Condition Monitoring Pays Off for Finnish Pulp & Paper Mill

How UPM Wisaforest Uses System 1® Software for Improved Asset Management

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Introduction

This article explores the use of System 1® software in conjunction with Trendmaster® Pro data acquisition hardware at a pulp and paper mill in Finland. Applied to nearly 50 discrete pieces of process machinery throughout the mill, the system has only been in operation since April 2004, yet has already been instrumental in identifying and solving more than ten separate machinery problems. An overview of the facility and the online condition monitoring system is presented, along with five case histories illustrating how equipment malfunctions are being identified and resolved.

Background

UPM-Kymmene's Wisaforest facility is a pulp and paper mill situated on the Gulf of Bothnia's coast in Pietarsaari, Finland. The pulp mill was originally constructed in 1935 and was designed around a sulfite process. The plant was switched to a kraft process during a 1962 rebuild, and then in 1976 underwent major upgrades to the hardwood and softwood pulp lines. Production capacity today is 800,000 Air Dried tons per annum (ADt/a) of pulp and 180,000 ADt/a of kraft and sack papers. The mill generates its own power and is entirely self-sufficient in this respect. It utilizes two production lines throughout, with exception of the new recovery island (WISA 800 REC project), discussed next.

The new recovery island at UPM-Kymmene's Wisaforest pulp and paper mill in Pietarsaari, Finland. The result of the WISA 800 REC project, the new unit boosted the mill's pulp output to 800,000 ADt/a while decreasing environmental discharge to best-available-technology levels.

WISA 800 REC Project

The WISA 800 REC (RECovery) project had several goals, summarized in Table 1. The project entailed a single line to replace the mill's two previous recovery lines, which were in bad mechanical condition and date from 1962 and 1975-1976, respectively. This new line is sized to meet the mill's pulp production capacity of 800,000 ADt/a. To achieve this capacity, the two existing fibre lines were improved, resulting in better strength properties of the pulp. Additionally, a new sawdust cooking line was added, providing more flexibility in the raw material base by allowing the use of sawdust as feedstock for selected pulp qualities, rather than burning it as had been done previously. This delivers both environmental advantages (fewer emissions) and process advantages by allowing the mill to draw from a larger pool of locally available sources for pulp feedstock.

In addition to the goals for the WISA 800 REC project, the scope was likewise very extensive as summarized in Table 2. The main equipment suppliers for the recovery island were Andritz Corporation for much of the process equipment, Siemens AG for the main turbo-generator, and Metso Automation for the process control system. For the condition monitoring (CM) system, GE Energy was chosen to supply their Bently Nevada® solutions consisting of System 1 software, Trendmaster Pro hardware, and a 3500 monitoring system. Startup of the new recovery departments occurred on-schedule in April 2004.

Table 1 –

GOALS OF WISA 800 REC PROJECT

- Become one of the most cost-efficient pulp mills in Europe
- Increase pulp capacity to 800,000 ADt/a
- Decrease the environmental discharge levels to best-available-technology
- Replace old and worn out equipment.
- Expand raw material options by using sawdust for pulp production (instead of burning it)

Table 2 –

SCOPE OF WISA 800 REC PROJECT

- **Service Module B**
  office building, control room, maintenance rooms
- **Evaporation Plant**
  7+ stages, (1,050 tons H_2O per hour, 82 - 85 % dry solids)
- **Recovery Boiler**
  steam production 180 – 205 kg/s, 92 – 102 bar, 492 – 505 °C, 4,450 tons dry solids per day
- **Back-Pressure Turbine-Generator***
  143 MW
- **Causticising Plant**
  10,000 m^3/day white liquor
- **Lime Kiln**
  750 tons of CaO per day
- **Steam Condensate Treatment**
  200 litres per second
- **Tall Oil Plant**
  192 tons per day

* According to Siemens AG, this is the world's largest back-pressure turbine generator used in the pulp & paper industry.

Table 3 –

CONDITION MONITORING SYSTEM SUMMARY

Department	Number of Machines	Machine Types	Monitoring System
Evaporation	6	pumps, mixers, fan	Trendmaster Pro
Recausticizing	18	pumps, compressors, mixers, filters, fan	Trendmaster Pro
Recovery Boiler	14	pumps, mixers, fans	Trendmaster Pro
Lime Kiln	11	pumps, mixers, filters, fans, lime kiln, supporting rolls and drives	Trendmaster Pro
Turbo-Generator	1	143 MW back-pressure steam turbine	3500 Series

The Lime Kiln rotates at extremely slow speeds (~10 rpm) on supporting rolls that use fluid-film bearings.

The Condition Monitoring System

Employees working with the WISA 800 REC project defined the scope of the CM system. Production line leaders, assisted by the maintenance department, first defined the machines that were most critical for the plant production. Once the machines to be addressed were determined, the appropriate monitoring technology was then identified. The results of the plant's evaluation are summarized in Table 3.

Large, high-speed turbomachinery generally warrants a conventional rack-based continuous monitoring system, and the plant chose Bently Nevada proximity probes coupled with the 3500 Series Machinery Protection System. With exception of the lime kiln, as discussed below, all other machinery uses rolling element bearings and is more appropriately addressed by a monitoring system using a scanning architecture. Accelerometers (Bently Nevada 200350) were deemed appropriate for these machines, linked to the Bently Nevada Trendmaster Pro system. Both the 3500 and Trendmaster hardware were equipped with System 1 software connectivity, allowing these systems to be linked into a common diagnostic platform.

