Design and Instrumentation of a Large Reverberation Chamber

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1. INTRODUCTION

In the early 1980s, the U.S. Department of the Interior's Bureau of Mines Pittsburgh Research Center required that a large reverberation acoustic facility be constructed. This facility was designed to determine the sound power level emissions of mining equipment, especially continuous miners and jumbo drills. A contract for a conceptual design of a reverberation chamber was awarded to Wyle Laboratories of Huntsville, AL, which had extensive experience in the design, construction, and accreditation of acoustical reverberation chambers. The following standards were referenced as guidelines for the design of the chamber: ANSI S1.31-1980, "Precision Methods for the Determination of Sound Power Levels of Broadband Noise Sources in Reverberation Rooms" and ANSI S1.32-1980: "Precision Methods for the Determination of Sound Power Levels of Discrete-Frequency and Narrowband Noise Sources in Reverberation Rooms." Specific requested criteria included that the room be large enough to accommodate typically large mining equipment and that there be adequate acoustical modal density in the frequency range of interest. It was also required that the room dimensions would support broadband acoustical measurements down to the 100 Hz third octave band.

With the closing of the Bureau of Mines in 1996, this reverberation chamber lay dormant for a number of years. However, this facility is now part of the National Institute for Occupational Safety and Health's (NIOSH's) Pittsburgh Research Laboratory (PRL). One of NIOSH's missions is to decrease noise induced hearing loss among the nation's mineworkers. To this end, PRL researchers are refurbishing and instrumenting this reverberation chamber to facilitate assessment of the various engineering controls being developed to decrease the sound power level emissions of mining equipment. Early on, this work has sought to bring the chamber up to the level of ISO 3743-2[1] standard for engineering grade measurements for broad-band noise, with a longer range goal of improving the lab to meet the requirements of ISO 3741[2] standard for broadband precision grade measurements.

2. DESIGN OF THE REVERBERATION CHAMBER

The nominal room dimensions are 18.3 meters long by 10.3 meters wide with a height of 6.7 meters. The chamber volume is 1,286 cubic meters. These dimensions are important, as few reverberation facilities are large enough to test typically huge mining equipment. The floor is poured concrete with a sealer to make it acoustically reflective. The walls are built of hollow concrete block, 16 inches long x 8 inches high by 12 inches thick. Each block has two hollow cores. The hollow block cores were completely filled with concrete with horizontal and vertical steel reinforcing bars 16 inches on center. This was done to supply a very stiff acoustical wall and to ensure safety. The room was designed to withstand (with a safety factor of 2) continuous sound levels of 130 dB at any single frequency down to 100 Hz. The ceiling is pre-cast pre-stressed concrete sections with a poured 2-inches-thick concrete cap. Two layers of block filler were applied to the walls and one layer to the ceiling. Epoxy and enamel paints were applied over the block fillers to provide highly reflective acoustical surfaces. Figure 1 shows the calculated room modes below 125 Hz and illustrates that there is small and uniform spacing between the modes. The large steel equipment entry door (34.8 square meters) comprises ¼ - inch steel plate with numerous stiffeners. Although the door stiffeners have a pattern to them, the edge effects of the door make the stiffener pattern fairly acoustically random. Also, the door is offset from the centerline of the chamber, to increase the acoustical randomness and modes of the chamber.

Figure 2 shows the chamber with a roof bolter, sandstone block and support fixture in place prior to testing. Just to the right of the sandstone block is a video camera, which is used to observe the testing as well as for video recording. Cylindrical ducts in the chamber walls allow for the passing of instrumentation cables (microphones, sensors, etc.) into the control room. Line voltage is available at numerous locations within the chamber and there is also a duct available for the passing of a trailing cable to provide electrical power for the heavy mining equipment typically tested in the chamber. There is also a sump pump, trough and drains to collect and discharge waste-water that may be generated during testing.

