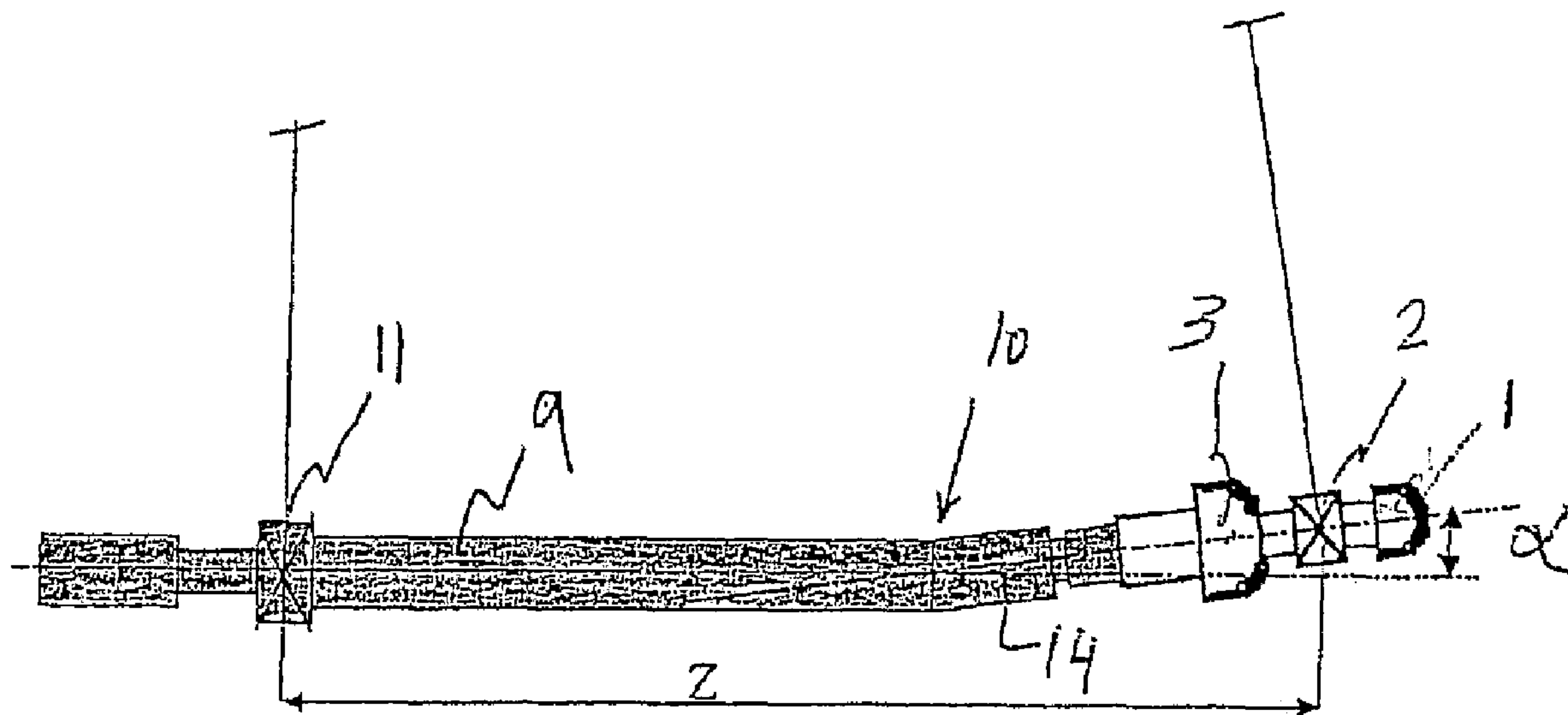




(86) Date de dépôt PCT/PCT Filing Date: 2004/05/18
(87) Date publication PCT/PCT Publication Date: 2004/12/02
(45) Date de délivrance/Issue Date: 2012/08/28
(85) Entrée phase nationale/National Entry: 2005/11/14
(86) N° demande PCT/PCT Application No.: EP 2004/050834
(87) N° publication PCT/PCT Publication No.: 2004/104360
(30) Priorités/Priorities: 2003/05/21 (EP03076533.3);
2003/10/01 (EP03103639.5)

(51) Cl.Int./Int.Cl. *E21B 7/06* (2006.01),
E21B 10/26 (2006.01)
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(54) Titre : FORET ET SYSTEME POUR PERCER UN TROU
(54) Title: DRILL BIT AND SYSTEM FOR DRILLING A BOREHOLE



(57) Abrégé/Abstract:

A drill bit having a central longitudinal axis and comprising: - a pilot section (1) for drilling a pilot bore section of the borehole; - an under-reaming section (3) in a following position with respect to the pilot section (1); - a connecting shaft (4) extending between the pilot section (1) and the under-reaming section (3); - a stabilising section (2) located between the pilot section (1) and the under-reaming section (3), wherein the stabilising section (2) fits inside the pilot bore section and is capable of laterally stabilising the drill bit while allowing rotation of at least the pilot section (1).

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
2 December 2004 (02.12.2004)

PCT

(10) International Publication Number
WO 2004/104360 A3

(51) International Patent Classification⁷: **E21B 7/06**, 10/26

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(21) International Application Number:

PCT/EP2004/050834

(22) International Filing Date: 18 May 2004 (18.05.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

