REMOTE DIAGNOSTIC SERVICES FOR GEARLESS MILL DRIVES

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ABSTRACT

Gearless mill drives (GMDs) are the workhorse in the mineral processing industries, more specifically when it comes to grinding crushed ore and cement (in various production stages) in semi-autogenous (SAG) mills and large ball mills. They are renowned for their excellent reliability and robustness, long lifespan, and little need for maintenance, and thus yield a low total cost of ownership (TCO).

A GMD represents a major investment for a mineral processing plant, and its availability is pivotal for the grinding process. As a basic rule, shut-down periods are to be minimized, but even much more important is that unscheduled shut-downs be avoided.

In this contribution, we will present a portfolio of innovative remote diagnostic that consist of the following three key components:

1. Trouble shooting is a form of corrective maintenance and is based on state-of-the art remote access technology, thus enabling highly skilled engineers to access the current sensor readings anytime and from anywhere in order to resolve urgent problems together with the GMD user.
2. Periodic maintenance reports are a form of preventive and predictive maintenance and aim at continuous improvement based on long-term historical records and analyses of multiple measured signals. These detailed reports highlight the health and operational status of the GMD and are periodically (e.g. 3 months) submitted to the customer.
3. Remote condition monitoring spans across preventive and predictive maintenance and is based on continuous recording and automatic analyses of relevant signals using advanced algorithms. The main issue is how to handle the enormous flood of data in an intelligent manner. The results of these analyses are made available to both the GMD user and supplier in real time in order to increase the availability and reliability of the GMD.

In this paper, we consider various parts of the GMD, e.g. the cycloconverter, the ring motor, the auxiliary devices (e.g. cooling and lubrication systems), and also phenomena related to the mill itself (e.g. state and quantity of charge). The signal analysis techniques range from simple threshold-based analyses to complex time and frequency domain analyses. We will illustrate the benefits of the proposed approaches with some selected examples.

KEYWORDS

gearless mill drive, service, maintenance, remote diagnostics, monitoring

INTRODUCTION

Efficient and reliable operation of the grinding process in the mining and cement industries is paramount nowadays given the increasing industrial production and scarce resources. In the face of the soaring demand and high commodity prices, overall equipment effectiveness (OEE) plays a significant role in the financial performance of a mine, which can easily be overlooked in the age of energy efficiency.

The gearless mill drive (GMD) can be considered the workhorse for specific grinding processes found in the mineral processing industries. Therefore, it is of particular importance to ensure that its operation is

- as rarely interrupted by unplanned downtime as possible, and
- as close to optimal operating conditions as possible.

In this contribution, it will be shown how remote diagnostic services (RDS) for GMDs contribute towards achieving the two abovementioned goals.

The structure of this paper is as follows:

- The rest of the *introduction* will give more information about gearless mill drives, their features and advantages, and their application areas, followed by an introduction into the concept of OEE and an explanation of different types of maintenance.

- The following section will explain in detail the overall structure of the *service portfolio* (the so-called temple of service) and show how remote diagnostic services are embedded.

- Afterwards, the *technology* on which remote diagnostic services are based will be presented, more specifically the two ABB products Remote Access Platform (RAP) and DriveMonitor (DM).

- The section on the actual *remote diagnostic services* offered constitutes the main part of this paper and will shed some light on the three offerings troubleshooting, periodic maintenance, and condition monitoring.

- The *conclusion* will give a brief summary of the elements of this contribution and also indicate perspectives for future developments and extensions of the portfolio of remote diagnostic services and services for GMDs in general.

Gearless mill drives

As was mentioned above, a gearless mill drive constitutes both an important part, but also one of the most critical elements of a concentrator or a cement plant. Their purpose is to ensure the continuous rotation of specific types of tumbling mills, more specifically autogenous grinding (AG) mills, semi-autogenous grinding (SAG) mills, or ball mills.

The most important components of a GMD are the following ones:

- The *stator* is a massive electro-mechanical structure built around the grinding mill, hence its alternative names “wrap-around motor” and “ring motor” (see Figure 1). Its purpose is to generate a magnetic field in the air gap turning exactly with the desired speed of rotation of the mill. The electrical three-phase winding of the stator is supported by the stator frame. Depending on the size of the mill, the stator can be of the foot-mounted (medium-sized mills) or the pedestal-mounted type (large mills), measure up to 20 m in height, and easily weigh several hundreds of tons.

- The *rotor* consists of a large number of rotor poles (on the order of 60 to 80) mounted on the mill flange which specifically exists for this purpose. Therefore, the mill itself is the rotor, and no additional power train (e.g. gearbox, shaft, or coupling) is required. Rotor and stator together form a synchronous motor whose concept and structure is quite similar to hydro-generators.

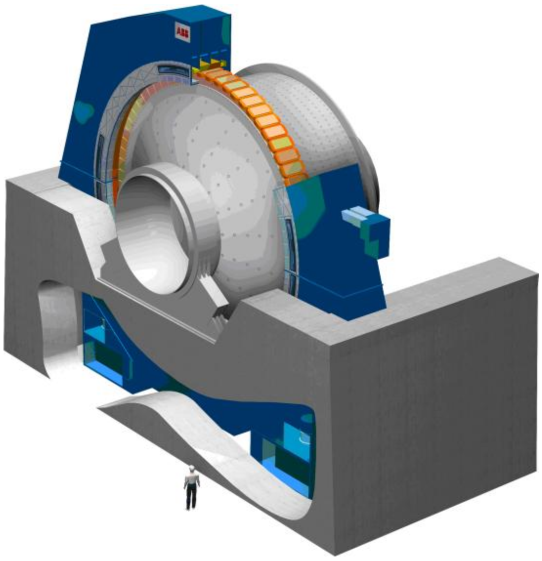


Figure 1 – A ring motor

- The *cyclo-converter*, combined with one *transformer* per phase on the grid side, has the purpose of converting the grid voltage (50 or 60 Hz) to a suitable (variable in both amplitude and frequency) three-phase supply voltage with which the stator winding is fed in order to generate the abovementioned rotating magnetic field. Its basic components are banks of thyristors. Cyclo-converters exist in three different versions (6-pulse, 12-pulse, and 18-pulse version) with increasing performance and declining interference (i.e. harmonics) with the grid.

- The *excitation converter*, which has an excitation transformer on the grid side, ensures that the rotor poles are feed with the appropriate direct (DC) excitation current and voltage.

- A set of *auxiliary devices*, e.g. cooling and ventilation system for the stator and the cyclo-converter, as well as the braking system for the mill, ensure important auxiliary functions required for a smooth operation of the mill and the GMD.

- Finally, intelligent *control, protection, and visualization* functions are paramount to the operation of a GMD. These functions can be found in the power-electronics controller (PEC) of the cyclo-converter, the programmable-logic controller (PLC) coordinating mostly the auxiliary functions, and various personal computers (PCs) such as the human-machine interface (HMI) PC or the Transient Recorder (TR) PC.

