Aug. 25, 1970 J. C. COYNE ET AL 3,525,405

GUIDED BURROWING DEVICE

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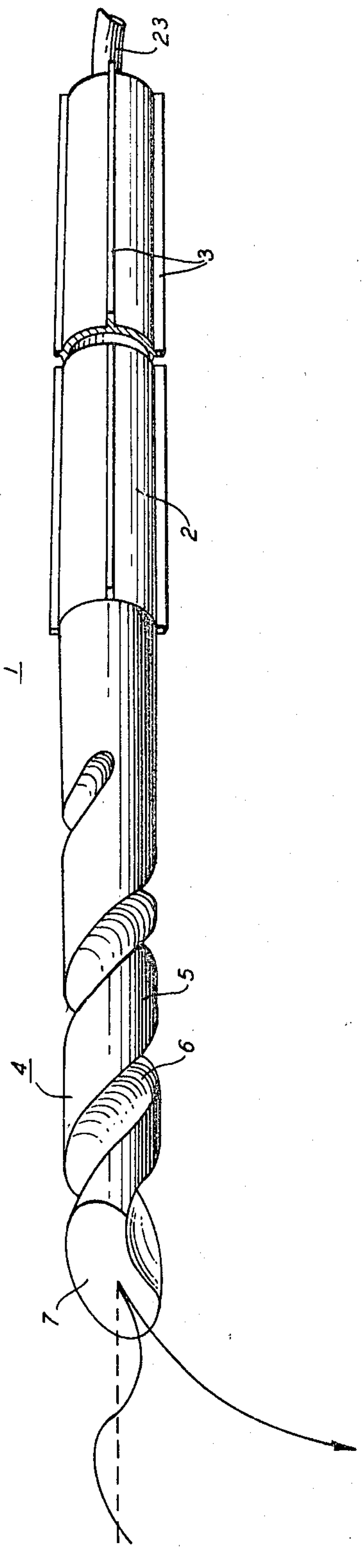

