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Measuring Noise From a Continuous Mining Machine

By Roy Bartholomae, John Kovac,
and John Robertson

UNITED STATES DEPARTMENT OF THE INTERIOR

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MEASURING NOISE FROM A CONTINUOUS MINING MACHINE

By Roy Bartholomae,[1] John Kovac,[2] and John Robertson[3]

ABSTRACT

Noise generated by continuous mining machines in underground coal production is an important health hazard. Bureau of Mines Contract J0387229 covers investigation of this noise through laboratory tests of simulated cutting operations and through in-mine noise measurements. The results of these investigations indicate that coal cutting noise and conveyor noise are dominant sources of mining machine operational noise. Typical noise levels for both cutting and conveying operations are approximately 97 dBA (decibels A-weighted). For full operation of all machine systems, the overall sound pressure level is approximately 101 dBA. In-mine and laboratory test results show excellent agreement in both A-weighted overall levels as well as in A-weighted one-third-octave band spectra.

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INTRODUCTION

BACKGROUND

In response to the Federal Mining Health and Safety Acts of 1969 and 1977, which established maximum noise levels permissible for mining personnel, the Bureau of Mines has undertaken a number of research programs aimed at reducing the noise associated with mining operations.

One of the more serious noise problems in the coal mining industry is associated with the operation of continuous mining machines in underground coal production. The continuous mining method is by far the most common underground coal extraction procedure in use today; over 2,000 machines are in operation, accounting for approximately 60 pct of the total tonnage of coal mined underground in the United States.[4] Figure 1 shows the operating time per shift and noise level in the major mode of operation for typical underground face equipment. The continuous mining machine ranks second only to the pneumatic stoping drill as a source of underground noise at the face. Because of the severity of continuous mining machine noise, the present widespread use of this equipment, and its increasing future application, the Bureau has undertaken a comprehensive noise control program for continuous mining machines.

STATEMENT OF THE PROBLEM

The overall noise levels observed around continuous mining machines result from the combined contributions of several "independent" noise sources. These sources, which are keyed to the various operations of the machines, can be divided into four general categories: Cutterhead, conveyor, drive train, and hydraulic system.

A noise survey system was conducted on a representative sample of continuous mining machines,[5] and a summary of the results is presented in figure 2. These data show that the cutterhead and the conveyor are major noise sources in terms of their contribution to the overall noise level generated by the continuous mining machine. The drive train and hydraulic system, on the other hand, are secondary noise sources because of their smaller contribution to the overall noise levels. In addition, drive train and

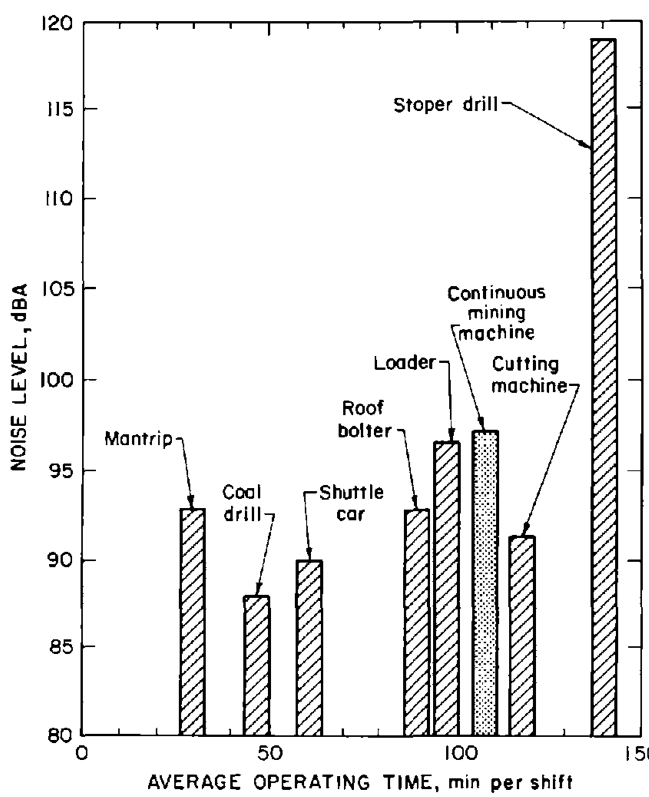

FIGURE 1. - Noise level time data for underground face equipment.

[4]Bobick, T. G., and D. G. Giardino. The Noise Environment of the Underground Coal Mine. MESA Informational Report IR 1034, 1976, 26 pp.

[5]Madden, R. Abatement of Noise of Continuous Mining Machines. Phase II: Noise Sources and Control. Bolt Beranek & Newman, Inc. report under BuMines Contract H0155113, February 1976, 67 pp.; available for consultation at Pittsburgh Research Center, Bureau of Mines, Pittsburgh, Pa.

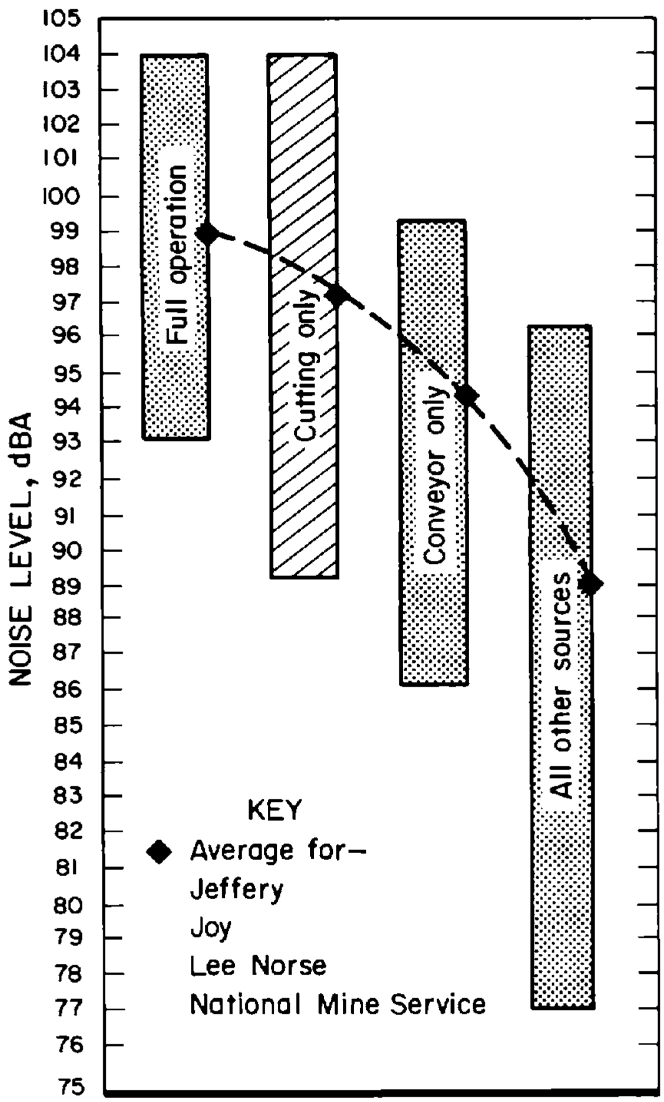

FIGURE 2. - Contribution of major sources for continuous mining machine.

hydraulic system noise is largely dependent on the design and operating condition of the individual machines.[6]

At present, the Bureau has two major programs underway to investigate continuous mining machine noise: (1) contract H0155113, "Abatement of Noise of Continuous Mining Machines," Bolt Beranek & Newman, Inc.; (2) contract J0387229, "Investigation and Control of Noise Generated During Coal Cutting," Wyle Laboratories.

