

## QUIETED PERCUSSION DRILLS

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## ABSTRACT

Percussion-type rock drills are commonly used in both coal and metal-nonmetal mines; they produce extremely high noise levels (110 to 120 dBA) and have complex noise-generating mechanisms. Therefore, engineering noise controls for percussion drills have been very difficult to

achieve. However, substantial progress has been made toward this goal through the use of retrofit techniques and percussion drill redesign. This paper provides an overview of Bureau-sponsored research programs aimed at reducing the noise produced by percussion drills.

## INTRODUCTION

Percussion-type rock drills, especially pneumatic drills, are the noisiest machines used on a regular basis by the mining industry. Handheld and machine-mounted "jumbo" percussion drills are the most common means of drilling production blastholes and roof bolt holes in underground metal and nonmetal mines. Handheld "stopper" drills are also used in coal mines; although their use has decreased in recent years, they are still used for "spot" bolting in roof fall areas and other mine locations where machine-mounted rotary roof bolters cannot reach. Typical noise levels of unmuffled percussion drills range from 110 to 120 dBA at the operator's position, potentially resulting in exposures of more than 10 times the limits allowed under Federal regulations. For this reason, the Bureau of Mines has directed substantial research efforts toward the control of percussion drill noise.

greatly to the total drill noise level. Therefore, stopper drill noise has a wide spectral distribution, and all three noise sources shown in figure 1 must be controlled to achieve a substantial noise reduction.

Because exhaust noise levels alone can be as high as 112 to 114 dBA (1),<sup>2</sup> an exhaust muffler is the first and most important component of any noise control treatment for pneumatic drills. Mufflers for the hand-held pneumatic drills used in mining have usually taken one of two forms: (1) a canister, lined duct, or other chamber-type device attached to the drill exhaust port; or (2) a wraparound, jacket-type muffler that completely surrounds all or part of the drill body, including the exhaust port. The second type of muffler, if designed and constructed properly, can reduce drill body noise as well as exhaust noise. However, both types of mufflers share a common problem--freezing. This occurs when moisture in the rapidly expanding, rapidly cooling exhaust air condenses and freezes on the inside surfaces of the muffler and drill body. After a short period of time, perhaps only a few minutes, the ice buildup restricts the flow of exhaust air, and the resulting back pressure causes the drill to stall.

## NOISE SOURCES AND ABATEMENT TECHNIQUES

Hand-Held Drills

Figure 1 shows the three most prominent noise sources on a typical pneumatic stopper drill: (1) drill steel vibration, (2) drill body vibration, and (3) air exhaust. Although exhaust noise is often the dominant source, drill body and drill steel vibration frequently contribute

<sup>2</sup>Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

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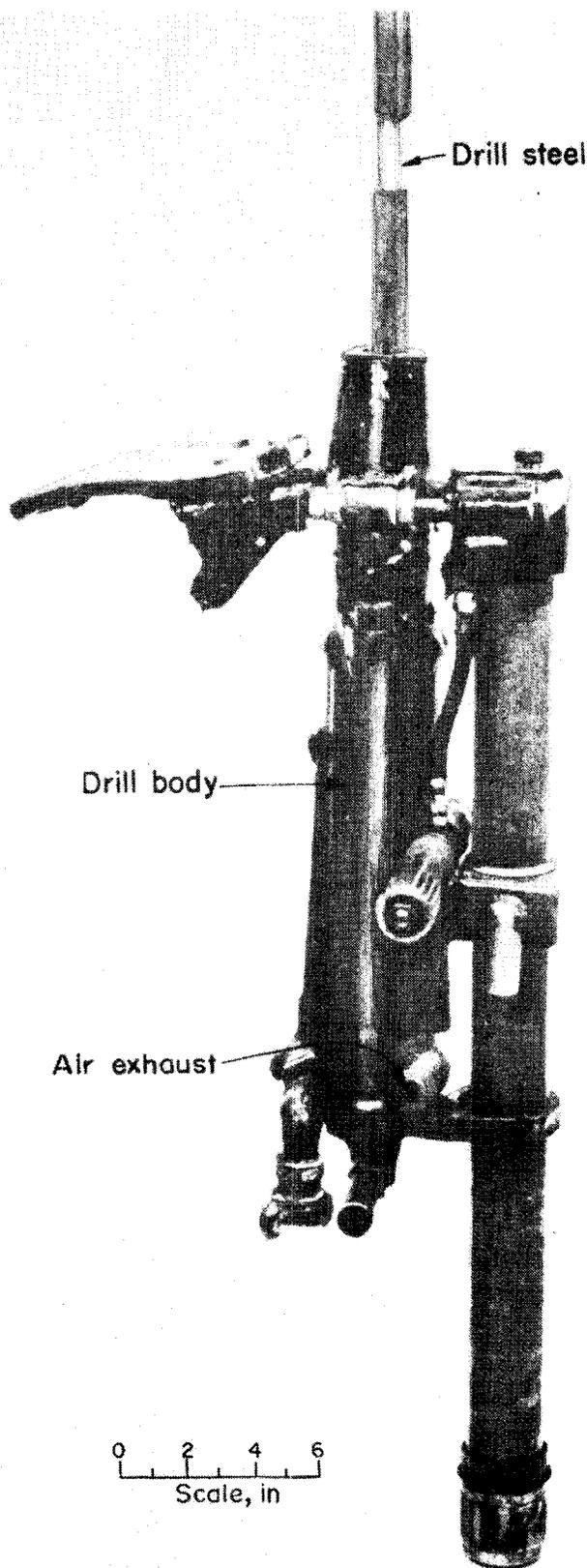


FIGURE 1. - Noise sources of typical hand-held stoper drill.

Numerous muffler designs for hand-held mining drills have been developed by equipment manufacturers, mining companies, and government researchers. Many of these designs are reviewed in a recent Bureau-sponsored report by Dutta and Runstadler (2) and in various MSHA publications (3). Muffling schemes as simple as adding a section of rubber tire to the drill exhaust port have resulted in noise reductions as great as 9 dBA. However, the noise levels of these muffled drills were still unacceptably high (greater than 110 dBA). Therefore, as described later in this paper, the Bureau sponsored a research program to redesign the standard hand-held mining drill for noise control purposes.

Drill steel vibration alone produces noise levels of about 105 to 110 dBA at the operator's position (4-5), mostly because of transverse stress waves within the steel. In contrast to longitudinal stress waves, which effectively transmit percussive energy from the drill to the rock, transverse waves serve no useful purpose and merely generate noise. Extensive tests have shown that transverse waves result mainly from off center (e.g., piston-to-steel) impacts, worn drill chucks, and bent drill steels.

Better fitting, longer lasting drill components would obviously reduce the severity of drill steel (and drill body) noise but could not eliminate it because of the high-energy nature of the percussive process. Aside from drill manufacturers' efforts to produce more efficient drill hardware, only a few studies have investigated methods to reduce drill steel and drill body noise. Visnapuu and Jensen (1) developed a constrained-layer damping system for the drill steel, which consisted of a thin-walled tubular metal collar bonded to the drill steel by viscoelastic material. This "sheathed" steel was prepared by slipping the metal tube over the steel and pouring the liquid viscoelastic filler into the annulus. A similar system was used by Summers and Murphy (6) to produce a 6-in.-long isolation-damping collar for the end of the steel closest to the drill body.

Although drill steel coating and col-laring techniques such as those described can reduce noise, studies by Hawkes (4-5) showed that they can reduce the drilling rate significantly, are subject to abra-sion, and can move axially along the steel because of failure of the visco-elastic bond. However, Hawkes concluded that an independent "shroud tube" sur-rounding the steel would be able to suppress drill steel noise while avoid-ing these problems. The redesigned coal stoper discussed later in this paper uti-lized the "independent" shroud tube con-cept suggested by Hawkes.

