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Design of a Compact Muffler for a Jumbo Drill

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
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DESIGN OF A COMPACT MUFFLER FOR A JUMBO DRILL

by

A. Visnapuu,[1] S. E. Lay,[2] J. R. Martin,[3] and A. E. Schwaneke[4]

ABSTRACT

The Bureau of Mines, as a part of its goal to minimize occupational hazards associated with mining and mineral processing operations, has developed and field tested a compact exhaust air muffler for mechanized, jumbo-mounted pneumatic rock drills. The muffler is constructed of 1/8-inch sheet steel and has nominal dimensions of 1-3/4 by 9 by 13 inches. A directed air passage, flexible neoprene baffles, and an expandable slit-type outlet are incorporated to reduce drill exhaust air noise and eliminate muffler icing. Field tests in actual mining operations showed a 15-dbA reduction in exhaust noise and an 8- to 12-dbA reduction in overall drilling noise with no icing problems or decrease in drill performance. Data are presented on muffler construction, laboratory, and field test results.

INTRODUCTION

The pneumatic rock drill creates one of the most severe noise hazards in mining and quarrying. A 1971 Bureau of Mines survey of 21 coal mines showed that workers using this type of drill to install roof bolts were exposed to noise levels in the range 104 to 118 dbA, the highest noise ratings of the activities observed (4).[5] In mechanized, jumbo drilling operations, noise levels in the range 102 to 123 dbA have been reported or calculated (2, 6). In principle, the pneumatic rock drill used in mines today is very similar to that used at the turn of the century. Improved materials have made it more durable, and with the addition of self-propelled mounts and hydraulic mechanisms, the drill has become larger in size and capacity. Most of the development effort has been directed toward increased productivity, and noise

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[5]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

control has received only minor consideration until recent years. The trend toward mechanized, self-propelled jumbo drilling rigs with two or more drills has only intensified the operator noise exposure problem. Although some new equipment presently on the market is available with integral muffled drills, no retrofit mufflers are available from the manufacturers for the many older unmuffled drills still in use, and it may be a number of years before they are phased out and replaced by the new integral muffled drills. Thus a need exists for practical retrofit mufflers for these older drills. This paper reports the results of a Bureau of Mines research project in cooperation with the Ozark Lead Co. to develop a compact, retrofit exhaust muffler for mechanized jumbo drills that is capable of reducing the severe exhaust air noise without penalty in performance.

The primary source of noise energy in direct-exhausting pneumatic rock drills is the air exhaust. Estimates of the contribution to the total drilling noise energy range from 65 to 94 percent for the air exhaust, 11 to 29 percent for drill steel, and 2 to 6 percent for the sum of machinery, operating surface, and remaining sources (1, 3, 5, 7-8). The observed variability in the energy estimates is not unreasonable considering the many types of pneumatic drills and drill steels that are used in a wide range of operating environments. Rather, it is remarkable how all these studies show that air exhaust noise predominates. In terms of A-weighted sound pressure levels, a 90-percent reduction of the total A-weighted noise energy will produce a 10-dbA reduction in the overall noise level. A 99-percent reduction in A-weighted noise energy would result in a 20-dbA reduction in overall noise. Air noise is generated by the high-velocity, cyclic release of compressed air to the atmosphere producing broadband random noise interspersed with a characteristic staccato sound related to the impact rate of the drill piston. Because the air exhaust is the major source of acoustic energy, its noise contribution must be reduced first to achieve any significant reduction in overall noise.

Other factors that must be considered in developing an exhaust air muffler for jumbo drills include resistance to icing, effect of muffler on drill performance, and durability. Compressed air systems in mines may contain considerable amounts of water vapor. Spent compressed air released by the drill may reach temperatures as low as 14° F owing to adiabatic expansion (5). Air vented directly to the atmosphere leads to no icing problems, but when passed through a muffler, serious internal ice accumulation leading to complete blockage may occur. Thus for a muffler to be acceptable, means must be provided to prevent or pass through any ice that forms. Also, the muffler back pressure must be kept at a minimum to prevent any slowdown of the blow rate and productivity. The muffler must be durable to withstand the rough usage normally subjected to drills.

