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(12) (19) (CA) **Demande-Application**

(21) (A1) **2,224,720**
(86) 1996/06/26
(87) 1997/01/16

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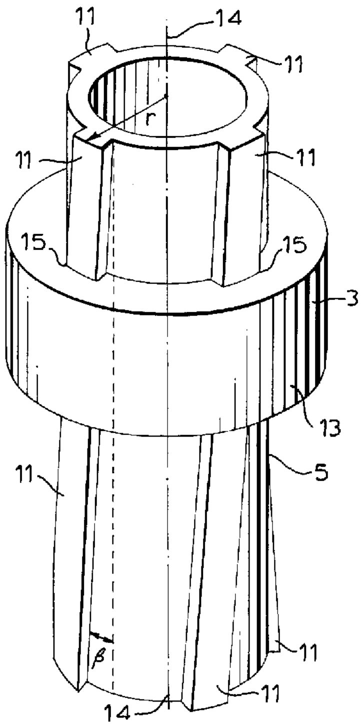
(51) Int.Cl.[6] E21B 44/00, E21B 17/07
(30) 1995/06/27 (95201736.6) EP

(54) **PROPULSEUR HYDRAULIQUE POUR TRAIN DE SONDE**

(54) **HYDRAULIC THRUSTER FOR USE IN A DRILL STRING**



(57) Cette invention concerne un propulseur hydraulique (1) qui permet d'engendrer une force de poussée sur le foret situé à l'extrémité inférieure d'un train de sonde. Ledit propulseur comporte un premier élément (3) que l'on peut connecter à une partie supérieure du train de sonde et un second élément (5) que l'on peut connecter à une partie inférieure du train de sonde, lesdits éléments étant disposés de façon télescopique l'un par rapport à l'autre et pouvant transmettre le couple de torsion entre les parties supérieure et inférieure du train de sonde au cours du forage. L'invention concerne également un passage pour fluide (9) qui traverse lesdits éléments (3,5)

(57) A hydraulic thruster (1) for generating a thrust force to a drill bit located at the lower end of a drill string is provided. The thruster comprises a first member (3) connectable to an upper part of the drill string and a second member (5) connectable to a lower part of the drill string, said members being telescopingly arranged relative to each other and being capable of transmitting torque between the upper and lower part of the drill string during drilling. A fluid passage (9) for passing through said members (3, 5) for drilling fluid flowing through the drill string towards the drill bit and means (11, 15) for generating an inward telescoping reaction of

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et qui permet à un fluide de forage de s'écouler à travers le train de sonde en direction du foret, ainsi que des organes (11, 15) qui engendrent entre lesdits éléments une réaction télescopique dirigée vers l'intérieur lorsque le couple de torsion est transmis de la partie supérieure à la partie inférieure du train de sonde au cours du forage.

said members upon transmission of torque between the upper and lower part of the drill string during drilling are provided.

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International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : **E21B 44/00, 17/07**	**A1**	**(11) International Publication Number:** **WO 97/01693** **(43) International Publication Date:** 16 January 1997 (16.01.97)

(21) International Application Number: PCT/EP96/02798

(22) International Filing Date: 26 June 1996 (26.06.96)

(30) Priority Data:
95201736.6 27 June 1995 (27.06.95) EP
(34) Countries for which the regional or international application was filed: AT et al.

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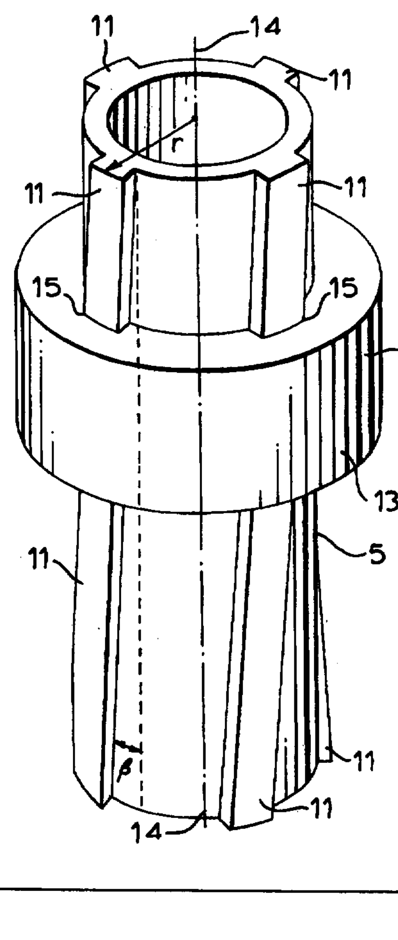
(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: HYDRAULIC THRUSTER FOR USE IN A DRILL STRING