[Editor's Note: For additional information on the classification of machinery criticality and selection of corresponding monitoring technology, please refer to the article *Trendmaster Goes Pro* in the Second Quarter 2004 issue of ORBIT, pp 30-47.**]**

The massive bearings on the lime kiln supporting rolls are fluid-film type and the rotational speed is very low (approximately 10 rpm). Initially, the plant determined that these 16 bearings would use X-Y proximity probes for vibration monitoring. However, this decision was made late in the project, after the kiln had been supplied and installed, making transducer retrofits considerably more difficult than if this had been specified to the OEM for factory installation of probes. Consequently, it was necessary to equip these bearings with accelerometer transducers. It was recognized that this was not an ideal application, but project constraints dictated this compromise. In order to provide rpm and phase reference information, Keyphasor® transducers were installed observing a suitable shaft discontinuity on each clutch.

Wisaforest selected three experienced CM technicians to be the primary users for the condition monitoring system, and these individuals have full configuration privileges for the entire system. In addition, there are five display licenses at the plant, one permitting a display client in the control room, and four for various maintenance and operations personnel elsewhere in the plant.

Project Execution

The project startup meeting was held on 3 December 2003. One of the first items that needed to be defined was the total number of measurement points. This number would determine how many Trendmaster Pro Dynamic Scanning Modules (DSMs) would be required, as each DSM can handle multiple transducer inputs. The number of DSMs required represents a balance between wiring costs, DSM costs, and scanning times. For this reason, each application must be evaluated on a case-by-case basis. While a single, centrally located DSM can handle hundreds of measurement points, the wiring costs can be quite high. In addition, the more points assigned to a single DSM, the slower the scanning time will be as it must multiplex among all its inputs. The most economical solution is often to install multiple DSMs, where a cluster of measurement points occur, and then to link the DSMs using conventional wired or wireless Ethernet. Due to the small bandwidth requirements, this can often be achieved over existing plant networks rather than requiring a dedicated CM network.

For the WISA 800 REC project, it was determined that 10 DSMs would be the optimal number, reflecting the appropriate balance of wiring costs, hardware costs, and scanning times. Next, the locations for these DSMs were determined. This will vary from one application to the next based on wiring topology, availability of power and network connections, and other factors. The final step was to determine project installation scope. It was decided that Wisaforest would be responsible for providing all Local Area Network (LAN) connections along with locally available power at each DSM location. The GE Energy team would be responsible for installing all sensors, cabling, cabling shields, junction boxes, and DSMs. In addition, they would be responsible for the installation and configuration of the System 1 software along with integration to the plant's process control system.

When field hardware installation was approximately 20% complete, System 1 software installation commenced. A significant element of the overall project was to configure the software with appropriate monitoring parameters such as alarm settings, frequency bands, point labeling, and many other details. The machines in the facility vary from one another in many ways including operating speed (1 – 3000 rpm), drive mechanism (direct, belt, and gear), and operating mode (constant speed, variable speed, constant load, variable load).

This entails a high level of cooperation between numerous suppliers, plant personnel, and GE Energy to determine and document the correct values for all settings, and then enter these values into the software's configuration screens.

In addition to the items already noted, a project of this magnitude entails many other details, a few of which are summarized below:

- Server model and its installation location
- Determination of LAN type (copper or fiber) and connections thereto
- Labeling of cables and sensors
- System wiring topology
- Interconnection of DSM hardware and 3500 System to System 1
- Ongoing dialog with machinery OEMs
- External computer support

- Coordination of machine test schedules with readiness of CM system, allowing analysis of start-up data
- Integration with process control system and appropriate data types for display to operators

The last bullet in the above list merits additional discussion. Originally, the project scope did not include an interface between the process control system and System 1 software. However, as the usage scenarios of the CM system were further defined, the ability for operators to view basic condition information using their process control system was deemed important, while still providing in-depth diagnostic capabilities for rotating machinery engineers via System 1 software's user interface. This resulted in two primary user interfaces: one for operators, and one for machinery specialists. A bi-directional OPC link was used for this interface, allowing the plant to not only import direct amplitudes and alarms from the System 1 platform into the DCS, but also to export numerous process variables from the DCS into the System 1 database.

[Editor's Note: You can read more about the usefulness of process data correlation in a CM system and the importance of making select CM data viewable in the plant control system in the article *Best Practices for Asset Condition Management* in the Third Quarter 2001 issue of ORBIT, pp. 46-47.**]**

Taking the New Recovery Unit into Operation

As anyone who has been involved in a plant startup can attest, one of the most crucial times for the CM system is when machines are tested and brought online for the first time. Problems that may not have been apparent at the factory may surface, or the installation of the machine may have introduced problems (e.g., alignment, piping strain, lube contamination, etc.). Consequently, a very important aspect of the project was to ensure that the CM system was configured and ready for use as each machine was started up.

The first test runs for the new recovery unit started on 12 February 2004. Through careful advance planning and schedule coordination, the CM system was ready to begin monitoring these machines. As other machines were subsequently brought online, the System 1 configuration and commissioning were coordinated to coincide with their start-up dates as well.