The drill used in the development program was a Joy RPD,[6] high-frequency (3,000 impacts per minute), short-stroke machine widely used in the Missouri lead belt on two-boom jumbos. The drill, along with a striker bar and carriage plate, were loaned by Ozark Lead Co. Although the above specific drill was used in this study, it was felt that the results obtained would be applicable to jumbo-mounted drills in general.

[6]Reference to specific equipment, trade names, or manufacturers does not imply endorsement by the Bureau of Mines.

EXPERIMENTAL PROCEDURES

Testing Arrangement and Facilities

The drill, supported by its carriage plate, was mounted 4 feet above a hard concrete floor over a cutout section at one edge of a heavy wooden platform. The striker bar end of the drill faced toward the back edge of the platform. Mounting the carriage plate over the opening permitted the exhaust to be vented directly downward to simulate the most common position during mine operation. To further simulate mine drill operation, without actually drilling into rock, an air piston arranged to act in opposition to the RPD striker bar was employed. It consisted of a handheld drill with the internal mechanism modified so that constant air pressure on the piston forced it forward only. The modified drill was mounted opposite the RPD on the platform and a section of drill steel was used to couple the striker bar of the latter to the piston of the former, as shown in figure 1. Using this arrangement, a thrust similar to that of normal operation could be maintained on the RPD

