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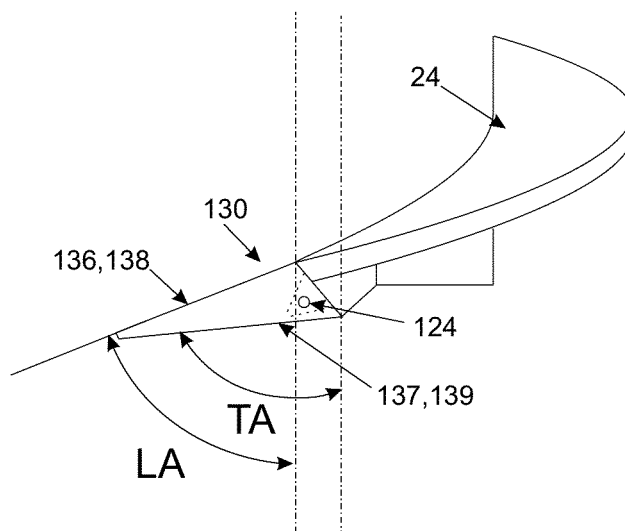
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(54) **NO VIBRATION STONE COLUMN DRILL**

(57) A drill including a drill flight where, the drill is a tubular drill including a drill body which is a tube, such that the drill flight is attached to a body outer surface of the drill body and the body outer surface is the exposed

outer surface of the drill body wherein, the drill body further includes one or more compactors, where each compactor present extends radially from the drill body..



**Fig. 26**

## Description

### Technical Field

**[0001]** The present invention is a drill for forming an in ground granular column or an improvement to such a device.

### Background Art

**[0002]** In ground granular columns of aggregate are used to provide a foundation, improve drainage or stabilise the ground. Some of these columns incorporate a binder such as concrete to improve their stability.

**[0003]** There are a variety of devices used to create these granular columns, one which improves the radial compaction of the wall and vertical compaction of the column is shown in Figure 1. In this variant the drill (1) is a dual concentric drill design with a first drill (2) and a second drill (3). The second drill (3) is inside the first drill (2) during the drilling phase. Once the drill (1) is at full depth the second drill (3) is engaged and extended beyond the terminal end (4) of the first drill (2). The second drill (3) then feeds the granular material from the hopper (5) through a central void in the first drill (2) to the base of the column to be formed. During the formation of the column the rate of withdrawal and granular material feed rate is controlled to compact the granular material. The device shown incorporates an expanded section (7) of the first drill (2) to reduce skin friction during insertion and improve radial compaction of the wall of the hole. Unfortunately this terminally located uniformly expanded section (7) can, unless the operator is skilled, result in increased torque requirements and be problematic in hard ground.

**[0004]** The drill (1) shown in Figure 1 is shown in cross section in Figure 2 to show the engagement mechanism used to drive the second drill (3) relative to the first drill (2).

**[0005]** Figure 3 is an enlarged section of the area circled in Figure 2 which shows the drill shaft (8) of the second drill (3). Equispaced about the circumference of the drill shaft (8) are four pairs of rollers (9), each roller in a pair of rollers (9) is longitudinally separated from the other roller, i.e. each individual roller in a pair of rollers (9) is spaced along the length of the drill shaft (8). Figure 4 shows a top view of the epicyclic gearbox (10) driven by the rotary head of the drilling rig. The ring gear (11) and the first drill (2) rotate together and when the drill shaft (8) of the second drill (3) is engaged with the sun gear (12) then the second drill (3) rotates with the sun gear (12). To allow this engagement the sun gear (12) includes a central tunnel (13). The central tunnel (13) is cross shaped and each arm of the cross is dimensioned to accept a pair of rollers (9). During the drilling of the hole prior to formation of the granular column the sun gear (12) rotates without the second drill (3) rotating. Once the drill (1) is at full depth the pairs of rollers (9) are pushed into the central tunnel (13) so that the sun gear

(12) and second drill (3) rotate at the same time. The wear and damage caused when engaging this four pair of rollers (9) configuration can require significant maintenance, and the skill required by an operator to minimise this damage is high.

**[0006]** Granular columns formed in-situ can suffer from contamination as the drill is rotated and withdrawn, this can compromise the properties of the column formed.

**[0007]** Teeth retained at the end of drill and other earth moving equipment are held in place by keepers, these keepers accept a wide variety of teeth. Unfortunately with the variation in properties between hard and soft ground specific teeth are required to optimise the power requirements and drill efficiency. The requirement for specific teeth for each ground type increases the cost as a full set of each configuration is required on site.

**[0008]** Any discussion of the prior art throughout the specification is not an admission that such prior art is widely known or forms part of the common general knowledge in the field.

**[0009]** The present invention provides an alternative to one or more of the current machines which may overcome one or more of the deficiencies of current or provide a useful choice to a consumer.

### Disclosure of Invention

**[0010]** The present invention provides a drill with a drill flight and a drill body, where the drill body further includes one or more compactors, where each compactor present extends radially from the drill body.

**[0011]** Preferably each compactor present is a minimum of 1m to 3m from the ground terminal end of the drill, where the ground terminal end is the end of the drill configured to enter the ground first.

**[0012]** Preferably each compactor extends, at least partially, between two facing portions of the drill flight (24). Preferably the facing portions are circumferentially separated by between 270° and 360°. In a preferred form one or more compactor is longitudinally aligned with the drill. In a further preferred form one or more compactor is not longitudinally aligned with the drill.

**[0013]** Preferably the distance each compactor present extends radially from the drill body is between 0.1 and 1.2 times the flight height (FH), where the flight height (FH) is the distance between a peripheral edge of the drill flight and the drill body.

**[0014]** Preferably the drill flight has a pitch P, and each compactor present independently extends 0.1 P to 1P along the length of the drill.

**[0015]** Preferably each compactor present is, independently, at an angle of 0° to 90° to the longitudinal axis of the drill.

**[0016]** Preferably at least one compactor present is attached to the drill flight at one end. Preferably at least one compactor present is not attached to the drill flight at either end.

**[0017]** Preferably the drill is a tubular drill including a

drill body which is a tube and the drill flight is attached to a body outer surface of the drill body, where the body outer surface is the exposed outer surface of the drill body.

### Brief Description of Drawings

**[0018]** By way of example only, a preferred embodiment of the present invention is described in detail below with reference to the accompanying drawings, in which:

Figure 1 is a pictorial view of a prior art machine for forming a granular column with an expanded section located at a terminal end;

Figure 2 is a cross sectional view of the prior art drill shown in Figure 1;

Figure 3 is an enlarged view of an engagement section of the shaft of the second drill in the prior art drill shown in Figure 2;

Figure 4 is a top view of the epicyclic gearbox used in the prior art drill shown in Figure 1;

Figure 5 is a side view of the first end of a first variant of the drill;

Figure 6 is a side view of the first end of the drill shown in Figure 5 turned a quarter of a turn clockwise;

Figure 7 is a pictorial view of the first end of the first variant of the drill in use with an 'aggregate bubble', with a portion of the drill sectioned to show the flow of aggregate within the drill body;

Figure 8 is a side view of the first end of a second variant of the drill with a transition zone rather than a transition point;

Figure 9 is a side view of a third variant of the drill which includes an inner feeder;

Figure 10 is a side view of the third variant in use;

Figure 11 is a side view of the third variant in use forming a granular column;

Figure 12 is a side view of a fourth variant which has no change in flight angle for the drill flight but includes compactors;

Figure 13 is a side view of the fourth variant shown in Fig. 12 turned ¼ turn clockwise;

Figure 14 is a cross sectional view of the fourth var-

iant along the line C-C in the direction of arrows;

Figure 15 is a series of views of (i) a compactor aligned with the longitudinal axis of the drill and (ii) a compactor at an angle CA to the longitudinal axis of the drill;

Figure 16 is a series of cross-sectional views (i) to (vi) of the drill body along the line C-C in the direction of the arrows with the drill flight removed but shown as a dashed line for clarity, each with a different configuration of compactors;

Figure 17 is a series of views showing different compactor configurations, with (i) to (vi) being top views and (vii) to (x) being side views of a section of the drill with the compactor attached, views (iv) to (vi) show compactors that are a plurality of sub-compactors;

Figure 18 is a pictorial view of a twin start drill combining the complementary features of the first, second or third variant and the fourth variant forming a compacted wall granular column;

Figure 19 is a pictorial view of a sixth variant which includes a displacement unit and an engagement section with isolation unit;

Figure 20 is an enlarged view of the displacement unit in the sixth variant partially cutaway;

Figure 21 is an enlarged view of the engagement section including the isolation unit separated from the sixth variant;

Figure 22 is a cross sectional view of the alpha gearbox along line C-C in the direction of the arrows;

Figure 23 is a view of the ground terminal end of the drill which is a twin start drill with a keeper attached to the end of each drill flight;

Figure 24 is a side view of an asymmetric tooth viewed from each side;

Figure 25 is an end view of the drill flight with a keeper attached to an asymmetric tooth in a first configuration;

Figure 26 is a side view of the drill flight with a keeper attached to an asymmetric tooth in a first configuration;

- Figure 27 is an end view of the drill flight with a keeper attached to an asymmetric tooth in a second configuration;
- Figure 28 is a side view of the drill flight with a keeper attached to an asymmetric tooth in a second configuration;
- Figure 29 is a side view of the ground terminal end of the drill with a drill tooth shown attached to the drill flight and an additional flight;
- Figure 30 is a side view of the first end of a drill which includes compactors, a transition between a primary flight angle and a secondary flight angle in combination with a drill tooth on each of the flights;
- Figure 31 is a side view of a portion of the drill in partial cross-section where there is a feed conduit present in the feeder;
- Figure 32 is a series of cross-sectional views A1, B1, C1 and D1 showing the formation of a bonded stone column using the hollow feeder variant;
- Figure 33 is a cross-sectional view of a tension element variant;
- Figure 34 is an enlarged section of Figure 34 showing the ground terminal end of the drill with tension element in more detail;
- Figure 35 is a series of cross-sectional pictorial views showing a method of preparing a bonded or un-bonded stone column with a tension device using the fourth embodiment, steps A2, B2 and C2 are shown;
- Figure 35A is a series of cross-sectional views which show the continuation of the method started in Figure 34, steps D2 and F2 are shown;
- Figure 36 is a plan view of a gear unit which includes a sun gear, an engagement unit and engagement bias units;
- Figure 37 is a side view of the sun gear unit with the sun gear shown in cross section along line X-X in Figure 36 in the direction of the arrows;
- Figure 38 is a series of pictorial views ((i), (ii) and (iii)) showing a portion of the feeder or second drill engaging with the sun gear unit;

Figure 39 shows a side view of a drill in partial cross section with the combination of features that are believed to be the best for general applications.

**[0019]** Please note that the drawings are representative only and the relative dimensions may be exaggerated for clarity.

#### 10 DEFINITIONS:

##### [0020]

15 FLIGHT: when used herein this is a strip of material that follows a helical path like a spiral staircase;

OUTER DIAMETER: When referring to objects with a cross section that is not circular this is intended to mean the diameter of a circle scribed by the longest line segment from the centre of the object to the periphery of that object.

PITCH the length of the shortest line segment between similar points on a flight;

30 TUBE: when used herein a tube is meant to indicate a long hollow member whose outer cross-sectional profile may be circular any other shape (triangular, rectangular, hexagonal, octagonal, etc.) and whose inner cavity is circular, or approximately circular/elliptical.

#### 40 FIRST VARIANT

**[0021]** Referring to Fig. 5 and 6 a first end (20) of a twin start drill (21) including a drill body (23), a drill flight (24) and an additional flight (25) is shown. With Figure 6 being the drill (21) shown in Figure 5 turned one quarter turn clockwise.

**[0022]** The first end (20) of the drill (21) is the end of the drill (21) that includes the ground terminal end (26). The ground terminal end (26) is the terminal end of the drill that enters the ground first when drilling commences.

**[0023]** The drill body (23) is a tube which includes a body outer surface (27). The body outer surface (27) is the outer, exposed, surface of the drill body (23) which the drill flights (24,25) are attached to.

**[0024]** The first and second drill flights (24,25) in this first variant are equispaced around the perimeter of the drill body (23), when viewed in cross section.

**[0025]** In this first variant the additional flight (25)

makes only 1/3 turn before terminating, in other configurations the additional flight (25) may be a part turn, many turns or anything in between e.g.  $\frac{1}{4}$ ,  $\frac{1}{3}$ ,  $\frac{1}{2}$ ,  $\frac{2}{3}$ ,  $\frac{3}{4}$ , 1, 1.25, 1.33, 1.5, 1.66, 1.75, n, n.25, n.33, n.5, n.66, n.75 (where n = 2 to 10). It is expected that the additional flight (25) will make n.m.p turns before terminating, where n=0 to 10, m=0 to 9 and p = 0 to 9.

**[0026]** The drill flight (24) has a primary section (28) at a primary flight angle (A1) and a secondary section (29) at a secondary flight angle (A2). Where the flight angle (A1, A2) of the flight (24,25) is the angle between a line perpendicular to the longitudinal axis of the drill body (23) and a line tangential to the flight, this is sometimes called the angle of attack of a flight (24,25). The drill flight (24) starts at a primary flight angle (A1) and transitions to a secondary flight angle (A2) at an angle transition point (30). The angle transition between the primary flight angle (A1) and the secondary flight angle (A2) occurs at a transition distance (TD) from the ground terminal end (26). The primary flight angle (A1) is expected to be from 5° and 35° and the secondary flight angle (A2) from 30° and 70° providing  $A2 \geq A1 + 10^\circ$ .

**[0027]** The transition between the primary flight angle (A1) and secondary flight angle (A2) are shown in Fig. 5 and 6 as a sharp or sudden transition at the angle transition point (30).

**[0028]** The transition distance (TD) is expected to be from 0.2m to 0.6m from the ground terminal end (26).

**[0029]** Referring to Fig. 7 the first end (20) of the drill (21) is shown, in use, with a 'bubble' (33) of aggregate (32) formed around the primary section (28) of the drill (21).

**[0030]** Referring to Fig. 5, Fig. 6 and Fig. 7 the change in flight angle (A1, A2) occurring the transition distance (TD) from the ground terminal end (26) of the drill (21) is believed to trap a 'bubble' of aggregate (32) around the primary section (28) as the aggregate (32) encounters too much friction on the steeper secondary section (29) to move further along the body outer surface (27). This bubble (33) of aggregate (32) reduces or eliminates the contaminants reaching a granular column (34) being formed by the drill (21) as it is withdrawn from the ground.

**[0031]** The first end (20) of the drill (21) is shown in partial cross-section with the drill body cavity (35) and body inner surface (36) revealed. The body inner surface (36) is the exposed inner wall of the drill body (23) which forms the boundary of the drill body cavity (35). The aggregate (32) flows through the drill body cavity (35) and out first end (20) and into the ground/hole formed by the drill (21). The aggregate (32) moves in the direction of the arrows marked a and b. The movement of the aggregate along the length of the drill body cavity (35) may be by gravity, pressurising the aggregate (32) or by conveying it by a mechanical device. The pressurising of the aggregate (32) could be by simply pushing the aggregate (32) into the drill body cavity (35).