The emphasis of the first contract is the investigation and control of continuous mining machine conveyor noise; the emphasis of the second contract is the investigation and control of cutterhead noise. The results reported in this paper were obtained under the latter contract. Both contracts are largely based on the laboratory investigation of continuous mining machine noise. Because problems of logistics, productivity, and permissibility greatly impede research and development studies under insitu conditions, the development of meaningful laboratory test methods was a primary objective of the present study. The present paper emphasizes (1) the development of laboratory apparatus and test methods for the investigation of continuous mining machine noise and (2) evaluation from laboratory test results of the noise source characteristics. Future studies will investigate noise control concepts and lead to the development of prototype quiet hardware.

TECHNICAL APPROACH

Work under contract J0387229 has contributed significantly to a definition and better understanding of the noise produced by continuous mining machines, with specific emphasis given to coal cutting noise. The technical approach to this study has been based on extensive laboratory testing of a Lee-Norse HH105[7] continuous miner cutting a synthesized coal (syn-coal) seam. To facilitate accurate interpretation of laboratory results, supplementary tests have been conducted to define the physical and acoustical characteristics of the syn-coal seam. Also, the accuracy of laboratory simulation has been evaluated by comparing laboratory noise data with similar data taken during the insitu operation of a continuous mining machine underground.

Specific areas of emphasis under the present contract have been (1) development of a syn-coal seam to facilitate

[6]Work cited in footnote 5.

[7]Reference to specific products does not imply endorsement by the Bureau of Mines.

laboratory studies of continuous mining machine coal cutting noise in the Wyle mining noise test facility (MNTF), (2) laboratory noise studies of a Lee-Norse HH105 continuous miner in the MNTF, and (3) in-mine noise studies of a Lee-Norse HH265[8] continuous miner. Results from each of these areas of study are summarized in the following sections. In addition, a comparison of in-mine and laboratory noise measurements is presented.

DEVELOPMENT OF SYNTHESIZED COAL SEAM

The work to develop a syn-coal seam consisted of preliminary studies using a small sample of several recipes to determine the most favorable recipe from the viewpoint of cutting forces and noise as a function of cutting conditions. The most favorable recipe was selected on the basis of similitude of these parameters to those of real coal. For both syn-coal and real coal samples, tests were performed using the Wyle-Bureau linear cutting apparatus (LCA) located at Wyle's Huntsville, Ala., facility (fig. 3). This facility provided for measuring the three orthogonal components of cutting force for a typical pick speed and depth of cut.

Based upon the results from preliminary studies of various syn-coal recipes, preparations were made for casting a large seam of syn-coal in the Wyle 100,000-ft^3 (2,831-m^3) reverberation chamber. The recipe used was 42 pct stoker-grade coal, 42 pct bottom ash, and 16 pct portland cement. As this seam was poured, sample blocks were cast for each truck load of mixture for later calibration using the LCA. A summary of test results for both syn-coal and real coal is presented in table 1. These results indicate that the Wyle syn-coal is harder than real coal, whereas preliminary tests showed good agreement. This discrepancy is explained by the absence of air bubbles in the commercially mixed samples. Figure 4 shows typical coal and syn-coal samples before and after cutting.

Although the Wyle syn-coal is harder, the recipe appears to give a good approximation of real coal on the basis of noise measurements as shown in figure 5. These results show that the acoustic efficiency of noise generation from the mechanical power expended to cut coal is approximately the same for real coal and syn-coal. This fact provides for correlating laboratory noise studies using syn-coal with other tests using real coal on the basis of mechanical power expanded (i.e., cutting force, F_z, times velocity of cut, V_c). Further evidence that the syn-coal seam provides good acoustic similitude between in-mine and laboratory tests is discussed later.

LABORATORY NOISE STUDIES IN THE MNTF

Noise studies were performed in the MNTF using a Lee-Norse HH105 continuous miner. These studies focused on the investigation of coal cutting noise for a continuous mining machine using a syn-coal seam in a surface acoustic test facility. Figure 6 shows the miner in the MNTF. A number of significant studies have been performed and are briefly summarized in chronological order, as follows:

Test A.--Tests were performed to record "idling" noise for the major continuous mining machine subsystems. Included were (1) main hydraulic pumps, (2) cutterhead rotation with main hydraulic pumps, and (3) unloaded conveyor with main hydraulic pump. Recorded data consisted of reverberant sound pressure levels.

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[8]In-mine noise studies were made of a HH265 miner since a HH105 was not readily available for study. Future activities under this contract may include in-mine and laboratory tests of the same miner.

TABLE 1. - Cutting force variation with coal type[1]

Coal type	Depth of cut, in (cm)	Cutting force, lb (N)[2]								
		$\bar{R}$	$\tilde{R}$	$\bar{R}_p$	$\bar{F}_z$	$\tilde{F}_z$	$\bar{F}_y$	$\tilde{F}_y$	$\bar{F}_x$	$\tilde{F}_x$
REAL COAL										
Blue Creek[3]	1/2 (1.27)	607 (2,700)	325 (1,446)	470 (2,091)	386 (1,717)	238 (1,059)	399 (1,775)	257 (1,143)	28 (125)	168 (747)
Do[3]	1 (2.54)	925 (4,115)	541 (2,407)	764 (3,399)	668 (2,972)	399 (1,775)	606 (2,696)	359 (1,597)	50 (223)	270 (1,201)
Pittsburgh Seam No. 1[3]	1/2 (1.27)	515 (2,291)	245 (1,090)	390 (1,735)	303 (1,348)	172 (765)	368 (1,637)	199 (885)	1 (4)	100 (445)
Do[3]	1 (2.54)	958 (4,262)	590 (2,625)	557 (2,478)	484 (2,153)	301 (1,339)	474 (2,108)	315 (1,401)	88 (392)	173 (770)
Pittsburgh Seam No. 2[4]	1/2 (1.27)	773 (3,439)	406 (1,806)	594 (2,642)	456 (2,028)	318 (1,415)	464 (2,064)	420 (1,868)	108 (480)	227 (1,010)
Do[4]	1 (2.54)	1,037 (4,613)	646 (2,874)	756 (3,363)	778 (3,461)	600 (2,669)	528 (2,349)	443 (1,971)	4 (18)	264 (1,174)
Illinois No. 6[4]	1/2 (1.27)	694 (3,087)	329 (1,463)	549 (2,442)	465 (2,068)	289 (1,286)	418 (1,859)	266 (1,183)	67 (298)	164 (730)
Do[4]	1 (2.54)	1,112 (4,947)	525 (2,335)	762 (3,390)	877 (3,901)	497 (2,211)	501 (2,229)	344 (1,530)	-58 (-258)	297 (1,321)
SYN-COAL										
DOE formula[3]	1/2 (1.27)	925 (4,115)	411 (1,828)	722 (3,212)	564 (2,509)	304 (1,352)	673 (2,994)	315 (1,401)	13 (58)	229 (1,019)
Wyle formula[3]	1/2 (1.27)	1,834 (8,158)	685 (3,047)	1,452 (6,459)	1,022 (4,546)	456 (2,028)	1,447 (6,437)	613 (2,727)	45 (200)	299 (1,330)

[1]Becker, R. S., and G. R. Anderson. An Investigation of the Mechanics and Noise Associated With Coal Cutting. BuMines OFR 60-81, 1980, 275 pp.; NTIS PB81-215394.

[2]Explanation of symbols:

R = Resultant force. Superscript − = mean force. Subscript x = x-component.
R_p = Pick axial force. Superscript ~ = rms force. Subscript y = y-component.
F = Component force. Subscript z = z-component.

[3]Cuts made at 64 ips (1.6 m/s); however, effect of cutting speed on cutting force is negligible.

[4]Cuts made at 80 ips (2.0 m/s); however, effect of cutting speed on cutting force is negligible.

