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Benefits of continuous data acquisition from critical large drive systems in a mine operation

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Introduction

Operational safety, optimized plant availability (system reliability) and energy efficiency are basic requirements to remain competitive in the current mining market. Rotary electrical machines (motors) alone or in combination with mechanical gear such as speed reducers (gearboxes), couplings, brakes and rigging must run trouble-free 24/7. This applies everywhere: at the pit of a mine or underground,

along the coarse ore transportation, bulk material handling yard or at the ore processing facility for grinding, pumping or material segregation. However in this paper we will focus on the reliability of drive trains for grinding.

With power sizes commonly exceeding thousands of kilowatts (>1340 hp) Squirrel Cage Induction Motors (SCIM) and Synchronous Motors (SM) are frequently used as part of large Variable Speed Drive trains (VSD), mostly in combination with power electronic devices in the form of Variable Frequency Converters (VFC), to enable process speed regulation either a) to maintain good product quality / process effectiveness, b) to adjust the throughput in an efficient manner or c) to mitigate collateral effects to other users (as soft starters). Wound Rotor (slip ring) Induction Motors (WRIM) can also be used; adding diversity to the installed equipment population and consequently requiring additional specific know-how, capital spares and skilled labor for maintenance, service and troubleshooting in order to minimize downtimes and keep operating expenses under control.

Grinding and Drive Train Diversity

High Pressure Grinding Rolls (HPGR) have been used for many years in comminution circuits [1], with each roll nowadays reaching power ratings of up to 5700 kW (7,640 hp). A HPGR uses gearboxes to operate at a very low speed (rpm) and electrical powered Variable Speed Drives to maintain optimal performance and to equalize roll wear. A complete HPGR drive train nowadays consists of:

Medium Voltage Isolation Transformers
Variable Frequency Converters
Squirrel Cage Induction Motors
Couplings with articulated shaft extensions
Gearboxes (speed reducers)

The challenges for HPGRs include the dynamic behavior of the power network (voltage fluctuations) and the movable roll (ore hardness and its size variations) which can lead to collateral effects in the moving parts with large inertia such as coupling and gear reducers. Figure 1 shows a drive train of a 2x 5700 kW (~15,000 hp) power rating.

Figure 1: Typical mechanical Drive Train of a large HPGR, powered up by two squirrel cage induction motors with variable frequency converters

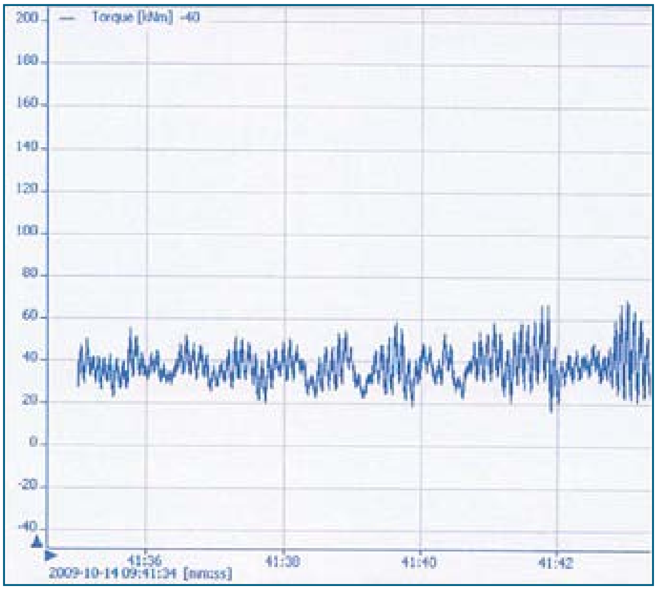

Figure 2: Torque fluctuations are of irregular magnitude and shape in normal HPGR operation.

By scaling the power rage up to the megawatt range we start to work with Autogenous (AG), Semi- Autogenous (SAG) and Ball mills. Traditionally moved through a girth gear either with single or dual pinion, there are several variable speed drive trains alternatives in the market:

a) using gearboxes attached to high speed Squirrel Cage (SC) motors with VFCs or Wound Rotor Induction Motors (WRIM) using slip energy Recovery (SER) devices, with a typical motor shaft rated speed of 750 rpm up to 1200 rpm, depending on the electrical network (50 Hz or 60 Hz) and
b) the simplified direct drive type; a more energy efficient solution either with Low Speed Synchronous Motors (LSSM) and most recently the highly reliable Low Speed Induction Motors [2].

Figure 3 shows a ball mill with a dual pinion drive 2x 6500 kW with low speed induction motors (LSIM). The dual pinion drives demand tight tolerances in the torque between the two motors [2] to dynamically equalize the load on both pinions so that, in the long run, their duration is secured and the system availability guaranteed.