#### Machine-Mounted "Jumbo" Drills

Figure 2 shows the major components of a typical jumbo drill rig, and figure 3 shows its noise-producing mechanisms. As with hand-held drills, the three major noise sources of pneumatic jumbo drills are the air exhaust, drill steel, and drill body, and the two most essential noise control treatments are an exhaust muffler and an enclosure around the drill steel. Exhaust muffling techniques for jumbo drills have included (1) piping it away from the operator through ductwork, (2) attaching a canister-type muffler to the exhaust port, and (3) placing the en-tire drifter inside an acoustical en-closure. To date, it appears that the acoustical enclosure technique has been the most effective because it reduces drill body noise as well as exhaust noise, and is the least susceptible to freezing. Drill steel coating, rubber collars, and shroud tubes have been used on jumbo drills to suppress drill steel noise; again, the shroud tube appears to be the most promising technique be-cause it is not physically coupled to the drill steel. Bureau-sponsored research on acoustical enclosures and shroud tubes for pneumatic jumbo drills is described in detail later in this paper.

In recent years, hydraulically powered jumbo drills have become very popular in the mining industry. In terms of noise control, hydraulic drills have a distinct advantage over pneumatic drills

because air exhaust noise is nonexistent. However, hydraulic drills are by no means "quiet," because drill steel vibration, body vibration, and noise produced by hole-flushing air combine to produce typ-ical noise levels of 110 to 113 dBA at the operator's position. Therefore, the Bureau is currently investigating various noise control techniques for hydraulic percussion drills.

#### BUREAU-DEVELOPED NOISE-CONTROL TECHNIQUES FOR HAND-HELD DRILLS

##### Stoper Retrofit Treatments

Figure 4 shows the stoper drill retro-fit treatment developed by Summers and Murphy (5). The wraparound, jacket-type muffler was made of a flexible sheet of polymer material. Poured-in urethane end caps held the jacket muffler in place and isolated it from drill body vibration. The drill steel was treated with the 6-in-long composite damping collar de-scribed earlier.

In underground tests at the Bureau's Pittsburgh (PA) Research Center, an un-treated stoper (fig. 1) produced noise levels of about 115 dBA. Addition of the jacket muffler resulted in a 13-dBA noise reduction, and the drill steel collar produced an additional 2-dBA reduction. The quieted noise level of 100 dBA would permit about 2 h of operating time per shift (versus zero with the untreated stoper) without violating Federal noise regulations. The retrofit package in-creased the total drill weight by about 10 lb.

Retrofitting stopers (jacket muffler only) were tested in 15 operating under-ground coal mines, and noise reductions of 7 to 8 dBA were consistently obtained. The 13-dBA experimental noise reduction was not achieved in the underground mine tests. The drill feed rate was not con-trolled nor the noise control treatments maintained as diligently as they were in the Bureau's experimental mine. Never-theless, the typical muffled noise lev-els (105 to 106 dBA) were low enough to

permit a doubling of the allowable operating time per shift. Unfortunately, drilling rates with the modified stoper

were about 15 to 50 pct slower than with an unmuffled stoper.

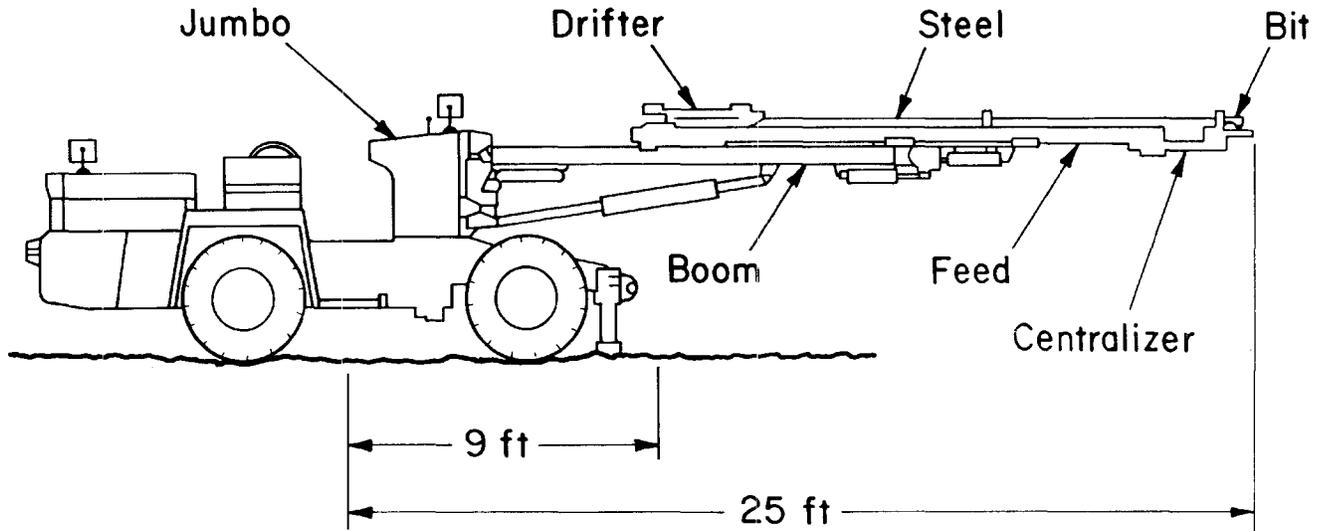


FIGURE 2. - Major components of jumbo drilling rig.

