uptime magazine

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Hydro: Magnetic flux • A06 module • Field news • Case study / Turbo-machinery diagnostics uptime megazine 1·11

Brüel & Kjær Vibro

Uptime Megazine is a newsletter published by Brüel & Kjær Vibro to keep you up-to-date with new machine monitoring trends and technologies. This issue focuses on hydroelectric power station monitoring.

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Cover photo: Ermenek dam, monitored by VC-6000 Compact Monitor.

Effective Hydropower Monitoring Demands

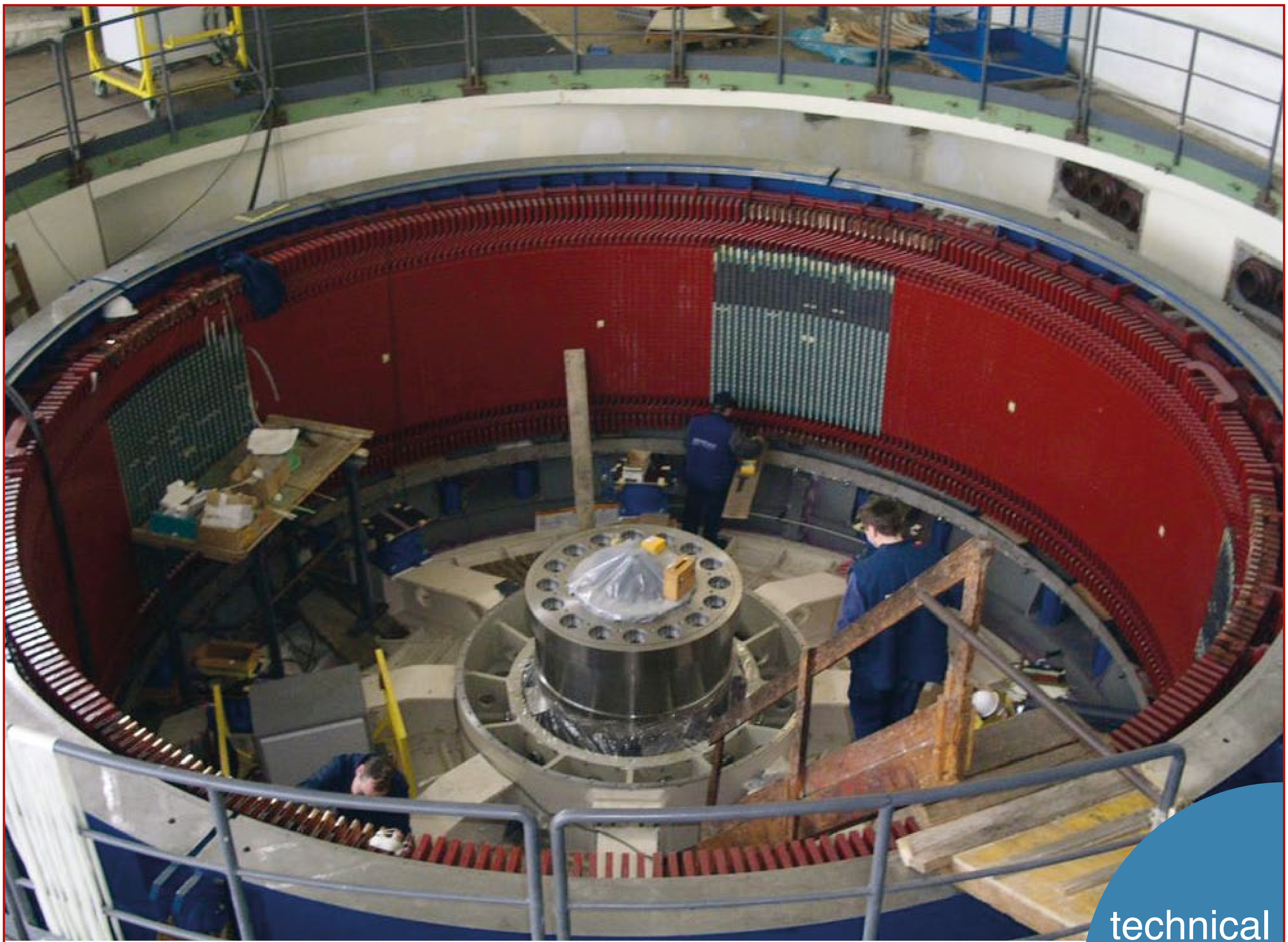
Today's global installed hydropower capacity of approximately 780 GW, represents approximately 20% of the world's electricity or about 88% of electricity from all renewable sources. Despite rapid development from other renewable energy sources such as wind, biomass and solar, hydropower capacity has grown in leaps and bounds over the years and is still growing. Only 25% of the potential capacity has been realized up to now! In this powerful sector of the energy market, what does this mean in terms of hydro machine operation and maintenance? A lot; machine uptime is more important now than ever before!

This issue of Uptime is dedicated to hydropower generating unit monitoring. Brüel & Kjær Vibro have been monitoring hydropower turbines for over 15 years worldwide. With significant experience in monitoring all types of machines in all types of hydroelectric configurations, ranging from under 1 MW to 700 MW, Brüel & Kjær Vibro have developed and implemented monitoring strategies ranging from simple safety installations to comprehensive safety/condition monitoring applications involving advanced measurement techniques for the generator, shaft/bearings, turbine and auxiliaries. Read more about this in the case story and technical article in this issue of Uptime.

In this issue we also present the new **SM-610-A06 hydro monitoring module** to the **VC-6000** data acquisition system. The introduction of the SM-A06 simplifies vibration monitoring of medium sized units for both safety and condition monitoring applications using **Compass 6000**. In most cases a single module is sufficient for monitoring an entire hydro unit!

Visit our web site for more information on our hydro monitoring techniques, applications and products. In addition to the hydro theme for this issue of Uptime, there is also a special feature section on **turbo-machinery diagnostics**. Diagnostic services have always played an important role in the expertise we offer our customers, and we are including a case story on this particular subject. This demonstrates how we can turn measurement data into actionable information that provides the longest lead time to failure, enabling you to be proactive in machine maintenance activities so they can be undertaken in a planned manner. I am delighted to launch this special edition of Uptime, and hope you enjoy reading it!

Alfred Schübl
Hydro key account manager



technical focus

Magnetic Flux Monitoring of Hydro Generators

Special monitoring techniques are needed to monitor the unique design of hydro generators.

In order to extract the maximum energy available from a particular water head, the hydrogenerating units at a hydroelectric power station have to rotate at relatively slow speeds; 50-300 rpm.

This makes the hydro generators unique as electrical machines, since turbo-generators used in other utilities rotate at 3000/3600 rpm. The slow rotation of the hydro generators necessitates many rotor poles in order to generate power at line frequency. An enormous rotor is therefore needed to accommodate the large number of poles, sometimes exceeding 12 m in diameter. Such a large generator, with a relatively small air gap, is susceptible to small deformations that can create enormous imbalance forces. The resulting vibration can cause premature failure of bearings and other components.

The massive area of the generator also makes it susceptible to hot spots, looseness, and other irregularities. There are several specialized measurement techniques to detect and diagnose these problems, but this article will focus on one such technique; the magnetic flux measurement.

Purpose for monitoring the magnetic flux

The magnetic flux monitoring technique is primarily intended for detecting shorted rotor turns and incipient ground faults on rotor salient pole windings. A short generally occurs if the winding insulation is damaged or degrades over time. A shorted turn on a rotor pole will not necessarily require the machine to be immediately shut down for service but it will degrade performance. It can cause hot spots and force the field current to increase. It can also create an unbalance that results in excessive vibrations and overheating.

