DESIGN AND PERFORMANCE OF ACOUSTICAL TECHNOLOGY CENTER OF CUMMINS POWER GENERATION

White paper by Dr. Shashikant More

On October 6, 2011, Cummins Power Generation inaugurated its Acoustical Technology Center (ATC) in Fridley, MN, USA. This state of the art facility was constructed by Industrial Acoustics Company and is one of the largest in the power generation industry in the world. The hemi-anechoic chamber is 105 feet long, 80 feet wide and 36.5 feet high, with cut-off frequency of 50 Hz and is both, ISO 3745:2003 and ISO 3744:2010 compliant. The background noise levels with and without running air handling system is satisfying NC20 and NC35 criterion, respectively. The air handling system is fully capable of removing more than 11 MM Btu/hour amount of waste heat on hottest day in summer and is capable of noise testing generator sets with several fuel types (Gas, Diesel, JP8, Natural Gas, and Propane). Installed load bank capacity at ATC is up to 4.4 MW. ATC has a remote cooling system for noise testing generator sets and engines, and also has a special provision for noise testing marine generator sets. This facility allows measurements to be conducted in a controlled environment throughout the year. It allows increased measurement precision and eliminates issues with testing causing any annoyance to the neighboring communities.

INTRODUCTION

Noise regulating authorities nationally and internationally are enforcing more stringent noise regulations than those from a few years ago[1]. Even noise awareness of the customers is increasing and they are demanding more low noise level products than before. Community awareness of the noise levels and noise induced annoyance due to power generation products is driving the developments in the area of noise control. To devise noise control strategies and develop quiet generator sets, it is necessary to use more sophisticated acoustic tools such as noise measurement facilities (environment) and other advanced instrumentation. In mechanical industries, such as power generation and automotive, several companies made a significant investment in developing acoustic facilities with anechoic or hemi-anechoic chambers for precise noise measurements[2-3]. By using such a controlled environment for noise measurements, it is possible to deliver a quieter and pleasant sounding product, which is one of the key aspects for success in competitive markets such as power generation.

Recently, Cummins Inc. inaugurated the Acoustical Technology Center (ATC) at Fridley, MN, USA. The ATC comprises two hemi-anechoic chambers, a control room, a build area, and office space. It also has a provision for a reverberation chamber. The facility is one of a kind as it is fully customized from the point of view of Cummins Inc.'s wide range of products testing requirements. In this manuscript the design and development of the ATC and its capabilities is briefly discussed. The testing that was performed to check the performance of the large hemi-anechoic chamber is described.

ACOUSTICAL TECHNOLOGY CENTER (ATC)

FIGURE 1 *Outside view of Acoustical Technology Center (ATC), located at south side of the main plant of Cummins Power Generation at Fridley, MN, USA.*

The Acoustical Technology Center (ATC) is located at the South-East part of the main plant of Cummins Power Generation, Fridley, MN, USA. The ATC was designed and constructed by Industrial Acoustics Company (IAC). Note that the description in this manuscript is limited to the design and development of the large hemi-anechoic chamber.

CAPABILITIES

The facility is the largest of its kind (in power generation industries) in the world with a hemi-anechoic chamber with dimensions of 105 feet length, 80 feet width, and 36.5 feet height. The reason behind the large dimensions for this chamber was the objective of achieving noise measurement capability at more than 7 meter distance from the face of the largest generator set that Cummins Power Generation is producing. In Figs. 1 and 2 are shown the exterior of the ATC and interior of the large hemi-anechoic chamber, respectively. The large hemi-anechoic chamber with precision grade rating and with cut-off frequency of 50 Hz is both, ISO 3745:2003[4] and ISO 3744:2010[5] compliant. In addition, other applicable standards include ISO 8528 Part 10, ISO 6798, and EEC 200/14. In Fig. 3 is shown the noise measurement system based on the above mentioned standards with 59 microphones used for the noise measurements of a diesel engine powered generator set with 2250 kW capacity.

The anechoic wedge treatment consists of Industrial Acoustics Company's "Metadyne" perforated-metal wedges designed to achieve a 50 Hz cutoff. The floor of this chamber is made of thick and high density durable concrete so that it can support the weight of the biggest possible generator set that Cummins Power Generation is producing. The concrete floor is epoxy coated to improve its chip and scratch resistance and also fuel and chemical resistance.