(57) Abstract

A hydraulic thruster (1) for generating a thrust force to a drill bit located at the lower end of a drill string is provided. The thruster comprises a first member (3) connectable to an upper part of the drill string and a second member (5) connectable to a lower part of the drill string, said members being telescopingly arranged relative to each other and being capable of transmitting torque between the upper and lower part of the drill string during drilling. A fluid passage (9) for passing through said members (3, 5) for drilling fluid flowing through the drill string towards the drill bit and means (11, 15) for generating an inward telescoping reaction of said members upon transmission of torque between the upper and lower part of the drill string during drilling are provided.



HYDRAULIC THRUSTER FOR USE IN A DRILL STRING

The present invention relates to a hydraulic thruster for generating a thrust force to a drill bit located at the lower end of a drill string. Hydraulic thrusters are generally applied in order to generate the desired weight on bit (WOB) which is the force exerted by the drill bit to the bottom of the borehole, or to isolate axial vibrations of the drill string from the bottom hole assembly. Especially in deviated wellbores or horizontal wellbores a considerable amount of axial force of the drill string is dissipated by friction between the drill string an the borehole wall, necessitating the application of a thruster to generate the desired WOB. A common thruster consists of two telescoping members of which the fixed member is connected to an upper part of the drill string, and the travelling member is connected to the downhole assembly, whereby an axial spline/groove arrangement enables torque to be transmitted between the two members. The thruster allows the downhole assembly to move axially relative to the upper part of the drill string. The delivered thrust force is thus independent of the axial position of the drill string, and furthermore the thrust force is independent of the inclination of the drill string which may vary between a vertical orientation and a horizontal orientation. Furthermore, the WOB can be accurately controlled as it depends on the effective cross-sectional area of the thruster and on the difference between the internal fluid pressure of the thruster and the external pressure thereof. Also the thruster improves the dynamic behaviour of the assembly by the axial decoupling of the drill bit from the drill string.

US patent No. 4,901,806 discloses a device for use in a drill string to control the force applied to the drill bit (i.e. the WOB), and to decouple the axial vibrations acting on the drill string, which device therefore in effect forms a thruster. The known thruster comprises a first member connectable to an upper part of the drill string and a second member connectable to a lower part of the drill string, said members being telescopingly arranged relative to each other and being capable of transmitting torsional forces between the upper member and the lower member during drilling, and a fluid passage passing through said members for drilling fluid flowing through the drill string towards the drill bit.

A problem associated with the known thruster is the occurrence of WOB variations due to variations of the drilling fluid pressure. Such pressure variations may occur, for example, due to pressure pulses generated during measurement while drilling. The fluid pressure variations tend to induce an outward telescoping movement of the device thereby causing variations in WOB. The problem is even more pronounced in case a downhole drilling motor is applied to drive the drill bit, which motor is located between the thruster and the drill bit. When the torque of the downhole motor increases, for example because of increasing frictional forces at the drill bit, the fluid pressure at the fluid inlet of the motor increases and thereby also the fluid pressure in the thruster. This leads to a further outwardly telescoping tendency of the thruster and consequently to an increasing WOB and corresponding torque at the motor. The increased motor torque requires again an increased fluid pressure at the motor inlet and hence also at the thruster, leading to a further outwardly telescoping tendency of the thruster, etc. This process leads to uncontrolled behaviour of the thruster/motor/bit combination and as a result the system may stall out. The drilling process is thus severely hampered and damage to one or more of the components may result.

US-A-1,688,994 discloses a hydraulic thruster for generating a thrust force to a drill bit located at the lower end of a drill string, comprising a first member connectable to an upper part of the drill string and a second member connectable to a lower part of the drill string, said members being telescopingly arranged relative to each other and being capable of transmitting drill string torque during drilling, a fluid passage passing through said members for drilling fluid flowing through the drill string towards the drill bit, and means for generating an inward telescoping reaction of said members upon transmission of drill string torque during drilling, said means comprising at at least one helical spline provided at least one of said members and arranged in a corresponding helical groove provided at the other of said members, the spline and groove co-operating so as to transmit torque between the upper and lower part of the drill string during drilling. The WOB of this known thruster depends on the bit/rock friction coefficient which shows large variations.