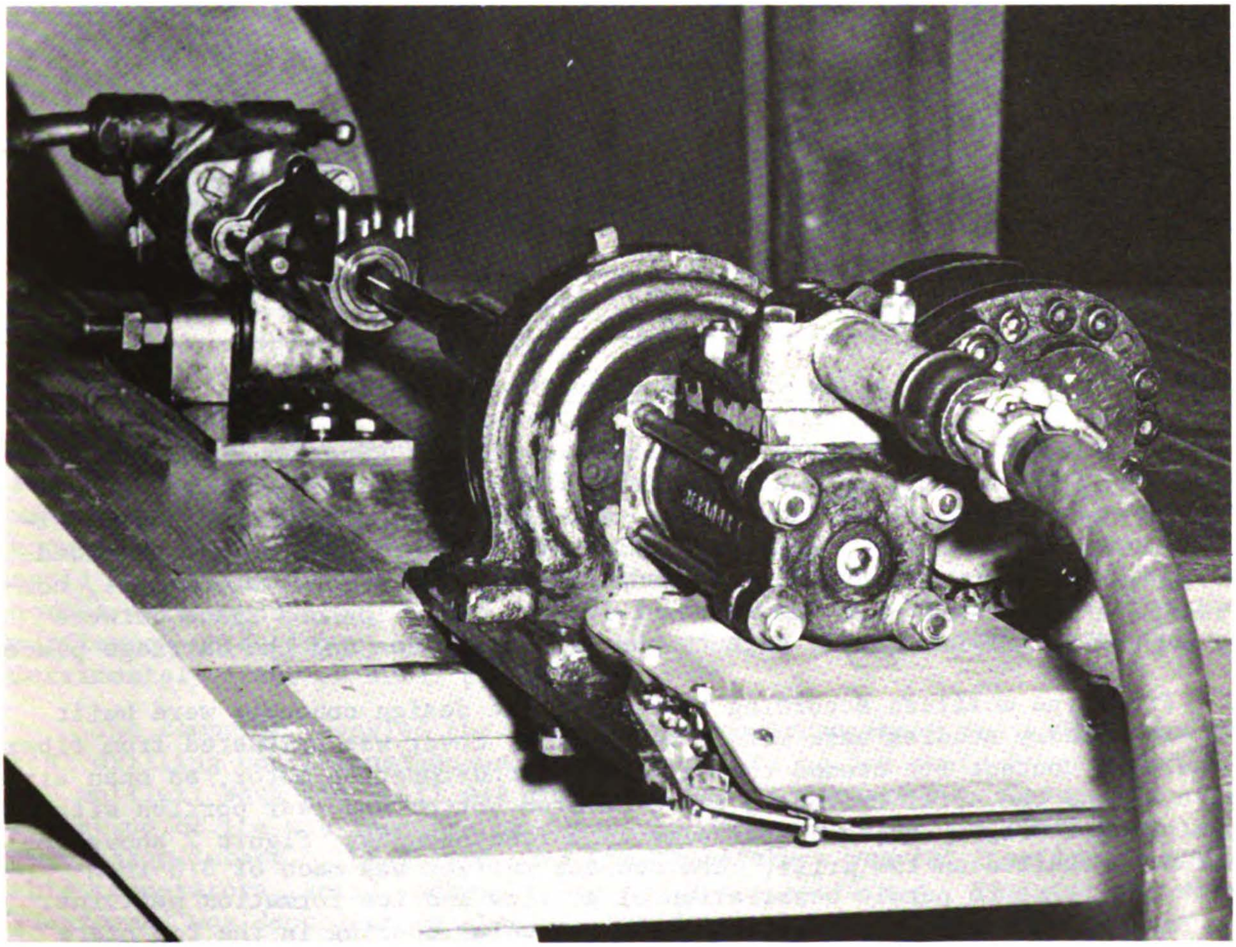


FIGURE 1. - Laboratory test stand drill mounting used to simulate drilling thrust on RPD striker bar. The RPD with an experimental compact muffler installed is in the foreground.

striker bar. Providing a thrust on the RPD striker bar was essential to produce conditions conducive to ice formation because a free running drill generally will not produce ice. Air pressure at 90 psi was used to operate the RPD drill, but the independent hydraulic rotation motor, which was an integral part of the machine, was not operated. Air pressure on the opposing air piston was 110 psi, which produced an approximate thrust of 650 pounds against the striker bar.

A description of the laboratory and sound analysis instrumentation used in this development work has been described previously (9).

Table 1 summarized the noise levels observed during operation of the standard RPD drill on the test platform. The levels were measured at four positions around the drill as indicated in the table, under both simulated drilling and free running condition. As can be gleaned from the table, the levels are nearly the same for both operation modes at the respective microphone locations. Based on previous noise level measurements for this type of drill at operator position in the mine, the values at 60 inches above and to side of exhaust port correspond most closely to those observed in the mine.

TABLE 1. - Unmuffled drill noise levels on laboratory test stand

Operating condition	Microphone location and noise level, dbA			
	40 inches behind and 20 inches below exhaust port	60 inches above and to side of exhaust port	160 inches behind drill and exhaust port	60 inches in front and 20 inches above drill front end
Free run...	122	119	112	114
Under load.	120	120	113	116

Muffler Concepts and Development

Two muffler concepts were considered and tested. One was a muffler cover designed to fit closely over the outline of the entire drill-rotation motor-carriage plate combination and utilize the open volume underneath as the muffler expansion chamber. The exhaust air would exit around openings provided for air, water, and hydraulic line feedthroughs. The second was a small, compact muffler to fit in an approximate 1-3/4- by 9- by 13-inch space between the downward-venting exhaust port on the drill cylinder and the carriage plate.

Prototype mufflers according to each of the design concepts were built and preliminary studies were made. The muffler cover was laminated from fiberglass to a contact fit around the drill front end-rotation motor, an open airspace around the drill cylinder, and a covered bottom and rear portion with openings for air, water, and hydraulic line feedthroughs. Figure 2 shows the muffler installed on the drill. The compact muffler was made of 3/8-inch-thick Plexiglas to permit observation of airflow and ice formation patterns. The exhaust entered the muffler through a circular opening in the top plate that mated against the circular outer edge of the exhaust port. The opposite end was designed to accommodate a variety of test exhaust ports. Figure 3 shows the muffler with two 3/4-inch-ID, 3-inch-long exhaust ports installed on the drill.

FIGURE 2. - Prototype fiberglass muffler cover installed on the RPD drill.