The rotor, the stator, and most of the auxiliary devices are located close to the mill, while the cyclo-converter, the excitation converter, the control, protection, and visualization functions, and the relays controlling the auxiliary devices, are situated in the so-called E-House, an air-conditioned and dustproof container. For more details about the components of a GMD and about the way it functions, the interested reader is referred to Errath (2006).

The alternatives to GMDs, depending on the mill size, speed, and power rating, are conventional ring-geared mills with one or two pinions driven by sets of medium-voltage converters and motors. Usually, additional gear boxes are required in order to benefit from the optimum speed range of the drive and converter.

There are multiple advantages that GMDs offer over ring-geared mills:

- The most significant benefit is the increased efficiency which is approximately 95 % compared to 92 to 93 % for a ring-geared mill drive. The main reason is the lack of gears and gear boxes.

- The absence of gears (and therefore the absence of contact between stator and rotor and resulting problems, e.g. backlash) leads to a lower complexity that may translate into a reduced failure rate and thus to an increased reliability. Furthermore, the amount and the intensiveness of maintenance required tends to be lower. Both contribute to a higher availability of the mill.

- GMDs are quite robust concerning the way they can be operated. Their variable-speed converter allows for specific service modes such as inching, creeping, and controlled roll-back, thus superseding additional motors for such cases. Furthermore, the synchronous motor offers full torque even at low speed.

- GMDs typically have a long lifespan. As a matter of fact, the first GMD installation in a cement plant in France dates back to 1969 and is still in operation today (albeit with some revamps).

- Although the capital expenditure for GMDs is higher compared to ring-geared mill drives, the total cost of ownership (TCO) is still lower because of the abovementioned factors (i.e. efficiency, availability, and lifespan).

More details about the features and advantages of GMDs can be found in Ahrens & Gonser (2007) and in Ravani & Bomvisinho (2010). As of today, the installed base of ABB GMDs, including some units that are being commissioned and will enter service soon, is approximately 100 units.

A GMD is a singular investment for a concentrator or a cement plant in the sense that the whole operation depends on its proper functioning. Typically, a mining company exploits the economies of scale by using one large mill instead of two smaller ones, resulting in a significantly higher efficiency.

The downside of this approach is that there is no redundancy whatsoever, i.e. an unplanned stop of the only mill leads to a complete loss of production during this period. Also, the possibility of stocking of intermediate products (e.g. crushed or ground ore) is not an option or at least quite limited in most cases (for instance, the flotation process requires freshly ground ore in order to work properly). The implications of these facts on the insurability of GMDs are manifold and can be read in Bos et al. (2011).

Overall equipment effectiveness

It is worthwhile to highlight the generic concept of overall equipment effectiveness (OEE) in the context of remote diagnostic services.

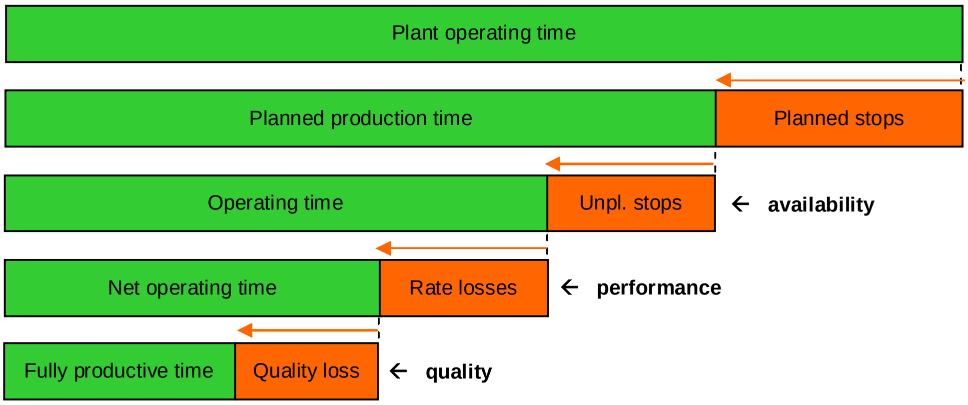


Figure 2 – Availability, performance, and quality

OEE is a composite key performance indicator made up of the following three basic indicators whose meaning can be inferred more easily from Figure 2:

- *Availability* is the ratio between the operating time and the planned production time of a plant or equipment. The difference between the two is the sum of the duration of all unplanned stops, hence the more frequent and the longer the unplanned stops are, the lower the availability.
- *Performance* is the ratio between the net operating time and the operating time. The difference between the two is called “rate losses”, referring to a time-based equivalent of a deteriorated production rate. Therefore, the more frequently, the longer, and the more severely the plant or equipment is operated away from optimal conditions (e.g. its speed and power rating), the lower the performance is.
- *Quality* is the ratio between fully productive time and net operating time. The difference between the two is called “quality loss”. This time-based indicator summarizes the periods during which poor-quality product was produced.

When calculating the abovementioned metrics, it may be important to consider the concentrator as a whole. For instance, an unplanned mill shutdown will obviously affect availability, but it may as well have an adverse effect on performance and quality. To be more precise, when the mill is started again, it may not be possible to run it at full speed right away (thus leading to a reduced performance), and it may also temporarily cause off-spec concentrate production in the downstream flotation process (thus leading to a reduced quality).

Despite the remarks made above, quality will not be considered further in this paper because it is hard to grasp let alone to measure.

As a matter of fact, OEE can be determined from the abovementioned indicators by expressing them in relative terms, e.g. as a percentage between 0 and 100 %, and by subsequently calculating their product:

$$\text{OEE} = \text{availability} \cdot \text{performance} \cdot \text{quality} \tag{1}$$

More details about OEE can be found in Productivity Press Development Team (1999).

Some additional statements about availability seem appropriate at this point. Availability is a composite key performance indicator itself because it depends on two metrics, the *mean time between* *failures* (MTBF) and the *mean time to recovery* (or mean time to repair, MTTR), where both are measured in units of time (e.g. days). Also, both are statistical quantities, referring only to the expected value and not to the actual duration, and typically have to be determined from previous experience.

MTBF is a measure of reliability and is directly linked to the failure rate λ (measured in the number of failures per unit of time, e.g. failures per day) of an equipment:

$$\text{MTBF} = 1/\lambda \qquad (2)$$

In the case of equipment composed of different units with different failure rates, MTBF can be systematically determined using a block diagram and some basic formulae depending on the type of dependency between the units.

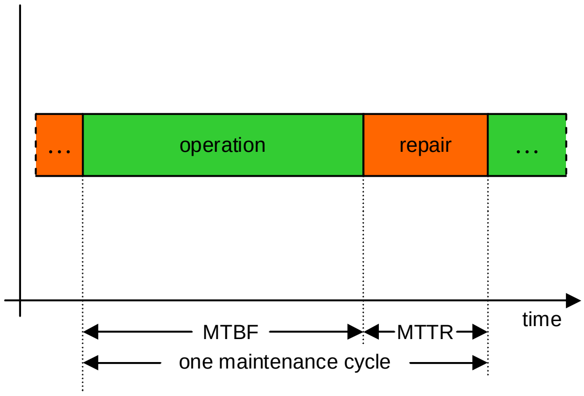


Figure 3 – Availability and how it is determined by both MTBF and MTTR

MTTR is the time that is statistically required in order to recover the functionality of equipment subsequent to a failure and therefore is a metric of “maintainability”. MTTR includes the actual time to perform the reparation, but also other delays such as the lead time for ordering spare parts, travelling time, and so forth.

