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DEVELOPMENT OF AN ANECHOIC CHAMBER

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Mining Research Centre

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Development of an Anechoic Chamber

by Miron SAVICH*

ABSTRACT

In the Institute of Mineral Industry Research at St. Hilaire, an anechoic chamber was constructed for the measurement of noise from light and medium hammer drills. The principle features of the chamber are its simplicity and cheapness.

The general dimensions of the chambe. ~re outside, 9 × 6 × 6 ft, and inside, 6 × 3 × 3 ft. It is lined with dihedral-shaped wedges manufactured from Eccodamp MG foam (density 35 kg/km³). The chamber is continuously ventilated and supported on rubber pads. It provides natural frequency under load of less than 7 Hz. The insulation against noise in the vicinity of the building is good according to our measurements. Brüel and Kjaer (B and K) equipment was used for all tests. Mention is also made of the microphone orientation system, the measurement cable installation, and the electrical installation.

Finally, some measurements on the completed chamber, with regard to their free-field performances, are described. Calibration predicts cut-off frequency at 400 Hz. These measurements show that the chamber can be used for good measurements above 400 Hz and under extreme outside conditions.

1. INTRODUCTION

The anechoic chamber in the Institute for Mineral Industry Research at St. Hilaire was constructed in 1969 and 70 for the Department of Mining Engineering and Applied Geophysics, McGill University, Montreal.

The principal acoustic characteristics desired were determined during the initial research to provide a simple, economical, anechoic chamber. These principal acoustic characteristics were related mainly to the analysis of noise from pneumatic rock drills above 500 Hz, especially those pitches which are critical to understanding speech and hearing loss.

In this paper, the extensive study of the anechoic chamber is summarized with the calibration measurements. These measurements show that the anechoic chamber can be used for exacting measurements and under extreme outside conditions.

To perform these measurements, the author gave his own variant of the anechoic chamber, constructed exclusively for the measurement of noise of light and medium drill hammers under different thrust (power pressures).

Anechoic Chamber: Pneumatic Rock Drill: Noise Analysis

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2. DESIGN CONSIDERATIONS

The anechoic chamber (Figure 1) was patterned after a similar room at the University of Queensland, Australia (1). The dimensions are as follows:

outside: 9 × 6 × 6 ft;
inside: 6 × 3 × 3 ft.

Inside, the chamber is lined with wedges of polyurethane ether fixed on wooden frames.

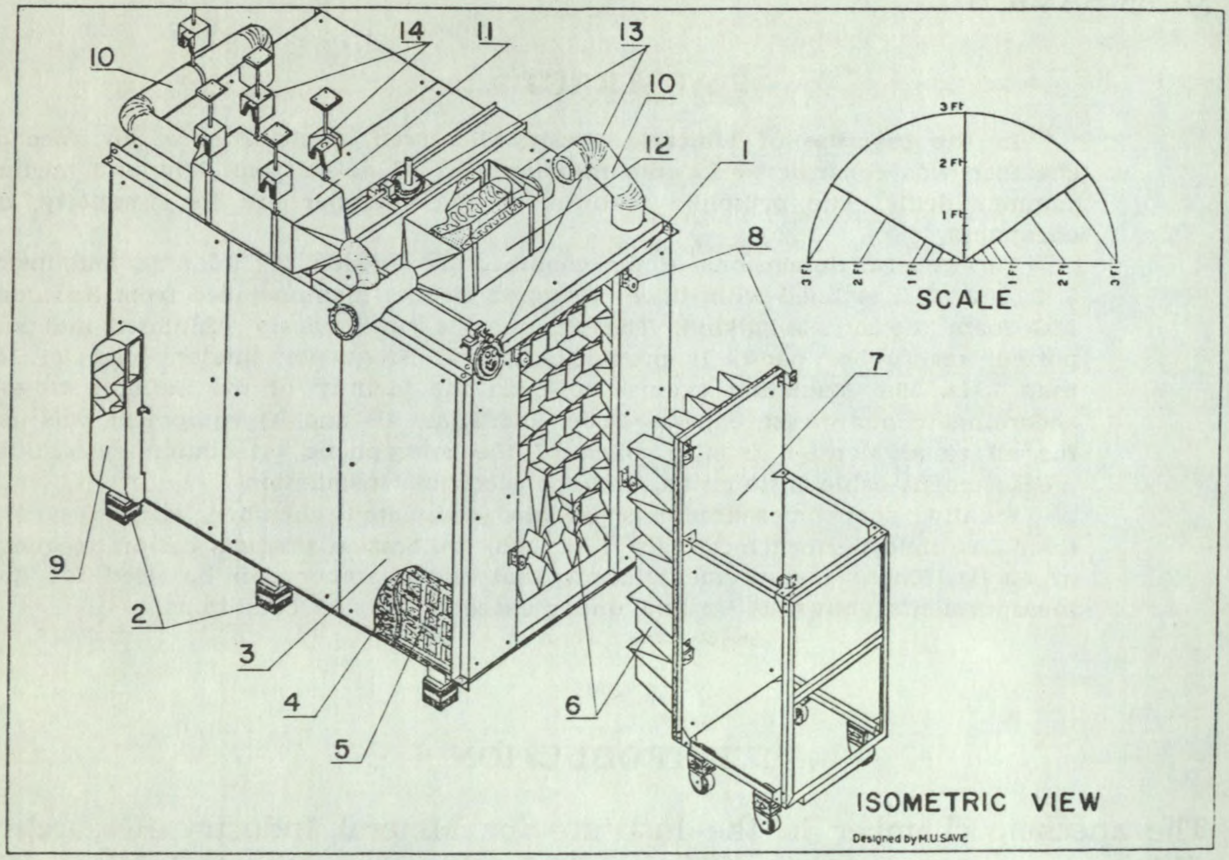

Figure 1: The Anechoic Chamber of the Institute for Mineral Industry Research at St. Hilaire (1 — Basic frame. 2 — Rubber pads, 3 — Asbestos plate, 4 — Rock wool, 5 — Wooden frame, 6 — Wedges, 7 — Door, 8 — Lock, 9 — Input silencer, 10 — Pipes, 11 — Quiet-duct silencer (exhaust), 12 — Quiet-duct silencer (ventilation), 13 — Microphone orientation system, 14 — Vibration isolation)

2.1. Isolation from Mechanical Vibrations

The anechoic chamber is supported by six rubber pads (hardness 50^0 Shore). Each isolation assembly consists of two pieces of rubber 6 × 6 × 1 ½ in. separated by pieces of three-ply wood 6 × 6 × 1 in. It provides natural frequency, under load of less than 7 Hz (1, 2, 3).

