

[54] **SUBTERRANEAN PENETRATOR STEERING SYSTEM UTILIZING FIXED AND ROTATABLE FINS**

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[51] Int. Cl. **E21b 7/08**

[58] Field of Search **175/19, 73, 94, 26, 92**

[56] **References Cited**

UNITED STATES PATENTS

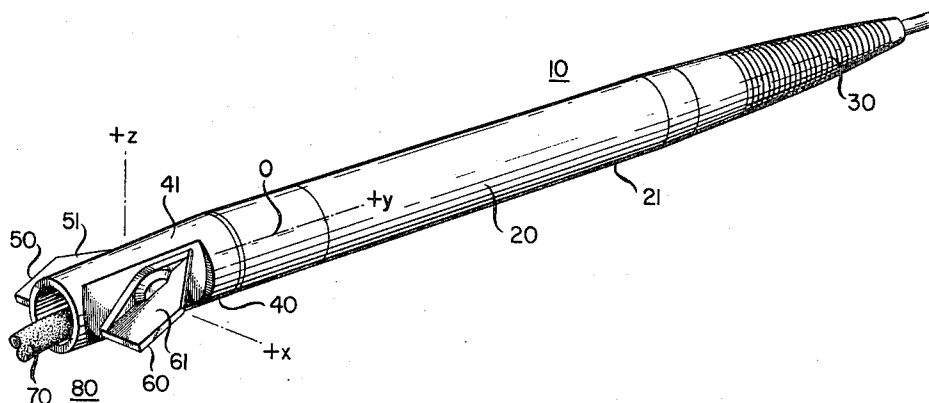
3,375,885	4/1968	Scott et al.	175/94 X
3,465,834	9/1969	Southworth	175/73 X
3,525,405	8/1970	Coyne et al.	175/19
3,589,454	6/1971	Coyne	175/73

Primary Examiner—Ernest R. Purser
Assistant Examiner—Richard E. Favreau
Attorney, Agent, or Firm—C. E. Graves

[57] **ABSTRACT**

A steering system for a subterranean penetrator includes a fixed fin and a rotatable fin. The fixed fin is advantageously attached to the exterior rear portion of the penetrator at an angle of approximately 25° with the penetrator's longitudinal axis. The rotatable fin is located diametrically opposite to the fixed fin, the axis of rotation thereof being perpendicular to and intersecting the penetrator's longitudinal axis. An associated actuating mechanism located within the penetrator adjustably orients the position of the rotatable fin. Rotation of the penetrator about its longitudinal axis is effected when the rotatable fin is antiparallel to the fixed fin or to a lesser degree when the rotatable fin is substantially parallel to the penetrator's long axis. Curvilinear penetrator motion along the desired steering plane is effected when the rotatable fin is parallel to the fixed fin, the axis of rotation of the rotatable fin being perpendicular to this plane. In one embodiment of this invention, the rear portion of the penetrator which houses the fins is inwardly tapered at approximately 4° to allow use of substantially smaller fins and/or produce higher steering rates for a given length penetrator. It is an advantage of this invention that it does not require the articulatable tail and its associated actuating mechanism of prior art subterranean penetrators.