There are several factors that affect the magnetic flux density; namely the physical air gap between the stator and poles, temperature of the wind-

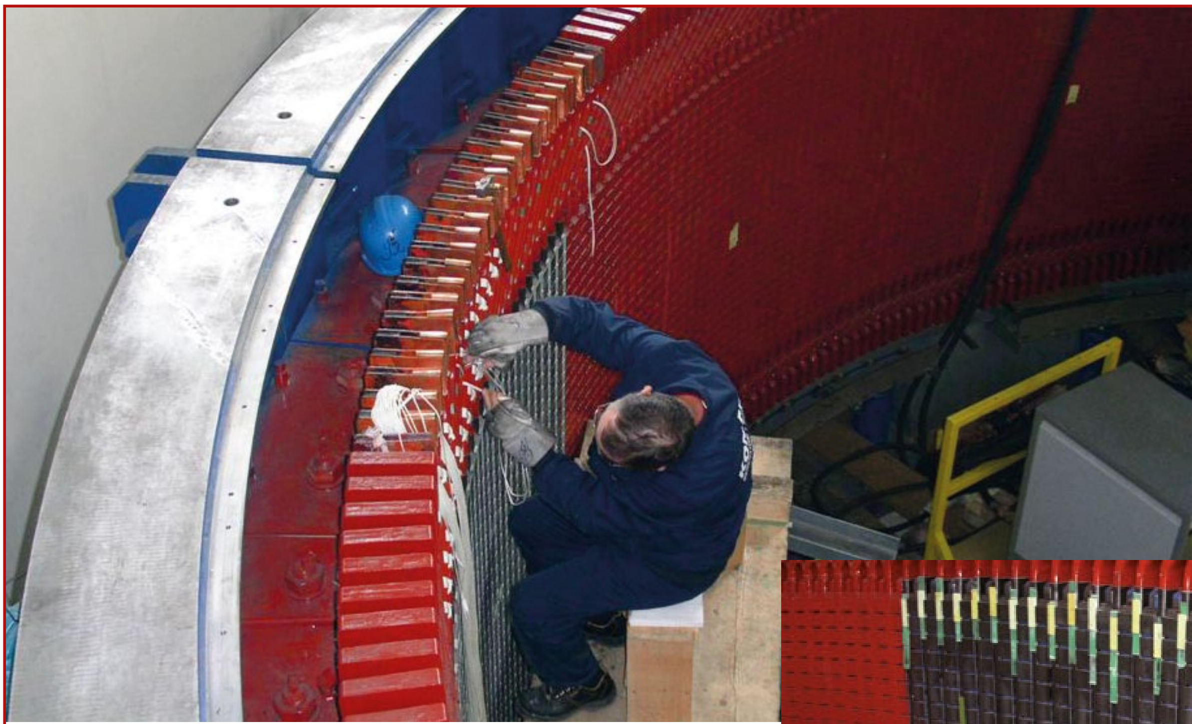


Figure 1. Preparation of a hydro generating unit stator (prior to installing the magnetic flux sensor).

ings and the exciter field current and voltage. Therefore to more accurately monitor to alarm limits and to simplify trending, magnetic flux should be correlated to these process parameters. The most important correlation for a magnetic flux measurement, however, is with the air gap measurements. This helps to determine if a generator unbalance is due to physical reasons (change in air gap) or electrical reasons (a shorted pole turn).

Variations in the magnetic flux measurements can be small, so an accurate measurement is required for each pole. As an example, on a 72-pole machine with 20 turns/pole, a single shorted turn will reduce the magnetic flux measured by only 5%.

Sensor

The magnetic flux sensor system (e.g. Brüel & Kjær Vibro EQ 2430) includes a long thin sensor that is permanently glued to the inner wall of the stator. It is attached to a signal conditioning box/ power source a few meters away by signal wires that pass though the stator ventilation channels or between the ends of the windings. The sensor measures the magnetic flux of each passing rotor pole face. The signal from the conditioning unit is referenced to a phase/ speed tacho, so the signal from each individual pole can be identified. These signals are conditioned, compared to alarm limits in the **Compass** monitoring system and then stored in the database.

The magnetic flux sensor resembles an air gap sensor (e.g. Brüel & Kjær Vibro EQ 2431) and in fact both are installed in the same way, but this is

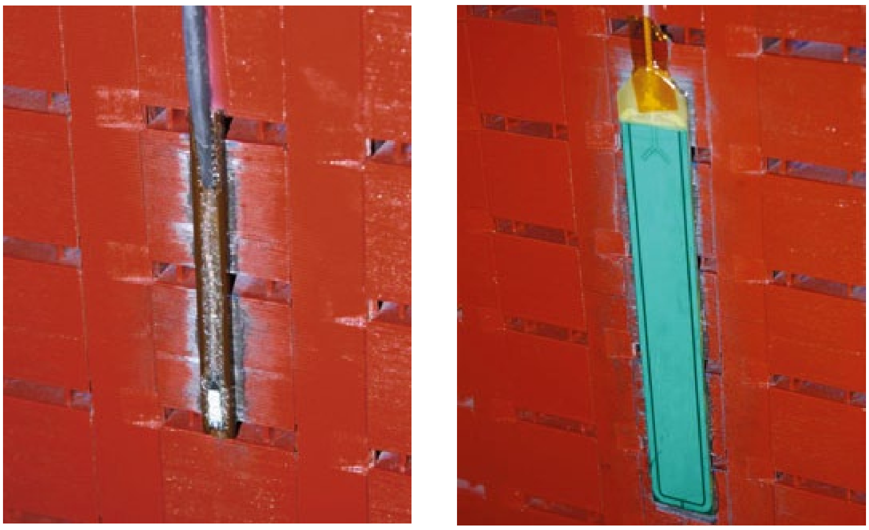
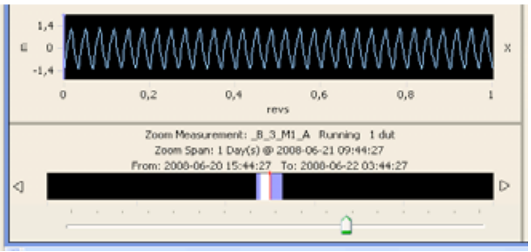


Figure 2. Magnetic flux sensor shown on the left, air gap sensor shown on the right.



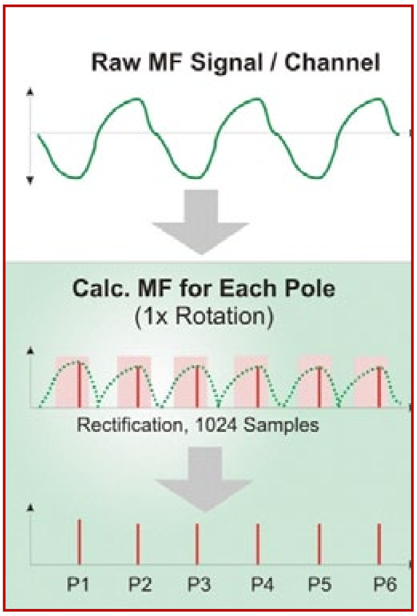


Figure 3. Compass 6000 plot above showing the raw time signal that is saved in the database for diagnostic purposes.

Figure 4. Maximum peak value extracted for each pole (single value) to be used for monitoring, trending and alarming purposes.

where the similarity ends. The air gap sensor operates on a capacitive principle for measuring distance between the stator wall and the passing rotor pole face. The capacitive current measured between the sensor plate and the passing rotor pole is proportional to the dielectric value between these surfaces, which in turn is proportional to the physical distance (i.e. the air gap). A magnetic flux sensor measures the magnetic field between the stator and the passing rotor pole face and operates on an entirely different principle, namely the Hall effect (see the inset describing the theory behind the Hall effect).

Data Monitoring and Diagnostics

The magnetic flux signal is used in an automatic monitoring capacity to detect a possible shorted turn. It is also used in a diagnostic capacity as a plot display to distinguish, for ex-

Hall Effect – The theory behind the operation of the magnetic flux sensor

The magnetic flux sensor measures the magnetic flux density using the Hall effect. This principle was discovered by Dr. Edwin Hall in 1879 but has only been used within the last 30 years since the development of solid state electronics. Imagine a thin rectangular conductor or semi-conductor that has current flowing through it. In the absence of a magnetic field, there would be no voltage across the width of the conductor perpendicular to the current flow, as shown in Figure 5. The Hall effect occurs if a magnetic field cuts perpendicular through the rectangular conductor. This produces a potential across the width of the conductor, that is proportional to the current and the flux density of the magnetic field perpendicular to the conductor, as shown in Figure 6.

A Hall effect element similar to that shown in the figures below is built into the magnetic flux sensor. Assuming the sensor current is constant, the output sensor voltage of the sensor, i.e. the Hall effect voltage $V_{H,}$ will be directly proportional to the strength of the magnetic field of each passing rotor pole.

technical focus

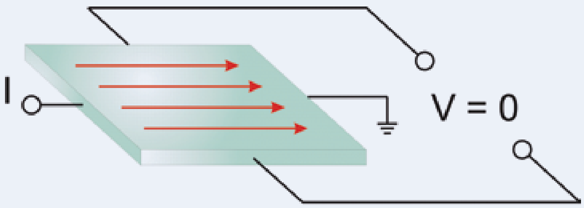


Figure 5. No magnetic field present.

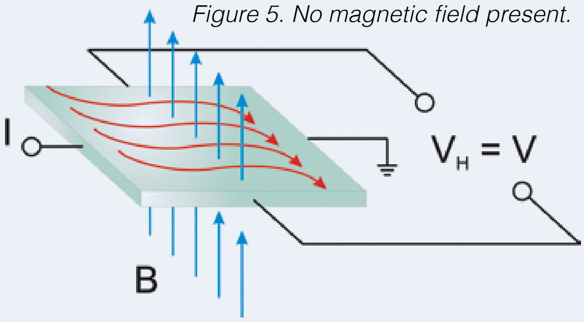


Figure 6. Hall effect principle, magnetic field present.