03076533.3 21 May 2003 (21.05.2003) EP

03103639.5 1 October 2003 (01.10.2003) EP

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

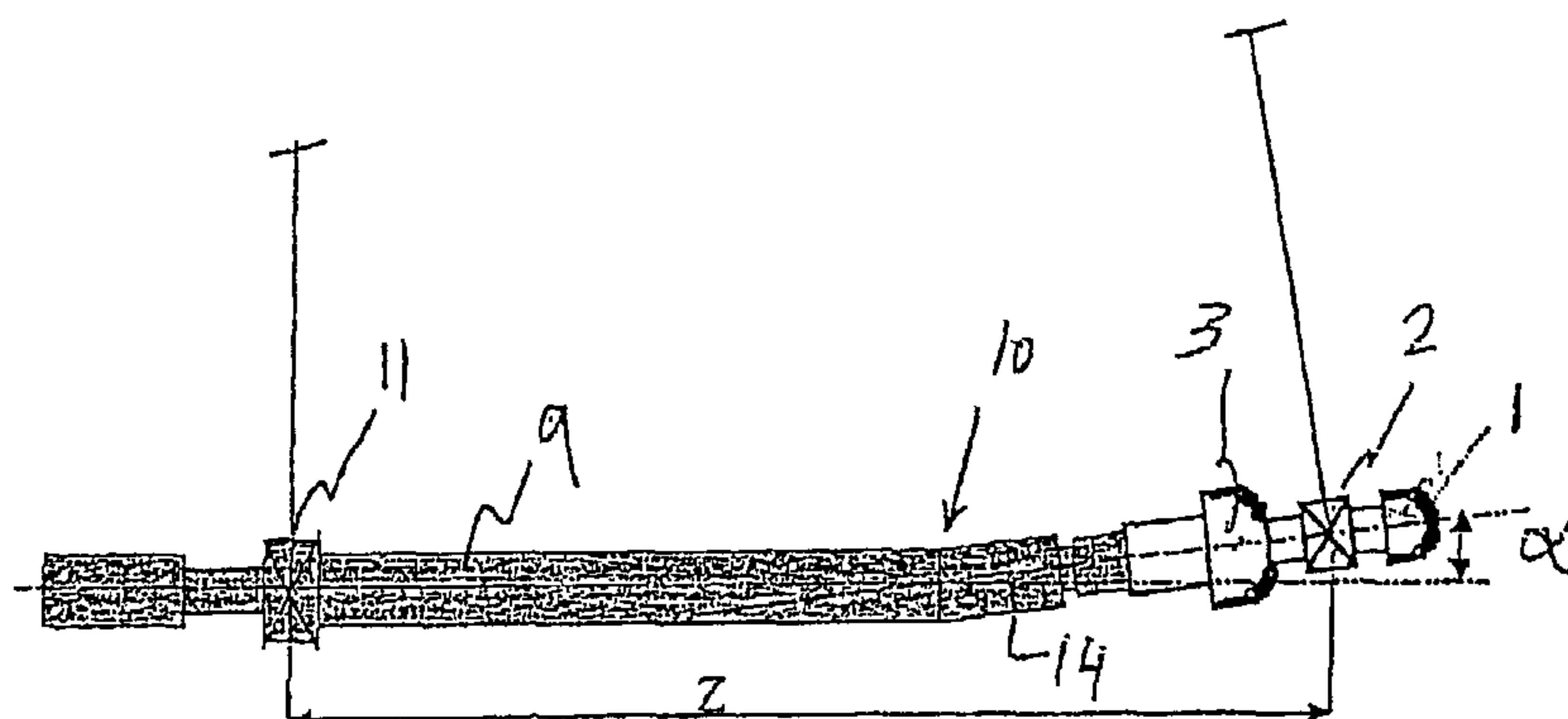
- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

(88) Date of publication of the international search report:

6 January 2005

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: DRILL BIT AND DRILLING SYSTEM WITH UNDER-REAMER- AND STABILISATION-SECTION



(57) Abstract: A drill bit having a central longitudinal axis and comprising: - a pilot section (1) for drilling a pilot bore section of the borehole; - an under-reaming section (3) in a following position with respect to the pilot section (1); - a connecting shaft (4) extending between the pilot section (1) and the under-reaming section (3); - a stabilising section (2) located between the pilot section (1) and the under-reaming section (3), wherein the stabilising section (2) fits inside the pilot bore section and is capable

of laterally stabilising the drill bit while allowing rotation of at least the pilot section (1).

DRILL BIT AND SYSTEM FOR DRILLING A BOREHOLE

The present invention relates to a drill bit for drilling a borehole in an object, the drill bit generally extending around a central longitudinal axis, and to a system for drilling a borehole in an object.

5 US patent 4,492,276 describes a known drilling system with a known drill bit. The known drilling system comprises an elongate rigid housing with a main central longitudinal axis to which the known drill bit with its own longitudinal axis is coupled such that its axis is
10 under a non-zero tilt angle with respect to the main central longitudinal axis. The drill bit is mounted in a bearing housing on the elongate housing. The elongate housing is provided with a mud motor that can independently drive the drill bit from the rotation of
15 the drill string. A string stabiliser is provided on the top end of the elongate housing and a bearing housing stabiliser is provided near or on the bearing housing relatively close to the drill bit.

For drilling a straight hole, the bearing housing
20 stabiliser and the string stabiliser are activated to engage with the object where the borehole is being drilled in. At the same time as driving the drill bit, the string is rotated thereby driving the elongate housing into rotation independently from the mud motor
25 action. This is called super-imposed rotation while drilling mode. For allowing the elongate housing to rotate, the string stabiliser and the bearing housing stabiliser are both provided with bearings. In sliding drilling mode, the drill string is not rotated, resulting

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in a curved borehole being drilled by the drill bit as a consequence of it being mounted under an angle and being laterally supported by the bearing housing stabiliser.

The known system has various disadvantages.

5 Firstly, when switching from super-imposed rotary drilling to sliding mode drilling ledges are created in the hole which tend to hold-up the assembly and jeopardize directional performance. Associated with the creation of the ledges, large side forces are applied to
10 the bit/output shaft of the mud motor.

Secondly, in super-imposed rotary drilling mode an over gauge hole is drilled which may have a drift diameter smaller than the nominal hole size. This phenomenon is caused by hole spiralling.

15 Thirdly, for standard mud motors, a restricted height is available for the bit because the distance between the bearing housing stabiliser and the drill bit largely governs the directional characteristics of the system.

And lastly, in a significantly over gauge hole the
20 bearing housing stabiliser does not contact the hole wall anymore which makes the system ineffective.

It is an object of some embodiments of the invention to provide a drilling system and a drill bit for over gauge drilling, that can in particular be used for
25 directional over gauged drilling.

According to a first aspect of the invention there is provided a drill bit for drilling a borehole in an object, the drill bit having a central longitudinal axis and comprising:

- 30 - a pilot section for drilling a pilot bore section of the borehole in the object;
- an under-reaming section in a following position with respect to the pilot section, the cutting

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diameter D_u of the under-reaming section being larger than the cutting diameter D_p of the pilot section;

- a connecting shaft extending between the pilot section and the under-reaming section;
- a stabilising section located between the pilot section and the under-reaming section, wherein the stabilising section fits inside the pilot bore section and is capable of laterally stabilising the drill bit relative to the object while allowing rotation of at least the pilot section relative to the object.

According to a second aspect of the invention, there is provided a system for drilling a borehole in an object, the system comprising a drill bit in accordance with the first aspect of the invention, which drill bit is coupled to an elongate extension member whereby the central longitudinal axis of the drill bit extends under a specified included tilt angle greater than zero with respect to the main longitudinal axis of the elongate extension member, whereby the pilot section and the under-reaming section of the drill bit are driven independently from rotational movement of the extension member.

It has been found that by provision of the stabilisation section between the pilot and the under-reaming section, a straight hole can be drilled using super-imposed rotation while drilling mode without any further stabilising means, and a curved hole can be drilled using sliding mode drilling. Thus, at least the bearing housing stabiliser, which causes most problems in the prior art system, can be omitted.

Suitably said rotation comprises rotation about the central longitudinal axis of the drill bit.

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In some embodiments, said rotation comprises rotation about an axis extending in lateral direction of the drill bit.

5 In some embodiments, the pilot section is rotatable about said lateral axis relative to the stabilising section.

10 In some embodiments, the pilot section is rotatable about the central longitudinal axis relative to the stabilising section. To allow selective locking out of such rotation, suitably the drill comprises locking means for selectively disabling rotation of the pilot section about the central longitudinal axis relative to the stabilising section.