It is an object of the invention to provide an improved thruster which provides a controlled WOB and which overcomes the problems of the known thruster.

In accordance with the invention there is provided a hydraulic thruster for generating a thrust force to a drill bit located at the lower end of a drill string, comprising a first member connectable to an upper part of the drill string and a second member connectable to a lower part of the drill string, said members being telescopingly arranged relative to each other and being capable of transmitting drill string torque during drilling, a fluid passage passing through said members for drilling fluid flowing through the drill string towards the drill bit, and means for generating an inward telescoping reaction of said members upon transmission of drill string torque during drilling, characterized in that each spline (11) is arranged at a helix angle β relative to the longitudinal axis of the thruster, of between

$$0.8 \arctan (r.A_i/k_m) < \beta < 1.2 \arctan (r.A_i/k_m);$$

wherein r = average outer radius of the thruster;

A_i = effective cross-sectional thrust area of the thruster;

k_m = the motor constant defined as the motor torque per unit pressure drop across the motor.

The inward telescoping reaction upon transmission of torque counter-acts the tendency of the thruster to telescope outwardly by the fluid pressure fluctuations, so that thereby the uncontrolled sequence of increasing fluid pressure, WOB and torque of the prior art thruster is avoided.

Suitably a plurality of said splines and grooves are distributed regularly along the interface between the inner and outer member.

The thruster according to the invention is advantageously applied in a drill string including a downhole motor driving the drill bit, the downhole motor being arranged between the thruster and the drill bit.

The invention will be described hereinafter in more detail, with reference to the accompanying drawings in which:

Fig. 1 schematically shows a longitudinal cross-section of an embodiment of the hydraulic thruster according to the invention;

Fig. 2 schematically shows a perspective view of the thruster of Fig. 1;

Fig. 3 schematically shows an alternative embodiment of the thruster according to the invention;

Fig. 4 schematically shows a partial cross-section of yet another embodiment of the thruster according to the invention; and

Fig. 5 shows a view along the line V-V of Fig. 4.

Referring to Fig. 1 there is shown a thruster 1 including a cylindrical outer member 3 and a cylindrical inner member 5 telescoping within the outer member 3, the inner member 5 having an annular piston 7 sealed by a suitable seal from the inner surface of the outer member 3. The members 3, 5 have a common fluid passage 9 for drilling fluid to flow through the thruster 1. The outer member 3 is connected at its upper end to the upper part of a drill string (not shown), and the inner member 5 is connected at its lower end to a lower part of the drill string including a hydraulic downhole motor (not shown). The inner member 5 is provided at its outer surface with helical splines 11 extending from the piston 7 along a substantial portion of the length of the inner member 5. The outer member 3 has a lower part 13 provided with helical grooves 15 which correspond to, and co-operate with, the splines 11 of the inner member 5. As shown in

Fig. 2, in which for reason of clarity only the lower part 13 of outer member 3 is indicated, the splines 11 and grooves 15 are oriented at a helix angle β relative to the longitudinal axis 14 of the thruster 1. The helix orientation is such that during right hand rotation of the thruster 1 during drilling, when torque is transmitted from the outer member 3 to the inner member 5, the splines 11 and grooves 15 induce an inwardly telescoping reaction to the members 3, 5. Furthermore, in Fig. 1, A_i indicates the effective thruster area and r indicates the average radius of the splines/grooves.

During normal operation of the thruster 1, drilling fluid is pumped through the drill string and the thruster to the fluid inlet of the downhole motor which drives a drill bit. With P_o being the fluid pressure outside the thruster and P_i being the fluid pressure inside the thruster, the thrust force induced by the fluid pressure is:

$$F_t = (P_i - P_o).A_i \qquad (1)$$

and the WOB is:

$$WOB = F_t + F_g - T \tan(\beta) / r \qquad (2)$$

in which F_g is the gravity force of the lower part of the drill string (i.e. the travelling part);

T is the motor torque.

