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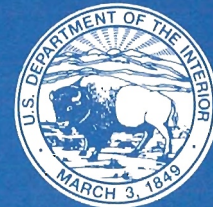
DEC 27 1994

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Measuring the Sound Power Level of Percussion Drills

By Robert R. Stein

UNITED STATES DEPARTMENT OF THE INTERIOR



BUREAU OF MINES



RI 9524

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Report of Investigations 9524

Measuring the Sound Power Level of Percussion Drills

By Robert R. Stein

**UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary**

**BUREAU OF MINES
Rhea L. Graham, Director**

International Standard Serial Number
ISSN 1066-5552

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm centimeter

dB decibel

kHz kilohertz

kW kilowatt

N newton

W watt

Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

MEASURING THE SOUND POWER LEVEL OF PERCUSSION DRILLS

By Robert R. Stein¹

ABSTRACT

Occupational noise caused by the rock drills used in mining was investigated by the U.S. Bureau of Mines. Using a large reverberation chamber and an automated drill test fixture (ADTF), the sound power levels of mining drills were measured to determine if there are types of drills that are advantageous from a noise production standpoint. Test results show that while there are not large variations among types of drills, there are still some choices that could produce a positive effect on overall noise exposure. It is also shown that lower noise exposures are possible using larger drills because of higher production rates and better operator positioning.

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INTRODUCTION

Mining technology is not immune to the forces that drive general industry forward. The same economic logic applies and necessitates constant improvements in productivity. One of the primary ways this is accomplished is by improving the technology.

Unlike general industry, however, the technology applied to mining is subject to a larger number of constraints. After centuries of civilization, the mineral products supplied by the mining industry are still mainly the ones that were desired by primitive human beings and they are still located in the earth. Access to and removal of these products must accommodate ever-increasing geologic demands. Since the most obvious deposits are mined first, most of the high-grade surface deposits were exhausted by the midtwentieth century. As new mines are opened, they inevitably will set new records for depth, remoteness, or the low grade of the ore. Another source of constraints has been added by the increased population that mining helps to support. Social forces require that mining be performed with undetectable disturbance to the surrounding environment, thus further increasing the demands on mining technology.

Methods and practices have developed to cope with the increasingly rigorous demands that were encountered over the years, but one aspect has not changed since mining was first practiced by human beings. Rock must be broken to attain the desired mineral product. All of the technological advances achieved in mining's history have yet to yield a more effective way to do this than through the application of mechanical energy directly to the rock. The use of explosives expedites mechanical breakage; however, explosives are very ineffective unless they are placed within a rock mass where they can exploit the rock's inherent weakness in tensile strength. This means that where natural openings do not already exist, they must be created. This is done most often by drilling holes in a well-defined pattern.

Drilling techniques fall into two general categories, which can be defined as rotary and percussive. From a noise perspective, rotary drilling offers a much better platform from which to make improvements; however, rotary drilling is limited in its range of application by an inability to penetrate hard rock economically, particularly at smaller hole diameters.

Rotary drilling is performed using either drag bits, roller bits, or diamond bits. The use of diamond bits is reserved for exploratory drilling in which a rod-shaped core of rock is retrieved for geological analysis. Diamond drilling is not practical for production holes because of the expense and relatively low rate of advance. Drag and roller bits break rock by mechanisms that are different from those used in diamond drilling and from each other.

The drag bit subjects rock to both thrust and torque, which causes the cutting force to occur at an angle to the rock face (*I*).² The cutting edge of the drag bit must be forced into the rock surface by the thrust applied to the drill column. This allows the force due to the torque to build up directly ahead of the bit edge as the rock deforms elastically under the increasing load. As the load applied exceeds the yield strength of the rock, it fails, allowing the bit to jump ahead through the failed material until it comes in contact with an unbroken surface. This process is very similar to that of linear drag bits and results in a cyclic loading of the bit surface and cutting edge. As the bit dulls, the thrust force necessary to force the bit into the rock increases, thus reducing the penetration rate. This can be offset by increasing the thrust on the drill column, but the wear rate on the bit is accelerated and a practical limit is reached beyond which the load carrying capacity of the bit and drill column is exceeded. The success of rotary drilling depends mainly on the material from which the cutting edge of the bit is fabricated. The physical demands are severe, requiring high strength, hardness, and abrasion resistance in a geometry that is not favorable. The most common material used, tungsten carbide, suffers from spalling and brittle fracture along with simple wear. More advanced materials, such as synthetic diamond composites, fare somewhat better but are much more expensive. Rotary drilling with drag bits is highly competitive when applied to the proper types of rock, but it is incapable of economically drilling holes in very hard formations.

