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Allgood

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[54] **TUNNEL EXCAVATION WITH ELECTRICALLY GENERATED SHOCK WAVES**

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[52] **U.S. Cl.** **299/14,** 175/56, 175/404, 241/1, 299/56

[51] **Int. Cl.** **E01g 3/04,** E21c 27/22

[58] **Field of Search** 299/13, 14, 15, 56, 57; 175/55, 56, 404; 241/1

[56] **References Cited**

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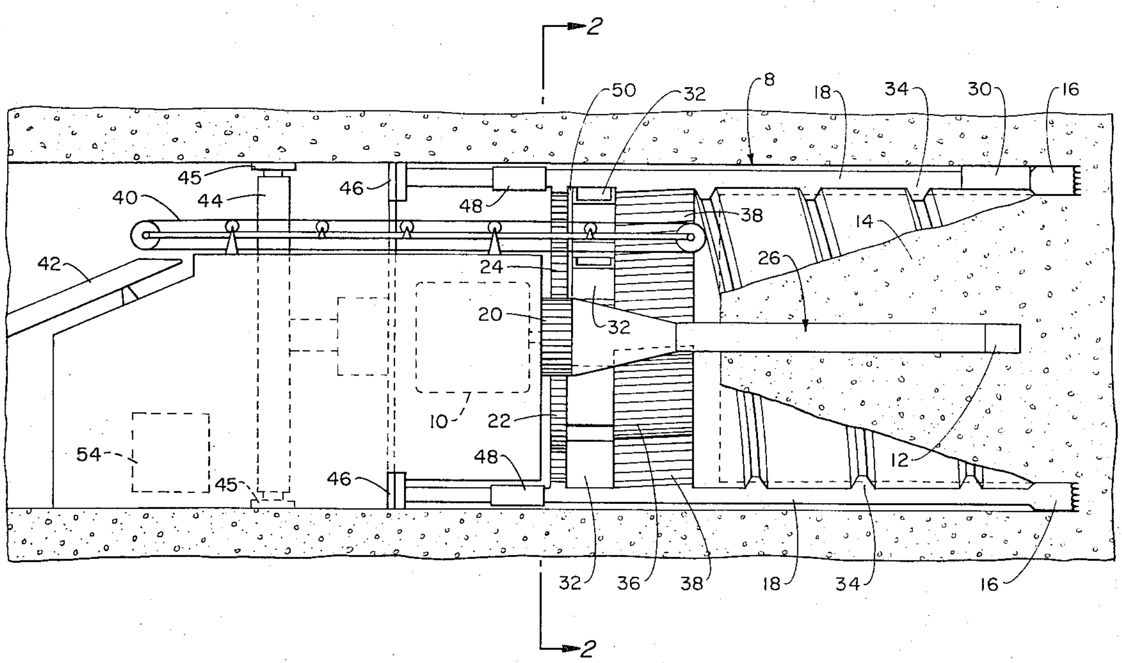
[57] **ABSTRACT**

An apparatus and method for excavating tunnels with electrically generated shock waves. The tunneling apparatus is comprised of a rotatable barrel for cutting a peripheral ring about a core and a bit which simultaneously bores a hole in the center of the core. The drive for the rock bit also contains electrodes which are pulsed to produce shock waves in the core to peel off a desired thickness of rock layer.