The motor torque T depends on the fluid pressure at the motor inlet P_i and the fluid pressure at the motor outlet P_{mo} :

$$T = k_m(P_i - P_{mo}) \qquad (3)$$

in which k_m is the motor constant defined as unit torque delivered per unit pressure drop across the motor. The bit torque T is substantially linearly dependent on WOB:

$$T = A_b.WOB \qquad (4)$$

where A_b is the bit/rock friction coefficient.

The fluid pressure drop across the bit nozzles can be written as:

$$\Delta P = 0.5\ \rho\ v^2 \qquad (5)$$

where ρ is the drilling fluid density and v the average fluid velocity in the nozzles.

With $\Delta P = P_{mo} - P_o$ (6)

$$v = Q / A_n \qquad (7)$$

where Q is the fluid flow rate and A_n is the effective cross-sectional area of the nozzles it follows from equations (1) - (7) that

$$WOB = \alpha^{-1}(\rho\ Q^2 A_i / 2A_n{}^2 + F_g) \qquad (8)$$

where $\alpha = 1 - (A_i A_b / k_m) + (A_b \tan(\beta) / r)$

The parameters A_i and k_m are design parameters which can be accurately selected. However the bit/rock friction coefficient A_b depends on the bit and rock formation properties and shows large variations. This problem is overcome by selecting

$$\tan(\beta) / r = A_i / k_m \qquad (9)$$

so that

$$WOB = (\rho\ Q^2 A_i / 2A_n{}^2 + F_g) \qquad (10)$$

thereby eliminating the dependency of WOB on the bit/rock friction coefficient. In this manner it is achieved that the effect of varying friction between the bit and the rock is eliminated without determining the magnitude of such varying friction.

For example, with a thruster of outer diameter of 0.1651 m (6.5"), $A_i = 0.013\ m^2$, $r = 0.065$ m, and with a motor having a motor constant $k_m = 0.0009\ m^3$, it follows from equation (9) that

$$\beta = 43 \text{ degrees.}$$

In the above description it has been assumed that equations (1) - (10) are exact. However in practice slight variations in some of the parameters may occur, and it has been found that adequate reduction of the dependency of WOB on the bit/rock friction is achieved if the helix angle β is selected between

$$0.8 \arctan (r.A_i/k_m) < \beta < 1.2 \arctan (r.A_i/k_m) \quad 11)$$

More preferably the helix angle is between

$$0.95 \arctan (r.A_i/k_m) < \beta < 1.05 \arctan (r.A_i/k_m) 12)$$

An implication of equations (9), (11) and (12) is that the helix angle β depends on the motor constant k_m, so that the thruster would have to be selected in dependence of the motor type. Referring to Fig. 3, an alternative embodiment of the thruster according to the invention can be applied with reduced dependency on the motor type. The alternative thruster 20 has an inner member 22 provided with a set of helical splines of varying helix angle, and an outer member 26 provided with a set of corresponding grooves 28.

Normal use of the alternative thruster 20 is similar to normal use of the thruster described with reference to Figs. 1 and 2, however with the additional feature of optionally varying the effective helix angle by raising or lowering the drill string in accordance with the motor type applied.

Referring to Fig. 4, instead of applying fixed grooves 28 as in the embodiment of Fig. 3, in another embodiment of the thruster according to the invention a plurality of guides 30 are positioned in corresponding recesses 32 of the thruster outer member 34, each guide 30 being provided with a groove 36 in which a spline 38 of the thruster inner member 40 is positioned. Each guide 30 is rotatable around a radial shaft 42 fixedly connected to the outer member 34. In this manner it is achieved that the helix angle of the grooves 36 of the outer member 34 conforms to the varying helix angles of the splines 38. It is to be understood that instead of the guides 30 being connected to the outer member 34, the guides can alternatively be connected to the inner member, in which case the splines are provided at the outer member.

Instead of the downhole motor being arranged between the hydraulic thruster according to the invention and the drill bit, the hydraulic thruster can alternatively be arranged between the downhole motor and the drill bit.

