Borealis Porvoo in Finland is a fully integrated petrochemical complex which comprises five separate plants and employs 850 people. In this paper, the authors describe the condition monitoring (CM) approach employed, which is built around the use of the complex's Metso Distributed Control System (DCS) and ABB process history (PMS) as the primary portal for online data. All the assets in the complex are included in a CM programme which utilizes a route-based portable data collector (PDC). In addition, the most 'critical' assets (such as turbomachinery and screw compressors) are monitored with GE's Bently Nevada 3500 Series continuous machinery protection systems, connected to the DCS and PMS.

Online Condition Monitoring reaps benefits for Borealis

An important component of Borealis' strategy is that rather than using separate condition monitoring software for their online systems, they transmit the condition data from these systems to their DCS, allowing operators to see both asset condition information and process information within a single HMI (Human Machine Interface) environment. This eliminates the need for operators to learn an entirely different system and ensures that condition data and process data are available simultaneously on the process control system. This, in turn, helps ensure that asset condition receives as much attention as process condition.

Identifying a Need for Periodic Online Monitoring

In addition to 'critical' and 'non-critical' assets, a third category was identified by Borealis's engineers in the Summer of 2008 when they upgraded four seawater pumps and recognized that the PDC routes alone were inadequate. These so-called 'essential' assets would not necessarily require continuous machinery protection, but would require an online system to collect data on a more frequent basis than through the monthly PDC regime, particularly during startups. Such a system would need to provide special signal processing functionality, such as acceleration enveloping, normally associated with the monitoring of rolling element bearings. As with the machinery protection systems deployed on the complex's 'critical' assets, the online system for addressing 'essential' assets should provide condition data directly to the DCS.

Borealis consequently identified the following requirements for an online system for these newly identified 'essential' assets (ie their four seawater pumps – *see Figure 1*) whose asset status fell somewhere between critical and non-critical. The pump trains consist of an electric motor, gearbox, and the driven machine (seawater pump), all using rolling element bearings. The online system must, therefore, be capable of detecting fault development in these machines at an early stage.

Figure 1 – Overhead view of seawater pump, one of four used in Borealis' ethylene plant

Each machine uses different bearings and runs at different rotational speeds controlled by the intermediate gearbox. Thus, it must be possible for the signal conditioning (such as filtering) for each measurement point and its derived parameters to be set independently of any others. In other words, a 'shared' filtering and signal-processing scheme whereby all channels used the same settings would not meet the requirements. Thus:

- The online system must allow a direct interface to the DCS.
- The online system must use the DCS as the primary display environment rather than requiring separate, special-purpose condition monitoring software.
- The online system must provide buffered outputs, allowing a route-based PDC to be easily. connected for collection of dynamic signals as needed and during monthly routine routes.
- The online system should provide at least one direct amplitude value from each pump to track condition in real time during startups.
- Direct overall amplitude alone is insufficient for condition monitoring purposes – the online system must, therefore, be able to provide more comprehensive data than just overall amplitude, without the need to rely on the PDC.

Borealis approached GE's Bently Nevada team with these requirements and after careful review the following solution was proposed: each pump would be monitored via eight accelerometers: 2 on each motor, 4 on each gearbox and 2 on each pump. Thus:

- One accelerometer from each pump would be connected to a Bently Nevada 1900/65A monitoring

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system *(Figure 2)* - a multi-channel stand-alone system capable of accepting up to 4 vibration inputs and 4 temperature inputs. Signal processing could be applied to each vibration input, allowing a single input to generate up to four different measured parameters such as direct amplitude, enveloped acceleration, integrated acceleration (ie velocity), and others. Because it is a continuous monitoring system, at least one channel on each pump train is continuously monitored and trended, allowing real time data display during pump startups.

- The monitoring system would be connected to the Metso DCS via Modbus® protocol.
- The other 7 accelerometers from each pump train would be routed to a junction box (*Figure 3*) that splits the signals between a 'scanning' (rather than continuous) online system and a buffered output connector. A selector switch would allow the user to route the desired signal to the buffered output connector for connection to a PDC, but would not affect whether the signal was routed to the 'scanning' system.
- The 'scanning' system would employ the Bently Nevada™ Trendmaster® Dynamic Scanning Module (DSM). A DSM *(Figure 4)* can accept several thousand sensor inputs (vibration, temperature, pressure, etc) and sequentially scan each of its sensor inputs in a polling fashion. It is a cost-effective approach for online monitoring points that does not require continuous machinery protection.
- The DSM would communicate its intermittently measured values to the Metso DCS via Modbus® protocol.
- The ABB PMS would thus provide a unified display environment for the online data from the 3500 series continuous monitoring systems, the 1900/65A systems for one accelerometer on each seawater pump, and the DSM hardware for the intermittently sampled data from the other 7 accelerometers on each seawater pump.

Figure 2 - A Bently Nevada 1900/65A Monitoring System

Figure 3 - Junction box showing selector switch for connection of accelerometer signals to PDC

Figure 4 - A Bently Nevada™ Trendmaster® Dynamic Scanning Module (DSM)

This system allows the condition monitoring data summarized in *Table 1* to be sent to the DCS.