**[0032]** During the drilling phase, where the drill (20) is used to form a hole in the ground to the required depth

a blanking device (37) may be present to prevent or minimise the ingress of material into the drill body cavity (35). This blanking device (37) can be any device, a single piece or multi-piece construction, that accomplishes this. In Fig. 7 this blanking device (37) is shown as a single item dislodged and embedded at the base of the 'bubble' (33) of aggregate (32).

## SECOND VARIANT

**[0033]** Referring to Fig. 8 a second variant is shown with a transition zone (38) rather than a transition point (30) (see Fig. 5 or Fig. 6). Where the transition zone (38) is a smooth transition between the primary flight angle (A1) and secondary flight angle (A2). It is expected that this transition zone will extend circumferentially around the drill between 0.05 and 1 times the circumference.

## THIRD VARIANT

**[0034]** Referring to Fig. 9 a third variant of the drill (21) is shown, in this variant a coaxially aligned feeder (40) lies within the drill body cavity (35) to feed material along the length of the drill (21). This feeder (40) is shown as an auger with a feeder flight (41) and a feeder first end (42). With the feeder flight (41) being the flight of the feeder (40) and the feeder first end (42) being the terminal end of the feeder (40) located closest to the ground terminal end (26) of the drill (21). It should be noted that the feeder (40) does not need to be an auger, it can be any device that can be used to feed the aggregate along the length of the drill (21), e.g. bucket conveyor, vibrating rod, etc.

**[0035]** This third variant may have a transition point (30) as shown in the first variant (Fig. 5 to 7) or transition zone (38) as shown in the second variant (see Fig. 8).

**[0036]** Referring to Fig. 10 and Fig. 11 the third variant is shown in use with the feeder (40) having been moved co-axially in relation to the drill body (23) so that the feeder first end (42) is shown extending beyond the ground terminal end (26) of the drill body (23). The feeder (40) is rotated to feed aggregate (32) from the drill body cavity (35) as the drill (21) is withdrawn from the ground towards the ground surface (50) to form a granular column (34). The feed rate of aggregate (32) by the feeder (40) in combination with the withdrawal rate of the drill (21) helps determine the density of the granular column (34) formed. The 'bubble' (33) of aggregate (32) acts to isolate the granular column (34) being formed from being contaminated with contaminants.

**[0037]** The twin start configuration has been found to penetrate the ground better than a single start/flight drill but single or multi start drills have been found to work.

**[0038]** In additional embodiments (not shown) there may be two or more flights not equi-spaced about the perimeter of the drill body (23), when viewed in cross section.

#### FOURTH VARIANT

**[0039]** Referring to Fig. 12 and 13., where Fig. 13 is the drill (21) shown in Fig. 12 rotated ¼ turn clockwise, a fourth variant of the drill (21) is shown. The drill (21) shown is a single start drill which includes:

- a drill flight (24) with an outer diameter of D and a pitch P;
- a drill body (23) with an outer diameter of d;
- a first end (20);
- body outer surface (27); and
- two compactors (60).

**[0040]** The drill body (23), drill flight (24), first end (20) and body outer surface (27) are essentially the same as that described in variants 1 and 2 except the drill flight (24) does not change angle.

**[0041]** The drill flight (24) has a flight height (FH) of  $((D-d)/2)$ , that is the flight height (FH) is the height of the drill flight (24) above the body outer surface (27).

**[0042]** Referring to any one of Fig. 12 to 14, each compactor (60) is a protrusion extending away from the body outer surface (27) in the same direction as the drill flight (24). Each compactor (60) includes a compactor base (61), a compactor first end (63), a compactor second end (64) and a compactor face (65).

**[0043]** The compactor base (61) is the face of the compactor (60) that is attached to (welded, glued, fused, riveted, keyed or held on by nuts & bolts, screws or similar) or coterminous with the body outer surface (27).

**[0044]** The compactor alpha face (65) is the face of the compactor (60) directly opposite the compactor base (61).

**[0045]** The compactor first end (63) is the end of the compactor (60) that is closest to the ground terminal end (26) of the drill (21) and the compactor second end (64) is the end of the compactor (60) furthest from the ground terminal end (26).

**[0046]** Each compactor (60) extends, at least partially, between two facing portions of the drill flight (24), where the facing portions can be rotationally separated by between 270° and 360°. The compactors (60) shown in Fig. 12 to 14 are lengthwise aligned with the longitudinal axis of the drill (21), in other variants they may be angled in relation to the longitudinal axis of the drill (21).

**[0047]** In the fourth variant shown in Fig. 12 to 14 two compactors (60) are present, with one compactor (60), the first compactor (67), co-terminating with the drill flight (24). The remaining compactor (60), the second compactor (68), shown in Fig. 12 and 14 only, terminates without either compactor end (63, 64) contacting the drill flight (24).

**[0048]** The distance, along the longitudinal axis of the

compactor (60,67,68) in question, between the compactor first end (63) and the compactor second end (64) is the compactor length (69).

**[0049]** The length each compactor (60,67,68), from compactor first end (63) to compactor second end (64), extends along the length of the drill (21) is the compactor drill length (70). When the compactor (60,67,68) is aligned with the longitudinal axis of the drill (21) the compactor drill length (70) is the same as the compactor length (69). When a compactor (60,67,68) is angled with relation to the longitudinal axis of the drill (21) then the compactor length (69) is greater than the compactor drill length (70).

**[0050]** Each compactor (60), independently, extends away from the body outer surface (27) between 0.1 FH and 1.2FH.

**[0051]** Referring to Fig. 15(i) and 15(ii) a compactor (60,67,68) is shown at different orientations, separated from the drill (21) (see Fig. 12, 13) with the broken line L-L representing the longitudinal axis of the drill (21).

**[0052]** In Fig. 15(i) the compactor (60,67,68) is longitudinally aligned and the compactor length (69) and the compactor drill length (70) are the same.

**[0053]** In Fig. 15(ii) the compactor (60,67,68) is angled at a compactor angle (CA) in relation to the longitudinal axis L-L and the compactor length (69) is greater than the compactor drill length (70). The angle can be anything from -90° to 90°, with a 0° compactor angle (CA) being that shown in Fig. 15(i).

**[0054]** Referring to Fig. 12 and 13 the distance from the ground terminal end (26) to the first end (63) of the compactor (60,67) located closest to the ground terminal end (26) is the compactor-tip separation (CS).

**[0055]** In use it has been found that using compactors (60,67,68) with a compactor-tip separation (CS) of 1m to 3m rather than a terminally located expanded section (7) of the drill (1) as used in the prior art (see Fig. 1 and 2) that one or more of the following occur an improved wall compression/compaction as the hole is formed and/or better penetration of harder or denser ground material. The compactors (60) have been found to reduce torque build up during the drilling of harder or denser materials, this allows deeper columns and/or denser materials to be drilled successfully.

**[0056]** As shown in Fig. 16 (i) to (vi), which is a cross sectional view of the drill body (23), with the drill flight (21) as a dashed line for clarity, along the line C-C shown in Fig. 12 in the direction of the arrows., additional variants are shown. As shown there can be anything from 1 to 10 compactors (60) circumferentially distributed, symmetrically or asymmetrically, about the body outer surface (27) with each independently having a compactor drill length (70) of between 0.1P and P (see Fig. 12 or 13).

**[0057]** Referring to Fig. 17 (i) to (x) compactors (60) of different shapes are shown, with Fig. 17 (iv) to (vi) showing compactors (60) made up of a series of sub-compactors (71), and Fig. 17(vii) to Fig. 17(x) showing side views of a portion of the drill (21) with the compactor (60) at-

tached.

**[0058]** Fig. 17(i) to 17(x) in more detail show:

- (i) An obround compactor; (60);
- (ii) A tapered compactor (60);
- (iii) An obround compactor with flat compactor alpha face (65);
- (iv) A compactor (60) made up of three circular sub-compactors (71) aligned vertically;
- (v) A compactor (60) consisting of a large obround sub-compactor (71) above a large obround sub-compactor (71);
- (vi) A compactor (60) that includes two sub-compactors (71) one angled in relation to the other;
- (vii) A compactor (60) whose alpha compactor face (65) is angled;
- (viii) A compactor (60) where only a portion of the compactor base (61) is attached to the drill (21);
- (ix) A compactor (60) with a curved alpha compactor face (65);
- (x) An alternative compactor (60) with a curved alpha compactor face (65).

**[0059]** The shape of the compactor (60) can also be any compatible combination of the shapes shown. In some configurations the compactor (60) may be a strip of material, a wiggly strip or any solid geometric shape. Where the compactor (60) is attached to the body outer surface (27) by all or part of the compactor base (61) and/or attached to the drill flight (24) by all or part of the compactor first end (63) and/or attached to the drill flight (24) by all or part of the compactor second end (64).

#### FIFTH VARIANT

**[0060]** Referring to Fig. 18 a fifth variant combining the complementary features of the first, second, or third variant in combination with the fourth variant is shown forming a compacted wall (80) granular column (34). In this variant the compactors (60) form a compacted wall (80) from the spoil created during the drilling operation, this is believed to reduce the frictional effects of the wall of the hole on the drill flight above the compactors (above indicates the drill flight (24) between the compactors (60) and the ground surface (50)). Then, as the drill (21) is withdrawn with the aggregate (32) being fed, the granular column (34) is formed.

**[0061]** The combination of the angle change in the drill flight (24) and the compactors (60) results in the formation of a compacted wall (80) granular column (34) with:

- (a). a reduced contaminant level; and
- (b). a granular column (34) with a greater cross-sectional area;

than a granular column (34) formed by a drill (1) with a terminal expanded section (7) as shown in Fig. 1 or Fig.

2. This sixth variant exhibits the same advantages over the variants incorporating only one or:

- a change in drill flight angle (A1, A2) (see Fig. 6); or
- one or more compactors (60) located some distance from the ground terminal end (26).

**[0062]** As indicated earlier as the flight angle (A1, A2) (see Fig. 6) increases the force required to move the aggregate (32) along the drill flight (24) increases. This is believed to cause the formation of a bubble (32) of aggregate (32) around the primary section (28) which reduces the contaminant level in the granular column (34) formed. The secondary flight angle (A2) and the difference between the primary flight angle (A1) and the secondary flight angle (A2) in combination with the aggregate feed rate and drill (21) withdrawal rate determines the properties of the granular column (34).

#### SIXTH VARIANT

**[0063]** Referring to Fig. 19, and where necessary any of Fig. 20 to 21, a sixth variant similar to the third variant is shown, in this variant a displacement unit (85) as described in WO 2014/091395, that is it incorporates a displacement unit (85) that is engaged when the drill (21) is in use to improve the compaction of a granular column (34) (see Fig. 18) formed.

**[0064]** Referring to Fig. 20 a partial cutaway view of the displacement unit (85) including a guide channel (86) and one or more guidance means (87). The guide channel (86) is a circumferential channel that follows a wave like path, and the guidance means (87) is a device that rides along the guide channel (87) when the displacement unit (85) is engaged. The displacement unit (85) is attached to the feeder (40), where the feeder (40) may be a second drill (88), such that, when in use, it moves the feeder (40) axially with respect to the drill (21).

**[0065]** The feeder (40) includes a feeder shaft (89) and a feeder second end (90) where:

- the feeder shaft (89) is the central shaft of the feeder (40) which has the feeder flight (41) attached; and
- the feeder second end (90) is the terminal end of the feeder (40) opposite the feeder first end (42).

**[0066]** The feeder shaft (89) terminates at the feeder first end (42) and the feeder second end (90). In this sixth variant the feeder second end (90) terminates at the displacement unit (85) so that when the feeder (40) is driven the displacement unit (85) is also engaged.

**[0067]** Referring to Figure 19 and 21 the engagement section (91) of the feeder shaft (89) is shown, this engagement section (91) includes two diametrically opposed drive units (92) where each drive unit (92) is shown as a pair of longitudinally aligned rollers or keys. In other variants there may be a single key rather than a pair of rollers or keys.

**[0068]** The engagement section (91) lies between the drive units (92) and the displacement unit (85). The engagement section (91) includes an isolation unit (93) and the isolation unit (93) includes a connection unit (94) and a bias unit (95). The connection unit (94) is shown as including two connection plates (96) and two sliding units (97) which span a gap between two feeder shaft sub-sections (98,99) of the feeder shaft (89).

**[0069]** Each connection plate (96) includes a longitudinally aligned connection slot (100) which is engaged with one of the sliding units (97). Each connection slot (100) is shown as an obround slot through the respective connection plate (96). Each sliding unit (97) is engaged with one of the connection plates (96) such that in use it can slide along the length of the complementary connection slot (100). Each sliding unit (97) is shown as a bolt but it could be a T-shaped pin, mushroom headed rivet/pin or anything similar.

**[0070]** The bias unit (95) lies between the two feeder shaft sub-sections (98,99) and applies a bias force between the two feeder shaft sub-sections (98,99) to maintain them at a maximum separation distance. The bias unit (95) can be a coil spring, flat spring, pneumatic cylinder, two like poles of a magnet, a combination of these or anything that similarly forces the two feeder shaft sub-sections (98,99) apart.

**[0071]** Referring to Fig. 22 a cross sectional view of an alpha gearbox (110), which is an epicyclic gearbox, is shown. The alpha gearbox (110) includes an alpha sun gear (111) with an engagement channel (112). The alpha sun gear (111) is similar to that shown in Fig.4 but the cross shaped central tunnel (13) is replaced with a pair of diametrically opposed engagement channels (112,113).

**[0072]** Referring to any one of Fig. 19 to 22 the engagement of the feeder (40) will be described.

**[0073]** The drill (21), shown in Fig. 19, or the drilling rig (115) shown in Fig. 1, includes a push unit (116) which is configured to push the drive units (92) into the complementary engagement channel (112,113). As the alignment is unlikely to be optimum the sliding unit (97) slides along complementary connection slot (100) against the bias force applied by the bias unit (95) until the drive units (92) are aligned with the complementary connection slot (100). Once the drive units (92) are aligned with the complementary connection slot (100) they are pushed into those complementary connection slots (100) and the feeder (40) is now rotationally driven by the alpha gearbox (110).

**[0074]** The bias unit (95) allows the connection unit (94) to change length to reduce shock loading and/or reduce damage to the drive units (92) or alpha sun gear (111) as the feeder (40) and/or displacement unit (85) is engaged.

**[0075]** Any of the variants that include a feeder (40) can incorporate the isolation unit (93) to minimise damage when the feeder (40) drive is engaged.

## ASYMMETRIC DRILL TOOTH

**[0076]** Referring to Fig. 23 the ground terminal end (26) of a drill (21) is shown with a standard square based pyramidal keeper (120) attached to the drill flight terminal end (121), where the drill flight terminal end (121) is the end of the drill flight (24) closest to the ground terminal end (26).

**[0077]** The drill shown in Fig. 23 is a multi-start drill thus there is an additional flight (25) shown. The additional flight (25) includes an additional flight terminal end (122) which is the terminal end of the additional flight (25) located closest to the ground terminal end (26).

**[0078]** There is a standard square based pyramidal keeper (120) attached to the additional flight terminal end (122).

**[0079]** For clarity a standard square based pyramidal keeper (120) is a rectangular based pyramid with a vertex, the keeper tip (123), furthest from the respective flight terminal end (121,122). The standard keeper (120) (see Fig. 23) includes an aperture dimensioned to accept a keeper pin (124) (see Fig. 26 or 28).