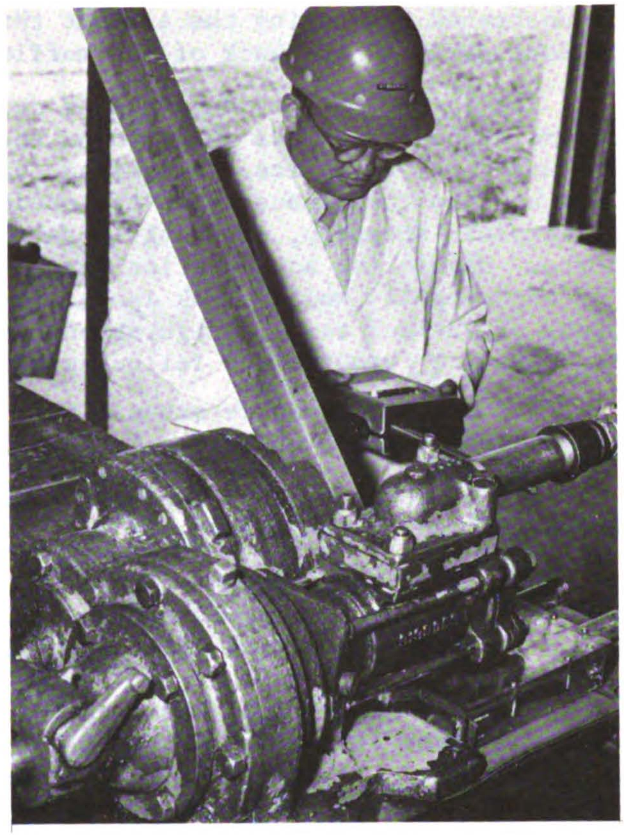


FIGURE 3. - Prototype compact Plexiglas muffler installed on the RPD drill.

The preliminary studies revealed that although the fiberglass muffler covers provided good sound attenuation, they were bulky, difficult to install and seal to provide satisfactory feedthroughs, and would probably interfere with normal drill operation. The compact muffler showed a much greater tendency to accumulate ice yet still provided good sound attenuation. Because it could be fitted readily into a small space where it would not interfere with normal drill operation, it was decided to concentrate on determining whether a muffler of this size could be designed so that it would not ice up or have a detrimental effect on drill performance.

The campaign revealed that the air piston arrangement did indeed simulate real drilling conditions because copious amounts of ice could be produced in the muffler; when the drill was run free, no ice formation was observed. The formation of ice was found to be dependent on ambient air temperature at the compressor intake. Ice formed when the temperature was 75° F or below; above this temperature, solid, adherent ice could not be formed. The quantity of ice formed was dependent on absolute humidity.

Early in the test campaign it became apparent that the small-volume, reactive muffler could reduce the exhaust noise level up to 20 dbA if the ice could be passed through. The ability of the muffler to reduce noise was readily demonstrated by venting the air out through two 3/4-inch-ID, 3-inch-long exhaust ports at the back of the muffler.

Ice in the muffler accumulated over the entire inner surface. Most severe accumulation was observed on the muffler base, directly under the drill exhaust port, where ice stalagmites tended to build up. Sometimes they would grow up into the exhaust port to impede airflow to the point of drill slowdown or complete stoppage, or break loose to be trapped at the muffler exhaust ports. Severe ice accumulation also occurred at corners, and likewise, the ice occasionally would break loose and clog the exhaust ports. An extensive study of various test configurations indicated that for a muffler to break up and pass ice through, the following three conditions must be met.