The quiet-duct silencer and the pipe are supported by vibration-free ceiling hangers. Where the pipe passed through the walls, it was isolated by soft rubber.

In the anechoic chamber the support for the hammer drill is contained in a concrete column which is buried under the floor of the building. The sand

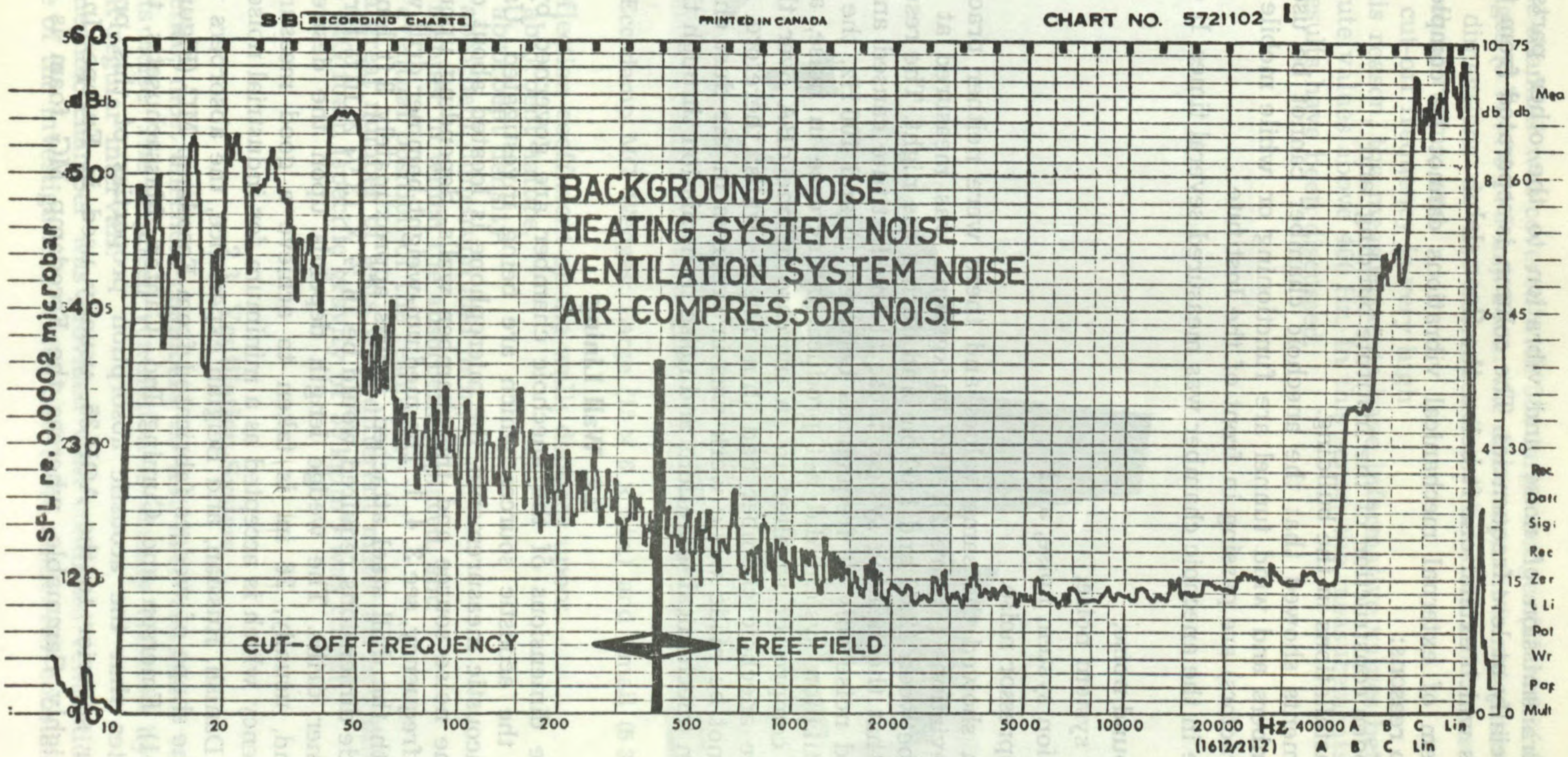

Figure 2: Recorder Spectrogram of Total Background Noise (1/3 Octave Analysis)

reduces the transmission of noise and vibration to the other parts of the building, especially at low frequencies. The column is separated from the floor slab by boards which extend one ft below the floor slab.

The problem of external mechanical vibrations cannot be completely resolved for two reasons:

a) the wooden construction of the Institute building, and

b) other installations in the building.

The measurements showed that the anechoic chamber cannot be used while the dust chambers and wind tunnel are functioning or while mobile vehicles (trucks and tractors) are passing in front of the Institute.

Total noise in the anechoic chamber was measured several times. It consisted of:

a) background noise,

b) heating system noise,

c) ventilation system noise, and

d) air compressor noise.

The spectrum showed the same values and there were neither practical nor theoretical deviations (Figure 2). The background was measured at intervals for one year between 12:00 and 1:00 pm and during the night. The results were the same in that the heating system noise at the Institute caused an increase in background noise only at frequencies between 10 and 100 Hz, the anechoic chamber ventilation system did not produce an increase in noise, and noise from the air compressor resulted in an increase of one dBA over the whole spectrum. The anechoic chamber had thin outside walls; therefore, measurements could not be made while work was in progress in the dust chamber in a nearby room (mechanical vibrations and noise transmission through the walls).

2.2. Wall Lining

The inside dimensions of the anechoic chamber are governed by the dimensions of the acoustic sources which are being investigated. Usually, in making the acoustic measurements, the microphone is located about one metre from both the noise source and the chamber walls, depending upon the absorption and frequency, see 3. 4. 1. The medium-weight hammer drill was 2 ½ ft long and, with the drill steel attached, it was approximately 3 ft long. In this case, the inside dimensions required would be 16 ½ × 13 ¼ × 10 ft for medium-weight hammer drills. The wedge length depends upon the desired cut-off frequency and, usually, 26 in. is taken to achieve a good measurement at 100-Hz frequency which is accepted as a minimum for industrial noise (2, 4).