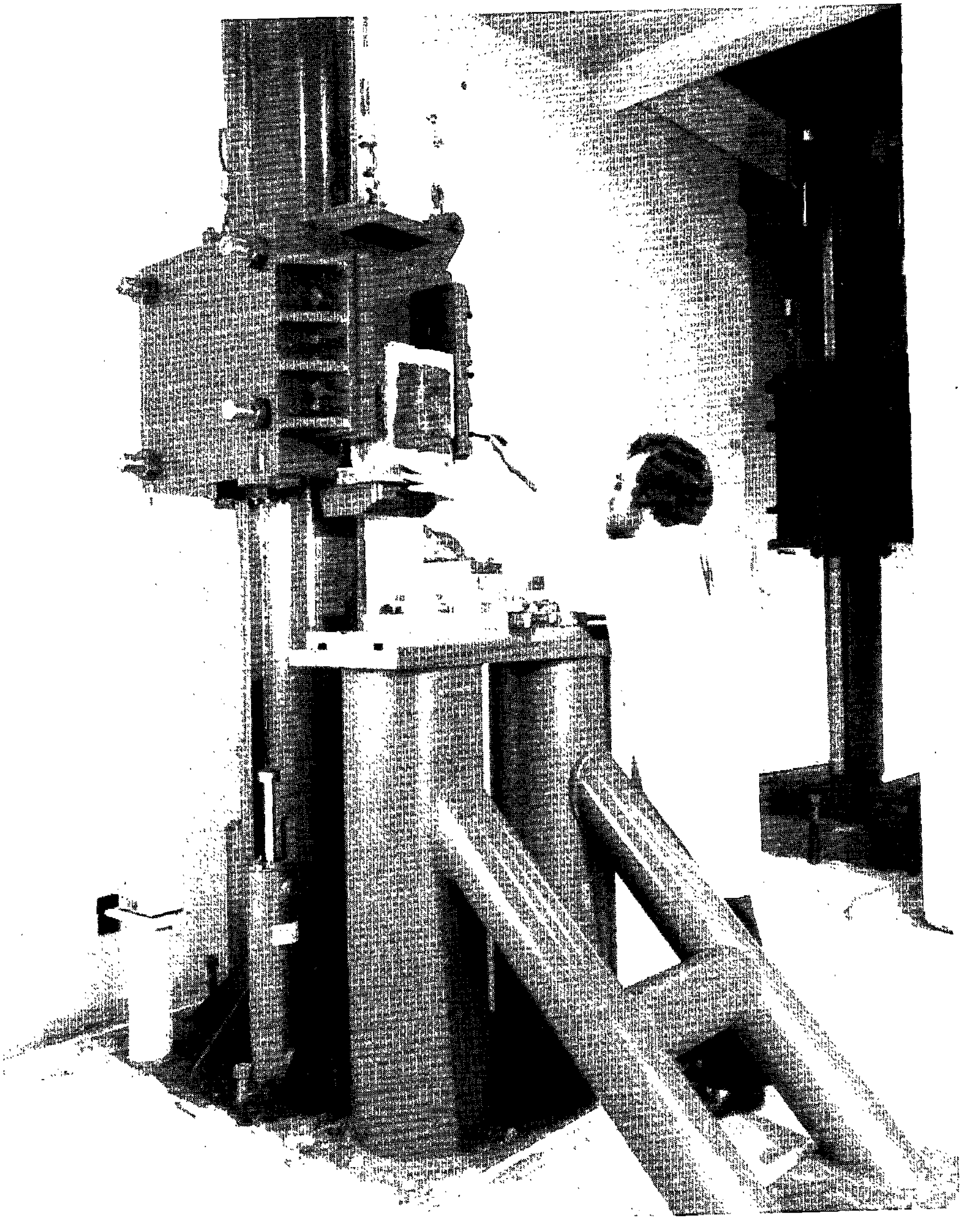

FIGURE 3. - Wyle-USBM LCA before the installation of anechoic enclosure.

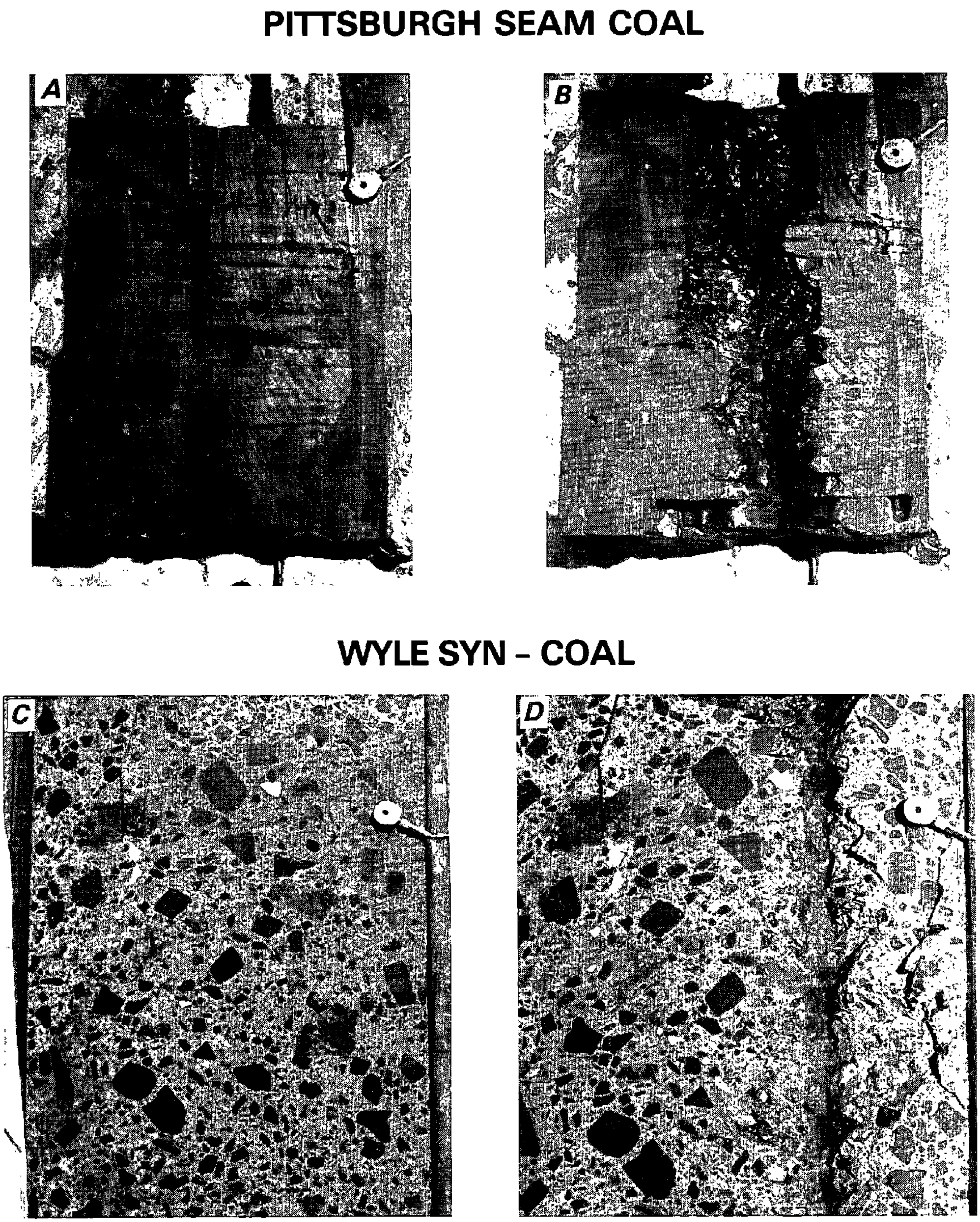

FIGURE 4. - Real and syn-coal samples before (A, C) and after (B, D) 1/2-inch (1.27-cm) depth of cut at 64 ips (1.6 m/s).