**[0080]** Referring to Fig. 24 a single drill tooth (130) is shown from both sides, Fig. 24 (i) is the side view from a first side and Fig. 24(ii) is the side view from the opposite side. The drill tooth (130) includes a keeper recess (131), a tooth base (132) and a tooth edge (133). The keeper recess (131) is a recess in the tooth base (132) dimensioned to accept a keeper (120) which includes a keeper recess tip (135). The keeper recess tip (135) is the feature of the keeper recess (131) furthest from the tooth base (132). When the keeper (120) is in use (see Fig. 25 to 28) holding a drill tooth (130) the keeper (120) is within the keeper recess (131), such that the keeper tip (123) is immediately adjacent the keeper recess tip (135).

**[0081]** The tooth edge (133) is the edge of the drill tooth (130) furthest from the tooth base (132).

**[0082]** When viewed side on the drill tooth (130) lies at a tooth angle (AT) to the tooth base (132). Where a tooth angle (AT) is the minimum angle between the tooth base (132) and a line extending from the midpoint of the tooth base (132) and through the tooth edge (133).

**[0083]** The tooth base (132) is the face of the drill tooth (130) that faces the flight terminal end (121,122) of the associated drill flight (24) or additional flight (25) when in use.

**[0084]** The drill tooth (130) further includes a first face (136) and a second face (137) which are each faces adjacent to the tooth base (132).

**[0085]** Referring to Fig. 25 and 26 a drill tooth (130) attached to a drill flight (24) is shown in a first configuration. In the first configuration the first face (136) is the leading face (138) when the drill (21) is forming a hole. In this configuration the second face (137) is the trailing face (139).

**[0086]** Referring to Fig. 27 and Fig. 28 a drill tooth (130) attached to a drill flight (24) is shown in a second configuration. In this second configuration the second face



(137) is the leading face (138) when the drill (21) is forming a hole. In this configuration the first face (136) is the trailing face (139).

**[0087]** The leading face (138) lies on a plane that is at a tooth leading angle (LA), where the tooth leading angle (LA) is the angle between a plane lying on the leading face (138) and a line parallel to the longitudinal axis of the drill (21).

**[0088]** The trailing face (139) lies on a plane that is at a tooth trailing angle (TA), where the tooth trailing angle (TA) is the angle between a plane lying on the trailing face (139) and a line parallel to the longitudinal axis of the drill (21).

**[0089]** Referring to Figure 29 a drill tooth (130) is shown attached to a drill flight (24) and an additional flight (25). In this configuration one drill tooth (130) is shown extending further than outer circumference of the drill (21) and the other less than the circumference of the body inner surface (36) (shown in dashed lines).

**[0090]** Referring to any one of Fig. 25 to 29, in particular Fig. 26 and 28, the drill tooth (130) is dimensioned such that:

- in the first configuration, Fig. 25 and 26, the tooth leading angle (LA) is between 30° and 70°; and
- in the second configuration, Fig. 27 and 28, the tooth leading angle (LA) is between 30° and -30°.

**[0091]** The first configuration is more suitable to harder/denser ground and the second configuration is more suitable for softer/less dense ground. The presence of a tooth improves the formation

**[0092]** Though described with reference to a keeper (120) that is a square based pyramid other standard keeper shapes used to retain drill/excavator teeth are also envisaged.

**[0093]** The asymmetric tooth variant can be used in combination with any of the variants described, or it can be implemented separately.

## SEVENTH VARIANT

**[0094]** Referring to Fig. 30 a drill (21) combining a drill flight (24) with an angle transition point (30) or a transition zone (38) (see Fig. 8), an additional flight (25), compactors (60) and the asymmetric drill tooth (130) shown in Fig. 24 to 29 on each of the flights (24,25) in a first configuration Fig. 30(i) and a second configuration Fig. 30(ii) is shown. Fig. 30(i) shows each drill tooth (130) in a hard/dense ground position, and Fig. 30(ii) shows each drill tooth (130) in the soft/less dense position. In some configurations (not shown) there may be no additional flight (25).

## EIGHTH VARIANT

**[0095]** This variant combines the seventh variant with the features of the sixth variant, with zero to three addi-

tional flights (25) present, and it is believed that this combination will be the optimum in many situations.

## HOLLOW FEEDER VARIANT

**[0096]** Referring to Figure 31 a hollow feeder (40) variant of the drill (21) is shown in partial cross section, omitting any gearboxes or optional components for clarity. In this variant the feeder (40) is a tube that includes a feed conduit (150), where the feed conduit (150) is a void running the majority of the length of the feeder (40) with an alpha end (152) and a beta end (153).

**[0097]** Where the alpha end (152) is close to, or coterminal with the feeder first end (42) and the beta end (153) is located close to or at the feeder second end (90). The alpha end (152) or the beta end (153) may exit through the side of the feeder (40), be coterminal with the feeder first end (42) or feeder second end (90) respectively, or both exit through the side of the feeder (40) and the feeder ends (42,90).

**[0098]** The beta end (153) is fluidly connected to a bond agent conduit (156) which, when in use conveys a bonding agent (157) from a source (158) to the feeder (40). Thus, in the simplest form the feeder (40), in this variant, is simply an open-ended tube.

**[0099]** There may be more than one alpha and beta end (152,153) that are, or include, one or more apertures through a side wall of the feeder (40).

**[0100]** The drill (21) may include blanking devices (37) that are configured to seal the open end of the drill body (23) as the drill (21) is inserted to prevent material contaminating the bonded stone column formed. The blanking devices (37) shown are small pieces of material or a disk releasably attached between the drill body (23) and the feeder (40) that are able to be dislodged when necessary but, the blanking device (37) could be a concrete/metal cone (not shown) or plate that shields the open end of the drill body (23).

**[0101]** In this variant the feeder (40) preferably includes a conduit seal (159) to seal the alpha end (152) as the drill (21) is inserted into the ground, this conduit seal (159) needs to seal against the ingress of material into the feed conduit (150). For example:

a. The conduit seal (159) is a plug of material kept in place within the feed conduit (150), the pressure being increased to dislodge the conduit seal (159) when required.

b. The conduit seal (159) is a flow of fluid through the feed conduit (150) at a sufficient pressure to prevent ground material accessing the feed conduit (150).

c. The conduit seal (159) is a cap over the beta end (152) held in place by a tensioned wire (not shown) as the drill (21) is inserted.

d. The conduit seal (159) is a cap held in place by an adhesive as the drill (21) is inserted, the adhesive being dissolved by a solvent when required.

e. The conduit seal (159) is a cap resting against an annular ring inside the feed conduit (150), the cap is prevented from falling out as the drill (21) is inserted by tack welds or another form of frangible connection (wax, adhesive etc). When the drill (21) reaches the required depth, pressurised fluid is fed into the feed conduit (150) breaking the frangible connection (s) dislodging conduit seal (159) as the drill (21) is withdrawn.

**[0102]** Referring to Figure 32 a method of preparing a bonded stone column (160) using the drill (21) with a hollow feeder (40) will now be described. The method includes the following steps, in order:

Step A1: Insert drill (21) into the ground (170) to the desired depth;

Step B1: Adjust the position of the drill body (23) and feeder (40), if necessary, until the feeder first end (42) is spaced apart from the drill body (23);

Step C1: Dislodge the conduit seal (159), if present, and feed one or more materials (180,181,182) into the drill body cavity (35) to the ground terminal end (26) whilst feeding a bonding agent (157) through the feed conduit (150);

Step D1: Withdraw the drill assembly (2) whilst controlling the feed rate and other parameters of the material or materials (180,181,182) and the bonding agent (157) to form a bonded stone column (190) with the desired characteristics.

Step B1 is optional, but preferred, and the conduit seal (159) may not be present.

**[0103]** In step A1 the drill (21) is inserted into the ground. To prevent any detrimental amount of ground material entering the centre of the drill body cavity (35) the feeder (40) may be rotated, alternatively blanking device/s (37) (shown in Figure 31) may be present that prevent the ground material moving inside the drill body cavity (35) during this step. It should be noted that a detrimental amount of ground material is an amount of ground material sufficient to affect the integrity of the bonded stone column (160) formed. If a conduit seal (159) is present this prevents any detrimental amount of ground material entering the feed conduit (150). If the blanking device (37) is a concrete cone then this should also act as conduit seal (159), in fact it is believed that a unitary conduit seal (159) and blanking device (37) may have advantages over separate devices. Once the drill (21) is at the required depth step B1 is undertaken.

**[0104]** In step B1, when undertaken, the relative vertical positions of the drill body (23) and the feeder (40) is adjusted until the ground terminal end (26) and the feeder first end (42) are spaced apart (vertically displaced). This may be accomplished by moving the feeder (40) further into the ground (170), withdrawing the drill body (23) or a combination of these. If blanking devices (37) are present then these need to be dislodged or removed, for example by a momentary reversal of the feeder (40) before step B1 is undertaken, or dislodged as step B1 is undertaken. The blanking device/s (37) may be retained by a breakable link (a small weld for example), be hinged/pivoted flaps, a combination of these or any other suitable means to prevent the ingress of foreign material into the drill body cavity (35). It is expected that the vertical separation between the ground terminal end (26) and the feeder first end (40) will be from 50mm to 350mm.

**[0105]** The optimum separation distance, if present, is determined by the aggregate size and composition, the diameter of the drill (21) and/or feeder (40), the dimensions of the drill body cavity (35), the configuration of the drill (21) or feeder (40), the properties of the bonding agent/s (157), the characteristics of the bonded stone column (160) required or a combination of these parameters. Once step B1 is completed then step C1 is then actioned

**[0106]** In step C1 the conduit seal (159) is dislodged or removed and then one or more materials (180,181,182) are allowed to pass into the drill body cavity (35) to exit out of the ground terminal end (26). At the same time, if appropriate, a bonding agent (157) is fed through the feed conduit (150) and the feeder (40) rotated to mix the materials with the bonding agent (157) and form the bonded stone column (160) from the mixed material (191). The mixed material (191) is the material (180,181,182) blended with bonding agent (157)). This step will normally require that the feeder (40) is rotationally driven directly or indirectly in the direction that feeds the materials (180,181,182) to the ground terminal end (26) to start forming the bonded stone column (160). The bonding agent (157) is most likely to be grout or a similar known aggregate bonding agent with or without additional additives, the materials (180,181,182) are likely to simply be aggregate that falls within a predetermined size range. The materials (180,181,182) can, for example, be any or all of the following aggregate, cement + water, one or more bonding agents compatible with aggregate, aggregate + bonding agent/cement/water and concrete. Step D1 is then undertaken to form the bonded stone column (160) with the desired characteristics.

**[0107]** In step D1 the one or more materials (180,181,182) are fed to from the ground terminal end (26) whilst the drill (21) is withdrawn at a controlled rate and the feeder (40) is rotated at a controlled rate. At the same time, the required amount of bonding agent (157) is fed through the feed conduit (150) and the feeder (40) rotated to mix the materials (180,181,182) with the bonding agent (157) and force the mixed material (191) out

of the drill (21). By controlling the type and amount of bonding agent (157) mixed with the material (180,181,182) and measuring and controlling various drill (21) parameters a bonded stone column (160) with the desired characteristics can be formed, these characteristics include the density and porosity of the column at any point. The parameters measured and controlled include one or more of rotational speed and direction of the drill (21) or feeder (40), the speed the drill (21) is withdrawn, the feed rate of the drill (21), the drill (21)/feeder (40) torque requirement, materials (180,181,182) feed rate, bonding agent (157) feed rate, etc. By controlling the torque requirements of the feeder (40) and the composition fed to the ground terminal end (35) the radial and vertical compaction of the bonded stone column (160) can be varied. In addition, the penetration of the materials (180,181,182) into the ground (170) surrounding the bonded stone column (160) can be controlled, thus it is possible to form a bonded stone column (160) with specific wall properties.

**[0108]** The drill (21) provides support for the ground (170) as the bonded stone column (160) is formed. With the materials (180,181,182) being forced radially and axially by the rotation of the feeder (40) and drill (21) assisting with the compaction of the surrounding ground (170) and surface of the bonded stone column (160) as it is formed.

**[0109]** The bonded stone columns (160) are expected to have the aggregate present forced out radially forming compressed walls with good ground penetration and require much less, if any, vibration. Though this radially compaction is dependent on the rotational speed and dimensions of the drill (21) and feeder (40).

**[0110]** If the ground terminal end (26) and feeder (40) are spaced apart then this spacing may also be varied as the drill (21) is withdrawn to modify the bonded stone column (160) properties at specific points.

**[0111]** By controlling the composition of the bonded stone column (160) at any point it is possible to create zones in the column which have increased density, increased porosity for drainage at specific levels, or other specific properties. It should also be noted that the aggregate size/composition/structure can be varied by feeding in different materials (180,181,182) at different rates, and varying the type and amount of bonding agent (157) fed through the feed conduit (150) can be varied at the same time.

**[0112]** The hollow feeder variant is intended to be used in combination with a variant including a primary flight angle (A1) and secondary flight angle (A2) (see Fig. 6 or 8) and/or one or more compactors (60) (see Fig. 12 to 18); in combination with any number of other compatible variants described herein.

## TENSION ELEMENT VARIANT

**[0113]** Referring to Fig. 33 and Fig. 34 a further variant similar to the hollow feeder variant in that it includes a

feeder (40) with a feed conduit (150) is shown. This tension element variant includes a releasable tension device (200)

including a tension unit (201) and tension link (202). The tension unit (201) is intended to form part or all of the base of a stone column (34,160) (see Fig. 11 or Fig. 34 for example) formed, possibly extending beyond the side walls of the stone column (34,160) formed. The tension link (202) is intended to link the base of the stone column (34,160) to a structure to reduce or eliminate the effect of uplift on that structure.

**[0114]** The tension device (200) includes a tension unit (201) and a tension link (202). The tension unit (201) is shown as a flat disk extending across the ground terminal end (26) effectively sealing the open end of the body drill (23) and feeder (40), however, it may extend beyond the edge of the drill (21).

**[0115]** The tension unit (201) may be a plate of any shape (circular, elliptical, triangular, rectangular or any other polygonal shape), or even a three-dimensional object such as a cone, pyramid (truncated or not), portion of a sphere or ellipsoid, or similar. The tension unit (201) may extend beyond the edges of the drill body (23), or be combined with at least one blanking device (157) to seal the ground terminal end (26).

**[0116]** The tension link (202) is shown as a rod or solid wire that lies at least partially within the feed conduit (150). The tension link (202) is shown attached to and extending from the tension unit (150) to a point beyond the feeder second end (90). The tension link (202) is expected to be a rod, chain, wire (solid or stranded) or a combination of these. The tension link (202) may include additional surface features such as, ribs or rings (helical, linear or circumferential, continuous or broken) that are configured to engage with the material (180,181,182) of a stone column (34,160) as it is formed.

**[0117]** In some variants the tension unit (201) extends beyond the outside of the drill body (23), in others it may not completely close the drill body cavity (35). In the latter case this may require the use of blanking devices (157) to prevent unwanted material from entering the drill body cavity (35) or feed conduit (150). The size of the tension unit (201) will determine the uplift overcome and as such it can be sized for specific purposes. In some configurations there may be features incorporated into the tension unit (201) to allow it to be driven by the drill (21) or feeder (40), for example teeth, keys, keyways, slots, notches, or combinations of these, these features may disengage automatically as the stone column, bonded or not, is formed. As the blanking devices (157) are optional they are not shown in Figure 35 or Fig. 35A.