In this chamber, the background noise levels without running the air handling system is satisfying NC20 (Noise Criterion), and with air handling system running to the fullest capacity of 222500 ft^3/min (CFM) is satisfying NC35 criterion. This state-of-the-art air handling system is fully capable of removing more than 11 MM Btu/hour amount of waste heat on hottest day in summer. This unique air handling system gives an advantage in conducting noise testing on Cummins Power Generation's biggest possible generator sets, while maintaining the environmental conditions along the guidelines given in ISO 3745 and 3744 standards. In the ATC not only generator sets, but also engines fueled with Diesel, JP8, Natural Gas, and Propane, as well as the mufflers used on various generator sets are tested. The ATC has three electrical load banks with the biggest one having a capacity of up to 4.4 MW. The ATC has a remote cooling system for noise testing the generator sets or engines that do not have pre-installed cooling systems. There is a special provision for noise testing marine generator sets which require wet exhaust system for their operation.

FIGURE 2 *Inside view of the Hemi-anechoic chamber (part of ATC) with a rental generator set (trailer mounted container) which is 48 feet long, 13 feet high, and 8 feet wide.*

JUSTIFICATION AND ADVANTAGES

Prior to the construction of ATC, noise testing was conducted at an outdoor facility called the Sound Pad. The Sound Pad, which had asphalt flooring and thick, wooded surroundings was located on the south side of the main plant. Due to the harsh weather conditions in Minnesota, USA during the winter season, the noise testing at the Sound Pad was limited for few months in spring and summer time period. Uncontrolled and high background noise levels due to the windy conditions and other additional noise sources such as manufacturing operations, trains, and airplanes were restricting the noise testing to certain kW ranges of generator sets. The low noise level generator sets (lower kW capacity) were difficult to test as background noise levels were overpowering the noise levels generated by these low range generator sets. Also, the higher capacity generator sets were difficult to test because of noise induced annoyance caused by the high noise levels to the surrounding communities. With the ATC, not only can precise measurements be conducted, but also they can be conducted in a controlled environment with targeted temperature and humidity parameters, and also with very low level background noise. The biggest advantage, however, is the ability to conduct noise testing and developmental work throughout the year without causing any annoyance to the neighboring communities.

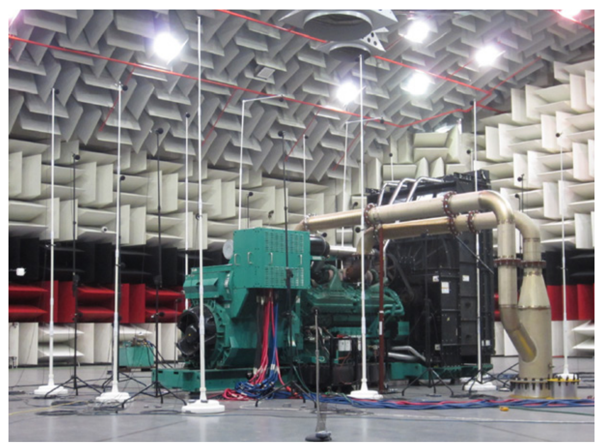
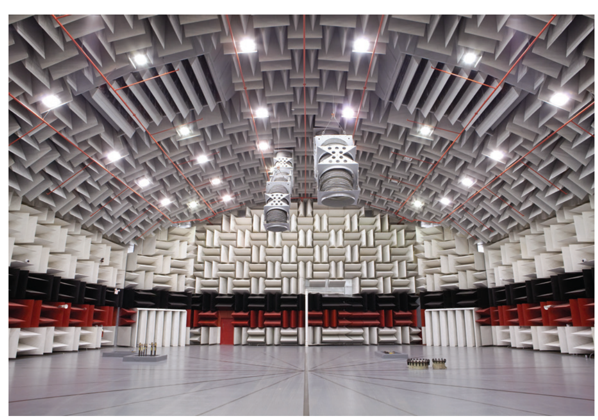


FIGURE 3 *Noise measurement set up with 2250 kW capacity generator set and 59 microphones.*



QUALIFICATION AND PERFORMANCE

Acoustic qualification of the large hemi-anechoic chamber encompassed measurements of background noise levels with ventilation systems in operation, and verification of free field performance in accordance with Annex A of ISO 3745 standard[4].

In addition to the acoustic performance of the large hemi-anechoic chamber, the performance of air handling and fuel systems, electrical load banks, and other mechanical systems which are required for full operation of the chamber were also tested. Please note that the information given in this manuscript is related to the acoustic qualification of the large hemianechoic chamber only.