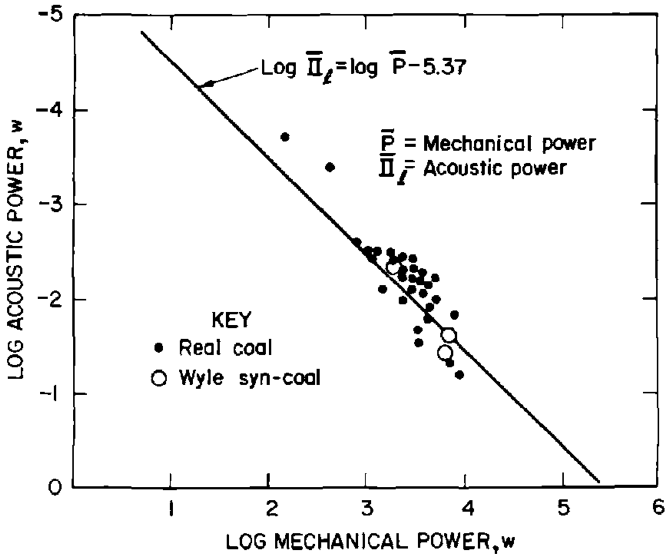

FIGURE 5. - Variation of acoustic power with mechanical power for linear cuts of real and syn-coal samples.

Test B.--Sump and shear cuts were made in the syn-coal seam to provide for the measurement of coal cutting noise. Recorded data consisted of reverberant sound pressure levels and coal face acceleration. These were the first cuts into a flat, simulated coal face. Subsequent cuts were into a simulated coal face that was concave, corresponding to the arc of the miner boom arm and cutting head.

Test C.--Sump and shear cuts were made in the syn-coal seam only a partial width (26 in [0.66 m]) of the cutting head. The primary purpose of this test was to evaluate an instrumented pick that had been adapted to the cutting head. In addition to pick force data, the reverberant acoustic and coal face vibration data were collected.

Test D.--Acoustic data were taken for the operation of the continuous miner conveyor loaded with syn-coal cuttings.

Test E.--Sump and shear cuts were made in the syn-coal seam with the full-width cutting head and an instrumented pick. For this test, the instrumented pick was "floating" on the load cell rather than rigidly attached. (Initial tests conducted of the instrumented pick, test C, were for a rigid mount to the load cell.) Recorded data included pick force, reverberant sound pressure levels, and coal face vibration.

Test F.--Sump and shear cuts were made in the syn-coal seam with the cutting drum covered with acoustic treatment. This treatment consisted of approximately 2 in (5 cm) of acoustic foam with an exterior covering of vinyl. The purpose of these tests was to absorb drum head vibrational noise in order to establish source-specific contributions to the overall coal cutting noise environment. Recorded data consisted of pick force and reverberant sound pressure levels. Also, loaded conveyor noise with the tail boom fully deflected (45° to the left) was recorded.

Test G.--Shear cuts in the syn-coal seam were made at a depth of approximately 18 in (46 cm) to assess the effect of deep-cut loading conditions on coal cutting noise. At this depth of cut, it was possible to actually stall the cutting head unless careful control of advance rate was maintained. Configurations consisted of (1) acoustically treated drum head and boom arm, (2) acoustically treated drum head, and (3) untreated baseline machine. Recorded data consisted of pick force and reverberant sound pressure levels.

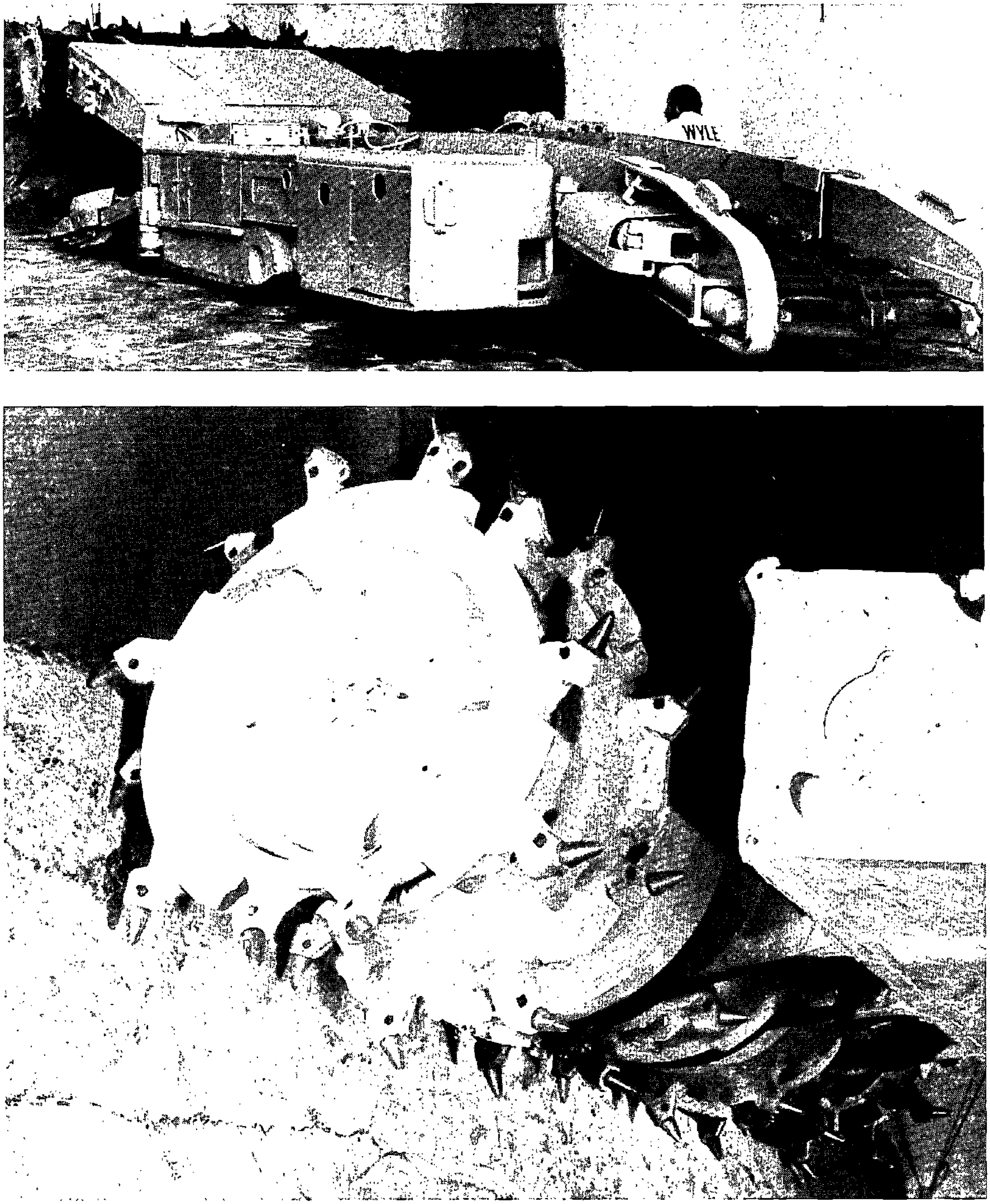

FIGURE 6. - Lee-Norse HH105 continuous miner at the MNTF—overall view (top) and closeup of cutterhead and syn-coal seam (bottom).

SUMMARY OF A-WEIGHTED OVERALL SOUND PRESSURE LEVELS

A summary of the test results is presented in table 2. These data are A-weighted overall sound pressure levels measured in the reverberant field. The reverberant levels appear to give a good approximation of levels at the operator station when they are compared with measurements taken underground. Several important observations from table 2 should be noted:

1. The predominant sources of noise are conveyor operation and coal cutting. For normal operation with a loaded conveyor, these two major sources produce approximately equal noise levels (93 to 100 dBA).

2. Unloaded conveyor operation results in the single most severe noise, particularly for a deflected tail boom, where the "clanking" of conveyor flights along the sideboards and tail roller is especially influential in producing noise.

3. According to the MNTF coal cutting noise studies, the drum cutting head could account for up to a 10-dBA increase in noise above that due to coal fracturing. This is evident in the 3.5- to 10.2-dBA noise reduction observed in the results for the acoustically treated drum head.