By 1 April 2004, when the new recovery unit officially began full-time operation, all measurement points had already been collecting data for several weeks. Subsequently, the team turned its attention to "fine tuning" alarm levels and other system configuration settings, now that actual data was available from the operating machines. During these adjustments, no machine failures could be allowed, and faulty operating conditions needed to remain visible. Wisaforest and GE Energy worked collaboratively to successfully accomplish these objectives in a timely fashion.

As previously mentioned, although the plant started full-time operation on 1 April, machinery testing commenced several weeks prior to that date. During this start-up phase, a number of machinery problems were identified by the CM system, allowing proactive intervention and remedy – even before the entire plant went "live." This early payback of the system and its usefulness during startup activities had been a high priority for the Wisaforest project team and was part of the justification for installing the system in the first place. All participants were extremely pleased that the system demonstrated its value so early in the project. After full-time operation commenced, the system continued to deliver value by logging many other machinery "saves." Several of these saves are summarized next.

Case History #1

Problem: Bearing Lubrication
Machine: Secondary Air Fan
Unit: Recovery Boiler

The secondary air fan is a 600 kW direct-driven overhung fan that is critical for the recovery boiler operation. Shortly after startup, abnormal changes in trends of the high-frequency data from the inboard bearing accelerometer were noted. Figure 1 is taken directly from the System 1 software, showing a 2-month trend of high-frequency data from the accelerometers on the inboard and outboard bearings. The elevated levels on the inboard bearing (blue) compared to the outboard bearing (orange) are readily apparent.

Access platform for Secondary Air Fan.

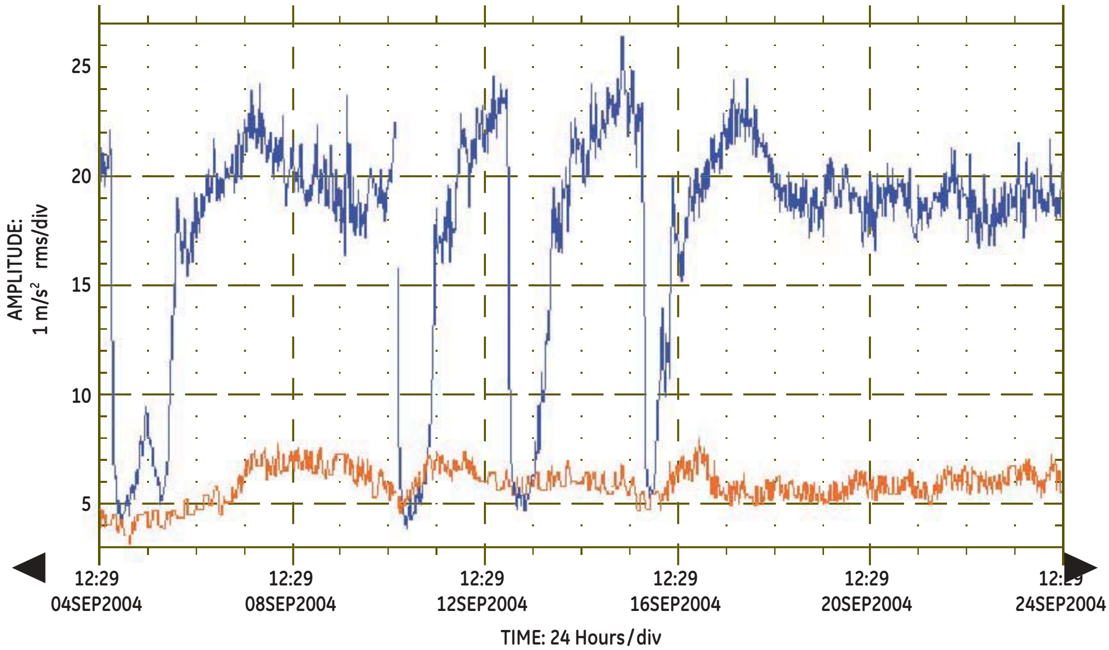

Figure 1 – **Trend of high-frequency vibration amplitude from inboard bearing (blue) and outboard bearing (orange) showing elevated vibration levels at inboard bearing. The "dips" show the intermittent operation of the lubrication system, allowing the inboard bearing vibration to temporarily decrease to normal levels.**

Spectral analysis suggested that the bearing's outer ring was wearing prematurely, and the root cause was ultimately traced to problems with the bearing lubrication system. The prominent "dips" in the trend plot correspond to intermittent operation of the lubrication system, showing a marked decrease in vibration for the inboard bearing when lubrication was flowing properly.

Even though root cause was identified, implementing the changes to the lubrication system was a lengthy process, and the machine was required to operate in the interim. Thus, although the bearing had to be replaced twice during the first six months, the CM system proved very useful in scheduling these replacements, allowing the plant to monitor bearing degradation closely and intervene at the right times, before catastrophic bearing failure and collateral machine damage occurred. Also, these outages could be planned, allowing the bearing change-outs to be performed when impact to production was minimized.

THE CM SYSTEM PROVED VERY USEFUL IN SCHEDULING THESE REPLACEMENTS, ALLOWING THE PLANT TO MONITOR BEARING DEGRADATION CLOSELY AND INTERVENE AT THE RIGHT TIMES.