FIG. 1

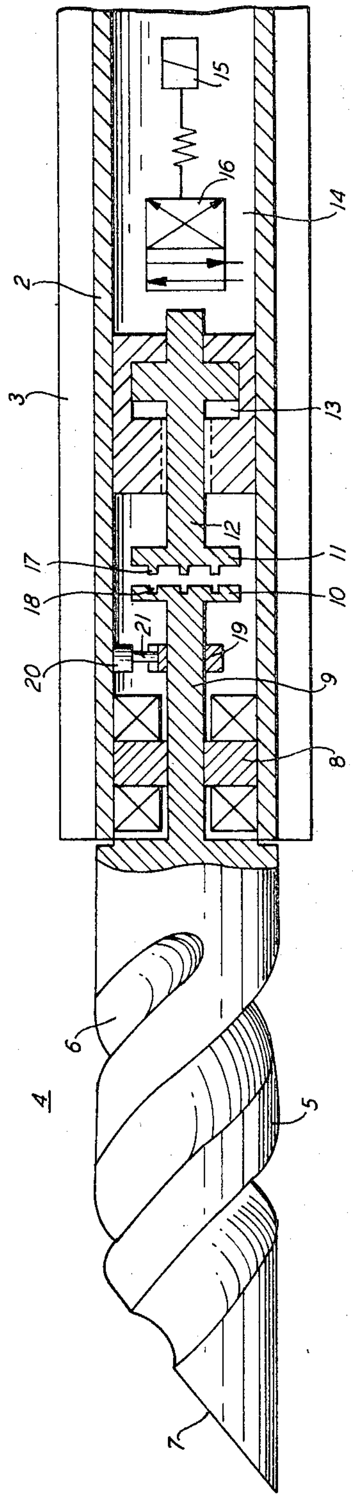

FIG. 2

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FIG. 4

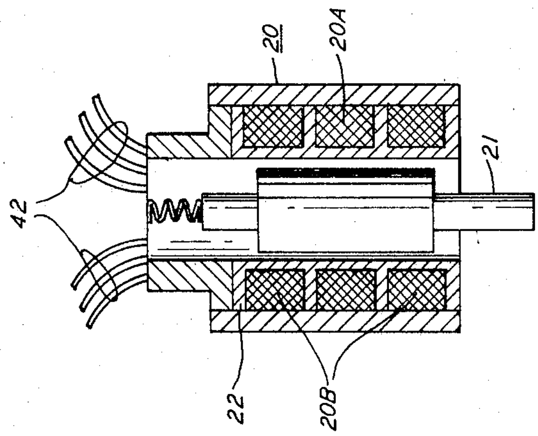
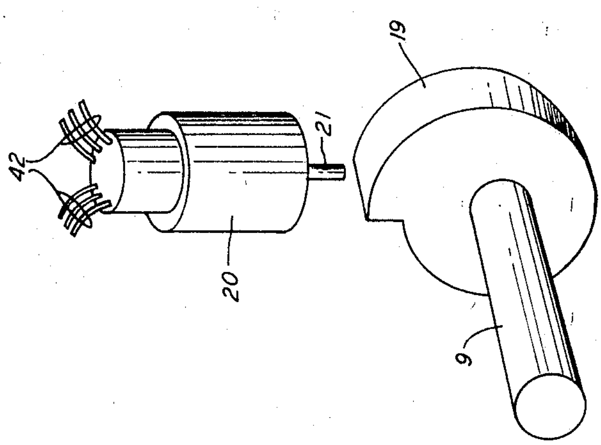


FIG. 3



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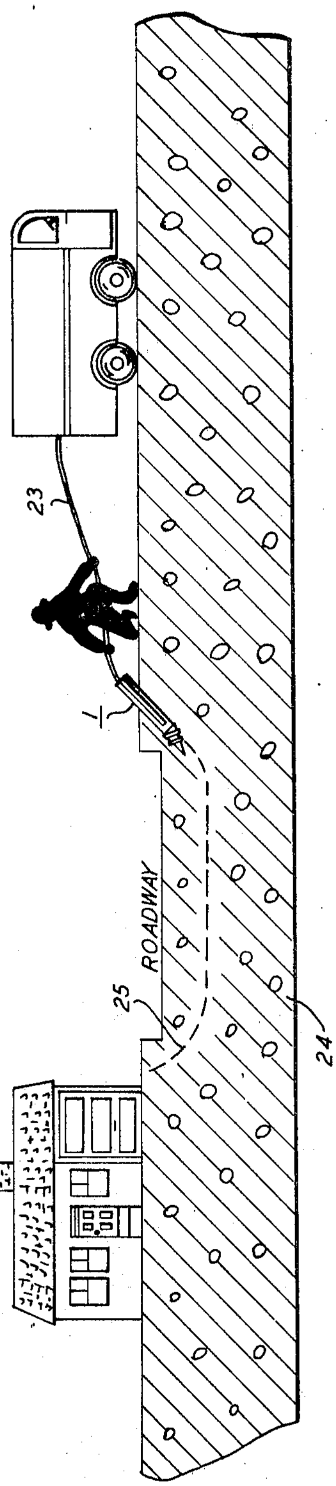