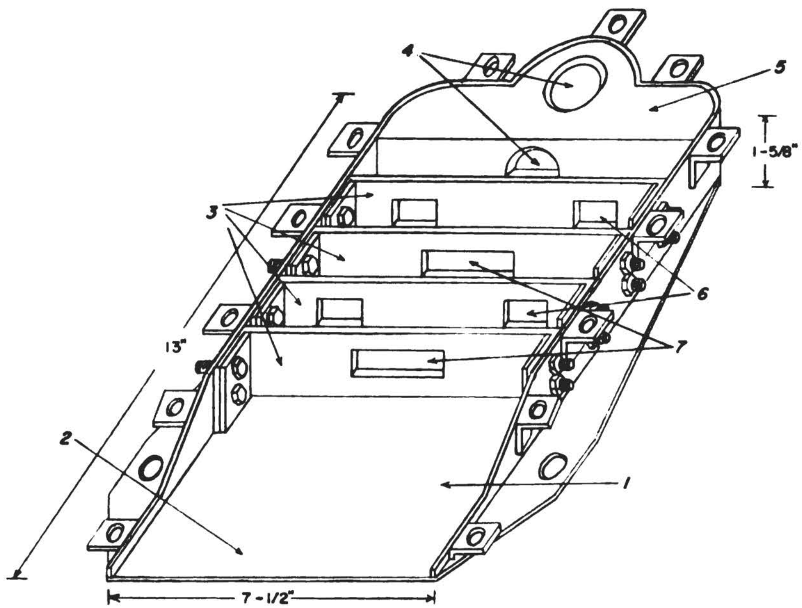
1. The air from the exhaust port must impinge directly on a vibrating or nonadherent surface where the ice cannot accumulate.

2. As the air passes through the muffler, it must pass over surfaces where ice cannot accumulate.

3. The transition from the muffler body to the exhaust port must be gradual to avoid ice entrapment and the exhaust port should be free to expand to allow large pieces of ice that may still form to pass out freely.

Figures 4 and 5 show the final muffler and cover, respectively. The muffler and cover are constructed of 1/8-inch-thick steel plate. The body has 1-1/2-inch-high welded sides that taper down to 1/4-inch height at the outlet end. The assembled muffler is mounted between the drill carriage plate and cylinder and is held in place in the rear by two bolts through the mounting holes shown on the outer extension of the base plate. In the front, the muffler is compression tightened in place between the carriage plate and cylinder. The front end of the muffler is filled with a castable urethane rubber insert with a curved air passage to redirect the airflow into the baffles without prior adiabatic expansion. The neoprene rubber baffles are arranged perpendicular to the airflow through the muffler with alternate edge and center holes. The baffles are the same height as the inner muffler, but 2 inches longer than the case width, so that they can be attached to the sides by folding their ends under metal fastening plates. The fastening plates are secured to the muffler side by two bolts through each plate, baffle, and side with self-locking nuts. The outlet end and part of the tapered cover section has a major portion of metal cut out and is covered with a sheet of neoprene rubber secured by a fitted metal section.

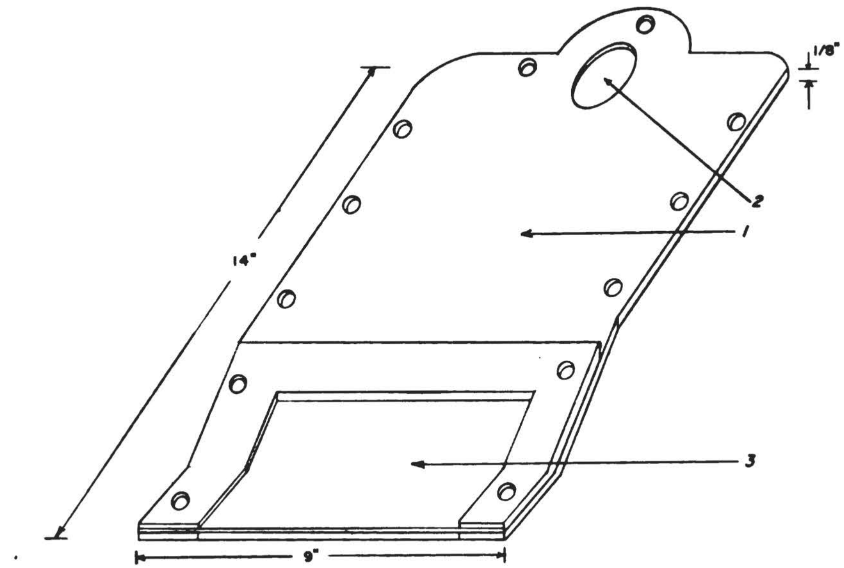
The muffler reduces exhaust air noise by internal reflections, smoothing of airflow, elimination of direct acoustical path, and reduction of air exhaust velocity. Ice accumulation is eliminated by the flexible neoprene baffles and the manner in which airflow is directed at and through them. Figure 6 is a cross-section schematic of the muffler showing airflow through it. The curved air passage directs the airstream at center closed portion of the first baffle, setting it in vibratory motion. Next, the air is directed through the two edge openings at the closed sides of the second baffle, followed by flow through the center opening of the second baffle at the closed section of the third. This sinusoidal airflow path is repeated