BACKGROUND NOISE LEVELS

To determine the background noise levels inside the large hemi-anechoic chamber of the ATC, sound pressure levels were measured near the center of the chamber, and along the perimeter of the region extending 23 feet from the face of the largest test specimen (48 feet length, 13 feet height, and 8 feet width) expected in the chamber. The background noise measurement layout is shown in Fig. 4. Background noise levels were measured with respect to the five different configurations of the air handling system which are listed below,

- General chamber ventilation (normal air circulation)
- Mode 1 – for low range (low kW capacity) generator sets
- Mode 2 – for low to mid-range generator sets
- Mode 3 – for mid to high range generator sets
- Mode 4 – for high range generator sets.

In Table 1 are given the background noise levels recorded at nine different locations inside the large hemi-anechoic chamber with respect to the above mentioned modes of operation of

FIGURE 4 *Background noise measurement layout for Cummins Inc.'s large hemi-anechoic chamber.*

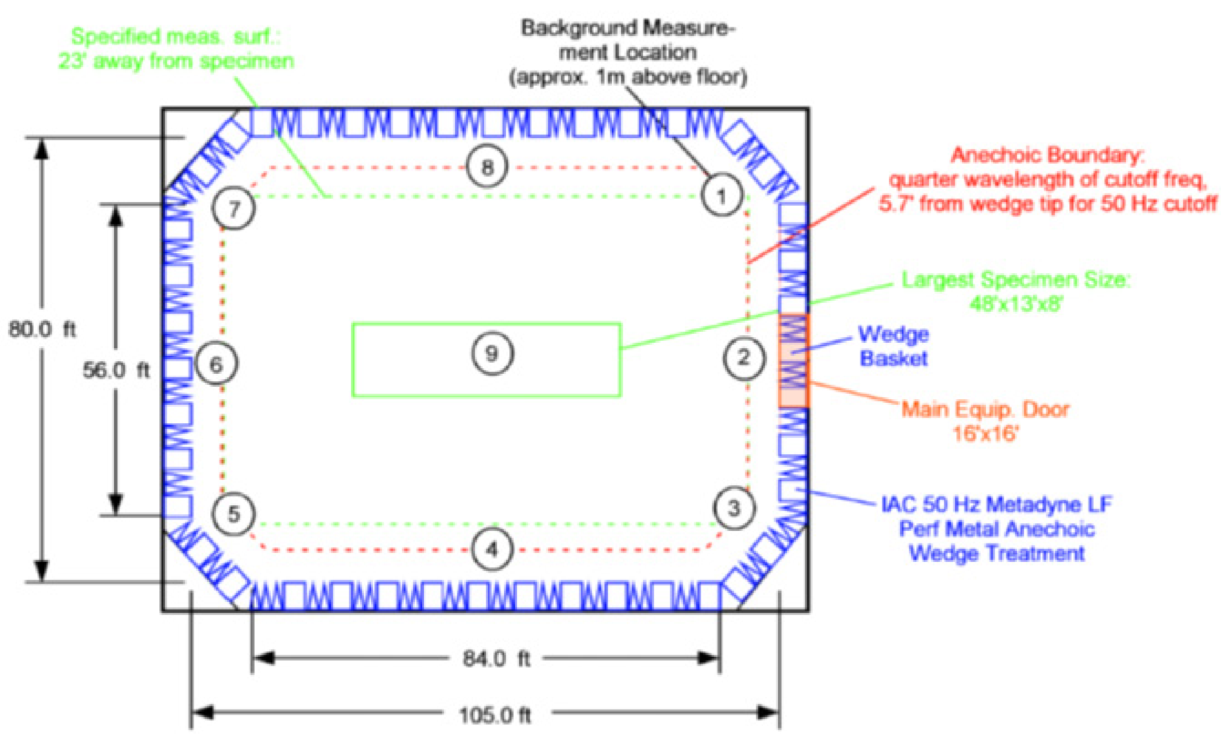


TABLE 1

Summary of background noise levels measurements inside hemi-anechoic chamber at Cummins Inc.'s ATC at various ventilation modes. Refer measurement locations shown in Fig. 4.

	Measurement Locations								
	1	2	3	5	5	6	7	8	9
Ventilation Mode	**Measured NC Levels, dB**								
General Ventilation	15	15	15	15	15	15	16	15	15
Mode 1	16	16	16	16	16	16	16	16	16
Mode 2	15	17	15	17	15	16	15	15	15
Mode 3	20	18	21	20	22	20	25	20	20
Mode 4	33	30	34	31	35	33	33	31	32

TABLE 2

Summary of background noise level measurements inside hemi-anechoic chamber at Cummins Inc.'s ATC with lights ON and OFF. Refer measurement locations shown in Fig. 4.