Case History #2

Problem: Resonance
Machine: Lime Kiln Driver
Unit: Lime Kiln

The lime kiln is a large machine, approximately 4.7 meters (15.4 feet) in diameter and 135 meters (443 feet) long, with extremely slow rotational speeds (as low as 5 rpm). Two drivers provide rotational power, and, depending on production conditions, the kiln must run at different operating speeds. When the kiln ran at higher speeds, higher vibration levels were noted, occurring predominately at 2X. This led plant personnel to initially conclude it was an alignment problem, but realignment of the drivers did not correct the situation and vibration levels remained elevated. A re-examination of the vibration data was conducted, this time by looking at phase and rpm data in addition to amplitude and frequency (Figure 2 and Table 4).

One of two drives for the plant's massive Lime Kiln.

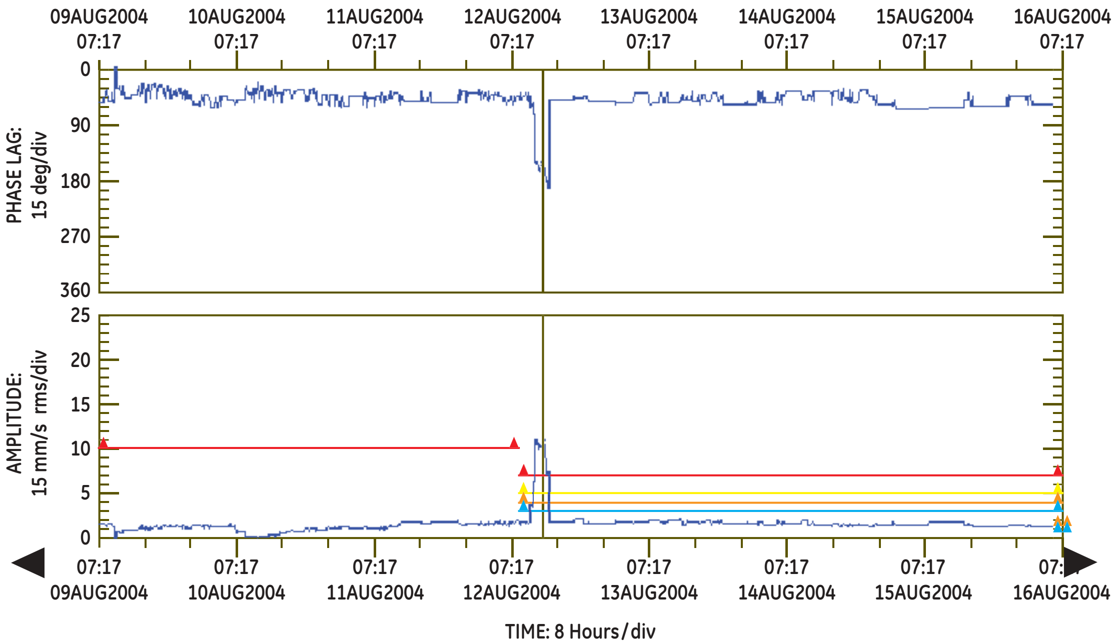

Figure 2 – **Amplitude/Phase/Time (APHT) plot of vibration data from lime kiln drive rollers with motor speed varying between 991 rpm and 1083 rpm.**

Table 4 –

SUMMARY OF 2X AMPLITUDE AND PHASE DATA WITH RPM AND DATE/TIME STAMPS

Date/Time	Speed (rpm)	Amplitude (mm/s rms)	Phase Lag (deg)
12 Aug 2004 10:29:30	991	1.50	51
12 Aug 2004 10:32:23	1030	3.72	64
12 Aug 2004 10:46:47	1031	3.76	62
12 Aug 2004 10:49:40	1033	3.81	60
12 Aug 2004 11:06:58	1050	6.30	74
12 Aug 2004 12:59:24	1066	10.10	160
12 Aug 2004 13:05:10	1068	10.88	166
12 Aug 2004 13:13:49	1083	6.94	184
12 Aug 2004 13:54:11	996	1.82	52

Amplitude reaches a maximum and phase undergoes a 90-degree shift (relative to phase at 991 rpm) at approximately 1070 rpm. Vibration occurs at twice running (excitation) speed or 1070 x 2 = 2140 cpm (36 Hz).

THE PRIME MINISTER OF FINLAND, PUSHED THE "MAXIMUM OPERATION" BUTTON.

Figure 2 is an Amplitude/Phase/Time (APHT) plot where the horizontal axis is time. It has characteristics very similar to a Bode plot, whose horizontal axis is machine speed rather than time; namely, if the machine speed is changing markedly with time, an APHT plot can show a resonance response, just as a Bode plot. The classic features of resonance are two-fold: First, the filtered (1X, 2X, etc.) amplitude will increase to a maximum at a rotational speed that excites the resonance, and then will decrease as the machine speed goes above this frequency. Second, the phase lag will undergo a 180-degree shift, generally passing through approximately 90 degrees at the point of resonance.