11 Claims, 6 Drawing Figures



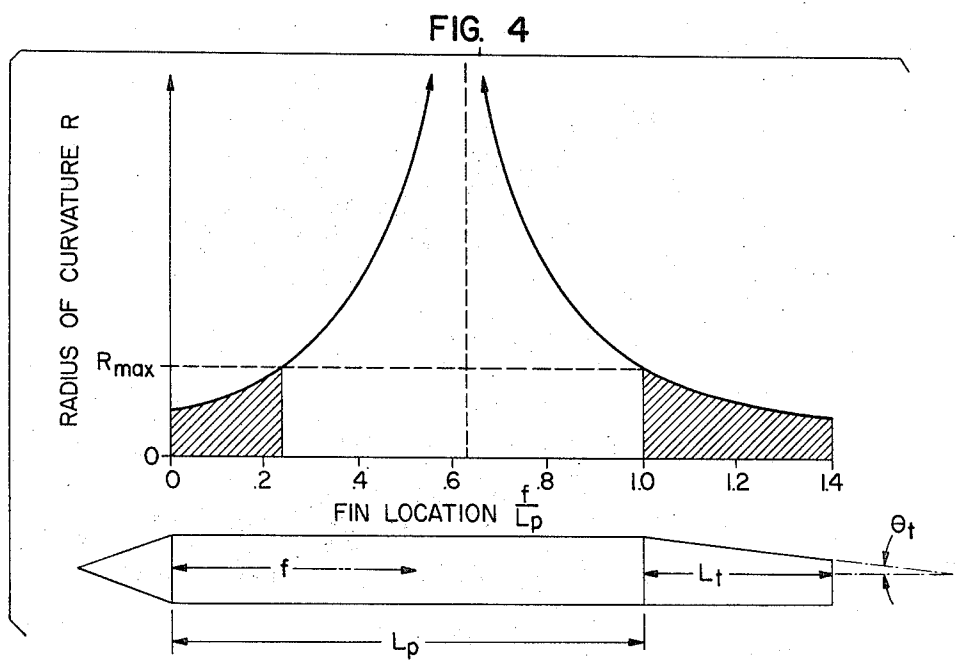
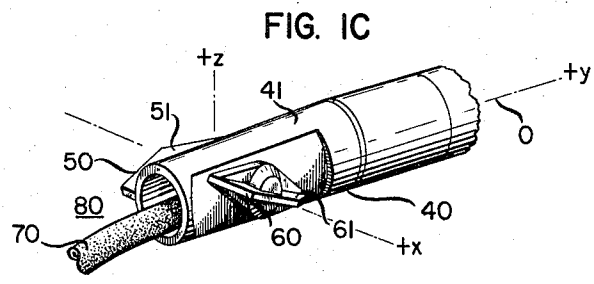
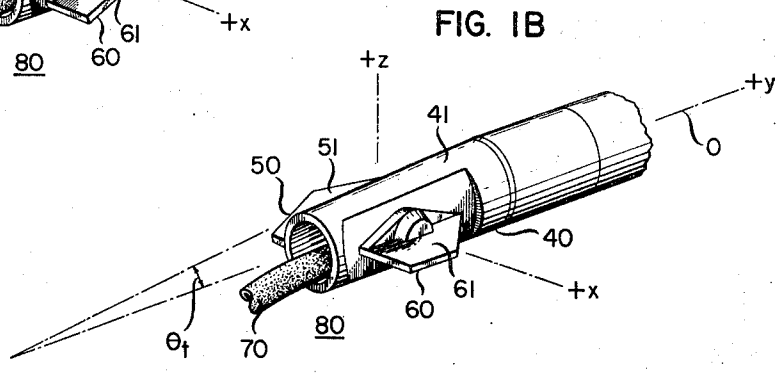
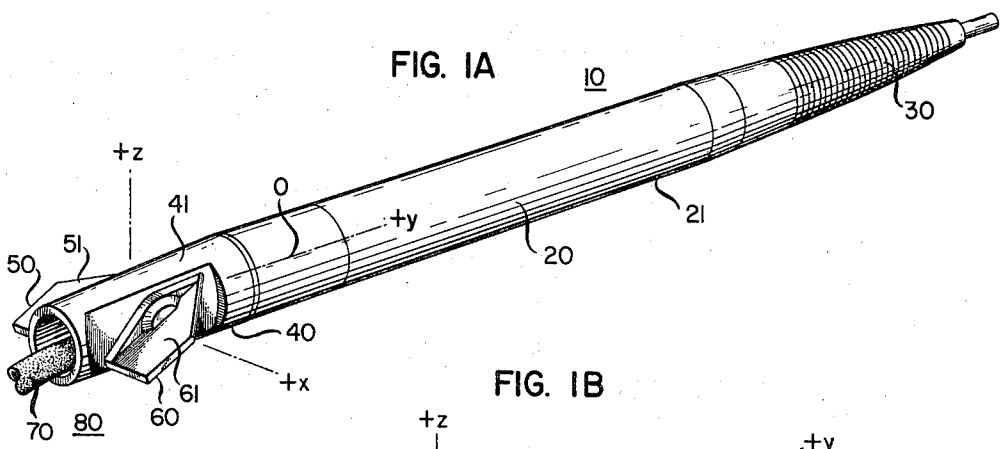