Figure 3 shows how both MTBF and MTTR determine availability at the same time. It can be easily seen that one “maintenance cycle” (the statistical average is considered) is composed of the time period during which the equipment operates properly (MTBF) and the time period required for reparation (MTTR). Availability is now defined as follows:

$$\text{Availability} = \text{MTBF} / (\text{ MTBF} + \text{MTTR}) \qquad (3a)$$

If it can be assumed that the MTTR is small compared to the MTBF (which should be the typical case in practice), in other words MTTR << MTBF, Equation (3a) simplifies as follows:

$$\text{Availability} = 1 - \text{MTTR} / \text{MTBF} \qquad (3b)$$

Equation (3b) shows more clearly how availability is influenced by the MTBF and the MTTR. An increase of the MTBF will leader to a higher availability, while an increase in the MTTR will lead to a lower availability, which is no surprising result.

The particular importance of OEE (and the underlying basic indicators for that matter) is the close link to the cost of lost (or off-spec) production. For instance, an unplanned stop, a rate loss, a quality loss, or generally a reduction of OEE equivalent to a single production hour can easily translate into several millions of US dollars, depending of course on the size of the mine and the specific value of the mineral.

Maintenance

Maintenance refers to the process of restoring or preserving the ability of equipment to function properly. Three different types of maintenance actions can be distinguished (although their definitions may vary among different authors, and there exist complementary definitions such as condition-based maintenance as well):

- *Corrective maintenance* means to restore the state of functionality of equipment subsequent to a failure, which is the case shown in Figure 4. Typically, the failure appears by surprise, and therefore prerequisites for the required maintenance action (e.g. availability of spare parts) may not be fulfilled, the circumstances are often not optimal (e.g. failures during week-ends), and the activities are often more expensive compared to activities prepared long in advance (e.g. express shipping of spare parts or flights on short notice). Also, corrective maintenance can be quite costly in terms of OEE because the repair time is typically longer.

- *Preventive maintenance* refers to preserving the state of functionality of equipment without any existing failure or downtime. Preventive maintenance is typically performed based on a maintenance schedule (scheduled or periodic maintenance) that specifies at which point in time (either calendar-based or operating time-based) specific maintenance actions should be performed. The advantage of preventive maintenance is that these actions can in most cases be aligned with a planned downtime period, and therefore do not incur additional losses in terms of OEE.

- *Predictive maintenance* is the process of preserving the state of functionality of equipment without any existing failure or downtime by determining its current condition (condition-based maintenance) and deciding based on this condition whether (and which) maintenance actions are required. As for preventive maintenance, predictive maintenance activities can often be aligned with planned downtime periods. The downside of predictive maintenance is the high effort linked to determining the equipment condition.

Maintenance actions can operate on different levers in order to maximize OEE. The most significant lever is to increase availability. However, problems related to performance (rate losses) and quality (quality losses) may also be addressed by maintenance actions.

Unfortunately, the most common approach to maintenance of GMDs in practice is still corrective maintenance. The reason for this is that in a lot of cases, the need for and the value of maintenance only becomes apparent as soon as the equipment ceases functioning. The benefits of (well-chosen and well-performed) preventive and predictive maintenance actions often go unnoticed because their most important purpose is to avoid downtime.

SERVICE PORTFOLIO

During the last couple of years, ABB in general and the ABB Business Unit Minerals in particular, have made significant investments in terms of money, time, and other resources, in order to improve and enhance their service portfolio and thus the value offered to customers in the mining and cement industries.

In the following, the service portfolio offered by ABB for GMDs (“temple of service”) will be detailed first. Then, the remote services will be briefly listed, and their embedding in the overall portfolio will be shown.

The temple of service

While several services for GMDs have been existing for many years now, a service portfolio in the strict sense, together with a dedicated service organization, has been gradually put into place over the last couple of years and first presented to the public in Koponen (2009). The graphical analogy of a temple was chosen in order to highlight some fundamental facts about the service portfolio. Figure 4 shows the temple of service.

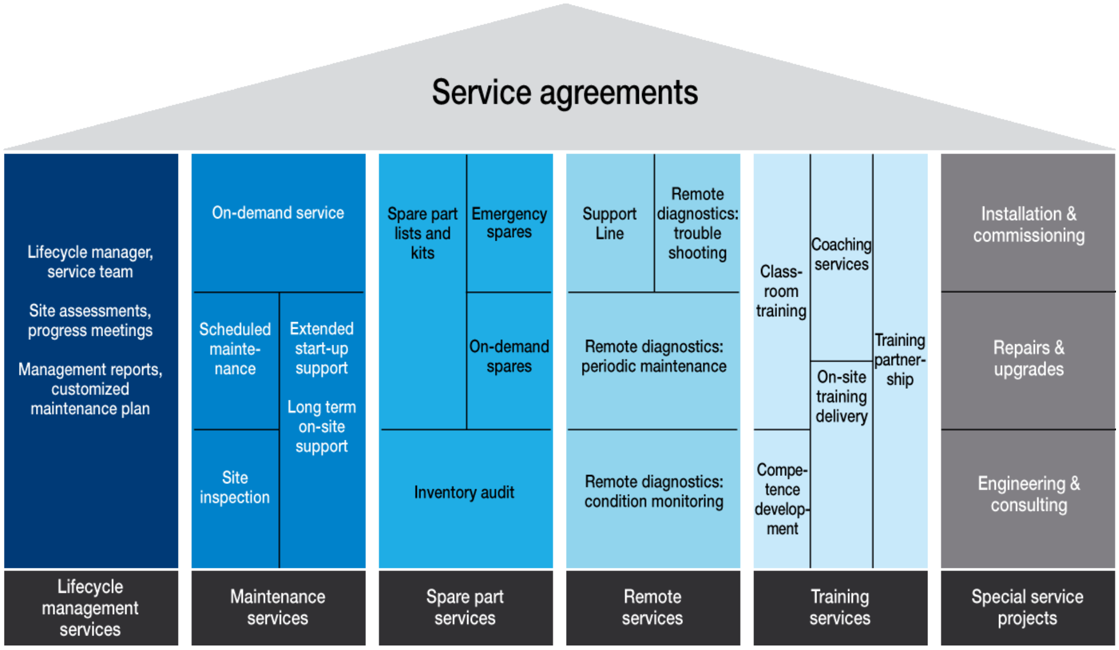


Figure 4 – The temple of service

The service portfolio consists of six different pillars which, as a whole, constitute a comprehensive set of services offered for GMDs and which complement each other. Each pillar comprises multiple services of varying ABB and customer involvement. Generally, the more basic services are at the top, while the advanced services can be found at the bottom of each pillar. The pillars are as follows:

- *Lifecycle management services* address the need for comprehensive services that cover the whole lifecycle of a GMD, i.e. service offerings customized to the position of the GMD in its lifecycle. They comprise site assessments, progress meetings, management reports, and customized maintenance plans. The team and the activities within lifecycle services for a specific site are coordinated by a lifecycle manager who acts as a single point of contact for the customer.