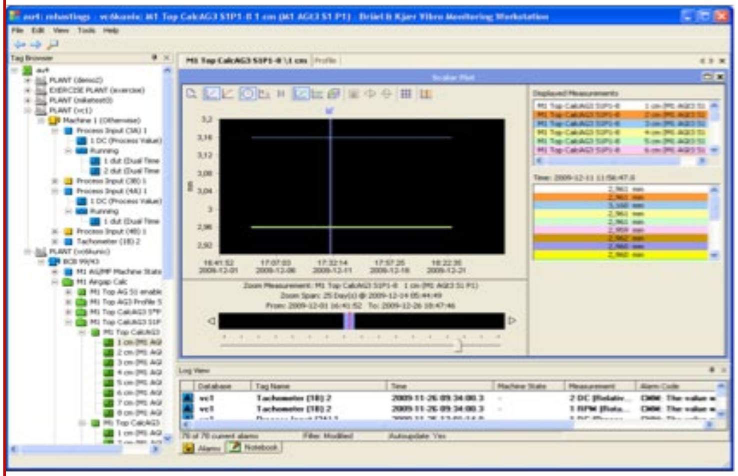


Figure 7. Compass 6000 multi-trend plot showing the maximum peaks for each pole, trended over time. These values are monitored to alarm limits.

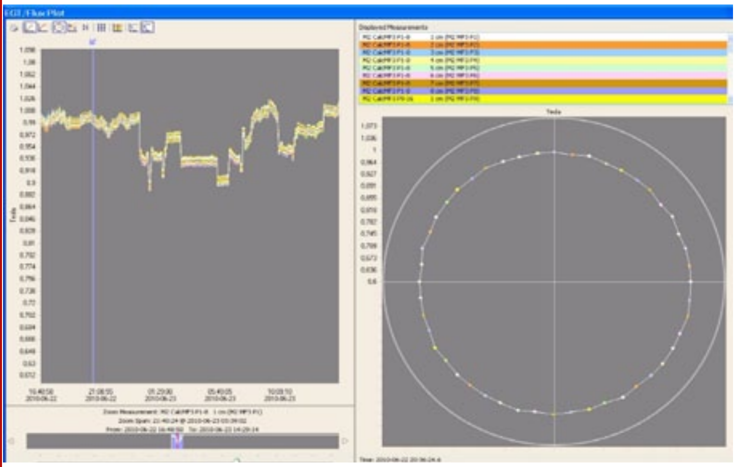
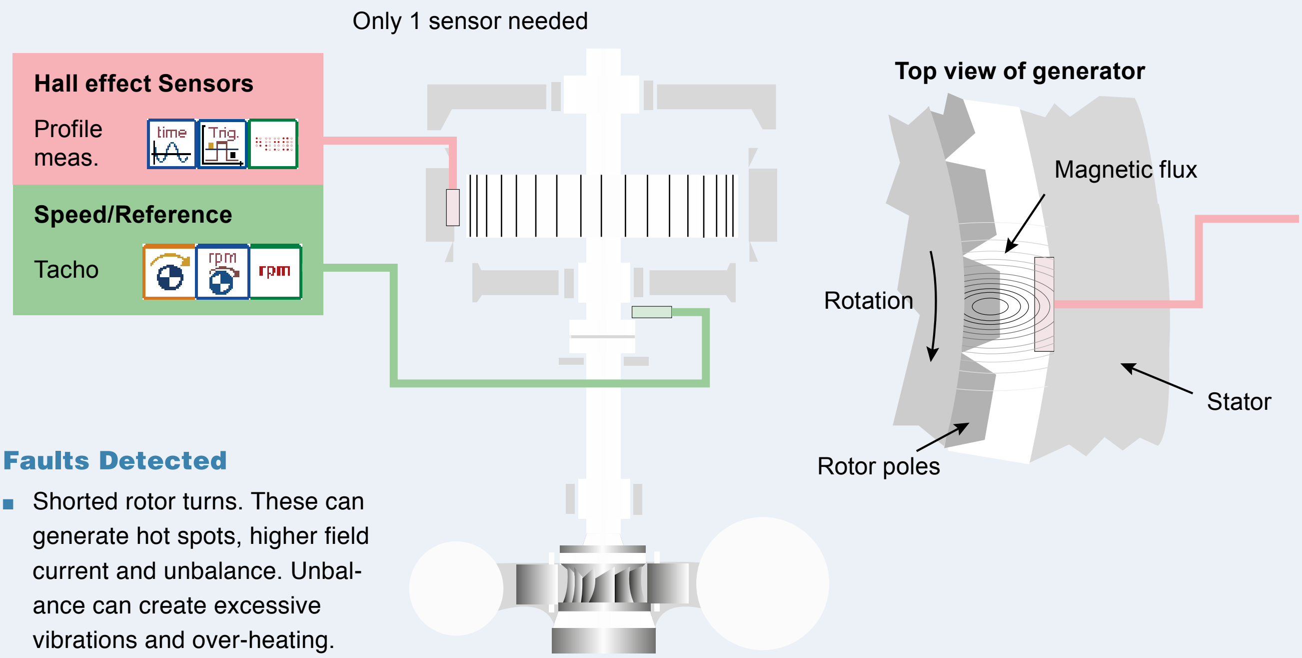


Figure 8. Compass 6000 plot showing the magnetic flux maximum peak value for each pole for one rotation in a circular plot.

ample, between rotor/stator deformation and a shorted turn.

The raw time signal for one rotation of the rotor shows the magnetic flux for each pole, as seen in Figure 3. This signal provides valuable diagnostic information, but it is not monitored to alarm limits. For this purpose the signal is conditioned as shown in Figure 4. A single maximum peak value for each pole is extracted and is monitored to alarm limits and trended over time as shown in Figure 7. These values, corresponding to a specific pole, can be correlated to the values from other poles, or correlated to process conditions such as winding temperature, exciter current and voltage, and air gap measurements. The

Magnetic Flux Measurements



Faults Detected

- Shorted rotor turns. These can generate hot spots, higher field current and unbalance. Unbalance can create excessive vibrations and over-heating.
- Often correlated with air gap and excitation voltage and current

Figure 9. Overview of magnetic flux monitoring strategy

same peak values are also displayed in a circular plot for a single rotation of the rotor at a given process class, or overlapping data from earlier rotations as shown in Figure 8.

Compass enables magnetic flux monitoring to be categorized on the basis of specific machines states, which can be the above mentioned process parameters, or the generating unit loading or operational regimes such as pumping, generating, compensating, etc. This allows "cleaner" trending, earlier and more reliable automatic fault detection and simplified plot comparison for diagnostic purposes.

Conclusion

Magnetic flux monitoring enables accurate detection of shorted turns in a rotor pole, that if left uncorrected, reduce the performance of the generator. The magnetic flux measurement is used by Brüel & Kjær Vibro to complement its integrated monitoring strategy for hydropower turbines. Due to its sensitivity to process conditions, it is not suitable as a stand-alone technique and should be correlated to process conditions and air gap measurements as well.

Dedicated Hydro Monitoring Hardware

product news

VIBROCONTROL 6000™ (VC-6000), Brüel & Kjær Vibro's data acquisition unit (used as a rack based safety monitor or in conjunction with Compass 6000 for integrated condition monitoring), offers a hydro-specific monitoring module; **SM-610-A06**. This module, tailored to meet the monitoring requirements of the hydro industry, enables vibration monitoring of an entire hydroelectric machine in a single module! The module is designed as a flexible, user-defined platform for all kinds of hydro installations, and includes a wide range of user-defined measurements. A unique machine state function allows safety and condition monitoring to be undertaken with corresponding Alert and Danger alarm limits. This provides accurate, early and reliable fault detection capability.

Features:

- **Inputs** Up to 11x vibration, up to 2x axial position, 3x binary inputs and up to 2x speed inputs (for machine state definition) and a 1x master trigger input signal (for other modules)
- **Outputs** – Up to 8x DC outputs and 2x relays (with user-defined voting logic)
- **Machine states** – 6 user-defined machines states (up to 8 for safety monitoring applications)
- **Hot swappable module**

Contact your local Brüel & Kjær Vibro sales representative for more information!

Figure 1. View of the Xiaowan hydroelectric power station, 6 x 700 MW

field news

Hydro Monitoring Projects in Southwestern China

Brüel & Kjær Vibro has won a bid to install monitoring systems on three large hydroelectric power stations in the Yunnan province; the Ruilijiang hydro plant on the Ruili River, and the Xiaowan and Jinhong hydro plants on the Lancang (Mekong) river. The latter two are part of an enormous eight cascade hydropower station scheme on the Lancang River that will have the capacity to generate 16 GW.

Highlights of the hydroelectric power stations

- **Xiaowan Hydropower Station** (小湾水电站) - With 6 installed hydro turbine generator units of 700 MW each, Xiaowan Hydropower Station is the largest single-unit capacity presently available in the world for such a water head segment. The Xiaowan Dam is also the world's highest arch dam (300 m) and the second largest hydroelectric power station in China after the Three Gorges Dam. The Xiaowan Hydropower Station also holds a special status in the sense that the operation of its last generating units in 2010 boosted China's hydropower capacity to being the world's largest.