KEY

/ Base plate
2 Exit port
3 Flexible baffles
4 Inlet air passage
5 Filled-in front end
6 Edge baffle holes
7 Center baffle holes

FIGURE 4. - Schematic drawing of final compact muffler case.



KEY

/ Top cover
2 Inlet port
3 Resilient exhaust port cover

FIGURE 5. - Schematic drawing of final compact muffler case cover.

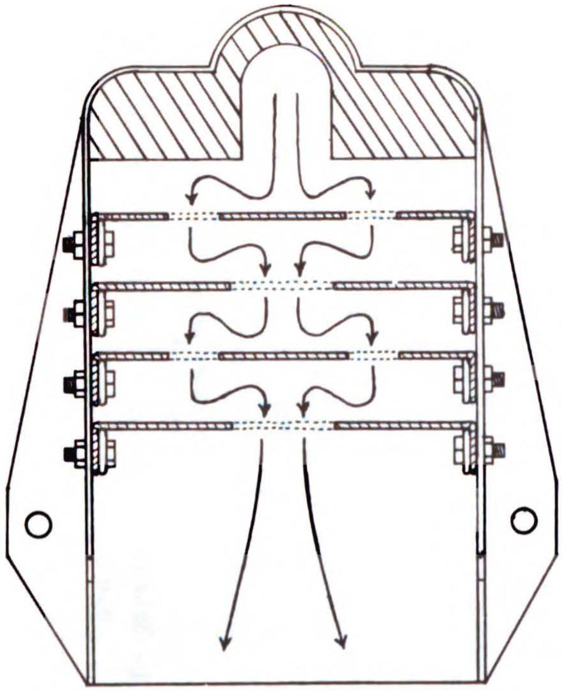


FIGURE 6. - Cross-section schematic of compact muffler showing exhaust airflow path.

until the air has passed all the baffles and set them in strong vibratory motion that prevents ice accumulation on their surfaces. Baffle edges rubbing against the top and bottom muffler surfaces prevent ice buildup there. The slit-type outlet, with one of the long sides covered with neoprene rubber, is designed to flex to allow passage of large pieces of ice that may form in the muffler.

RESULTS

Laboratory Tests

Two mufflers, constructed as shown in figures 4 and 5, were subjected to extensive noise abatement and ice accumulation tests in the laboratory prior to final field tests in the mine. Results of the tests are summarized in table 2. The tests show that in the free running condition, the exhaust noise decrease ranged from 14 to 19 dbA in comparison with data in table 1. When the air piston was used to place a load on the striker bar, the decrease in noise ranged from 6 to 14 dbA. Increase in noise for muffled operation under load is due to steel and striker bar noise from the front end, as clearly indicated by the readings 60 inches in front and 20 inches above the drill front end.