- *Maintenance services* cover all on-site activities such as on-demand service, scheduled maintenance, site inspections, extended start-up support or long-term on-site support. The need for these activities may arise from a maintenance plan (see pillar lifecycle management services), from remote diagnostic services (see pillar remote services), or from a customer demand.

- *Spare part services* refer to all spare-part related service activities like spare part lists and kits, emergency spares, and on-demand spares, but also to more extensive offerings such as spare part inventory audits. As for maintenance services, spare part services may be triggered by maintenance plans, by remote diagnostic services, or by a customer demand.

- *Remote services* comprise the telephone support line, but also more advanced remote diagnostic services such as troubleshooting, periodic maintenance, and condition monitoring. They will be explained in more detail in a dedicated section.

- *Training services* complement the other services by offering customer training of different types and (ABB and customer) involvement. The training services offered are class-room training in an ABB location, coaching services, competence development, and on-site training delivery. Furthermore, comprehensive training partnerships can be agreed on.

- *Special service projects* refer to one-time projects of varying extent, for example installation and commissioning, repairs and upgrades, and engineering and consulting. The interested reader is referred to Ahrens (2008) for more details.

An important point is the existence of service agreements which are jointly defined between the customer and ABB and which form the roof of the temple of service. Service agreements are individual for each customer and are therefore capable of addressing specific customer needs. Furthermore, they are important in order to coordinate services from different pillars.

TECHNOLOGY

This section has the purpose of providing more details about the two technologies whose existence is crucial for remote diagnostic services, Remote Access Platform and DriveMonitor.

Remote Access Platform

Remote Access Platform (RAP) is an ABB product that was developed in order to provide a powerful, secure, reliable, and comprehensive toolset for remote internet access while keeping complexity, in particular related to access authorization, set-up, and maintenance, low. RAP is based on remote access technology from NextNine (www.nextnine.com) and was tailored to the specific requirements that ABB has in the area of remote service for various industries.

RAP is a fairly recent product – it was launched officially in 2009, but its installed base is growing rapidly and is already approximately 400 installations as of today in a wide range of industries, e.g. oil and gas, pulp and paper, metals, and minerals. The first RAP installation for GMDs was commissioned end of 2009, and there are currently 10 installations in this area, with 20 monitored GMDs.

As will become clearer in the rest of this contribution, RAP represents a lot more than a mere remote desktop connection and is an enabling technology for all of the abovementioned remote diagnostic services in the sense that it provides a very powerful toolset that can cope with a variety of different requirements related to remote access.

To be more specific, the main features of RAP will be described in the following:

- *User interface:* RAP comes with a web-based graphical user interface that provides all the required means for interaction, e.g. browsing, searching, and visualization functions. A paramount aspect of the user interface is the streamlined access authorization, in other words only a single set of credentials is required, and a single log-in procedure gives access to the whole set of remote sites connected via RAP that the specific users has user privileges for. Also, management of these user privileges is straightforward, transparent, and offers much freedom in order to grant or deny specific access rights. This user interface supersedes management of credentials, dongles, and token generators needed for different remote sites using traditional virtual private network (VPN) connections. In addition, remote access is not restricted to ABB staff, but can be granted to customer staff and third-party staff as well.

- *Security:* RAP has a strong security concept that complies with international standards, e.g. ISO/IEC 27001. As a matter of fact, the only network requirement at the remote site is an outbound https connection (port 443, worldwide acceptable standard for encryption – transport layer security/secure sockets layer (SSL)) to two predefined IP addresses. These addresses correspond to secure ABB servers that manage all the traffic and connection requests. The remote connection is initiated from the remote site, i.e. RAP regularly polls the ABB servers for pending remote connection requests, and no remote activities can be triggered from outside the local network. As mentioned above, RAP is strict in ensuring that only authorized users are granted access. Furthermore, it is possible for the customer to control remote access sessions, i.e. granting or denying connection requests.

- *Audit trail:* RAP keeps track of all remote activities, e.g. file transfers and remote desktop sessions, allowing the customer to keep an eye on these activities. This audit trail can be browsed in a straightforward manner in the user interface. Figure 5 shows an extract of an audit trail as seen in the RAP user interface.

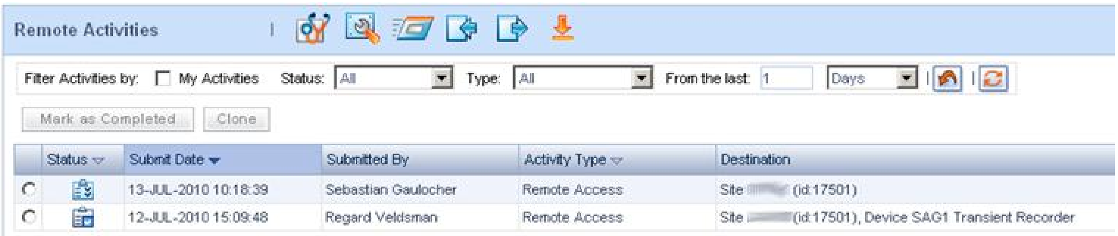


Figure 5 – Audit trail of remote activities in the RAP user interface

- *Notifications and alarms:* RAP offers the possibility to set up notifications and alarms. More specifically, RAP sends the two types of messages in the form of e-mails or short messages (short message service, SMS) as soon as predefined conditions are met. Figure 6 shows some messages that were triggered based on the remaining free disk space on a number of monitored computers.

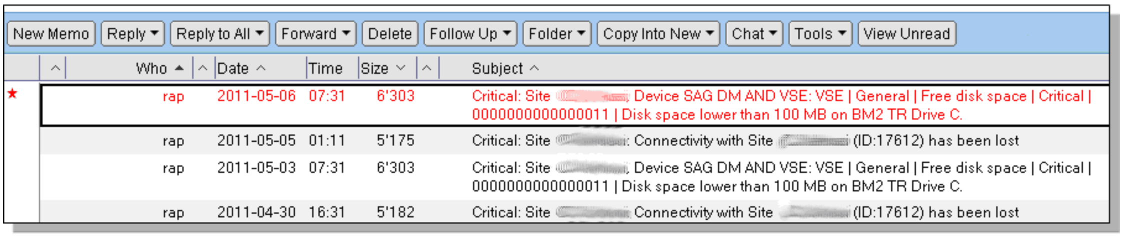


Figure 6 – E-mail notifications send by RAP

- *Monitoring of connection status:* RAP continuously monitors the status of the remote connection. For instance, RAP will automatically notify the user in case of an outage of the computer network on site, a computer shutdown, a restart of RAP, or of similar events.