- **Jinghong Hydropower Station** (景洪水电站) – The fourth hydroelectric power station downstream from Xiaowan in the enormous Lancang river cascade scheme. Jinghong has 1750 MW generating capacity and a 108 m high dam. Construction began in 2003, and was completed in 2008. Part of the power generated will be sold to Thailand under an agreement with China.

- **Ruilijiang Hydropower Station (瑞丽江水电站)** – Located on the Ruili River in Dehong County, close to the Myanmar border. It has 600 MW generating capacity.

Hydro Power Station	Units	MW/Unit
Ruilijiang	6	100
Jinhong	5	350
Xiaowan	6	700

Massive hydro expansion

The hydro projects mentioned are only a few of the total number to be built as part of China's plan to expand its installed hydropower capacity from a current 200 GW to 300 GW by 2015. This is in response to a concerted effort to cut carbon dioxide emissions. China has long relied on coal to fuel its economic growth with about 83 percent of its electricity produced by coal-fired stations, but this is rapidly changing. China plans to cut its carbon emissions per unit of gross domestic product (GDP) by 40 to 45 percent by 2020. China also undertook a commitment to generate 15 percent of its power from non-fossil sources by 2020, up from the current 7.8 percent. Brüel & Kjær Vibro are proud to take part in this ambitious renewable energy expansion project.

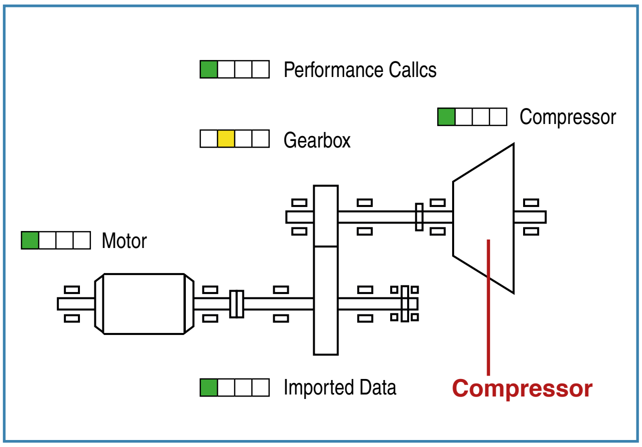
Monitoring Strategy

All 17 hydro-generating units are monitored for safety using the Brüel & Kjær Vibro VC-6000 data acquisition unit (except for Ruilijiang, which is monitored by the VC-4000). The new SM-610-A06 hydro module is being used in the Xiaowan project!

Early detection of a compressor impeller crack

case study

Turbo-machinery, unlike hydro generating units, operate at high speeds and have their own unique set of potential failure modes. Fortunately most of these can be readily detected using an advanced condition monitoring system such as Compass 6000. There are, however, some turbo-machinery faults that require diagnostic expertise to both detect and diagnose. This case story addresses exactly such an instance and demonstrates the fact that advanced diagnostic tools such as ADVISOR can greatly assist monitoring specialists. But these tools can in no way replace them. Brüel & Kjær Vibro offers diagnostic expertise as a service to companies that either lack these monitoring specialists or have over-burdened diagnostic groups.



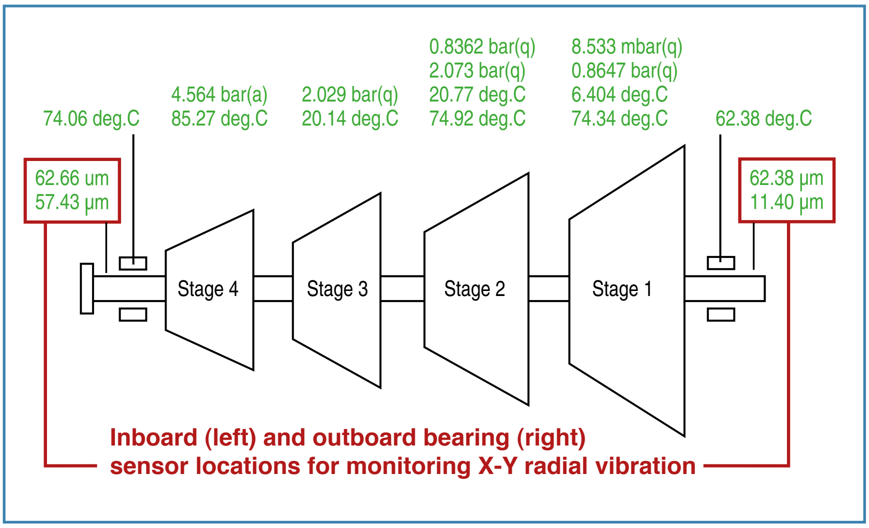


Figure 1. Compressor train (top) and inboard and outboard vibration measurement points (bottom).

This case story was adapted from of a paper written by Erik van Deursen from Hoek Loos/Linde Gas Benelux (Netherlands), Gert Hoefakker, Brüel & Kjær Vibro (Netherlands), and Peter Surland and Mike Hastings, Brüel & Kjær Vibro (Denmark). It was presented at The Institution Of Mechanical Engineers (ImechE) conference “International Conference on Compressors and Their Systems”, in London, UK, 10-12 September 2007.

Summary

Rotor vibration and phase condition monitoring limits were exceeded for a 25 MW centrifugal compressor. Although the vibration levels were still 60% below the safety system alarm limits, the Rotating Equipment Engineer decided to shut down the machine for inspection. A 25 cm crack was found on the impeller. If the Compass condition monitoring system had not been monitoring this machine, it is possible the safety system could not have detected the crack before failure. This could have resulted in destroying both the rotor and casing. Later investigation revealed that the shaft crack could have been detected even earlier if the automatic machine diagnosis program ADVISOR, running on the Compass platform, was being utilised.

Introduction

The 4-stage, 25 MW centrifugal compressor is used in an air separation process. The 5-year old compressor is a critical machine to the process, and has no spares. The machine has been monitored since it was commissioned.

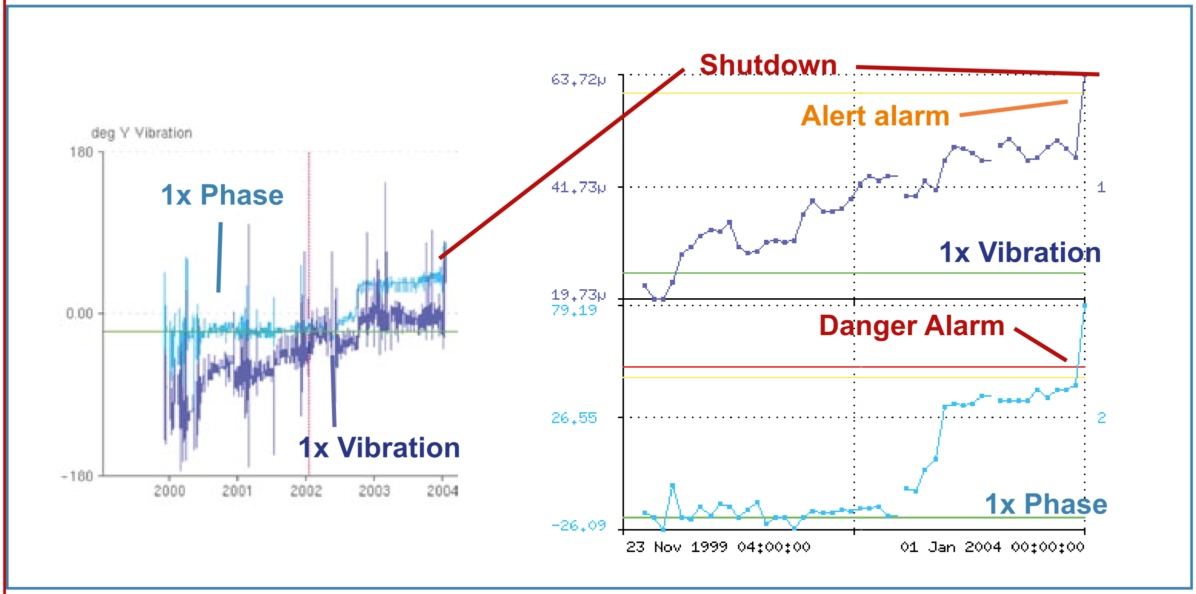


Figure 2. Vector radial vibrations on the inboard bearing: Alert alarm limits exceeded by 1x vector magnitude vibration at running speed. Danger alarm exceeded by 1x vector phase.