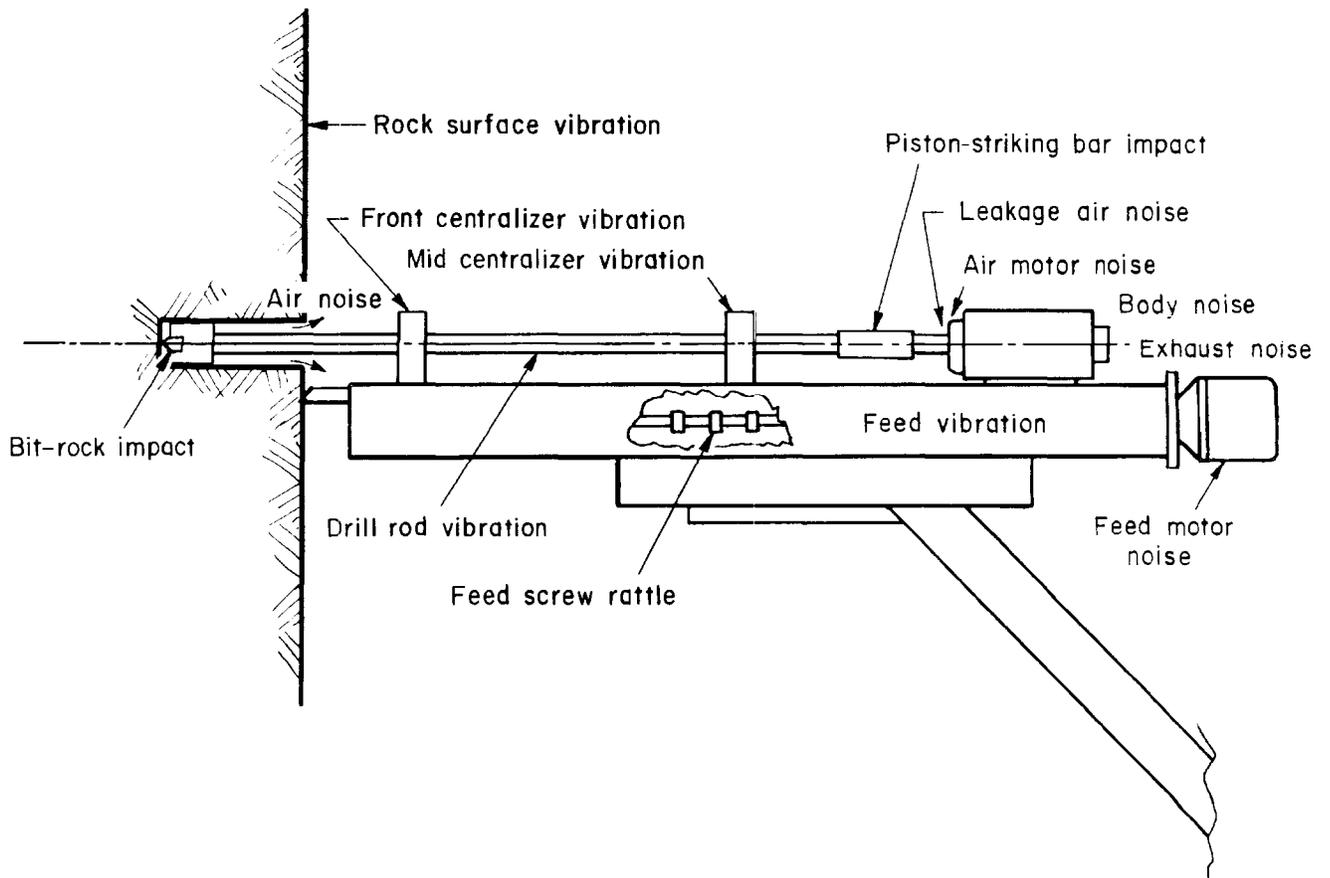


FIGURE 3. - Noise sources of jumbo-mounted drills.



FIGURE 4. - Stoper drill with retrofit noise control treatments.

### Stoper Redesign

Because the stoper retrofit noise control treatments were only partially successful, the Bureau sought greater noise reductions and improved drilling performance through stoper redesign. The Bureau-sponsored redesign effort (2) included the following four major steps: (1) redesign of the drill steel rotation mechanism and other drill parts, (2) development of a compact, effective muffler-enclosure device, (3) development of a shroud tube to attenuate drill steel noise, and (4) redesign of all drilling controls. The redesigned stoper was then field tested in several operating underground coal mines.

#### Redesign of Drill Steel Rotation System and Internal Parts

Standard stoper drills achieve drill steel rotation through a "rifle bar" arrangement (see figure 5). The oscillating piston strikes the drill steel on its backstroke, a fluted hole in the center of the piston rides over the similarly fluted rifle bar, thus causing the piston, chuck, and drill steel to rotate. The pawl-and-ratchet ring at the back of

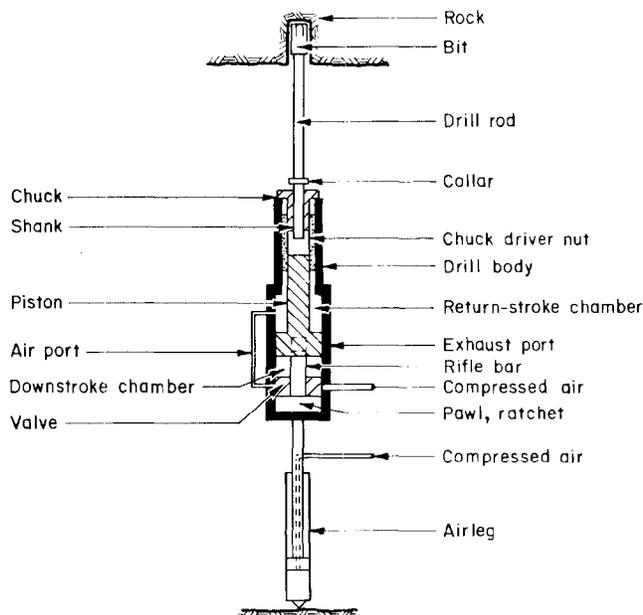


FIGURE 5. - Components of typical stoper with rifle-bar rotation.

the drill cylinder maintains drill steel rotation in only one direction. Because the piston stroke length and helical angles of fluting are all fixed for any given drill, the rotation torque is constant. The rotation speed is therefore dependent on the thrust level provided by the drill feed leg.

The redesigned stoper (fig. 6) utilized an independent drill steel rotation system (i.e., a separate air motor and gear arrangement) that gave it several distinct advantages over drills with rifle-bar rotation. First, drill performance was improved because the rotation speed was no longer dependent on thrust. That is, the poor penetration rates associated with over-rotation (not enough thrust) and drill stalling problems due to under-rotation (too much thrust) were eliminated. The piston was always able to travel through its full stroke, thus increasing drilling power, and rotation speed could be changed to suit different rock conditions without affecting the piston blow frequency. Second, the multiple internal impact points of the rifle-bar system were eliminated, thus reducing the high-frequency rattling noise produced by standard stoper drills. Third, the piston diameter was reduced, without sacrificing drilling power, by eliminating the need for the fluted hole in its center. This resulted in a smaller overall drill diameter and facilitated the subsequent addition of the muffler-enclosure device.

The independent drill steel rotation system allowed several other beneficial internal design changes to be made. Because the piston was no longer responsible for rotation, it was redesigned to serve as the valve controlling the flow of compressed air within the drill cylinder. This "valveless" method of piston operation was inherently more efficient and problem-free than a valve system; in addition, the elimination of the standard "flapper" and "kicker-port" valves negated another potential source of high-frequency noise. The annular clearance between the chuck and shank was reduced to 0.02 in, and the upset shoulder on

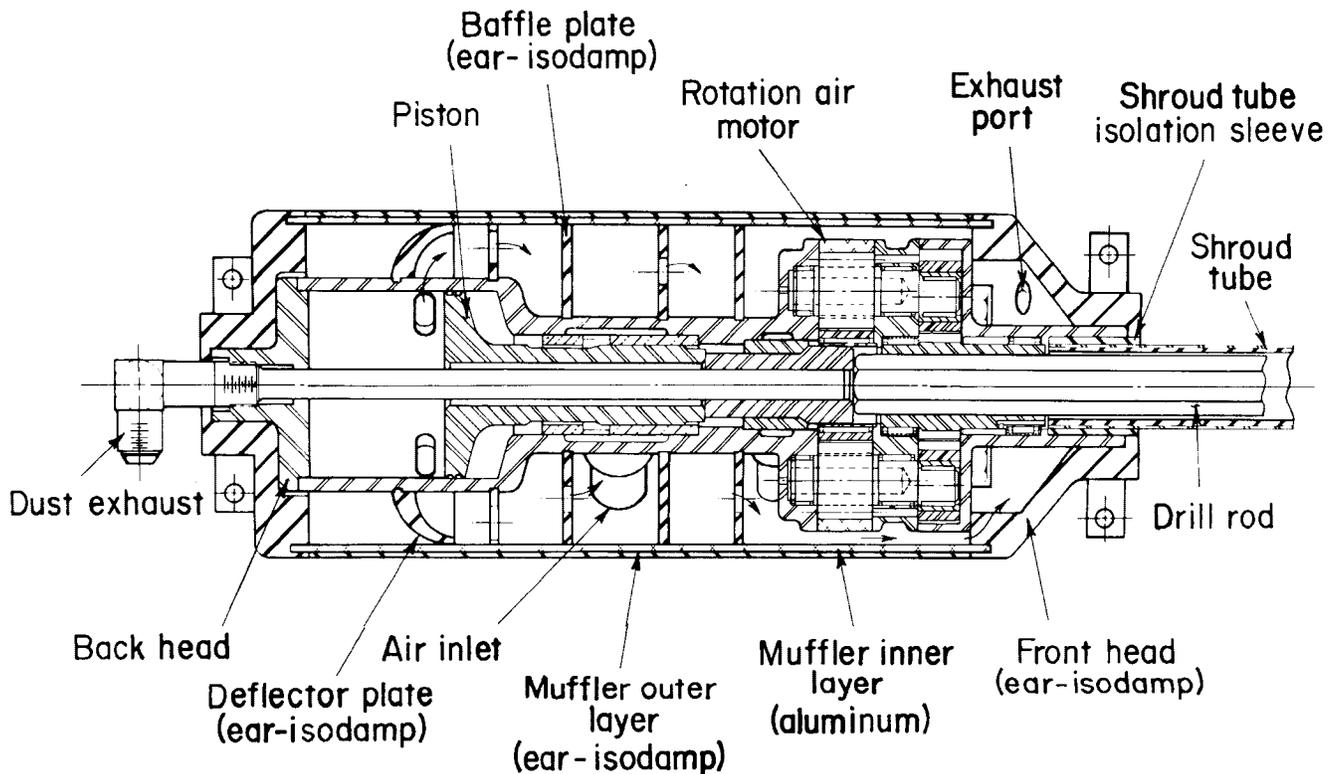


FIGURE 6. - Internal components of redesigned, "quiet" stoper.

the standard drill steel was eliminated. These two design changes reduced the misalignment and rattling impacts occurring at the top of the drill body and reduced the severity of the transverse waves produced by offcenter shank-to-steel impacts.