From 1900/65:	• **Direct amplitude (RMS)** Units: RMS velocity (mm/s) Purpose: general machine condition • **Enveloped amplitude** Units: peak acceleration (m/s²) Purpose: bearing condition • **High-frequency acceleration** Units: peak acceleration (m/s²) Purpose: gear teeth condition
From DSM:	• **Direct amplitude (RMS)** Units: RMS velocity (mm/s) Purpose: general machine condition • **Direct amplitude (0-pk)** Units: Velocity (mm/s) Purpose: general machine condition • **Enveloped amplitude (RMS)** Units: RMS acceleration (m/s²) Purpose: bearing condition • **Enveloped amplitude (0-pk)** Units: peak acceleration (m/s²) Purpose: bearing condition • **High-frequency acceleration** Units: peak acceleration (m/s²) Purpose: gear teeth condition • **Filtered Velocity – Rotor Region** Units: Peak velocity (mm/s) Purpose: unbalance, misalignment, looseness, and other malfunctions that occur predominantly near the machine's rotative speed (1X) • **Filtered Velocity – Prime Spike** Units: Peak velocity (mm/s) Purpose: well-developed bearing problems that occur at frequencies well above shaft rotative speed (1X)

Table 1 – Summary of static data values supplied from online CM hardware to DCS.

A very important feature of the resulting system is that it not only provides these additional static values to the DCS beyond just simple overall values, but also the filtering frequencies for each of the static values in *Table 1* can be configured individually for each measurement point, thus enabling clear and precise analysis tools to be developed for various purposes.

Case History 1: Gearbox Bearing Problem

Soon after the system had been commissioned, operators noticed high-frequency vibration trends starting to increasve on all measurement points for the gearbox on one of the pumps, although overall velocity trends did not show any changes until several months later. *Figure 5* shows the relatively stable trend of the overall velocity levels while the high-frequency acceleration levels show a clear upward trend.

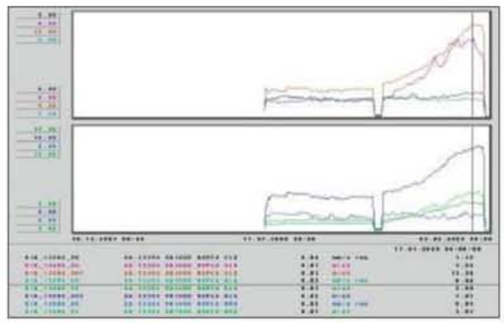

Figure 5 – PMS screen showing trends of gearbox high-speed shaft upper and lower bearing vibration, filtered to various frequencies and with various signal conditioning applied.

Armed with this early warning information from the online system, PDC data was gathered showing impacting occurring at a frequency corresponding to the inner ring. Normally, this would suggest the bearing was worn out. However, because the gearbox was brand new, the OEM was consulted for an opinion, and a vibration survey and endoscope inspection were also carried out. The vibration survey (*Figure 6*) showed impacting occurring at a frequency corresponding to the bearing's inner ring. The endoscope inspection (*Figure 7*) showed damage to the rolling elements themselves. Based on the results, it was agreed that the upper bearing was faulty and the pump was subsequently scheduled to be removed from service.

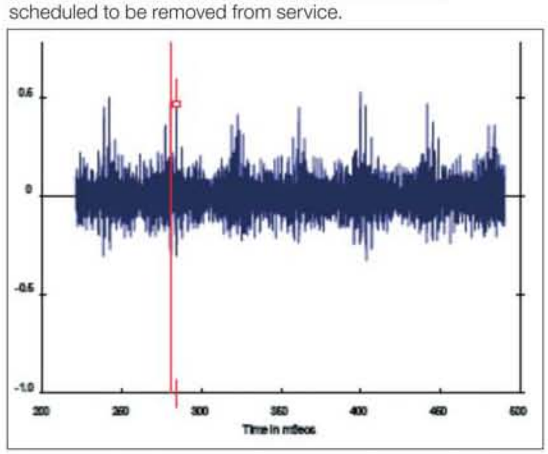

Figure 6 - Timebase from PDC showing impacts occurring at inner ring fault frequency

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Figure 7 - Photo showing damaged inner ring (on the left) surface on the hs shaft.

Case History 2:
Snow induced resonance:

On the evening of 24 November 2008 there was a severe snow storm, which resulted in large accumulations of very wet snow. The control room operators noticed that the overall RMS velocity started to increase on the non-drive end of one of the pumps, but all other vibration values were stable (*Figure 8*).

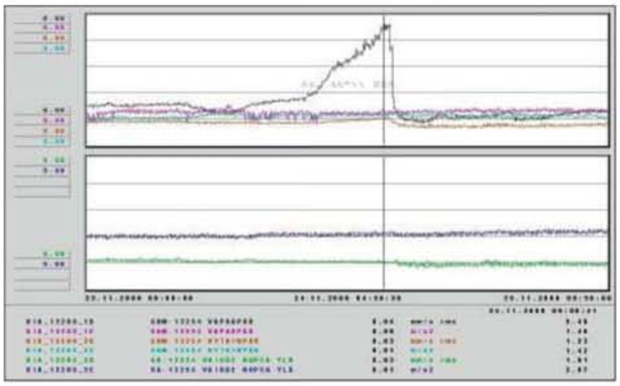

Figure 8 – PMS screen showing trends of pump NDE bearing where overall RMS velocity increases markedly, but all other parameters from this bearing remain relatively stable.