4. Main hydraulic pump noise produces only moderate noise levels. A slight reduction in pump noise occurred during cutterhead rotation.

TABLE 2. - Summary of A-weighted overall sound pressure levels measured in the reverberant field

Operating mode	dBA
Idling:	
Main hydraulic pumps	83.5- 84.1
Main pumps plus cutterhead rotation	81.5
Main pumps plus unloaded conveyor:	
With straight tail boom	98.7
With tail boom deflected 50 pct	102.7
With tail boom deflected 100 pct	104.6
Main pumps plus loaded conveyor:	
With straight tail boom	93.3
With tail boom deflected 100 pct	100.3
Coal cutting--baseline configuration:	
Sump--0 to 8 in (0 to 20 cm)	94.8
Shear--approximately 8-in (20-cm) depth	97.0
Deep shear--approximately 18-in (46-cm) depth	99.6
Coal cutting--acoustically treated drum:	
Sump--0 to 8 in (0 to 20 cm)	91.2
Shear--approximately 8-in (20-cm) depth	92.6
Deep shear--approximately 18-in (46-cm) depth	89.4

A-WEIGHTED REVERBERANT NOISE SPECTRA

IDLING NOISE

A-weighted one-third-octave-band noise spectra taken in the reverberant field of the MNTF for the main hydraulic pumps and the unloaded conveyor are presented in figures 7 and 8, respectively. Discrete tones are evident in the pump noise spectra, with slight variations occurring from test to test. The unloaded conveyor noise spectra clearly show the increase in spectrum levels as the "clanking" increases with an increase in tail boom deflection.

For the loaded conveyor operation, a noise reduction, relative to an unloaded conveyor, of approximately 5 dBA results. The loaded conveyor noise spectra for straight and fully deflected tail booms are shown in figure 9.

COAL CUTTING NOISE

A-weighted one-third-octave-band spectra for both sump and shear cutting operations are presented in figure 10. Noise levels during sumping operations were below those for shear cutting owing to a difficulty in obtaining the same feed rate achieved during shear. This limitation was due to limited miner traction and the fact that certain portions of the coal face were not fully cut away during sumping because of the absence of bits in front of the boom arms that support the drum cutting head. For the deep-cut spectrum in figure 10, the miner cutting head was loaded almost to the stall point, and these data should represent near maximum loading conditions on the cutting head for this machine.

A-weighted one-third-octave-band noise spectra for the acoustically treated drum are presented in figure 11. Sump and shear cut for this configuration correspond closely to those conditions for the baseline bare-head configuration tests. Consequently, a comparison of figures 10 and 11 will reveal potential noise reduction that could be effected by developing a quiet-cutting head. As previously noted, this noise reduction could range up to 10 dBA; a 5- or 6-dBA reduction is probably a realistic goal since, in most instances, the drum probably would be only moderately loaded, as represented by the 8-in (20-cm) depth shear cuts.

IN-MINE NOISE STUDY

In-mine noise data were recorded during the operation of a Lee-Norse model 265 Hard Head continuous miner in the Pond Creek Mine at Rawl, W. Va. The following is a summary of the results and analysis of this study.

Noise data were recorded at three locations around the miner with the miner operating in several different modes to facilitate the identification of predominant noise sources. The test procedure consisted of operating the miner in idling and coal cutting modes and recording the noise for each major subsystem (main hydraulic pump, conveyor, and cutting head) as the subsystems were activated, both independently and in combination with each other. During these tests, measurements were taken (1) at the operator's station, (2) near the main pump on the opposite side of the miner from the operator's position, and (3) near the cutterhead. Figure 12 shows the general location of the measurements, and table 3 summarizes the noise data for the Lee-Norse 265 miner.

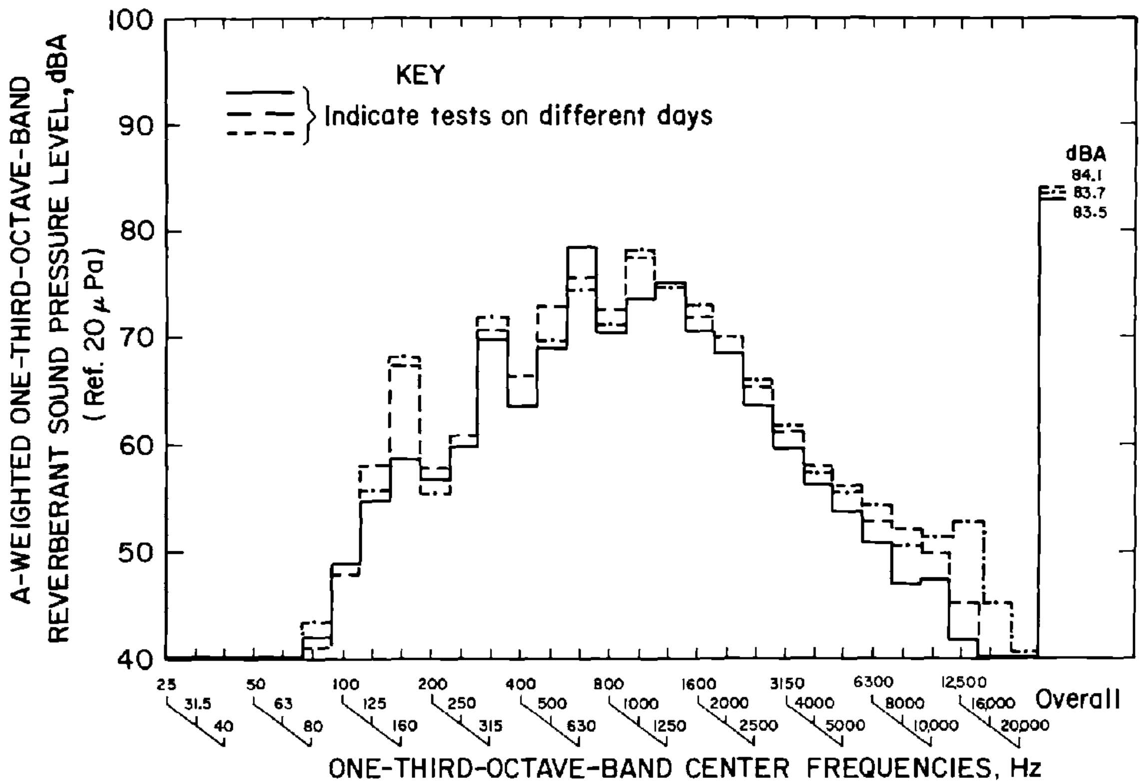

FIGURE 7. - Typical reverberant noise spectra of main hydraulic pumps at idle.

