Technical Description of the SENTRY™ System by Horsburgh and Scott.

Document purpose: The information is for REFERENCE ONLY to illustrate the broad capability of the SENTRY solution which includes hardware and software. Each SENTRY solution is configured to the specific application requirements unique to each customer.

Details of ‘Deliverables’ are in the reference Proposal which does take precedence (wherever differences exist).

The Challenge of ‘Uptime’: Improve machine reliability, product quality, throughput by detecting component defects before they result in machine failure or reduction of product quality. Leverage the information collected via Statistical techniques to optimize the Process.

SENTRY™ was created to solve this Challenge.

The Physics: All dynamic machines have turbines / motor / belts / gears / vanes / bearings that generate waveform vibration energy, based on their physical configuration, operating characteristics, and internal components.

The Solution Concept: In the Medical Industry, an EKG (combined with other medical diagnostic devices) can analyze and diagnose heart waveforms, respiration and other health metrics of a Patient before, during and after (for example) a heart attack. With this information, combined with an experienced Medical Team of Doctors, Corrective Action plans can be created specific to the Patient unique Needs.

Conceptually identical as an EKG combined with experienced Medical personnel; SENTRY collects, analyzes and diagnoses machine vibration, temperature and stress data/problems combined with a Team of Experienced H&S Engineers, advanced electronic and software techniques. H&S then creates a “Health” and Wellness plan specific to the equipment application.

How SENTRY measures machine Performance: The vibration energy on the surface of the machine is the sum of vibrations generated by the internal components i.e. bearings, gears, couplings, shafts, belts, sheaves, spindles, motors and the process itself i.e. slurry flows, etc..
The vibration energy is collected by sensors (referred to as accelerometers) which convert the energy into an electrical signal. Data Acquisition methods are used to convert the signal into useable Computerized data streams. This data is then integrated (via a software algorithm) with torque, strain, temperature for a complete “picture” and 3-D “movie” of Machine Condition through a process of **Condition Assessment**.

Once this information is compared against **baseline** data (i.e. how the machine “should” behave when fully operational and problem-free), diagnosis and Corrective actions can be made with confidence.

This process can be extended to support proactive initiatives including: **Predictive and Condition-based Maintenance Plans, Process optimization**.

**SENTRY Condition Assessment and Equipment Optimization supports:**

1. RT (Real Time) Collection / Analysis
2. Sensors Simultaneously Sampled – SSH
3. OPC (Object Linking and Embedding for Process Control) Communication - Load Optimization
4. Operating (“pushing”) equipment to its limit which maximizes production “throughput”.

**SENTRY. THE Basis for Powerful Condition Monitoring:**

ODS – Operational Deflection Shapes: 3-D Animation Illustrating Motion and Deflection.

FEA - Finite Element Analysis: Compliments ODS Theoretical Limits, shaft deflection, gear / bearing loading.

**SENTRY RMU - (Remote Monitoring Unit):** Robust Systems for field application including wireless data transfer.

**SENTRY MCA - (Motor Circuit Analyzer):** motor diagnostics.

PI Networks - Plant Information and Web (Internet, E-mail) Communication.

**SENTRY Trending** - Integrated with SENTRY for Long Term Trends.

**SENTRY. The ideal Platform for:**

**Predictive and Condition-based Maintenance:**

Collects Vibration, Temperature, Strain, Torque data on Motor Drives, Gearboxes for real time on-line condition assessment of transient events. Data can be integrated with operational data to enhance reliability.
**Dynamic Modeling:**

The data used to build an ODS model (a 3-D movie to “see” all mechanical stresses) of the system can be enhanced to determine loading sensitivity and theoretical equipment limits.

**3-D ODS Development and Analysis:**

**SENTRY and DDE links:** provides animation display of both Time and Frequency domain data acquired during forced structure response.

Analysis of animation: of spatial response in slow motion provides motion of one part to another including a temperature disturbance profile.

3-D models of the analyzed structure can be quite complex. SENTRY can combine sub-structures with simple geometrics to isolate these complexities and reach conclusions quicker.

Orientation of tri-axial and radial accelerometers provide transducer measurement direction of response.

Spatial interpolation of unmeasured points provides shape values based on neighboring measured points.

ODS analysis is performed with sweep (time set data histories) and dwell (structure response at a single frequency) functions.