While Figure 2 does not label each individual data point with its corresponding rpm, System 1 software is capable of providing this information as a tabular output. The points clustered between 10AM and 2PM on 12 August 2004 showed the most dramatic shifts in amplitude and phase, and coincided with a change on the kiln from low-speed operation to high-speed operation and back again. A tabular output of the data points in Figure 2 was generated, and a subset of this data is summarized in Table 4, clearly showing the correlation between amplitude/phase changes and running speed, and helping to confirm a structural resonance at approximately 36 Hz.

During subsequent maintenance on the unit, the supports for the drivers were stiffened and strengthened, raising the resonant frequency of the structure and eliminating the vibration problems.

[Editor's Note: Resonance is a well-understood phenomenon in machines and structures, and operation of rotating machinery at a running speed that coincides with a resonance is never done deliberately. Sustained operation at a structural resonance frequency can result in very high vibration amplitudes, fatiguing connections and components, and prematurely wearing the entire machine. However, as this case history shows, it can be equally damaging to operate a machine at a speed that coincides with one-half of the resonant frequency – allowing the normally small 2X vibrations generated by the machine to excite this resonance. Resolution of this problem was instrumental in ensuring the kiln could achieve expected maintenance intervals and maximum useful life.**]**

Case History #3

Problem: Bearing Failure
Machine: Exhaust Gas Fan
Unit: Recovery Boiler

The official dedication for the WISA 800 production unit took place on 24 August 2004. The Prime Minister of Finland was in attendance, and, as part of the ceremonies, pushed the "maximum operation" button, allowing the recovery boiler to reach world-record production capacity for a time. This mode of operation required the exhaust gas fans to run faster, and the CM group began to notice an increase in 2X vibration amplitudes on fan #3, as evident in the APHT plot of Figure 3.

Access platform for Exhaust Gas Fan #3.

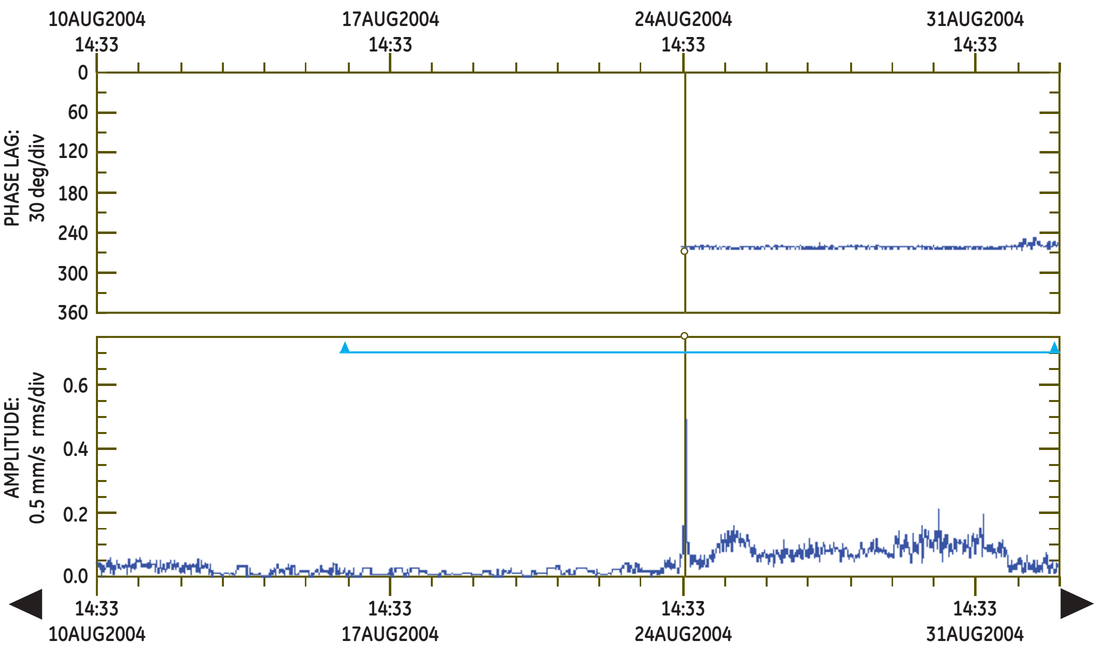

Figure 3 – **Amplitude/Phase/Time (APHT) plot of 2X vibration data from outboard bearing accelerometer on Exhaust Gas Fan #3. Note that amplitudes prior to the cursor location on the plot were so low that phase readings would not trigger consistently; as vibration amplitudes increased, phase readings stabilized.**