- *Remote desktop sharing:* This functionality is probably the most frequently used one. Remote desktop sharing refers to establishing a connection either via the Remote Desktop Protocol (RDP) or via the Virtual Network Connection (VNC) protocol. Several users, e.g. ABB experts and experts from the customer head office, can connect simultaneously and perform activities on the same screen. Also, remote desktop sessions can be recorded in the form of a video file for the purpose of audit, later reference, and training.

- *File transfer:* The importance of this functionality is often underestimated when it comes to remote connections. File transfer refers to the possibility of manually transferring files to the remote site or downloading files from it. Also, it is straightforward to set up automatic file transfers to or from site. The data generated on the various computers in GMD installations (e.g. transient recordings or logged data) is considerable, and automatic file transfers are a very efficient means of transferring this data in order to save it in a database. Furthermore, they allow the automatic distribution of software and patches, e.g. regular Microsoft Windows and antivirus software updates.

- *Task automation:* RAP comes with a functionality called Virtual Support Engineer (VSE) that is based on the Perl scripting language. The VSE allows automation of a multitude of remote tasks and therefore significantly reduces the need for manual interventions. The VSE is also a key component in generating alarms and notifications.

- *Product line:* Although RAP can be configured completely individually in order to account for the specifics of each GMD installation, RAP comes with a feature called product line. A product line is a set of functionalities that is predefined for a specific installation. For instance, there exists a product line specifically for GMDs that comprises all the analysis rules, alarms, notifications, and other important definitions important for remote diagnostic services for GMDs.

- *Remote web browsing:* A functionality different from remote desktop sharing, but of high importance as well, is remote web browsing. This feature refers to accessing a predefined (but possibly dynamic) web site that can be hosted on the computer on which RAP is installed. Such a remote web site can be used in order to store information relevant to executing remote diagnostic services, e.g. computer passwords, nameplate data of the GMD, and the like. Also, a complete web site with a status page, results of analyses, and with graphical displays, e.g. important trends of measured signals, can be put into place.

- *Multiple devices:* Each RAP installation represents a main access node on a remote site. In most practical cases, several computers and other devices (e.g. PLCs) are subject to the abovementioned remote access requirements. To this end, RAP offers the possibility to register multiple devices as local nodes. After a basic set-up involving installation of VNC and FTP servers on each device, these devices can be accessed as simply as the main access node. There exist different RAP license types that cover different maximum numbers of devices and a different scope of remote functionality.

- *Installation:* The installation of RAP is straightforward and takes approximately 15 minutes, provided that the abovementioned network requirements have been fulfilled (firewall configuration) prior to the installation. Very little configuration steps have to be done, and the information required for the installation, e.g. proxy server address, are clearly specified by ABB. RAP has modest requirements in terms of computer hardware and can be installed on any Microsoft Windows-based PC.

Later in this paper, it will be shown how different of the abovementioned functions are being used by the various remote diagnostic services.

DriveMonitor

DriveMonitor is the second important technological component upon which the abovementioned remote diagnostic services are based. It is an award-winning (Frost & Sullivan Best Practices Award 2008, see Frost & Sullivan (2008)) diagnostic intelligent system. The first DriveMonitor ever was commissioned in early 2007, with almost 300 installations today, mostly related to medium-voltage variable-speed drives (e.g. ABB ACS 6000) in different industries, e.g. mining, cement, metals, oil and gas, and marine.

DriveMonitor has first been installed on a GMD near the end of 2010, and approximately 10 units are currently in operation or being installed. The third generation of DriveMonitor, DriveMonitor 3000, is currently in use. Figure 7 shows a DriveMonitor 3000.

Figure 7 – DriveMonitor 3000

DriveMonitor is basically a Microsoft Windows-based industrial PC that is very well adapted to the rugged environment that is found in most mining operations. It has a very small footprint in terms of dimensions and weight and can be mounted on a Deutsches Institut für Normung (DIN) rail. DriveMonitor comes with a solid-state hard disk and the common interfaces, e.g. various universal serial bus (USB) sockets, a personal system/2 (PS/2) socket and a digital visual interface (DVI) socket. Furthermore, DriveMonitor has two Ethernet sockets that can be associated to two distinct internet protocol (IP) address ranges and an ABB distributed drive communication system (DDCS) socket in order to enable it to communicate with medium-voltage drive control boards. Electrical power must be provided on a standard 24 V socket which can be found in any GMD E-House, but a 110 V or 230 V power supply can also be provided if necessary. In the case of a temporary loss of electrical power, DriveMonitor restarts itself automatically.

On a software level, DriveMonitor borrows most its functionality from the well-established ABB 800xA automation system found in multiple industries, enhanced with a powerful database (Microsoft SQL (structured query language) Server). Furthermore, every DriveMonitor comes with a preconfigured installation of RAP and therefore is fully remote-enabled. Its main purpose is to provide a powerful and streamlined platform for the following tasks:

- Real-time collection of signals and data from different sources
- Consolidation and long-term storage of the input data in a database (historian)
- Processing of the input data using intelligent algorithms and computation of key indicators about the monitored system
- Visualization of the input data as well as the results
- Transmission of notifications and alarms

More details about DriveMonitor can be found in Kosiba et al. (2009) and Wnek at al. (2006).

REMOTE DIAGNOSTIC SERVICES

In this section, the abovementioned remote services (fourth column from the left in Figure 4) will be briefly described in order for the reader to get an overview over the concept of remote services. Figure 8 shows the pillar of remote services, along with an association to the previously mentioned types of maintenance (corrective, preventive, and predictive maintenance).

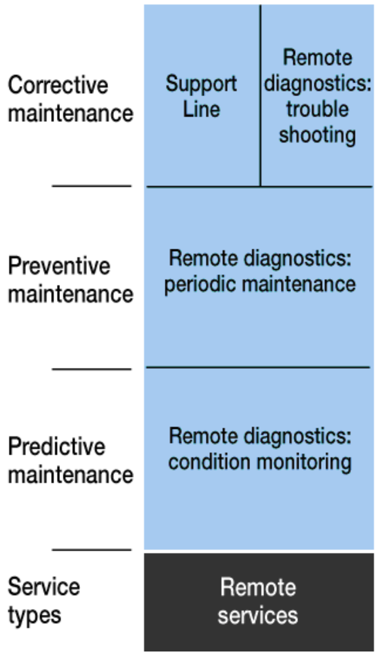


Figure 8 – Remote services and their association to different maintenance types

Support Line

Support line is a remote service that consists in offering telephone support to the customer in case of urgent problems and therefore clearly belongs to the category of corrective maintenance (as introduced above). Assistance can also be given by e-mail or fax if necessary. This service has been in place for many years without requiring advanced technology. Nevertheless, it represents value for the customer because it helps settling certain types of problems swiftly by providing easy, fast priority access to ABB's extensive worldwide support network.

