

## DRILLING MACHINES

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### Summary

The principal drilling methods used in mines today are mechanical ones in which a drill drives cutting tools into rock by means of static or dynamic force. Percussion rock drills are the most commonly used equipment for drilling in small-scale surface or underground mining situations, whereas rotary crushing drills or down the hole drills (DTHs) are generally employed for mining in large-scale surface mines.

Recently, many percussion rock drills have been converted from pneumatic operation to hydraulic operation, because of associated gains in efficiency and performance. Moreover, the design and operation of percussion rock drills has been improved based on shock wave theories. The rig weight of percussion rock drills can be made quite light because of the small thrust required, whereas the rig weight of rotary drills strongly influences their ultimate drilling performance.

Different drilling rigs are manufactured and used to meet a variety of drilling requirements. Generally speaking, percussion drilling with top hammers is appropriate for drilling small holes in hard rock, DTHs for large holes in hard rock, and rotary drilling for large holes in soft to medium hard rock.

## **1. Introduction**

### **1.1. Principles of Rock Drilling**

The principal methods of rock drilling used in mines today are mechanical and driven by either impact or simple rotation. Alternative methods, employing heat, flame, high-pressure water, or high voltage electric discharges, for example, are used only in particular situations or in laboratory studies.

The predominant purpose of drilling in mines is to construct blastholes for tunneling or mining, although subsidiary drilling is used to insert rock bolts or cable bolts, or to facilitate exploration or mine drainage.

When drilling in rock, the sharp end of the drilling tool, or bit, is driven into the rock by means of a dynamic (percussion, in which the bit rotates slightly in response to each stroke) or static force (rotation). The material excavated by the bit is stripped out of the hole by shearing as the bit advances. The bit generally has a knife-edge made of steel alloy or an inserted carbide tip, or is composed of multiple round, conical, ballistic, or parabolic button tips made of hard alloy that are inserted into the leading face.

In some cases, the rotary cutting method can be used without percussion in drilling very soft rock such as coal or limestone that contains little silica. However, rocks amenable to this method are relatively rare, and it is consequently not a common drilling approach.

In the rotary crushing method, a three-cone bit similar to that employed in oil well drilling is used. The bit is constructed of three cones covered in variously shaped teeth or buttons that rotate freely like planetary gears and crush the rock as the drilling rig rotates the bit (see *Offshore Drilling and Production Equipment*). Teeth made of steel alloy are used at shallow levels in soft rock, and carbide buttons are used for hard rock. Air is blown through the drill-rod to remove cuttings and to cool the rotation bearings and the bit.

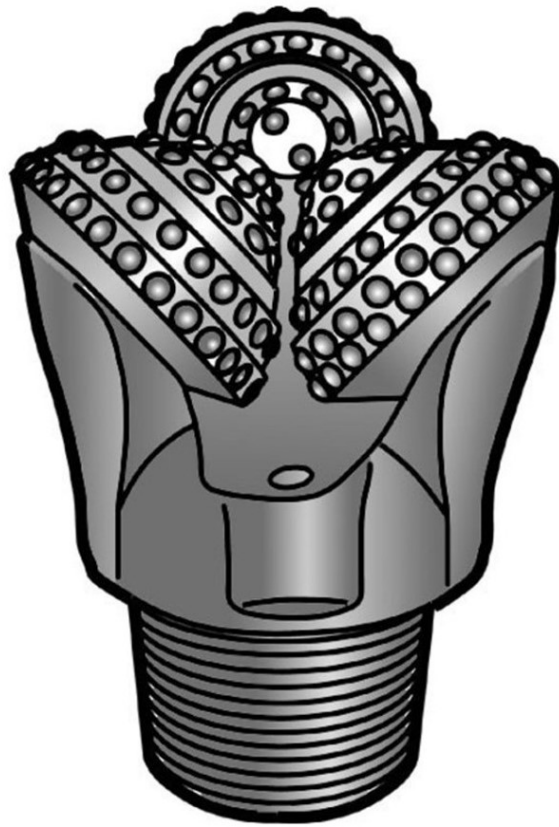


Figure 1: Three-cone bit

With percussion drilling, the bit is driven into the rock by either a top hammer, in which case the drill rods transmit the impact of a blow at the surface, or a “down the hole drill” in which the hammer itself is in the hole and impacts the bit directly.