By using Danish, Russian, and Belgian experience, the absorbers were constructed in the shape of wedges fabricated from Eccodamp MG (Figure 3) (5, 6, 7, 8, 9, 10, 11). Emerson and Cuming Inc., Canton, Massachusetts, the manufacturer, states that the acoustic absorption properties of this product are equivalent or superior to the AOP-35, usually used in Europe. In addition, AOP-35 is highly flammable, whereas the Eccodamp MG foam is not flammable. The chamber was covered with 584 large wedges (15 $\times$ 6 $\times$ 6 in.) and 256 small wedges (5 3/4 $\times$ 6 $\times$ 6 in.). From the dimensions it is noted that:

a) the dimensions do not correspond to the standard measurements for anechoic rooms; and

b) the cut-off frequency is very high.

For this reason, the measurements have informative values between 400 Hz and absolute values above 400 Hz. In this sense, the measurements were made, and the results have been discussed.

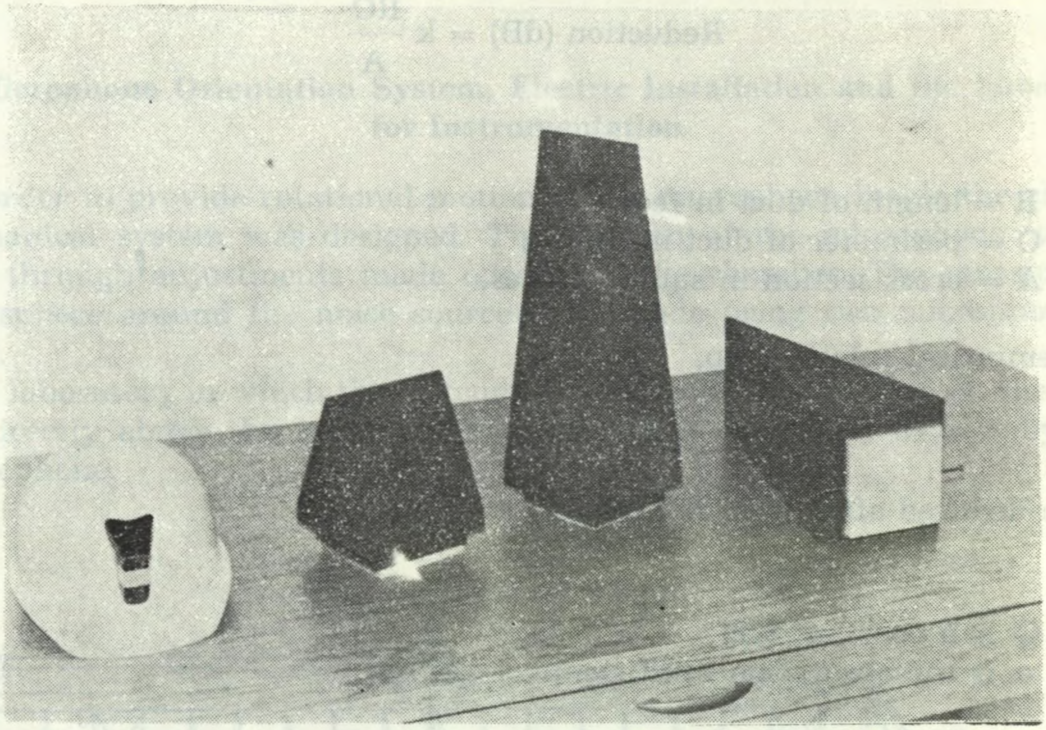

Figure 3: Eccodamp MG Wedges: Large (15 $\times$ 6 $\times$ 6 in.) and Small (5 3/4 $\times$ 6 $\times$ 6 in.)

The reflection coefficient of the walls depends upon:
— the absorbent nature,
— the absorbent density,
— the absorbent dimension and form,
— the manner in which the absorbent is placed, and
— the eventual position of the resonator.

From a great number of tests with different materials and different forms, Eccodamp MG foam (specific gravity of 35 kg/m³) was chosen.

2.3. Ventilation System

In practice, most anechoic chambers do not have continual ventilation because of its noise. The required ventilation is usually effected by opening the chamber at regular intervals.

This anechoic chamber was provided with continual ventilation because of the nature of the investigations which had to be made. Air consumption by the medium hammer drill was about 170 cfm, so a fan (Type 12 DLS, cap. 400 cfm) was installed to exhaust this air from the chamber. The details of this ventilation system are shown in Figure 1.

The input silencer was constructed as a labyrinth of small wedges as seen in Figure 1.

The noise reduction due to a quiet-duct silencer is proportional to the length of the duct, the perimeter of the cross section, and the absorbing coefficient of the lining; it is inversely proportional to the cross section.

$$\text{Reduction (dB)} = k \frac{RO}{A} \qquad \text{(Eq. 1)}$$

where:

R = length of duct in feet;
O = perimeter of duct in inches;
A = cross section in square inches.

The empirical relationship,

$$k = Qa^{1.4} \qquad \text{(Eq. 2)}$$

has been deduced after Hale J. Sabine,

where:

Q is a constant (12);
a is the absorption coefficient.

From the Equation 1, it may be shown that an increase of the ratio "O/A" indicates that:

i) small ducts are more efficient than large ducts; and
ii) rectangular ducts are more efficient than square ducts.

The noise reduction may be calculated from Eq. 1, except that when this is done, "O" includes both sound-absorbing sides of the splitter.

The relationship between the noise reduction with splitters and without splitters, is given by:

$$R_s = R_d \left(\frac{xN}{x + y}\right) \qquad \text{(Eq. 3)}$$

R_s = reduction with splitters;
R_d = reduction without splitters;
N = number of splitters;
x = length of longest side; and
y = length of shortest side.

The octave band noise reduction characteristics are as follows (13):

	Frequency Bands						
	63	125	250	500	1000	2000	4000
dB	4	5	5	8	16	22	12

2.4. Microphone Orientation System, Electric Installation and the Laboratory for Instrumentation

In order to provide rotational motion of the microphone inside the chamber, a mechanical system was designed. The position of the microphone was controlled through adjustments made outside of the chamber. The measurements in the sphere around the noise source were made using two microphones (Figure 4).

The laboratory in which the instruments were set up is located on the ground floor directly above the anechoic chamber and is connected with it by cables and telephone.