Roller bits subject the rock to thrust alone, breaking the rock mainly through compressive failure, and are thereby able to successfully drill much harder formations than when using drag bits. Roller bits make use of multiple small bearing surfaces mounted on cone-shaped wheels that are rolled across the hole face by the torque applied to the drill string. The thrust load is magnified by its application through the small bearing surfaces in contact with the rock. Localized compressive failure occurs immediately under the bearing points with little or no propagation from one point to the next, depending upon the rock being drilled. The thrust requirements are extremely high and are usually achieved by applying the weight of the drill carriage to the drill string. It is not uncommon for roller cone drills to use thrust exceeding 445,000 N. Only large internal bearings are capable of withstanding the high thrust levels required in very hard rock formations. Roller bit drills operating in these formations usually drill holes that are 30.5 cm in diameter or greater. The combination of high thrust and large holes makes roller cone drilling

²Italic numbers in parentheses refer to items in the list of references at the end of this report.

impractical in most underground operations. Underground mining techniques usually require smaller holes and drilling in a variety of orientations that do not accommodate using the weight of the machine to supply the thrust.

Percussive drilling utilizes the energy from an impact to break rock. Whether in a manual or a mechanized system, the energy imparted to a hammer by accelerating it over some distance is released instantaneously on a drill column. The very high stresses that are generated in the drill column are transmitted very efficiently to a bit that is in contact with the rock at the time of the blow. Percussion bits further concentrate the stress by focusing it onto very small surfaces at the bit-rock interface. The stress transmitted into the rock exceeds the material strength in all failure modes, but compression and shear failure are responsible for most of the rock broken. The rock immediately under the bit contact point fails in compression, creating a small crushed zone. The bit further penetrates the crushed zone and creates shear forces in the adjacent rock, causing some additional material to fail in shear mode (2). Between successive blows, the bit is indexed by rotation to bring it into contact with a fresh surface and the percussion cycle is repeated.

The current state of materials science is capable of supplying percussion drilling needs quite well. Tungsten carbide is used for most percussion cutting surfaces, and the geometry of the bit inserts is much more favorable in terms of withstanding the stresses imparted by the drilling action than in the inserts used for drag-type rotary drilling. Drill steels are made of heat-treated steel and are well

matched to the bits in terms of wear life. Steels that are reasonably cared for and turned end for end in use provide many meters of drilled hole before failure. Drills are composed of various types of hardened steels and are very rugged. The limiting component is the piston, sometimes referred to as the hammer, that oscillates within the drill housing and strikes the drill steel or shank, depending on the drill design. Stress levels are extremely high in the hammer, which also is subject to fatigue failure because of cyclic loading. Impact velocities must be controlled to provide an adequate wear life.

It is apparent that drilling technology has been advanced to a state where it will not be completely deleted from the mining process any time in the foreseeable future. In light of this fact, the U.S. Bureau of Mines (USBM) has performed this work to assist in the process of reducing operator exposure to drill noise as part of its overall mission to perform research that benefits miner health and safety. Even though they are still among the loudest noise sources in mining, modern drills are quite efficient and, when they are operated by experienced drillers, they can be employed in ways that help to reduce noise exposure. Previous noise data published for commercially produced drills consisted of sound pressure measurements and were subject to the inconsistencies inherent in using sound pressure measurements. By establishing accurate methods of measuring drill sound power levels, occupational health specialists in the mining industry will be provided with the data they need to help protect miners' hearing.

EXPERIMENTAL PROCEDURE

A large amount of effort was expended in developing a uniform way to quantify the noise generated by percussion drills. Drilling done in the field is subject to a high number of operational variables that affect the noise levels measured. Not the least among these variables is the operator; different operators develop various techniques to control the drill that result in different sound levels. The operator is both directly and indirectly responsible for the varying power and thrust levels supplied to the drill as it is operating. A critical factor affecting sound pressure level measurements is the acoustic environment. Wide variations are found in mine settings, ranging from wide open spaces at some surface operations to highly reverberant, enclosed spaces in underground mines. The material and the geometry of the surface being drilled also have an affect on the overall sound pressure levels measured. Smaller, but still considerable, effects arise from the bit type and sharpness, the type of steel and its length, and the operational condition of the drill. The most desirable

measurement conditions would occur from having a known or controlled acoustic environment and automated drill operation. To achieve uniform test conditions, testing was done in the reverberation chamber of the USBM Pittsburgh Research Center noise control laboratory. The drills were run on a specially developed, automated drill test fixture (ADTF).