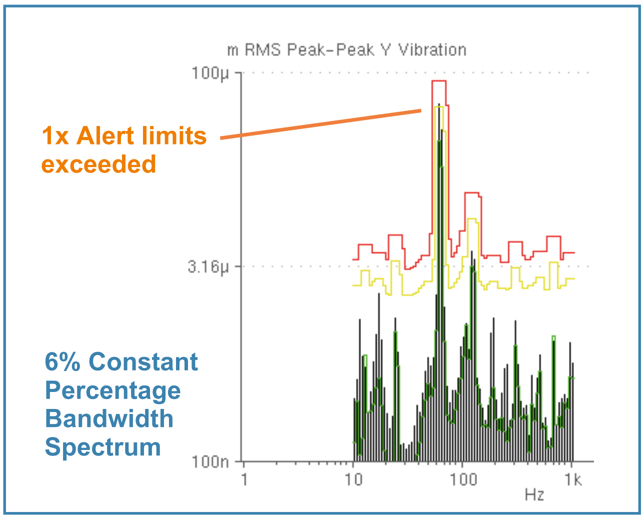


Figure 3. Spectrum radial vibrations on the inboard bearing: Alert alarm limits exceeded by 6% constant percentage bandwidth spectrum (CPB6%) at running speed.

Monitoring Strategy

A combined Compass condition monitoring and diagnosis system and safety monitoring system is used at the air-separation plant for monitoring three machines. The condition-monitoring portion of the system is used in a predictive maintenance strategy for detecting faults at an early stage of development. Both vibration and process parameters (many of these are imported from the distributed control system) are automatically monitored at periodic intervals. Brüel & Kjær Vibro also provides remote and on-site diagnostic services on request from the customer for analyzing faults.

The Compass system installation on the compressor includes X-Y displacement sensors on the inboard and outboard bearings, as shown in Figure 1.

Measurements at each sensor point include:

- DC
- Bandpass (10-1000 Hz, RMS peak-peak)
- 1x, 2x vector measurements (RMS peak-peak magnitude and phase), ½x magnitude (RMS peak-peak)
- 6% Constant Percentage Bandwidth (10.3 to 1030 Hz, RMS peak-peak), 23% Constant Percentage Bandwidth (2 to 1000 Hz, RMS)

Fault Detection

In January 2004 several condition-monitoring alarms were abruptly generated, primarily on the inboard X-Y displacement sensors on the compressor rotor:

- CPB6% exceeded its 54.38 µm alert limits at running frequency (61.30 Hz)
- 1x vector radial vibration level exceeded the 60 µm alert limits (25 µm is normal)
- 1x phase exceeded the 90° danger limits.

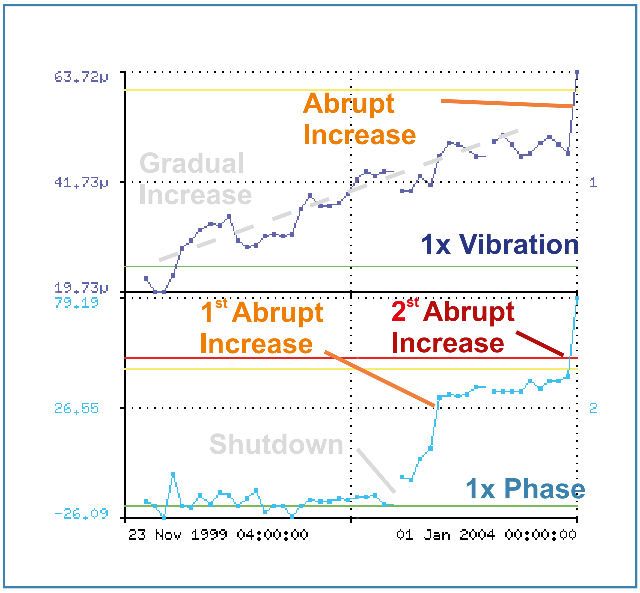
The alert-alarm levels were well below the safety monitoring system trip level of 130 µm overall vibration level (phase is not monitored for trip), but they caught the attention of the Rotating Equipment Engineer. This was partly due to the 1x phase shift of 65° from the normal value for over a year (alert level is 85°), while the 1x vibration level has been gradually increasing from around 30 µm to over 50 µm for a period of around 3 years (see Figure 2).

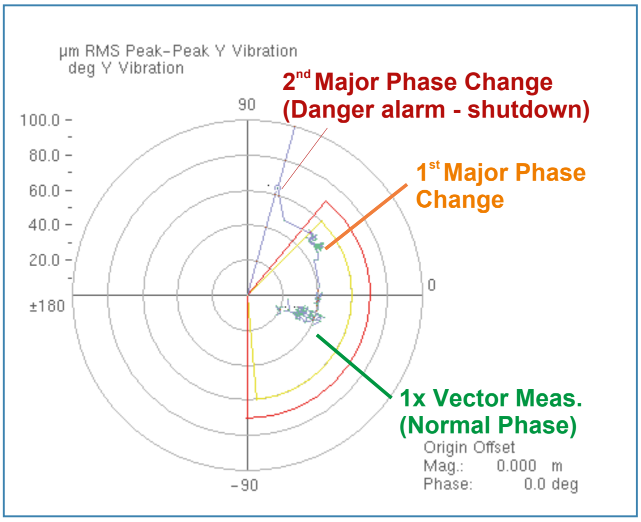
The Engineer initially suspected the problem was mechanical unbalance caused by fouling, so a camera inspection was ordered.

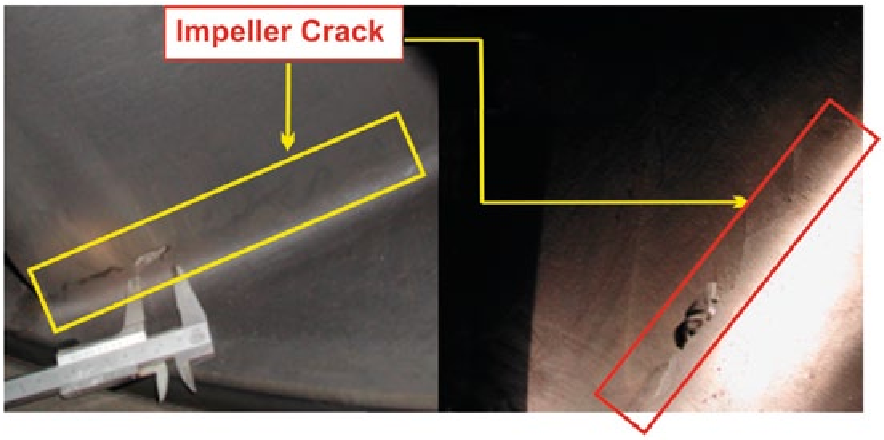
Machine Inspection and Repair

The first thing noticed during inspection was crackling of the cooling water piping with parts of the pipe missing. When the compressor was opened, there was no evidence of fouling as previously thought, but a large crack was found on the base of

Figure 4. 1x vibration magnitude increased gradually from 2001 to 2004, where there was an abrupt increase in January 2004. 1x vector phase increased abruptly first after the shutdown in June 2002, and then again in January 2004.







one of the first stage impeller blades. The damaged impeller could be repaired but it was quicker to install a new one, which resulted in a 12-week shutdown. If Compass had not been monitoring this machine, it is possible the protective monitoring portion of the system could not have tripped the machine in time to prevent a catastrophic failure. Such a failure could have destroyed both the rotor and casing, which would have resulted in 12 months of downtime.

Post Fault Analysis and Diagnosis

Looking back at the data in Figure 2, the changing 1X vibration and phase is an indication of a shaft/rotor crack[1]. It is interesting to note that the vibration was higher at the inboard bearing position (stage 4) than the outboard (stage 1) position where the impeller crack appeared (see Figures 1 and 2). The compressor manufacturer confirmed this to be consistent for this type of machine. The effects of the mass balance between the first and fourth stage can influence the location where the first stage 1X vibration will be evident.

Compass had averted a catastrophic failure of the machine, but there was little lead-time to cost-effectively plan maintenance. Moreover, the initial diagnosis was incorrect as it was based on the premise of unbalance due to fouling, which is quite different from a rotor crack. The compressor had to be shut down quickly which resulted in unplanned downtime. Could the fault have been detected automatically? Maybe earlier? Could it have been correctly and automatically diagnosed as an impeller crack?

[1] There is a lot of literature on rotor crack detection using vibration analysis. There are also a number of different vibration analysis techniques used. References [1-6] give an overview of some of these techniques and [7] gives a description of a crack detection technique using 1X magnitude and phase measurements for detecting cracks in gas turbine blades and rotors.

Looking at Figure 5, there were obvious symptoms already back in September 2002 that indicated the beginning of a phase change. There had been a shutdown in June the same year but the compressor was never opened for inspection at that time. For this reason it is doubtful that this shutdown could have aggravated the problem. There were also indications even further back to September 2001 where the vibration levels began to gradually increase. But it is unlikely these symptoms would have ever been noticed since they were below the alarm levels. The phase increased in October 2002 but it quickly leveled off and remained stable for a year and a half. Therefore, no real concern would have been raised. The gradually increasing vibration level was still below alarm limits right up until the last moment. When both the magnitude and phase suddenly increased, the machine had to be manually shut down.