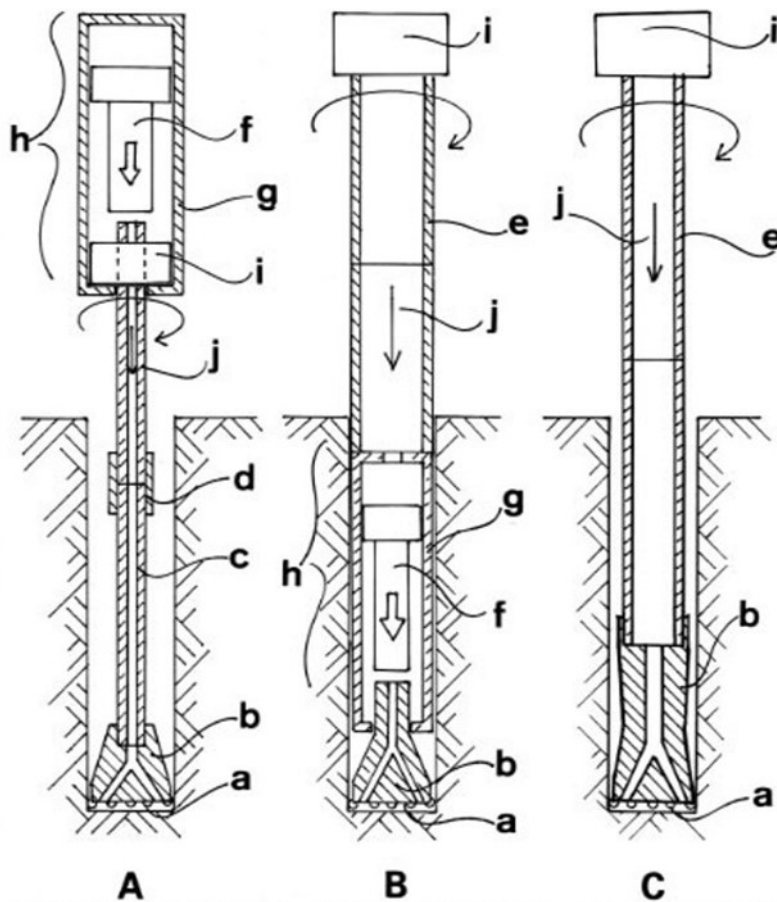


Figure 2: Schematic drawings of three types of drill

A) top hammer, B) DTH, C) simple rotary drill

a) tip, b) bit, c) rod, d) sleeve, e) drill pipe, f) piston, g) cylinder, h) percussion mechanism, i) rotation mechanism, j) flushing

## 1.2. Drill Adaptability

The type of rock drill used in mining drilling is generally determined by the hole diameter required and the mechanical properties, principally hardness, of the rock. A top hammer is commonly employed for drilling of holes less than 125 mm in diameter in all but the hardest rock, although a rotary cutting method may instead be used for soft rock. For hole diameters greater than 125 mm, rotary crushing with a three-cone bit is used in rock weaker than an upper limit that depends on the diameter of the hole, and DTH drilling is used for harder rocks. If rotary drilling is feasible, drilling performance will generally be higher than obtainable with DTHs. In practice, small-diameter drilling is required in underground mining and tunneling, medium-diameter drilling in quarries, and large-diameter drilling in large-scale open pit mining.