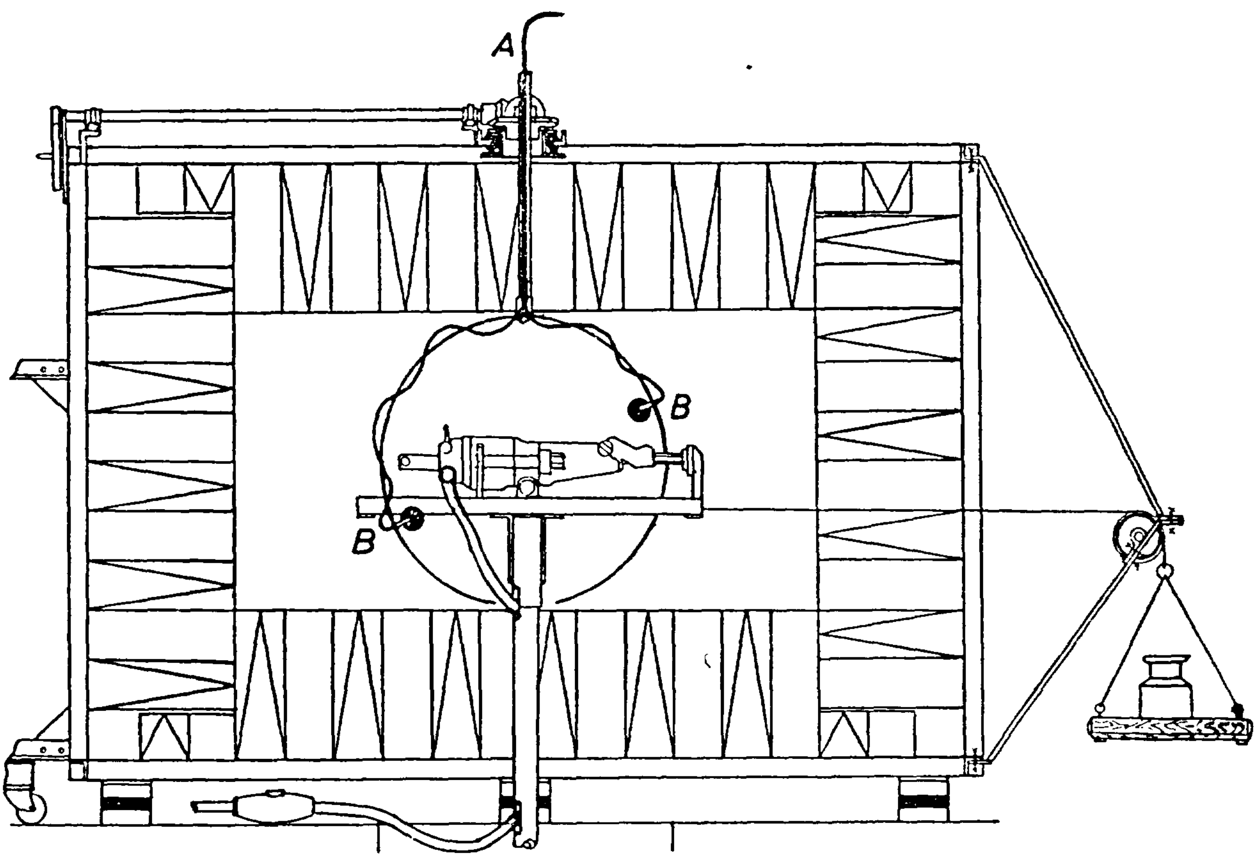

Figure 4: Arrangements for Measuring the Noise from Hammer Drills (A — AO 0028 (10 m)), B — Microphone UA 0052 — 4133)

3. INSTRUMENTATION

The following instruments were used for the testing of the anechoic chamber: Audio Frequency Spectrometer (B and K*, Type 2112, Figure 5), Level Recorder (B and K, Type 2305, Figure 4), and Random Noise Generator (B and K, Type 1402, Figure 11).

Various trade associations and engineering groups have standardized test codes for measuring the noise from certain devices, such as electric motors, transformers, fans, and blowers. These codes are often referenced as part of a specification in order to standardize the measurement procedure to be used in checking for compliance to a maximum noise requirement.

Figure 5: Arrangement for Measuring the Sound Characteristics

3.1. Audio Frequency Spectrometer (B and K, Type 2112)

The audio frequency spectrometer is designed for analyses and linear measurements in acoustics, electro-acoustics, electronics, and vibration in the frequency range 22 to 45,000 Hz. Means for the connection of extension filters are available thereby extending the selective frequency range from 11 to 45,000 Hz. The spectrometer consists of an input circuit, and input amplifier, a filter section, an output amplifier, and a meter circuit.

* Brüel and Kjaer (Canada) Limited.

3.2. Level Recorder (B and K, Type 2305)

The level recorder is designed for accurate recording of signal levels in the frequency range 2 to 200,000 Hz. Typical applications are recording of spectrograms, frequency response characteristics, reverberation decay curves, and noise and vibration levels. The instrument records either on lined paper or on amplitude/frequency calibrated paper.

3.3. Random Noise Generator (B and K, Type 1402)

The noise generator produces a noise signal with uniform spectrum density in the frequency range 20 to 20,000 Hz having true (normal) Gaussian amplitude distribution.

3.4. Microphones

The B and K condenser microphones are designed for measuring sound. A complete condenser microphone consists of a microphone cartridge and a microphone preamplifier.

It consists essentially of a thin metallic diaphragm mounted close to a rigid back plate. The diaphragm and back plate are electrically insulated from each other and constitute the electrodes of a capacitator.

Two classes of condenser microphones are available, the free field microphone and the pressure microphone. The cartridges available in four different nominal diameters are tabulated below (14, 15).

Microphone Diameters	Free Field	Pressure
1 inch, 23.77 mm	Type 4131	Type 4132
$^1/_2$ inch, 12.70 mm	Type 4133	Type 4134
$^1/_4$ inch, 6.35 mm	Type 4135	Type 4136
$^1/_8$ inch, 3.175 mm		Type 4138

The microphone preamplifier UA 0052 (½ in.) has an extremely high input impedance which presents virtually no load to the microphone cartridge.

The microphone extension cable is available with B and K connectors at both ends. This cable was necessary because of the distance between the instrumentation laboratory and the anechoic chamber (Figures 4 and 11).

3.4.1. Selection of Microphone Orientations

The nature of the sound field, the measurement condition, and the purpose of the measurements determine which class of microphone will give the best data. The five measurement conditions, as shown in Figure 8, will be discussed.

The response of a microphone to a sound field depends upon the location of the microphone with respect to the sound source. The near- and far-field conditions (Figure 6, A and B) relate to the source radiation behaviour as a function of its distance from the sound source and the free-field while the reverberant-field conditions have to do with the external environment. Most sound measurements are made in the far field, because the interest in the total sound radiated from the noise source. The distance between the microphone and the source should be 3 to 4 times the largest dimension of the radiating source. The measured power levels are in best agreement down to values of $r/a = 2$, in which r is the radius of the test hemisphere and a is the maximum motor or machine dimension (1, 16).