SOUND POWER MEASUREMENTS

To facilitate valid comparisons between drill types, sound power was measured rather than sound pressure. Sound power is a measure of the acoustic energy radiated from a noise source and is independent of variables that arise from the acoustic environment in which the source is located. Sound power levels, expressed in decibels, are therefore independent of measurement location.

To make sound power measurements accurately, it is necessary to control the environment in which the drill will

be tested. All of the drill tests performed during this investigation were conducted in a large reverberation chamber utilizing the substitution method as described in International Standards Organization standard 3741 for measuring sound power levels.

In the substitution method, a source of known sound power level is placed in the test environment and the sound pressure levels are measured in one-third-octave bands. Room correction factors are then developed by comparing the measured sound pressure levels against the known sound power levels. The known source is then replaced by the test object in the test environment. The sound power level of the test object can then be calculated by measuring the sound pressure level and applying the room correction factors.

During testing, sound pressure levels were detected by an array of 8 to 16 fixed microphones spaced randomly in the reverberation chamber. The microphone output was fed through two Bruel & Kjaer F-type 2811, eight-channel multiplexers to a Bruel & Kjaer type 7057 sound power calculator. The sound power calculator is a dedicated instrument for measuring sound power levels. Equipped with both octave and one-third-octave filters, the sound power calculator is capable of reading out directly in decibels the sound power level by applying the room correction factors developed for the standard source to the sound pressure levels measured for the test object. In addition, it controls the sample time and synchronization of the multiplexers in a manner that avoids sampling multiplexer switching events.

SOUND INTENSITY MEASUREMENTS

Sound intensity is a measure of the sound energy passing through a fixed surface in space in energy per unit area. Sound intensity levels, like sound power levels, are derived indirectly by measuring sound pressure levels. A special probe is used to hold two phase-matched microphones at a precise spacing oriented such that the microphone diaphragms are parallel and facing one another. A purpose-built, dual-channel, real-time analyzer uses the signals from the probe to calculate the sound intensity level that exists at the probe location. By defining a precise control volume that envelops a test object, the sound power of the test object can be calculated from the measured sound intensity levels.

Sound intensity was used during this investigation to perform source contribution measurements rather than overall sound power measurements. Because of the operating requirements and test conditions, sound intensity methods were not quite as repeatable as substitution method measurements for the overall sound power (3).

AUTOMATED DRILL TEST FIXTURE

Eliminating the operator was accomplished by using ADTF to perform the drill tests in the reverberation chamber of the noise control laboratory (figure 1). The ADTF was designed around a standard process controller used in industry to monitor and control many types of production processes. In the case of the ADTF, the process controller was used to monitor and control hydraulic and pneumatic power supplies to conduct controlled tests of the drills.