	Measurement Locations								
	1	2	3	5	5	6	7	8	9
Lights on/off	**Measured NC Levels, dB**								
On	15	15	15	15	15	15	15	15	15
Off	15	15	15	15	15	15	15	15	15

the air handling system. Background noise levels measurement were also conducted with respect to the chamber lights ON and OFF modes. In Table 2 are given the background noise levels related to the chamber lighting modes. Although, the targeted background noise levels with and without the air handling system in operation were NC20 and NC35, respectively, the actual measured background noise levels were found to be well within the targeted limits when the HVAC system and chamber lights are in operation.

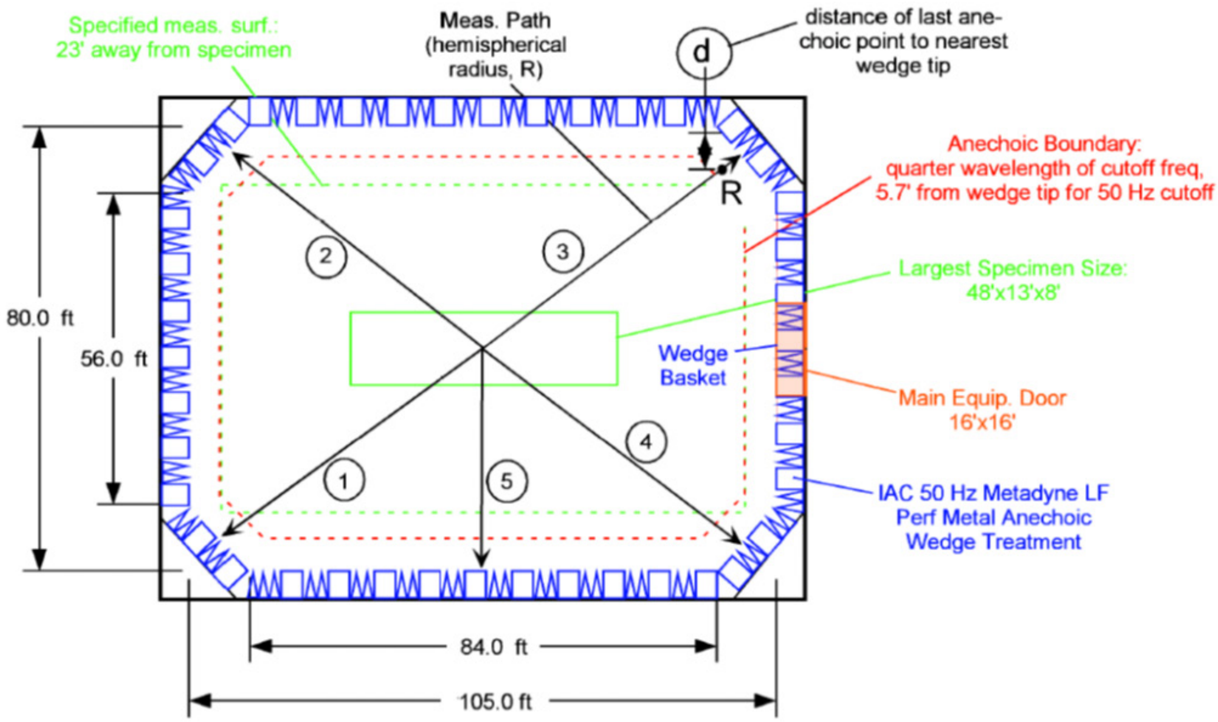
FREE-FIELD MEASUREMENT REGION

One of the objectives for constructing this large hemi-anechoic chamber was to achieve a free-field environment[4] region, large enough to measure noise data down to 50 Hz at more than 7 meters from the face of the largest possible generator set that Cummins is manufacturing or will manufacture in the near future. To achieve this, the interior of the chamber was lined with specially designed anechoic wedges. The free-field properties of the chamber were then verified by standard inverse square law measurements along five paths per Annex A of ISO 3745[4] using 1/3rd Octave band filters and a random noise test signal.