Typically, the support line is resorted to in cases where an equipment malfunction leads to downtime, and therefore a prompt reaction is required, i.e. emergency cases. The main purpose is to assist the customer to maintain the ongoing production and performance of the equipment at a constant and high level. For this reason, the support line for GMDs (but also for other types of ABB equipment) is available around the clock, i.e. 365 days per year and 24 hours per day, in the form of a call center. The telephone operators are capable of communicating in most of the common languages, not only German and English.

Also, the support line process is clearly defined, and all support line cases are tracked using a case tracking system in order to ensure proper and swift follow-up. One specific support engineer is charged with the complete responsibility for a case and triggers appropriate measures in order to resolve the problem. Using a documented problem escalation process, the responsible person can rapidly involve ABB experts of different fields on the whole planet and from different disciplines and business units, depending on the precise problem to be solved. Furthermore, this service as well as its organizational set-up provide a guarantee that support line cases are addressed within a specified response time and also ensure that the process does not get locked on the way (e.g. due to unclear responsibilities). In order to match individual customer needs, customized levels of support can be given.

Remote Diagnostics: Troubleshooting

Trouble shooting is quite distinct from the support line in the sense that it is based on a remote computer connection (RAP) that constitutes an enabling technology for this service.

Trouble shooting is gaining more and more importance given the ever increasing complexity (and performance) of the abovementioned control, protection, and visualization functions found in a GMD installation and the required software, computers, and network equipment. In most cases, solving problems occurring on these components does not require physical presence, but only availability of the computer inputs and outputs (e.g. displays, keyboards, etc.) that a person physically present on site would have. In other words, “a picture is worth a thousand words”. Therefore, trouble shooting reduces the frequency of costly travels and enables ABB experts to focus on a specific problem in their area of specialization in real time, i.e. without losing time for side tasks such as traveling, travel preparation, etc.

Similarly to the support line, trouble shooting can be associated to the methods of corrective maintenance, subject to a guaranteed response time. The decisive advantage of solving control, protection, and visualization-related problems remotely is a considerable gain of time until the problem is resolved and therefore a drastic reduction of unplanned downtime of the GMD as well as maintenance cost. Trouble shooting is available 365 days a year and 24 hours a day. Since trouble shooting often turns out to be a cooperative problem solving process between ABB and the customer, it may represent a significant learning experience for customer staff.

The technological foundation for trouble shooting is Remote Access Platform (RAP), providing a standardized solution across the entire installed base. Trouble shooting strongly relies on the features of RAP such as the secure and encrypted connection, the audit trail, recording of remote connections, alarms and notifications, and minimal configuration requirements. The fact that RAP monitors the connectivity status continuously and sends alarms in case of problems ensures that the remote connection is for sure available when required.

Upon customer request, automated security and antivirus updates can be provided along with trouble shooting for all local devices connected to RAP. Also, despite the strong RAP security features, customer specific VPN solutions can be integrated with RAP.

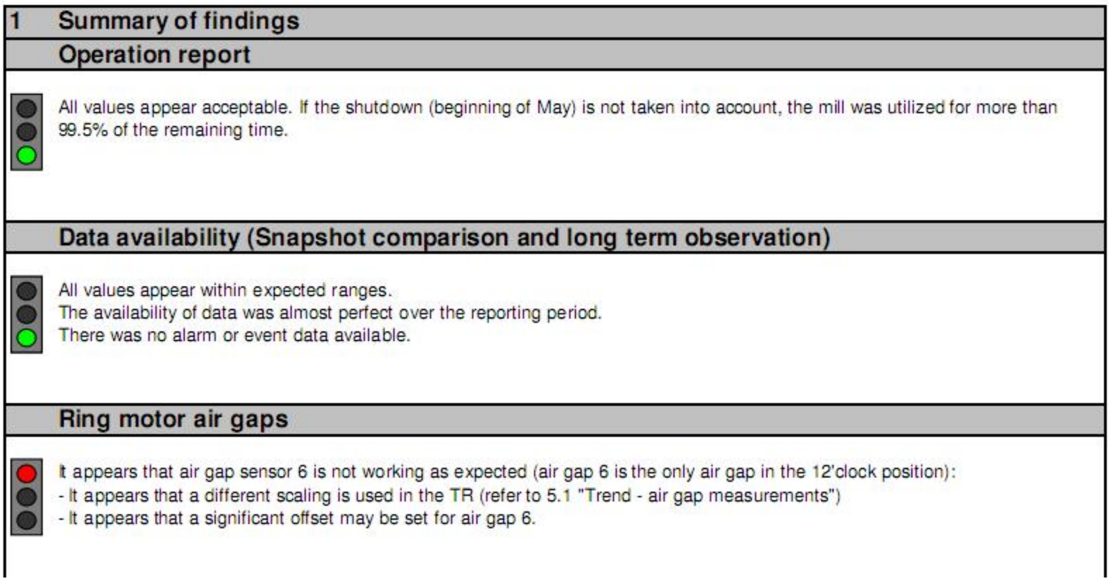
Remote Diagnostics: Periodic Maintenance

Periodic maintenance belongs to the area of preventive maintenance, but may also be considered predictive maintenance, depending on the specific failure phenomenon.

This service offering consists of a periodic, e.g. once per quarter, remote assessment of the health and operational condition of the GMD, in other terms scheduled drive system check-ups. To this end, signals relating to the GMD from all available sources (e.g. signals from the PLC, the plant DCS, and from the Transient Recorder) are collected continuously. Automatic analyses, complemented by manual observations and recommendations by GMD experts, are then condensed into a written report which is sent to the customer. A follow-up phone conference ensures that all open questions are clarified and the recommendations can be put into practice. As of today, a typical quarterly periodic maintenance report comprises approximately 40 pages, depending on the available data sources, and will most likely grow in size and scope as more analyses become available.

The main objective of periodic maintenance is to detect a deterioration of the health state of the GMD and take appropriate measures before a failure happens and causes unplanned downtime. Periodic maintenance relies on both abovementioned technologies, namely RAP and DriveMonitor. The data required for generating a periodic maintenance report is collected in a fast and automatic way and transmitted automatically to the responsible person within ABB. Also, the report is delivered within two weeks after the end of the reporting period.

Figure 9 shows the first page of a periodic maintenance report. It contains the executive summary with the most important observations and comments as well as recommendations for maintenance actions in order to solve the identified problems. The executive summary directs the reader's attention to the urgent and important facts by using traffic lights indicating the status of a category of analyses, e.g. those around the air gap measurements. The recommendations focus on practical actions that should be taken to correct any present or probable future problem.



1 Summary of findings

Operation report

All values appear acceptable. If the shutdown (beginning of May) is not taken into account, the mill was utilized for more than 99.5% of the remaining time.

Data availability (Snapshot comparison and long term observation)

All values appear within expected ranges.
The availability of data was almost perfect over the reporting period.
There was no alarm or event data available.

Ring motor air gaps

It appears that air gap sensor 6 is not working as expected (air gap 6 is the only air gap in the 12'clock position):
- It appears that a different scaling is used in the TR (refer to 5.1 "Trend - air gap measurements")
- It appears that a significant offset may be set for air gap 6.