15 If the drill bit is operated to drill a curved borehole section whereby the drill bit is tilted relative to an upper section of the drill string, there can be a tendency of the drill bit to drill in a direction perpendicular to the plane formed by the intended curved borehole section. Such tendency is caused by an increased drag force at one side of the drill bit due to tilting of the drill bit in the borehole. In order to limit such tendency it is preferred that the stabilising section is positioned such that L_1 is larger than L_2 , wherein

25 L_1 = the distance between the operative centre of the stabilising section and the operative centre of the pilot section;

L_2 = the distance between the operative centre of the stabilising section and the operative centre of the under-reaming section.

30 It is thereby achieved that the increased drag force at one side of the pilot section due to tilting, is substantially cancelled by the increased drag force at one side of the under-reamer section due to tilting,

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whereby said respective increased drag forces act in mutually opposite directions.

In some embodiments, the cutting diameter (D_p) of the pilot section is larger than half the cutting diameter (D_u) of the under-reaming section, and wherein the stabilising section is positioned such that L_2 is larger than half L_1 .

5 In some embodiments, the stabilising section is positioned such that the ratio L_2/L_1 is substantially equal to the ratio D_p/D_u .

According to one aspect of the present invention, there is provided a drill bit for drilling a borehole in an object, having a central longitudinal axis and comprising: a pilot section with a cutting diameter D_p for drilling a pilot bore section of
10 the borehole in the object; an under-reaming section with a cutting diameter D_u in a following position with respect to the pilot section, the cutting diameter D_u of the under-reaming section being larger than the cutting diameter D_p of the pilot section; a connecting shaft extending between the pilot section and the under-reaming section; a stabilising section located between the pilot section and the under-reaming section,
15 wherein the stabilising section fits inside the pilot bore section and laterally stabilizes the drill bit relative to the object while allowing rotation of at least the pilot section relative to the object, wherein the stabilising section and the pilot section are substantially concentrically arranged; and wherein the pilot section is rotatable about the central longitudinal axis relative to the stabilising section; further including a
20 locking means for selectively disabling rotation of the pilot section about the central longitudinal axis relative to the stabilising section.

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The invention will be described hereinafter in more detail and by way of example with reference to the accompanying drawings in which:

5 Fig. 1 schematically shows a general cross sectional view of a drill bit according to the invention;

Fig. 2 schematically shows a cross section of an embodiment;

Fig. 3 schematically shows generally a drilling system;

10 Fig. 4 explains the drilling bit orientation with respect to the hole in case of sliding mode drilling;

Figs. 5a and 5b respectively illustrate the drag forces on the under-reaming section cutters and the pilot section cutters; and

15 Fig. 6 illustrates the geometry of the drilling system for minimising the wear and tear on the lateral stabilisation section of the drill bit.

In the Figures like reference numerals relate to like components.

20 In the example, the object is formed by an earth formation and the drill bit is in particular suitable for drilling a borehole into an earth formation.

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Referring to Fig. 1 there is shown a drill bit comprising a pilot section 1, a lateral stabilisation section 2, an under-reaming section 3 and a connecting shaft 4 extending between the pilot section 1 and the under-reaming section 3 and rigidly connecting these parts. The pilot section 1 and the under-reaming section 3 are provided with cutters 5. These cutters 5 can be of any suitable type. Such a drill bit is useable for drilling a borehole in an object.

Generally, the lateral stabilisation section 2 is arranged to support lateral loads from the drilling system or lateral loads from the drilling action of the pilot section 1 and under-reaming section 3, without cutting rock in the direction of the lateral load. There are various embodiments to achieve this.

In a first embodiment, a stabiliser blade arrangement with 360 degrees azimuth coverage is provided, whereby the blades are equipped with wear resistant elements having poor cutting properties in lateral direction. Such wear resistant elements can for instance be formed of diamonds set with the flat face towards the wall of the hole. Depending on the axial cross sectional contour of the blade arrangement, the lateral stabilisation section can be axially rotatable inside the borehole with respect to the object, or laterally rotatable, or both. For both lateral and axial rotatability, the contour should have an essentially spherical waist such as a melon-type shape to optimise the sliding performance. For axial rotatability only, the contour can have a straight axial section such that the blades together form an essentially cylindrical surface against the object around the central axis. In the latter case, the leading edge of the blades, which can be the end of the blades closest to the pilot

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section, may be inwardly tapered to facilitate axial slidability.

5 The slots between the stabilisation blades enable mud to pass. Alternatively, a number of axial holes can be provided in a full annular bladeless stabiliser arrangement.

10 In a second embodiment, the lateral stabilisation section includes an outer part 6 which is mounted rotatably with respect to the connecting shaft 4 between the pilot section 1 and the under-reaming section 3. This part can be a sleeve type part which is mounted rotatably around the connecting shaft 4. In this embodiment, the sleeve does not have to rotate in the borehole during drilling, and it only slides in along the hole direction
15 which eliminates any cutting capability. Also in this embodiment, means for allowing passage of mud should be provided.

20 Preferably, locking means are provided which allows for locking the sleeve against the connecting shaft. In this way, the sleeve can rotate temporarily in the borehole if desired which can be made use of for instance for drilling out a blocking area that may be present in the borehole above the pilot section. When locked, at least the axial rotability of the pilot section with
25 respect to the stabilising section is disabled so that both are rotated together.

30 In a third embodiment, the outer part is mounted rotatably around a ball joint section in the connecting shaft. This enables both axial rotatability of the connecting shaft 4 with respect to the outer part and tiltability, or lateral rotatability. Fig. 2 shows an example of the third embodiment, whereby sleeve 6 is rotatably mounted to a ball joint 7 provided in the

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connecting shaft 4. Sleeve 6 and ball joint 7 interact via any bearing surface allowing for both rotation about the central longitudinal axis of the drill bit and about an axis orthogonal to that.

5 Optimum sliding performance of the embodiment of Fig. 2 is achieved for a cylindrical section with a tapered leading edge 8.

10 As indicated in Fig. 1, the distance between the centres of the cutting structures of the pilot section 1 and under-reaming section 3 is defined as L , and the distance between the centre of the pilot section 1 and the lateral stabilisation section 2 is defined as L_1 . The gauge of the pilot section 1 is defined as D_p and the gauge of the under-reaming section 3 is defined as D_u . In
15 the present example the lateral stabilisation section 2 has the same nominal diameter as the gauge of the pilot section 1, but it may also be under-gauged or over-gauged if desired.

20 Fig. 3 shows schematically a drilling system including one of the above described drilling bits arranged for achieving a steerability of the drilling system. There is an elongate extension member 9 in the form of a positive displacement motor (PDM), which can be a PDM mud motor. The drill bit is coupled to the elongate
25 extension member 9 via bearing housing 14. The PDM is arranged to drive a drive axis inside a housing. The drive axis (not shown) is rotatable relative to the housing and it is coupled to the drill bit for driving at least the pilot section 1 into rotation relative to the
30 housing. The elongate extension member 9 is provided with an activatable string stabiliser 11. The housing is provided with a knee 10, such that the bearing housing 14, and consequently the drill bit, is coupled to

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the elongate extension member 9 under an angle $\alpha > 0^\circ$. The plane defined by the centre line of the PDM mud motor housing and the centre line of the bearing housing is referred to as the tool face plane.