**[0118]** The tension unit (201) can be releasably attached to one or more of the following: the ground terminal end (26), the drill body (23), the feeder first end (42) or any other feature of the drill (21) by any suitable releasably connection

type known including keyway, threaded section, magnetically, pneumatic connection, frangible connection, fric-

tion, dissolvable bonding agent or combination of these. The tension unit (201) can also be held in place by tension in the tension link (202).

**[0119]** Referring to 35 and Fig. 35A an alternative method of forming a bonded or un-bonded stone column (34,160) is provided. In this variant a bonded stone column (160) is formed with an integrated tension device (200) to counter or reduce the effect of uplift.

**[0120]** In more detail this variant method for the fourth embodiment includes, with some steps optional (B2 and F2 for example) or the same as for the hollow feeder variant method of use thus they are omitted for clarity (E3 for example):

Step A2: Insert the drill (21) into the ground (170) to the desired depth;

Step B2: Adjust the position of the ground terminal end (26) and feeder (40), if necessary, until the ground terminal end (26) and the tension unit (202) are spaced apart;

Step C2: Dislodge the tension unit from the feeder (40)/ feed conduit (150), if necessary, and feed one or more materials (180,181,182) through the drill body cavity (35) to the ground terminal end (26);

Step D2: Withdraw the drill (21) whilst controlling the feed rate and other parameters of the material or materials (180,181,182), similar to step D2. For example, bonding agent (157) may also be fed through the feed conduit (150);

Step F2: The tension link (202) is connected to the structure (210) and, at the appropriate time, may be tensioned to the required level. This depends on the building code requirements and the materials used,

**[0121]** Step A2 is similar to step A, A1 or A2, as it involves inserting the drill (21) into the ground (170) until it is at the desired depth. The tension unit (201) acting alone or in combination with other features (blanking devices (37)) to minimise the ingress of undesirable material into the drill body cavity (35) and/or, where present, the feed conduit (150). Step B2 or step C2 is then undertaken.

**[0122]** Step B2 is optional, though if present in this step the tension device (200) is released from the ground terminal end (26) and remains releasably attached to the feeder (40) as the ground terminal end (26) and feeder (40) are vertically spaced apart by moving the drill body (23) and /or the feeder (40). It should be noted that releasing the tension device (200) may be accomplished by releasing the tension unit (201). Once the ground terminal end (26) and feeder (40) are at the desired spacing step C2 is undertaken. If blanking devices (37) are present then they may be dislodged in this step or any following step.

**[0123]** Step C2 involves releasing the tension unit (201) from the drill (21) and/or feeder (40), dislodging or releasing any blanking device/s (37) that is/are present and feed one or more materials (180,181,182) and/or bonding agent (157) as required to start the formation of a bonded stone column (160), then carry out step D2. Noting that if an un-bonded granular column (34) is required then no bonding agent (157) will be fed.

**[0124]** In step D2, as the drill (21) is withdrawn, one or more materials (180,181,182) are allowed to pass through the drill body cavity (35). At this stage the feeder (40) will be rotated to force the materials (180,181,182), which in this case can be dry materials (aggregate for example), premixed dry and bonding materials, or separate dry and bonding materials, radially outward. Some water or other fluid may be added to lubricate the dry materials. If a bonding agent (157) is to be used it can be fed in at this step at the required time (not shown in Fig. 35/35A see Fig. 32).

**[0125]** The materials (180,181,182) move into contact with at least part of the tension unit (201) to assist in retaining the tension unit (201) at the base of the column (34,160) as it forms. If a rigid tension link (202) is used this may also assist in retaining the tension unit (201) at the base of the column (34,160) as it is formed.

**[0126]** Step D2 may be followed by step E3, but this depends on whether bonding agent (137) needs to be fed into additional elements forming part of the column (34,160) (not shown in Fig. 35/35A see Fig. 32). After step D2, step F2 may be undertaken.

**[0127]** In step F2 the tension link (202) is disconnected from the drill (21) and either attached to an appropriate part of a structure (210) and tensioned, or left in a position so that once the column (190) is sufficiently bonded (where a bonded column is formed) or the structure (210) is completed it can be.

**[0128]** In any of the embodiments measuring and controlling various drill (21) parameters a bonded stone column (160) with the desired characteristics can be formed, these characteristics include the density and porosity of the column at any point. The parameters measured and controlled include one or more of rotational speed and direction of the drill (21) and/or feeder (40), the speed the drill (21) is withdrawn, the feed rate of the feeder (40)/drill (21), the drill (21)/feeder (40) torque requirement, material (180,181,182) feed rate, if used the bonding agent (157) feed rate, the longitudinal separation between the ground terminal end (26) and the feeder (40), etc. By controlling the torque requirements of the feeder (40) and the composition fed to the ground terminal end (26) the radial and vertical compaction of the bonded stone column (160) can be varied. In addition, the penetration of the materials (180,181,182) into the ground (170) surrounding the bonded stone column (160) can be controlled, thus it is possible to form a bonded or granular stone column (34,160) with specific wall and/or volumetric properties.

**[0129]** In the embodiments described the steps have

been identified with a letter these steps could equally be given a word label as follows.

**[0130]** The steps labelled containing an A (A1 or A2) are essentially an insertion step where the drill assembly is inserted to the proper depth for the column required.

**[0131]** The steps containing a B (B1 or B2), are optional but, where present, are essentially a separation step where the position of the ground terminal end (26) relative to the feeder (40) is adjusted.

**[0132]** The steps containing a C (C1 or C2) are essentially a feed step where the steps following the separation step necessary to move from the insertion step to the formation step are undertaken.

**[0133]** The steps containing a D (D1 or D2) are essentially a formation step where the drill (21) is withdrawn from the ground (170) forming a bonded or un-bonded stone column (190).

**[0134]** The steps containing an F (F2) are optional but, where present, are a connection step where a structure (210) is attached to the bonded or granular stone column (34,160) via the tension link (202) or other connection device.

**[0135]** Where a tension device (200) is used it provides the link between the structure (210) and the column (190) as such an un-bonded column is able to act as ground improvement and provide a means of resisting uplift forces.

**[0136]** The tension element variant is intended to be used in combination with a variant including a primary flight angle (A1) and secondary flight angle (A2) (see Fig. 6 or 8) and/or one or more compactors (60) (see Fig. 12 to 18); in combination with any number of other compatible variants described herein.

### Sun Gear Unit Variant

**[0137]** Referring to Fig. 36 (and Fig.2, 19 or 22 where needed) a plan view of a sun gear unit (220) variant which includes a sun gear (12,111), an engagement unit (222) and an engagement bias unit (224) is shown. This variant is intended to replace the sun gear (12,111) in an epicyclic gearbox for use with any of the variants described to reduce the damage incurred to the central tunnel (13) or engagement channels (112,113) when the feeder (40) or second drill (3) is engaged with the sun gear (12,111).

**[0138]** Referring to Figure 37 a side view of the sun gear unit (220) is shown with the sun gear (12,111) in cross section (along line X-X in Fig. 36 in the direction of the arrows) is shown so that details of the engagement unit (222) and engagement bias unit (224) can be seen.

**[0139]** The engagement unit (222) includes an engagement tunnel (226) (shown in dashed lines) which is a co-axially aligned, open ended longitudinal void. In certain configurations the engagement tunnel (226) (see Fig. 2, 3, 4, 19 or 22 where needed) is the central tunnel (13), or it includes engagement channels (112,113). In all cases the engagement tunnel (226) is adapted to releasably engage with complementary features on the feeder (40)

(see Fig. 31) or second drill (3) (see Fig.2) so that the sun gear (12,111) can drive them.

**[0140]** The engagement unit (222) includes a first flange (231), a second flange (232) and a linking section (233). The first and second flanges (231,232) form the opposite terminal ends of the engagement unit (222) with the linking section (233) lying between. The linking section (233) and the first flange (231) co-terminate at the first flange sun face (234) and the linking section (233) and the second flange (232) co-terminate at the second flange sun face (235). The flange sun faces (234,235) face each other, and the sun gear (12,111).

**[0141]** The sun gear (12,111) includes a sun gear (SG) first face (236) and a sun gear (SG) second face (237) which are the exposed faces of the sun gear (12,111). The SG first face (236) faces the first flange sun face (234) and the SG second face (237) faces the second flange sun face (235).

**[0142]** The engagement bias unit (224) contacts both the SG first face (236) and the first flange sun face (234) applying a bias force to separate them. The engagement bias unit (224) is shown as a spring, however it can be any device that applies a bias force between faces, for example, a pressurised ring, a series of small springs, one or more leaf springs, piece of spring steel or similar resilient material, a pair of magnets with like poles facing, one or more pieces of elastomeric material; or a combination of two or more of these.

**[0143]** If the engagement unit (222) is used with the first flange (231) uppermost then a single engagement bias unit (224) between the SG first face (236) and the first flange sun face (234) may be sufficient. If the engagement unit (222) is not used with the first flange uppermost then a second engagement bias device (239) (shown in dashed lines in the figure) between the SG second face (237) and the second flange sun face (235) may be needed to ensure the engagement bias device (224) still applies a bias force between the SG first face (236) and the first flange sun face (234).

**[0144]** The linking section (233) is shown as a splined cylinder with linking splines (240) which engage with matching sun gear splines (241) in the sun gear (12,111). The splines (240,241) are complementary and adapted to allow differential co-axial motion of the engagement unit (222) in the direction of arrow Y in relation to the sun gear (12,111) whilst transmitting any rotational motion of the sun gear (12,111) to the engagement unit (220).

**[0145]** Figure 38 shows a series of steps, (i), (ii) and (iii) where a section of a feeder (40) which includes drive units (92) engages with engagement channels (112,113), or similar complementary features in the engagement tunnel (226). In these representations the engagement bias unit (224) is shown in dashed lines for clarity.

**[0146]** In step (i) the feeder is moved in the direction of arrow F while the sun gear (12,111) rotates in the direction of arrow S.

**[0147]** In step (ii) the drive units (92) have contacted

the first flange (231) and the force applied by the feeder (40) via the drive unit (92) to the engagement unit (222) causes the distance between the SG first face (236) and the first flange sun face (234) to decrease. This reduction in distance reduces the force applied through the drive units (92) allowing the sun gear (12,111) to move in relation to the drive units (92) until they align with the complementary engagement channel (112,113). The drive units (92) are shown as rollers, this is the preferred configuration, however they could be strips of material, non-rotating or rotating, or any other shape that allows them to engage with a complementary feature in the engagement tunnel (226).

**[0148]** In step (iii) the drive units (92) are aligned and engaged with the complementary engagement channel (112,113). As the force applied by the feeder (40) has reduced the engagement bias unit (224) moves the first flange sun face (234) away from the SG first face (236) as the feeder (40) moves in the direction of arrow F until the feeder (40) is in the required position. The feeder (40) is now driven by the sun gear in the direction of arrow S.

**[0149]** As the engagement unit can move in relation to the feeder (40) as it is engaged with the engagement unit (222) the damage caused by this engagement is reduced (when compared to a configuration without any form of sun gear unit (220)), especially if the feeder (40) moves erratically or suddenly in relation to the sun gear (12,111).

**[0150]** It should be noted that although two engagement channels (112,113) and drive units (92) are shown there could be any number from 1 to 20.

### Best Mode for Carrying Out the Invention

**[0151]** Referring to Figure 39 a variant including the preferred general features from the various earlier variants is shown in partial cross-section. This variant is believed to be the best general combination of features, it does not include the features of the hollow feeder (40) variant (see Fig. 31) or tension device (200) (see Fig. 33) as these are less general.

**[0152]** This variant includes a drill flight (24) and the additional flight (25) both with an asymmetric drill tooth (130) as this allows onsite customisation for the ground conditions. This feature is described in more detail under the heading Asymmetric Drill Tooth.

**[0153]** The drill flight (24) includes an angle transition point (30) or transition zone (38) as this is believed to provide a higher quality granular column (34) (see Fig. 18 for example). This feature is described in more detail under the First Variant, Second Variant, Third Variant and Sixth Variant headings.

**[0154]** The drill body (23) includes one or more compactors (60) to improve the wall quality of the hole and/or granular column (34) (see Fig. 18 for example). This feature is described in more detail under the Fourth and Fifth Variant headings.

**[0155]** The epicyclic gearbox (10) including the sun gear unit (220), shown in cross-sectional view similar to

that of Fig. 37 with the planetary (250) and ring gear (11) also shown in cross section for clarity. This feature allows engagement of the feeder (40) with the sun gear unit (200) less damage than configurations without an engagement bias device (224). This feature is described in more detail under the Sun Gear Unit Variant heading.

**[0156]** If a bonded stone column (160) (see Fig. 32) is required then the features of the Hollow Feeder Variant (see Fig. 31) may be desirable.

**[0157]** Where a range is given all integer or decimal values between those numbers are able to be independently selected to for a suitable range. That is for the range x to y all sub ranges in between are also disclosed as preferred options. By way of example only, if the range of 1 to 5 was given then the preferred ranges are 1 to 2, 1 to 3, 1 to 4, 1 to 5, 2 to 3, 2 to 4, 2 to 5, 3 to 4, 3 to 5 and 4 to 5, as well as 1, 2, 3, 4, or 5 separately. If decimal numbers are used then the range terminal value can be any decimal within the original range given, with the least significant decimal increment being a single unit, e.g. a range of 1.1 to 2.3 increments by 0.1, and a range of 2.123 to 3.4 increments by 0.001. So, if a range of 0.5 to 1.1 is given then this is intended to allow the following ranges 0.5 to 0.6, 0.5 to 0.7, 0.5 to 0.8, 0.5 to 0.9, 0.5 to 1.0, 0.5 to 1.1, 0.6 to 0.7, etc. with a generalised formula (for this example) of a.b to c.d where a and c are 0 or 1; b is 1,5,6,7,8 or 9; d is 0,1,6,7,8 or 9; c is equal to or greater than a and c.d is equal to or greater than a.b.

### Claims

1. A stone column drill (21) including a drill flight (24) where,  
the drill (21) is a tubular drill including a drill body (23) which is a tube, such that the drill flight (24) is attached to a body outer surface (27) of the drill body (23) and the body outer surface (27) is the exposed outer surface of the drill body (23) characterised in that, the drill body (23) includes one or more compactors (60,67,68), where each compactor (60,67,68) present extends radially from the drill body (23) and each compactor (60,67,68) extends, at least partially, between two facing portions of the drill flight (24) .
2. The drill (21) as claimed in claim 1, wherein, each compactor (60,67,68) present is a minimum of 1m to 3m from a ground terminal end (26) of the drill (21).
3. The drill (21) as claimed in claim 1 or 2 wherein, the facing portions are circumferentially separated by between 270° and 360°.
4. The drill (21) as claimed in any one of claims 1 to 3 wherein, one or more compactor (60,67,68) is longitudinally aligned with the drill (21).