The problem is that no one had noticed these early indications of a developing fault.

Brüel & Kjær Vibro offers ADVISOR, an automatic machine diagnostic program that can be installed as an add-on to Compass. ADVISOR was not installed at the time of the impeller crack, so the customer asked Brüel & Kjær Vibro to retroactively scan the compressor database with the ADVISOR diagnostic program. The Rotating Equipment Engineer wanted to know if the developing impeller crack could have been detected earlier using this automatic diagnosis technique.

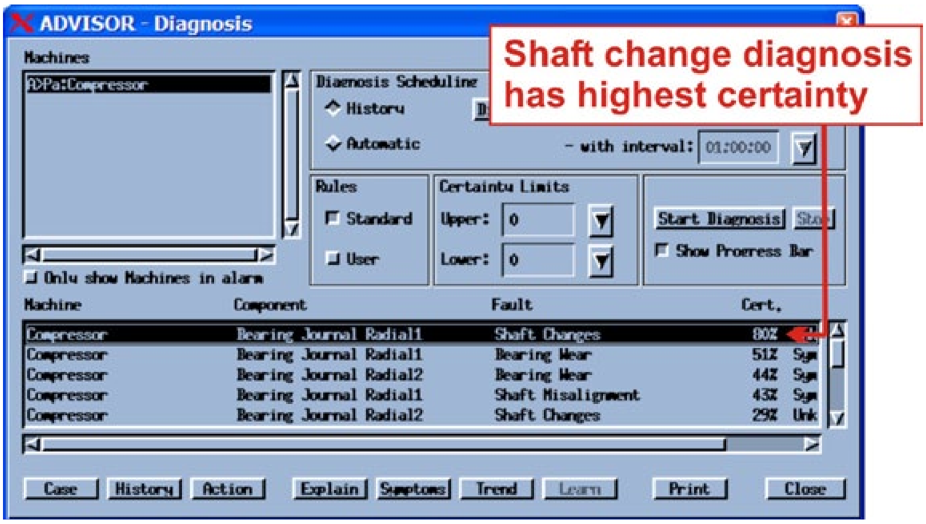


Figure 5. ADVISOR lists all likely and unlikely diagnoses for a given database scan. The diagnosis with the highest certainty after 21 November 2002 is the "shaft change" (i.e. a rotor dynamic change, such as a change in stiffness, which can result when there is a rotor crack). Other machine faults can be seen listed below this one.

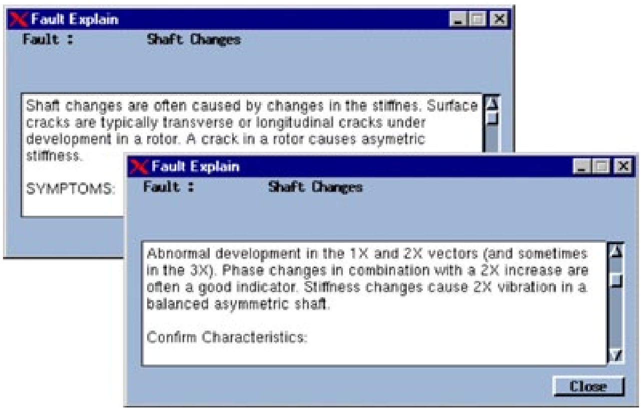


Figure 6. ADVISOR description explaining the rules and symptoms used in the diagnosis.

Automatic machine diagnosis system

ADVISOR, the neural network-based automatic machine diagnostic program that runs on Compass, classifies measurements recorded by looking at the pattern of the levels at machine characteristic frequencies (correlated to potential failure modes of the machine) in the vibration spectrum. As soon as a machine shows "non standard" behavior, this is automatically identified and converted into a machine problem. This means automatically diagnosing a fault requires only some initial data where the machine is assumed to be in good condition. It is not necessary to set up alarm limits to diagnose a fault.

ADVISOR evaluates the complete database on a regular basis (e.g. hourly) or it starts when it is triggered by an event. The results of the evaluation are:

- List of calculated certainty of diagnosis of potential faults
- Description of the diagnoses of the potential faults (rules, symptoms)
- Plots showing a trend of the certainty of the diagnosis over time

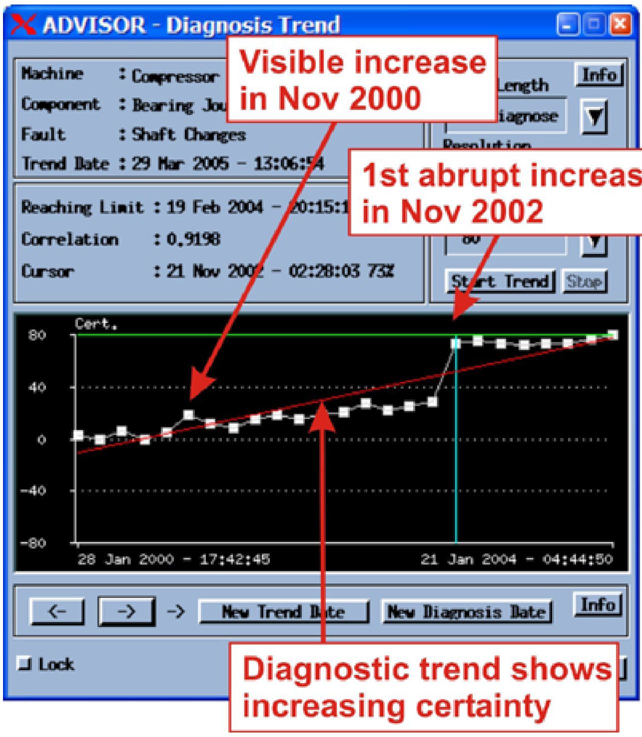


Figure 7. This plot shows the calculated certainty of the shaft crack diagnosis by ADVISOR. Already by 21 November 2002 the certainty of diagnosis was up to 80% (the highest certainty level of the system). Even though the certainty levels of the rotor crack diagnosis are relatively low prior to this date, the diagnostic trend has been increasing in terms of probability (certainty) the entire time.

Conclusion

Safety systems are not always effective in protecting a machine against faults such as blade or rotor cracks. It is difficult to detect the minute energy changes caused by a slowly developing crack using overall vibration measurements. Once a crack has reached critical proportions, the rotor could conceivably fail before high vibrations are detected by a safety system.

There is a greater likelihood that rotor cracks can be detected at a relatively early stage of development by using any number of transient or steady-state vibration analysis techniques. 1X and/or 2X vector measurements are one possible technique. The changes, however, can be subtle and below the defined alarm limits, making it necessary to trend the values over time. This can be exhausting work for a diagnostician to look at all data even before they exceed alarm limits. An automatic trend alarm function for each measurement would be more useful, but this would have to be set up individually for each measurement.
An automatic expert system such as ADVISOR provides the optimal solution since it would look at several symptoms at the same time when making a diagnosis – not just one. As described in the preceding case story, ADVISOR can be used at any time to search the entire monitoring system database for symptoms. As the symptoms begin to develop over time to fulfill the criteria established in the diagnostic rules, the certainty of the diagnosis also increases. The calculated diagnosis certainty can then be plotted and trended to give advance warning of a fault. The diagnoses created by ADVISOR can also be automatically sent as a file to a maintenance management system or operator.

Using such a system can significantly reduce the workload of the system user while simultaneously providing earlier warning of a developing fault. The program can also be used to fine-tune diagnosis rules and symptoms and to "verify" the diagnoses done by others.

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field news

Hydro Monitoring Projects in Turkey

Brüel & Kjær Vibro has recently won a bid to install monitoring systems on five hydroelectric power stations in Turkey. These include the Birecik and Ermenek hydro plants in the Euphrates basin, part of the strategically important Southeastern Anatolia Project (G*üneydoğu* Anadolu Projesi, GAP) for developing this rural part of the country.

Highlights of the hydroelectric power stations

- **Birecik** – One of 19 hydroelectric dams of the Southeastern Anatolia Project of Turkey, Birecik is located on the Euphrates near the town of Birecik 80 km west of the Sanliurfa Province in the southeastern region of Turkey. The Birecik dam is a structure constituted of a concrete gravity and clay core sand-gravel fill with a height of 62.5 m from the foundation. The power station has 6 vertical axis Francis units, each of 112 MW, With a 317 m^3/s flow from a 42 m head, these units will generate an average of 2.5 billion kWh per year.
- **Boyabat** – Located in Sinop province in the country's Black Sea region, 15 km southwest of Durağan, on the Kızılırmak River. It has a 195 m high concrete dam, and includes three vertical shaft Francis turbines of 170 MW each with 157 m^3/s flow. Upon commissioning the dam will generate 1.5 billion kWh/year.
- **Ermenek** – The double curvature, asymmetrical, thin concrete arch dam body, which will have a height of 210 m, is among the two highest dams in Turkey and the 6th highest in Europe. The dam is being constructed in an extremely deep and narrow gorge, having a width of less than 150 m at its top, and as little as 5 m at its bottom.
- **Büyügdüz** – A small 2 x 30 MW installation.
- **Sarihidir** – A small run-of-the-river installation near the town of Nevsehir.