The maximum free-field distance in a path is defined here as the furthest point, R, along each path for which the measured sound pressure level vs. distance decay from the acoustic center of the test sound source falls within the allowable deviations from the decay predicted by the inverse square law as described in Annex A of ISO 3745. The schematic diagram of the inverse square law measurement layout in the large hemi-anechoic chamber is given in the Fig. 5. In Table 3 are given the maximum measured free-field distances along each of the five measurement paths as a function of frequency. Also, in Fig. 6(A) – (E) are plotted the measured sound pressure level decay against measurement path radius at every 4 inches (100 mm) of increment for the five different measurement paths, respectively.

The R (radial distance to the last anechoic point from the source) and d (distance from the last anechoic point to the nearest wall) values with respect to all the measurement paths, establish the

FIGURE 5 *Measurement path layout for conducting Inverse Square Law Tests per Annex A of ISO 3745.*



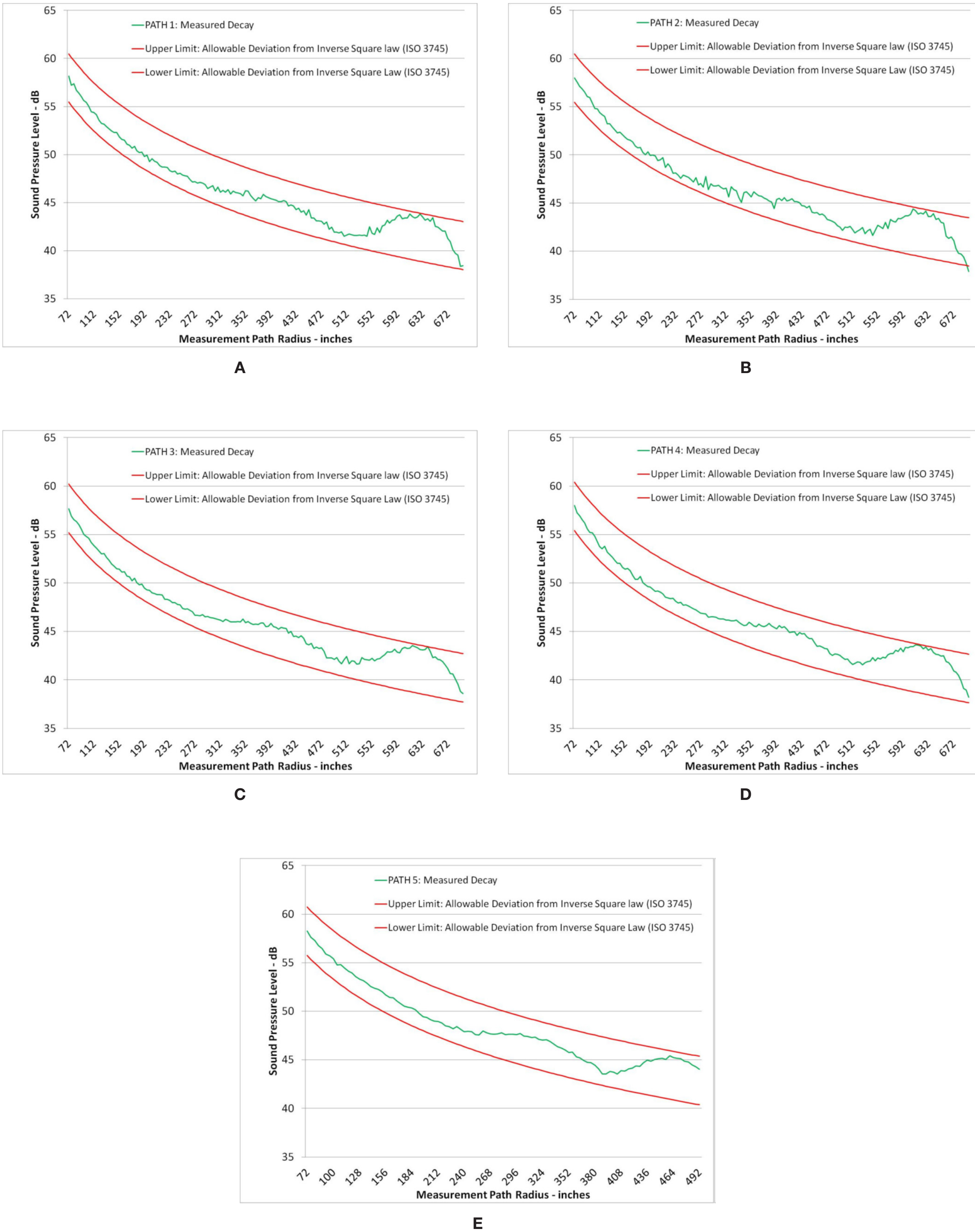
maximum size of the free-field region (as defined in ISO 3745[4]) inside the test chamber. From Table 3, it can be seen that this free-field region over the frequency range of measurement (50 – 10000 Hz) for the large hemi-anechoic chamber extends to points 4.5 feet or less from the nearest wall. This is well within the 5.7 feet or λ/4 (quarter wave length at 50 Hz cut-off frequency) distance typical of 50 Hz cut-off chambers.
As seen in Fig. 5, this free-field region also encompasses the noise measurement region at 7 meter distance from the face of the largest possible generator set. Finally, please note that the environmental correction factor (K_2) for the free-field region described above also meets the requirements for measurements in accordance with ISO 3744[5].