The original instrumentation system included sixteen type 1 microphones hung in a random pattern throughout the chamber. The "state-of-the-art" technology of the time required multiplexing to sample the microphones sequentially. When the noise source was stationary and not varying with time during the measurements, this system was excellent. Unfortunately many types of large mining equipment have varying and/or moving noise sources, e.g., chain conveyors moving on a continuous miner, and drill steels, which move during the drilling of a hole. During initial certification of the chamber, this potential problem was accounted for and all tests involving drills, chain conveyors, etc. met ANSI S1.31.

3. REFURBISHING THE CHAMBER

Early refurbishing efforts focused on determining which instrumentation system would best fit the needs of NIOSH as well as whether to choose a traversing microphone and boom(s) system or a microphone array system. A microphone array system was chosen for the following reasons: the room was originally instrumented with a microphone array which functioned adequately; such a large room would require not one but several booms to mount traversing microphones on; placing booms on the chamber floor could on occasion be difficult due to the size of the device under test; and after consulting with directors of similar labs located throughout the country, it was felt that a microphone and boom traverse system might introduce additional maintenance problems. Once this was decided, it was necessary to estimate the number of microphones necessary to meet the applicable acoustical standards. ISO 3741 specifies a method to estimate the number of microphones and noise source positions using the standard deviations of the sound pressure levels sampled at the microphone positions. Per the standard, a six-microphone array was used along with a Bruel & Kjaer 4204 reference noise source. A series of tests was run, recording the noise signals with a Racal A480, a digital tape recorder. From this, third octave band sound pressure levels were calculated at frequencies ranging from 100 to 10 kHz. This testing revealed that a minimum of fifteen microphones was required with a single source position. The single source position is important, as meeting ISO standard specifications for minimum distances between noise sources, microphones, chamber walls, etc. severely limits possible noise source locations, given the large equipment. On occasion, additional source positions may be necessary.

A twenty-two-channel Bruel & Kjaer Pulse system was selected as the best choice for instrumenting the chamber. This allows for fifteen microphones and additional data channels for sensors, such as temperature, pressure, relative humidity, speed, thrust, etc. The Pulse system also has the advantage of real-time data collection and analysis. Data are written into an Excel spreadsheet, and the necessary calculations are made to determine the sound pressure level, sound power levels, and standard deviations. Software flags indicate when the data do not meet acoustical standard criteria, such as when the background noise is too high, or environmental data (temperature and relative humidity) have varied too much. PRL envisions developing an archive of noise signals of all equipment tested in the chamber. Also, though not in place yet, a protocol is being developed for a procedure to store the noise signals to DVDs.

Once the Pulse system was installed, PRL could better continue our assessment of the current state of the testing facility. With the Pulse system and fifteen microphones in place, PRL could again estimate the number of microphones necessary to meet certain standard criteria. Figure 3 illustrates the results of a microphone quantity estimation test as given in ISO 3741. For each third octave band from 100 to 10 kHz, an estimate of the sound pressure level and standard deviation, S_m, were generated. These were then compared to the maximum allowable standard deviations as given in ISO 3741 Annex E. We see that the chamber performs quite well up to and including the 4 kHz third octave band. At this point however, standard deviations increase significantly to a maximum of 2.3 at 6.3 kHz. Also in Figure 3, an estimation of the number of microphones, N_m, is plotted vs. the right-hand axis. It was determined that six microphone positions would suffice out to 4 kHz, beyond which the standard deviation rises above 1.5, necessitating fifteen microphones.

The huge size of the chamber, while necessary for the testing of large equipment, creates several problems. First, it was anticipated that absorption of the noise signal by the large air volume of the chamber would create problems, particularly at higher frequencies, i.e., greater than 1 kHz. This problem would be most evident by an increase in the standard deviations of sound pressure levels sampled by the fifteen microphones. To solve this problem, it was necessary to humidify the chamber air and PRL chose to employ three whole house humidifiers to accomplish this. They were placed throughout the chamber and raised the relative humidity within the chamber from a relatively dry condition, e.g., 15% RH, to a level mentioned in the standards as satisfactory, 70% RH, within two hours. Simply wetting the chamber floor down with water would reduce this time even further.