#### Muffler-Enclosure Device

The new drill body design necessitated the development of the special muffler-enclosure device shown in figure 6. The inner part of the muffler-enclosure consisted of a series of ring-shaped, perforated metal baffle plates around the drill body. The outer shell of the enclosure consisted of two layers--an inner aluminum layer and an outer layer made of EAR Isodamp 1002<sup>3</sup> polymer material. During drilling, the exhaust air from the piston chamber and rotation motor moved upward through the perforated baffle

plates and left the acoustical enclosure through an exhaust hole near the top of the drill.

The muffler-enclosure attenuated both drill body noise and air exhaust noise, and the baffle plates vibrated to inhibit ice buildup on the inner surfaces of the enclosure. A flexible deflector plate near the exhaust port of the piston chamber directed the air toward the top of the drill and also helped reduce icing. In extended laboratory tests using compressed air saturated with water vapor, icing problems were virtually nonexistent.

#### Shroud Tube

The shroud tube of the redesigned stoper drill was a simple steel tube designed to fit a 1-in hexagonal drill steel and 1-3/8- to 1-3/4-in drill bits. Its outer diameter was small enough to allow it to follow the drill bit into the hole, and its inner diameter was large enough to keep it from touching the drill

<sup>3</sup>Reference to specific products does not imply endorsement by the Bureau of Mines.

steel (1/16-in annular clearance). The tube was connected to the top of the drill body through a rubber sleeve (see figure 6) to provide isolation from drill body vibration.

#### Redesign of Drilling Controls

The drilling controls of the redesigned stoper had several unique, advantageous features. All controls were mounted on the feed leg such that the operator could stand 2-1/2 ft away from the machine (versus 1 ft on a conventional stoper), thereby exposing him or her to less noise. Hammer, thrust, and rotation controls were located together for easy operation.

During drilling, the operator first moved the primary drill throttle handle to a special "collaring" position. This supplied pressure to the feed leg and started a light hammering action without rotation. After the bit had made sufficient penetration to assure a straight hole, the operator moved the throttle to the "full on" position (hammer, feed, and rotation). A separate control could be used to alter rotation speed as necessary, and a special valving spindle allowed automatic reduction of stalling torque under high feed leg pressure. When the hole was completed, the operator moved the throttle to a special "drill retract" position. In this position, the hammering action ceased, and the feed pressure decreased to allow the feed leg to collapse; however, rotation continued and the drill bit augered its way smoothly out of the hole.

#### Underground Tests of Redesigned Stopers

Six of the prototype quiet stopers were manufactured, and four were tested in operating underground coal mines. The average noise level of the "quiet" stopers was about 102 dBA in these mines, approximately a 15-dBA reduction versus standard stopers. Importantly, the redesigned drills were lighter and their penetration rates were faster than the stopers they replaced, thus increasing their acceptance by the miners. Freezing

problems did not occur, and only minimal wear was noted when the drill parts were examined at the conclusion of the field tests. The success of the redesigned drill was demonstrated by the fact that three of the four test mines offered to buy the drills when they became commercially available. The only disadvantage of the redesigned stoper was that the shroud tube required removal and replacement during the drill steel changing process. Since this proved to be time-consuming, operators often drilled without the shroud tube, partially negating the effectiveness of the redesigned drill. However, noise levels without the shroud tube were still about 107 dBA, substantially lower than standard stopers or stopers with retrofit mufflers.

#### Redesign of Hand-Held Hardrock Drill

Because of the success of the redesigned coal stoper, the Bureau has sponsored a program (7) to redesign a hand-held drill suitable for use in hard-rock mines. The basic design features of the "quiet" hard-rock drill (fig. 7) are the same as those of the "quiet" coal stoper--independent rotation, valveless operation, muffler-enclosure, shroud tube, and redesigned controls. However, the size, shape, and stroke length of the piston of the quiet coal stoper had to be changed substantially to achieve the higher blow energy needed in the hard-rock version of the drill. Computer modeling of the drills' percussion cycles (piston positions, porting arrangements, air pressures, etc.) greatly facilitated this process.

The quiet hand-held hard-rock drill differed from the quiet coal stoper in several other ways (compare figures 6 and 7). First, the outer cover of the hard-rock drill was made of cast aluminum rather than the aluminum-EAR composite; this reduced its weight and made it easier to fabricate. Second, the ring-shaped baffle plates were eliminated in the hard-rock version of the drill because the flexible exhaust deflector alone was found to be sufficient to inhibit ice buildup. Third, the drill

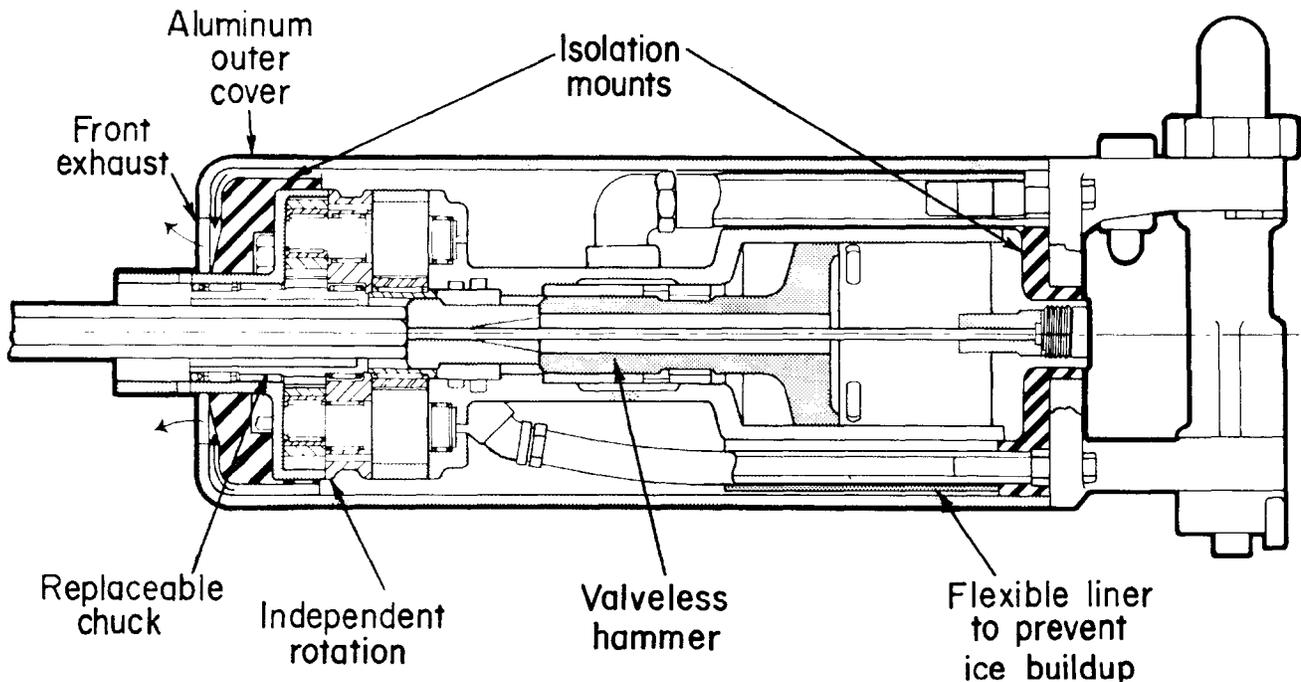


FIGURE 7. - Internal components of quiet hand-held hardrock drill.

cylinder was mounted within the outer cover through rubber pads that isolated the cover from drill cylinder vibration. These design changes resulted in a powerful, quiet, lightweight hard-rock drill.