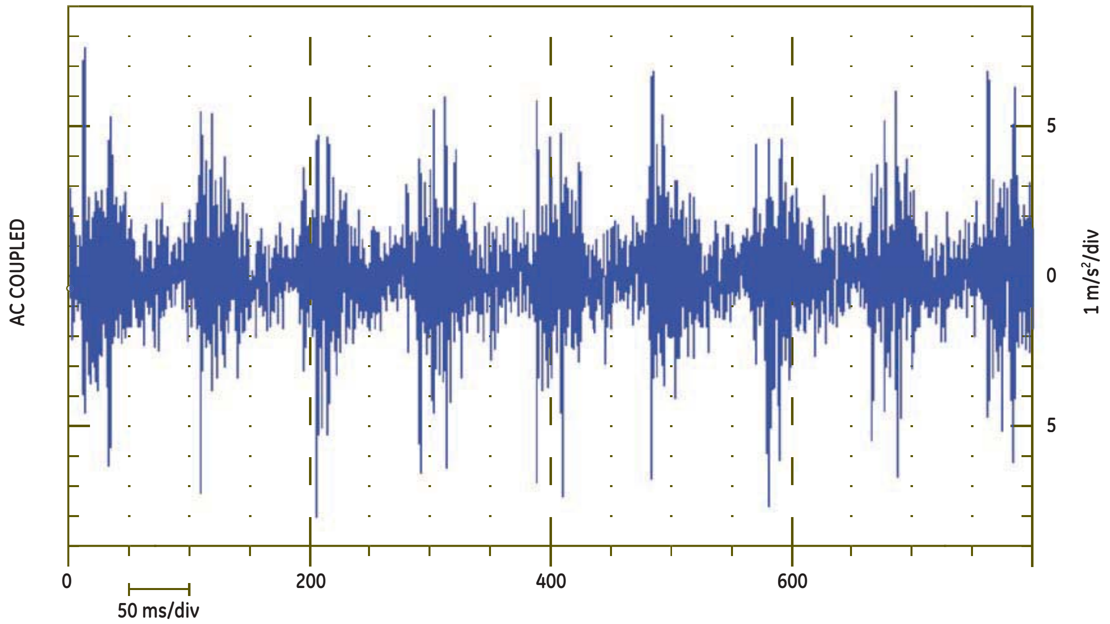

Figure 4 – **Unfiltered timebase plot from outboard bearing accelerometer on Exhaust Gas Fan #3. Note characteristic "ringing" phenomena as inner race defect is impacted by rolling elements.**

Closer examination revealed that the outboard bearing of fan #3 had likely sustained a crack in the inner ring, which can be noted in the timebase of Figure 4. The characteristic "ringing" phenomenon observable in the timebase occurs at the inner ring defect frequency as the cracked inner ring repetitively rotates through the load zone and the rolling elements contact it with greatest force.

Subsequent to that event, the bearing has been monitored closely, allowing operations to continue without replacing the bearing. The defect does not appear to be progressing and is not serious enough to necessitate a bearing replacement until a more convenient time can be scheduled.

[**Editor's Note:** It is not clear whether an invoice for a new bearing will be sent to the Finnish Prime Minister's office.]

FOR WISAFOREST, THE ECONOMIC BENEFITS HAVE SUBSTANTIALLY EXCEEDED EXPECTATIONS… RESULTING IN AN ESTIMATED PAYBACK TIME FOR THEIR INVESTMENT OF JUST 8 WEEKS.

Case History #4

Problem: Faulty Coupling

Machine: White Liquor Pump

Unit: Recausticizing

A typical pulp mill has hundreds of pumps. At Wisaforest, 15 of these were deemed suitably important to connect to the CM system. In late May 2004, as shown in Figure 5, increased vibration levels were noted on the motor driving the white liquor pump. Further analysis revealed that the rubber element in the coupling had deteriorated, allowing metal-to-metal impacting. The coupling was subsequently repaired and vibration levels returned to normal.

White Liquor Pump showing motor and coupling guard.

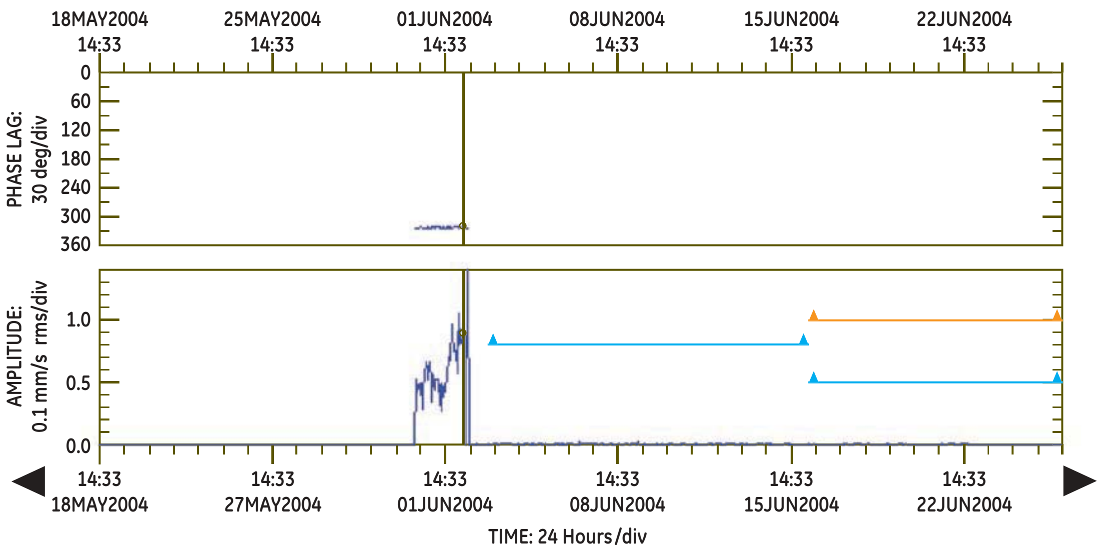

Figure 5 – **Amplitude/Phase/Time plot of 2X data from accelerometer on motor driving the white liquor pump. Note abrupt increase in vibration amplitude beginning on 30 May 2004. A deteriorated coupling insert was found to be the cause, and was replaced on 1 June 2004, returning vibration levels to normal values.**

Case History #5

Problem: Bearing Deterioration

Machine: Mixer Adjacent to Rotary Filter

Unit: Recausticizing

Rotary filters are one of the most difficult machines to monitor since their rotational speed can be extremely low – as little as 0.5 rpm. The bearings are fitted with accelerometers and acceleration enveloping is one of the signal processing techniques used to help identify degradation and other anomalies.