An additional concern was ensuring that the relative humidity and temperature of the chamber air would not stratify, i.e., the relative humidity and temperature would remain homogeneous throughout the chamber. Therefore, in addition to the humidifier fans, a floor fan is used to mix the chamber air. To test for homogeneity, the chamber was sectioned off by a two-meter grid and relative humidity and temperature measurements were made at the grid intersections, then analyzed to determine if they varied significantly throughout the chamber (see Table 1 for the results). From the low standard deviations of the environment measurements, it was assumed that the air temperature and relative humidity were homogeneous. Results of standard deviation estimation tests at relative humidity's of 35% and 68% are given in Figure 4. As expected, the greatest effect of the increased humidity is shown as decreased standard deviations at the higher frequencies.

Another concern was the background noise. Because humidifiers and fans are used in the chamber, it was important to quantify their noise levels. Several times per week, background noise levels, and the noise levels of the humidifiers at low and high settings and the fan are made to develop a time history. This allows us to estimate possible effects on test results and to see if the test environment background noise levels have changed over time. Figure 5 shows the averaged noise data to date. ISO 3741 standard states that when using the comparison method to calculate sound power, the background noise levels must be at least 15 dB below those of the reference sound source and those of the device under test. In the case of machines and equipment likely to be tested by PRL, the background noise levels in the chamber are not expected to be a limiting factor for precision grade sound power level determinations. Third octave band sound pressure levels of the Bruel & Kjaer 4204 reference noise source, along with negative 15 dB error bars are shown in Figure 5. As compared with the vast majority of equipment PRL envisions evaluating, the 4204 reference noise source is a relatively quiet device. It is believed that effective testing could be conducted with the humidifiers on their lowest setting, although it is unlikely that this would be done.

4. ON-GOING WORK

NIOSH will continue in its quest to meet the acoustical standards mentioned earlier to help protect workers against noise-induced hearing loss. To this end, PRL researchers are establishing calibration, document and quality control programs; databases of test results, microphone calibrations, background and reference noise source levels; spatial temperature and relative humidity distributions; and other data to document the characteristics of the reverberation chamber and its instrumentation. Test standard operating procedures and protocols and test report documentation will also continue to evolve. PRL intends to use this information to assist in developing a quality system in accordance with the requirements of ISO 17025 to support the sound power level determination program. The Lab is also establishing an extensive library of acoustical standards. Further, PRL is considering extending its frequency range of interest down to the 50

Hz third octave band, a goal which few facilities could consider. Early indications are that the chamber can generate reliable and repeatable data in the 50 Hz range. However, diffusing elements may be required to qualify the chamber for measurement of tonal sources at low frequencies. Extending above 4 kHz will be especially difficult, as the enormous size of the chamber will make it difficult to improve higher frequency response.

5. SUMMARY

NIOSH-PRL is making significant progress toward refurbishing a large (1,286 cubic meters in volume) reverberation chamber. Results of preliminary testing led to the selection of a twenty-two-channel Bruel & Kjaer Pulse system as a real time data acquisition and analysis platform. This allows for the use of a fifteen-microphone array and engineering sensors for temperature, pressure, relative humidity, speed, thrust, etc. The large volume of the room suggests that air absorption of noise signals above 1 kHz may be significantly affected if the relative humidity of the chamber air falls below those values stated in the standards. Preliminary facility test results led to the installation of whole-house humidifiers to increase the room humidity and reduce the standard deviations of the higher frequency data.

The refurbished chamber meets standard deviation criteria for ISO 3741 standard in the 100 to 4 kHz third octave bands and PRL is considering extending the frequency range of interest down to the 50 Hz third octave band. Extending the frequency beyond 4 kHz while still meeting ISO 3741 standard deviation criteria may be difficult, as the huge size of the chamber makes it difficult to improve higher frequency performance.

On going work by PRL includes establishing assorted programs and databases to quantify the characteristics of the chamber and its instrumentation. Procedures, protocols, and test documentation will evolve as part of developing a quality system meeting the requirements of ISO 17025. This is in support of PRL's sound power level determination program that evaluates the effectiveness of engineering controls developed at PRL.

6. REFERENCES

[1]. Acoustics – Determination of sound power levels of noise sources using sound pressure – Engineering methods for small, movable sources in reverberant fields – Part 2: Methods for special reverberation test rooms, International Standard ISO 3743-2 (International Organization for Standardization, Geneva, Switzerland, 1994.