In addition, the "quiet" hard-rock drill had to be able to drill horizontal and angled production holes as well as vertical roof bolt holes. Therefore, the feed leg mounting mechanism and control arrangement of the coal stoper were redesigned for this purpose. The hammer and drill cylinder designs were also modified slightly to improve drill startup while in the horizontal position. A fiberglass feed leg was utilized to reduce overall drill weight.

A production-ready prototype of the redesigned, "quiet" hard-rock drill produced noise levels of 104 dBA (with shroud tube) to 107 dBA (without shroud tube) when tested in an underground hard-rock mine. Both the hard-rock and the coal versions of the "quiet" hand-held drill are now commercially available through Technological Enterprises Inc. (TEI), Littleton, CO. TEI reports that the new drills cost about the same as

standard (unmuffled) drills, and provide better drill control features. Other commercial drill manufacturers can obtain complete design details from the Bureau.

#### NOISE CONTROL TECHNIQUES FOR JUMBO DRILLS

As with hand-held percussion drills, the Bureau has investigated both retrofit and redesign measures for reducing jumbo drill noise. A potentially workable retrofit package was developed under Bureau contract (8) and is now being tested in-house to determine its long-term durability. The redesigned jumbo drill is now being field-tested by another contractor (9). As with stoper drills, the two major components of the noise-controlled jumbo drills were (1) a muffler-enclosure to attenuate air exhaust and drill body noise and (2) a shroud tube to attenuate drill steel noise.

#### Retrofit Treatments

Figure 8 shows the retrofit muffler-enclosure on a drifter with rifle-bar rotation. The muffler-enclosure had to surround the drifter completely because

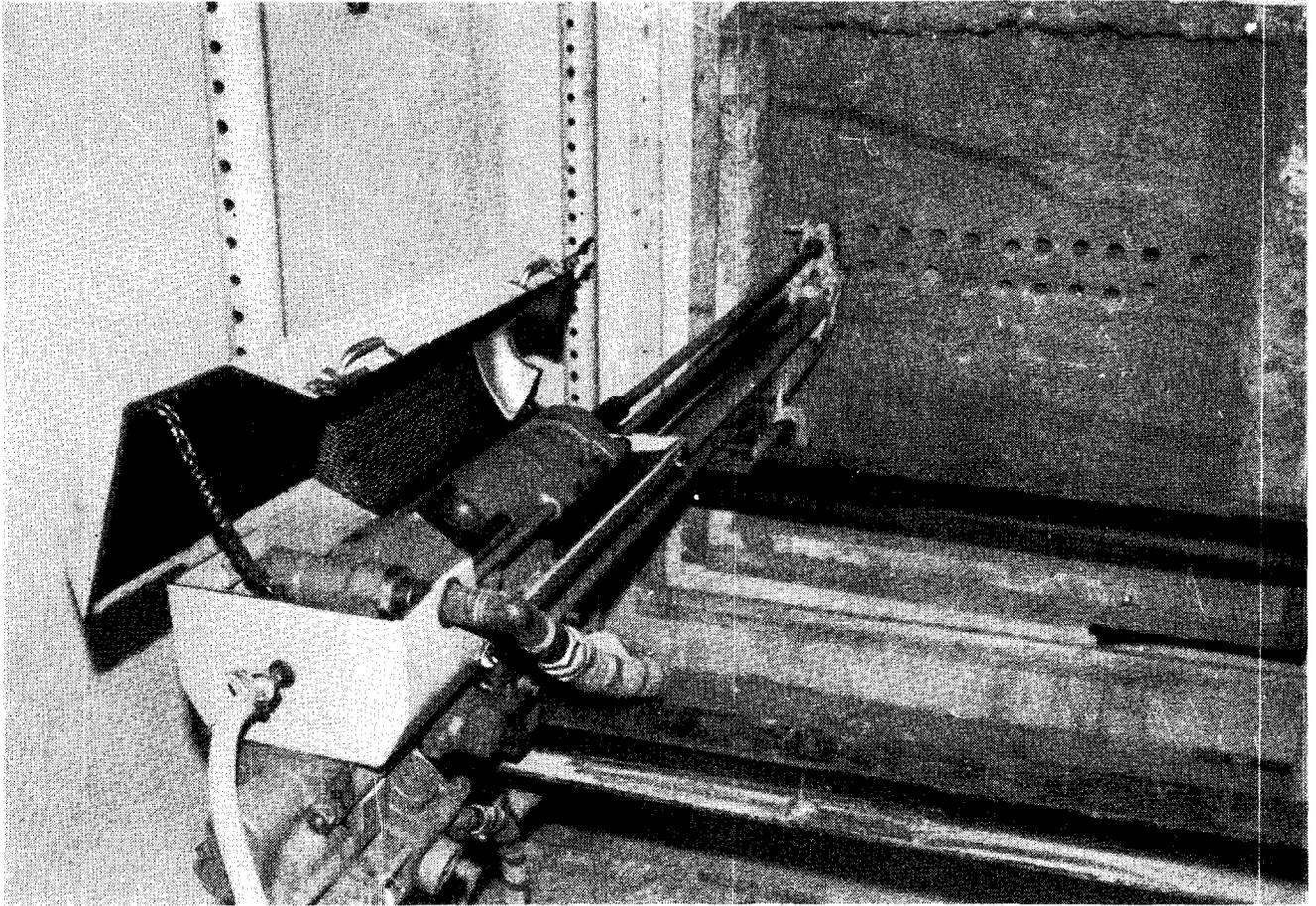


FIGURE 8. - Drifter within retrofit muffler-enclosure (cover open).

there were three air exhaust ports at different locations around the drill body. The halves of this two-piece, box-like enclosure fit together snugly around a horizontal centerline. Its octagon-shaped profile was a compromise reached after considering the requirements of interior volume, exterior slimness, noise-attenuating properties, and light weight. Figure 8 shows that the top portion of the enclosure was hinged to the bottom portion to allow easy access to the drill.

The schematic drawing of the muffler-enclosure (fig. 9) shows that the exhaust air exited the drill radially, struck the silicone rubber deflector at the top of the enclosure, and moved forward to escape through the front opening. Because the deflector was very flexible, it shook off any ice that began to form on it. After passing the deflector, the exhaust

air entered the fiberglass-lined muffler section at the front of the enclosure. (This muffler section can also be seen in figure 8.) A perforated metal plate held the fiberglass in place and a thin layer of Kapton film prevented it from absorbing oil and water. The exhaust air then left the enclosure through the opening at its front end. The three major advantages of this muffler-enclosure design were (1) exhaust noise was directed away from the operator and absorbed; (2) the cold exhaust air cooled the coupling and shank at the front of the drifter; and (3) the warm drill components heated the exhaust air, thus inhibiting ice formation.