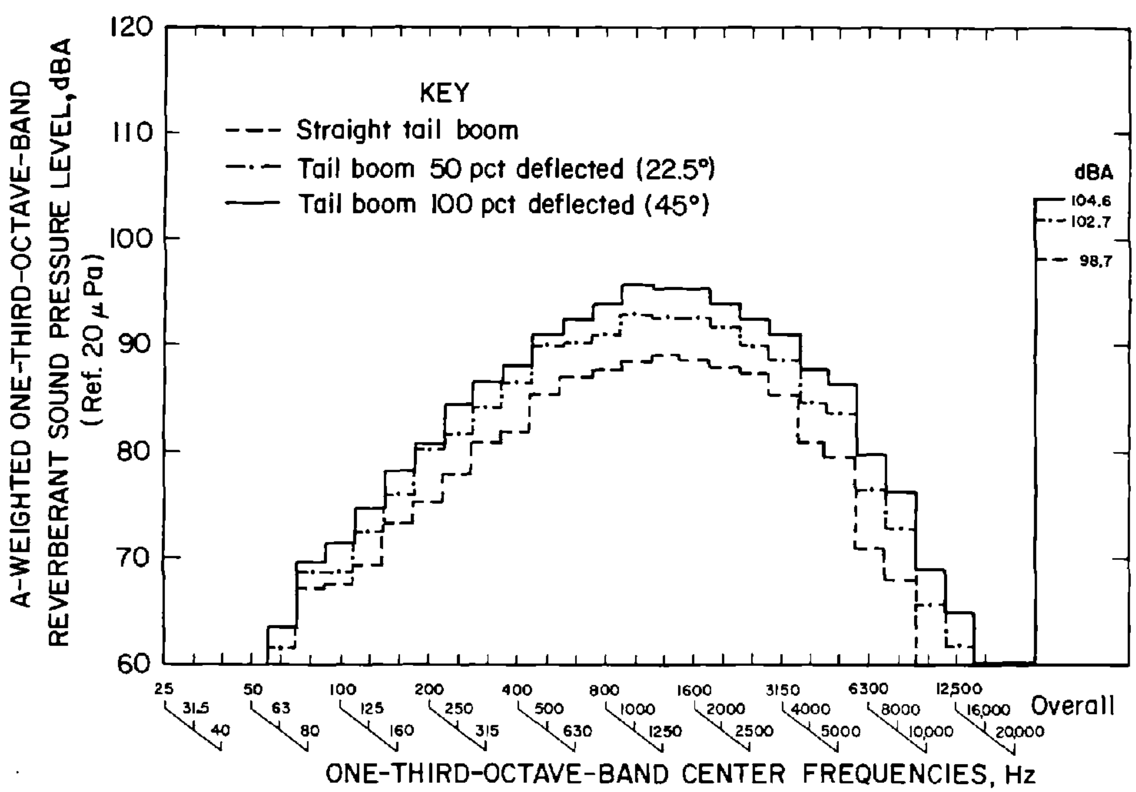

FIGURE 8. - Reverberant noise spectra of unloaded conveyor noise.

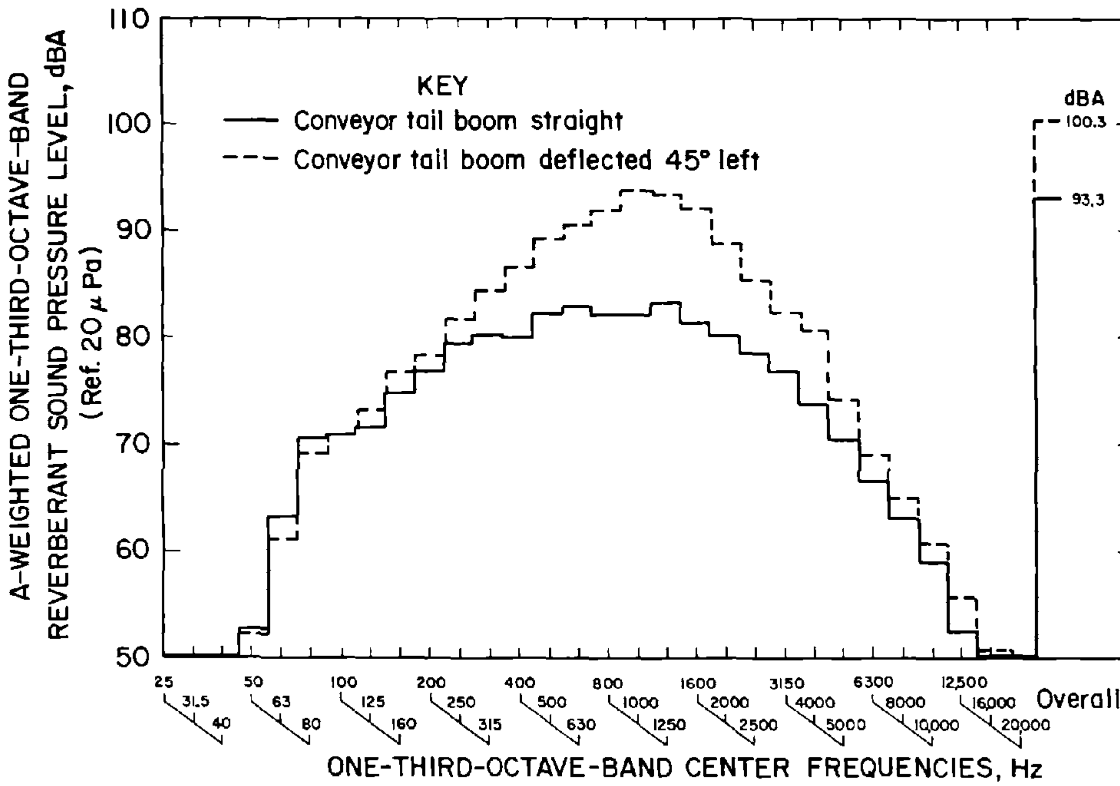

FIGURE 9. - Reverberant noise spectra of loaded conveyor.

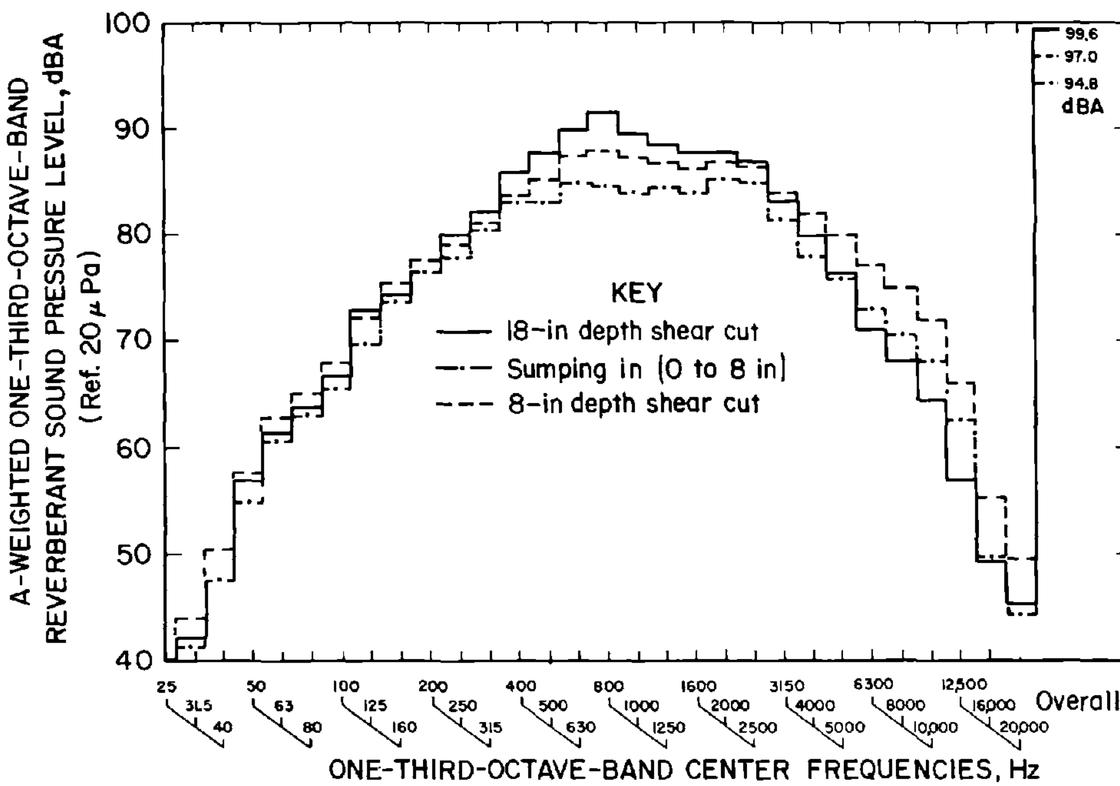

FIGURE 10. - Reverberant noise spectra of syn-coal cutting noise.

