EXOTIC METHODS

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STATE OF THE ART

Research is progressing on more than 30 new methods of disintegrating rock. In these methods, rock is removed by four basic mechanisms:

1. Mechanically induced stresses,
2. Thermal spalling,
3. Fusion, and
4. Chemical reactions.

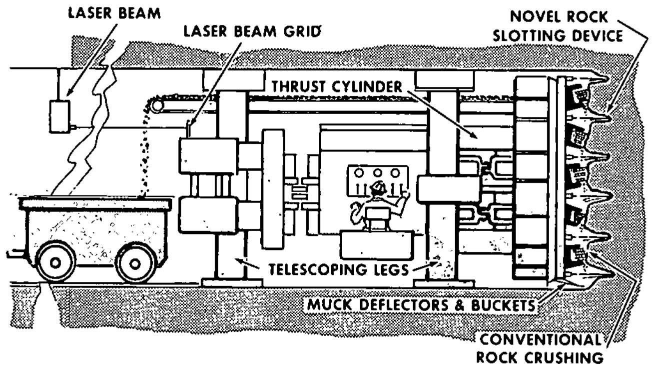
Drills that break the rock by mechanically induced stresses include abrasion, explosion, erosion, implosion, spark, and ultrasonic and high-energy projectiles. Continuous high pressure water jets operating at pressures of 68.9 to 413.7 MPa (10 000 to 60 000 lb/in^2) have demonstrated that they can effectively cut slots or holes in all types of rocks. Water cannons that fire water jets at rocks at high velocities and create stagnation pressures in excess of 6894.8 MPa (1 million lb/in^2) can blow large craters in even the hardest rocks. A 90-mm cannon that fires 3.9-kg (8.5-lb) concrete projectiles at velocities as high as 1524 m/s (5000 ft/sec) has been used to drive a 3.96-m (13-ft) diameter tunnel a distance of 16.8 m (55 ft) into hard granodiorite [172.4-MPa (25 000-lb/in^2) compressive yield strength]. These projectiles remove an average of 1134 kg (2500 lb) of rock per shot.

Devices that thermally spall rocks by heating them to 400 to 600°C include jet piercing, forced flame, electric disintegration, high frequency electric, induction, and microwave drills. These devices have little potential for tunneling because most rocks will not thermally spall.

Devices used to fuse rock at 1000 to 2000°C include electric arcs, plasmas, electron beams, lasers, and a system called Subterrene. These fusion devices could be used to fuse the entire tunnel face because of the high energy requirements for fusing rock. For example, a 6.1-m (20-ft) diameter tunnel machine advancing at 3 m/s (10 ft/h) would require a power output of 123.8 MW (166 000 hp) to fuse the entire tunnel face. Fusion devices could be used to cut slots in the tunnel face, thereby unsupporting the rock to be removed by the mechanical cutters. Experiments have shown that cutting these slots could increase the advancement rate by a factor of 2 or 3 while reducing the thrust requirement on the cutter head. If fusion devices were used to cut a 63.5-mm (0.25-in) kerf around the tunnel face, only 0.42 percent of the rock would have to be fused and the fusion power requirement would decrease to about 5.2 MW (700 hp). Focused heat sources such as lasers or electron beams could possibly cut narrower slots and thereby further reduce power requirements.

Chemical devices that use highly reactive agents such as fluorine have been used to drill sandstone, limestone, and granite. The high cost of the chemicals precludes their use as a primary rock-removal device. Research is progressing on chemicals that weaken rock and reduce the amount of energy required to mechanically break the rock. These chemicals could possibly be used in conjunction with conventional tunnel borers or with other exotic techniques that mechanically break the rock.

An exotic concept for a tunneling machine.



FUTURE RESEARCH

Methods for Joint Use of New and Conventional Devices

Research should be aimed at combining the use of new rock-disintegration devices with conventional disk and roller cutters. These conventional cutters remove rock efficiently, but they are limited in hard rock because of structural strength problems and because of their inability to transmit energy effectively to hard rock. By using new devices to slot the rock and conventional cutters to remove the unsupported rock, the advancement rate of tunnel borers could possibly be increased by a factor of 2 or 3.

Tests of New Devices

Proposed new techniques for cutting slots in the rock are high-pressure water jets (impulse and continuous), lasers, electron beams, and the Subterrene fusion device. These devices should be tested on small-diameter tunneling machines [1.2 to 1.8 m (4 to 6 ft)] to determine their true potential for tunneling.

Tests of High-Energy Impact Devices

Further testing should be done with the high-energy impact devices, both as the primary rock-removal devices and in conjunction with conventional cutters. Novel explosive tunneling techniques should also be tested since they have high power outputs and therefore have high potential advancement rates.

Tests of Fusion Devices

If breakthroughs are made on the power outputs of focused heat sources such as lasers or electron beams, they should be tested on conventional tunnel borers to assist the mechanical cutters. These fusion devices should have power outputs of at least 100 kW in order to be useful on large tunneling machines.