Hydro Power Station	Units	MW/Unit
Birecik	6	110
Boyabat	3	170
Ermenek	2	150
Büyügdüz	2	30
Sarihidir	2	6.4

Monitoring Strategy

All hydrogenating units are monitored for safety using the Brüel & Kjær Vibro VC-6000 data acquisition system (except for Büyügdüz, which is monitored by VC-920's, and the two units at Ermenek, which are monitored by the VC-6000 Compact Monitor).

Ermenek hydroelectric power station.

Massive hydro expansion

Turkey's energy needs are growing at 6-8% annually, which equates to around 1,5 GW to 2 GW of new generation capacity that is needed each year up until 2017. Much of this will be provided by greenfield coal plants and gas-fired plants in the short term, but Turkey has a vast hydroelectric potential of 128 billion kWh, of which only 35% is being used. Currently Turkey has 142 hydroelectric power stations with an installed capacity of 13 GW generating 46 billion kWh/year (2007). In an effort to increase renewable energy utilization, there are plans to develop 60 –100 billion kWh of hydropower potential by 2023.

One of the largest regional development projects in Turkey is the **Southeastern Anatolia Project** (Güneydoğu Anadolu Projesi, or **GAP**). This vast project includes hydroelectric power development, where it is planned to build 22 dams in the area. The Birecik and Ermenek hydro plants, to be monitored by VC-6000, are part of this important project, and will help bring economic livelihood to the region.

case study

VIBROCONTROL 1500 selected for monitoring small hydroelectric generating units in Norway

The VIBROCONTROL 1500 (VC-1500) vibration monitor was installed in the Aunfoss hydroelectric power station as a protective monitor for their 18 MVA hydro generating units. This vibration monitor proved to be well suited to this application not only because of its user-friendly operability, but also because of its extra functionality.

Aunfoss Facts:	
Catchment area	3000 km^2
Power	2x18 MVA
Annual production	199 GWh
Head	30 m
Flow	76 m^3/s

Aunfoss Hydro Power Plant

The Aunfoss plant, built in 1959, is one of several hydro power stations regulating the water flow on the Namsen River, known for its salmon. It consists of 2 x 18 MVA generating units equipped with vertical-shaft Francis turbines. Aunfoss was the first hydroelectric power station in the energy company Nord-Trøndelag Elektrisitetsverk (NTE) to install the Brüel & Kjær Vibro VC-1500 monitor for vibration monitoring.

NTE is a 92 year old Norwegian local energy utility with 16 main hydroelectric power stations north of the city of Trondheim. NTE has an installed capacity of 820 MW, which ranks them eighth among Norway's biggest power producers in a country where 99% of all electricity is produced from hydroelectric power. Most of the NTE's capacity is produced in small and medium-small hydro power plants equipped with 1 to 4 turbines. Over the last two decades, NTE and the other Norwegian hydroelectric power stations have changed from continuous operation to more partial load and periodic operation to better adapt to seasonal changes in water

Figure 2. Aunfoss generator hall.

supply and spot energy prices. The periodic operation, while more cost-effective, has placed a higher load on the machines due to the increased number of starts and stops of the generating units.

Previous Monitoring Experience

Historically, NTE's monitoring has been restricted to the lubricating oil temperature, pressure and levels on their hydroelectric generating units. More recently, some of the plants have extended their monitoring capability by adding vibration monitoring. Firstly, vibration monitoring gives earlier warning of most of the important developing faults in the bearings and shafts than other techniques. Secondly, effective asset management has become more important - not only with respect to machine protection but also for more effective operation and maintenance scheduling.

For these reasons, Aunfoss decided to add vibration monitoring capability in 2011. While NTE operate some hydro power stations that have not implemented a vibration monitoring solution, most facilities have already embraced the technique and implemented such monitoring systems with over half of NTE's hydro power stations being monitored using Brüel & Kjær Vibro vibration monitoring equipment! Over the years, Brüel & Kjær Vibro has delivered a range of different monitoring solutions to NTE encompassing the VC-2000 and VC-4000. These systems monitor hydro generating units ranging from 4 to 75 MW. In fact, Brüel & Kjær Vibro monitoring systems are currently being used to monitor over 150 hydro turbines in Norway.

Monitoring System Requirements at Aunfoss

As in the case of most other NTE power stations, Aunfoss requires that any new vibration monitoring system must complement the existing lubrication system monitoring, not replace it. The vibration monitoring system should be used primarily for protective monitoring of the thrust bearing, two guide bearings and the shaft, with the provision for seamless expansion to implement condition monitoring, either immediately or at a later time to mitigate the enormous cost of downtime. This downtime cost is not limited to lost production, but extends to reduced flow during the downtime, resulting in negative chain-reactions on the productivity of the downstream turbines.

The selection process for the ideal vibration monitoring system was not trivial. A typical rack-based safety and condition monitoring system has all the necessary functionality and remote monitoring capability for this type of application, but such a system would be too expensive for monitoring only one or two smaller hydro generating units. On the other hand there are many inexpensive vibration monitors available in the market, but they lack important functionality for effectively monitoring critical machines. After careful consideration and market research, Aunfoss selected the 2-channel VC-1500 moni-

Figure 3. VC-1500 vibration monitor

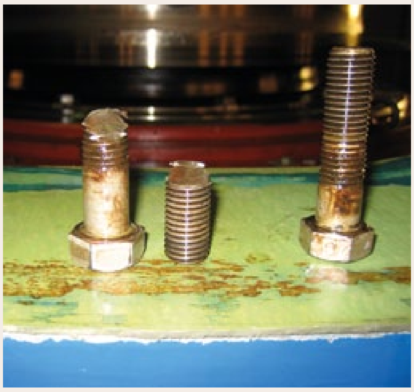

Figure 4. Generator bearing bolt damage (left). Damage to the generator bearing housing weld (right).

Case story – Undetected Failures

Prior to installing the Brüel & Kjær Vibro vibration monitoring system, Aunfoss, like other power stations at NTE, have seen failures that were not detected by their existing monitoring systems. This was one of the drivers for implementing vibration monitoring. At Aunfoss, as shown in Figure 4, the generator bearing bolts failed as a result of excessively high vibrations. A similar vibration related failure is evident in the weld of the generator bearing housing shown in the same figure. Both of these faults could have easily been avoided, with the problem detected with sufficient lead time for service action, by the operation of a vibration monitoring system.

case study

tor, because it proved to be the optimal solution offering reliable absolute vibration safety monitoring with some key condition monitoring functionality and an interface bus for exporting data.

VC 1500 Compact Monitor

The VC-1500 acquires vibration signals via accelerometers mounted on the bearing casing to monitor the condition of the shaft, radial sleeve bearings and the axial thrust bearing. The absolute radial vibration is integrated to a velocity signal that actually provides more complete vibration data on the components than what can be provided by a displacement sensor. The accelerometer does not have as wide a dynamic range as a displacement sensor at very low speeds, but this is not a problem in many applications, and it is much easier to install and maintain.

The VC-1500 monitor is a two-channel absolute vibration monitor with two user-defined alarms and relays. A 4-20mA output is also available for each channel. Additionally, the VC-1500 enables temperatures to be monitored from the same two channels but these are not currently being used at Aunfoss since the bearing temperature is being monitored by the existing instrumentation.

Data display, trending and system control of the VC-1500 is undertaken by a PC server via a USB/CAN bus interface. The VC-1500 unit itself has a local display for data trending and analysis.

Although the functionality is currently not being fully utilised at Aunfoss, one of the special features of the VC-1500 is remote operation via the Internet for acknowledging incoming alarms, resetting relays and changing measurement setups. There is also condition monitoring functionality that enables remote post mortem, trending and frequency analysis of the data.

Several VC-1500 devices can be integrated into a single network, thereby enabling effective monitoring and diagnostics of several machines. Two individually adjustable data transmission rates enable the user to respond flexibly over any distance within a plant.

