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(54) **Rotary drag-type drill bits and methods of designing such bits**

Drehbohr-Fräsmeissel und Verfahren zu deren Entwicklung

Trépans racleurs rotatifs et méthodes pour leur conception

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Description

[0001] The invention relates to the design of rotary drag-type drill bits for use in drilling holes in subsurface formations.

[0002] As is well known, drag-type drill bits comprise a bit body having a shank for connection to a drill string and a plurality of fixed cutters mounted on the bit body. A passage in the bit body supplies drilling fluid to nozzles in the surface of the bit for cleaning and cooling the cutters. In one common form of bit the bit body the leading face of the bit comprises a number of circumferentially spaced blades extending outwardly away from the central axis of rotation of the bit, cutters being mounted along each blade. In polycrystalline diamond compact (PDC) drill bits some or all of the cutters are preform cutters formed, at least in part, from polycrystalline diamond or other superhard material. One common form of cutter comprises a tablet, usually circular or part-circular, made up of a superhard table of polycrystalline diamond, providing the front cutting face of the cutter, bonded to a substrate which is usually of cemented tungsten carbide.

[0003] The bit body may be machined from solid metal, usually steel, or may be moulded using a powder metallurgy process in which tungsten carbide powder is infiltrated with a metal alloy binder in a furnace so as to form a hard matrix. The general design and methods of construction of such drill bits are well known and will not therefore be described in greater detail.

[0004] It is well known that rotary drag-type drill bits may under certain conditions, particularly at low rotary speeds, and high weight-on-bit, be subject to torsional vibration as a result of a phenomenon commonly referred to as "stick-slip".

[0005] In stick-slip the situation arises where the bottomhole assembly is rotating more slowly than the upper end of the drill string due, for example, to frictional torque acting on the bottomhole assembly, with the result that the drill string begins to wind up. Eventually, the torsional energy stored in the drill string is transferred to the bottomhole assembly and accelerates it to a rotary speed faster than the steady state rotary speed. This transfer of torsional energy from the drill string to the bottomhole assembly can occur periodically giving rise to torsional vibrations.

[0006] Such torsional vibration is undesirable since it can lead to rapid wear of PDC bits, particularly in harder formations, due to damage to the cutters as a result of impact loads caused by the torsional vibration. Torsional vibration can have the effect that cutters on the drill bit may momentarily stop or be rotating backwards, i.e. in the reverse rotational direction to the normal forward direction of rotation of the drill bit during drilling. The effect of such reverse rotation on a PDC cutter may be to impose unusual loads on the cutter which tend to cause spalling or delamination, i.e. separation of part or all of the polycrystalline diamond facing from the tungsten carbide substrate. It would therefore be desirable to be able to design rotary drag-type drill bits which will not be susceptible to stick-slip, or to be able to select from existing or proposed bit designs those which will be less susceptible to this phenomenon.

[0007] Hitherto, it has generally been considered to be desirable for rotary drag-type drill bits to be as dynamically stable as possible in order to minimise all types of vibration during drilling. It has also generally been considered desirable for drill bits to be dynamically balanced for the same reason, except in the case of so-called "anti-whirl" bit designs where a deliberately out-of-balance bit is designed so that the part of the periphery of the bit which is urged against the wall of the borehole by the net out of balance force is free of cutters so as to slide over the surface of the borehole.

[0008] The present invention is based on the surprising discovery that bits exhibiting lateral vibration which increases with rotary bit speed may be less susceptible to stick-slip than bits which do not exhibit this characteristic. It has been found that increase in lateral vibration with increasing rotary bit speed is correlated with increase in bit torque. When a bit having this characteristic is subject to the rapid increases in rotary speed which occur during stick-slip, the increase in torque which results from the increase in speed serves to provide positive damping of the torsional vibrations, with the result that the bit drills more efficiently and is less susceptible to damage. The reduction of torsional vibrations may also reduce the risk of fatigue in the drill string.

[0009] EP 0467580 describes a drill bit having its cutters arranged so as to cause a radial force imbalance.

[0010] The present invention makes use of this discovery in the design of drill bits, either by allowing to be selected for development and manufacture those proposed bit designs which are found to have the above characteristic, or by specifically designing drill bits, or associated downhole components, in a manner to ensure that the bit or component will exhibit such characteristic.