FIG. 5

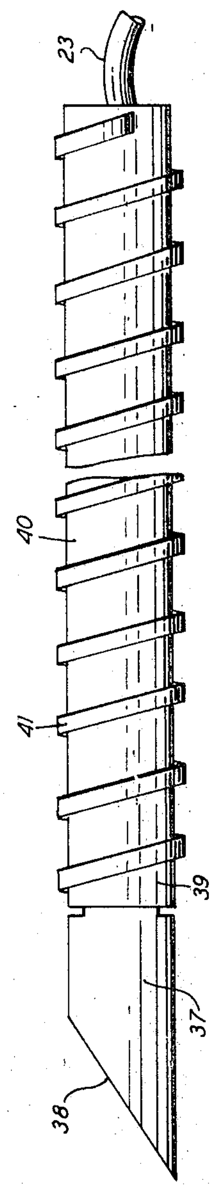

FIG. 11

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FIG. 9

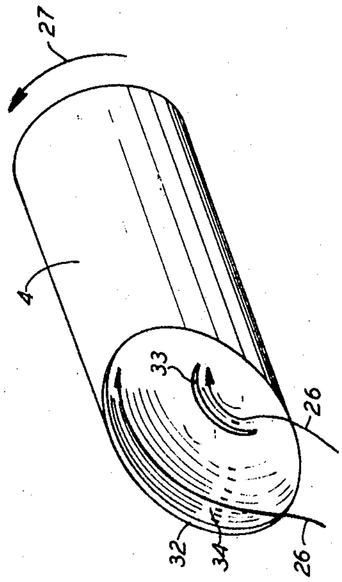


FIG. 10

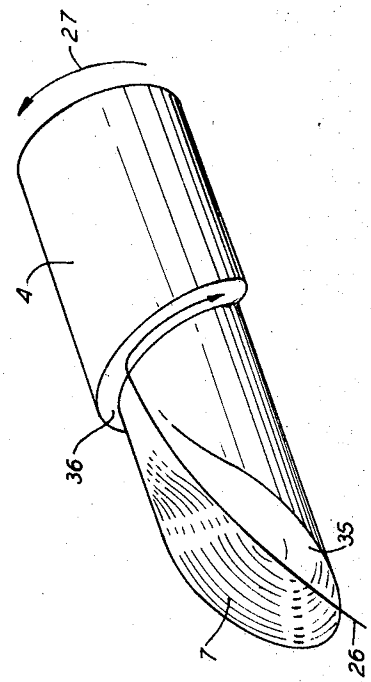


FIG. 6

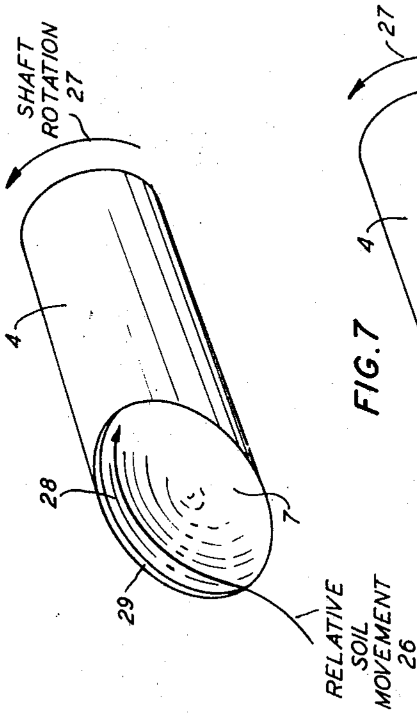


FIG. 7

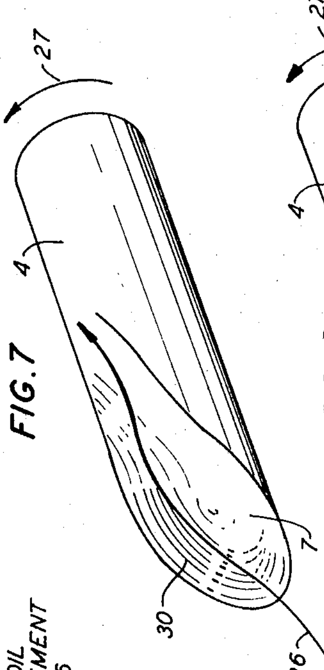
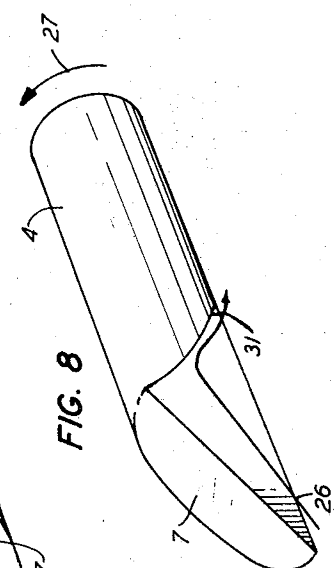