4 Claims, 4 Drawing Figures



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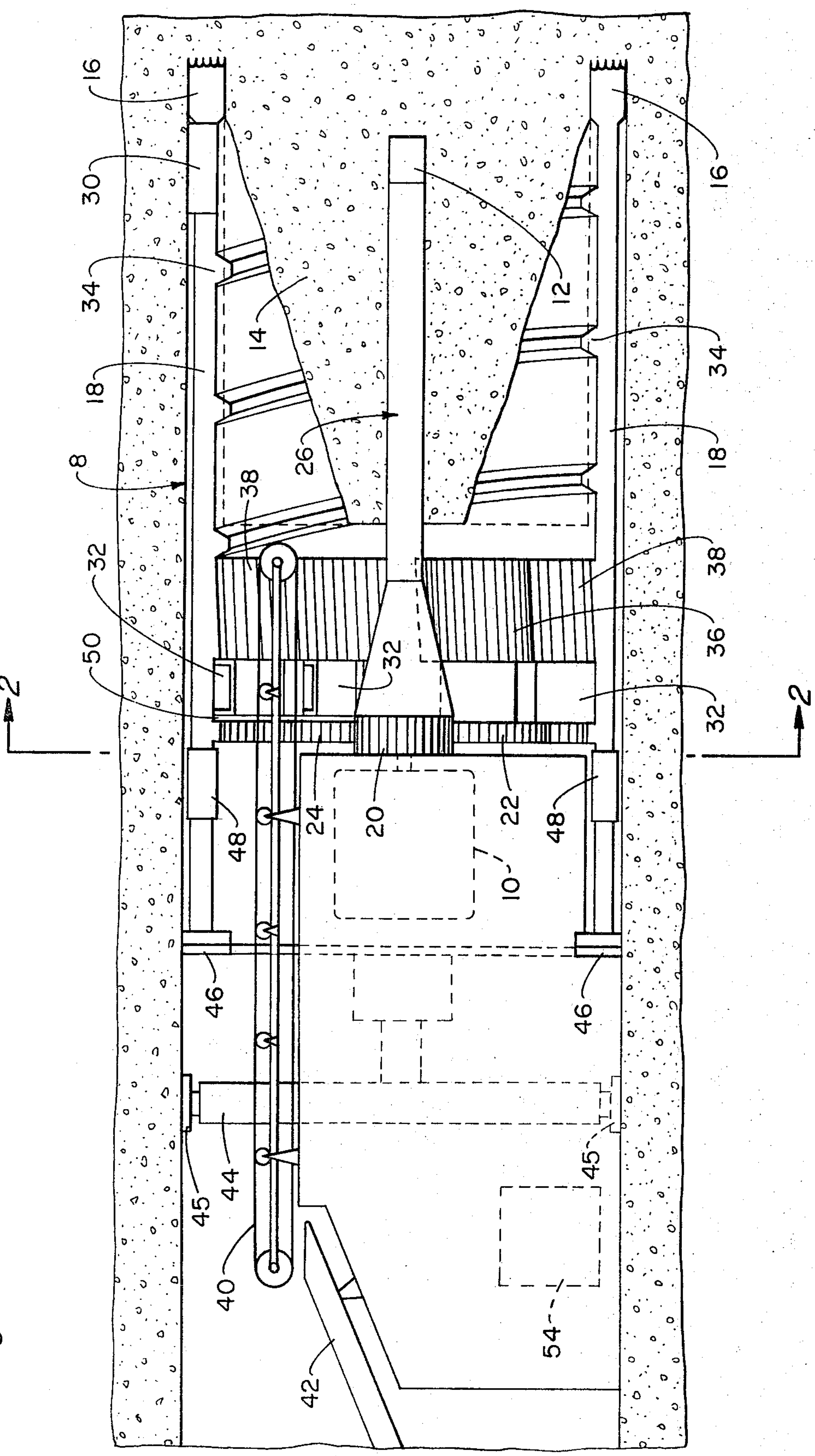


Fig. 1.

Fig. 2.

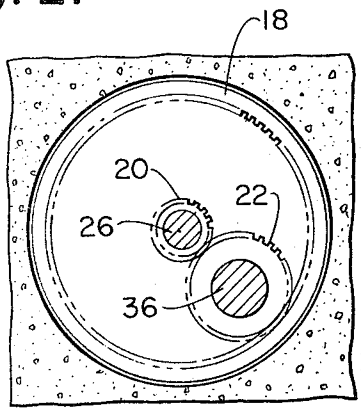


Fig. 3.