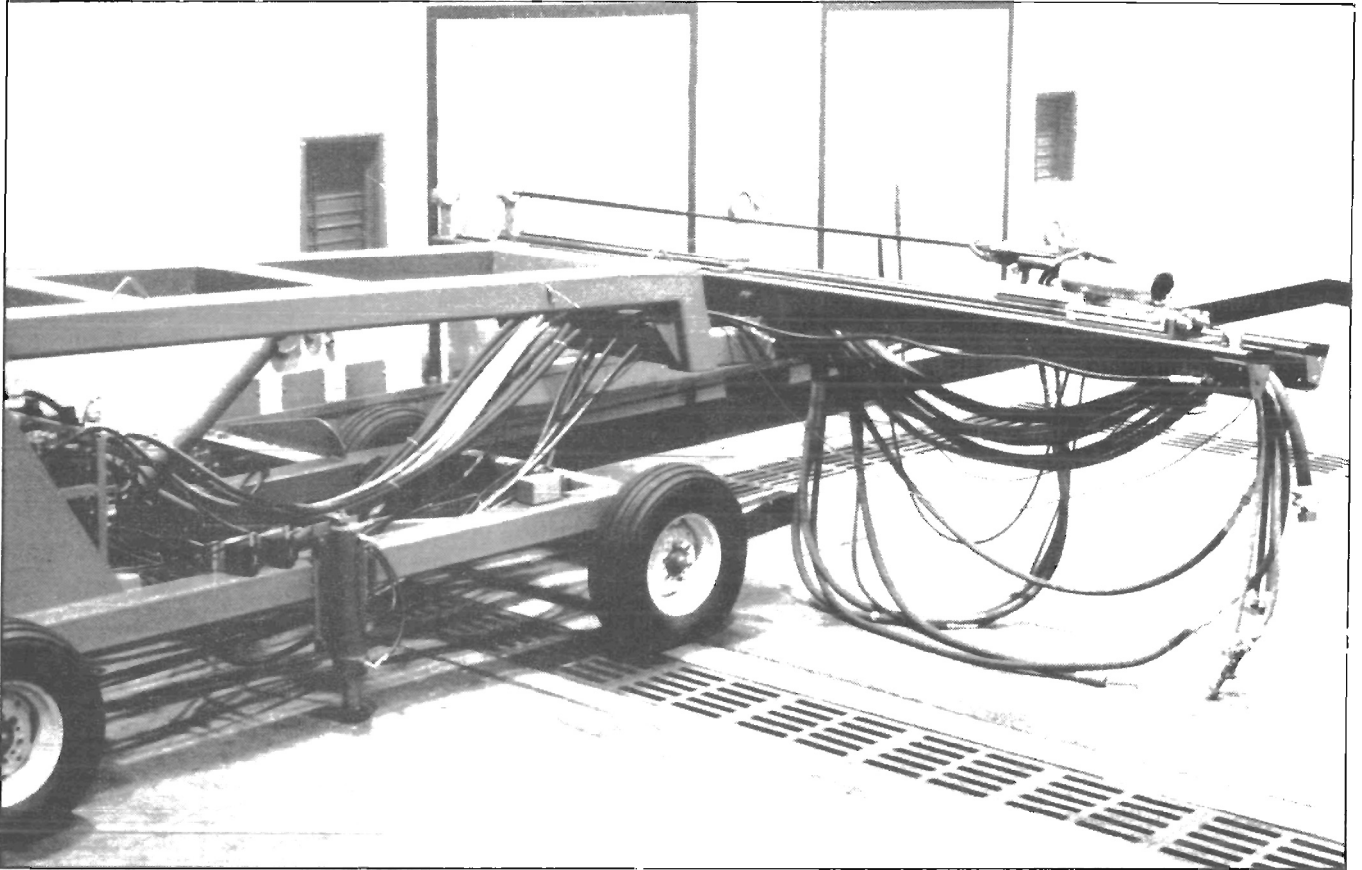
By using the ADTF, the operation of the drill became much more repeatable. Several tests were run on each drill to determine the proper operating parameters. Hammer supply pressure, rotation supply pressure, and feed thrust were varied until the drill performed at what was judged to be the optimum performance level in terms of penetration rate. Sound power output was found to be fairly insensitive to power input over the operating range of the drills (4). Thus, the sound power levels reported are fairly consistent in this regard and are not subject to operational qualifiers similar to those used when reporting the sound power levels for internal combustion engines.

For any individual test, set points were supplied by the operator for hole location, hammer supply pressure, feed thrust, rotation supply pressure, and hole depth via a personal computer that transferred the information to the program controller. The personal computer then monitored the test by polling the process controller periodically for test data and test stage information. The data were stored to a disk file along with sound power level data retrieved from the sound power calculator (5).

DRILLING MEDIUM

Control of the drilling medium presents several problems that conflict with the goal of performing all tests on one material. The first point to consider is that percussion rock drills are not all designed to drill rock of the same strength. For a given rock strength, there is a threshold blow energy that must be achieved to cause chipping. Once that threshold energy has been exceeded, drilling occurs. There is a limit, however, to the gains that can be attained by continuing to increase the blow energy. Overdriving the bit simply results in more crushing of the broken material that is trapped in front of the bit. This energy is wasted since the broken material could already have been removed from the hole as larger chips. Fortunately, the operating characteristics of a percussion drill provide a good mechanism to use in converting the unwanted blow energy into useful work.

Figure 1



ADTF in reverberation chamber.

The blow energy is a function of the piston stroke. A longer stroke provides a longer time for the piston to accelerate, thus resulting in a higher impact velocity and greater impact energy. Conversely, a shorter stroke will result in a lower impact energy. In addition, the length of the stroke affects the blow frequency. A shorter stroke results in a higher blow frequency. Thus, a drill that is designed to drill in a relatively soft rock usually possesses a high blow frequency and a relatively low blow energy. This combination is highly desirable in most sedimentary rocks, such as shales and sandstones. The bit is not over-driven and since the successive blows come at a higher rate, the hole is drilled more quickly. As the rock strength increases, the blow energy must increase to overcome the threshold stress level. Increasing the stroke to increase the blow energy reduces the blow frequency, but still yields a more productive balance in harder rocks.

Changing the stroke of the piston is done by changing the valve timing so that the pressurized fluid, oil, or compressed air is applied to the power stroke at a different point in time. This is a task that is best accomplished at the time the drill is designed and is not usually adjustable

once the design blow energy has been met. There are some exceptions in the case of hydraulic drills.

