Paper Machine Supercalender Vibration Analysis with a DSPcentric, Multichannel Dynamic Signal Analyzer
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ABSTRACT

Paper machines structures and components are notorious for being susceptible to vibration problems. Supercalender sections are perhaps some of the most glaring examples of these issues. These sections are used to impart very high quality surface characteristics to finished paper for optimal printing results. Denim and poly-covered rolls used in supercalender operation are designed to deform in the nip, leading to very difficult to troubleshoot vibration problems. While a variety of condition monitoring strategies have been adopted by the industry in general, they have typically fallen woefully short in the complete diagnostics of supercalender vibration issues. This paper discusses a realtime, DSPcentric dynamic signal analyzer, capable of a unique blend of rotating machinery and structural analysis measurements with simultaneous raw data recording and several dynamic test strategies that were employed to deliver dramatically superior results in the successful characterization and resolution of vibration issues that have long plagued such machinery.

INTRODUCTION

Permanent condition monitoring is employed to varying extents on most paper machinery. Although entire machines may be instrumented for online monitoring of vibration, pressure, temperature and other process signals, it is usually the most critical equipment that is set up for automated data acquisition and diagnostics. Single channel data collectors, used by technicians to perform route based measurements across machinery and/or an entire plant, still makes up the majority of the condition monitoring effort. The data is then uploaded to a system database that provides trending and some automated diagnostics tasks [1]. Permanent monitoring systems typically used multiplexed acquisition of signals, with very few, if any, signals acquired simultaneously. These systems incorporate a single analog-to-digital converter with a high-speed selector switch accessing signals from multiple sources [2]. So, while there may be a large number of signals being acquired, cross channel measurements such as phase are not possible.
Supercalender sections in paper producing plants are standalone machines that pass paper through a stack of rolls and are designed to control the caliper and surface finish of the paper. Obviously, the roundness and mechanical condition of the rolls needs to be maintained at the highest possible levels as they can generate both localized and system-wide vibration and identifying the ‘bad’ rolls can often be an impossible task with the aforementioned instrumentation. ‘Filled’ rolls, shown in blue in Figure 1 and polymer covered rolls, show in yellow, are the rolls used to impart a highly polished finish to the paper. One powerful tool used in the troubleshooting of roll related vibration is synchronous averaging which requires a 1/rev tachometer signal for each roll in the system. In order to identify natural frequencies in the system, the machine is typically accelerated and then decelerated through its operating speed range. This, however, results in an interruption to normal production and generally, only time enough for one or two ramps (called speed trials) is available. Therefore, it is imperative that as many locations as possible be instrumented with sensors for a given test run. Figure 2 shows a typical sensor whose output is velocity and a laser tachometer providing a 1/rev pulse train signal. Using modal and operating deflection shape (ODS) analysis software, frequency response function data is fit to specific frequencies of interest (rotational frequencies of rolls, natural frequencies, etc.) and the motion of the structure can be easily visualized leading to a better understanding of the system dynamics and hence, to a more effective resolution to the problem.
Many predictive maintenance and reliability personnel are now turning to high performance dynamic signal analyzers that offer highly mobile test platforms with significantly increased capability, both in input channels and analysis software. A recent advance in technology, gaining popularity in the industry, is the Abacus platform. Its unique DSPcentric design involves high performance signal processing, including digital decimation at the hardware level that in turn frees up the host computer for display and measurement storage [3]. Figure 3 shows a single Abacus chassis that connects to the host computer via Ethernet. The chassis may contain from 1 to 4 modules, each module consisting of 8 input channels, 2 output channels and 2 tachometer channels. Figure 4 shows the configuration inside each Abacus chassis. Each module contains a Gigaflop Digital Signal Processor to provide the computational power. The input and output channels use 24 bit ADCs and DACs. The chassis uses a Pentium processor to supervise traffic and supports streaming data to a 100 Gigabyte local disk at an aggregate rate of 20Mbytes/sec.
SYSTEM ARCHITECTURE

Abacus is a significant architectural advance. Each module contains its own signal processor as shown in Figure 4. The DSPcentric design is essential to the high realtime analysis bandwidth of the system. Even after decimation filtering the 1 Gigaflop DSP has plenty of spare capacity to always maintain realtime measurements. Whether operating at its maximum bandwidth of 49 kHz or a low 1 kHz, tri-spectrum average measurements with selectable overlap are available in realtime.

![Figure 4. Architecture of Single Abacus Board](image)

Each chassis contains its own disk storage. The local bus disk is essential to the high realtime recording rate of the system. The system uses the 132 MHz PCI bus within each chassis for optimum performance and availability of off-the-shelf components. Ethernet connectivity enables host PC-to-front end as well as wide area network communication.

