a directly connected capacitor, indirectly using a Rogowski coil, through a radio frequency receiver, by employing an



5 Photo of the bearing damage detected by the vibration data in figure 4.



6 Typical test setup for partial discharge using the StatorMONITOR system.

RTD lead, etc. The StatorMONITOR® online PD measurement system was developed by Sulzer Dowding & Mills to monitor, diagnose, and evaluate the condition of insulating systems used in the stator windings of HV motors and generators. The system is designed to detect insulation problems in their early stages, when remedial action would prove to be most beneficial in terms of the avoidance of unplanned downtime and consequential financial implications.

The StatorMONITOR system developed by Sulzer Dowding & Mills uses Rogowski coils as PD detectors. Data is collected online from the three phases simultaneously, which permits the distinction between discharges activity in the main insulation wall (for each phase), between phases, and in the end-windings. The system quantizes and records the basic discharge parameters associated with each individual PD pulse. These include the discharge pulse magnitude, its polarity, and its phase position relative to the power frequency.

Pattern recognition algorithms are then applied to these basic quantities to identify the type and severity of problems. They also help in the detection of and removals elimination of regular commonly known interference—such as that due to converter equipment or generator excitation systems—which could reduce the accuracy of analysis. The trending facilities of the system allow the identification of potential problems or degradation processes developing within the insulation. The fundamental requirement of the system is to detect discharge activity that may be harmful to the insulation system and its location.

Case study—partial discharge in highvoltage rotating machines

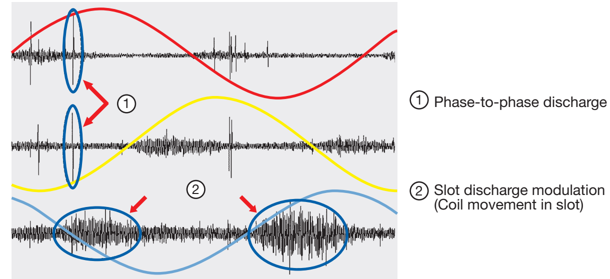
Three identical two-pole machines with the following specifications were tested for partial discharge using the StatorMONITOR system:

- Motor Size: 4 MW
- Voltage: 11 kV
- Duty: Induction motor
- Location: Offshore oil platform

A typical test setup is shown in 6.

Two of the three machines tested on site showed normal low-level discharge activity. However, the discharge levels on one machine were measured at 90 000 picocoulomb (pC) and suggested phase-to-phase discharge sites between the RED and YELLOW phases as shown below in figure 7. There was also evidence of slot discharge modulation normally associated with coil movement in the slot, identified as a distinct modulation of the discharge pattern. This effect was pronounced in the blue phase. Coil movement is most commonly associated with the presence of loose wedges.

It was recommended that this motor be removed from service and overhauled. The spare motor was scheduled to be installed during a planned shutdown three months later. This exchange was delayed a few months and later the motor suffered a winding failure just prior to the shutdown. An investigation of the winding after removal showed that the bracing had become loose, allowing a phase cable to rub and eventually discharge until a failure occurred in between this phase and another in the end-winding.



7 The discharge levels on one of the machines suggested phase-to-phase discharge (RED and YELLOW phases). There was also evidence of slot discharge modulation—most pronounced in the blue phase.

Figure 8 shows the photograph of the white powdery deposits in the end-winding as a result of discharge activity. Further investigation showed that there were approximately 10% of the wedges loose—also possibly due to the bracing problem.

Conclusions

Online condition monitoring using vibration analysis and partial discharge can detect failure mechanisms within a machine before catastrophic failures or unplanned outages occur. Engineers are able to take remedial action to keep the machine in serviceable condition and thus extend the life of the machine.

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8 White deposits in the end-windings as a result of discharge activity.