[2]. Acoustics – Determination of sound power levels of noise sources using sound pressure – Precision methods for reverberation rooms, International Standard ISO 3741 (International Organization for Standardization, Geneva, Switzerland, 1999.

Table 1- Maximum Difference Between Environmental Measurements and Standard Deviations.

	Test 1		Test 2	
	Delta	Standard Deviation	Delta	Standard Deviation
Temperature (degrees C)	3.2	0.7	2.5	0.5
Relative Humidity (%)	6.5	1.5	7.5	1.5

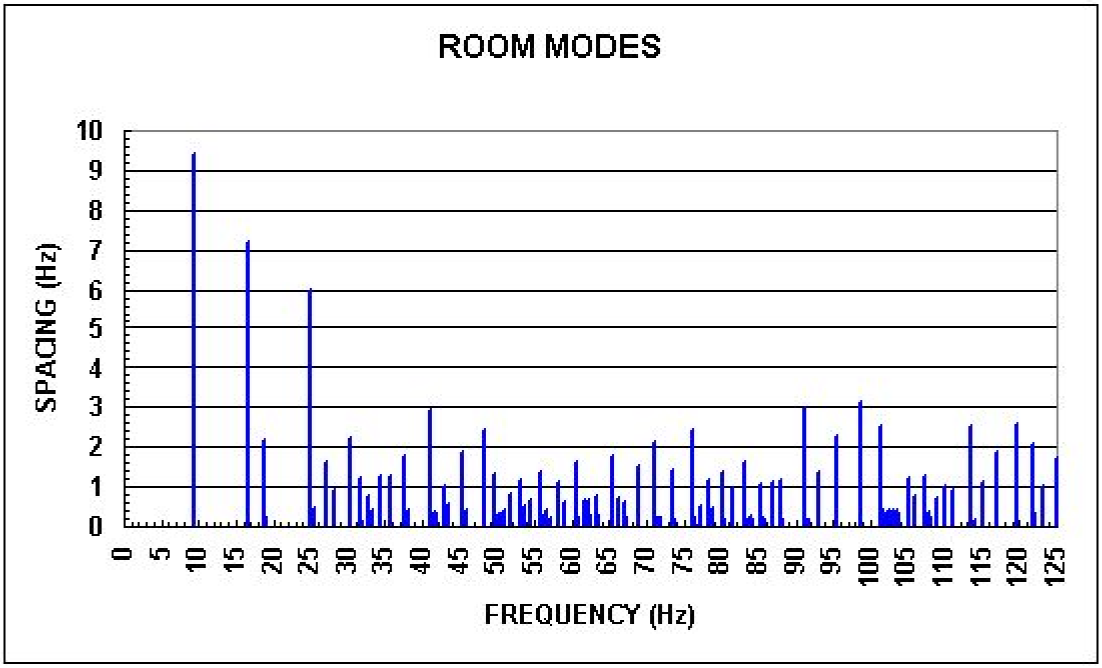

Figure 1. Room Modes.

Figure 2. Reverberation Chamber with Roof Bolter During Test Set-up.