5. The drill (21) as claimed in any one of claims 1 to 4 wherein, the distance each compactor (60,67,68) present extends radially from the drill body (23) is between 0.1 and 1.2 times a flight height (FH), where the flight height (FH) is the distance between a peripheral edge of the drill flight (24) and the drill body (23). 5
6. The drill (21) as claimed in any one of claims 1 to 5 wherein, the drill flight (24) has a pitch P, and each compactor (60,67,68) present independently extends 0.1P to 1P along the length of the drill (21). 10
7. The drill (21) as claimed in any one of claims 1 to 6 wherein, each compactor (60,67,68) present is, independently, at an angle of 0° to 90° to a longitudinal axis of the drill (21). 15
8. The drill (21) as claimed in any one of claims 1 to 7 wherein, at least one compactor (60,67,68) present is attached to the drill flight (24) at one end. 20
9. The drill (21) as claimed in any one of the preceding claims wherein, each drill flight (24) terminates at a terminal end 121,122 which includes a keeper (120) configured to retain an asymmetric drill tooth (130). 25

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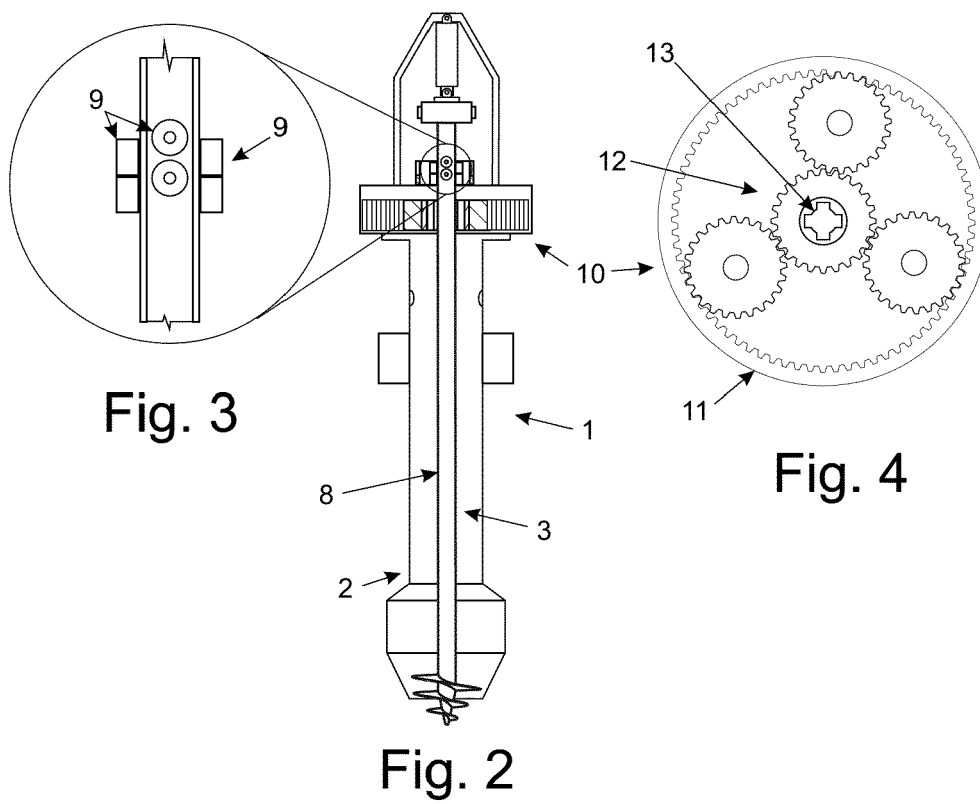
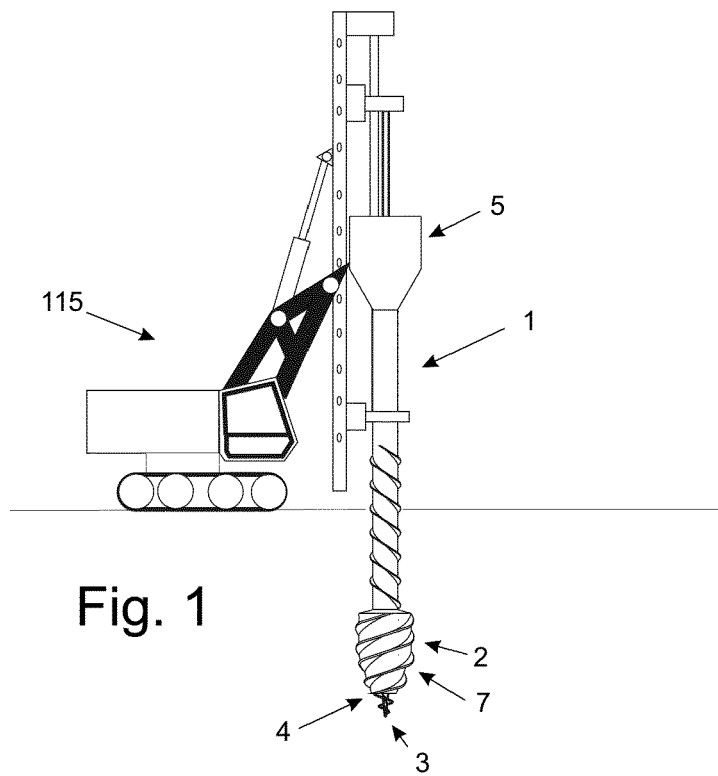
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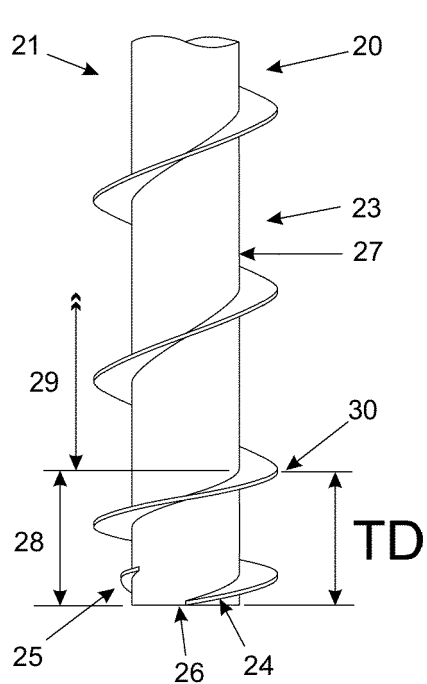


Fig. 5

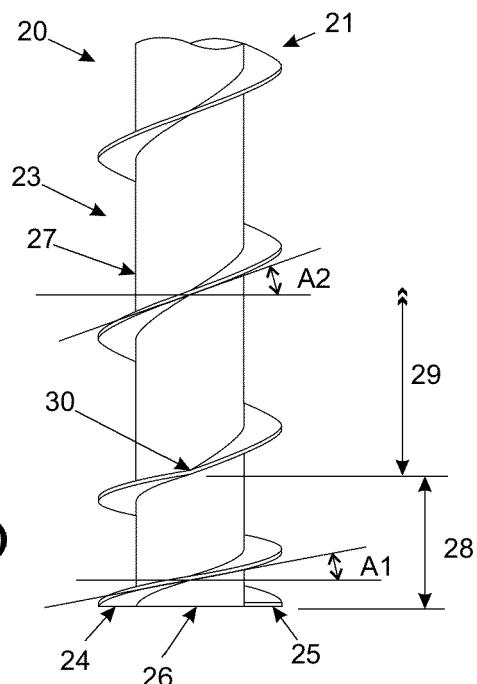


Fig. 6

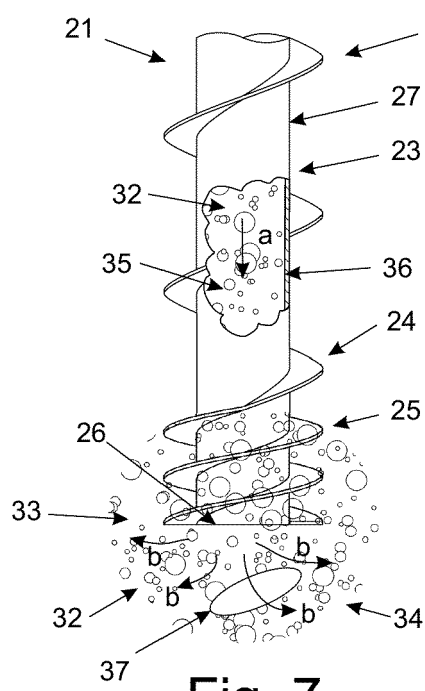


Fig. 7

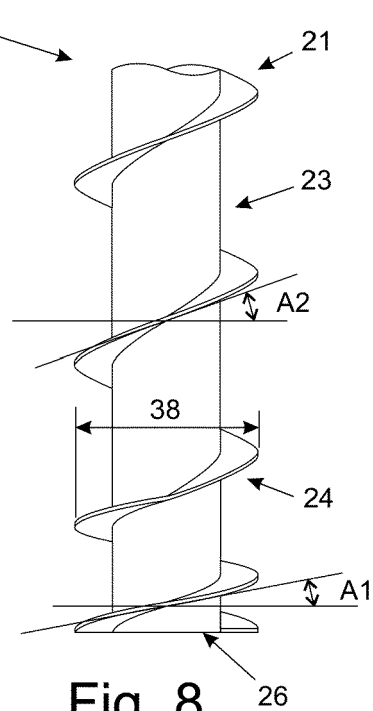


Fig. 8

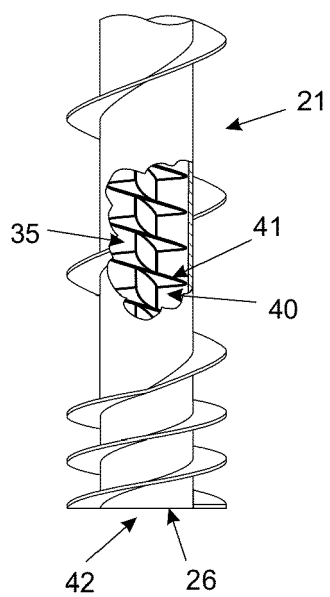


Fig. 9

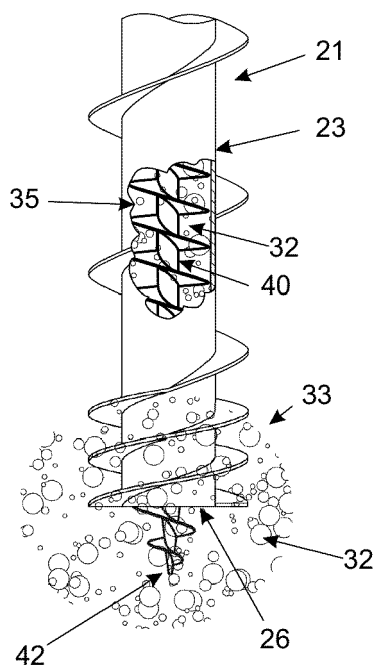
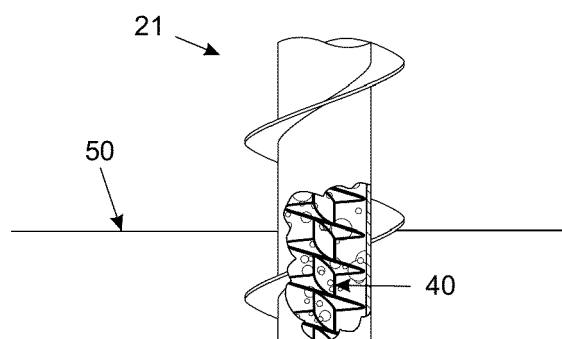