FIG. 8



United States Patent Office

3,525,405
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3,525,405

GUIDED BURROWING DEVICE

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Int. Cl. E21b 7/04, 47/02
U.S. Cl. 175—19 8 Claims

ABSTRACT OF THE DISCLOSURE

A subterranean penetrator or mole for use in burrowing at relatively shallow ground depths is steered by impingement of soil on the planar beveled face of its nose. As the mole advances, the soil impinges on flutes or the equivalent extending from the nose, causing the latter to rotate passively. In such case, the mole motion is a helix that approaches a straight line. Steering is accomplished by locking the nose in a selected position with respect to the nonrotating mole body, as with a clutch mechanism. The soil force component vertical to the nose face then causes the mole to arc in the plane normal to the beveled face and containing the mole's longitudinal axis.

This invention relates generally to subterranean penetrators of the type referred to as "moles;" and more particularly to an improved steering concept for such devices.

BACKGROUND OF THE INVENTION

Subterranean penetrators are of considerable current interest to the electrical power and telephone industries in connection with the installation of underground cable and wire. These penetrators, and especially the guidable moles, offer an alternative to the trenching and plowing techniques now employed which usually severely disrupt normal ground surface activity and often require costly resurfacing work.

The moles are a species of penetrator resembling in some respects a guided missile. Included in the mole proper is propulsion, steering and detection equipment, monitored and controlled from above ground. Examples of specific mole structures may be found in the patent applications of G. A. Reinold, Ser. No. 681,356, filed Nov. 8, 1967 and H. Southworth, Jr. Ser. No. 713,602, filed Mar. 18, 1968, now Pat. No. 3,465,834, both assigned to applicants' assignee.

The present invention is concerned with an improved solution to the mechanical steering of moles in three-dimensional soil.

By way of background, steering systems heretofore known are "active" in the sense that an external surface such as a vane or rudder must be moved against the soil by an actuator to establish a steering attitude. The steering vanes function much like the elevator or rudder of an aircraft. The physical force required to move any control surfaces into soil, however, is enormously large by comparison.

Other problems are also exhibited by present mole steering schemes. These include, for example, the difficulty of steering in near-frozen or highly compacted soil where the required forces are often beyond the capacity of hydraulic actuators. They include as well the initial distance of mole penetration required before the rear-end mounted steering vanes contact the soil and thus become functional. This problem, inherent to rear steering moles, results in a much deeper than necessary vertical penetration of the ground by the mole before it levels out.

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Accordingly, one object of the invention is to more effectively steer subterranean burrowing devices of the mole type.

A specific object of the invention is to substantially reduce the magnitude of forces needed to steer a mole.

An added object of the invention is to reduce the turning radius of a mole.

A further object of the invention is to simplify the mole planting process.

Another specific object of the invention is to more effectively combat the tendency of moles to edge upward toward the soil surface in the course of their travel.

SUMMARY OF THE INVENTION

The invention contemplates a front-steering mole in which the mole's nose is given a beveled face and is mounted for free axial rotation with respect to the mole body. As the mole advances, the soil impinges on spiral flutes or the like connected with the nose's outer surface, causing the nose to rotate. During nose rotation, the mole describes a helical path which with rapid nose rotation approaches a straight line. Steering is accomplished by locking the nose in a selected rotational position with respect to the fixed three-dimensional soil ambient. The soil force component vertical to the now-stationary nose face causes the mole to arc in a plane normal to the beveled face and containing the mole's longitudinal axis.

In an illustrative embodiment of this invention, rotational locking of the nose is achieved by a clutch controlled remotely.

Sensing of the bevel angle with respect to the soil ambient may be achieved as part of the overall guidance system of the mole. Several shapes of nose are specifically cited, with others readily envisionable, for imparting passive rotation to the nose as the mole advances in the soil. The essential elements in these cases are: a bevel or slant face of generally planar proportions, upon which a soil force component normal to the mole longitudinal axis can be developed; and a fixed surface reactive to the impingement of soil thereon to generate the passive rotation. The optimal bevel angle ranges between 30° and 35° as measured from the mole axis. One such reactive surface is a shaft with spiral flutes.