To cope with the variations in drill designs, it was decided that no single drilling medium would be suitable for all testing. The general requirements were for materials to be homogenous, easy to replace, and easy to shape to control the geometry of the exposed face. Concrete served readily as a low strength material and Barre granite as a hard medium since it is often used as a medium of comparison for performance tests, in addition to meeting the other requirements.

DEAD BLOCK

To measure the sound power of the drill body alone, a method had to be developed whereby a drill could be operated using no drill steel. This cannot be done by simply free oscillating the drill without a drill steel mounted in the chuck. The drill will not operate properly without striking a steel or a shank at the designed impact point. Some drills will not oscillate at all in the absence of feed thrust on the shank or steel. There must also be

some mechanism to absorb the energy that is being imparted to the struck member. These problems were overcome by using a device known as a dead block. The dead block utilizes the power from an active hydraulic circuit to counteract the percussive forces being imparted on the steel by the test drill. A counter rotation torque is also applied to represent the resistance to rotation provided by actual drilling in rock. This is necessitated by the need to keep threaded joints in the drill string tightly coupled. The dead block, which is about the size and weight of a large hydraulic drill, was mounted outside of the

reverberation chamber wall to isolate any noise radiated from it.

When testing a drill using the dead block, several trial runs were completed to facilitate adjustment of the hydraulic circuit to correctly balance the drill's percussive energy and thrust. Once this was accomplished, long-term, steady-state tests could be run on even the largest hydraulic drifters. This proved to be a very valuable asset for doing detailed measurements and supplemental tests using sound intensity techniques.

TEST RESULTS

Results from 14 different drills were chosen for a detailed analysis of their respective sound power levels and spectra. The selected models represented four categories of drills for comparison: handheld pneumatic, handheld hydraulic, machine-mounted pneumatic, and machine-mounted hydraulic. Handheld drills present a more severe problem from a noise control standpoint because it is difficult to isolate the operator from the machine as can be done with machine-mounted drills. For this reason, a larger number of handheld drills are represented in the data. Similarly, machine-mounted pneumatic drills have been losing favor with respect to hydraulic units and thus represent the smallest group tested.

POWER INPUT VERSUS SOUND POWER OUTPUT

One aspect of this investigation was to determine the relationship between the input power to the drill and the sound power level created. Designers of drill equipment are always concerned about the efficiency of the drill in terms of the amount of material removed for each energy unit spent, but are seldom concerned about how much noise is produced. In trying to control the noise of the drill or, more appropriately, limit noise exposure, it is useful to know if the noise output increases proportionately to the power input. The overall investigation approached this issue from two different standpoints and tried to consider the drill and the drill steel separately where possible.

The first approach was to investigate how sound power level varied over the operating range of a particular drill. This was done for two handheld drills. The second approach was to look at drills with varying production rates and compare their performance on a noise efficiency standpoint.

HANDHELD DRILLS

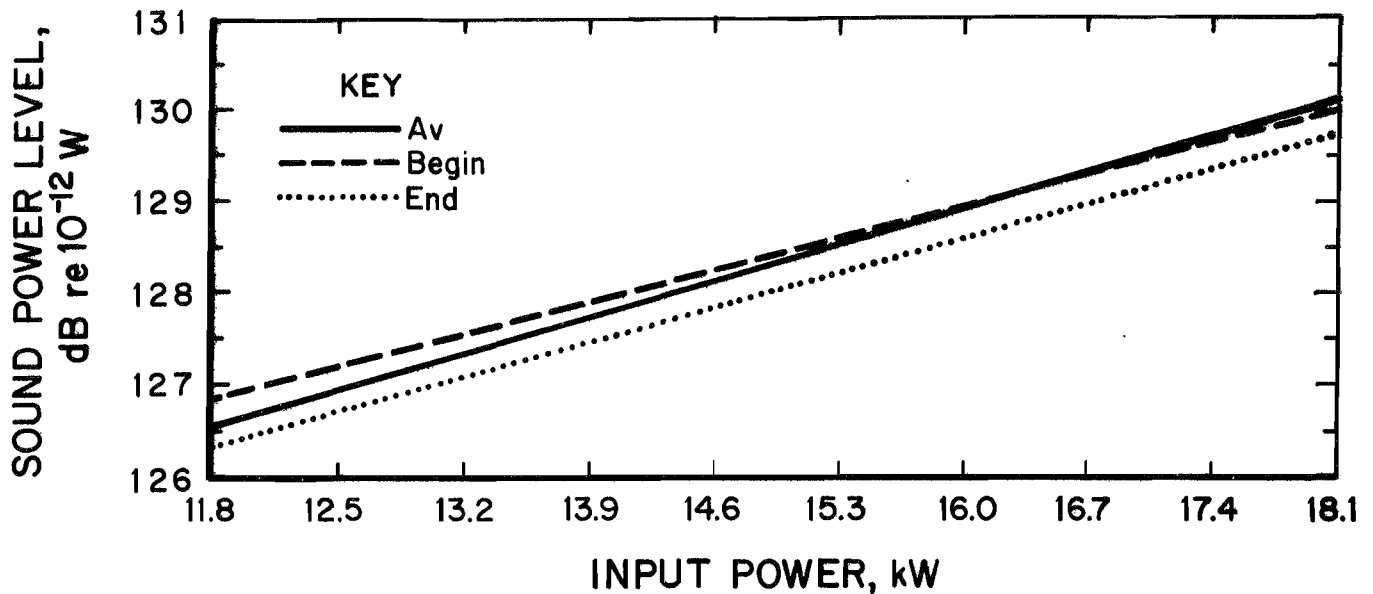
The two handheld drills selected for this phase of testing were a Gardner-Denver SF83 pneumatic drill and