Fig. 10

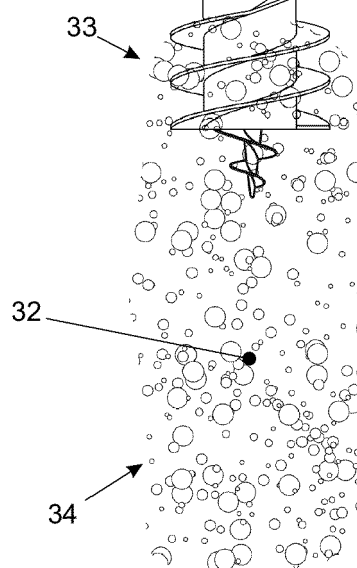


Fig. 11

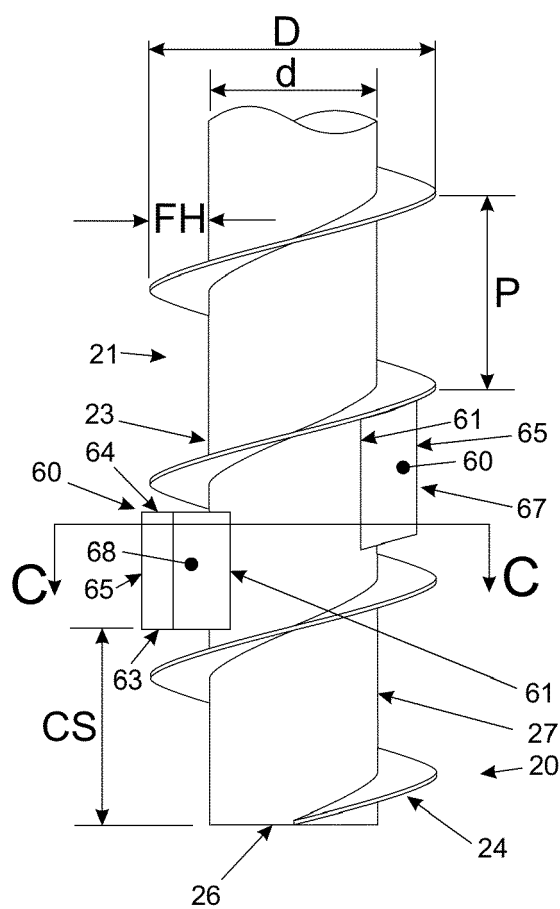


Fig. 12

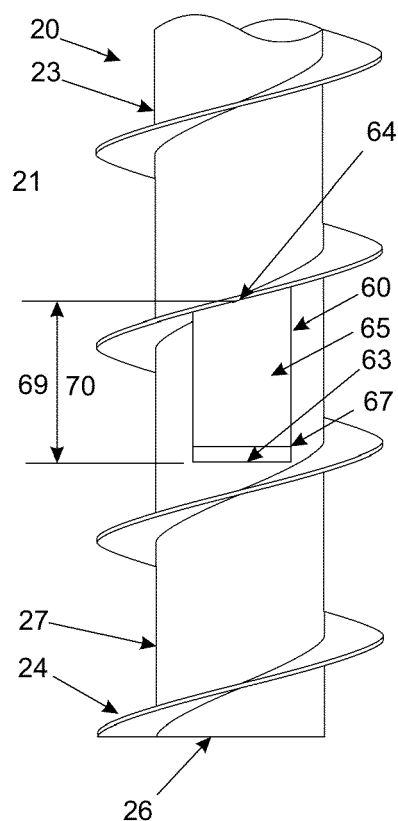


Fig. 13

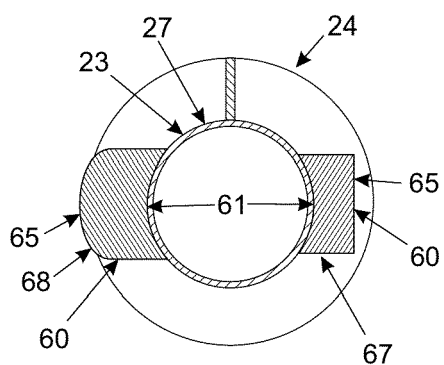


Fig. 14

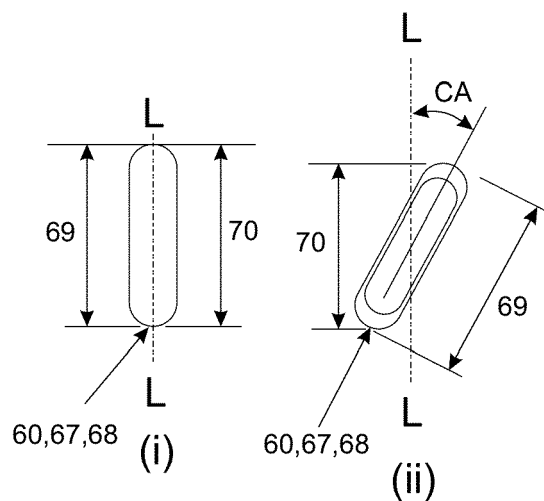


Fig. 15

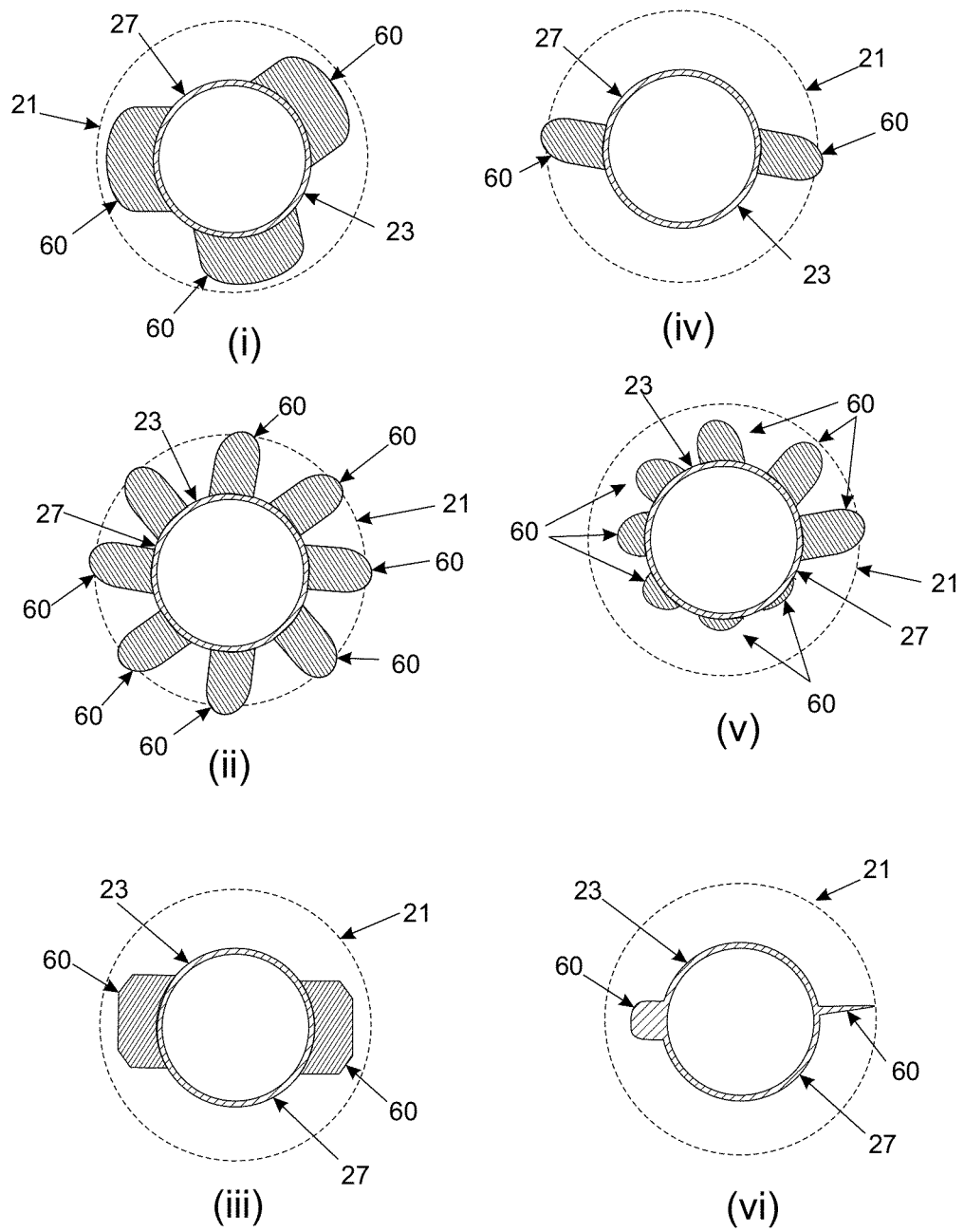


Fig. 16

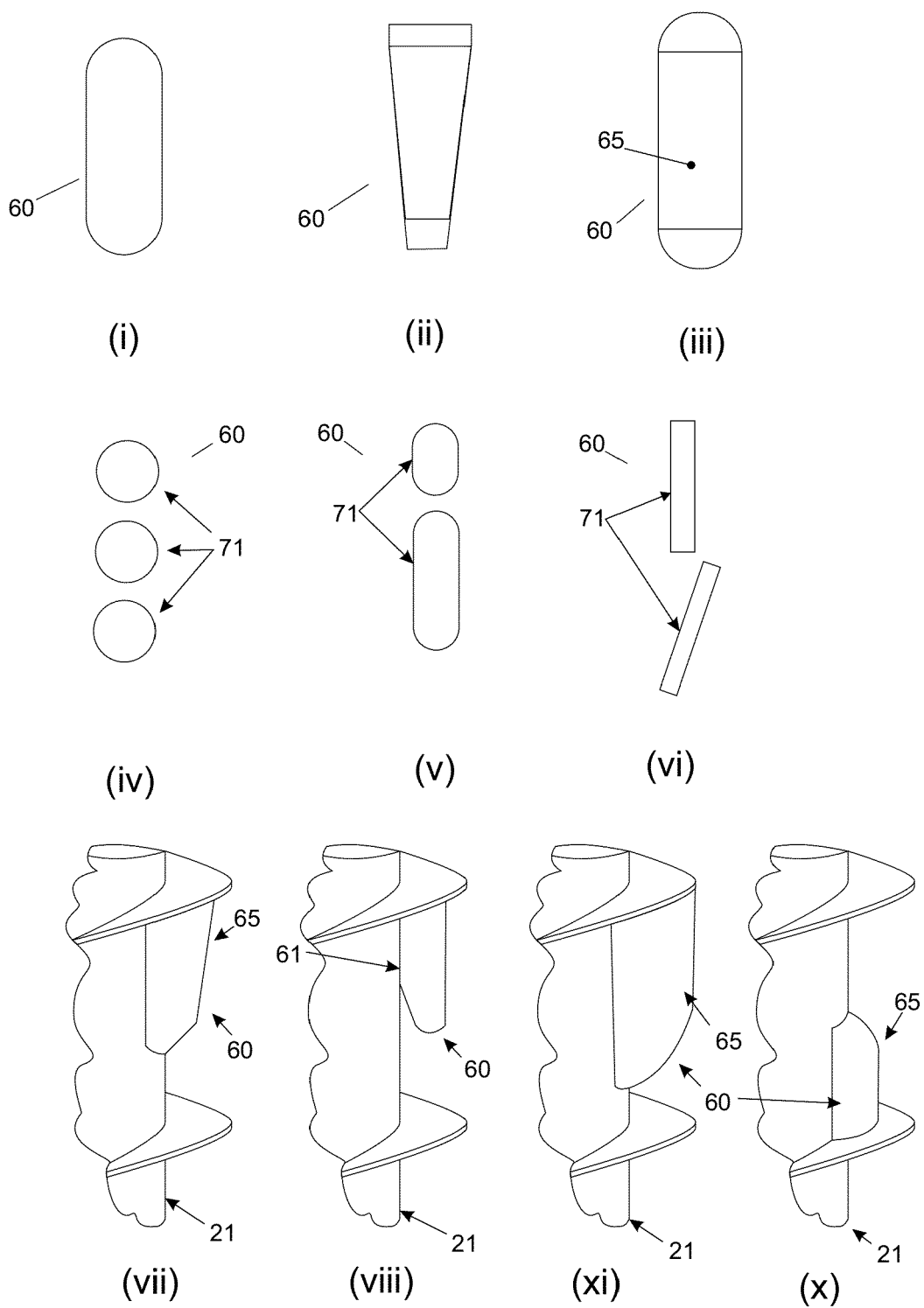


Fig. 17

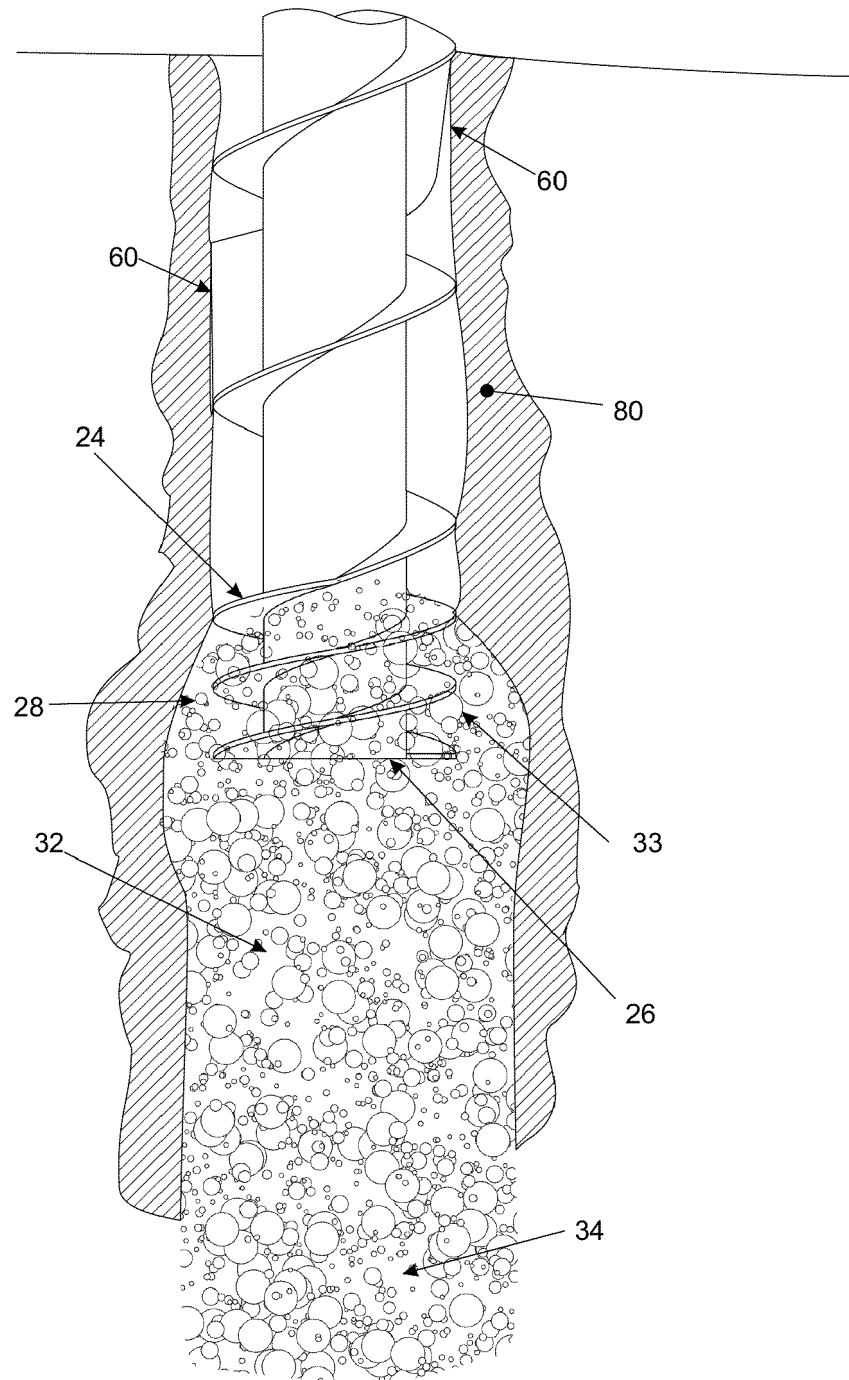
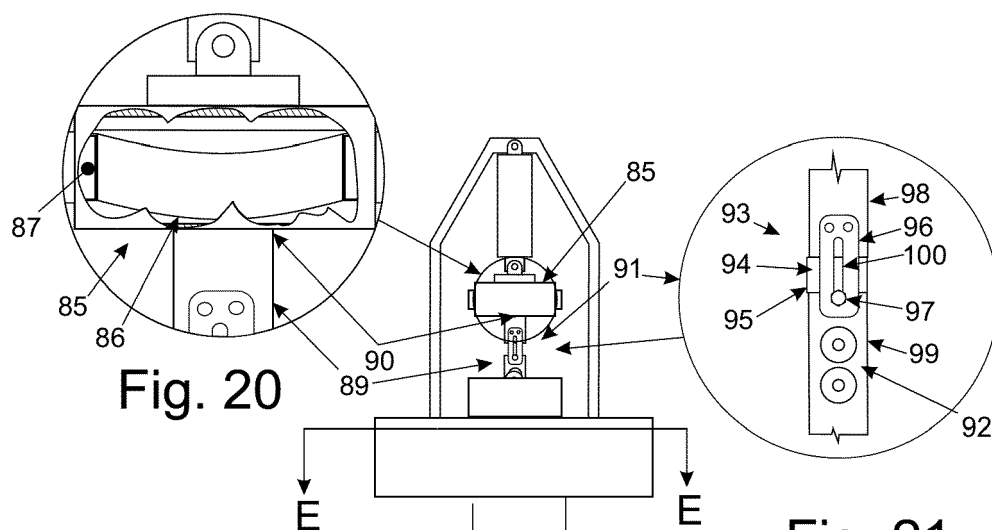


Fig. 18



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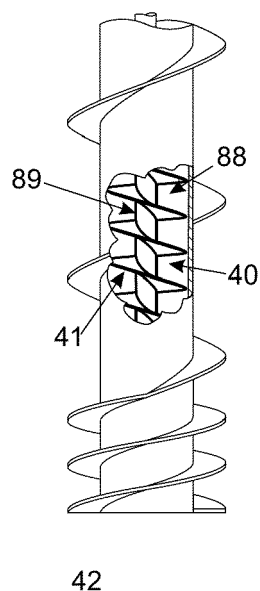