FIG. 3

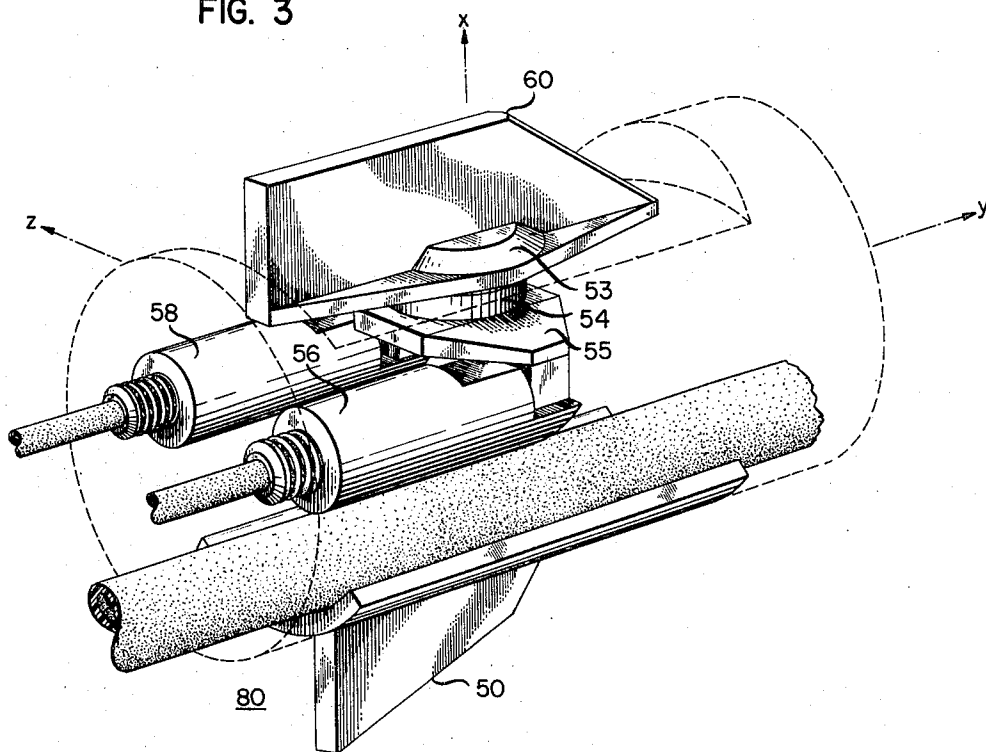
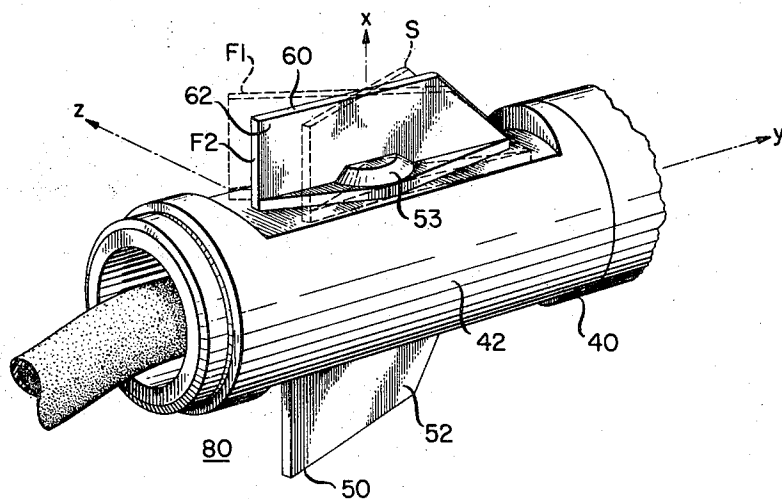


FIG. 2



SUBTERRANEAN PENETRATOR STEERING SYSTEM UTILIZING FIXED AND ROTATABLE FINS

FIELD OF THE INVENTION

This invention relates to subterranean penetrators or "moles" and, in particular, to a steering system therefor.