a Tamrock HH50 hydraulic drill. The SF83 pneumatic drill is widely used in underground metal-nonmetal mines and tunneling operations. It is typically mounted on a pneumatic feedleg and is used to drill holes for production (blasting) and roof support. The HH50 hydraulic drill on the other hand, is usually set up as a sinker. A sinker has no feedleg and is used to drill vertical holes into the ground. Thus, it is used primarily in surface operations for profile blasting and anchor bolts. Both drills in their respective applications put the operator in close proximity to the drill body and exposed him or her to high noise levels.

After the operational limits of the drills were determined, a series of tests was laid out to span the range of applicable input power levels for each drill. Since feed thrust is critical to drill operation and subsequent noise output, it was necessary to maintain constant thrust throughout each series of tests. This limited the range of input powers as the drills tended to stall at low power input when thrust was not decreased, and the drills tended to be underthrust at high power input levels when thrust was not increased. The input power range was therefore selected so that its median level corresponded approximately with the optimum performance level of the particular drill being tested.

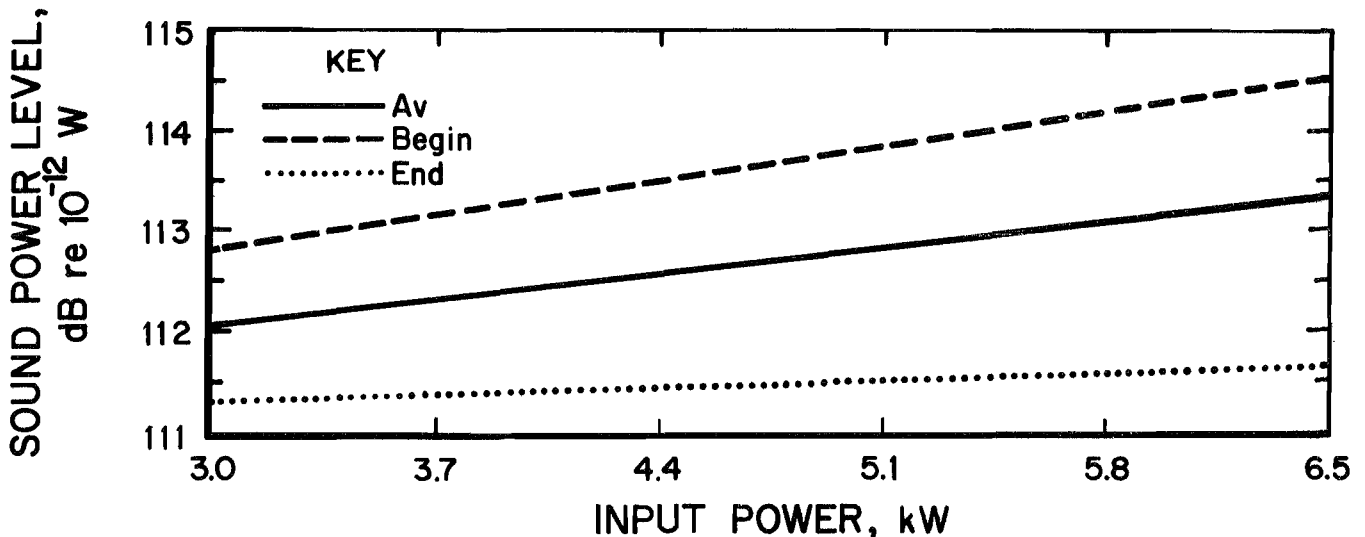
The results of the tests using these two drills are plotted in figures 2 and 3. The three lines in each plot represent the results of a least squares fit, linear regression of the sound power level, and input power level averages from the test beginnings, the test endings, and the average levels. By analyzing the data in this way, the sound power level produced by the entire drilling system, i.e., drill and drill steel together, can be compared with the sound power level produced by the drill. This is possible because the drill steel is almost completely shielded by the rock as the hole is nearing completion. The fact that the noise produced by the pneumatic drill is dominated by the exhaust and drill body radiated noise is apparent from the similarity of the three conditions. The sound power increases at approximately the same rate in all three cases,

Figure 2



Input power versus sound power output for pneumatic drill.