[0011] According to the invention there is provided a combination with a rotary drag-type drill bit of a device, and characterised in that the device is responsive to rotary bit speed and adapted to increase the bit torque with increase in bit speed, the rotary bit speed responsive device being provided either on the drill bit itself, or on an additional downhole component which, in use, rotates with the drill bit.

[0012] The rotary bit speed responsive device may include brake means adapted, in use, to bear on the formation being drilled with a force which increases with increase in rotary bit speed. The brake means may include elements which are displaced outwardly, with respect to the axis of rotation, to bear on the surrounding wall of the borehole in the formation being drilled. For example, the brake means may comprise a number of formation-engaging elements which are displaceable outwardly under the action of power means selected from: hydraulic pressure of drilling fluid supplied to the drill bit during drilling; a source of electrical power; axial motion of the drill bit under weight-on-bit.

[0013] In an alternative arrangement the rotary bit speed responsive device may comprise means to modify the orientation of a number of cutters mounted on the drill bit. For example, the device may be adapted to reduce the back-rake of cutters mounted on the drill bit with increasing rotary bit speed, since such reduction in back-rake will increase the bit torque.

[0014] Alternatively, or additionally the device may be adapted to increase the depth of cut of cutters mounted on the drill bit with increasing rotary bit speed.

[0015] In an alternative arrangement, the rotary bit speed responsive device may comprise means to increase the effective cutting diameter of the drill bit with increasing rotary bit speed. Such increase in effective cutting diameter will also increase the bit torque. In this case the nominal diameter of the drill bit is preferably the maximum effective cutting diameter permitted by the rotary bit speed responsive device. Thus, the drill bit will drill a full diameter hole when rotating at maximum speed, and will drill a slightly undersize hole when the bit speed drops below the maximum. Since the variation in effective cutting diameter will mean that some parts of the borehole will be undersize, it may be necessary subsequently to ream out these portions of the borehole to the full diameter.

[0016] In such an arrangement the drill bit may include a number of cutters or abrasion elements mounted on the bit body for movement inwardly and outwardly relative to the axis of rotation of the bit, the cutters or abrasion elements being moved outwardly in response to increasing rotary bit speed.

[0017] In another alternative arrangement according to the invention, the device responsive to rotary bit speed in order to increase the bit torque with increase in bit speed may comprise a mass rotatable with the bit and located outwardly of the axis of rotation of the bit. Such mass may be mounted in the bit body itself or in a further downhole component which is rotatable with the bit.

Brief description of the drawings:

[0018]

Figure 1 is a graph illustrating increase of lateral vibration with rpm in a rotary drag-type drill bit of low susceptibility to stick-slip;

Figures 2-5 are diagrammatic representations showing the increasing pattern of vibration with rpm in another drill bit of low susceptibility to stick-slip;

Figures 6 and 7 are graphical plots illustrating the correlation between torque and lateral vibration in a drill bit;

Figure 8 is a graph showing a plot of lateral vibration in a drill bit over time compared with increase in rpm over time;

Figure 9 is a corresponding plot of bit torque against time showing again the correlation between bit torque and lateral vibration;

Figures 10 and 11 are graphs showing torque plotted against rotary drill speed (rpm) for another design of drill bit,

Figures 12-14 illustrate diagrammatically three possible arrangements for achieving increase in bit torque with increasing rpm;

Figure 15 shows diagrammatically one possible method of powering the devices of Figures 12-14; and

Figures 16 and 17 show diagrammatically arrangements for increasing the effective diameter of a drill bit with increasing rpm.

[0019] Figure 1 shows the lateral vibration of a particular drag-type rotary drill bit (Bit A) plotted against rpm, the vibration being plotted as lateral acceleration in metres/s/s, and the data being acquired in laboratory drilling tests. This shows that Bit A is not stable, experiencing lateral vibration that rises quickly with rotary speed to 60m/s/s. However, contrary to the conventional teaching in the drill bit art, which considers that bit stability is required in order to reduce torsional vibrations, Bit A is found to exhibit a very low incidence of stick-slip while drilling.

[0020] This characteristic has been found in other PDC drill bits; and Figures 2-5 show the patterns of lateral vibration in an 8½ inch unbalanced drill bit (Bit B) with increase of rotary bit speed from 210 rpm to 300 rpm.