BACKGROUND OF THE INVENTION

Subterranean penetrators are being utilized to form underground tunnels for the placement of utility services such as telephone or electrical cables. Such subterranean penetrators generally include means for effecting the propulsion, detection, and steering functions. Advantages of subterranean penetrators over prior cable burial methods are increased speed of operation and lack of disruption of the ground surface.

Both hydraulically and pneumatically propelled subterranean penetrators are known. For example, Zinkiewicz U.S. Pat. No. 3,137,483 and Zygmunt U.S. Pat. No. 3,407,884 disclose pneumatically powered subterranean penetrators while Southworth U.S. Pat. No. 3,465,834 discloses a hydraulically driven version.

Several subterranean penetrator steering systems are also well known. One such system includes a tail which is articulatable relative to the penetrator's housing. This system, however, is limited since curvilinear motion could be effected only along one fixed plane. Another type system in which the plane of the articulatable tail can be controlled is disclosed in the above-mentioned Southworth patent, in Reinold U.S. Pat. No. 3,480,098, and in Coyne U.S. Pat. No. 3,589,454. In these systems the tail can be made to assume any desired planar attitude with respect to the penetrator body. Finally, Coyne et al. U.S. Pat. No. 3,525,405 discloses a subterranean penetrator including a planar beveled surface located at the front end of the penetrator housing while Coyne et al. U.S. Pat. No. 3,620,295 discloses a steering system including an articulatable tail having mounted thereon an active fin or fins.

In spite of such numerous prior art steering systems, effecting a practicable realization thereof has been difficult. For example, some of these systems require complex and numerous parts, exotic materials, excessive penetrator length and cross-sectional area, and involved control algorithms. Other numerous problems relating to the control dynamics of subterranean penetrators have also been encountered.

Objects of this invention are therefore to:

- a. provide a subterranean penetrator steering system which is practically realizable;
- b. reduce the weight, length, and complexity of a subterranean penetrator including an associated steering system;
- c. eliminate the need for an articulatable tail of any type and the apparatus required to actuate such a tail;
- d. provide steering capability equivalent to that of prior art systems.

SUMMARY OF THE INVENTION

According to the present invention, a subterranean penetrator steering system includes a fixed fin and a rotatable fin. The fixed fin is attached to the exterior of the penetrator at a positive angle with the penetrator's longitudinal axis. The rotatable fin is located diametri-

cally opposite to the fixed fin, the axis of rotation thereof being perpendicular to and approximately intersecting the penetrator's longitudinal axis. An associated actuating mechanism located within the penetrator adjustably orients the position of the rotatable fin. Curvilinear penetrator motion along the desired steering plane is effected when the rotatable fin is parallel to the fixed fin, the axis of rotation of the rotatable fin being perpendicular to this plane. Forward penetrator motion is effected by either of two modes, superimposed penetrator rotation about its longitudinal axis simultaneously occurring in either case.

According to the first forward mode, the rotatable fin is antiparallel to the fixed fin. In other words, the rotatable fin makes a negative angle with the penetrator's longitudinal axis equal in magnitude to that made by the fixed fin.

According to a second forward mode, the actuating mechanism allows the rotatable fin to be idle, in which case the fin automatically assumes some lesser negative angle with respect to the penetrator's longitudinal axis.

According to a specific embodiment of the invention, the fins are located at the rear of the penetrator, the fixed fin making an angle of approximately 25° with the penetrator's longitudinal axis.