No microphone position should be closer to the chamber boundaries than $\lambda/4$ ft, λ being the wavelength of sound at the centre frequency of the lowest frequency band of interest. Both of the above conditions could not be satisfied because the rock drills LION BBC 24 and 25 (Atlas Copco) are about 30 in. long. From these figures the radius (r) can be calculated as:

$$r = 5 \text{ ft}.$$

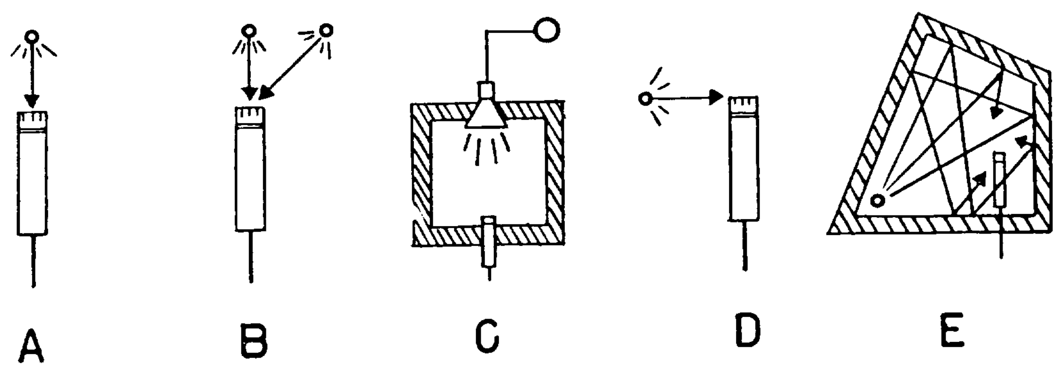

Figure 6: The Five Common Measurement Conditions that May Be Expected when Microphones Are Used (A — Perpendicular incidence — a free field, B — Omni-directional — a free field, C — Pressure — a small closed cavity, D — Grazing incidence — a diffuse field, E — Random incidence — a diffuse field)

If the lowest frequency band of interest is considered to be 250 Hz, then $\lambda =$ $= 4$ ft 3 in. The distance (d) from the microphone to the wedges in the chamber is:

$$d = 1 \text{ ft } {}^{3}/_{4} \text{ in.}$$

That is why the measurements in our chamber cannot have absolute values for frequencies above 5 kHz (increase 1 to 1.5 dB). Reflections of sounds usually exist (even outdoors), so the field is partly reverberant. The proper microphone must be selected and oriented in the sound field to minimize these effects. The area of the test hemisphere covers the limits of level fluctuations observed with small shifts in microphone position. This apparent variability is caused entirely by reflections. Because of these difficulties, extremely critical measurements are often made in anechoic rooms.

The calibration chart supplied with a condenser microphone cartridge (B and K, Type 4133) shows that the pressure response of the $^{1}/_{2}$-inch microphone is

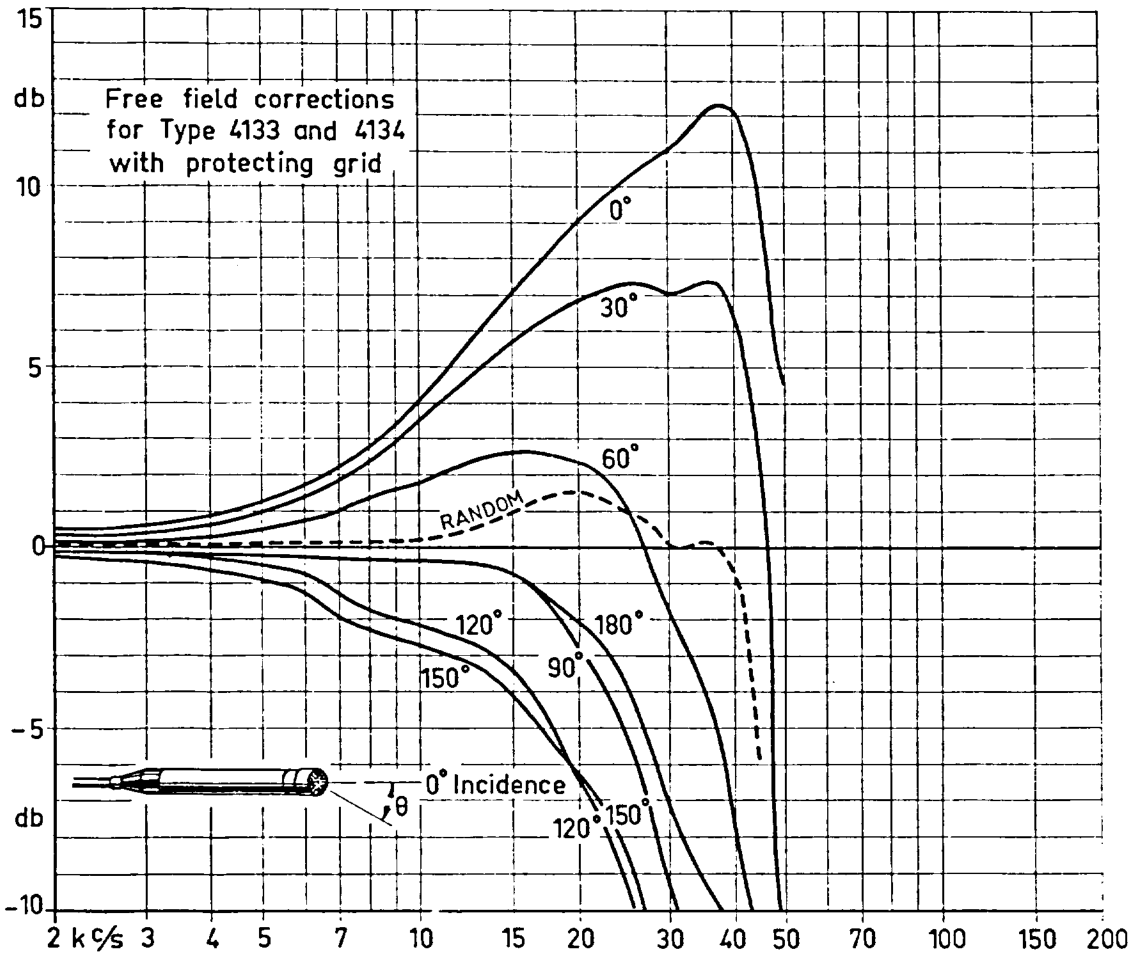

Figure 7: Typical Free-Field Correction Curves to be Added to the Pressure Characteristic of the Half-Inch Microphones, after B and K

flat to 7 kHz. Figure 7 shows that the grazing incidence correction is negligible over that range. The free-field corrections which represent the increase of sound pressure caused by the diffractions of the sound waves around the microphone are important only at high frequencies at which the wavelengths are comparable with the external dimensions of the microphone.