C L A I M S

1. A hydraulic thruster (1) for generating a thrust force to a drill bit located at the lower end of a drill string, comprising a first member (3) connectable to an upper part of the drill string and a second member (5) connectable to a lower part of the drill string, said members being telescopingly arranged relative to each other and being capable of transmitting drill string torque during drilling, a fluid passage (9) passing through said members for drilling fluid flowing through the drill string towards the drill bit, and means for generating an inward telescoping reaction of said members upon transmission of drill string torque during drilling, said means comprising at least one helical spline (11) provided at at least one of said members and arranged in a corresponding helical groove (15) provided at the other of said members, the spline and groove co-operating so as to transmit torque between the upper and lower part of the drill string during drilling, characterized in that each spline (11) is arranged at a helix angle β relative to the longitudinal axis of the thruster, of between

$$0.8 \arctan (r.A_i/k_m) < \beta < 1.2 \arctan (r.A_i/k_m);$$

wherein r = average outer radius of the thruster;

A_i = effective cross-sectional thrust area of the thruster;

k_m = the motor constant defined as the motor torque per unit pressure drop across the motor.

2. The thruster of claim 1, wherein said first member forms an outer member (3) and said second member forms an inner member (5).

3. The thruster of claim 2, comprising a plurality of said splines (11) and grooves (15) distributed regularly along the interface between the inner and outer member (3,5).

4. The thruster of claim 3, wherein each spline (11) is arranged at a helix angle β relative to the longitudinal axis of the thruster, of between

$$0.95 \arctan (r.A_i/k_m) < \beta < 1.05 \arctan (r.A_i/k_m).$$

5. The thruster of any of claims 1-4, wherein the helix angle of each spline (11) and groove (15) varies along the length of the thruster.

6. The thruster of claim 5, wherein at least one of each spline (30) and each groove (36) is rotatable around a radial axis (42) so as to conform the helix angle thereof to the helix angle of the other one of each spline (30) and groove (36).

7. The thruster of any of claims 1-6, wherein each spline (11) is provided at the inner member (5), and each groove (15) is provided at the outer member (3).

8. The thruster of any of claims 1-7, wherein the drill string includes a downhole motor driving the drill bit, the downhole motor being arranged between the thruster and the drill bit.