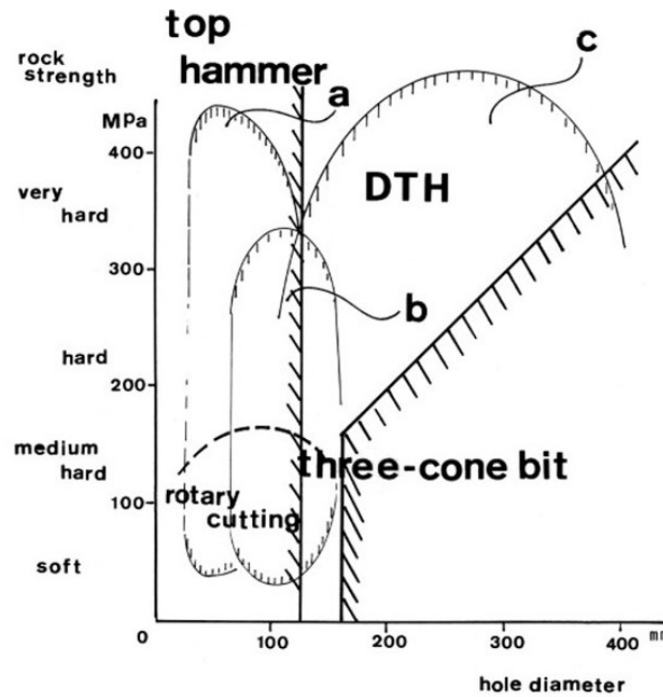


Figure 3: Typical drilling applications  
 a) underground mining and tunneling, b) quarrying, c) strip mining

For large-scale open pit mining, it is common to use rotary drilling rigs equipped with three-cone bits or DTHs to drill blastholes. These tools are mechanically compatible with each other, and make it possible to choose the most efficient method according to the particular rock hardness.

## 2. Construction of Drilling Equipment

The essential components of a drilling system are the rock drill, feed equipment, drilling rods, bit, supports against the drilling reaction, power source, and cuttings disposal equipment. Different drilling rigs are constructed with various combinations of these elements and other accessories for particular drilling purposes.

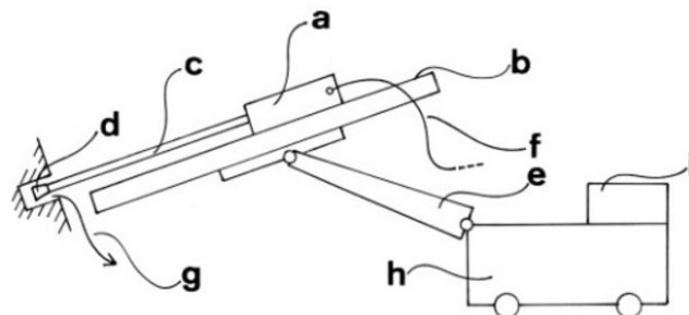


Figure 4: Drilling equipment components  
 a) rock drill, b) feed equipment, c) drilling rod, d) bit, e) support, f) operating media, g) cuttings discharge system, h) carrier, i) accessories

## **2.1. Working Fluid**

Either pneumatic or hydraulic energy is used to power rock drills in most cases. During the last 20 years, most percussion rock drills have been converted from pneumatic to hydraulic operation: in tunneling and construction work, most percussion rock drills are hydraulically driven but a certain number of drills used in mining operations remain pneumatically driven for various reasons. Hand-held rock drills and DTHs are almost invariably pneumatic. Current factors impeding a complete conversion to hydraulic drilling include the remaining lifetimes of existing equipment, maintenance issues, initial costs of conversion, and the risk of duplicate investments.

## **2.2. Thrust and Feed Equipment**

All drilling methods require a feeding system that pushes the drilling tool against the rock, maintains the advance of the bit as drilling progresses, and withdraws the tools once drilling is complete.

A heavy weight or a pneumatic (pusher-) leg is used with hand-held rock drills. For larger mechanized rock drills, whether pneumatic or hydraulic, the feed equipment is designed so that the drill sits on a carriage that travels along a feeder called the guide shell. An alternative system used with light pneumatic drills comprises a screw that is inserted into a nut built into the drill body itself and rotated by a feed motor that drives the drill bit (screw feed).

Most feed systems, however, are either chain or rope feeds. The chain feed incorporates a chain running along the guide shell that is driven by a pneumatic or hydraulic motor via a rotating sprocket. In a rope feed, the expansion and contraction of a hydraulic cylinder is transmitted to the drill via a rope passing through a sheave connected to the feed cylinder body. In hydraulically driven drilling systems, a hose reel is usually attached to the feed equipment.

An anti-jamming feed control for controlling the thrust is indispensable in hydraulic drilling systems, in order to avoid uncontrolled jamming of the bit.

## **2.3. Rotation System**

For percussion rock drills, a mechanism is necessary to rotate the bit between blows and monitor the torque on the bit to avoid jamming. Hydraulic or pneumatic rotation motors are most frequently used to rotate the rod, although small pneumatic rock drills often employ a rifle rotation system, in which the drilling rod is rotated by a piston via a rifle bar without the need for a pneumatic motor.