According to a more specific embodiment of the invention, the rear portion of the penetrator which houses the fins is inwardly tapered at approximately 4° to allow use of substantially smaller fins and/or produce higher steering rates for a given length penetrator. In this case, fins are advantageously located as far back along the tapered portion as is physically possible.

Features of this invention are therefore that:

- a. it utilizes a fixed or passive fin and a rotatable or active fin;
- b. the fins are located at the rear of the penetrator;
- c. the fixed fin makes an angle of approximately 25° with the penetrator's longitudinal axis;
- d. the angle made by the fixed fin with the penetrator's longitudinal axis is limited by the slip angle of the soil;
- e. the penetrator's rear portion including the fins is inwardly tapered;
- f. the taper angle at the penetrator's rear portion is approximately 4°;
- g. the rotatable fin's axis approximately intersects and is perpendicular to the penetrator's longitudinal axis;
- h. the fins are placed as far back along the tapered rear portion as possible;
- i. curvilinear penetrator motion along the desired steering plane is effected when the rotatable fin is parallel to the fixed fin, the axis of rotation of the rotatable fin being perpendicular to this plane;
- j. in the first forward mode penetrator motion is effected when the rotatable fin is antiparallel to the fixed fin;
- k. in another forward mode penetrator motion is effected when the rotatable fin is idle, in which case it automatically assumes some angle with respect to the penetrator's longitudinal axis;
- l. the angle made by the fixed fin with the penetrator's longitudinal axis is substantially greater than the taper angle at the penetrator's rear portion;
- m. the angle made by the fixed fin with the penetrator's longitudinal axis and the small taper angle at the

penetrator's rear portion are both measured in the same direction relative to the penetrator's longitudinal axis;

n. forward penetrator motion is accompanied by simultaneous penetrator rotation about its longitudinal axis;

o. it utilizes a fixed fin and a rotatable fin of substantially identical structure to effect both forward and curvilinear penetrator motion;

p. one surface of the fixed fin exclusively makes contact with the oncoming soil;

q. in one forward mode one surface of the rotatable fin exclusively makes contact with the oncoming soil; and

r. in another forward mode both surfaces of the rotatable fin simultaneously make contact with the oncoming soil.

Advantages of this invention are therefore that:

a. additional critical cross-sectional area is provided for the passage of through hoses and electrical cables;

b. it requires fewer and simpler components than do prior art steering systems;

c. the penetrator can be made lighter and its length smaller while providing an equivalent turning radius to that of prior art steering systems;

d. tapering the rear portion of the penetrator allows for smaller fins and/or a smaller turning radius for a given length penetrator; and

e. easier assembly and maintenance.

BRIEF DESCRIPTION OF THE DRAWING

The above and other objects, advantages, and features of the present invention will be better appreciated by a consideration of the following detailed description and the drawing in which:

FIG. 1A is an overall perspective view of a subterranean penetrator in the steering mode, while FIGS. 1B and 1C are partial views of the penetrator in each of two forward modes;

FIG. 2 is a detailed view showing the penetrator's rear portion including the steering system of the present invention;

FIG. 3 is a detailed cross-sectional view showing the steering system's actuating mechanism; and

FIG. 4 shows a graph and an associated outline of the penetrator steering behavior.

DETAILED DESCRIPTION

FIG. 1A is an overall perspective view of a subterranean penetrator and its associated steering system according to the present invention. Subterranean penetrator 10 includes elongated cylindrical housing 20, further including nose portion 30 and rear portion 40. Subterranean penetrator 10 is located in a surrounding soil medium, not shown. Central portion 21 of housing 20 includes a hammer, not shown, which cyclically impacts an anvil, also not shown, located within nose portion 30. Located behind this hammer is a detection package, also not shown. Extending from the rear of penetrator 10 is hose-cable combination 70 which carries both the electrical information and the power required to properly execute the propulsion, detection, and steering functions. The propulsion and detection functions are not part of this invention and therefore will not be further discussed herein.