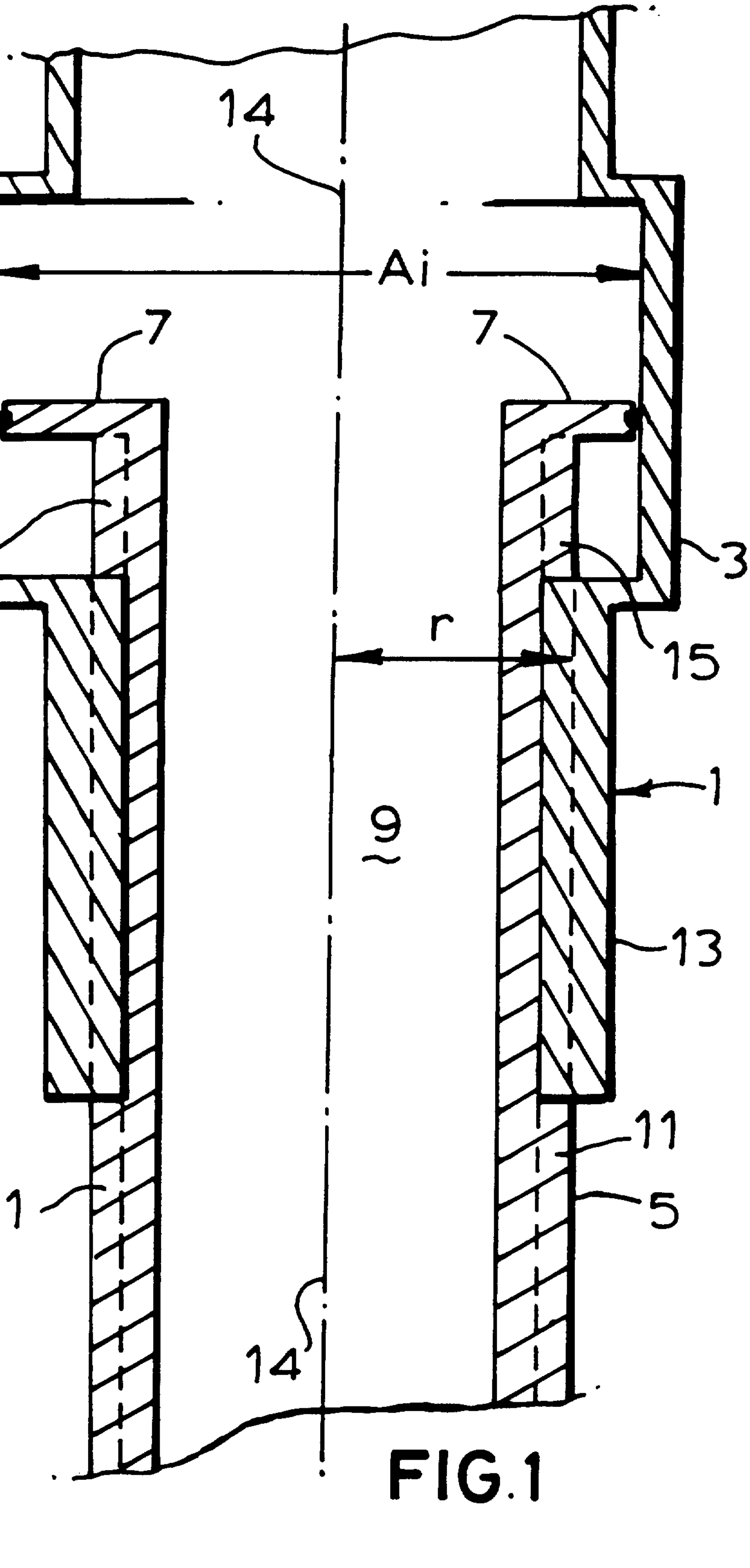


FIG.1

FIG. 2

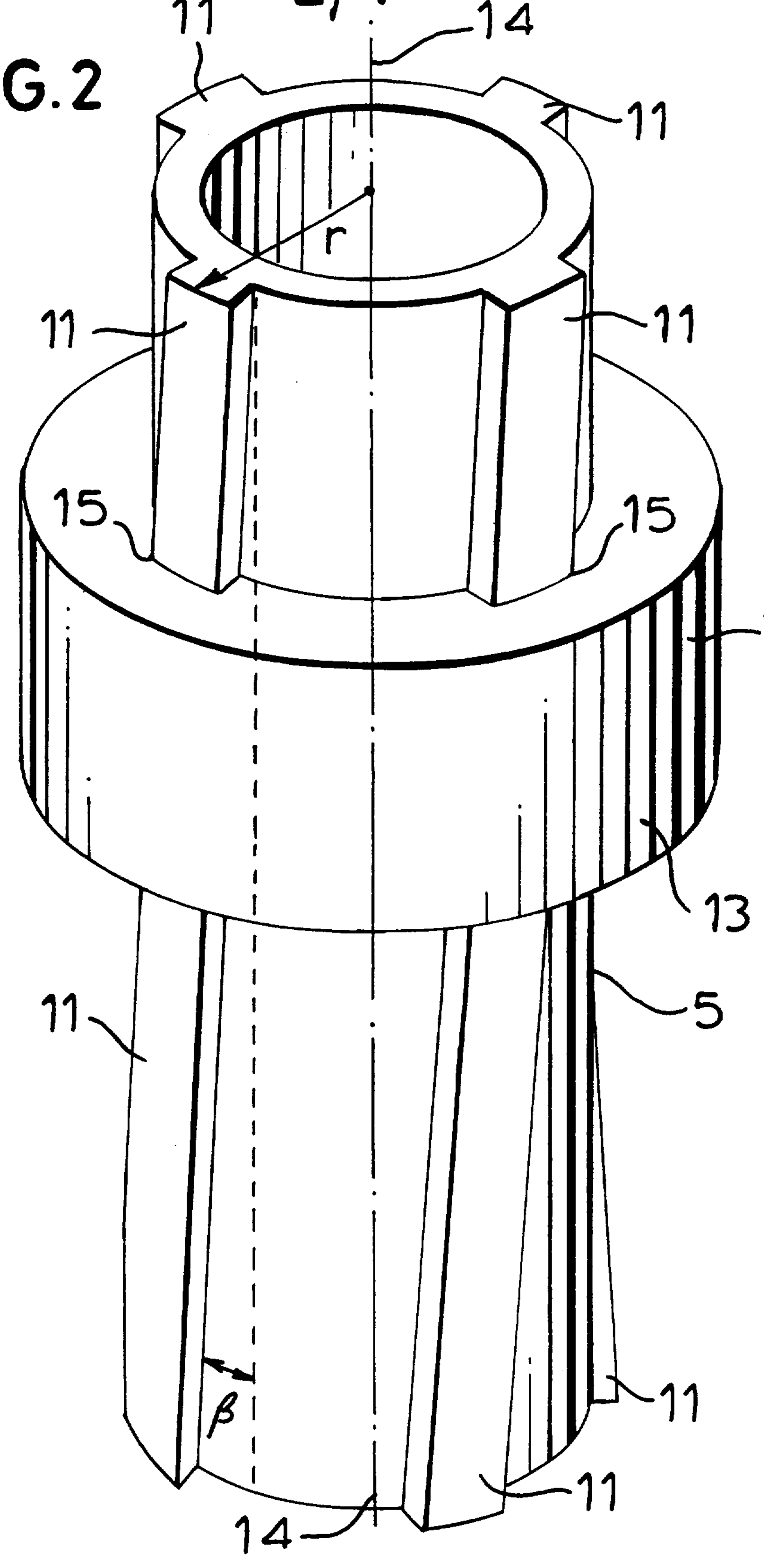


FIG. 3