The free-field correction curves for diverse angles of incidence are given in Figure 7. It can be seen that the random incidence (free-field) corrections are very small at audio frequencies. The same microphone will suit for both outdoor and indoor measurements. The grids are individually adjusted during manufacture in order to obtain this characteristic to within 0.2 dB up to 30 kHz and to within 0.5 dB above 30 kHz. This instrumentation, when equipped with the B and K condenser microphone, Type 4133, fulfills the IEC 179 recommendations for precision sound level meters.

Now the microphones can be evaluated for use under the five measurement conditions that were identified earlier herein. The requirements for free-field and pressure microphones and their proper orientation can be given as shown in Table 1.

TABLE 1

Application of Microphones

	Measurement Condition	Class of Microphone	Typical Application	Standard
A	Perpendicular Incidence	Free-field	Product noise	ISO; ASA
B	Omnidirectional Incidence	Pressure (small size) or Corrected free-field	Factory noise	ISO; ASA
C	Pressure	Pressure	Calibrate earphones	ISO; ASA
D	Grazing	Pressure	Moving sound source	FAA
E	Random Incidence	Pressure	Total acoustic power	ASHRAE

A single class of microphon~ is not adequate for all measurements. Proper application of microphones can provide acoustical data that are of maximum certainty and accuracy.

3.4.2. Windscreen (B and K, UA 0237)

While a microphone is exposed to wind, noise will be generated due to the variation of air pressure on the diaphragm. The three principal reasons for this are:

i) wind velocity variations;
ii) turbulence created around the microphone when it is placed in the wind;
iii) mechanical impacts and uncleanliness (pieces of hard rubber and oil).

In our case, free-field correction curves for windscreen B and K UA 0237 differ in the frequency range 5,000 to 10,000 Hz (Figure 8).

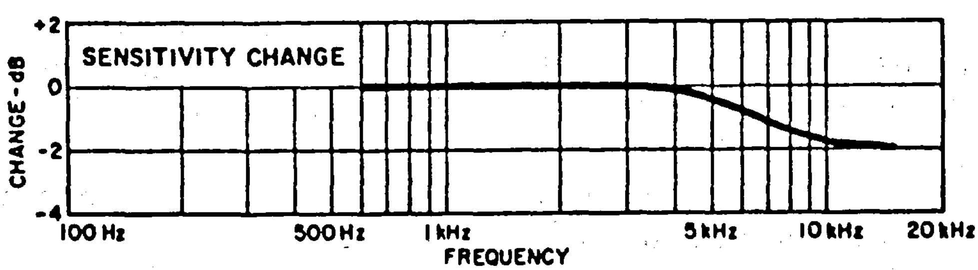

Figure 8: Changes in Sensitivity of a One-Inch Microphone Caused by a Windscreen

4. CALIBRATION

The supplier of the wedge lining for the chamber guaranteed the acoustical absorption qualities of the foam.

In free space, according to the inverse-square law, there will be a decrease of 6 decibels in the sound pressure level for each doubling of the distance. Figures 9 and 10 show the theoretical curve for the inverse-square law, starting with a measurement of half a foot. The acoustic source is located in the centre of the anechoic chamber. In front of the door, the measurement at a distance of 3 feet was not taken because of the door.

Random noise sources are used for tests of the inverse-square law in an anechoic room; therefore, the source size, phasing, and microphone orientation all become critical factors in the accuracy of the calibration (Figure 11).

The sound pressure level in the 1/3 octaves belonging to that octave band are computed. The results (Figures 9 and 10) show that the cut-off frequency occurs between 250 and 500 Hz, just as it was foreseen prior to the construction. In a free field, a tolerance of one dB in measurements technique is acceptable.

The two sides of the anechoic chamber show an approximately symmetrical picture. The measurements taken in front of the door (Figure 9) show greater deviations for the frequencies of 2000 Hz and 4000 Hz at a distance of 1 1/2 to 2 1/2 feet from the noise source. This indicates that the acoustic seal between the door and the chamber is not sufficient to provide good attenuation. At a distance of 1 1/2 ft in the zone of our measurements, the deviation is 1.8 dB which is acceptable because, for the frequencies 2000 and 8000 Hz, the results were good. The measurements taken opposite the door at the frequency of 500 Hz show a deviation at the distance of 2 to 3 ft which is out of the radius of the measurement sphere. The deviation occurs also at 2000 Hz at the distance of 3 ft (+ 1.6 dB). This result is accidental because, at the frequencies of 1000 Hz and 4000 Hz, the results are good. The measuring direction opposite the door in the anechoic chamber is the most favourable.

By measurements (1/3 octave band) it is confirmed that the limit of the cut-off frequency is between 350 and 400 Hz. As a general rule, the greater the attenuation desired at low frequency, the heavier and more expensive the room will be.

The maximum values of the deviation of sound pressure from the inverse-square law as a function of the distance from a point source are acceptable between 400 Hz and 8 kHz.

5. CONCLUSIONS

The anechoic chamber can be used for good measurements of noise from light and medium hammer drills.

The noise from the ventilation system can be attenuated to such a degree that the ventilator can be used during testing of the hammer drill.