Figure 9 – Executive summary

Periodic maintenance makes use of both long-term historical data as well as high time resolution snapshot data, e.g. from transient recordings, and thus gives a holistic view of the actual system health. At the same time, subsystem-specific analyses focus on several key areas of interest for the drive system, for instance:

- Operation report with an analysis of rotating speed, motor power, and line power usage (e.g. trends, histograms, forward and backward runtime)
- List of most frequent alarms and events
- Ring motor air gap analysis (e.g. eccentricity between rotor and stator, rotor out-of-roundness, stator deformation, pole movement)
- Grid voltages (e.g. total harmonic distortion, root-mean-square values, and harmonics)
- Ring motor currents and voltages (e.g. total harmonic distortion, root-mean-square values, and harmonics)

▪ Thermal behaviour (e.g. winding temperatures, cooling air and cooling water temperatures)

Figure 10 shows one detail from the air gap analysis. The signal of a single air gap sensor from a transient recordings (on the order of 60 seconds duration at 10 kHz resolution) is used in order to determine the pole profile and rotor shape of a 72-pole ring motor.

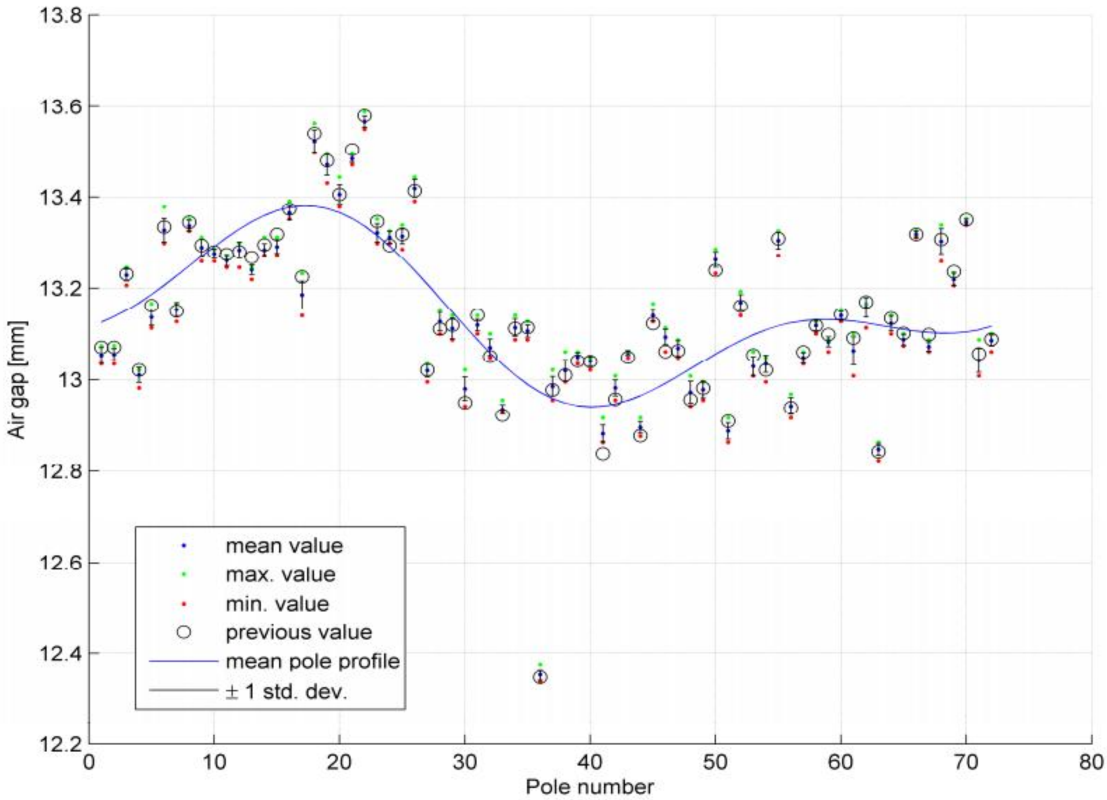


Figure 10 – Air gap analysis

Since several rotations happen over the transient recording, the mean, maximum, and minimum values of the air gap for each pole is shown. More specifically, the vertical axis indicates the (mean, maximum, and minimum) air gap between the stator at the point where the used air gap sensor is installed and the pole in question as it passes the air gap sensor. Furthermore, an error bar indicates the variability of the air gap for each pole (one standard deviation).

This so-called pole profile is subsequently used in order to determine the mean rotor shape, a fitted curve consisting of a constant part, a sine and cosine with the period of one rotation, and a sine and cosine with a period of half a rotation. Therefore, the mean rotor shape represents an ellipse (sine and cosine with a period of half a rotation) whose geometrical center may not have to coincide with the center of rotation (sine and cosine with a period of a rotation).

It is obvious that pole number 36 seems to be clearly closer to the stator than the other poles, a phenomenon which should be observed regularly. For this reason, the values of the same analysis in the precedent quarter form a baseline and are shown as black circles. Apparently, no significant changes have happened to the individual poles between the two reports. Of course, a baseline other than the previous report, e.g. the status directly after commissioning of the GMD or after a major maintenance action, may be used.

The last example may be appropriate to explain how periodic maintenance reports may be used for preventive, but also for predictive maintenance. The existence of an outlier in the pole profile, i.e. a significantly reduced air gap caused by a single pole, may directly lead to a maintenance activity. For instance, a lower limit of 12.5 mm could be defined, and violating this limit would trigger a mechanical adjustment of pole number 36. Along the lines of the abovementioned definitions of the different maintenance types, this would then be called preventive maintenance. On the other hand, the behaviour in time of the air gap at pole number 36 could be tracked. An extrapolation of the values of two subsequent reports could give an indication when a violation of a specific limit, e.g. 12 mm, is to be expected, and a predictive maintenance activity (again mechanical pole adjustment) could be triggered at the time just before this limit is reached or along with other planned service activities requiring a plant stop. In both cases, a significant reduction of cost of maintenance and other cost (e.g. cost of downtime and lost production) can be achieved compared to corrective maintenance (i.e. when the GMD trips because the trip limit of the air gap supervision system is violated).

A full demonstration periodic maintenance report is available upon request to the corresponding author.

Remote Diagnostics: Condition Monitoring

Condition monitoring is the third remote diagnostic service and, like periodic maintenance, can be associated to both preventive and predictive maintenance, depending on the type of phenomenon considered. Condition monitoring is a service that is becoming more and more important, in particular for rotating electrical machines, see Tavner (2008).

Similarly to periodic maintenance, condition monitoring relies on the two technologies RAP and DriveMonitor. It is similar to periodic maintenance in scope, i.e. the selection of phenomena related to the health and operational status of the GMD, but it has the purpose to deliver analyses in a continuous fashion (as opposed to once per reporting period). More specifically, it allows the user (either ABB or customer staff) to visualize and trigger analysis on demand, but it also performs analyses automatically 365 days per year and 24 hours per day without any need for human intervention.