The invention and its further objects, features and advantages are further delineated in connection with the detailed description to follow of an illustration embodiment.

THE DRAWING

FIG. 1 is a perspective side view of a mole embodying the invention;

FIG. 2 is a partial side view in section showing the nose mounting;

FIG. 3 is a schematic perspective view of an angle-sensing means;

FIG. 4 is a sectional side view of the angle-sensing means;

FIG. 5 is a schematic diagram illustrating the invention in use;

FIGS. 6–10 are schematic perspective views of alternanative nose structures; and

FIG. 11 is an alternate embodiment of the invention, shown in side view.

DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

FIG. 1 shows a subterranean penetrator suitable for carrying out the invention. The penetrator or mole, designated **1**, consists of a generally cylindrical propulsion section **2** with several longitudinal stabilizing fins **3** affixed to its exterior, and a forward section **4**. The propulsion system may be of the linear impact type described in the aforementioned patent application Ser. No. 713,602. The fins **3** serve to preclude undue rotation of propulsion section **2**.

STRUCTURE

Forward section **4** is substantially coaxial with section **2** and is mounted for axial rotation with respect to section **2**. In the FIG. 1 embodiment, forward section **4** comprises a shaft **5** with auger flutes **6**. Typically, shaft **5** is eight to twelve inches in length; and propulsion section **2** is five feet in length.

Pursuant to a prime facet of the invention, shaft **5** terminates in a beveled nose **7**. The nose **7** is a planar solid surface intersecting the mole axis at an angle optimally of from 30° to 35°. Forward section **4** is mounted in propulsion section **2** through thrust and journal bearings **8** shown in FIG. 2 in which a shaft extension **9** is normally free to rotate. However, the rotational freedom is arrested by some suitable mechanism such as a clutch which, for example, may include clutch plate **10** mounted on shaft **9** and a second clutch plate **11** mounted upon a nonrotatable piston **12**. Clutch plates **10** and **11** may be of the locking pin type for example.

Piston **12** travels in a hydraulic cylinder **13** which is governed by a control system **14** that includes a solenoid **15** and a directional hydraulic valve **16**. The hydraulic connections between valve **16** and cylinder **13** are conventional and accordingly not shown. Solenoid **15** is powered and remotely controlled through conductors contained in the main control line **23**.

Clutch plate **11** includes a plurality of pins **17**; and clutch plate **10** includes a corresponding number of engagement slots **18** for the pins **17**. When it is desired to allow free rotation of forward section **4**, including its slanted nose, the solenoid **15** is actuated so that the piston **12** is thrust to its rearward position as depicted in FIG. 2. When a locking of section **4** and section **2** is in order, solenoid **15** is operated to cause piston **12** to thrust forward to engage pins **17** into slots **18**. Other clutching and locking arrangements are, of course, readily envisionable by those practiced in the art.

The underlying inventive principle is that the slant-nosed forward section **4** when prevented from rotating with respect to the relatively fixed propulsion section **2**, will steer the mole in an arc. The radius of the arc, depending upon soil, nose bevel angle and mole length and diameter, varies between about 30 and 50 feet. The arc generally lies in a plane that contains the normal to the nose bevel surface and the mole axis. When the forward section **4** is allowed to passively rotate, then the movement of the mole is a helical path which approaches a straight line if the nose is rotating fast enough, i.e., 2 radian per foot of linear advance.

In implementing the inventive steering mechanism, it is of course desirable to detect and monitor the mole's position, heading and roll as well as the relative angular position of the forward rotating section **4** with respect to the nonrotating rear section **2**. The disclosure of Scott et al. Pat. 3,375,885 illustrates one method for steering a mole.