5 The drilling system of Fig. 3 is steerable in the following way. In operation, the PDM rotates the pilot section 1 and the under-reaming section 3 of the drill bit via the drive axis inside the housing. When the drill string is lowered without rotation, the drilling assembly
10 engages in a sliding mode with the earth formation to be drilled. As a result of the knee 10 in the drilling system, the drill bit drills under an angle with respect to the main axis of the elongate extension member 9, as a result of which the borehole will proceed in a under an
15 angle with the elongate extension member. At the same time the stabiliser 11 is sliding down the under-reamed section of the borehole. The overall result of the movement of the drilling assembly is that the borehole progresses in curved fashion. This is referred to a
20 sliding mode drilling. When, on the other hand, the extension member and the housing are rotated essentially about the main longitudinal axis for instance by rotationally driving the drill string, the drill bit will be forced into a wobbling motion whereby the lateral
25 stabiliser 2 acts as a wobbling centre. This causes super imposed rotary drilling and is referred to as rotation while drilling mode. On average, the drilling system will proceed in a straight path because there is no preferential direction for the knee 10.

30 The stabiliser 11 can be an expandable stabiliser of which the diameter can be increased compared to that while running the assembly in the hole, or a fixed stabiliser, such as a wear pad, to function as a support

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point for the drilling assembly. For facilitating the rotating while drilling mode, the pilot section 1 is preferably laterally rotatable, or tiltable, with respect to the lateral stabiliser 2. In particular, an embodiment wherein the pilot section 1 is laterally rotatable with respect to the stabilising section 2 ensures proper wobbling. In the latter case, the lateral stabiliser 2 is operative in sliding mode with respect to the earth formation.

In the system described above, the bearing housing is fixedly coupled to the elongate extension member. Alternatively, the drilling bit of the invention can be run on a rotary steerable drilling system whereby the drill string rotates continuously but the direction of the knee or the tool face can be operated in rotating mode or in fixed mode. In fixed mode, the elongate extension member rotates with respect to the knee whereby the azimuthal direction of the knee with respect to the borehole in the object is fixed to point the bit in a fixed direction. In rotating mode, the knee rotates together with string on command. The latter causes the wobbling of the bit and thus straight hole drilling.

The radius of curvature, or build-up rate, of the hole drilled by the drilling system is a function of the governing system parameters. The build-up rate of the assembly in sliding drilling mode is governed by the following parameters, assuming the lateral stabilisation section of the bit does not have any lateral drilling ability:

- the bend-angle of the bearing housing relative to the stator housing of the PDM mud motor; and

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- the along hole distance between the lateral stabilisation section 2 of the bit and the string stabiliser 11 above the PDM mud motor.

Any clearance of the string stabiliser 11 above the PDM mud motor will increase the build-up rate, and the fact that the bit has to be slightly tilted in the hole are two second order parameters with opposite effects on the build-up rate and are not considered any further here.

When the drilling system is drilling in sliding mode, as explained above, the bit is slightly tilted in the hole to ensure a circular arc is drilled. The bit hinges about the stabilising section 2. The impact of this on the drilling forces deviations compared to those representative for straight drilling are illustrated in Figs. 5a and 5b on the basis of the drilling of a build-up section.

To achieve a build-up section, the centre line of the bit has to make a small tilt angle (ϕ) with the centre line of the hole at the depth of the bit (see Fig. 4). This implies that the workload of all the pilot section cutters 5 located below the centre line of the bit is reduced by a certain amount represented by section 12 of the small circle in Fig. 5b. The reduction in total drag force of these cutters, dF_p , is pointing left when viewing along the bit centerline in the drilling direction. Similarly the work load of all the cutters above the centre line of the pilot section will increase by a small amount resulting in a resulting drag load increase of $+dF_p$ also pointing left (see Fig. 5b).

The under-reaming section 3 faces similar deviations in total drag load above and below the centre line, as is illustrated by section 13 in Fig. 5a.

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These deviations can cause the drill bit to walk, which means that the drilling system does not drill a curved trajectory in one azimuthal plane but that the drill bit has a tendency to deviate in a direction perpendicular to this tool face plane. In that case the bit has a tendency to change the azimuth of the hole.

The deviations can be quantified as follows:

$$dF_p = K_{lp} \times \phi \times L_1 \times D_p \quad (1)$$

wherein

K_{lp} is a constant representing the effect of cutting structure of pilot section 1 and formation drillability on cutting loads;

ϕ is the tilt angle of the bit in the hole being defined as the angle between the center line of the bit and the hole at the location of the centre of the stabilisation section;

L_1 is the distance between centre of the pilot cutting structure and the stabilization section 2; and

D_p is diameter of pilot section 1;

and

$$dF_u = K_{lu} \times \phi \times (L - L_1) \times D_u \quad (2) \text{ wherein}$$

K_{lu} is a constant representing the effect of cutting structure of under-reaming section 3 and the formation drillability on cutting loads;

L is the distance between the center of the pilot cutting structure and the under-reaming cutting structure as indicated in Fig. 1; and

D_u : diameter of the hole.

The walking tendency of the bit is eliminated in case the following equilibrium applies:

$$dF_p = dF_u \quad (3).$$

Formulas (1) and (2) are considered adequate representations because the drag load acting on the

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respective drill bit sections increases with increasing cutting depth, and because the cutting depth is substantially linearly dependent on the diameter of the respective drill bit section (i.e. pilot section or
 5 under-reamer section) and the tilt angle ϕ of the drill bit in the borehole.

This implies for the location of the lateral stabilization section 2:

$$L/L1 = 1 + K1u/K1p * Dp/Du \quad (4).$$

10 Assuming identical cutting processes for pilot section 1 and under-reaming section 3, this relation simplifies to:

$$L/L1 = 1 + Dp/Du \quad (5).$$

Thus, it is preferred that the geometry of the drilling bit is sufficiently close to this ideal relationship,
 15 with the advantage that the system drills only in the tool face plane.

When the "no walk" criterion is met as is discussed above, a minimum wear-and-tear criterion in azimuthal direction is also met because the bit is force-balanced
 20 in this direction as per equation (4).

In the vertical plane the bit should also be force balanced while being tilted in the hole. The design equation that achieves this is presented following the same approach as before for the "no walk" criterion.

25 Referring now to Fig. 6, dNu represents the total normal force increase acting on the cutters below the center line of the under-reaming section 3 of the bit associated with dFu in Fig. 5a. The same relation can be defined for the pilot section 1 between dNp and dFp .