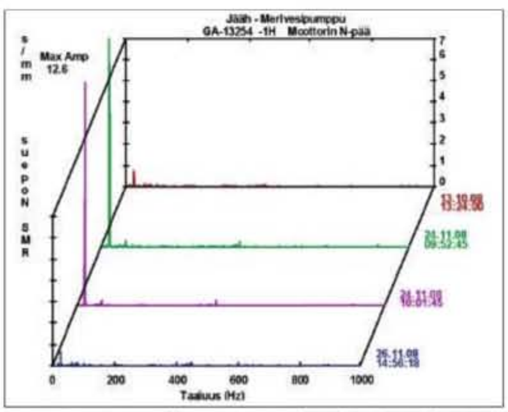

Figure 9 – Spectrum trend from PDC showing elevated 1X vibration but normal bearing-related frequencies (note that readings were taken with a magnetic-mount temporary sensor).

By 7am the following day, the trip level was reached, but it was agreed to wait until a CM technician could perform a closer analysis with a PDC, particularly as only a single variable was showing this dramatic increase. First, the system was checked to rule out any instrument faults as the cause of the high reading, and it was confirmed that none existed. Spectra collected by the PDC (*Figure 9*) showed high amplitude at only 1X (rotative speed) without corresponding increases at other bearing-related frequencies, indicating vibration primarily in the rotor region, consistent with the trends from the online system.

While technicians were looking at the pump, they noticed that there was heavy snow on top of the motor shield and, for no particular reason, began to remove it. They were immediately informed by control room operators that the vibration levels were decreasing. The technicians then removed all the snow, resulting in a return to normal vibration levels. Afterwards, it was verified (by an impact test) that the motor runs slightly below a structural resonance – *Figure 10*. It was further reasoned that the addition of mass to the system (in form of wet snow) had effectively reduced the frequency of this resonance to coincide with the excitation provided by the running speed (1X) of the motor. The result was significantly elevated levels of 1X structural vibration, exactly as observed. Mathematically, this effect can be expressed as – where ω is the resonant frequency, k is system stiffness, and m is system mass.

$$\omega = \sqrt{\frac{k}{m}}$$

It can be clearly seen that adding mass (ie increasing m) while holding the stiffness (k) constant has the effect of reducing the system's resonant frequency.

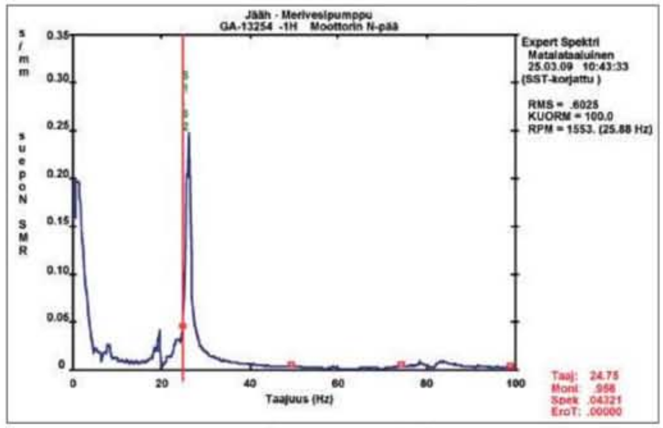

Figure 10 – Seawater pump resonance frequency measured with an impact test.

Conclusions

Both case examples illustrate the value of Borealis' online system for their seawater pumps. In the first instance, a bearing problem that would normally have gone unnoticed for at least a month between PDC rounds was spotted early on, allowing a defective bearing to be identified on a new gearbox and remedial action to be taken before serious damage could occur. In the second instance, operators were immediately alerted to a potentially damaging structural resonance and were able to correct it, albeit somewhat fortuitously. Because this incident made plant personnel aware of the close proximity between the structural resonance and the running speed of the motor, they will be able to proactively intervene in the future.

The online systems installed by Borealis work together to monitor their essential and critical assets, supplemented by a portable data collection regime. There are three significant factors that have contributed to this successful application:

1. Borealis uses their DCS and PMS as the primary user interface for vibration and process readings, helping to ensure that asset conditions are given as much attention as process conditions and that online CM systems are providing data in real time.
2. Borealis collects comprehensive static vibration data, not just overall amplitude values; additionally, they have access to dynamic data, which is absolutely vital in the ability to diagnose root cause.
3. Borealis now has an experienced machinery diagnostic engineer on-site, capable of interpreting dynamic data and correlating it with the static data available in the DCS.

In the future, Borealis intends to supplement their CM systems with online dynamic data collection, reducing the need to rely upon manually collected data from a PDC. This system can co-exist with the data currently delivered to their DCS and PMS, providing a simplified view of asset condition for operators while simultaneously providing a more detailed view of asset condition for machinery specialists.