An alternate scheme is to locate the detectors in propulsion section **2** of the mole **1** and to measure the relative angular position of the nose by some independent method. One such method is shown in FIG. 3 and consists of a simple spiral cam **19** rigidly attached to the rotating nose section through shaft extension **9**, a linear variable differential transformer **20** rigidly attached to the mole body, and a spring-loaded cam follower **21** which forms part of the core piece **22** of transformer **20**. The primary winding **20*a*** and secondary winding **20*b*** of transformer **20** are connected through wires **42** to a voltage reading device (not shown) at a monitoring station. Rotation of the cam **19** displaces the core piece **22** and produces a voltage output proportional to core displacement. Other methods of measurement can readily be envisioned.

OPERATION

In contrast to earlier penetrators which require that a trench be dug for their introduction into ground the mole **1** of the present invention advantageously is inserted from ground level into a soil bulk **24** below a roadway, for example, as depicted in FIG. 5. A shallow vertical pilot hole sometimes may be desirable to prime the mole **1** initially. Mole **1** is directed along a path **25** substantially as shown. The benefit of trenchless planting stems from the forward steering feature of the invention which enables the mole to commence steering as soon as fins **3** take hold.

The clutch plates **10, 11** are disengaged to allow free rotation of the forward slanted nose **7**. As the mole **1** is propelled into the ground, the soil engages the flutes **6**, causing nose **7** to rotate. A generally helical path is described by the forward motion of nose **7**. Turns are initiated by engaging clutch plates **10, 11** at a selected attitude of the slant nose **7** with respect to the soil ambient. Linear movement is acheived by disengaging clutch plates **10, 11**. As the mole progresses, it can tow the telephone or electrical cable to be installed in the ground.

Piston **12**, in addition to its translational movement, can be designed to rotate shaft **9** in either direction through clutch plates **10, 11**. This expedient can be implemented in numerous conventional ways, and provides a control over the rotational position of nose **7** with respect to section **2** which is not dependent upon the forward movement of the mole **1**. Such a positive control would, for example, substantially reduce or eliminate the overtravel which the mole occasionally undergoes in the process of orienting the slant nose **7**. With positive control, turns can be initiated or terminated at any point in the mole's travel. Moreover, a powered forward section with flutes or flights can be useful as a secondary propulsion system.

Numerous expedients to impart rotation to the forward section **4** can be envisioned. FIGS. 6 through 10 depict five alternative structures to develop the necessary rotation of a slanted nose such as **7**. In FIGS. 6 through 10, the soil path with respect to the slant face and the rotation-producing mechanism, and the direction of shaft rotation, are designated respectively by the numerals **26** and **27**. Similarly, in each of FIGS. 6 through 10, the numeral **7** denotes the slanted portion of the nose, corresponding to element **7** of the mole in FIG. 1.

In FIG. 6, rotation is imparted to a shaft **4** by a scoop **28** that is built up upon one side of slant nose **7**. A rib **29** in the shape of a semiellipse surrounds this scooped portion **28**. The soil moves in a curved path up and around scoop **28**, imparting an opposite rotation to shaft **4**.

The embodiment of FIG. 7 makes use of a warped or funnel section **30** built up to one side of the slant nose **7**. The soil follows an elongated course through the funnel, causing the desired rotation.

The expedient in the FIG. 8 embodiment involves a scoop **31** below the plane of slant nose **7**. Here the scoop takes the form of a flared snow plow with the soil flow pushing up on the plow. Additionally the net soil force normal to slant nose **7** produces a downward movement applied on the opposite side of the nose. The two movements are additive, and rotation is in the same direction as exhibited in the FIGS. 6 and 7 structures.

In FIG. 9, reliance for rotation is placed upon a pair of ribs **32, 33** between which a scoop **34** is defined. The structure is similar to that of FIG. 6.

Finally, the embodiment in FIG. 10 incorporates a ramp consisting of raised side sections of the slant nose **7**, with the soil being directed up this ramp. At the top, the soil impinges upon an auger flight **36** which causes an opposite rotation to the shaft **4**.

It is apparent that all of the embodiments described for generating the necessary free rotation can be constructed, as it were, in left-hand versions if so desired. In each such case, the rotation is in a direction opposite to the right-hand versions.