Figure 3



Input power versus sound power output for hydraulic drill.

indicating that the steel is not a major factor, although it does contribute some sound energy.

The overall noise produced by the hydraulic drill, however, is quite different since the drill body is the only significant noise source at the end of a test. The nearly flat slope of the "end of test" line indicates that the drill body radiated noise increases only very slightly with

increased power input. The noise contribution from the drill steel is a major influence and it is the controlling level during the earlier portions of the tests when the steel is exposed. The slope of the line representing the sound power levels at the start of the tests is steeper than that of the line representing the sound power levels at the end of the tests.

MACHINE-MOUNTED DRILLS

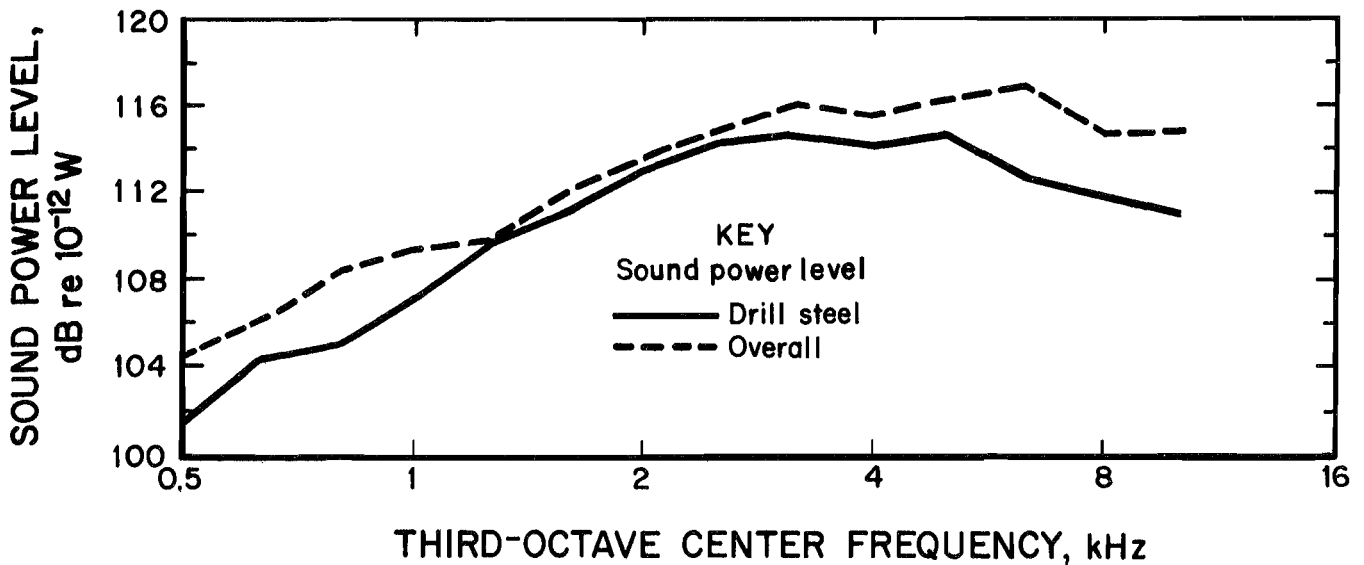
Tests of large hydraulic drills show the same dominance of the drill steel noise in the overall sound power. In these tests, sound intensity techniques were used to determine the contribution of the drill steel noise to the overall sound power level. Figure 4 shows the results of one series of tests that employed a large hydraulic drifter. The two spectral plots show the sound power level from the drill steel and the overall sound power level. As shown in the graph, the drill steel is a major component of the overall sound power level, in the 1.25 to 5 kHz frequency range.

As these data suggest, hydraulic drills are both more efficient from an energy standpoint as well as from a noise standpoint. The data also clearly show the potential for further noise reductions by reducing or eliminating the noise from the drill steel, which is not the case with most pneumatic drills. This can be seen clearly in figure 2. Even though the noise levels are not quite as high near the

end of the test, the dominant source is the same as the one at the beginning, which is the exhaust and drill body radiated noise. A quieted steel would yield noise levels reduced only by the small difference between the two conditions.