Figure 3: Dual pinion ball mill with 6500 kW Low Speed Squirrel Cage Induction motors using VFC

For larger applications the well-proven Gearless Mill Drive (GMD) technology has shown to be very effective since its introduction in mining in 1980; currently in operation for horizontal mills up to 40 feet (~12.2m) diameter with power ratings up to 28 MW, GMD offers the best solution in terms of energy efficiency and availability [3].

The GMD performance may offer the highest availability [4] but there are still auxiliary parts subject to wear and tear such as motors for blowers and pumps and dust filters which require attention.

Even the primary components like the associated Cyclo-Converter or the motor itself may, from time to time, need expert factory support to diagnose or troubleshoot in particular situations. Figure 4 shows four GMDs installed at high elevation, the two 28 MW SAG mills are beyond the capabilities of other drive technologies.

Figure 4: Two SAG Mills 24MW each and Two Ball Mills 16.4 MW each with Gearless Mill Drives

The question with respect to all these technologies is how do we best maintain operation of the mills and maximize the lifetime of the equipment used and when do we require additional external or "expert" support. This may differ for each component in the drive train:

- Large gearboxes (speed reducers) have specific needs like lubrication, cooling and vibration analysis as well as components subject to wear and tear which must be replaced in the midterm. However when is the best time to replace these with minimum production impact?
- Girth gear vibrations and deflections due to natural mill deformations causing asymmetrical forces [5]. How accurately can we anticipate the
- Effects of repetitive oscillations / mechanical
- Stresses in the long term?
- Variable Frequency Converters are typically very reliable after the commissioning phase is properly completed. There are however exceptions due to transitory effects (like switching capacitor banks or lightning discharges), unexpected changes in the electrical network or incorrect operation [6]. How do we identify if a transitory effect is causing continuous production disruption?
- Diverse motor technologies range from simple squirrel cage motors through wound rotor motors all the way up to the most complex synchronous motors either with brushed or brushless type excitation including wrap around motors for GMDs. Can every mine operator rely on having just a few motor experts and how often is in-depth know-how really needed?

In general, the level of support needed depends on the tools available to monitor and diagnose the equipment as well as the level of competence of the operators and maintenance staff responsible for the equipment.

Data Acquisition

Sensors and instrumentation as shown for instance in Figure 5; so-called field devices, such as resistance temperature detectors (RTD), accelerometers, barometers or even torque measuring devices are typically specified as part of large mechanical equipment but can also be added at site to existing equipment, if required. These devices deliver the signals required to monitor, protect and sometimes control the applications.

For the VFCs in particular the use of digital technology is indispensable. It enables precise acquisition of both internal and external electrical drive parameters like voltages, currents, frequencies, power, etc. with resolutions in the order of a few milliseconds.

There are multiple options in the market for the digitalization of analog data, resulting in continuous and precise measurement of sensor and signals including speed, torque, vibration, temperature and pressure. Continuous data acquisition and storage and, in many instances, the transfer of measured data, analyzed data and alarm messages from a plant to a remote service center via secure data communication is becoming a common practice for mine operators.

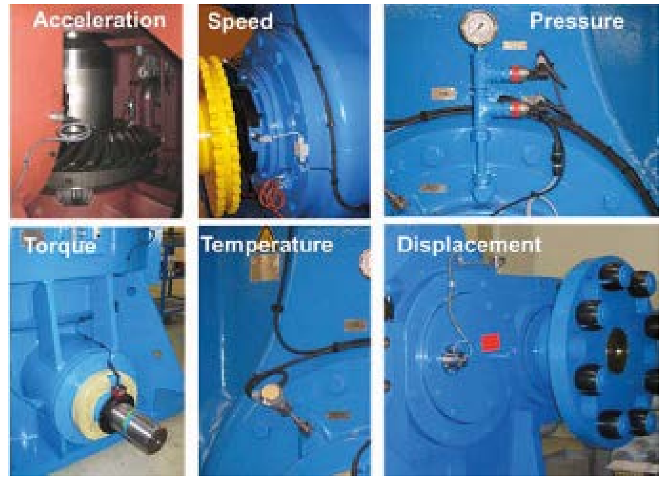

Figure 5: Examples of sensors installed in a large gearbox unit for a grinding mill

Transforming Data into Information

The key is how to use the data available for predictive maintenance purposes; for an accurate prognosis (early detection) of events, i.e. to identify and eliminate or mitigate any potential problem before it actually causes an unscheduled shutdown. Continuous condition monitoring with real time analysis of the status of the operations, vibration and torque measurements, or even noise tracking are typical examples of predictive measures used in modern mining applications. The use of state-of-the-art condition monitoring together with routine inspections by the maintenance staff or operator are all important condition monitoring techniques making use of the senses: look, listen, touch and smell.

There are three simple steps to follow with condition monitoring:

1) set up alarm limits based on manufacturer or standard recommendations
2) correlate the fault symptoms and
3) derive solutions based on the fault diagnosis by certified experts.