Figure 10 shows the components of the shroud tube surrounding the drill steel. The outer diameter of the shroud tube was slightly smaller than the bit diameter, allowing the tube to enter the hole

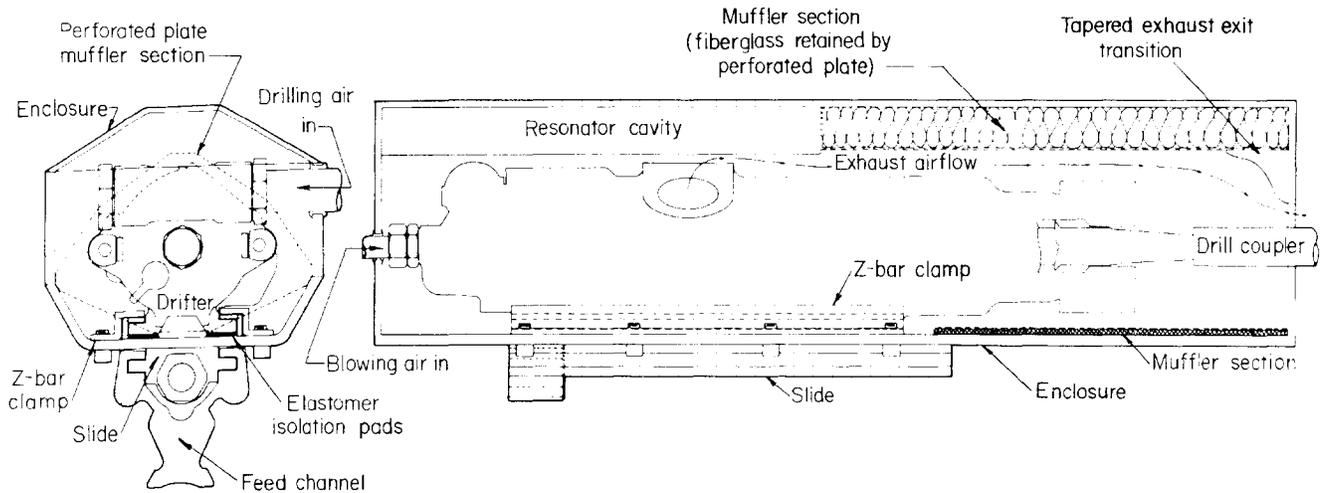


FIGURE 9. - Schematic view of retrofit drifter enclosure.

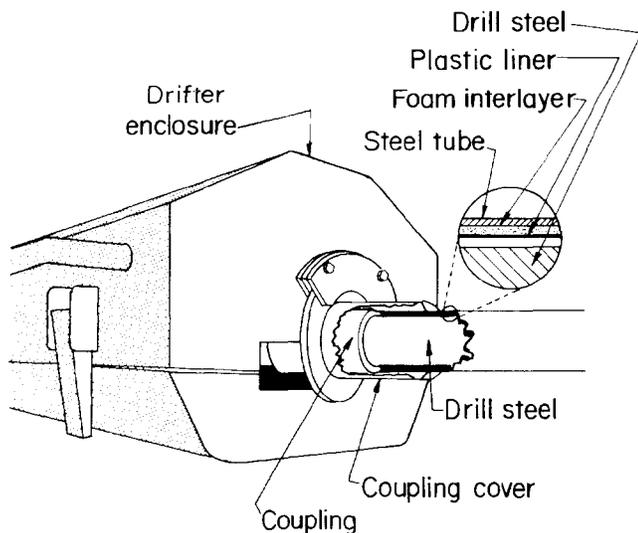


FIGURE 10. - Schematic view of retrofit drill steel shroud tube.

the tube to rotate slightly during operation. The foam interlayer absorbed some of the vibration imparted to the polymer, and the steel outer layer protected the two inner layers from damage. Exhaust air from the muffler-enclosure traveled forward through the annulus between the steel and the shroud tube, escaping just behind the bit.

Performance of the jumbo drill with and without the retrofit noise control treatments was evaluated first in the laboratory, then at an above-ground test site. Laboratory tests in a reverberation room (fig. 8) showed that the sound power level of the treated drill was 19.3 dBA lower than that of the untreated drill. At the aboveground test site, noise reductions of 16.5 to 18.5 dBA were recorded at the operator's position (table 1). Diagnostic tests showed that the

behind the bit. The inner polymer layer rode loosely on the drill steel, causing

TABLE 1. - Acoustical performance of retrofit jumbo drill noise control treatments, A-weighted overall noise level, decibels

Drill position	Base-line	Fully quieted	Reduction	Drill position	Base-line	Fully quieted	Reduction
ABOVEGROUND TESTS				UNDERGROUND TESTS			
Collaring hole, 10 ft of steel..	108.5	92	16.5	Collaring hole, 10 ft of steel..	117.5	105	12.5
Middle of hole, 5 to 6 ft of steel	107	88.5	18.5	Middle of hole, 5 to 6 ft of steel	116	101	15
End of hole, 1 to 2 ft of steel...	105.5	88	17.5	End of hole, 1 to 2 ft of steel...	115.5	101.5	14

muffler-enclosure accounted for about 11 dBA of this reduction; the shroud tube and/or the rock mass surrounding the drill hole accounted for the remainder. Ice formation and damage to the noise control treatments were negligible.

The retrofitted drill was then tested in an operating underground zinc mine. As shown in table 1, noise levels at the operator's position were 12.5 to 15 dBA lower than with the untreated drill. One of the reasons for the more modest noise reductions in the underground tests was that the confined, reverberant underground environment set up reflections that partially negated the advantage of directing the exhaust air away from the operator. (Note also that the overall noise levels were much higher underground than aboveground.) The noise levels of the treated drill show that it could have been operated for about 8 h per shift aboveground (88-92 dBA) and about 1-1/2 h underground (101-105 dBA) without violating Federal noise regulations.

The durability of the noise control treatments was evaluated by drilling approximately 10,000 ft of hole in the underground zinc mine. Although only about 500 ft were drilled with the shroud tube<sup>4</sup> the muffler-enclosure was used during the entire test period. Overall, the components of the muffler-enclosure were quite durable; the outside was not damaged, the fiberglass baffles were in good condition, the protective film had only two small holes, and the rubber exhaust deflector showed no signs of wear. The only damaged acoustical component was the rubber seal at the drill air inlet, which came off when the bolts supporting the drill mounting bracket failed. This failure, however, was not the fault of the acoustical treatments themselves.

Mine personnel reported very good operator acceptance of the partially quieted

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<sup>4</sup>The mine did not possess the 10-ft-long drill steels for which the shroud tube was designed; by the time the appropriate steels were obtained, the test period was almost completed.

drill (muffler-enclosure only) during underground tests, despite the need to fix damaged drill parts and support brackets on several occasions. The presence of the muffler-enclosure did not interfere significantly with either the replacement of broken parts or routine drill maintenance. Operators generally agreed that the treated machine drilled just as fast or faster than the unmodified drills used at the mine.

The Bureau is presently testing the fully quieted drill at its Pittsburgh (PA) Research Center to evaluate the durability of the shroud tube in figure 10 and other similar shroud tube designs. The effect of the shroud tube on operator acceptance (e.g., the ability to observe a stoppage of drill steel rotation) is also being evaluated.

#### Redesign of Jumbo Drill

Although the retrofit muffler-enclosure described would be quite effective for most jumbo drills with rifle bar rotation, it would not be appropriate for drifters containing independent drill steel rotation motors. This is because independent rotation drills are usually somewhat larger than rifle bar drills, and would require larger, heavier muffler-enclosures. The problem of air exhaust from the rotation motor would also have to be addressed. Therefore, the Bureau sponsored a program to redesign an independent-rotation jumbo drill for the purpose of reducing noise. A prototype of the redesigned drill is shown in figure 11.