TABLE 2. - Muffled drill noise levels on laboratory test stand, compact mufflers

Muffler	Operating condition	Noise level, dbA, and microphone location: 40 inches behind and 20 inches below exhaust port	60 inches above and to side of exhaust port	160 inches behind drill and exhaust port	60 inches in front and 20 inches above drill front end
1......	Free run....	103	100	96	98
1......	Under load..	106	106	101	110
2......	Free run....	106	102	98	100
2......	Under load..	108	108	102	110

Muffler ice evaluation was conducted at compressor intake and test site ambient temperatures ranging from 50° to 80° F. As noted before, no ice formation was observed for temperatures exceeding 75° F. Below this temperature, frost would accumulate on the outer surface of muffler cover, and ice particles could be observed in the exhaust airstream. The neoprene cover on the exhaust slit was observed to expand a number of times to emit rather large ice particles that otherwise would have been trapped inside. Examination of the

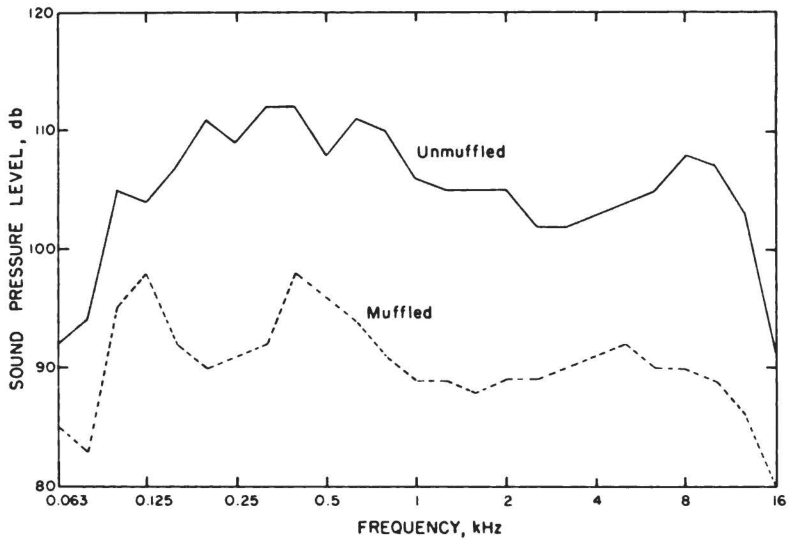


FIGURE 7. - One-third-octave-band noise levels of muffled and unmuffled jumbo drills in mine at operator console.

muffler after operating periods ranging from one-half to 10 minutes revealed some frost formation on the baffles and metal surfaces, but no accumulation. During all the simulated drilling tests, drill running rate was monitored closely with a real time spectrum analyzer to determine if any difference could be detected between muffled and unmuffled operation.

Mine Field Tests

Field testing of the mufflers was conducted on a production jumbo drill rig in the Ozark Lead Co. mine at Sweetwater, Mo. The tests were performed over a 2-day period to evaluate the full impact of the mufflers on noise and drilling performance. During the first day, noise levels and penetration rates were monitored without the mufflers and on the second day, with the mufflers installed. Also on the second day, the mufflers were monitored for evidence of icing and rigidity of attachment to the drill. All tests were conducted in the same ore zone with equal back heights to keep variation in rock properties and acoustical environment at a minimum. The same driller operated the drills on both days to keep operating techniques equal.

All noise level readings were taken at the operator's console. Observed noise levels during various operating and drilling conditions are summarized in table 3. From the table it can be seen that the muffler reduced the drill air exhaust noise level by 15 dbA for both single and dual operation, and overall drilling noise level by 8 to 12 dbA. Representative unmuffled and muffled jumbo noise levels are plotted in figure 7 as functions of the one-third-octave-band center frequencies. The graph shows noise level reductions from 6 to 21 db over the entire frequency spectrum. At the most sensitive midfrequency range, noise reduction was consistently 12 db or greater.

Drilling rates were measured on the basis of time required for the 12-foot steels to penetrate 11.5 feet into the rock. For the unmuffled drills, penetration times for 40 holes were monitored, and for the muffled drills, 28 holes were monitored. During both days, feed, rotation, and air pressures were kept as equal as possible. Results of the penetration tests are summarized in table 4.