A further variation of the basic invention is depicted in FIG. 11. This structure differs from that of FIG. 1 in that the nose rotation is generated not by the forward section but by the mole as a whole. In FIG. 11, a forward section designated **37** includes a slant nose **38** which is similar to the slant nose **7** of FIG. 1. As in the previous versions, the forward section **7** is rotatably mounted in a rear section **40**, and is engaged and disengaged therefrom through a clutch mechanism designated **39**. Clutch **39** can be of the type already described with respect to the FIG. 2 embodiment. The rear section **40** includes auger flights **41** along its outer edge. As the mole advances through the ground, its flights **41** cause the rear section **40** to rotate. If clutch **39** is engaged, the slant nose **38** will also rotate and thus describe a helical path through the ground. Relative rotation-sensing mechanisms of the type earlier referred to are employed to gauge the attitude of slant nose **38**. When it is desired to steer the mole, the clutch **39** is disengaged, allowing the slant nose **38** to stop rotating in unison with the rear section **40**. When a turn is completed, the clutch **39** is reengaged causing the slant nose **38** to commence rotating again. It is, of course, necessary to provide rotatable couplings (not shown) between the rear section **40** and line **23**. This method permits a reduction in length of the front section due to the absence of flutes and the mole becomes steerable immediately upon insertion into the ground.

In addition to the advantages already noted, each embodiment of the invention exhibits a reduced turning radius and a substantially reduced steering power requirement. These benefits arise because the nose bevel which effects the steering is built-in and therefore always available for use without the delays and power expeditures involved with forcing a steering element against the soil. Moreover, the tendency of moles to edge upwardly into the weaker soil regimes is readily countered in the present invention by instituting a delay in the nose rotation in favor of downside bias. Finally, the soil penetration rates during turns of moles equipped in accordance with the invention is greater than earlier moles because the tunnel area of soil being displaced to effect the tunnel is smaller.

It is to be understood that the embodiments described herein are merely illustrative of the principles of the invention. Various modifications may be made thereto by persons skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. Steering apparatus for a subterranean penetrator comprising: a slant-face nose rotatably mounted at the forward end of said penetrator;
- means for continuously rotating said nose during said penetrator's advance;
- means for sensing the rotational position of said slant face with respect to the penetrator proper; and
- means for locking said nose and said penetrator in any selected rotational juxtaposition.

2. A method of steering a mole in a soil ambient comprising the steps of:
- causing a slant-face nose at the mole's forward tip to rotate as the mole advances in the soil; and
- terminating the nose rotation at a selected attitude of the nose with respect to said ambient.

3. A subterranean penetrator comprising:
- a propulsion section;
- a forward section comprising a cylindrical shaft having a common longitudinal axis with said propulsion section, said shaft terminating in a slant-face nose;
- means for mounting said forward section with respect to said propulsion section for rotation about said common axis;
- means for imparting rotation to said forward section;
- soil engaging fins for rotationally stabilizing said propulsion section; and
- means for engaging and disengaging said forward and said propulsion sections in selected rotational juxtapositions.

4. A subterranean penetrator in accordance with claim 3, wherein said rotation-imparting means comprises helical flutes in the surface of said shaft for rotationally reacting to incident soil forces.

5. A subterranean penetrator in accordance with claim 3, wherein said slant-face nose comprises a surface each element of which is disposed to said longitudinal axis by an angle of between 25° and 35°.

6. A subterranean penetrator in accordance with claim 3, wherein said surface is substantially planar and intersects said longitudinal axis at an angle of between 25° and 30°.

7. A subterranean penetrator in accordance with claim 3, wherein said rotation-imparting means comprises soil contacting surfaces which are an integral part of said slant-face nose.

8. A subterranean penetrator in accordance with claim 3, wherein said rotation-imparting means comprises direct drive disposed in said propulsion section and coupled to said forward section.

References Cited

UNITED STATES PATENTS

3,298,449	1/1967	Bachman et al.	175—94 X
3,326,008	6/1967	Baran et al.	175—19 X
3,375,885	5/1968	Scott et al.	175—26

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U.S. Cl. X.R.

175—45, 61, 94