30 These relations can be expressed as:

$$dNu = K2u \text{ (cutting structure)} \times dFu \quad (6)$$

$$dNp = K2p \text{ (cutting structure)} \times dFp$$

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The forces dN_u and dN_p apply at an angle with the centerline of the bit. This angle is governed by the profile of the bit section. The lateral component of these forces can be expressed as:

$$5 \quad dN_{ul} = dN_u \times K_{3u} \text{ (cutting profile)} \quad (7)$$

$$dN_{pl} = dN_p \times K_{3p} \text{ (cutting profile)}$$

The minimum wear-and-tear criterion in the vertical plane, which is the tool face plane, is met when

$$dN_{ul} = dN_{pl} \quad (8),$$

10 and assuming that equation (3) is met, this yields:

$$K_{2u} \times K_{3u} = K_{2p} \times K_{3p} \quad (9).$$

In case identical cutting structures in terms of, for instance, type of cutting elements and back rake angles, are applied in the pilot section 1 and under-reaming section 3, this requirement simplifies to

$$15 \quad K_{3u} = K_{3p} \quad (10).$$

The parameters K_1 , K_2 , K_3 for under-reaming section 3 and pilot section 1 can be calculated for a specific bit design using bit force calculation software packages.

20 The shown embodiments provide relatively cheap steerable drilling systems suitable for directional over gauge drilling. The need for a bearing housing stabiliser is eliminated. The functionality of such a bearing housing stabiliser is taken over by the lateral stabilisation section 2 located between the pilot section 1 and the under-reaming section 3 of the drilling bit. This has several advantages:

- large lateral drilling forces acting on the PDM mud motor bearing section are eliminated;
- 30 - in super-imposed rotary drilling mode the hole is only marginally over gauge (in the order of millimetres), so that consequently the ledges formed

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in the hole when switching from rotary to sliding drilling mode are minimal;

- spiralling will not occur because of the small distance between the lateral stabilisation section and the cutting elements of the bit hole, resulting in a smoother borehole;
- the drilling system allows for longer bits without significantly affecting the directional drilling characteristics of the system;
- the drilling system provides a reliable directional drilling technique even for drilling operations involving a large under-reaming component;
- large lateral loads on the bearings of a steerable PDM mud motor are eliminated.

The embodiments described above serve as non-restrictive examples only. In particular the invention also embraces roller cone drilling bits and hybrid drilling bits having a drag pilot section and a roller cone under-reaming section or vice versa.

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CLAIMS:

1. A drill bit for drilling a borehole in an object, having a central longitudinal axis and comprising:

5 a pilot section with a cutting diameter D_p for drilling a pilot bore section of the borehole in the object;

an under-reaming section with a cutting diameter D_u in a following position with respect to the pilot section, the cutting diameter D_u of the under-reaming section being larger than the cutting diameter D_p of the pilot section;

10 a connecting shaft extending between the pilot section and the under-reaming section;

a stabilising section located between the pilot section and the under-reaming section, wherein the stabilising section fits inside the pilot bore section and laterally stabilizes the drill bit relative to the object while allowing rotation of at least the pilot section relative to the object,

15 wherein the stabilising section and the pilot section are substantially concentrically arranged; and

wherein the pilot section is rotatable about the central longitudinal axis relative to the stabilising section;

20 further including a locking means for selectively disabling rotation of the pilot section about the central longitudinal axis relative to the stabilising section.

2. The drill bit of claim 1, wherein said rotation comprises rotation about the central longitudinal axis of the drill bit.

3. The drill bit of claim 1, wherein said rotation comprises rotation about an axis extending in lateral direction of the drill bit.

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4. The drill bit of claim 3, wherein the pilot section is rotatable about said lateral axis relative to the stabilising section.

5. The drill bit of claim 1, wherein the pilot section and the under-reaming section are rigidly connected to each other via the connecting shaft.

5 6. The drill bit of one of claim 1, wherein the stabilizing section is positioned such that L_1 is larger than L_2 , wherein

L_1 = the distance between the operative center of the stabilising section and the operative centre of the pilot section;

10 L_2 = the distance between the operative center of the stabilising section and the operative center of the under-reaming section.

7. The drill bit of claim 6, wherein the cutting diameter (D_p) of the pilot section is larger than half the cutting diameter (D_u) of the under-reaming section, and wherein the stabilising section is positioned such that L_2 is larger than half L_1 .

15 8. The drill bit of claim 6, wherein the stabilising section is positioned such that the ratio L_2/L_1 is substantially equal to the ratio D_p/D_u .