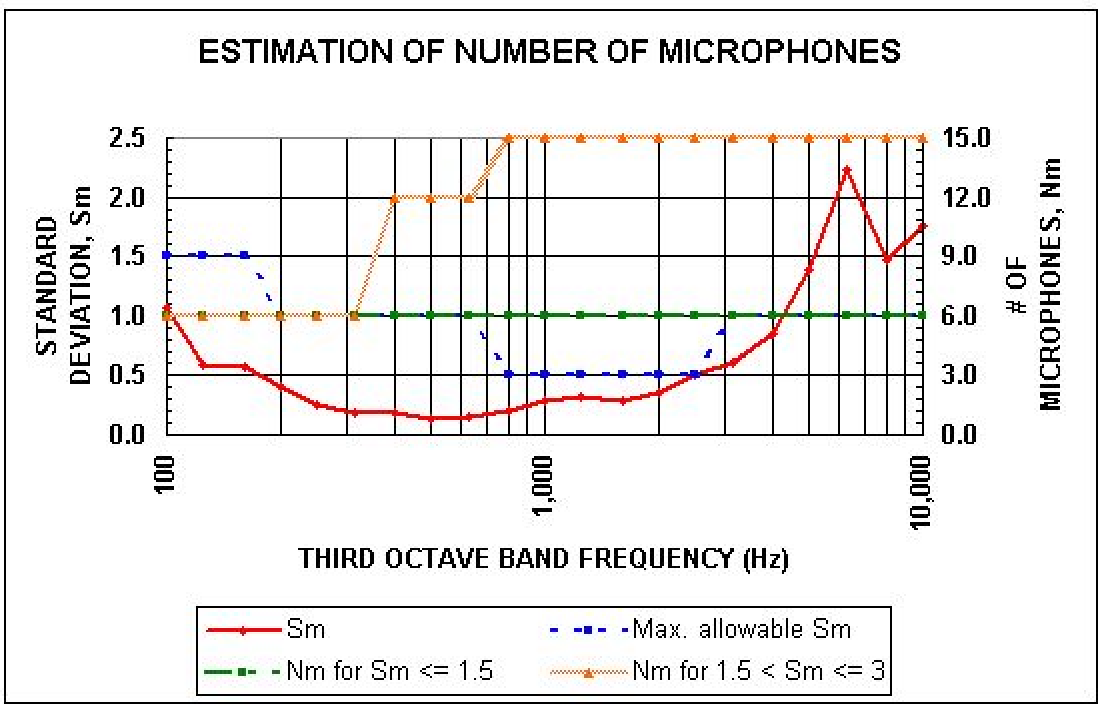

Figure 3. Estimation of Quantity of Microphones Given the Standard Deviation.