According to the present invention, steering system 80, which in this case is advantageously located on rear portion 40, further includes fixed fin 50 and rotatable fin 60. These fins are of substantially identical structure. Fixed fin 50 is attached to housing 40 by a well-known mechanical means, not shown.

For explanatory purposes only, a right-handed coordinate system including orthogonal axes X, Y and Z has been superimposed onto rear portion 40 of subterranean penetrator 10. It is apparent that the instantaneous forward direction and longitudinal axis O of penetrator 10 coincide with the Y-axis while the rotation axis of the rotatable fin 60 coincides with the positive X-axis. In FIGS. 1A, 1B, and 1C, the positive Z-axis is directed towards the top of the page. The relative positions of fins 50 and 60 are such that the negative X-axis intersects and passes through fixed fin 50.

According to this invention, fixed fin 50 makes a positive angle θ_f , not shown in the figure, with the positive Y-axis. Angle θ_f which is measured in a counterclockwise manner from the positive Y direction when viewing along the negative X direction, advantageously ranges between 25° and 30° and has a practical upper limit determined by the soil slip angle.

Fixed fin 50 and rotatable fin 60 respectively include upper surfaces 51 and 61. In a similar manner, fins 50 and 60 respectively include lower surfaces 52 and 62, not designated in FIG. 1. These latter surfaces are indicated in FIG. 2.

FIG. 2 is a detailed view showing rear portion 40 and associated steering apparatus 80 according to the present invention. For explanatory purposes, penetrator 10 has been rotated 90° about the Y-axis in a counterclockwise manner when viewing penetrator 10 along the positive Y direction. In this case, therefore, the positive X-axis is directed towards the top of the page. The Y and Z axes are shown accordingly. Shown in this figure are bottom cylindrical surface 42 of rear portion 40 and lower surfaces 52 and 62 of fixed and rotatable fins 50 and 60. Rotatable fin 60 is attached to its associated actuating mechanism at 53, as will be further discussed hereinafter.

According to the present invention, curvilinear motion of penetrator 10 along steering plane Y-Z is effected when rotatable fin 60 is parallel to fixed fin 50. This is designated by position S of rotatable fin 60. In the steering mode, therefore, lower surfaces 52 and 62 of fins 50 and 60, respectively, make contact with the oncoming soil to effect such curvilinear motion. In this mode fin 60 has been rotated in a counterclockwise manner relative to the positive Y-axis when looking along the negative X direction by its associated actuating mechanism, not shown in this figure. Fin 60 therefore makes a positive angle θ_r , not shown in the figure, relative to the positive Y direction which is equal to angle θ_f . It can be stated that the associated actuating mechanism is active or energized. No rotation or slight rotation of penetrator 10 about longitudinal axis O in the counterclockwise direction when viewing along the positive Y direction accompanies such curvilinear motion depending on system activation energy and possible small differences in fin size. See also FIG. 1A.

According to a first forward mode, motion of penetrator 10 along the positive Y direction is effected when rotatable fin 60 is antiparallel to fixed fin 50. See position F1 of fin 60. In this case, rotatable fin 60 makes a negative angle θ_r with respect to the positive

Y direction. Angle θ_r is equal in magnitude to θ_f and again has an upper limit defined by the soil slip angle. During this mode lower surface 52 of fixed fin 50 and upper surface face 61 of rotatable fin 60 make contact with the oncoming soil. Fin 60 has been rotated in a clockwise direction relative to the positive Y-axis by its associated actuating mechanism, not shown. Again, it can be stated that the associated actuating mechanism is active or energized. Also during this mode, uniform clockwise penetrator rotation at a rate R1 degrees/foot about its longitudinal axis O accompanies such forward penetrator motion, when viewing along the positive Y direction. Roll rate R1 is the result of the particular fin structure, fin angle, etc. See also FIG. 1C.