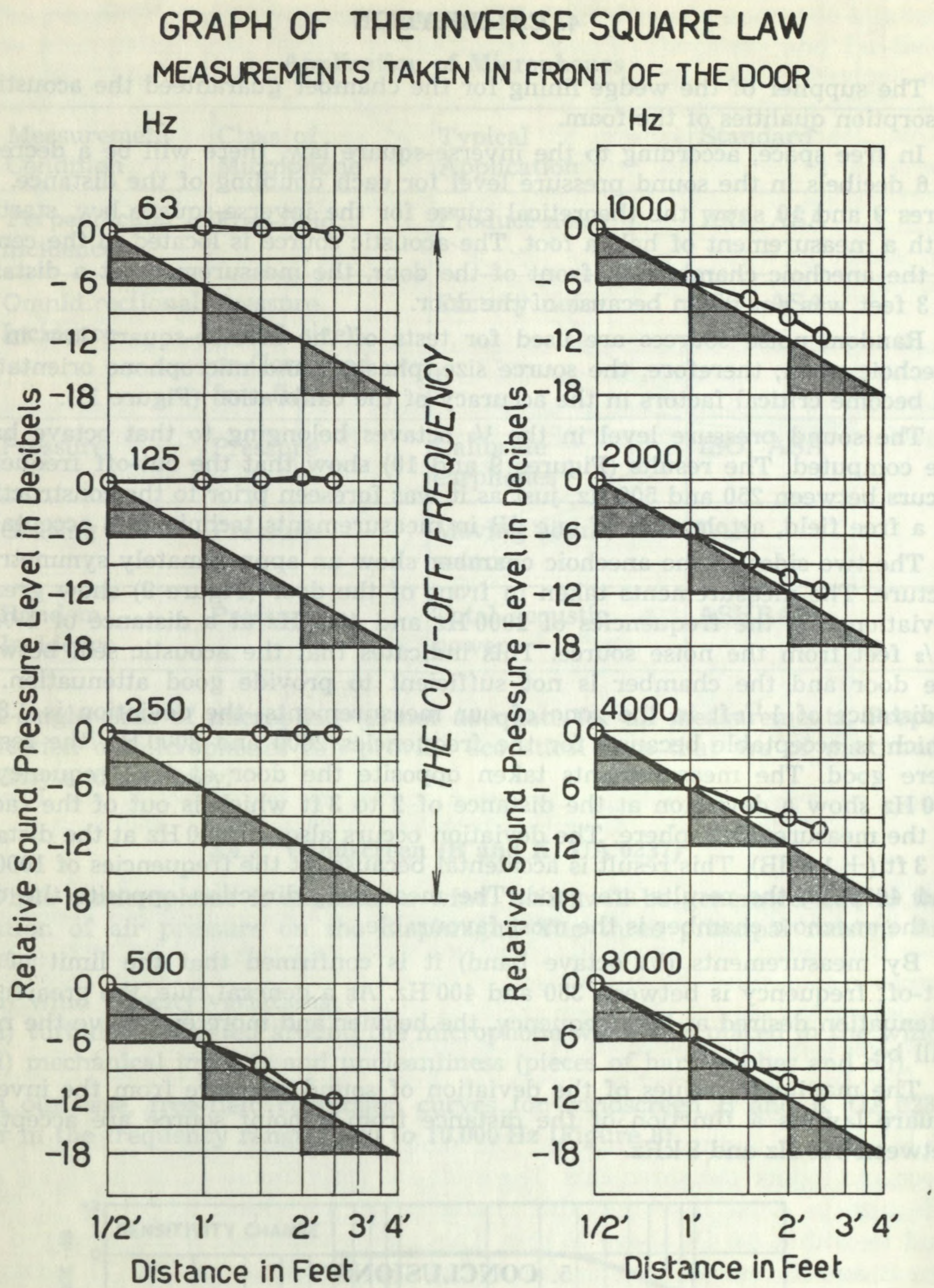

Figure 9: The Inverse-Square Law of the Anechoic Chamber (Front of the Door)

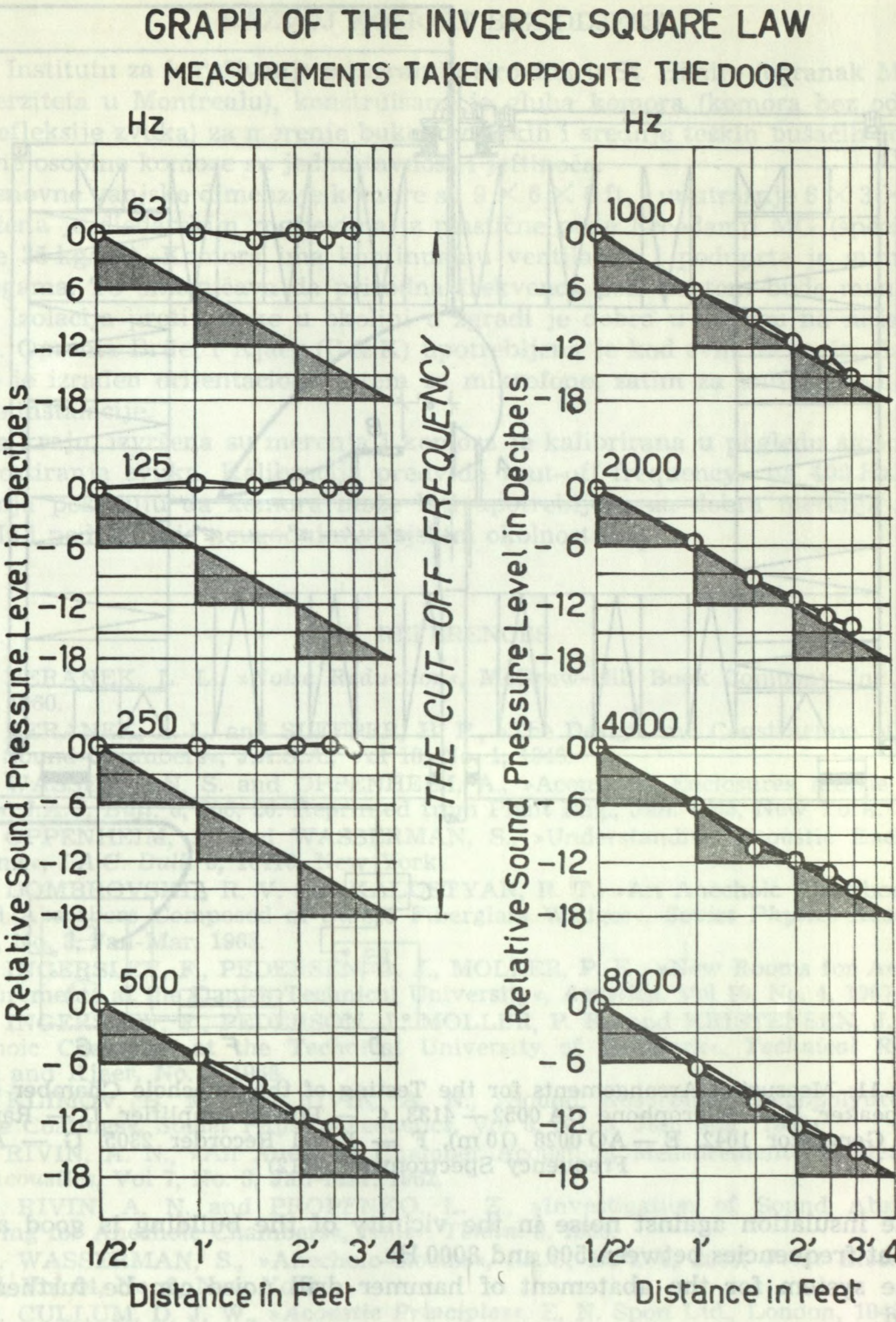

Figure 10: The Inverse-Square Law of the Anechoic Chamber (Opposite the Door)