Monitoring System Configuration

Two VC-1500 monitors are used for each turbine at Aunfoss (see Figure 5 on the next page). One monitor is used for the turbine guide bearing, which is equipped with two radial X-Y accelerometers installed 90 degrees

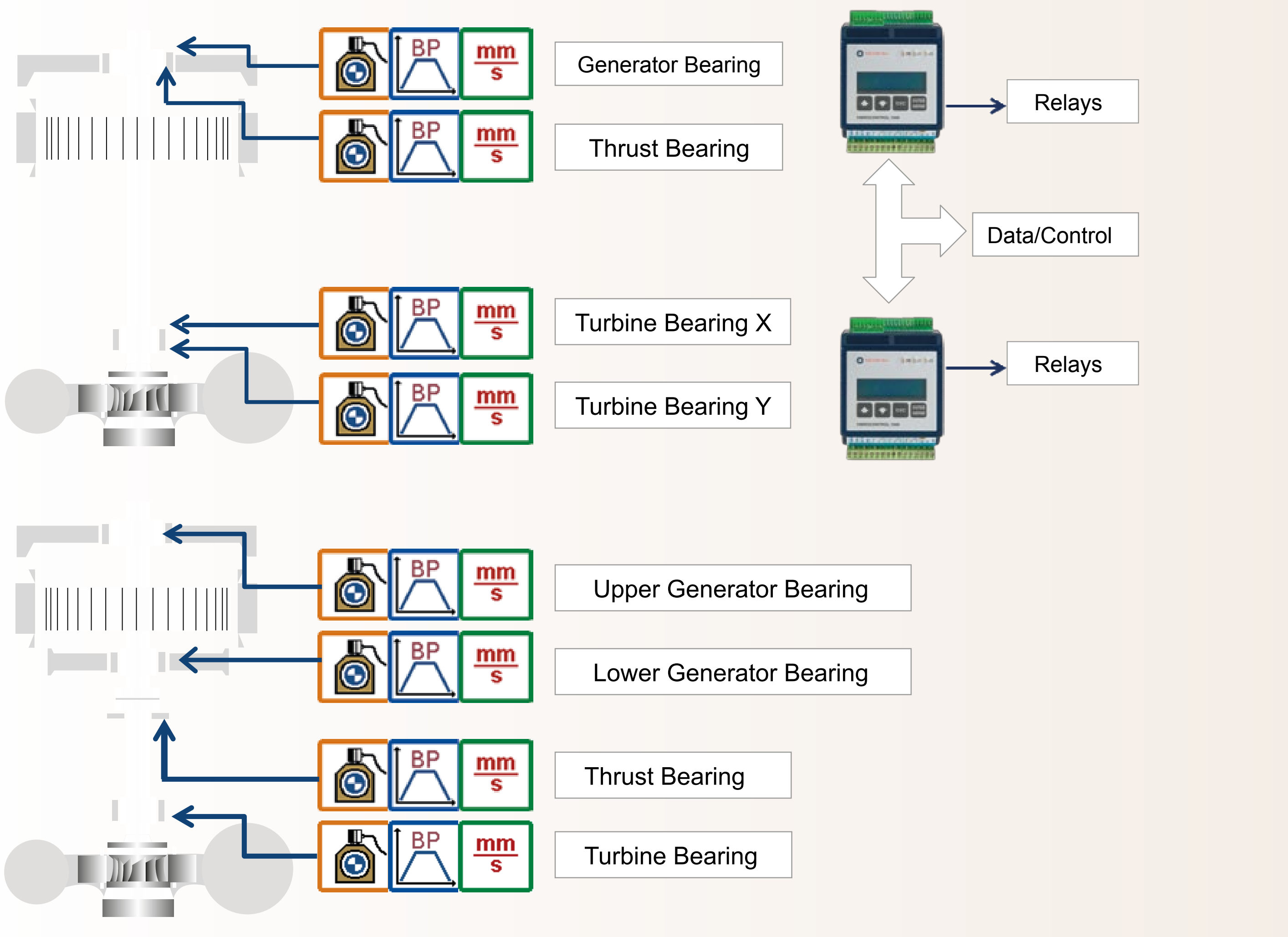

Figure 5. Top, the monitoring system configuration at Aunfoss. Bottom, a typical installation configuration for a 3-bearing hydro generating unit construction, of which NTE has several (this is shown for illustrative purposes).

apart. The second unit is used to monitor the generator bearing, with one accelerometer in a radial direction and the other for the thrust bearing in an axial direction. The accelerometer installation is shown in Fig. 6.

Relay signals are wired to the DCS and emergency shutdown system for tripping the machine if the vibrations indicate an impending failure (which could be catastrophic). A trip multiplier function in the VC-1500 prevents tripping the machine when high vibrations occur due to start-up/synchronization. Data display and system control can be undertaken locally or by a PC server via a USB/CAN bus interface. The two VC-1500 monitors are typically installed in a cabinet close to the generator in the power station, as shown in Figure 7.

Figure 6. Examples showing the accelerometer installation, highlighting the ease of installation and maintainability on the turbine bearing (Brüel & Kjær Vibro AS 0070/02 accelerometers are used). The accelerometers are shown mounted on the turbine bearing casing, with one in the X direction (right) and one in the Y direction (left). The generator bearing (not shown) is mounted with one X radial and one Z direction axial accelerometer, 90 degrees apart.

Vibration Measurements and Alarm Setup

As shown in Figure 4, each VC-1500 monitor is set up for a specific monitoring task. This is summarised in Table 1.

Conclusion

As a result of changes to operational strategy, many small generating units are subjected to extra loading which can lead to unpredictable and more frequent downtime. The downtime of a single unit can be costly because it can lead to a cascading effect of reduced productivity in the downstream chain. As demonstrated in the case story at Aunfoss, the original monitoring systems were not necessarily designed to detect all the important potential failure modes with sufficient lead time.

Aunfoss wanted to implement an effective vibration monitoring strategy to avoid this downtime and after thorough research and careful selection, decided on the VC-1500 vibration monitor for this purpose. The VC-1500 fulfils important market requirements, provides the necessary functionality not present in inexpensive vibration monitors and meets the economic requirements that expensive rack-based monitoring systems cannot fulfil. This is important for monitoring and protecting critical hydroelectric generating units that are relatively small, and installed in sets of one or two units per power station. The important functionality includes:

- Two alarm levels and trip override
- Absolute vibration measurements
- Standard economical transducer configuration
- Simple connections and user interfaces
- Condition monitoring capability such as trending
- Remote monitoring, data display and control

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Figure 7. Cabinet installation for the two VC-1500 vibration monitors.

Accelerometer Location (Orientation)	SETUP: Measurement	SETUP: Initial Alarm limits	Fault detection by absolute vibration from any vibration source
Generator bearing (Radial, X)	Overall velocity bandpass, RMS (ISO:1Hz - 1000Hz)	Alert limit = 2mm/s Trip limit = 4mm/s	Loose bearing, Loose foundation, bearing damage, lack of lubrication, overload, wear, misalignment, unbalance and any other radial vibration
Turbine bearing (Radial, X-Y)			
Thrust bearing (Axial, Z)	Overall velocity bandpass, RMS (ISO:1Hz - 1000Hz)	Alert limit = 2mm/s Trip limit = 4mm/s	Axial stator movement, thrust bearing problems, detection of any axial vibration

Table 1. Typical VC-1500 setup for monitoring small hydro generating units with two guide bearings.

events

2011-12

04 - 10 Oct. 2011

Smart 2011
Linz, Austria
International Conference and Exhibition
www.smart-automation.at

The 7th Smart Automation Austria will be held at the Design Center in Linz. The international event is the information and communication platform of the Austrian automation industry. Visitors of the automobile, chemical, electronics, plastics, and other producing industries will also be able to benefit from an extensive conference program. Brüel & Kjær Vibro products will be presented at the booth of our Austrian sales team.

23 - 27 April 2012

Hannover Fair 2012
Hannover, Germany
Power Transmission and Control Technology – Automation – Energy – Subcontracting and Services – Cutting Edge Technologies
www.hannovermesse.de

It remains without rival as a showcase of industrial technology, with more than 65,000 exhibitors from 65 countries. Brüel & Kjær Vibro's booth will be located in the Industrial Automation section.

20 - 22 Sept. 2011

HydroVision Brazil 2011
Rio de Janeiro, Brazil
International Conference and Exhibition
www.hydrovisionbrazil.com

Latin America's newest event focuses on advancing the development of the region's hydroelectric power and dams/civil structures sectors. HydroVision Brazil provides a strategic platform for introducing the region's development opportunities and expertise and features a practical, solutions-oriented conference program and simultaneous exhibition focused on new technologies, future trends and business solutions. Visit Brüel & Kjær Vibro at booth no.128.

17 - 19 Oct. 2011

Hydro 2011
Prague, Czech Republic
International Conference and Exhibition
www.hydropower-dams.com

Hydro is an annual conference in different parts of the world. The trade fair with symposia are dealing with all technical, environmental, social and economic aspects of hydro plants and future projects for developing multipurpose water resources in order to cover the increasing demand for energy in times of climate change. Our Austrian sales team will be on site to answer visitors' questions regarding monitoring technique of hydro power machinery.

3 - 6 June 2012

AWEA Wind Power 2012
Atlanta, USA
International Conference and Exhibition
www.awea.org/events/

The American Wind Energy Association's annual WINDPOWER Conference & Exhibition is recognized as one of the world's premier wind energy trade shows, bringing together attendees and exhibitors from every aspect of the industry. Exhibitors display the latest industry products and services from manufacturing leaders, component suppliers, and other wind energy organizations. In 2012, Brüel & Kjær Vibro will exhibit as part of the Danish Pavilion.