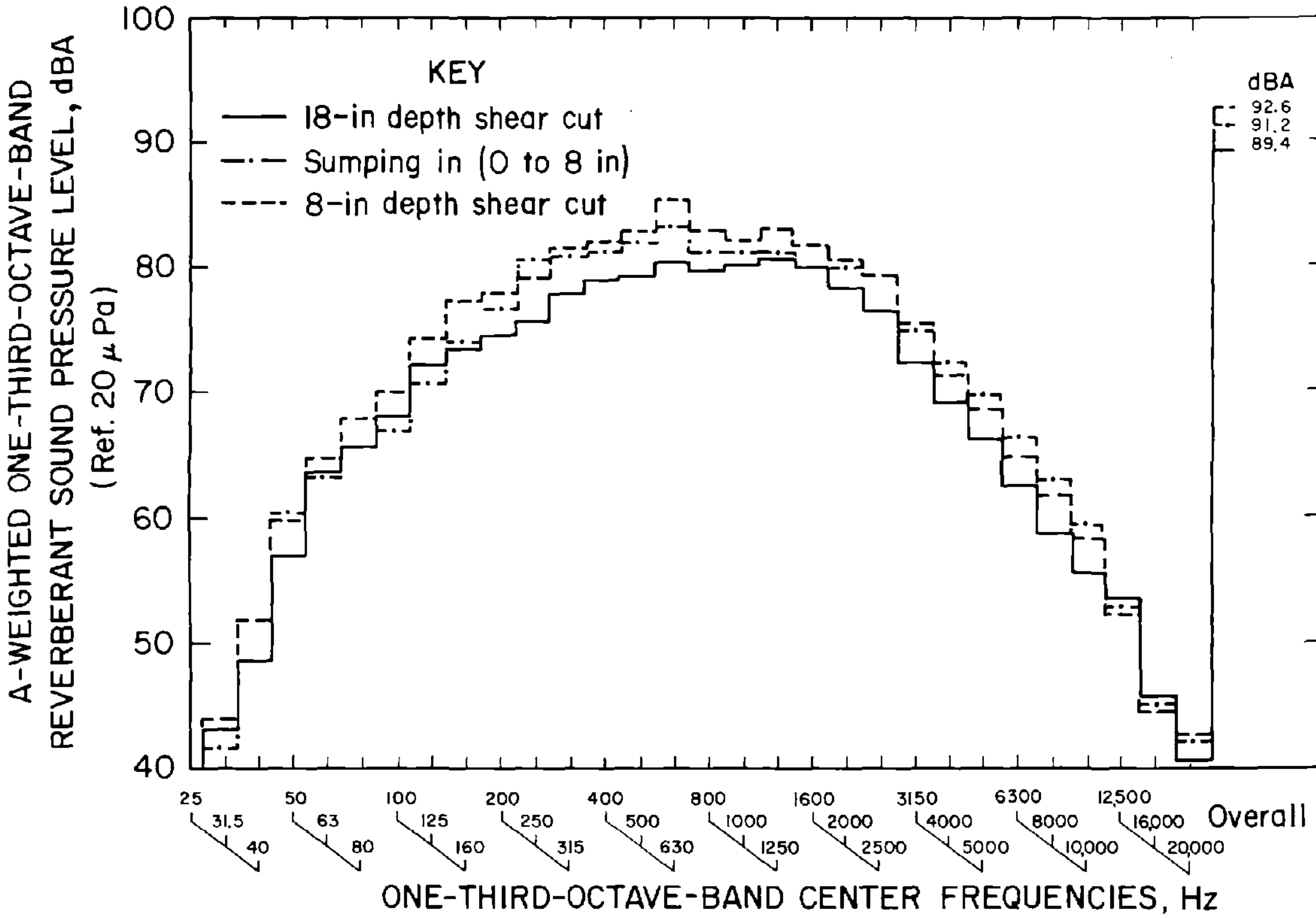

FIGURE 11. - Reverberant noise spectra of syn-coal cutting noise with drum heads covered with acoustic treatment.

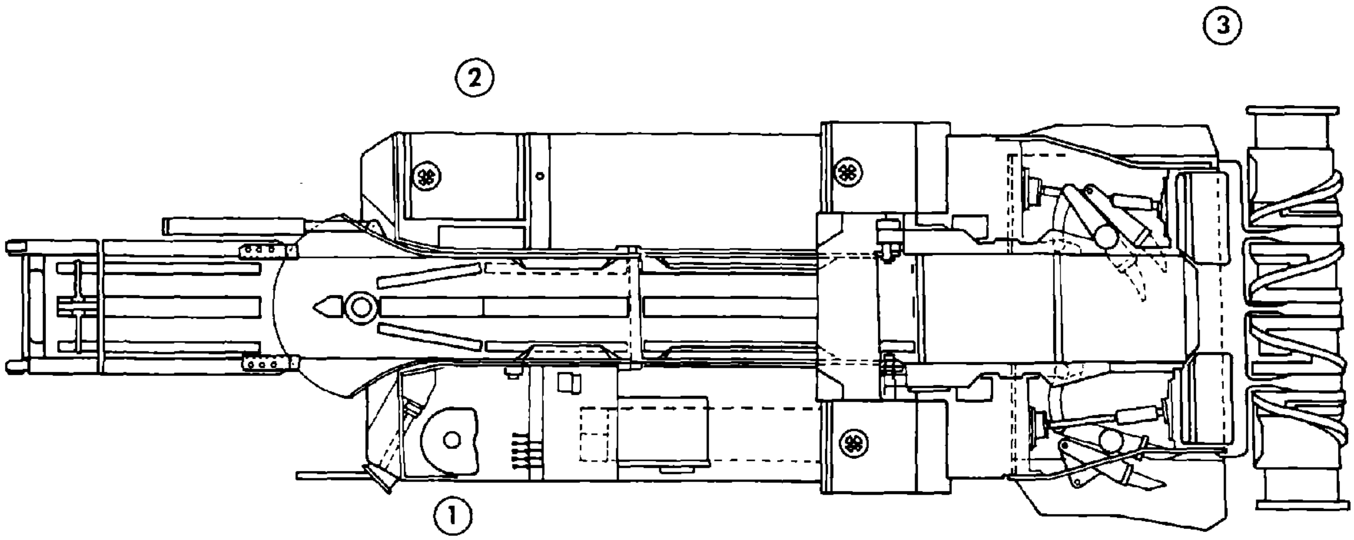

FIGURE 12. - Schematic of Lee-Norse continuous miner showing measurement locations.

TABLE 3. - Summary of noise data for Lee-Norse 265 continuous miner

Operating mode	Sound pressure level, dBA[1]		
	Position 1	Position 2	Position 3
Idling:			
Main pump......................	89.7	93.4	88.2
Main pump plus cutting head....	[2]88.7	NR	[2]85.0- 86.0
Main pump plus cutting head and conveyor (all systems on).....	[3]102.3	NR	99.4
Loading: Main pump plus conveyor	97.0	NR	NR
Cutting:			
Cutting head...................	[4]97.0	96.3	101.0
All systems on.................	[5]100.5-101.7	97.5-99.7	102.7

NR Not recorded.

[1]See figure 12 for position locations.

[2]Decrease in pump noise when cutterhead is activated causes a net reduction in total noise. Water spray caused 1-dB increase in noise at position 3.

[3]Note high level of conveyor noise. Clanking of flights on sideboards was present. Conveyor was slightly loaded with coal.

[4]Inferred from other measurements.

[5]Conveyor clanking caused a 1.2-dB increase in total noise when the conveyor tail boom was deflected.

Results are presented as A-weighted overall sound pressure levels for three measurement locations and different modes of operation. The most relevant data are position 1 results, which correspond to conditions at the operator's station. Measurements at positions 2 and 3 were taken to define the near-field characteristics of localized noise sources. The following noise characteristics were evident in the test results:

1. Predominant sources of noise at the operator's position are coal cutting noise from the face area and conveyor noise associated with the removal of coal from the face by the mining machine. These two sources of noise have approximately equal impact on the operator, each producing broadband noise with an overall A-weighted level of approximately 97 dBA. Overall noise levels experienced by the operator during coal extraction are approximately 100 dBA for a fully operational mining machine.