According to a second forward mode, motion of penetrator 10 along the positive Y direction is effected when rotatable fin 60 is idle—i.e., when this fin is not activated or energized by its associated mechanism. In this case, rotatable fin 60 automatically assumes some negative angle relative to the positive Y direction. See position F2 of rotatable fin 60. This, of course, is determined by the particular fin structure, fin angle, etc. As will be apparent to those skilled in the art, both upper and lower surfaces 61 and 62 of rotatable fin 60 make contact with the oncoming soil. In this case, forward motion of penetrator 10 is accompanied by uniform clockwise penetrator rotation at a rate R2 degrees/foot about longitudinal axis O. Rate R2 is somewhat less than the rate R1 mentioned above. Again, lower surface 52 of fixed fin 50 makes contact with the oncoming soil. In this case, as opposed to the steering and first forward modes, the actuating mechanism associated with rotatable fin 60 is de-energized or deactivated as will be further discussed with respect to FIG. 3. This second forward mode therefore allows for a simpler actuating mechanism having fewer components. This therefore results in more critical cross-sectional area being made available for through hoses and electrical cables which are necessary for the propulsion and detection functions. See also FIG. 1B.

FIG. 3 is a detailed cross-sectional view showing the actuating mechanism of steering system 80 used to adjustably orient rotatable fin 60. Again, rear portion 40 is seen from below, in which case the positive X-axis is directed towards the top of the page. As stated before, rotatable fin 60 is attached to its associated actuating mechanism at 53. Attached to rotatable fin 60 at 53 from below is shaft member 54, the center of which coincides with the X direction. Associated with shaft member 54 is lever arm member 55 which provides moment arms between the center of rotation of fin 60 and hydraulic cylinder members 56 and 58. A small hose, not shown, provides actuating pressure to cylinder member 56. Actuation of cylinder member 56 causes counterclockwise rotation of rotatable fin 60 when viewed along the -X direction. This is effected during the steering mode to make rotatable fin 60 parallel to fixed fin 60. A second small hose, also not shown, provides actuating pressure to cylinder member 58. Actuation of cylinder member 58 causes clockwise rotation of fin 60 when viewed along -X direction. This, of course, is effected during the first forward mode to make rotatable fin 60 antiparallel to fixed fin 50.

It will be apparent to those skilled in the art that cylindrical member 58, its associated small hose and lever arm portion, can be eliminated. In such a case, only cy-

lindrical member 56 is utilized to actively rotate fin 60 until it is parallel to fixed fin 50, this corresponding to the above-mentioned second forward mode. Eliminating cylinder member 58 and its associated components provides extra penetrator cross-sectional area for the through hoses and cables leading to the detection and propulsion systems. As mentioned before, rotatable fin 60 will automatically assume some negative angle relative to the positive Y direction. Again, the position assumed by rotatable fin 60 is always accompanied by contact of both fin surfaces with the oncoming soil.

According to the present invention, upper cylindrical surface 41 of rear portion 40 is inwardly tapered in such a manner that surface 41 makes a positive angle θ_r with the positive Y direction. See FIG. 1B. Angle θ_r is advantageously approximately 4 degrees. Having such a taper on rear portion 40 of penetrator 10 eliminates contact of rear portion 40 with the tunnel wall. Such taper allows for substantially improved steering when compared with that provided by a penetrator of the same overall length not having such a taper.

FIG. 4 shows a graph and an associated diagram which are explanatory of steering system behavior. Note that the abscissa of the graph and scale of the diagram correspond one to one. In FIG. 4 the abscissa is f/L_p wherein f is the distance of the fins from the front of the penetrator housing while L_p is the length of the penetrator housing, not including the tapered rear portion. The length of the tapered rear portion is L_t . The ordinate, in turn, is R, the radius of curvature. The graph of FIG. 4 has been analytically derived assuming predetermined fin parameters. It is apparent that steering of a subterranean penetrator according to the present invention can be effected by placing the fins at either the front or rear of the penetrator. It so happens that very little or no steering results when the fins are located along the central portion of the penetrator. If R_{max} is the maximum acceptable turning radius, then the fins must be placed as indicated by the left and right shaded areas. Further, appropriately placing the fins either on the front or the rear results in approximately equivalent turning radii. However, placing the fins on the front is difficult since the hoses would have to lead thereto. In addition, the steering system would be susceptible to unduly high impact stresses due to the impacting anvil. According to the present invention, therefore, placement of the fins along the rear of the penetrator is preferred.