Fig. 19

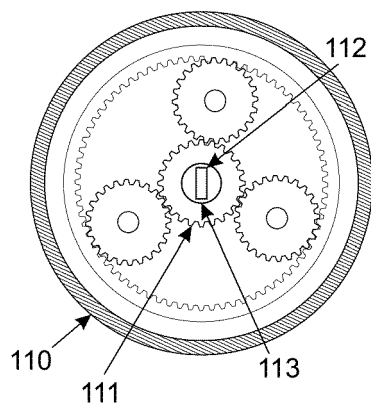


Fig. 22

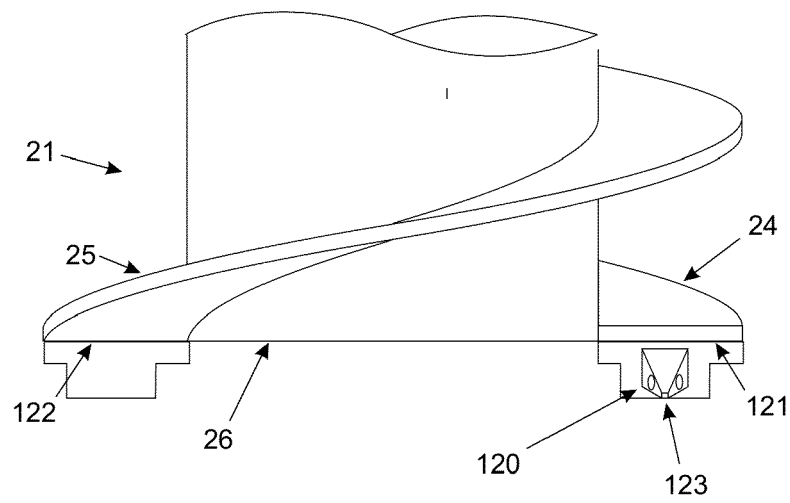


Fig. 23

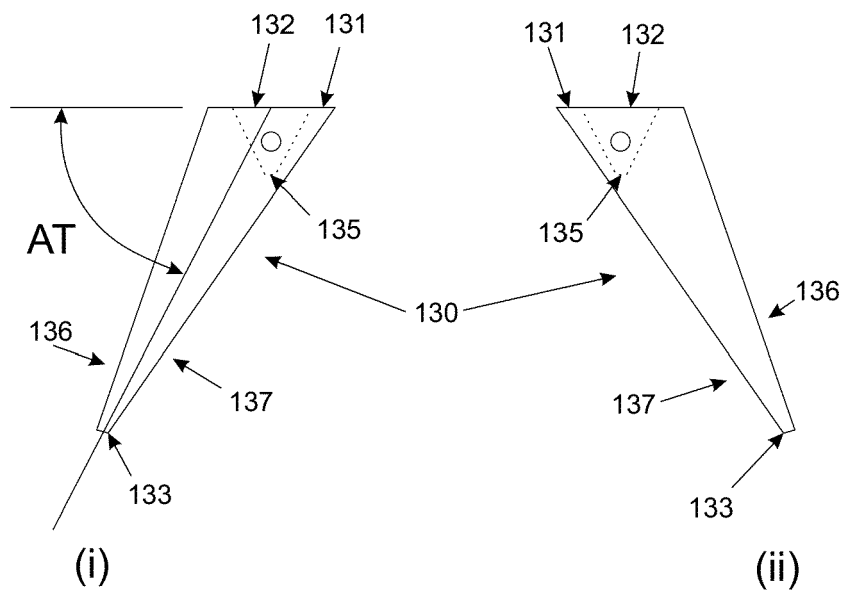


Fig. 24



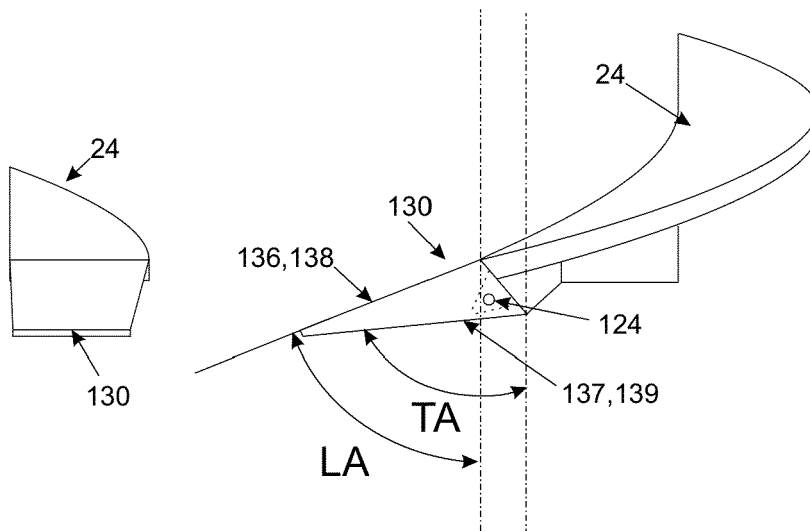


Fig. 25

Fig. 26

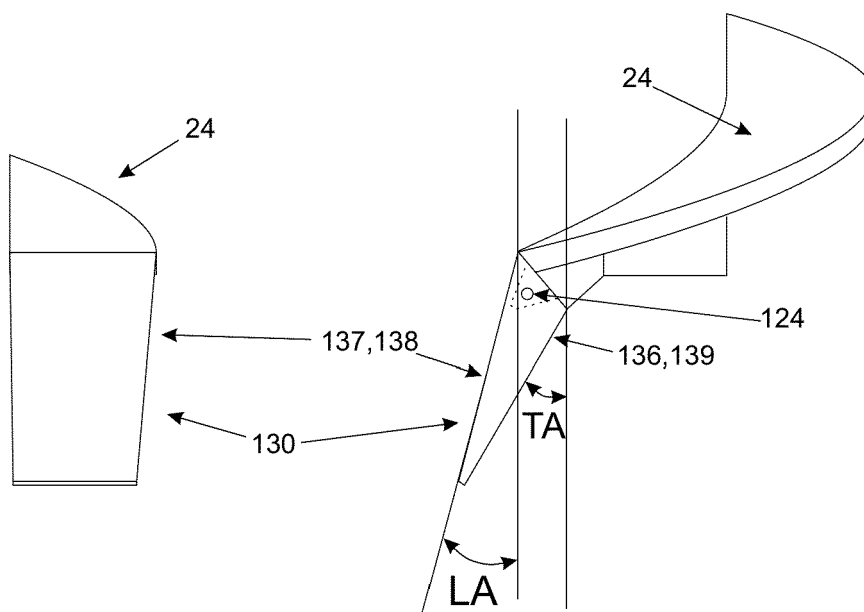


Fig. 27

Fig. 28

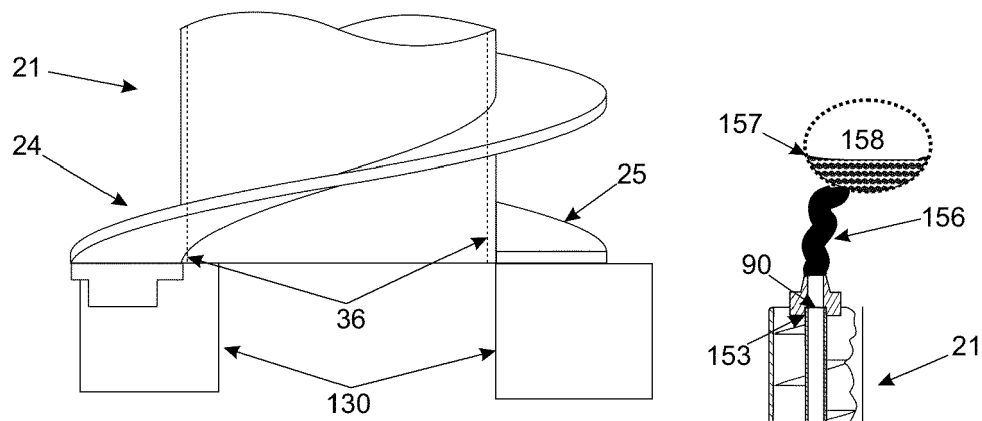


Fig. 29

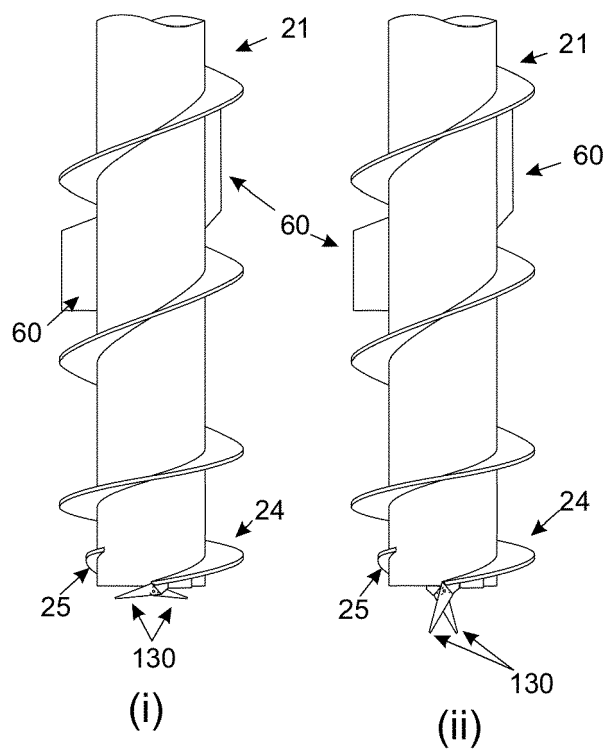


Fig. 30

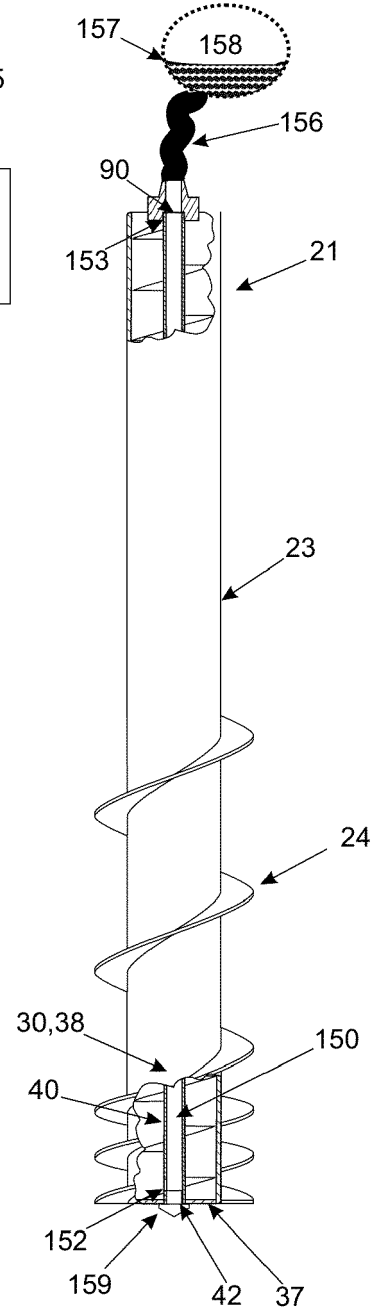
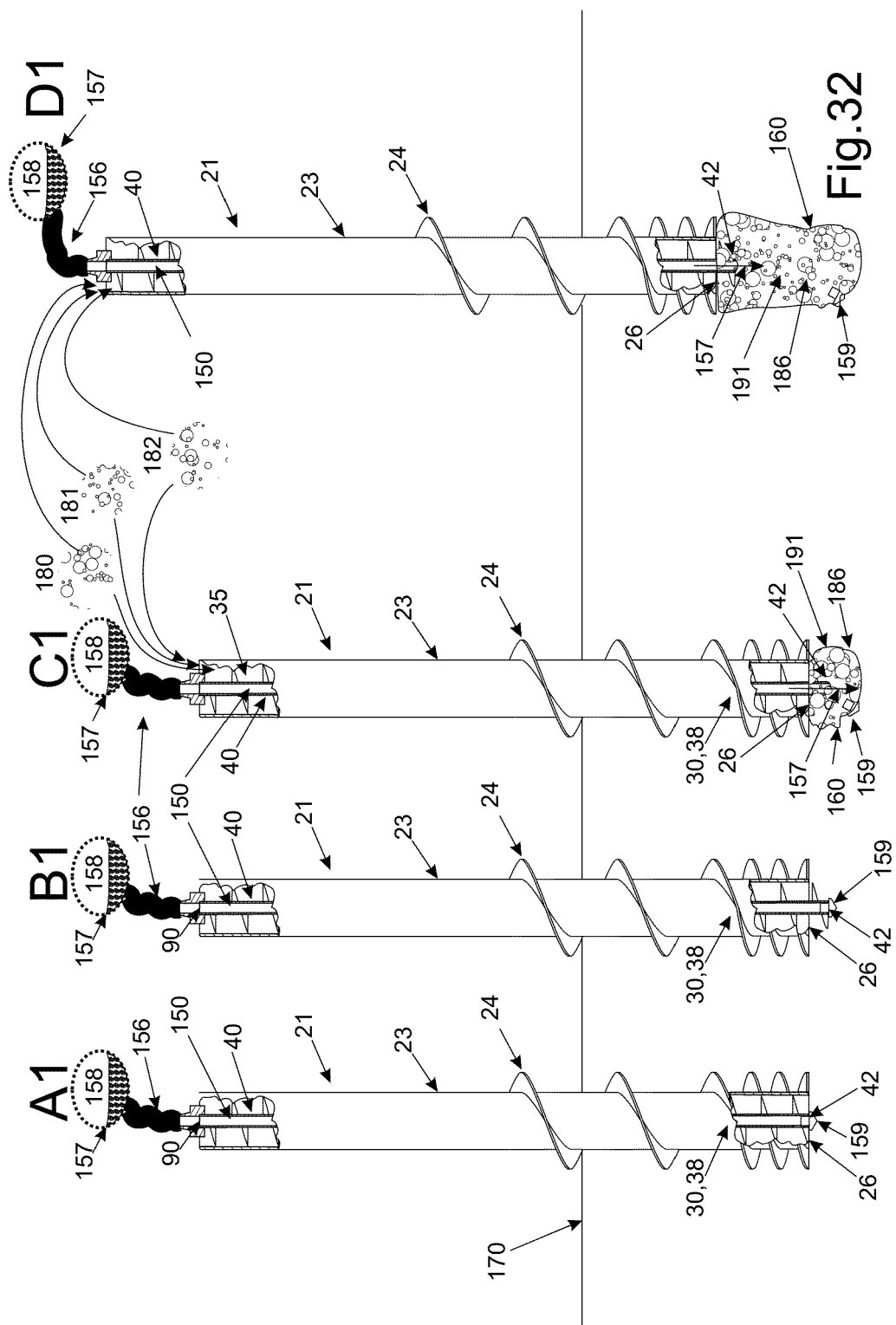