FIG. 1

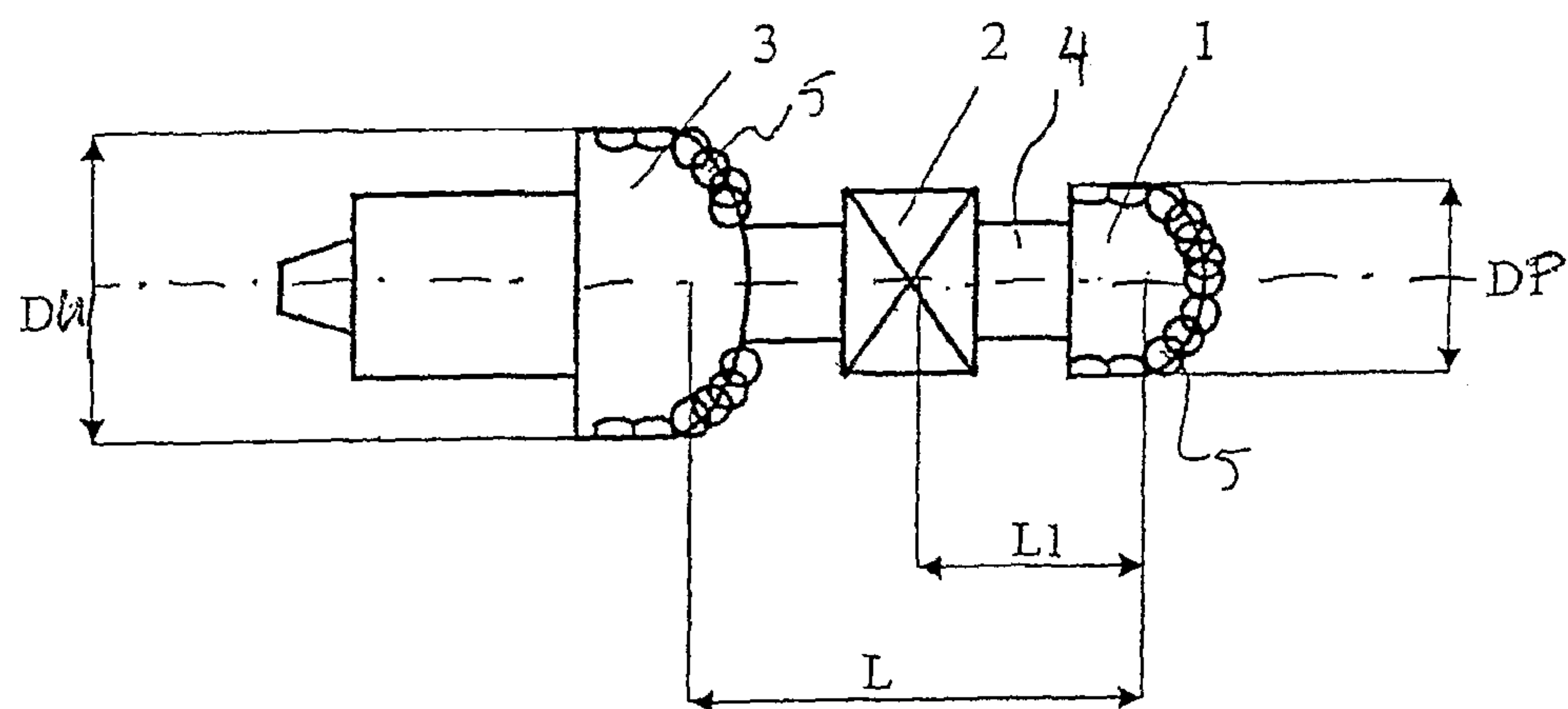


FIG. 2

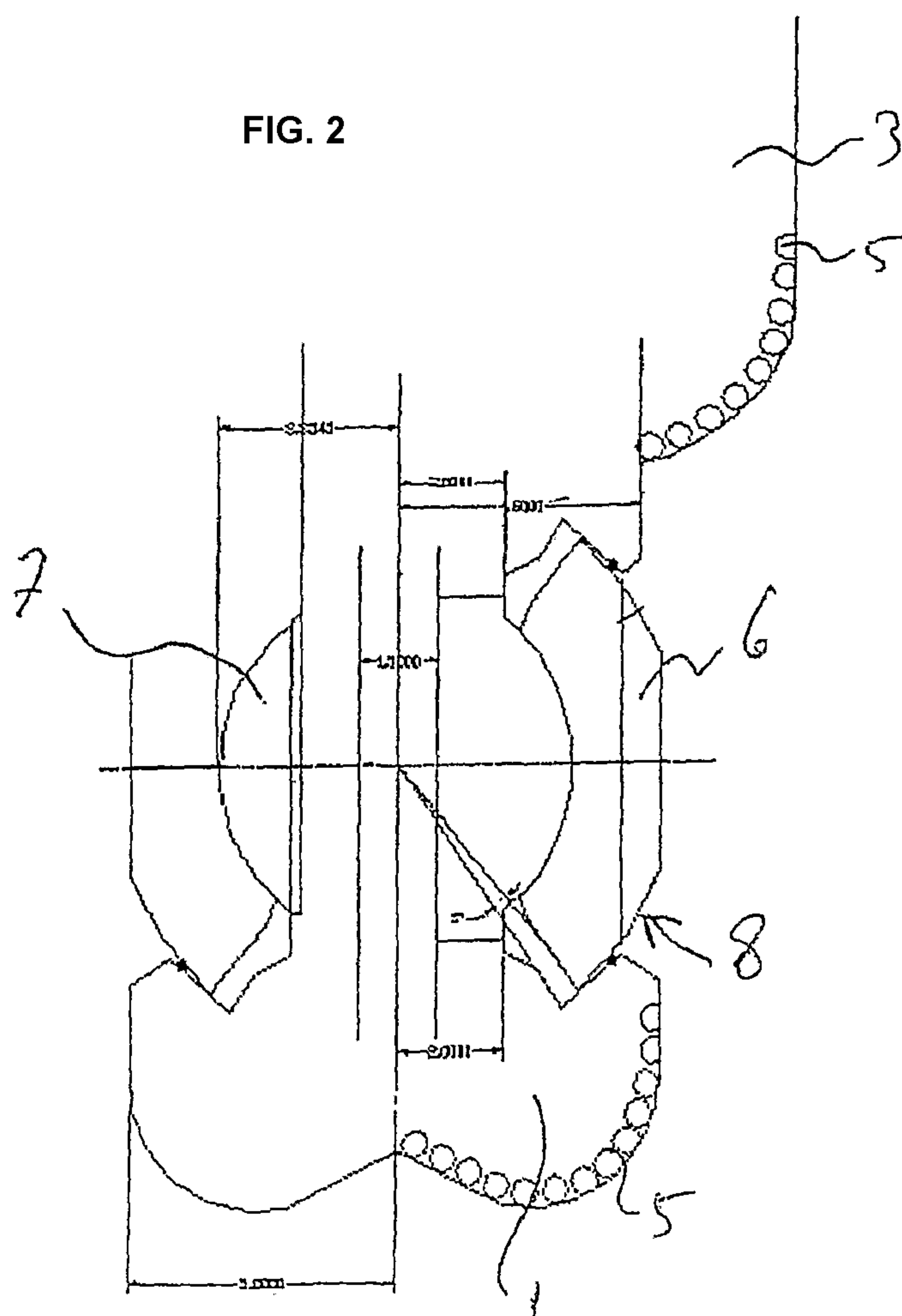


FIG. 3