TABLE 3. - Summary of mine field test noise levels measured at operator console

Drilling operation	Noise level, dbA			
	Without mufflers		With mufflers	
	One drill	Two drills	One drill	Two drills
Free running (not drilling).....	113	116	98	101
Lifter level....................	114-115	116	104-105	ND
Knee level......................	113-115	117	104-105	105-107
Belt level......................	112	115	104-105	106
Console level...................	115	115	104-105	107
Eye level.......................	114-116	115	104-105	106
Top.............................	112-114	115	104-105	107
Start of hole...................	116	118-119	104-105	107

ND Not determined.

TABLE 4. - Summary of penetration times for unmuffled and muffled drills

Test	Penetration time, minutes, for 11.5-foot steel length			
	Unmuffled drills		Muffled drills	
	Left boom	Right boom	Left boom	Right boom
1..............	4.04	3.42	ND	2.53
2..............	3.37	3.13	3.00	ND
3..............	3.77	2.85	3.08	2.59
4..............	ND	2.96	3.10	3.03
5..............	ND	3.89	3.11	3.06
6..............	2.80	3.74	2.88	3.08
7..............	3.06	ND	2.91	3.10
8..............	2.86	3.44	3.32	3.11
9..............	3.69	4.04	3.58	3.06
10..............	4.79	4.92	2.83	2.52
11..............	4.85	4.14	3.24	2.36
12..............	2.38	3.90	2.65	2.52
13..............	3.98	3.50	3.70	2.43
14..............	3.26	ND	3.28	2.77
15..............	3.45	ND	ND	2.90
16..............	2.58	2.75	ND	2.83
17..............	3.74	2.26	ND	ND
18..............	2.96	2.74	ND	ND
19..............	3.18	2.08	ND	ND
20..............	3.37	2.17	ND	ND
21..............	3.32	2.50	ND	ND
22..............	3.06	3.09	ND	ND
23..............	ND	2.94	ND	ND
Mean........	3.42±0.65	3.22±0.61	3.12±0.36	2.79±0.28
Range.......	2.38-4.85	2.08-4.92	2.65-3.70	2.36-3.11

ND Not determined.

DISCUSSION AND CONCLUSIONS

The results of the 2-day noise and penetration tests were impressive. Effective noise level with both drills running was reduced from 118 to 107 dbA. Actual pneumatic air exhaust noise, as measured on one drill in the mine, was reduced from 116 to 101 dbA, which is equal to the jumbo engine noise level when running at drilling power. Because the mufflers were so effective in reducing air exhaust noise, any further effort to improve muffler design would be questionable until engine, steel on steel, and rock on steel noise, which are in the 106- to 107-dbA range, are reduced. At no time did the mufflers show any signs of icing, loosening on the mounts, or bolts coming off the cover.

The penetration tests were good also, actually showing an increase in penetration rates when the mufflers were installed. It is doubtful that the increase in penetration rates can be attributed to the mufflers because of the limited number of tests, but the data indicate that the mufflers have not slowed down the drills.

The mufflers were left on the jumbos for a period of 1 month and performed well without any detectable reductions in drilling rate and icing. Based on these results, Ozark Lead Co. decided to build and retrofit their existing unmuffled jumbo drills with mufflers of the type. The retrofit mufflers were used for a period of 1-1/2 years and performed up to the field test predictions. During this period, the Ozark Lead Co. gradually replaced the RPD drills with the newer HF-RPD models which have an integral muffler, completing the changeover by the second quarter of 1977. However, the firm feels that the compact muffler concept described here is an excellent way of reducing the exhaust air noise of standard RPD drills or other unmuffled pneumatic drilling systems in harder rock that cannot use the new hydraulic and muffled high-frequency rotary percussion systems.

These laboratory and field tests and production use have demonstrated that retrofit mufflers, which significantly reduce air exhaust noise of jumbo drills, can be developed. Furthermore, the exhaust noise reduction is to levels below that of drill steel and drill machine noise. This is achieved without adversely affecting drill performance and without problems of ice accumulation. These two points are often brought out against the use of mufflers on handheld, feed leg, and jumbo-mounted pneumatic rock drills.

Although these results were achieved on a Joy RPD rotary percussion drill, it is felt that they would be applicable to other pneumatic jumbo drills.

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