Fig. 31



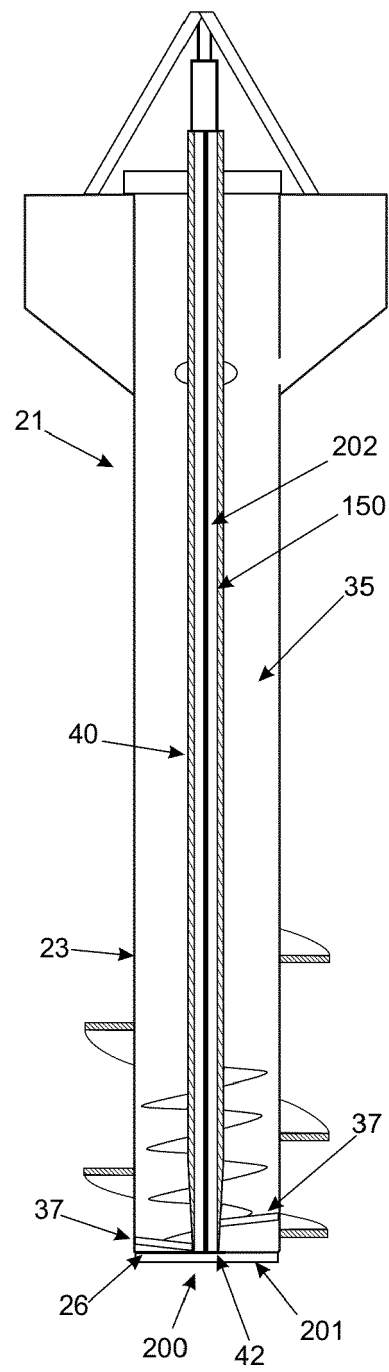


Fig. 33

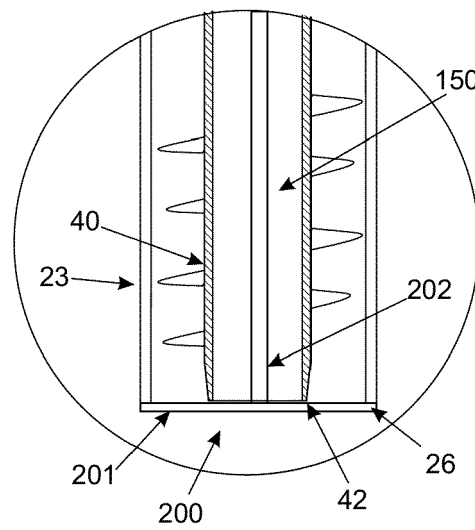


Fig.34

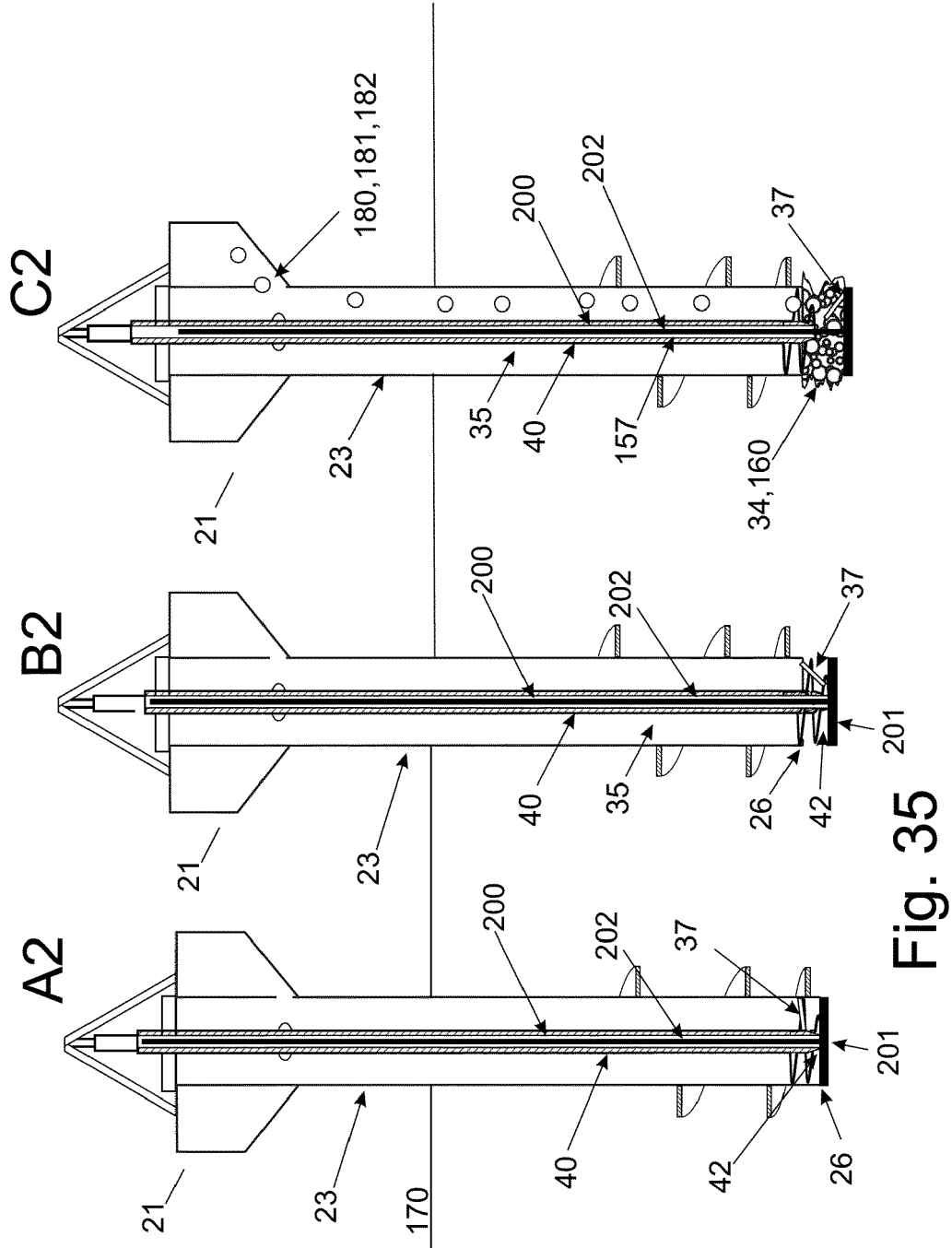
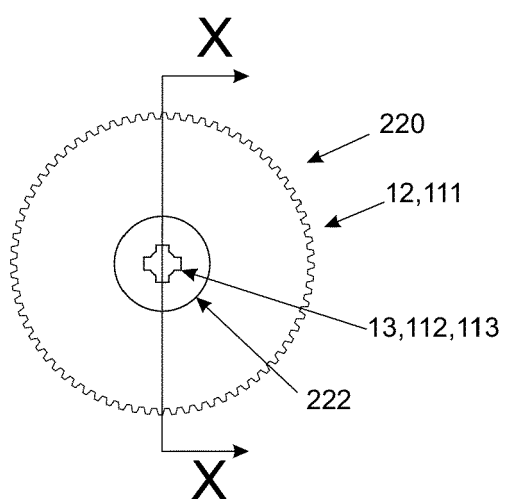
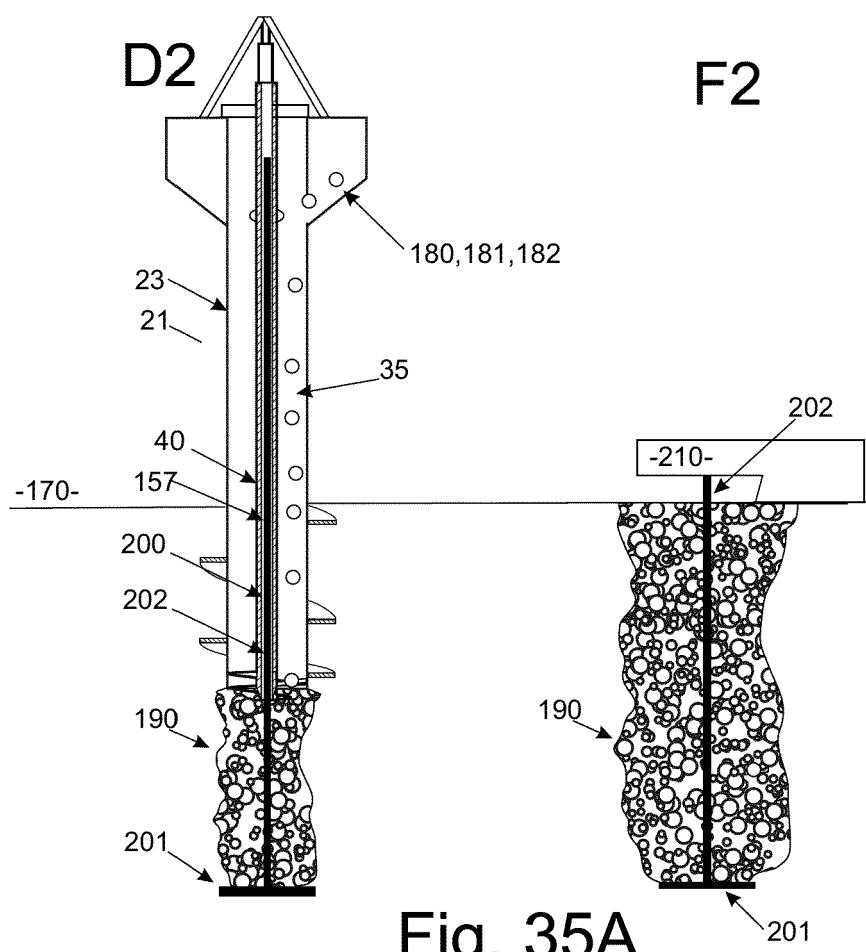


Fig. 35



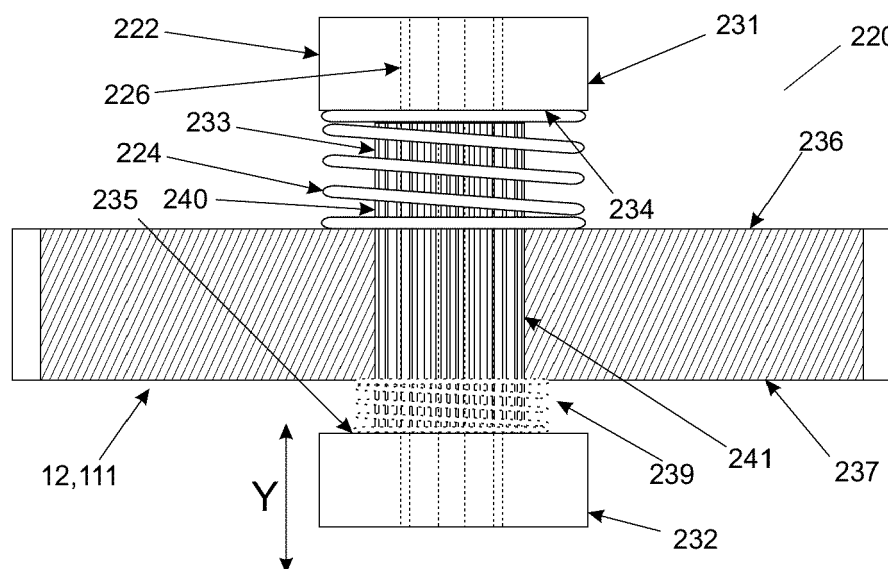


Fig. 37

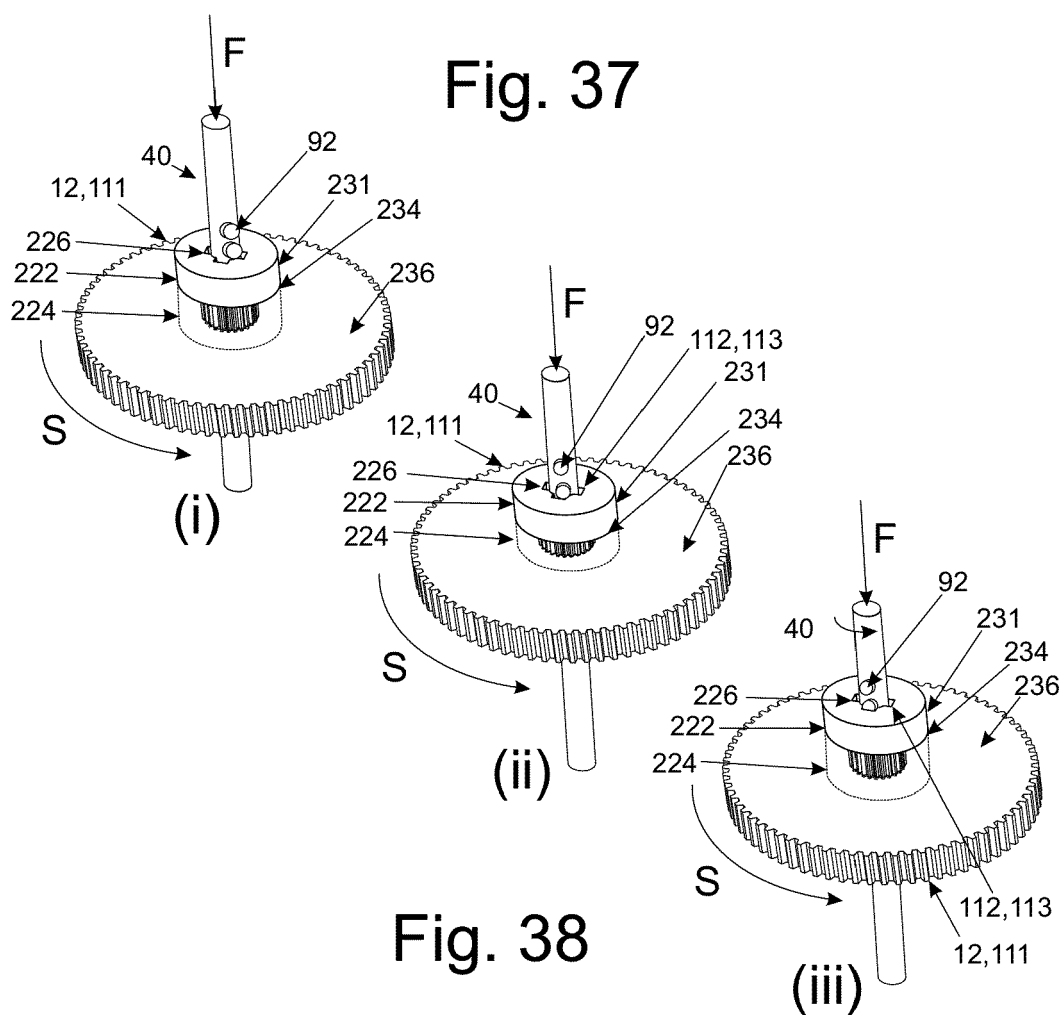


Fig. 38

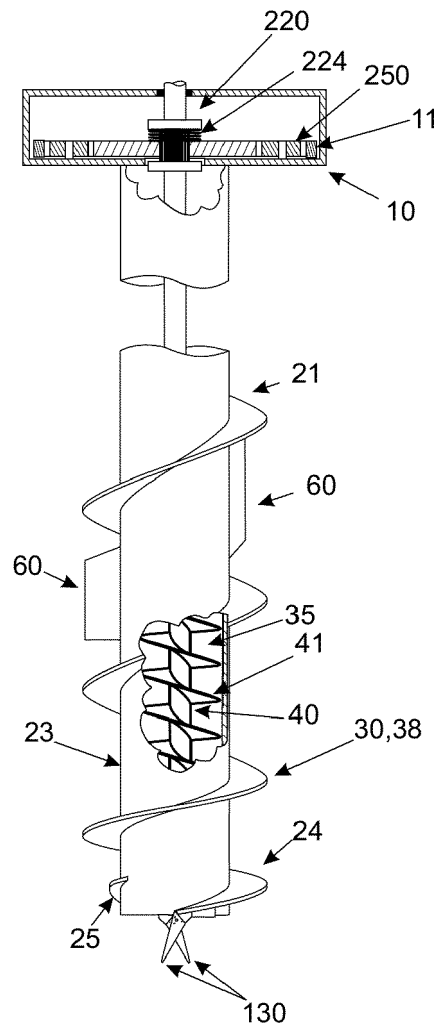


Fig. 39





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| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                               |                                                              |                                                        |
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