The graph shows qualitatively that a significant reduction in radius of curvature can be realized by locating the fins back on a tapered housing.

While the subterranean penetrator steering system of the present invention has been described in terms of specific embodiments, it will be apparent to those skilled in the art that many modifications are possible within the spirit and scope of the disclosed principle.

What is claimed is:

1. A system for controlling the motion of a subterranean penetrator along a soil medium, said penetrator having a cylindrical housing and said system comprising:

- a first fin fixedly attached to the exterior of said housing, said first fin making a first positive angle with the longitudinal axis of said housing;
- a second fin located diametrically opposite to said first fin and being rotatable relative to said housing, the axis of rotation of said second fin being perpen-

dicular to and approximately intersecting said longitudinal axis; and

actuating means located within said housing for rotatably orienting the position of said second fin;

curvilinear penetrator motion along the plane which is perpendicular to the axis of rotation of said second fin being effected when said second fin is parallel to said first fin; and

forward penetrator motion being effected when said second fin makes a negative angle with said longitudinal axis, superimposed penetrator rotation about said longitudinal axis occurring simultaneously therewith.

2. The system of claim 1 wherein said first positive angle is approximately 25°.

3. The system of claim 1 wherein said first positive angle has a maximum value equal to the slip angle of said soil medium.

4. The system of claim 1 wherein forward penetrator motion is effected when said second fin makes a negative angle with said longitudinal axis equal in magnitude to said first positive angle.

5. The system of claim 1 wherein said second fin is idle, said second fin assuming a small negative angle relative to said longitudinal axis.

6. The system of claim 1 wherein said first and second fins are located at the rear end of said penetrator housing.

7. The system of claim 6 wherein said rear end of the penetrator housing is inwardly tapered at a second positive angle which is substantially less than said first positive angle.

8. The system of claim 7 wherein said second positive angle is approximately 4°.

9. The system of claim 7 wherein said fins are located towards the rear of said tapered rear end.

10. A system for controlling the motion of a subterranean penetrator along a soil medium, said penetrator having a cylindrical housing and said system comprising:

a first fin fixedly attached to the exterior rear portion of said housing, said fin making a first positive angle of approximately 25° with the longitudinal axis of said housing;

a second fin located diametrically opposite to said first fin and being rotatable relative to said housing,

the axis of rotation of said second fin being perpendicular to and approximately intersecting said longitudinal axis, the rear portion of said housing including said first and second fins being tapered at a second positive angle of approximately 4°; and

actuating means located within said tapered rear portion for rotatably orienting the position of said second fin,

curvilinear penetrator motion along the plane which is perpendicular to the axis of rotation of said second fin being effected when said second fin is parallel to said first fin; and

forward penetrator motion being effected when said second fin makes a negative angle with said longitudinal axis equal in magnitude to said first positive angle, uniform penetrator rotation about said longitudinal axis occurring simultaneously therewith.

11. A system for controlling the motion of a subterranean penetrator along a soil medium, said penetrator having a cylindrical housing and said system comprising:

a first fin fixedly attached to the exterior of said housing, said first fin including an upper surface and a lower surface and making a first positive angle with the longitudinal axis of said housing;

a second fin located diametrically opposite to said first fin and being rotatable relative to said housing, said second fin including an upper surface and a lower surface, the axis of rotation of said second fin being perpendicular to and approximately intersecting said longitudinal axis; and

actuating means located within said housing for rotatably orienting the position of said second fin;

curvilinear penetrator motion along the plane which is perpendicular to the axis of rotation of said second fin being effected when the lower surfaces of said fins make contact with the oncoming soil; and

forward penetrator motion being effected when the lower surface of said first fin and at least the upper surface of said second fin make contact with the oncoming soil, superimposed penetrator rotation about said longitudinal axis occurring simultaneously therewith.

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