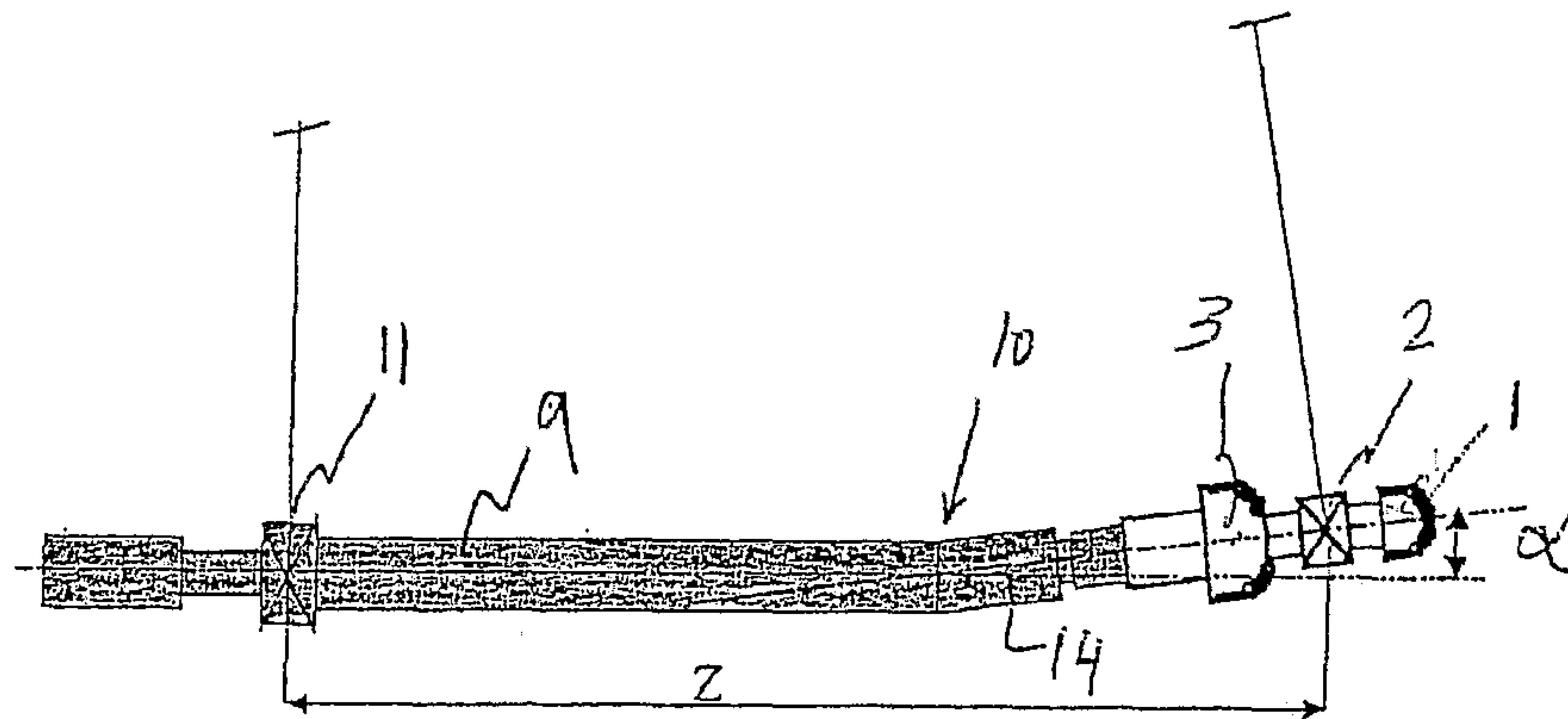


FIG. 4

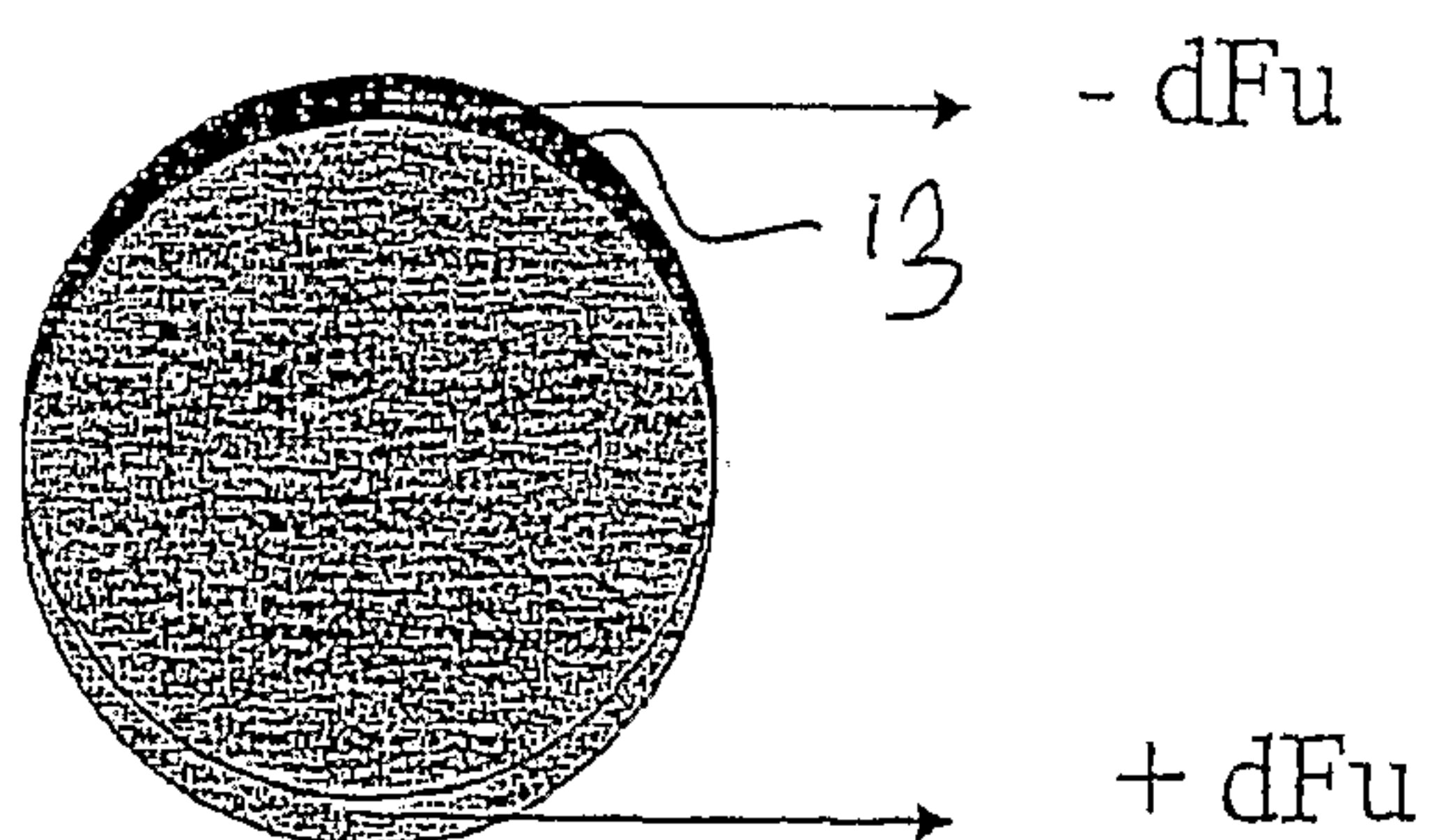
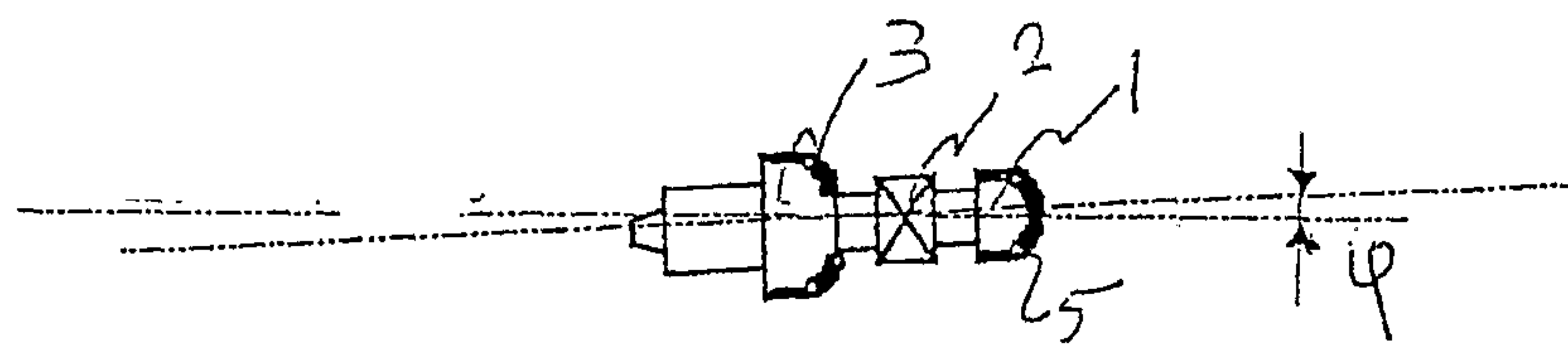