**The proven approach Strategy for Implementing an Integrated Condition Monitoring System:**

**Review** Plant operation, equipment reliability history, and identify critical components.

**Select technology** appropriate for the equipment to be monitored.

**Compile specification** for materials, select sensor locations, and monitoring equipment location.

**Install the solution:** Installation of monitoring equipment can be made by the customer, joint/shared effort (either a temporary or permanent installation), “turnkey” by Horsburgh and Scott (or a 3rd party).

**Commissioning** of system(s) by Horsburgh and Scott and establishing “baseline” data, alarm/fault response, data reporting, and remote communication links.
Review Plant operation (history). Example data:

Tracking Vibration vs. Mill Throughput. Plant Optimization data.

Select technology (packaging, etc.) and Compile specification (sensor locations). Examples:

Note: Each SENTRY System is selected to meet the customer application.

SENTRY Mill Master System VSA (Vibration Signature Analysis)
SENTRY Laptop and Desk Top System Packaging examples.

Ruggedized Environment NEMA enclosure.
Example of Sensor locations:

Vibration Data can Provide Valuable Insight into a Process Operation

Machine/Process Conditions Monitored via ICMS

1. Motor - Stator/Rotor/Bearings
2. Gearbox - Shafts/Gears/Bearings
3. Coupling - Alignment/Components
4. Structure - Foundation/Mounting/Isolation
5. Driven Unit - Impeller/Shafts/Lubrication/Blades/Casing/Piping
6. Controller - Process Conditions i.e. Cavitation, Surge, Flows
7. Electrical Drive - VSD SCR faults, Firing card failures

"No single variable can impart as much knowledge on machine/process condition as Vibration"

Typical Locations for Mill Stand Vibration Monitoring
Red or Yellow indicates which vibration sensor is in alarm or fault. Includes the location. SENTRY Graphical User Interface (GUI): Unlimited Flexibility in Customized Screens.
Common ’Screens’ for diagnosis:

The figure above is an example how the alarm log can be configured to not only log alarms but define the root cause source i.e. bearing defect, Roll eccentricity, lubrication problem, 3rd octave Chatter, 5th Octave Chatter, etc..
Fast Fourier Transform (FFT) frequency domain analysis example:

Advantage: Single Screen Diagnostics. The SENTRY Report screen provides detailed vibration analysis on a single screen (not two or more) for “At a Glance” determination of gearing problem(s).
The complexity of mechanical systems and dynamic forces. Example:

Simultaneous data: determines cause i.e. gear deflection, shaft misalignment, pitch line run out, etc.. In dynamic applications, shaft misalignment must also factor gear type to find a true 'root cause' solution.

Gear tip / root relief: compensates for tooth deflections, base pitch error, and variations in tooth profile. At excessive loads- first one then two pairs of teeth carry the load. Torsional vibrations during resonance will create higher amplitude.

Conclusion: The gear wear, load increases, axial movement of gears (with reduced ability to handle thrust) and a drive clutch configuration (with no coupling to accommodate thrust) all contribute to high vibration.
Example: The ODS motion depicts thrusting on High Speed shaft. Note: The Oscillation between IB and OB bearings. Load is transferred from one bearing to the other, primarily during processing of “low power ores”. With “high power Ores” the process throughput was significantly raised.

Combining SENTRY Signal Analysis with Field Inspections by the Horsburgh and Scott Engineering Support team:

Photo of gear mesh taken during gear inspection; the SENTRY vibration analysis features were used to determine the cause of the wear patterns observed on the gearing (i.e. SENTRY compliments and validates the inspection process).
ODS Diagram Autogenous Mill: Sole Plate with high speed pinion and intermediate gear roller bearings. As the colors move from blue to red they represent increased motion (vibration).

SENTRY “Snapshot” of the sole plate found the “root cause” problem: a “soft foot”.

FBD (Free Body Diagram) the results of ODS (Operational Deflection Shape) and FEA (Finite Element Analysis). Example:
MCA – Motor Current Analysis. SENTRY Electrical Phasor Analysis Screen MCA.

Example:
SENTRY Trending Package can be ported to the customer Plant Information System. Example:
Condition Assessment Flow Chart – SENTRY eliminates most of the design considerations as it is built into the software and hardware.