## **2.4. Drilling Rod**

The role of this element is the transmission of percussion or rotation power to the bit and the removal of cuttings from the bottom of the hole. Consequently, the drilling rod must be hollow in order to transmit fluid carrying the cuttings. When drilling long holes, it is usually necessary to connect a series of drilling rods together via threads; these threads

need to be easily unscrewed to detach the drilling rods, but firmly secured during drilling operation.

In percussion drilling with a top hammer, heat-treated round or hexagonal hollow steel pipes are usually used for the drill rod in order to withstand the high stresses of impact. They are typically 19–51 mm in diameter, and made of high-carbon alloy steel or cement steel,

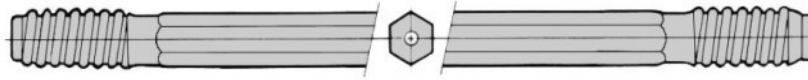


Figure 5: Drilling rod

Rods have male threads on either end and are connected to each other by means of coupling sleeves, which are short pipes tapped with female threads. Long holes are drilled by connecting a series of these rods together.

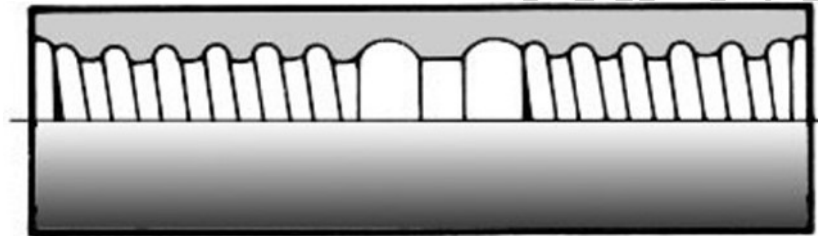


Figure 6: Coupling sleeve

In special circumstances, such as when drilling in rough formation or to prevent hole deviation, alloy steel pipes with large section moduli and diameters are used, so that there is only a small gap between the drilling rod and the hole wall. For rotary and DTH drilling, unlike with impact drilling, the rod needs to transmit primarily rotational energy. To prevent buckling of the drilling rod due to the high thrusts and torques, high-strength carbon steel pipes are typically used. With DTHs, which require large volumes of high-pressure air, pipes of large internal diameter are required to maintain stable drilling pressures.

## 2.5. Cuttings Removal (Flushing)

Compressed air is generally used in surface mining to discharge cuttings from the bottom of the hole, because of its efficiency in long downward-sloping holes and versatility. Care must be taken to ensure that the annular gap between the rod and the hole wall is neither too narrow nor too wide: if the gap is too narrow, it will become clogged with coarse cuttings, whereas if it is too wide the air velocity will be too low to carry the cuttings. In the latter case, the cuttings will be reground at the bottom of the hole, wasting drilling energy. For reasons of health and safety in underground mining, where many short horizontal holes are drilled, water is usually used to flush the cuttings.

Occasionally, detergent drilling is carried out, in which special surfactant agents are

added to flushing water to reduce the volume of fluid required, stabilize the borehole, and suppress dust generation. For similar reasons and to improve cuttings removal, foam generated with compressed air is sometimes used as an alternative.

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### **Biographical Sketch**

#### **H.Watanabe:**

1956-1970: After graduating from the Faculty of Engineering at the University of Tokyo, the author took up the position of mining engineer at Furukawa Co. Ltd., where he was engaged in mine planning, the supervision of workers engaged in underground mining, and the maintenance of mining equipment.

1971-1984: Designed rock drills and rigs, and developed hydraulic rock drills and breakers as the chief of the design section of the Rock Drill Division, Furukawa Co. Ltd.

1982-1989: Served concurrently as a part-time lecturer on pneumatic machines and rock drills at the Department of Mining Engineering, University of Tokyo

1985-1996: Managed the production and development of new rock drill-related products as Assistant General Manager and Associate Director of the Rock Drill Division, Furukawa Co. Ltd.

1989: Awarded a Doctorate of Engineering from the University of Tokyo (thesis title: “Characteristics and Efficiency of Hydraulic Rock Drills and Breakers”).

1997-1999: Engaged in R&D work on tunnel boring machines and giant magnetostriction rock drills as an adviser to Furukawa Co. Ltd.

2000: Retired.