FIG. 5A

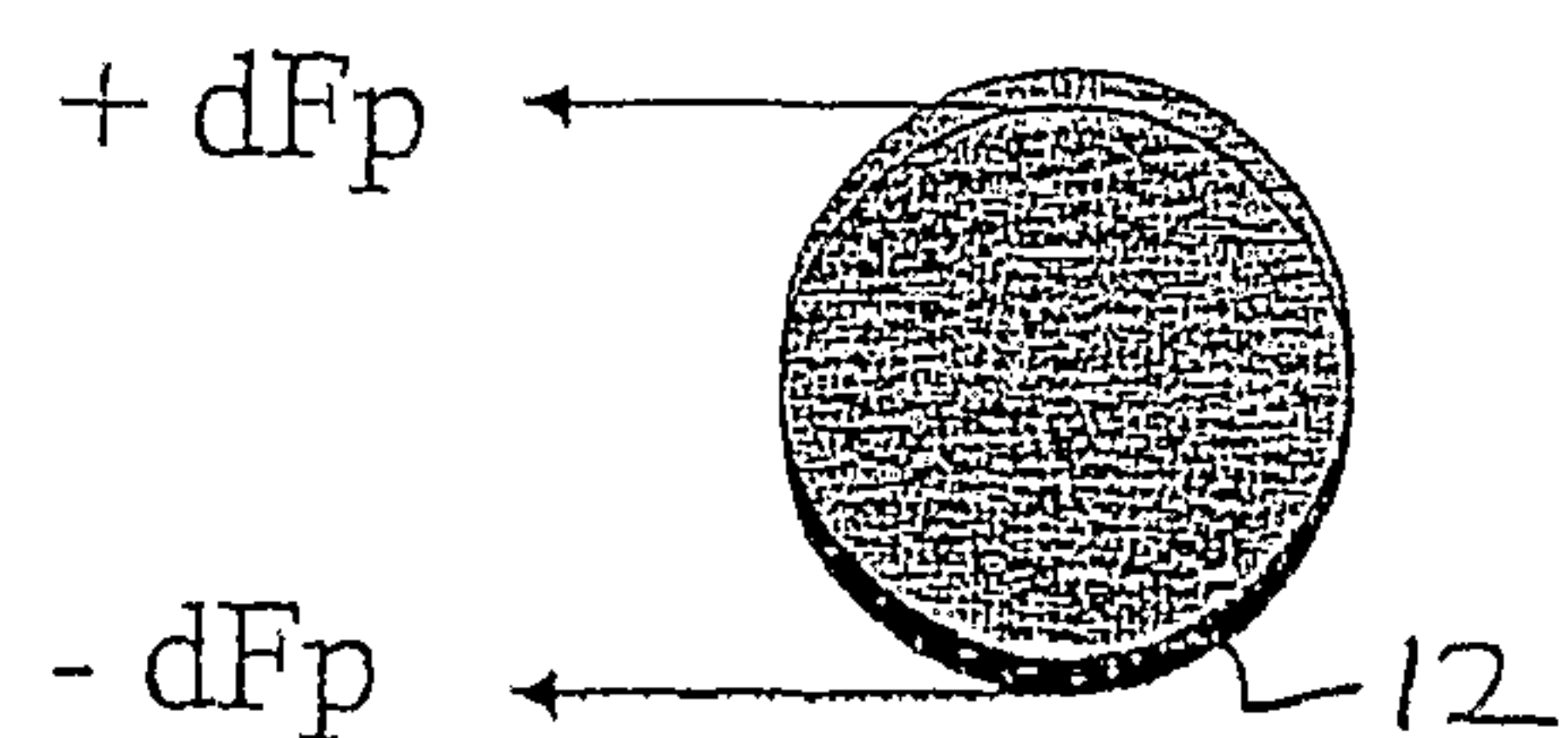


FIG. 5B

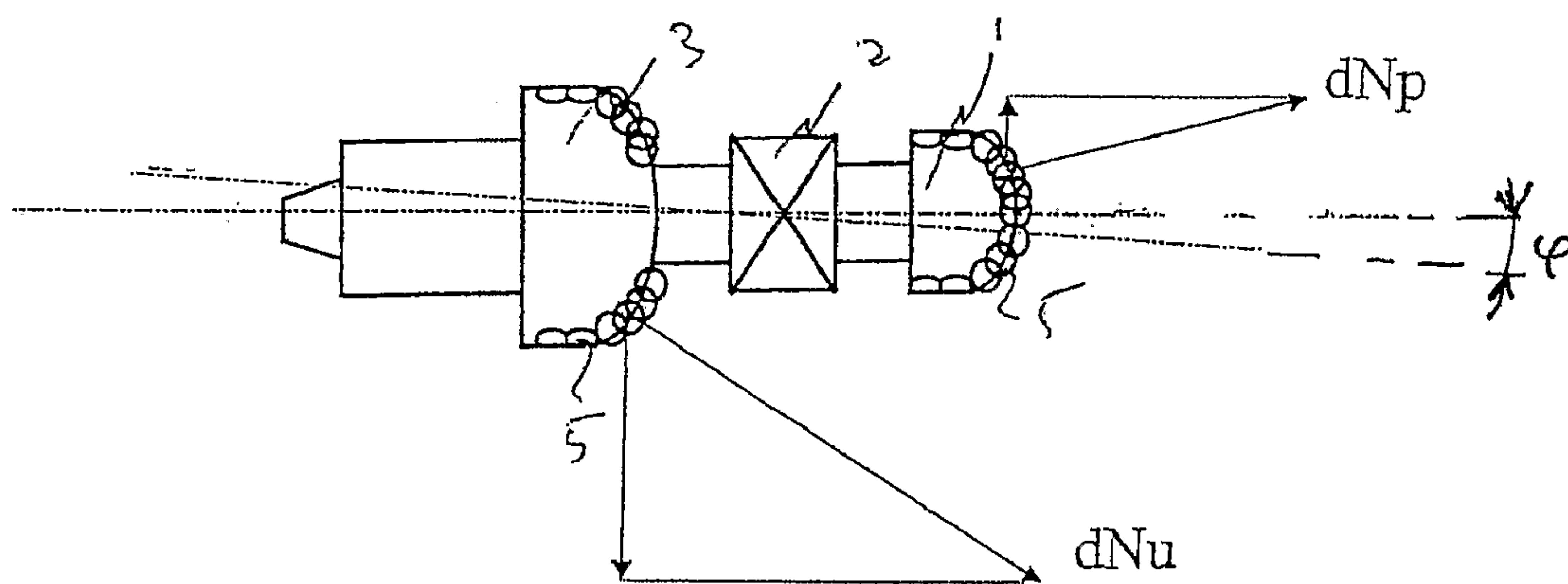


FIG. 6