TABLE 3

Maximum free-field distance (as defined in ISO 3745) along each measurement path as a function of frequency inside hemi-anechoic chamber at Cummins Inc.' ATC. Notations: R – radial distance to the last anechoic point of the measurement path from the source, d – distance from the last anechoic point to the nearest wall, and h – height of the last anechoic point from the floor of the chamber.

Measurement path	Frequency range (Hz)	R (ft.)	d (ft.)	h (ft.)
1	50 – 10000	58	1.3	22
2	50 – 10000	57.7	1.6	22
3	50 – 10000	58	1.4	22.3
4	50 – 10000	58	1.4	21.1
5	50 – 10000	41	4.5	20.5

FIGURE 6 *Mesaured sound pressure level decays at 50Hz inside large hemi-Anechoic chamber of Cummins Inc.'s Acostical Testing Center (ATC): (A) measurment path 1, (B) path 2, (C) path 3, (D) path 4, and (E) path 5.*



ABOUT THE AUTHOR

Dr. Shashikant More
Data Center,
Balance of Plant (BOP)
Engineering Leader

Dr. Shashikant More is the Engineering Leader, Balance of Plant (BOP) for the Data Center business at Cummins Power Generation. Prior to this role, he led the engineering team in the Global Vibro-Acoustics group in the Department of Applied Technology at Cummins Power Systems, Minneapolis, MN, USA as Engineering Manager, and was responsible for the Applied Mechanics Functional Excellence (AMFE) Acoustic Area for Global Applied Technology for Cummins. He received his Ph.D. in mechanical engineering with a specialization in acoustics from Purdue University.

Before joining Cummins, Dr. More conducted doctoral research on aircraft noise which was sponsored by the Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), and Transport Canada. He is an active contributor to the field of power generator noise research, including programs with the National Academy of Engineering (NAE), National Institute for Occupational Safety and Health (NIOSH) and the U.S. National Park Service (NPS). He is a member of Institute of Noise Control Engineering (INCE) and a reviewer of journal papers published in prestigious journals such as International Journal of Environmental Research and Public Health (IJERPH), Basel, Switzerland; Journal of the Acoustical Society of America (JASA), USA; and Noise Control Engineering Journal (NCEJ), USA.

A widely recognized industry expert, he provided regulation and directive inputs and guidance for CE and CPCB II and IV+ and co-authored ISO Standards – ISO 8528-10. Dr. More's work is considered for 32 patent applications, he has already received four patents and the rest of the applications are under review nationally and internationally. His contributions have helped Cummins become recognized as one of the leading manufacturers in the world of quiet Gensets.

SUMMARY

Cummins Inc. inaugurated the Acoustical Technology Center with large and small hemianechoic chamber on October 6, 2011. The large hemi-anechoic chamber which is the largest of its kind in the power generation industries is not only larger but also qualifies for precision grade acoustical measurements. The noise measurement data confidence level goes to the lowest frequency limit of 50 Hz (cut-off frequency). The air handling system in the large hemi-anechoic chamber of the ATC is capable of circulating large amounts of air with very low noise levels. This air handling system fully capable of removing more than 11 MM Btu/hour amount of waste heat on hottest day in summer. By using the ATC, not only can precise noise measurements be conducted, but also noise tests and developmental work can be carried out throughout the year without causing any noise induced annoyance to the neighboring communities.

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Shashikant More
Department of Applied Technology, Cummins Inc.
1400 73rd Avenue NE, Fridley, MN 55432, USA

Victor Clemente
Industrial Acoustics Company (IAC)
1160 Commerce Avenue Bronx, New York, NY 10462, USA

Cummins Inc.
Box 3005
Columbus, IN 47202-3005
U.S.A.

cummins.com

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