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AUDIBEL-DEVELOPMENT OF A WORLD CLASS PRODUCTION SOUND TEST PROCESS

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ABSTRACT
Caterpillar has ensured compliance to various sound level requirements for many years. However, current production test methodologies are not capable of cost effectively ensuring compliance to the new European Union (EU) Dynamic Sound Level Requirements. Failure to comply could result in loss of this key market. In order to provide Cat Manufacturing Facilities with the means to ensure compliance, a new sound test process was developed and implemented. Of primary importance was to identify and develop instrumentation capable of documenting compliance, process capability, and support failed machine diagnostics. Central to the new sound test process is Caterpillar's patented "AudiBel" Sound Test System, which has enabled Caterpillar to reduce test times, process and product costs, required support personnel, and allowed testing to be conducted by non-technical personnel.

1 - INTRODUCTION

Caterpillar measures the noise emissions of its construction equipment to ensure compliance to various worldwide commercial and regulatory requirements. Although developmental tests are initially conducted to verify all design goals are met, production machines must be statistically sampled to ensure all products produced are in conformance. By their nature, development tests take place over an extended period of time and are conducted by skilled technical personnel. By comparison, production tests must be completed quickly and utilize non-technical personnel to prevent shipping delays and minimize manufacturing costs. Caterpillar's production sound test program dates back to the 1970's when all tests were conducted outdoors conforming to existing sound-pressure type requirements. Process improvements, such as the indoor acoustic intensity technique documented by Sweeney [1], Miech [2], and Tweed [3] still proved to be labor intensive, time consuming, required a high level of operator expertise, and/or not capable of ensuring compliance to the new EU Dynamic Sound Level Procedures outlined in ISO 6395 [4] and ISO 6396 [5]. Additionally, techniques capable of assisting with the diagnosis of failed machines were extremely limited. The development and implementation of a process which would allow tests to be conducted in a matter of minutes by one, non-technical person offered an immediate opportunity to significantly reduce process costs. Further, efficient test methodology, implemented in conjunction with process refinements focusing on user-friendly data analysis, data reporting, and diagnostics, would enable process control and lead to a reduction in process variability.
Ultimately, this comprehensive process would result in lower product costs, lower rework costs, improved quality, and quieter product.

2 - PROCESS DEVELOPMENT

Conducting exterior sound power and operator ear sound pressure tests was lengthy and cumbersome. Six microphone measurement points are required to calculate the sound power with a seventh measurement point required to document the operator level. Additionally, product must be evaluated under several different dynamic machine operation cycles based on the machine type. A backhoe-loader, which is

covered under all four operational cycles, requires a total of 28 measurement points on each machine. Actual test time is only part of the process. Test instrumentation must be set up and calibrated prior to testing, then removed after the tests are completed. The overall process typically takes 3-4 hours (1 hour for set up/calibration, 1-2 hours of testing, 1 hour for data reduction/ analysis/ reporting) and has also required at least 2-3 support personnel. On average, 8 man/hours are needed for each machine test. Problem machine diagnosis and rework add even more time to the process. Product costs are also significantly impacted in that a process that is not under control will naturally demonstrate more variability and subsequently require more "cushion" to ensure compliance. Conversely, reducing process variability and the required "cushion" by, for example, 1 dB(A) can reduce product costs by several hundred dollars per machine.
As a first step, a multi-disciplined team was formed to identify the new production sound test process. The team initially performed several quality analyses, which were instrumental in guiding the development tasks. Supplier benchmarking was used to identify instrumentation options and new technologies, which might be available or could be developed. Other analyses documented customer needs, factors affecting process time, trade-offs involved with indoor versus outdoor dynamic testing, potential equipment problems, and projected cost savings. Bruel & Kjaer, Naerum, Denmark, was selected to assist the Caterpillar internal team finalize project goals, write the detailed system functional specification and provide all acoustic instrumentation. Bruel & Kjaer's newly introduced Pulse Platform would be the "engine" for Caterpillar's new automated system termed "AudiBel".

3 - PROJECT RESULTS

Caterpillar's "AudiBel" Sound Test System was designed, built, validated, and has been installed in 8 facilities with other installations planned. All project goals have been met or exceeded.

- Manpower has been dramatically reduced.
- Test process is completely automated.
- Process times have been slashed.
- Problem solving diagnostics have been provided.