2. When the tail boom on the conveyor is deflected, the conveyor flights impact upon the sideboards, causing a distinct "clanking" noise. This "clanking" may increase operator noise exposure by 1 to 2 dBA for a loaded conveyor and up to 5 dBA for an unloaded conveyor.

3. The main hydraulic pump produces noise characterized by discrete tones in the 630-, 1,250-, and 2,000-Hz one-third-octave bands. This subsystem operating alone exposes the operator to an A-weighted overall sound pressure level of approximately 90 dBA.

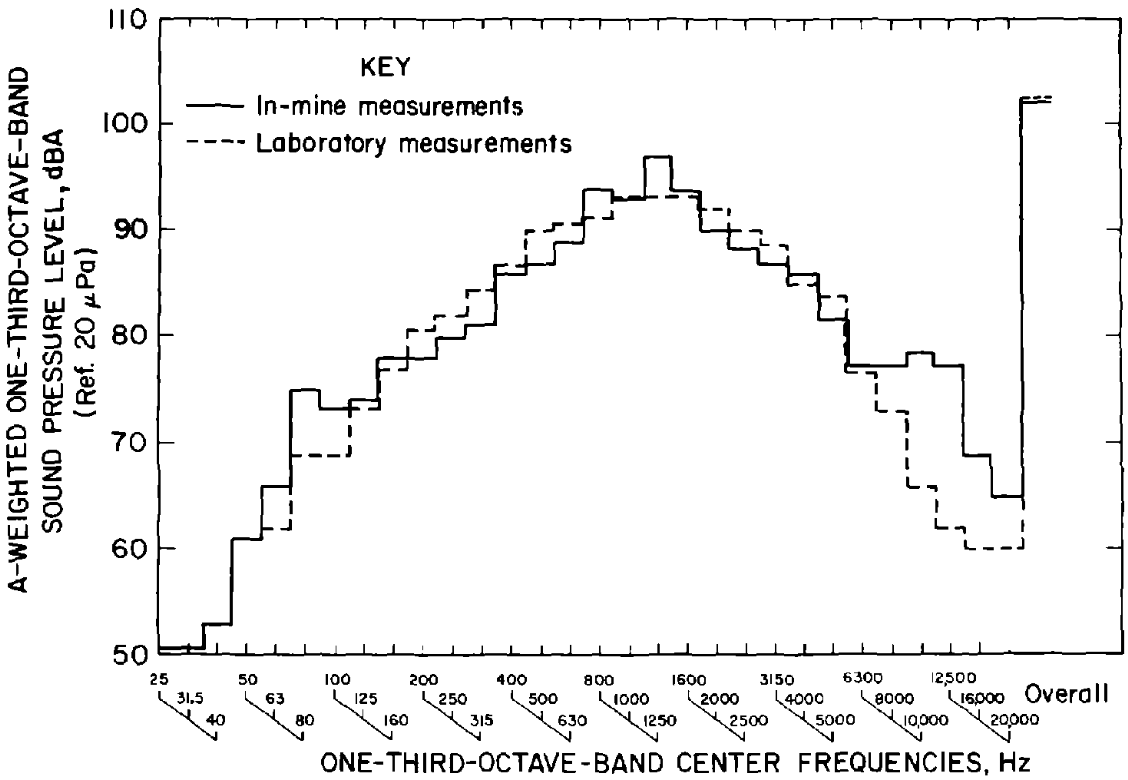

FIGURE 13. - Comparison of in-mine and laboratory measurements of unloaded conveyor noise with tail boom deflected.

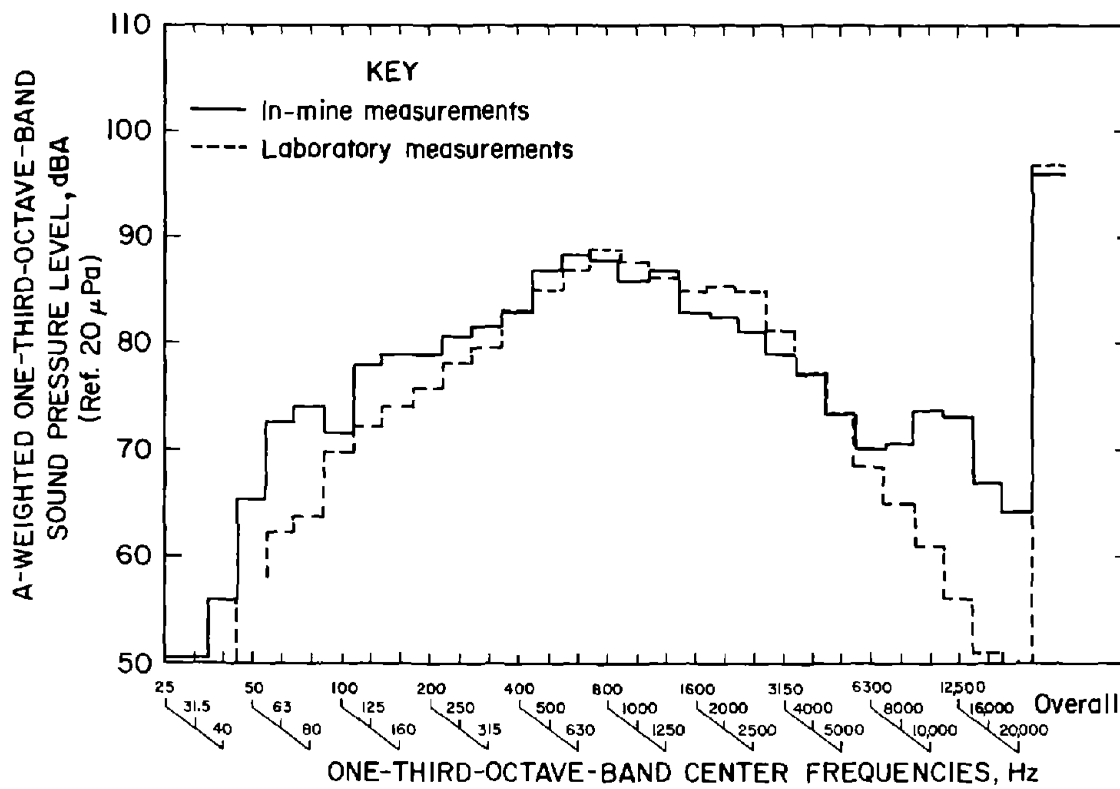

FIGURE 14. - Comparison of in-mine and laboratory measurements of coal cutting noise.

COMPARISON OF IN-MINE AND LABORATORY RESULTS

Previous studies[9] of the noise associated with the in-mine operation of a Lee-Norse 265 continuous miner revealed that the conveying and cutting operations produce approximately equal noise levels underground. A comparison of measurements taken in the MNTF with underground measurements is presented in figures 13 and 14. These data compare the in-mine one-third-octave-band spectra taken at the operator's position with the reverberant field spectra taken in the MNTF. Figure 13 presents noise data for unloaded conveyor operation, and the close agreement between in-mine and laboratory measurements is evident. Similar noise data are present in figure 14 for coal cutting with the conveyor off. The agreement shown in figure 14 is particularly significant since the laboratory measurements were taken for a continuous mining machine cutting a syn-coal seam. These results appear to establish the feasibility of performing noise control studies in the laboratory, as is being pursued under the present contract.

[9]Robertson, J. E. An In-Mine Survey of Noise Generated by a Lee-Norse 265 Hard Head Continuous Miner. Wyle Laboratories Tech. Memor. TM 79-7 (BuMines contract J0387229), August 1979, 32 pp.