Case Studies

Case 1) a condition monitoring system was installed in a 2500 kW gear reducer for a ball mill. After a number of years of smooth operation an abnormal increase in vibration was automatically detected by the system.

Fault symptoms indicated a significant increase of bearing play, causing gear meshing problems.

After cautious analysis of the operating parameters, experts found that the problem was caused by water content in the oil.

Once the oil was changed, the vibration did not increase any further. The mill has been in operation one year since the lubrication problem was detected at an early stage **Case 2)** asset analytics system installed to overlook two (2) GMDs of 38 feet (~11.6 m) diameter SAG mill drives; in a remote location, recording simultaneously data of relevant electrical and mechanical parameters with focus on the wraparound gearless mill motor (synchronous machines), its VFC (Cyclo-Converter), isolation transformers and their collateral and services (stator – rotor airgap, cooling media, ambient / electrical room temperatures, etc.).

Figure 6: 2500 kW multi stage gear unit for a ball mill in a silver mine

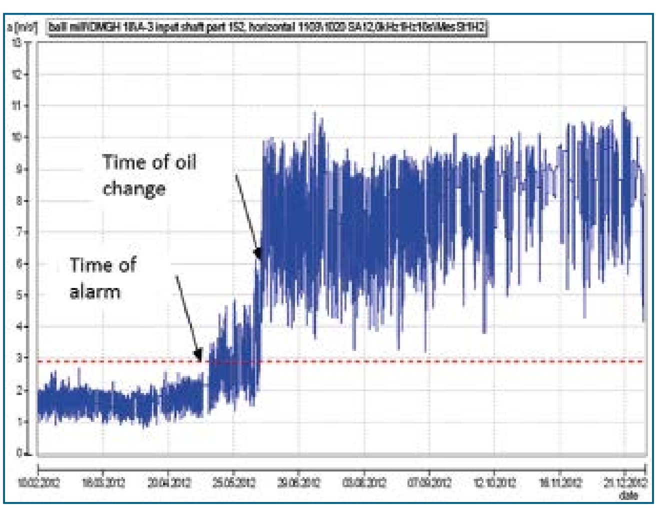

Figure 8: Vibration increase triggered after water filtered into the lubrication system; an oil change avoided further deterioration and earlier failure

This data is the basis of offline analysis:

1. aside of the traditional trend forecasting for early recognition of asset condition changes;
2. it also contrast the actual operating conditions with
   a) the engineering design parameters;
   b) vs. historical data to establish a graphical representation or "finger print"; the collection of fingerprints and measurements. The BIG DATA is transformed into information, via continuous streaming, pre-analyzing and structuring, into SMART DATA = graphic trends (path depending on load and surrounding conditions). With this information on hand the thermal utilization of the GMD is found; which particularly depends on an effective cooling system, the difference between measured and theoretical values also gives an accurate indication of the motor cooling condition.

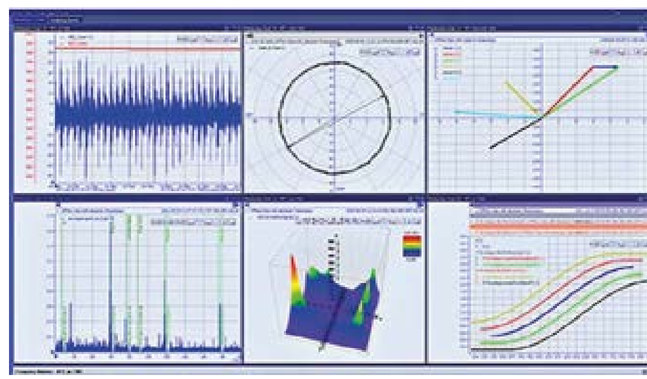

Figure 8: GMD screenshot and fast speed interface nodes for vibration and analog temperature recording

Measurements are considered as valid and different datasets are collected when the operation point (speed and power) is stable during a pre-defined period. Not only potential issues with the GMD motor cooling system are detected in advance and the predictive maintenance action is proactively planned for the

next scheduled shutdown; but also data acquisition helped to identify the real thermal reserve, potential for a future power increase in the electrical power of the entire GMD drive system to gain additional plant throughput.

Conclusions

Data retrieved from the field devices with the appropriate accuracy can be transformed into valuable information. If sufficient know-how is not available on site to analyze the data, the use of on- line expert advice can result in the prompt implementation of risk mitigation measures. This can maximize the remaining useful life of the worn/damaged mechanical gear under the careful eye of remote service experts. Early problem detection means that repair activities can be better harmonized with production plans, resulting in increased plant availability and a consequential reduction in repair and maintenance costs. Although the main focus of data acquisition for a condition monitoring system is to minimize machine failures and increase the availability of the monitored asset, it also opens an opportunity window to maximize plant throughput under certain operating conditions.

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Notice

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