Project Results	Actual	Goal	AudiBel
Process Man Hours	7-8 hours	30 minutes	15 minutes
Setup/Teardown Hours	2 hours	15 minutes	0
Manpower needs	3-4	1	1

Table 1.

Total Product and Process cost savings have been estimated at several million dollars. Potential product quality problems have also been avoided. Defective components have been identified and corrected prior to shipment resulting in warranty cost avoidance.
Figure 1 is a schematic of the AudiBel System Layout. AudiBel features include all-weather outdoor microphones, sometimes used with airport monitoring systems and set up on permanent stands eliminating setup/teardown with removal needed only for service related reasons. As required by the EU, four of the six sound power microphones are located at a height of 1.5 meters and easily accessible. Two tower microphones, located at a height of 11.3 meters for a 16-meter hemisphere, are mounted on folddown towers, which allow ready access for service and/or calibration. Photocell sensors, used to automatically start and stop driveby tests, are mounted on the lower microphone stands.
System hardware includes the AudiBel Host Desktop PC (w/Bruel & Kjaer Pulse Platform), B & K Data Acquisition Front End, Laptop PC with Radio Frequency (RF) communication hardware for remote control operation, B & K Sound Level Meter (Operator Ear), 5 Function Weather Station, Microphone Calibration Lightbar, and printer. At the heart of the system is the AudiBel Host and Remote Software. Figure 2 shows one of the easy to use test screens. The AudiBel software provides a user-friendly interface to the more sophisticated Pulse Software, which allows tests to be conducted by non-technical personnel with the highest level of accuracy. One man testing is accomplished through the Wireless Remote Control Laptop PC and allows the tests to be conducted by the machine operator. The Operator Sound Level Data is captured through a RS232 link between the Sound Level Meter and Remote PC.
Microsoft OLE (Object Linking & Embedding) is used to facilitate communications between the Host and Remote software programs and provides a fast and reliable link between the computers.

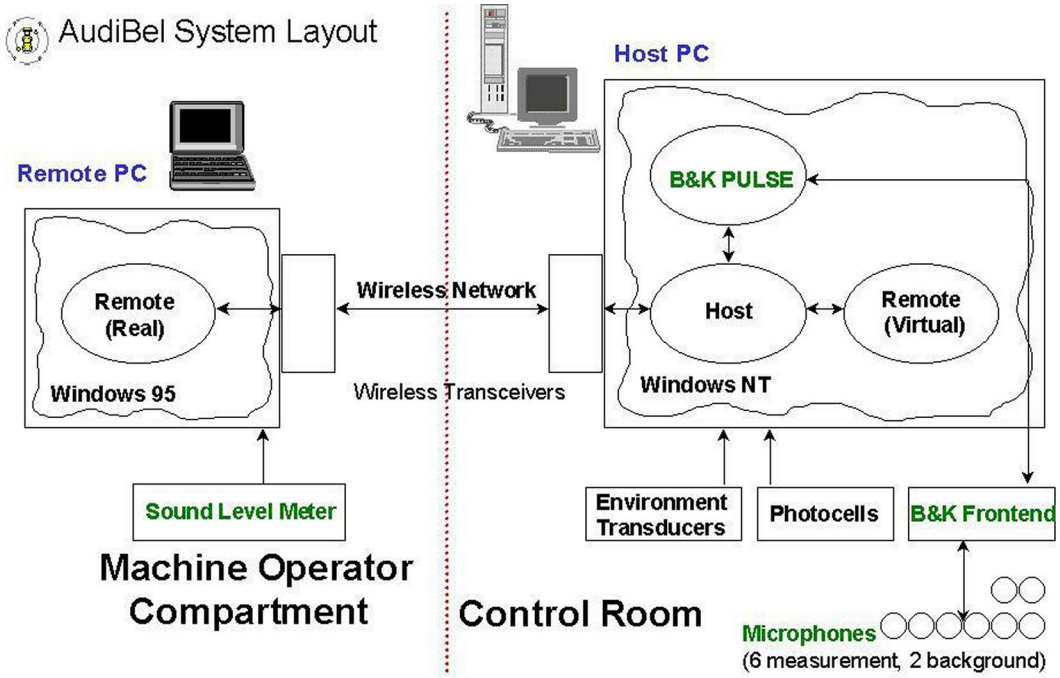

Figure 1: AudiBel system features.