- Failure Type / Mode: Failure Analysis
- Process Limits: Design Limit
- Machine Criticality
- Sensor/Wire Type: Accelerometer, g, incl plane Tri-Axial
- Sensor Style: Quartz/Ceramic Crystal +/- 20%
- Sensor Mounting: Hand, Magnetic, Adhesive, Stud
- Calibration: Chk Rolloff 1/3 Hz to 20K Spec/Shft Gain,
- Addl Sensors: Torque, Strain, Temp, Press, Flow

- Power Supply ICP-
- SSH: 3 microsec. Time delay w/333k sampling
- Filters: HP for roll off Anti-Aliasing are Analog Use 1st

- Process Speeds: FFT Spectrum is 1/3 Sample Rate
- Resolution: 12 bit provides 0.244 millivolts
- DSP Technology Selection: Success Approx. Conv.
- Input Bandwidth: 1/3 to 20,000 Hz typical
- Accuracy: +/- 0.02% reading, +/- 1 LSB
- CMRR/Gain: @ Gain = 1, 74dB at 60 Hz
- Sample Size: F(n) of Resolution Typical 1024 to 2048
- Sample Rate: F(n) of Machine Speed/Application

- Processor Architecture: 1.0 to 2.4 G Hz
- Memory HD and RAM: Dyn or Solid State / RAM & HD
- Long Term Storage Media: High Spd. X CD Rom

- Windows: XP, 7, Vista, or Linux
- DAQ Software: Testpoint & DasyLab, C++
- Graphical/Conventional: On-Line Zoom Req.
- Software Overhead vs. Sensor Count -
- Active X or DDE Link to Other Packages

- FFT Frequency Domain Spectrum: 1024 to 2048
- Frequency Banding Alarms/Faults: Independently Set
- Trending: With on-line zoom
- Data Windowing/Digital Filters: Hanning, Butterworth

- ODS Sensor maps & FEA Comparisons
- Model Animation / Sensitivity
- GUI: Vision independent graphics
- Time Domain Waveform: With Multi-alarms

- OPC: Client and/or Server
- VPN: Links for Off - Site Support
Creating a Baseline: OEM data input includes: number of gears, gear teeth, motor speed, motor rotor bars, belt configuration, shaft RPM, coupled with the operating parameters. The origins of each of the vibration signals (summed at the surface of the machine) are explicitly shown on the frequency spectrum. By comparing the collected vibration waveform to the defined spectrum, SENTRY monitors the condition of the internal components of the machine.

Once the Spectrum is created, it is divided into Frequency Bands based on the OEM data. The bands are positioned on the Spectrum (each with alarm thresholds to detect component defects).
The FFT Spectrum: The spectrum is used to provide detailed “alarm”/fault limits for specific components or defect conditions by dividing the frequency range into specific bands (each of a different bandwidth). A typical spectrum for vibration analysis is shown:

Critical Mechanical Component Problems can be Detected and Analyzed from the Frequency Spectrum

<table>
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<tr>
<th>Orders</th>
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<tr>
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<tr>
<td>5</td>
<td>9000</td>
</tr>
<tr>
<td>6</td>
<td>10800</td>
</tr>
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Typical Spectrum Frequency Band Definitions:

- Band No.1 = Sub-harmonics
- Band No.2 = Harmonic of turning speed, natural frequencies Fn
- Band No.3 = 2x and 3x turning speed – misalignment – mass imbalance
- Band No.4 = Looseness Harmonics, Gear Mesh
- Band No.5 = Bearing Frequencies
- Band No.6 = High Frequency Band
Motor Gear Drive – Misalignment BEFORE Alignment:

Motor Gear Drive – AFTER Alignment:
**Statistical Process Control (SPC):** A powerful tool for enhancing quality and efficiency in the production environment. The SENTRY software (including waveform signature analysis and integral spreadsheet) includes powerful and flexible SPC functionality.

SPC is based on a simple concept: the first step to improving a process is getting it to perform consistently.

SENTRY SPC technology involves identifying, understanding, and controlling variations in the process via signature analysis.

The first Step: Accurate Data collection. SENTRY automated features support waveforms which accurately depict the quality variables of a process.

The key questions SENTRY helps you answer:

- What data should you collect…from where…how can it be collected ?
- What should you do with the data once you have it?

This knowledge, coupled with the ability of the SENTRY software to provide key metrics to measure and resolve variables, is a highly refined SPC solution.

**SENTRY Systems:** SENTRY is currently in use at a wide range of facilities in various industries. SENTRY provides data collection and “alarm”/fault functions which are integrated into plant information systems to enhance plant reliability and safety.

Combining Plant operating data with meaningful reliability data allows the plant process to be optimized.

**With SENTRY, maximum ROI** (Return on Invest) is the logical and predicted result.

**SENTRY Systems Technology … Your Competitive Advantage.**

**Horsburgh & Scott...Your Uptime Partner.**