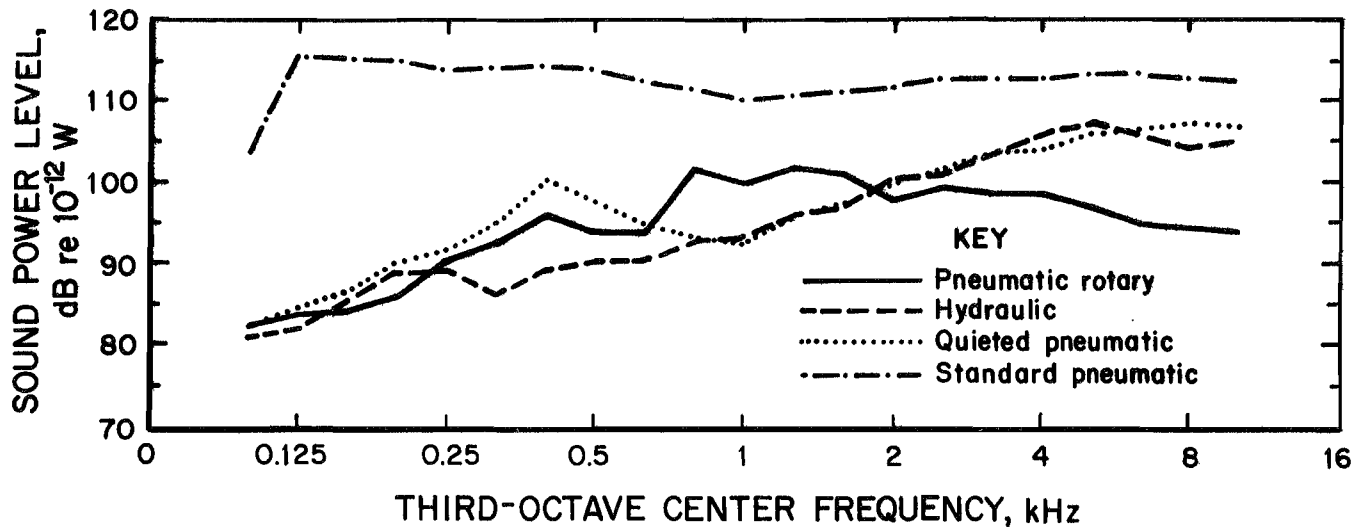
There are pneumatic alternatives in circumstances where a handheld drill is required; testing of reduced-noise pneumatic drills revealed noise levels comparable with their hydraulic counterparts. Figure 5 shows the sound power spectra of four different types of handheld drills. The highest spectrum belongs to a standard pneumatic, handheld percussion drill. The quieted pneumatic percussion drill compares quite favorably in terms of noise output with the two inherently quieter drills (the pneumatic rotary and the hydraulic percussion models) with the advantages of being able to drill much harder rock than the rotary drill and being mechanically simpler than the hydraulic percussion drill. This drill would also benefit from a suitable quiet steel technology.

Figure 4



Overall sound power contribution of drill steel.

Figure 5



Handheld drill comparison.

CONCLUSIONS

Noise control of percussion rock drills is a very difficult problem. Almost any measure taken to reduce the noise is counterproductive to the purpose of the machine. This is especially true of mechanisms designed to provide damping for vibrations. The percussion drill is, after all, a vibratory tool. Mechanisms designed to improve the transfer of energy seem to fare somewhat better. These are at least consistent with the basic concept that is being exploited to perform the desired task. Designs utilizing such mechanisms are also much more readily accepted by manufacturers and end users, which is critically important if there is to be any reduction of noise exposure among drillers.

The results of this study support the increased efficiency approach to reducing the noise exposure from percussion drills. The noise penalty resulting from the use of larger and more powerful drills is disproportionately small in comparison to the increase in power output and drilling speed. By using the larger drill, the drilling that needs

to be done can be accomplished in a shorter time. It requires far less effort on the part of the operator to maintain adequate feed pressure on a machine-mounted drill than on a handheld drill. Inadequate feed pressure increases the noise levels and decreases the drilling rate, a double penalty with regard to noise exposure. With machine-mounted drills there is also more potential for isolating the operator from the drill noise through the use of an acoustically treated cab. These factors combine to reduce the noise exposure of the operator.

The development of quieted steels will also be a major factor in further reducing the noise exposure from percussion drills. The overall sound power levels of hydraulic and quieted pneumatic drills are influenced by the noise from the drill steel. Reducing the amount of noise produced by the steel will be necessary to achieve further overall reductions utilizing the best existing or any improved drill technology.

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