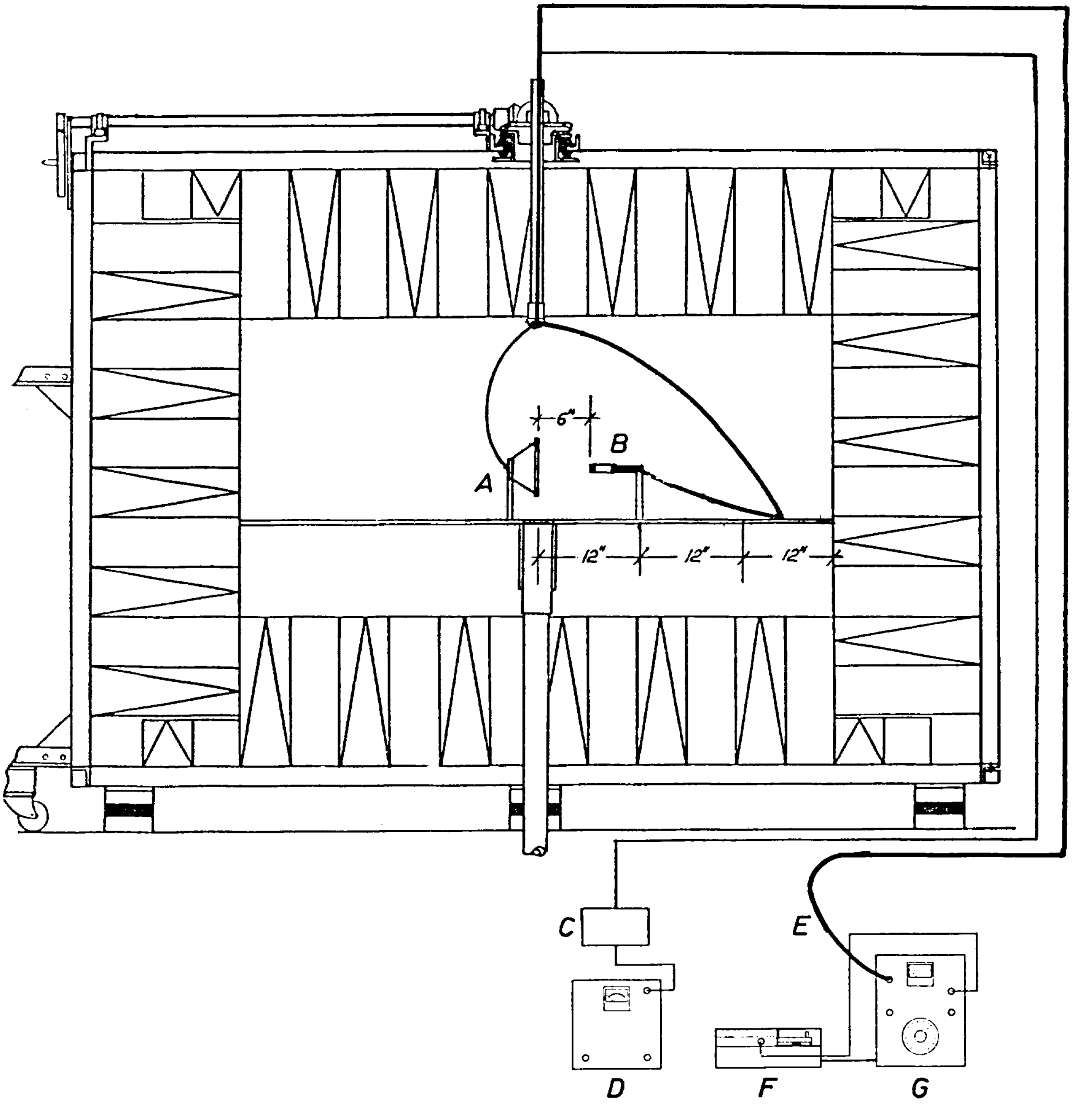

Figure 11: Measuring Arrangements for the Testing of the Anechoic Chamber (A — Loudspeaker, B — Microphone UA 0052 — 4133, C — Power Amplifier, D — Random Noise, Generator 1042, E — AO 0028 (10 m), F — Level Recorder 2305, G — Audio Frequency Spectrometer 2112)

The insulation against noise in the vicinity of the building is good above 95 dB at frequencies between 500 and 8000 Hz.

The system for the abatement of hammer drill noise can be further improved.

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RAZVOJ KOMORE BEZ ODJEKA

U Institutu za istraživanje mineralnih sirovina u St. Hilaire (ogranak McGill Univerziteta u Montrealu), konstruisana je gluha komora (komora bez odjeka, bez refleksije zvuka) za merenje buke kod lakih i srednje teških bušaćih čekića. Glavne osobine komore su jednostavnost i jeftinoća.

Osnovne vanjske dimenzije komore su 9 × 6 × 6 ft, i unutrašnje 6 × 3 × 3 ft. Obložena je diedarskim rogljevima iz plastične pene Eccodamp MG (specifične težine 35 kg/m^3). Komora ima kontinualnu ventilaciju i poduprta je gumenim podlogama. To omogućava da prirodna frekvenca pod teretom bude manja od 7 Hz. Izolacija protiv buke u okolini u zgradi je dobra u odnosu na naša merenja. Oprema Brüel i Kjaer (B & K) upotrebljena je kod svih merenja. Za merenje je izrađen orijentacioni sistem za mikrofone, zatim za kablovske i električne instalacije.

Na kraju, izvršena su merenja i komora je kalibrirana u pogledu slobodnog rasprostiranja zvuka. Kalibracija predviđa »cut-off-frequency« na 400 Hz. Ova merenja pokazuju da komora može biti upotrebljena za dobra merenja iznad 400 Hz i pod krajnje neugodnim vanjskim okolnostima.

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