In order to make a simple, compact muffler-enclosure for the drifter, the rotation motor was removed from the drifter body and relocated at the front end of the feed channel. This design change required the use of a specialized drill steel called a "kelly bar." The drifter supplied percussion to the rear end of the kelly bar while the new rotation mechanism (an air motor, belt drive, and gears) imparted rotation to its front end. A small muffler was placed on the

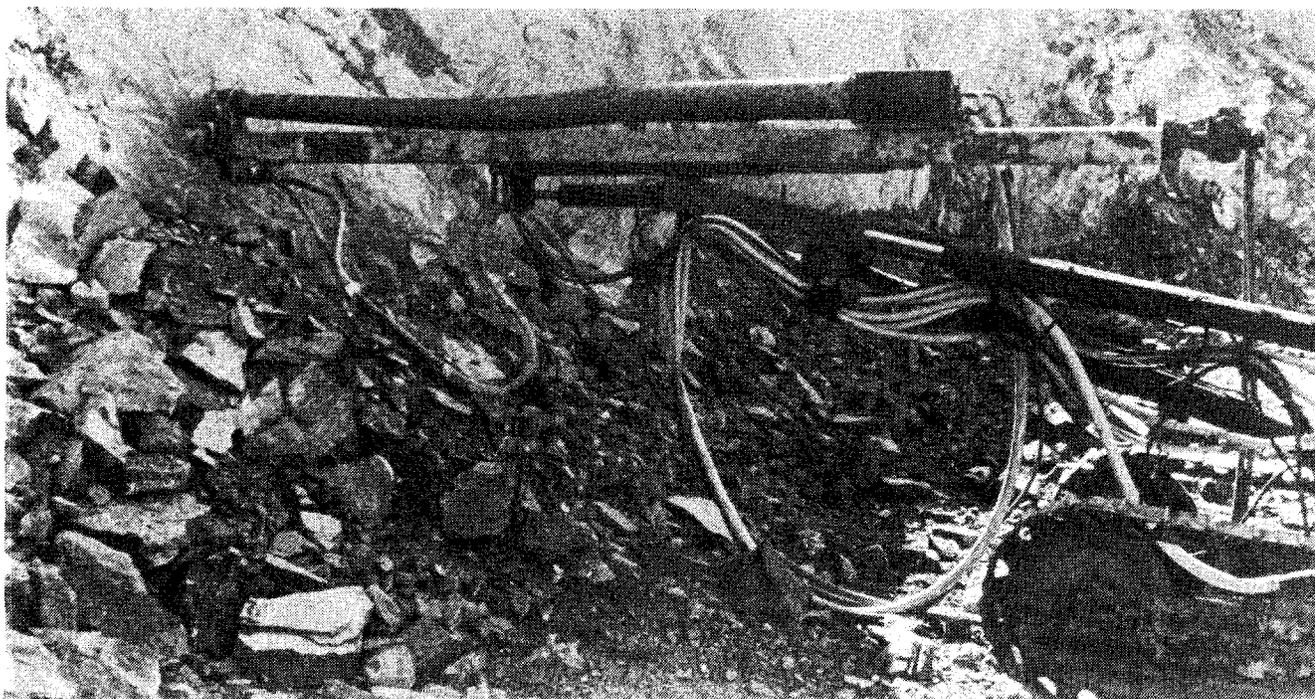


FIGURE 11. - Redesigned jumbo drill with collapsible shroud tube prior to drilling.

exhaust hose of the rotation air motor to attenuate its noise.

The modified drifter was then placed within a two-piece, boxlike enclosure made entirely of molded polymer material. The top half of the muffler-enclosure fit snugly atop the bottom half, and could be removed for easy access to the drill. The drifter was mounted within the bottom half of the enclosure through rubber bushings that isolated the feed channel from drifter vibration.

A shroud tube was also used on the redesigned jumbo drill to abate drill steel noise; however, its design was quite different than that of the shroud tubes on the retrofitted jumbo drill and the redesigned stoper. As shown in figures 11 and 12, the shroud tube on the redesigned jumbo drill was a collapsible steel coil of ~8-in diam. Unlike the shroud tube on the retrofitted jumbo drill, it did not touch the drill steel nor enter the hole during drilling. Instead, it was suspended firmly between the front portion of the drifter enclosure and the rear face of the kelly-bar rotation mechanism.

The springlike shroud tube was completely extended at the start of the drilling (fig. 11), and collapsed as the drifter moved toward the face (fig. 12). Exhaust air from the drifter moved forward through the shroud tube and a plunger-shaped rubber "stinger" (fig. 13) that was pressed against the rock face. The drifter exhaust air, hole-flushing air, and rock chips produced during drilling exited through the small gap between the stinger and the rock face. The stinger helped attenuate noise that would have otherwise have "escaped" from the collar of the hole.

Initial testing of the redesigned jumbo drill was conducted in a surface rock quarry (figs. 11-13) and in a nonproduction setting at the Colorado School of Mines experimental mine. Noise levels at the operator's position were about 96 dBA on the surface and about 100 dBA underground, a substantial reduction compared with 110 to 115 dBA of standard jumbo drills. The only significant problems noted during these tests were (1) repeated failure of the air- and/or water-flushing tube (probably unrelated

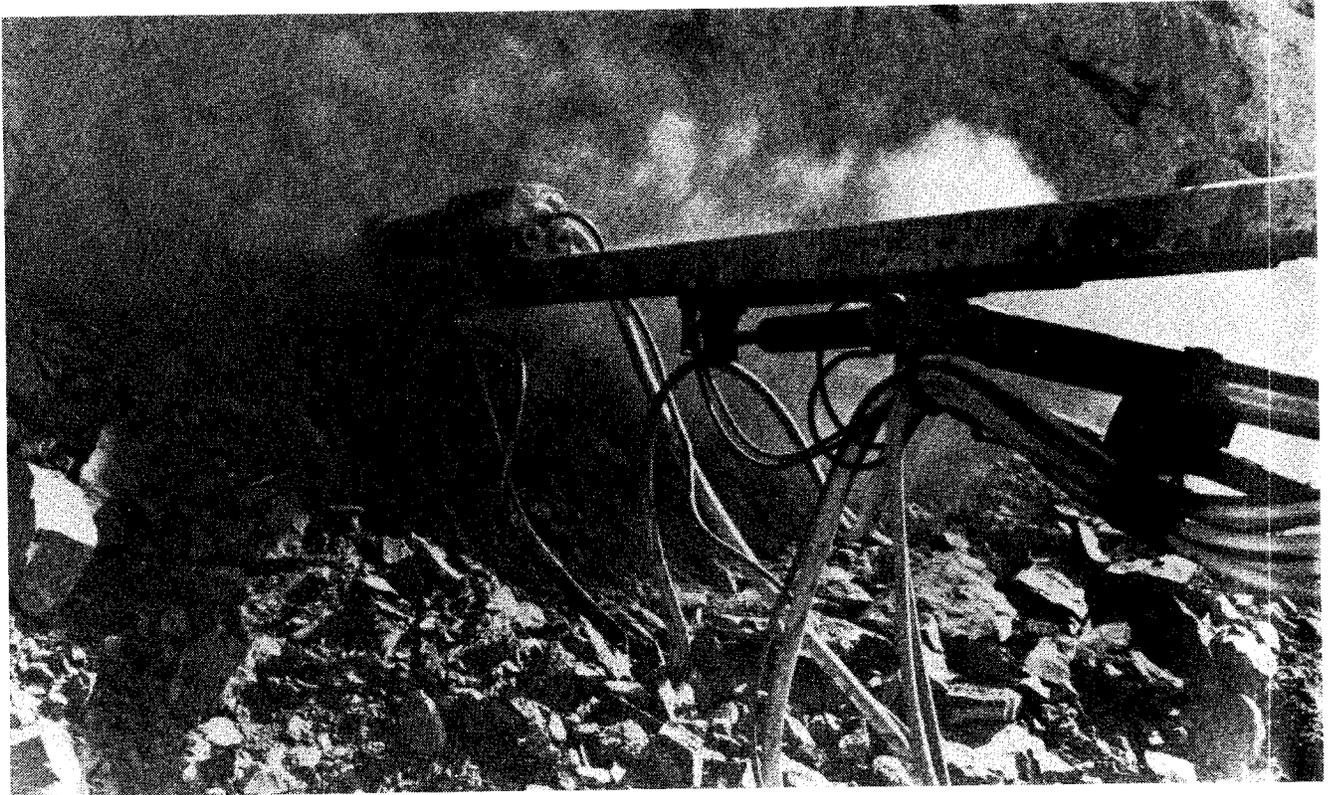


FIGURE 12. - Redesigned jumbo drill with collapsible shroud tube at completion of drilling.