Condition monitoring reads all relevant signals from different sources (see periodic maintenance) continuously and performs all analyses in real time. Also, condition monitoring has the vital capability to automatically send notifications, e.g. notifications about an imminent failure or a severe degradation of the health status to predefined receivers via e-mail or text message. This means that appropriate countermeasures can be started immediately, and as little time as possible is lost, leading to a reduction of unplanned downtime and therefore cost of lost production.

Figure 11 shows the graphical user interface in DriveMonitor used in order to visualize trends of signals and analysis results for condition monitoring. The trends that can be seen in Figure 11 are time trends of all the air gap sensors taken from a transient recording along with the predefined alarm and trip limits.

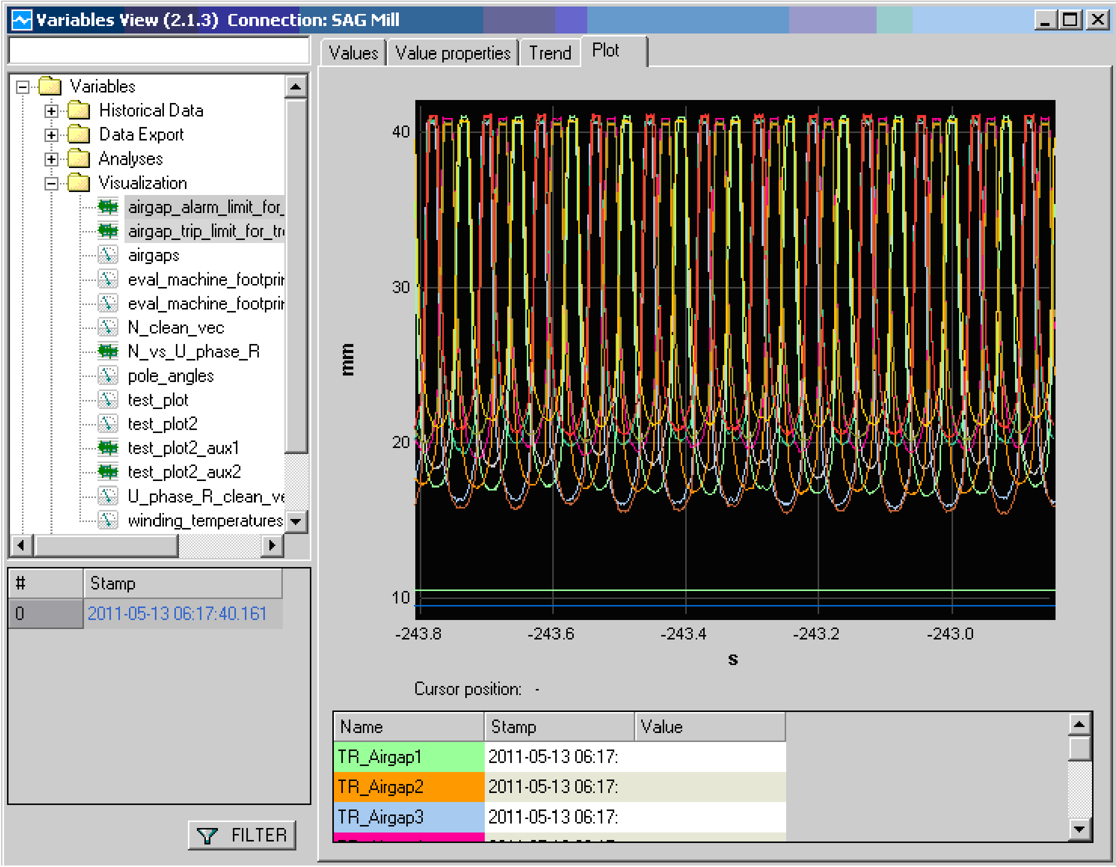


Figure 11 – Visualization in DriveMonitor

The DriveMonitor is connected to all relevant signal sources and reads all signals in real time. For instance, transient recordings are triggered regularly by DriveMonitor, and the resulting data files are copied and imported into the DriveMonitor database. On the other hand, all PLC signals are read via the OPC (OLE for Process Control) protocol. To this end, an OPC server is installed on the DriveMonitor.

The DriveMonitor software has been configured to perform automatic consolidation and storage of the abovementioned signals. More specifically, different types of logs with different consolidation periods (e.g. hourly, daily, monthly, and yearly log) and different consolidation functions (e.g. minimum, maximum, average, and number of elements) are generated for each signal and stored in the DriveMonitor database.

The main categories of the analyses performed in condition monitoring have already been mentioned in the previous subsection because they are to the greatest possible extent identical to periodic maintenance.

All analysis algorithms used in condition monitoring have been developed using Matlab and can be directly interfaced with the DriveMonitor software. The architecture of the analyses offered is completely modular. For these two reasons, it will be straightforward in the future to extend the scope of condition monitoring as new analysis algorithms become available. Furthermore, the distribution of updates of the algorithms is performed in a completely automatic and quick manner using RAP in order to ensure the use of up-to-date analysis algorithms at all times.

CONCLUSION

Summary

The scope of this contribution was to present remote diagnostic services for gearless mill drives. The main components of a GMD were illustrated and the different existing maintenance philosophies (corrective, preventive, and predictive maintenance) were shown. The importance of the composite key performance indicator overall equipment effectiveness was underscored.

In a second step, the ABB service portfolio for gearless mill drives was presented, and the scope and embedding of remote diagnostic services in the overall service portfolio was shown. Afterwards, the technologies on which remote diagnostic services are based, as well as the different types of remote diagnostic services offered, were illustrated.

Perspectives

The status presented in this paper should not be regarded as final. Although the abovementioned services are reality as of today already, there exist plenty of opportunities to go even further with remote diagnostics services. Some ideas, which are the subject of ongoing development, can be found in the following and give an indication of how the service offering may evolve in the future:

- An ongoing activity in order to enhance the scope of remote diagnostic services for GMDs is to install additional sensors and other instrumentation, e.g. Gap-Watch, a rotating air gap monitoring solution described in ABB Switzerland Ltd. (2010). Additional instrumentation comes in helpful in broadening the scope of the analyses offered in periodic maintenance and condition monitoring.

- In the areas of mining and cement, service offerings in general and remote diagnostic services in particular do not only exist for GMDs, but also for other critical equipment (such as mine hoists in underground mining and draglines and shovels in open-pit mining) and complete plants. An ongoing effort deals with harmonizing these service offerings and benefit from the resulting synergies.

- An important step forward is the closer integration of the abovementioned pillars of the temple of service. By considering different pillars simultaneously, e.g. lifecycle management and remote diagnostic services, or training services and remote diagnostic services, synergies can be levered and new opportunities with significant customer value may arise.

- A remote center for remote diagnostic services is currently being put into place in Switzerland and will be opened shortly. The purpose of this center is to channel all incoming information from various sites in one place, provide the necessary infrastructure (e.g. storage space, analysis and visualization tools, and databases), and offer ABB experts from around the globe a forum for giving their valuable input into remote diagnostic services 365 days per year and 24 hours per day.

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