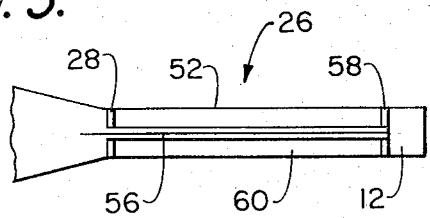
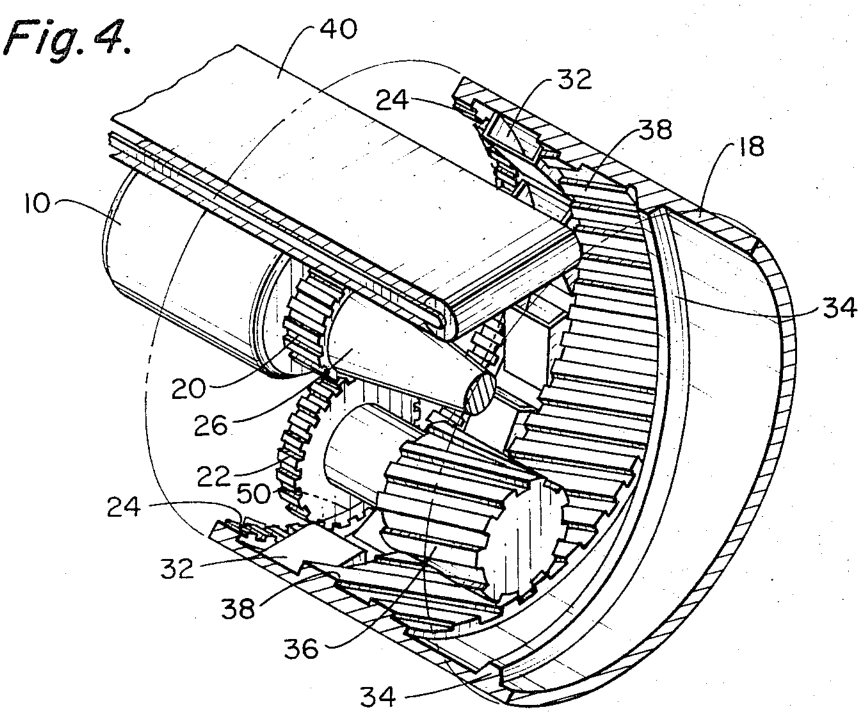


Fig. 4.



TUNNEL EXCAVATION WITH ELECTRICALLY GENERATED SHOCK WAVES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to earth boring devices and particularly to rock boring devices wherein stress waves are utilized for rock disintegration.

2. Description of the Prior Art

Typically, boring machines used to data consist of a rotating head on which is mounted a number of individual bits or cutters. Most of the advances in the art have depended on improvements in such bits and cutters. In effect, these cutters "chew" away the entire face of the opening being excavated. As a consequence, existing boring machines are unnecessarily limited in advance rate and by the maximum strength of rock which can economically be bored. Other investigators and inventors have recognized the deficiencies of existing machines and, with the motivation of a predicted multi-billion dollar market for rock excavation in the next ten yeaars, are developing a variety of schemes for rapid excavation of rock. Most of these schemes are impractical because of their large operating energy requirements. What is needed is a machine which uses less energy and permits greater advance rates than present ones. The present invention achieves this goal.

SUMMARY OF THE INVENTION

This invention is principally concerned with the excavation of tunnels by the disintegration of a trepanned rock core with a train of stress waves. First, a small central hole is bored and a thin perimetrical slot is trepanned at the face of the tunnel. As these operations progress, a train of stress waves is propagated from a pulser in the central hole. As the stress waves reflect from the exterior free surface of the core, successive layers of rock are "peeled" off.