In early September 2004, the CM group began to notice increased vibration levels on the filter's inboard bearing, observable in both the enveloped amplitude and the high-frequency amplitude trends (Figure 6).

The rotary filter. Accelerometers were mounted on the filter bearings and the gearbox (green, upper right); however, the problem was traced to an unmonitored mixer underneath the filter (concealed in lower left corner of photo).

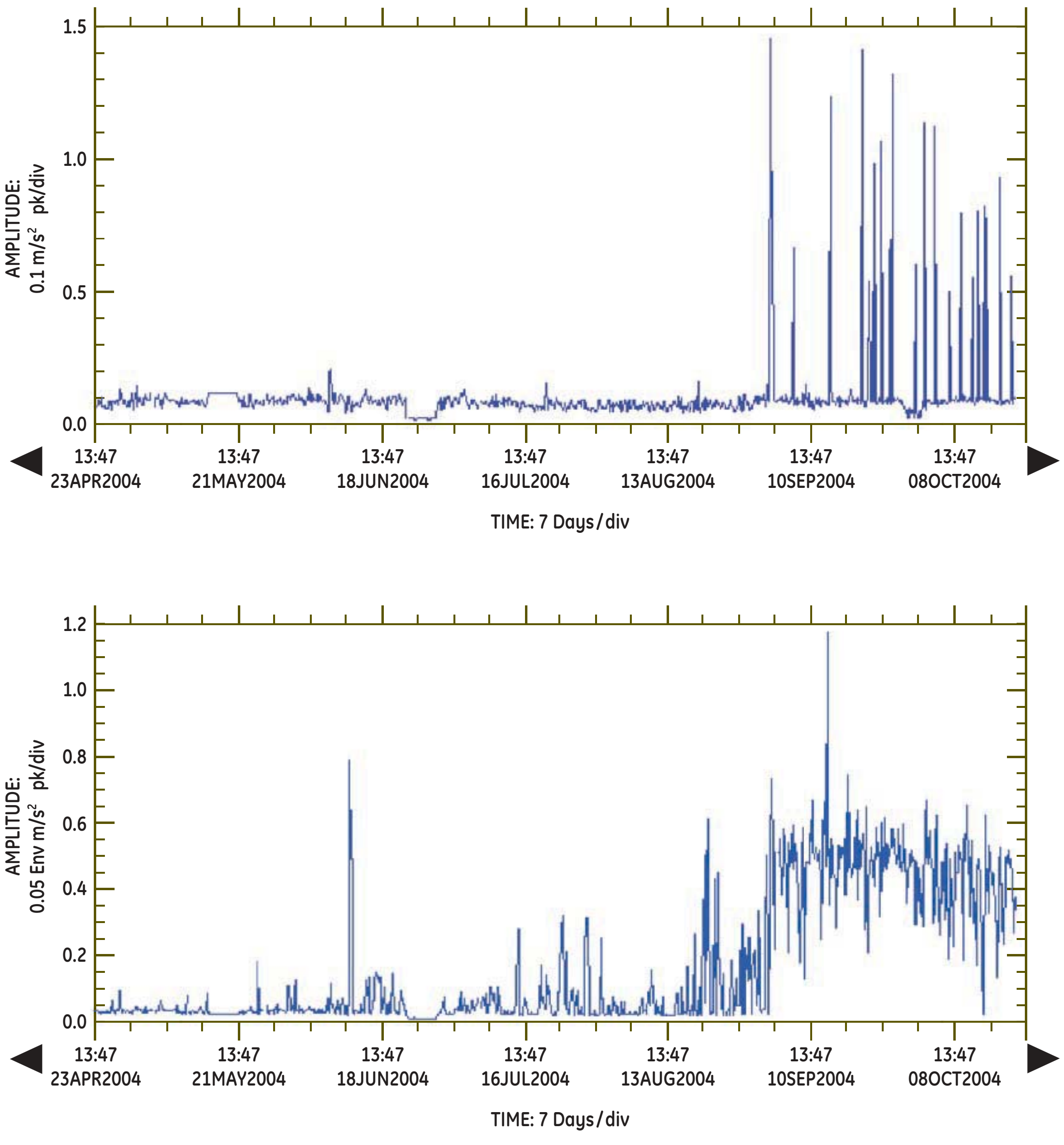

Figure 6 – **Amplitude trends from rotary filter bearing accelerometer showing high-frequency acceleration (top) and enveloped acceleration (bottom). Note increased amplitudes in both signals beginning on approximately 3 September 2004.**