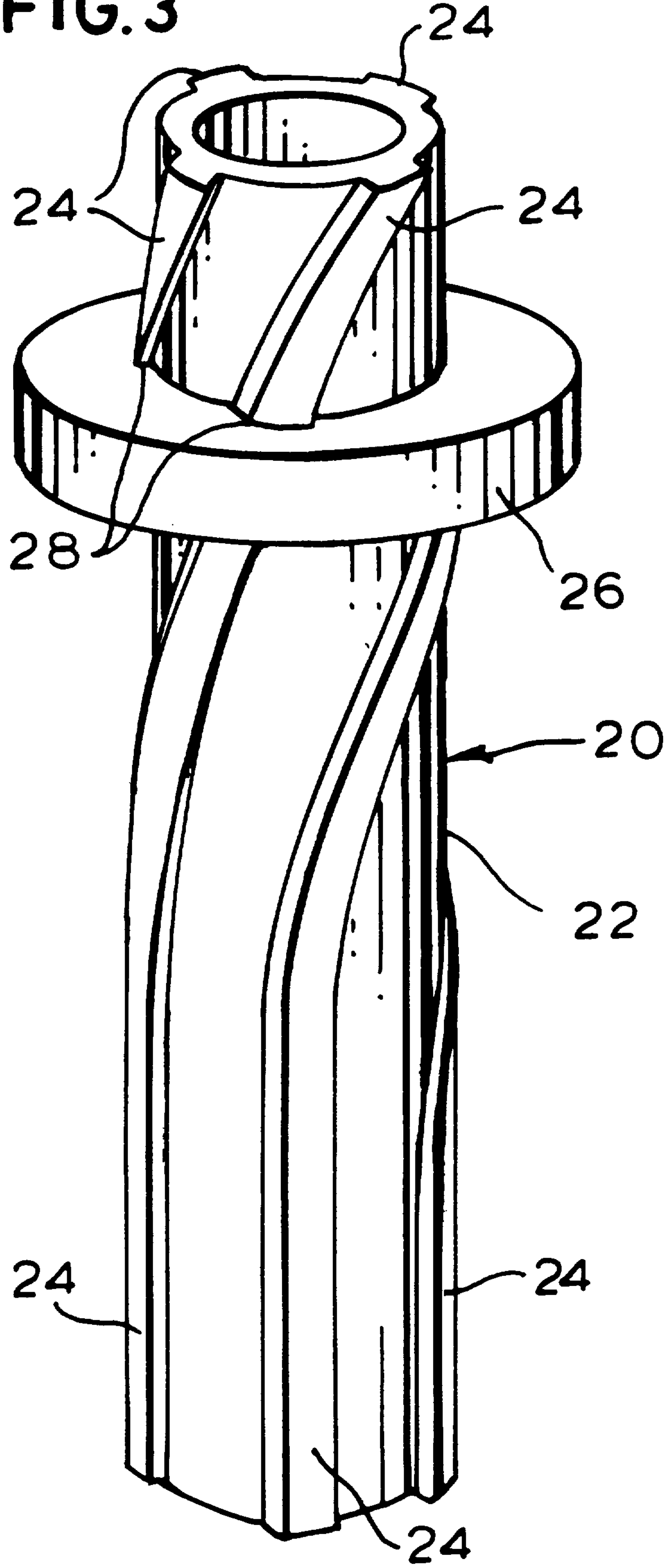


FIG. 4

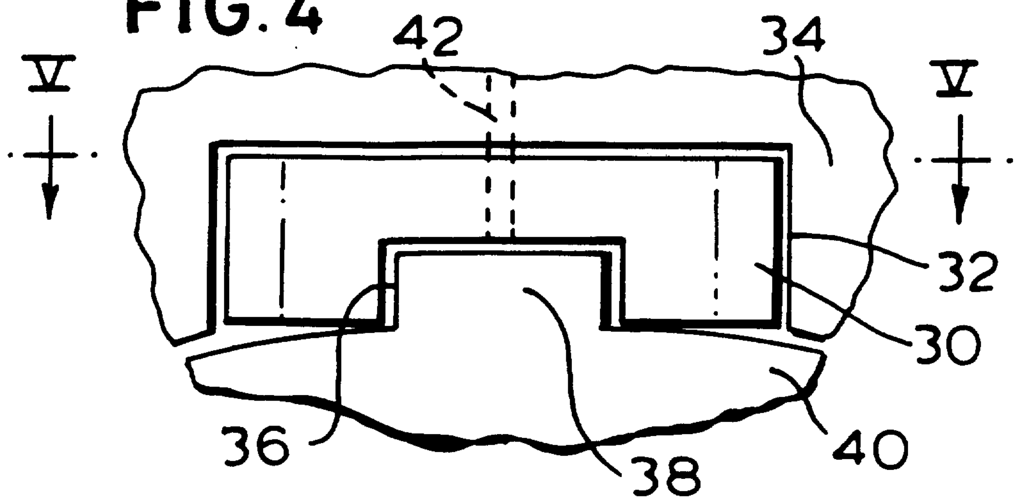
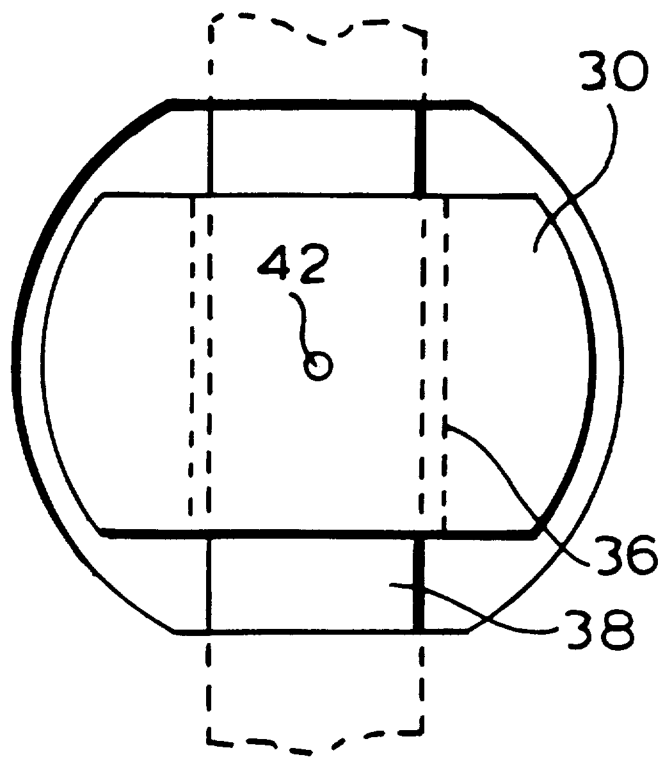
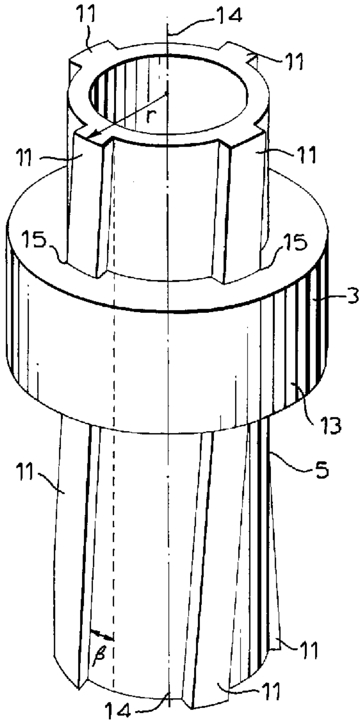


FIG. 5





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