Some of the primary advantages of this invention over prior art devices are:

1. Much less energy is required per unit of excavated material.
2. Only a fraction of the axial thrust is required.
3. Control of the particle size of the muck is possible.
4. Fracture of the walls from high contact pressure of mechanical thrusters is precluded.

These and other advantages accrue from incorporation in the machine of subsystems utilizing present state-of-the-art techniques.

OBJECTS OF THE INVENTION

An object of this invention is to provide a means for rapid and economical excavation of rock.

Another object is to provide apparatus utilizing stress waves for disintegration of rock.

Another object is to provide a method of excavating rock in which apparatus utilizing stress waves is employed.

Still another object is to provide stress wave apparatus for rock disintegration which expends only slight amounts of energy.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of a device incorporating the present invention showing the relation of the central boring device, cutters and stress wave mechanism.

FIG. **2** is a transverse sectional view along the line **2—2** of FIG. **1.**

FIG. **3** is an enlarged schematic view of the shock generator.

FIG.. **4** is a partial sectional view of the barrel and interior thereof showing details of the rock crushing means.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1,** the operation and structure of the invention is as follows. The power unit **10** drives the rotary bit **12,** which bores a hole in the center of the rock core **14.**

A variety of power sources are suitable for use, such as a Synchrogear Motor, manufactured by Emerson Electric Company.

Simultaneously, the core is trepanned by the cutters **16,** attached to the barrel **18,** driven through gears **20** and **22,** the latter of which meshes with a rack **24,** fastened to the barrel intrados. As the rock core **14** is trepanned, periodic cylindrical compression waves of high intensity and very short duration are propagated outward in the core by a pulser **26.** These waves reflect from the outer boundary as tensile waves which exceed the tensile strength of the rock and "peel off" a layer of rock. The thickness of the layer of rock removed is governed by the duration of the stress wave.

An approximate relation for the thickness of rock layer removed from the extrados of the core is expressed by the following equation:

$$t = \eta C f'_{td}/2\sigma\tau$$

where

η = shape factor

C = seismic velocity of the rock

f'_{td} = unconfined tensile strength of the rock

σ = amplitude of the compressional wave as it reaches the extrados

τ = effective duration of the stress wave

From the foregoing equation, it is apparent that the thickness of the layer removed is directly dependent on the duration of the stress pulse. This duration must be of the order of a few microseconds to keep the thickness small enough for easy handling.

As the barrel **18** progresses in the excavation operation, a suitable concrete or other liner is cast around the rock intrados to ensure safety of the equipment.

Grindings which pass outside of the barrel **18** are picked up by bucket **30** and dumped inside through the hole beneath it as the bucket **30** reaches the crown position. Pieces of rock peeled from the core fall to the bottom of the barrel and are transported toward the multiplicity of pick-up buckets **32** by an inwardly extending helical-shaped vane **34.** Enroute the material passes a crusher **36** where any large pieces of rock are broken to a small enough size to be transported in the buckets **32.** In the band of the barrel **18,** which passes under the rock crusher, there are short segments of long pitch helixes **38** (FIG. 4). These segments aid in crushing the rock and in the rapid transport of the broken material into the buckets **32** and, thence, to the conveyor **40**.

The rock crusher **36** is more clearly illustrated in FIG. **4.** The rock crusher **36** may be any conventional type but the roll type, shown in FIG. **4,** manufactured by Universal Crusher Company, Cedar Rapids, Iowa, is preferred. As the rock peeled from the core passes from the helical-shaped vane **34** (FIG. **1**) to the long pitch helixes **38,** any large rocks are crushed into smaller pieces by the meshing of the gears of rock crusher **36.** The crushed rock is then rapidly transported by the long pitch helixes **38** into open ended buckets **32,** which scoop them up as the barrel turns and deposits them on conveyor **40.** Conveyor **40** dumps into chute **42** (FIG. **1**) which may empty into a disposal conveyor system or into mucking cars.