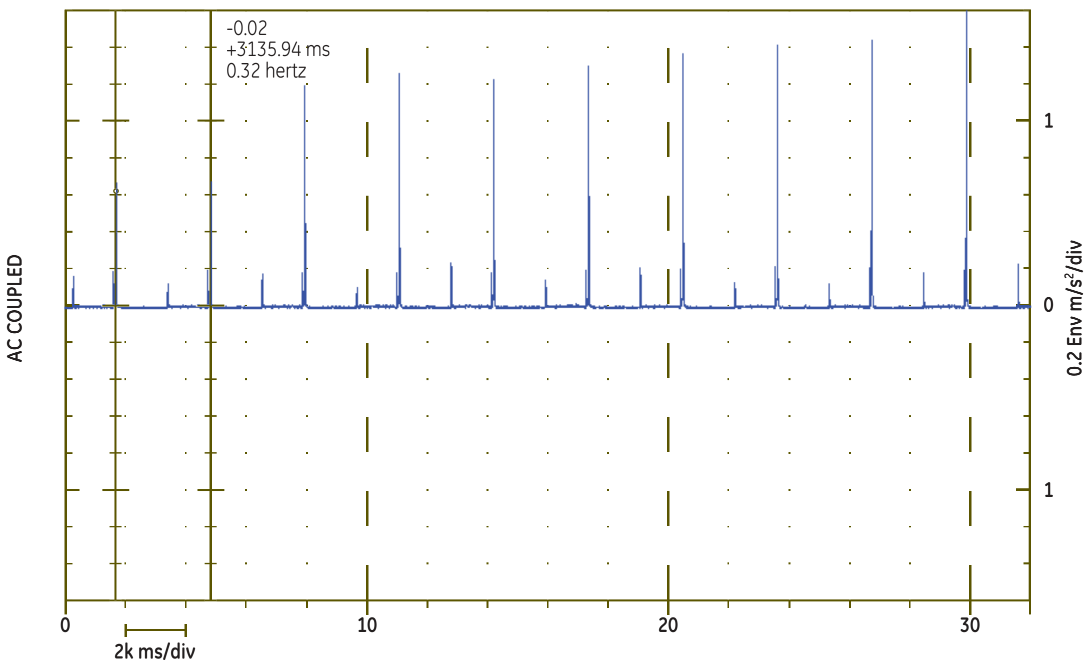

Figure 7 – **Timebase plot of enveloped acceleration showing clear evidence of impacting. Spectral analysis yielded frequencies that did not coincide with bearings used on the rotary filter, leading the plant to look for faults elsewhere.**

The enveloped acceleration timebase (Figure 7) showed very clear evidence of periodic impacting, but examination of the spectral components did not yield any frequencies corresponding to the bearing geometries or rotative speeds of the filter or its gearbox. A visual examination of the filter gave the reason: it was not the filter at all, but rather a separate mixer, located below the filter, with a damaged bearing. Although the mixer was a *totally unmonitored machine*, the impact vibrations occurring from its faulty bearing were being mechanically coupled into the accelerometer on the filter bearing, located nearby. The root cause was found to be broken lubrication piping feeding the mixer bearing, which was subsequently repaired. However, the bearing had been irreparably damaged and had to be replaced. This case history is particularly noteworthy in that it demonstrated the sensitivity of the monitoring system to detect changes in even unmonitored machinery. While certainly not recommended as a deliberate CM strategy, it was an unexpected – and, as it turned out – valuable fringe benefit.

Payback

While the users of the CM system are very pleased with its diagnostic capabilities, it is important that we are able to continually justify to plant management and operations the value of condition monitoring and diagnostics in general. For Wisaforest, this translates to economic benefits, and those benefits have substantially exceeded expectations. Several of the machines highlighted in these case histories have a critical role: they will cause a complete stop in plant production if they do not run,

STRONG CREDIBILITY HAS BEEN ESTABLISHED WITH MANAGEMENT REGARDING THE VALUE OF CONDITION MONITORING.

representing substantial lost production costs. Plant personnel have avoided several total outages through use of the system, resulting in an estimated payback time for their investment of just 8 weeks.

Both the maintenance and production departments now view the system as far more than just a tool for strengthening preventive maintenance capabilities – it is viewed as a tool for increasing the mill productivity. Strong credibility has been established with management regarding the value of condition monitoring and its role in ensuring plant uptime, leading the plant to consider expanding the system to additional equipment.

Summary

Wisaforest is achieving ongoing success with their CM system for several reasons:

- Proven, quality technology from a knowledgeable supplier was chosen as the basis for the plant's CM program.
- The plant enlisted the assistance of the supplier to help install and implement the technology correctly.
- Adequate transducers were installed where feasible, including speed/phase, rather than just vibration, allowing confirmation of faults that would have been difficult or impossible to isolate when limited to only amplitude and frequency data (e.g., case history #2).
- Start-up activities were coordinated to include the condition monitoring system as "must have" capabilities before a machine was brought online.
- Plant management made certain that everyone understood the CM program's goals and objectives, and that there was buy-in from all parties. This helped ensure that the system would be used proactively and consistently.
- The CM system was integrated with the process control system, allowing operators to have early visibility to developing conditions, and allowing process data to be available for correlation with vibration data when performing in-depth diagnostics.
- Results were documented, allowing the users to quantify the system's value to management and other stakeholders in the plant.

Consequently, the WISA 800 REC project has led to not only a world-class facility, but world-class asset management practices and world-class results.