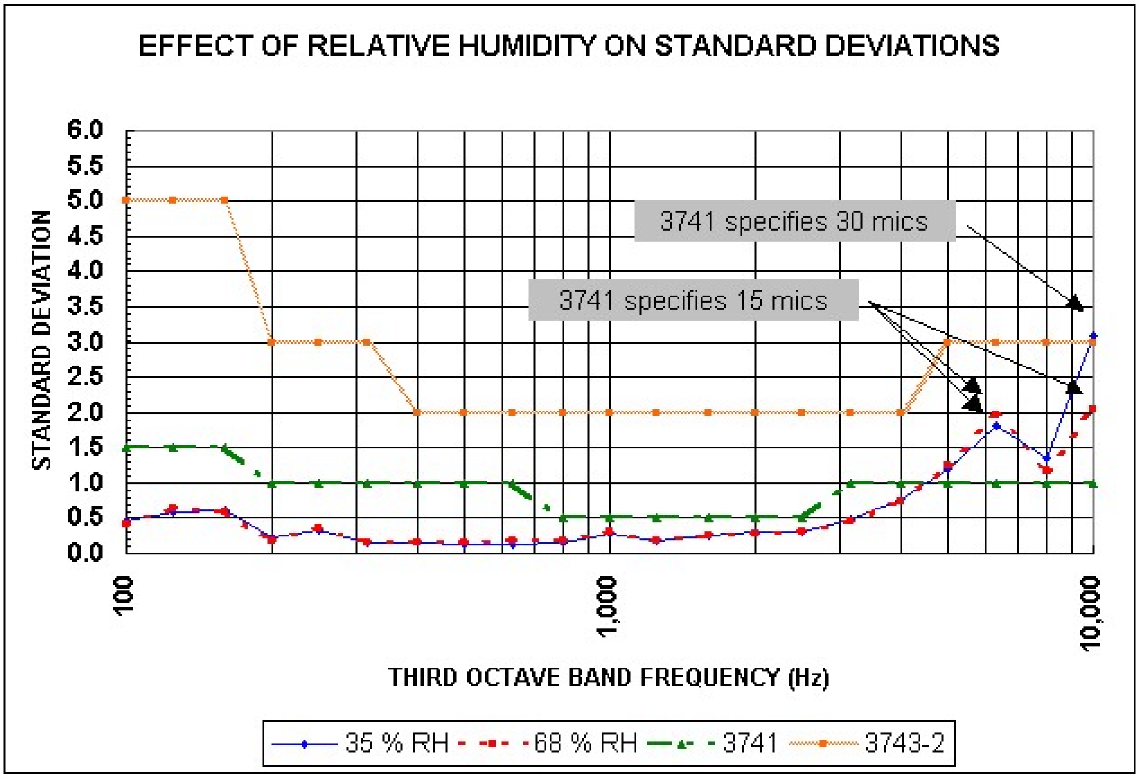

Figure 4. Relative Humidity Effect on Standard Deviations.

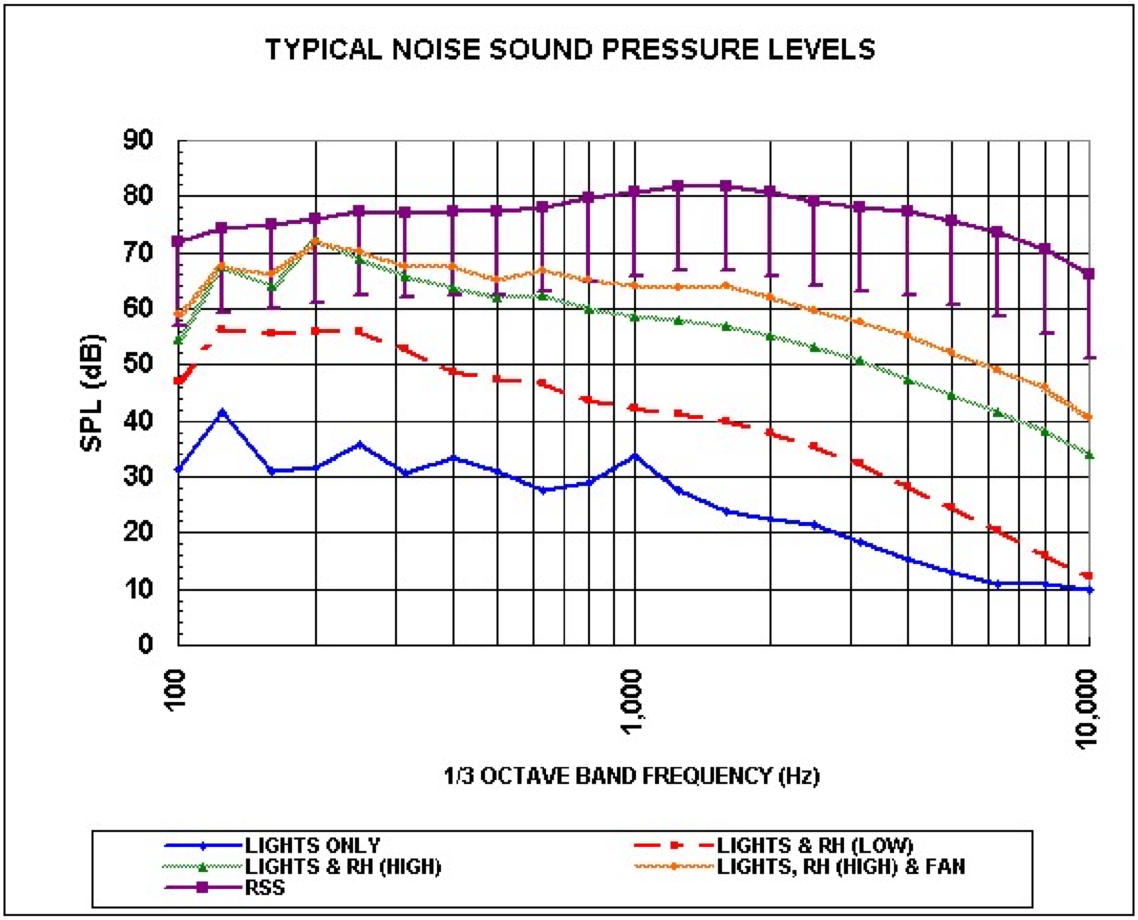

Figure 5. Background Noise Levels.