Item **44** is one of two reaction and thruster elements that take the longitudinal load and cause the machine to advance. The thrust is applied through thrust bearings **46** to the barrel **18.** Rollers **48** maintain the alignment and prevent the extrados of the barrel from wearing away as it rotates. The annular rings **50** prevent crushed material from getting under the drive unit.

Several types of thrusters could be used with the Universal excavator. One such thruster is manufactured by the Jarva Inc., Solon, Ohio. Legs **45** (only two of which are shown for the sake of clarity) are clamped and a thrust is applied to thrust bearing **46** by hydraulic thrusters (not shown). After the hydraulic thrusters are fully extended, legs **45** are unclamped and the drive portion (not shown) of the thruster is moved forward. Somewhat different thrusters are available from other manufacturers but they operate on the same principle. The disadvantage of these mechanical and hydraulic thrusters is that they can damage the tunnel walls. Therefore, a polytoroidal thruster, which is the subject of Patent application Ser. No. 353,282, filed Apr. 23, 1973, by Dr. Howard Gaberson, is highly preferred. The polytoroidal thruster operates on the principle of vermicular motion. That is, a series of inflatable bags in the form of a cylinder, which are sequentially inflated and deflated, provide the thrust.

The pulser **26** is comprised of a rock bit **12** and drive **56** for advancing the entire unit. Pulser **26** also contains a controlled pulse shock wave generator, shown in FIG. **3,** which operates by creating an electrical discharge between a cathode **28** and an anode **58** through a fluid **60.** An ideal electrohydraulic pulser unit is manufactured by Environment-One (E–1) Company. The general principle of operation is described in a paper entitled "Electrohydraulics" by W. R. Brown, M. Allen and E. C. Schron, Science Journal, March 1968. In the present concept, the load is transmitted to the rock through a flexible cylindrical diaphragm **52.** The electronics of the system are housed at **54** in the rear of the boring machine **8.** Air is forced down through drive **56** and returns via a parallel path with the grindings from the bore hole produced by rock bit **12.**

Thus, it is clear that only small quantities of the rock face are removed by the bit **12** and the cutters **16;** hence, only a small amount of axial thrust is needed. Furthermore, because the rock is removed in relatively large pieces, considerably less energy is required.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

I claim:

1. A stress wave rock boring device comprising:

a hollow, rotatable barrel having a plurality of cutters positioned peripherally at the forward end of said barrel for trepanning a core;

means for boring a hole in the center of said core;

means for simultaneously driving the barrel and center hole boring means;

said center hole boring means including a controlled-pulse shock wave generator comprising:

a cathode and anode with a fluid positioned therebetween;

means for creating an electrical discharge between the cathode and anode, creating a controlled-pulse shock wave which travels radially outward and reflects from the boundary of the core, thereby peeling off a desired thickness of rock layer.

2. The stress wave boring device of claim **1** wherein the approximate thickness of rock layer removed from the entrados of the core is defined by the following equation:

$$t = \eta \, C \, f'_{td}/2\sigma \, \tau$$

where

η = shape factor

C = seismic velocity of the rock

f'_{td} = unconfined tensile strength of the rock

σ = amplitude of compressional wave as it reaches the extrados

τ = effective duration of stress wave

whereby the thickness of the layer or rock removed is directed dependent on the duration of the stress pulse.

3. The stress wave rock boring device as defined in claim **1** further including a helical-shaped vane mounted on the interior wall of said barrel to force the pieces of rock peeled from said core toward the aft end of said barrel;

a series of spaced buckets mounted near the aft end of said barrel and adapted to transport said rock out of the barrel; and

a conveyor means upon which said rock is placed for further removal of said rock.

4. A stress wave method of removing rock comprising:

cutting a peripheral ring about a core of rock;

boring a center hole in said core;

generating shock waves by applying electrical pulses to electrodes in said center hole to simultaneously produce stress waves of controlled amplitude and duration which travel outward and reflect from the boundary of the core, thereby peeling off a desired thickness of rock layer.

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