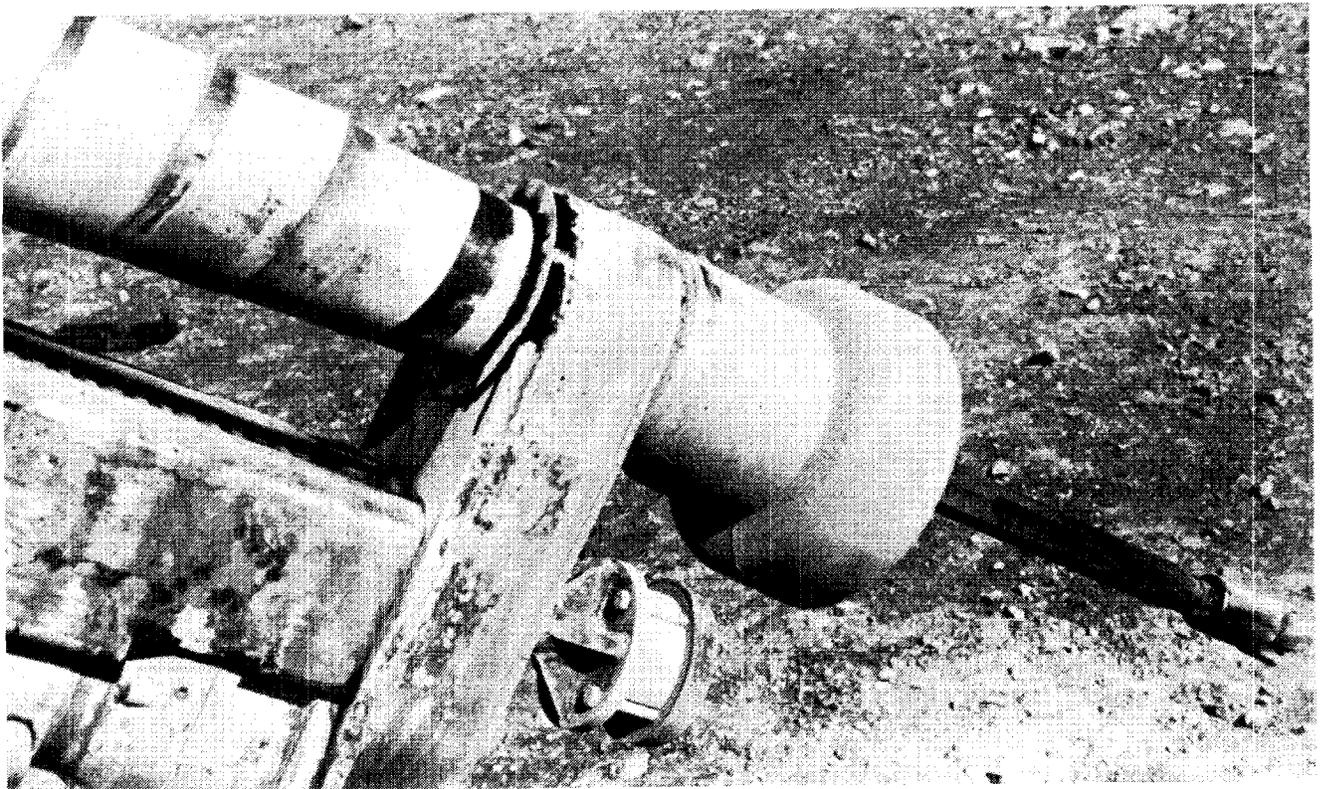


FIGURE 13. - Plunger-shaped stinger and kelly-bar rotation system at front end of feed channel.

to the noise control treatments) and (2) inability to observe drill steel rotation.

Before the redesigned jumbo drill is taken to an operating underground mine for further testing, it will be modified to facilitate longhole drilling, where numerous lengths of drill steel are used. With the present design, the shroud tube must be collapsed by hand in order to add drill steel, an awkward and somewhat dangerous process. The design modification will include an automatic drill steel changing apparatus that will improve both the productivity and safety of the redesigned drill. Details of the drill steel changing mechanism and results of underground "production" tests will be documented in future Bureau reports.

#### CONCENTRIC DRILL STEELS

Perhaps the most innovative technique for controlling drill steel noise is the concentric drill steel concept, now being investigated under Bureau contract (10). The two basic components of the concentric steel are an inner "pulse transmission rod" and an outer "torque tube." As their names imply, the inner rod transmits percussive energy to the bit but does not rotate, while the torque tube supplies rotation and acts as a shroud tube to attenuate noise produced by the inner rod. The torque tube is acoustically isolated from the inner rod by buttonlike rubber inserts. The inner rod is solid, and hole-flushing air or water passes through the annulus between the rod and tube.

The concentric drill steel has the following distinct advantages over any other drill steel shrouding technique developed to date:

1. Drill steel life should increase because the inner pulse transmission rod is solid (no blow tube) and will not be exposed to the high torques and external scratching that usually initiate failure.

2. Less expensive steel alloys can be used because percussion and torque will

be transmitted through different structural members.

3. Miners should readily accept concentric steels because (a) the drill steel changing process will be no more complex than the present process and (b) they will be able to observe drill steel rotation at all times.

4. Existing drills can be retrofitted easily to accept concentric steels.

Construction of a prototype concentric drill steel is now underway, and field testing will begin in 1984. This first prototype has been designed to fit a popular pneumatic drifter model; similar prototypes are now being designed for other pneumatic drifter models, a hydraulic drifter, and the "quiet" hand-held drills discussed earlier in this paper.

#### IN-HOUSE BUREAU RESEARCH ON DRILLING NOISE

During the past 2-yr, the Bureau's Pittsburgh (PA) Research Center (PRC) has acquired the equipment and facilities necessary to conduct extensive in-house research on percussion drill noise. Initial tests are now being performed outdoors at PRC, using a concrete block as a drill medium, and underground at the Bureau's Lake Lynn Laboratory, an abandoned underground limestone mine. Detailed investigations of drilling noise will be conducted inside a reverberation building that is now being constructed at PRC (completion scheduled for mid-1984). As in the past, Bureau research will focus on two basic areas--muffling of drill exhaust noise and control of drill steel noise.

#### Exhaust Mufflers

In order to investigate the muffler freezing problem more closely, the Bureau has acquired (1) a three-boom jumbo rig, (2) two pneumatic drifters, (3) two of the "quiet" hand-held drills described earlier, (4) a portable air compressor, (5) a portable compressed air aftercooler and dryer, (6) a portable water injection

system, and (7) a complete, continuous airflow and water flow monitoring system. With the aid of these items, the Bureau will conduct controlled muffler freezing tests using a wide variety of drill and muffler designs. The noise-reducing capabilities and freezing characteristics of the various drill-muffler combinations will be documented and reported in subsequent Bureau publications.

#### Drill Steel Noise Controls

The major in-house tool for investigating drill steel noise is a complete, portable hydraulic drilling system

cently acquired by the Bureau. Because the hydraulic drifter produces no air exhaust noise, it is the ideal machine for this purpose. Initial investigations will focus on the durability, field-acceptability, and noise-reducing capabilities of "in-the-hole" shroud tubes similar to the tube on the retrofitted drifter described earlier. The front end cap of the hydraulic drifter has been modified to accept shroud tubes of various sizes and materials (plastics, metals, polymer materials, etc.). Concentric drill steels and drill body enclosures for hydraulic drifters will also be evaluated using this machine.

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