Two levels of system calibration are available and can be conducted quickly by one person. A formal acoustic calibration is performed through Pulse via AudiBel. Once initiated, through the Host Program, the Yellow-Red-Green Calibration Lightbar, mounted in view from the microphone locations, begins flashing. Yellow, indicates system is in a wait mode, Red, after the calibrator has been placed on a microphone, indicates calibration is in progress, and Green, indicates a successful calibration. The operator can then proceed to the next microphone, completing all six in about 5 minutes. In addition, the transducer electronics can be checked with the punch of a key through B & K's unique "Charge Injection Calibration" and prolongs the intervals required between formal acoustic calibrations.
The AudiBel Software also features a Machine Database used to archive and access all pertinent descriptional machine information, i.e. model and arrangement numbers, engine speeds, pass/fail criteria, and required machine operations. When conducting tests, the operator selects from a preset list of machines and is automatically provided with machine specification data that will be included on the test report. The entire test process, taking approx. 15 minutes, finds one hourly operator powering up the system, performing the calibration, and then taking the remote, with the operator microphone attached, to the cab of the machine. After selecting the machine, he proceeds through the various test cycle sequences for that machine. Only those sequences appropriate for the selected machine are displayed. After tests are completed, a report is automatically printed and data archived. In addition to the overall pass/fail results and environmental data, the diagnostic frequency data is also captured and displayed to assist with failed machines. Summary statistics software is used to generate population means, standard deviations, etc. and provides valuable design and process feedback.
In addition to the AudiBel System development, it was also necessary to create the appropriate facility infrastructure, which would be needed to support process control. Facility implementation teams were formed and provided in-depth education and training that covered basic acoustics, good test practices, advanced diagnostics and troubleshooting techniques. Accountabilities were assigned throughout the organization for machine testing, system maintenance, and system recertifications with the process fully documented. The Caterpillar AudiBel Sound Test System has been patented and the entire test process independently certified by the EU Notified Body in Germany, TUV.

4 - SUMMARY

Caterpillar has developed and implemented a "state-of-the-art" Sound Test Process which utilizes the patented AudiBel Sound Test System and has allowed for the implementation of statistical process control. Reductions in process costs, product costs, and quality improvements have resulted. In addition, documentation and overall awareness of each machine's design capability, through the implementation

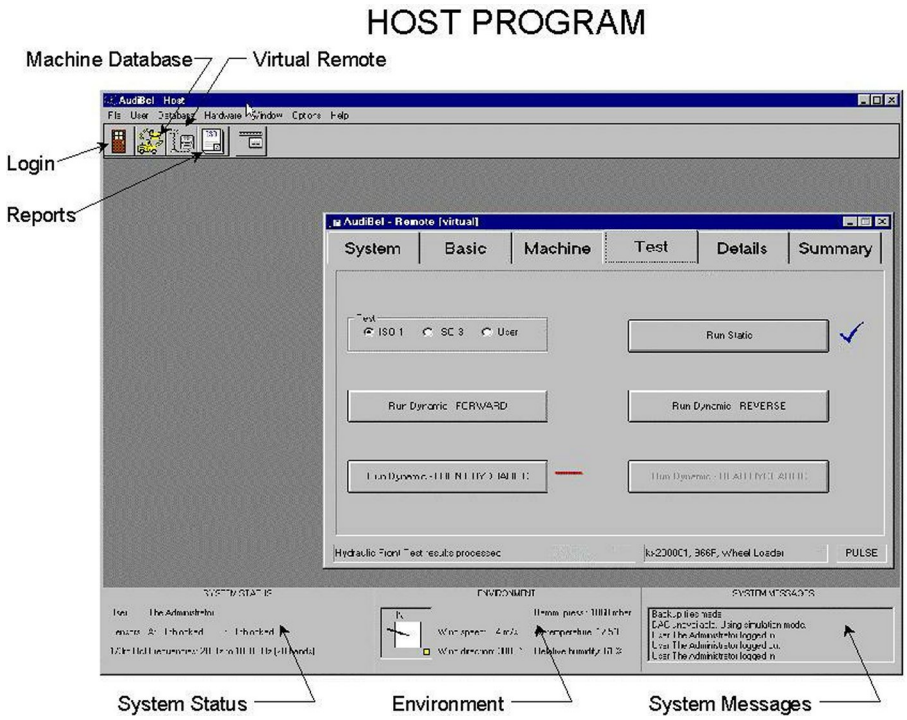

Figure 2: AudiBel system features.

of this process, has led to across the board reductions in process variability.

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