Specifications for Dynamic Range, Signal to Noise ratio, Total Harmonic Distortion, Alias Rejection and Channel-to-Channel match show that Abacus is an
analog front end that does justice to the 24 bit digitizers. It is the first time that a
dynamic signal analyzer is able to deliver a 150 dB dynamic range in a spectrum,
the entire potential of the 24-bit ADC. Figure 5 shows the flow of data through the
ADC. At its full bandwidth, the input dynamic range is 120 dB, a testament to the
analog design and the 24-bit Delta-Sigma technology. Robichaud [4] has
prescribed a dynamic range of at least 114 dB for machinery diagnostics
applications, but with the technology readily available, that specification is almost
obsolete. Many test and measurement experts believe that the sensor can be
allowed to be weakest link in a measurement chain. That is not true of the analyzer
used for any type of vibration testing.

At lower bandwidths the dynamic range increases, reaching 150 dB at
bandwidths below 1000 Hz. The answer lies in signal processing; onboard DSP is
used for decimation filtering with selective noise rejection. The front end analog
anti-alias filter (AAF) has a cut-off frequency of 350 kHz. Following anti-alias
filtering the data passes through various stages of the Delta-Sigma ADC (stage 1
being a 12.8 MSps modulator or high frequency converter), where the data has 1 bit
resolution. After that the data is digitally downsampled 128 times to yield one of
three primary sample rates, all around 100 kSps (42 kHz), and the data is now 24
bit. Finally, the data is processed in the DSPs, where further downsampling occurs
as needed. For the example in Figure 5 the final data is 5 kSps, and is 32-bit
floating point precision. It should also be noted that the incoming data stream can
be recorded to the local bus disk at the analysis bandwidth or at a different
bandwidth, derived from the same initial clock rate.

ANALYSIS TECHNIQUES AND PROBLEM SOLVING TOOLS

While the specific details of any given project are outside the scope of this
paper, this section examines the various analysis tools and methods applied in
supercalender vibration testing. Troubleshooting equipment in the field can be a
very difficult task and given the number of measurement locations in such
machinery, the task can quickly seem insurmountable. However, a combination of
flexible graphical displays, powerful analysis features and simultaneous realtime
measurement and throughput-to-disk recording capabilities makes it easier to tackle
even the most complex problems. Figure 6 shows how the vibration at a given
measurement location is visualized in both time and frequency domains and in both
acceleration and velocity units. Using a specially designed graph control tool, the
user is then able to index from one measurement location to another. When
performing simultaneous synchronous averaging, dynamic roll profiles (made up to
synchronous time averaged data for one shaft revolution, in a 0-360° polar format)
for every measurement channel may be switched to using a convenient layout
manager as shown in Figure 7. Since the hardware supports the simultaneous
measurement of up to 8 tachometer channels in a single run (note: this may be
increased easily by networking together additional Abacus chassis), it is easy to
analyze the contribution of each roll in the system to every measurement location.
This is the most dramatic aspect of this toolset.
The measurements described above serve to quickly isolate problems associated with one or more rolls. The earlier a roll whose surface is developing a corrugated pattern is identified and taken out of operation for grinding and refinishing, the less material that needs to be removed [5]. However, the system as a whole is also plagued by resonant vibration, where the rotational frequencies of the various rolls and their multiples, excite local or global natural frequencies. The size of the machine sections and the poor access to measurement locations makes standard excitation techniques using modal hammers or shakers ineffective. Therefore, speed trials are used to pinpoint natural frequencies and the speed ranges within which they excited. By recording data at a high sample rate, the data may be reanalyzed several times over multiple frequency spans to provide the best resolution over the entire frequency span as shown in figures 8 and 9.
Frequency response function measurements are also simultaneously exported to external modal analysis software formats (e.g., MeScope) so that operating modal and ODS analysis may be performed to provide clear visualization of the motion of different points in the system. Figure 10 shows motion of a single flyroll (used to maintain paper web tension) at 50.3 Hz, caused by excessive looseness that provided impulsive and usually severe ambient vibration to the sensitive filled and polymer-covered rolls in the stack.

Figure 11 shows the first machine direction natural frequency of the entire roll system at 7.2 Hz, characterized by a front to back rocking motion and that resulted in a resonance condition right in the middle of the normal operating speed range.

Figure 8. Identification of Low Frequency Structural Resonance

Figure 9. Identification of Higher Frequency Stack Resonance
CONCLUSIONS

Recent advances in signal processing solutions for noise and vibration test applications make it necessary for industrial facilities to look beyond the typical but limited solutions of the past three decades. The key to successful diagnostics of supercalender stack vibration is simultaneous acquisition of vibration and roll speed data from every roll in the system and a comprehensive set of measurement functions that help isolate roll related and system natural frequencies. One aspect of the diagnostics, involving the electrical and mechanical drives and related torsional vibration has not been discussed and is the subject of work currently in progress.
REFERENCES


2. Multiplexing in PC-Based Data Acquisition Systems by Fred R. Schraff, P.E., IOtech Inc. Adapted from an article that appeared in ECN, September 1997.