[0021] Figures 6 and 7 show the correlation between lateral vibration and torque in Bit B. In Figure 6 torque/weight-on-bit, in feet, is plotted against lateral acceleration, in m/s/s, and it will be seen that increasing torque is accompanied by increasing lateral vibration in Bit B over three different tests, whereas in a test of a similar fourth balanced bit (Bit C), circled in Figures 6 and 7, the correlation does not occur and there is no significant increase in lateral vibration with increase in torque.

[0022] Figure 7 shows this characteristic even more clearly where a dimensionless factor = (torque/wob)/(mm/rev) is plotted against lateral acceleration.

[0023] Figures 8 and 9 further show the correlation between torque and lateral vibration in a further drill bit (Bit D). In the graph of Figure 8 both rpm and lateral acceleration of the drill bit are plotted against time. Comparing Figure 8 with Figure 9, where torque is plotted against time, it will be seen that the pattern of variation in torque corresponds generally to the pattern of variation in lateral vibration, this being seen particularly in the correlation between the torque spike in Figure 9 which matches the vibration spike in Figure 8 in the 7-9 second time span.

[0024] Figures 10 and 11 show graphs of torque plotted against rpm for Bit A, which exhibited low tendency to stick-slip, and it will be seen that in each case there is an increase in torque with increasing rpm. This is shown particularly clearly in Figure 10 which shows data acquired from laboratory test drilling. The characteristic is still present, though less strongly marked, in Figure 11 where the data was acquired from field drilling.

[0025] It has been found that drill bits which are susceptible to stick-slip do not exhibit this rising torque/rotary bit speed characteristic.

[0026] Analysis has also shown that positive damping is achieved when the depth of cut increases with increasing rotary speed. As will be appreciated, generally speaking increase in depth of cut will lead to an increase in bit torque so that a correlation between bit torque and depth of cut is to be expected.

[0027] It is proposed that Bit A, and other bits having the characteristics described, exhibit a low tendency to stick-slip because of a coupling of lateral vibration and torque which produces a positive damping characteristic which may be referred to as "Dynamic Damping" because dynamic effects are providing positive damping to prevent stick-slip.

[0028] To test this hypothesis, and to examine the contrary conventional view that force balanced, low vibration bits are less susceptible to stick-slip, two versions of Bit B were made: a balanced version with an out-of-balance force of only 2.2% of weight-on-bit, and another, unbalanced bit, with an out-of-balance force of 9.1% of weight-on-bit. In the testing of these bits, operating parameters were selected to induce stick-slip. These included drilling through hard formation, high weight-on-bit and low rotary speed. The balanced version of the bit demonstrated stick-slip while the unbalanced version did not. This test provided a result at odds with the conventional force-balancing hypothesis and hence support for the hypothesis on which the present invention is predicated.

[0029] Laboratory testing with the same two bits showed the force-balanced bit, which exhibited stick-slip, to have low lateral vibrations and negative dependence of bit torque on rpm (negative damping). The less balanced bit showed stronger lateral vibrations at higher rpm and a positive bit torque/rpm relationship (positive damping). The torque/rpm relationship was also apparent from data acquired downhole.

[0030] The appreciation of the above relationship between torque, lateral vibration and/or depth of cut and rotary bit speed in drill bits which are less susceptible to stick-slip has led to the concept, according to the present invention, of using these characteristics in the design of drill bits.

[0031] The simplest application of the concept in bit design is to ascertain the appropriate relationships for proposed or existing bit designs to select those designs which exhibit the rising torque/rotary bit speed characteristic, or correlated lateral vibration or depth of cut characteristics, which have been shown to indicate low susceptibility to stick-slip. The effect of modifications to a basic bit design on stick-slip susceptibility can be determined by ascertaining these relationships for the modifications and selecting that modification where the relationships indicate that the actual drill bit will exhibit low susceptibility to stick-slip.

[0032] Although the data necessary to determine the characteristics may be acquired from actual drill bits, for example by downhole data acquisition, it will be appreciated that the primary advantage of the invention is that it will allow proposed bit designs to be selected for lack of susceptibility to stick-slip before the bits are actually developed and manufactured. In this case, the characteristics of a proposed design may be determined by the use of analytical software by which a computer model of a proposed design of drill bit may be created, as previously mentioned. For the purposes of the present invention a particularly suitable form of analytical software is that of the kind which uses the methods described in U.S. Patent Application No. 09/160,282. This software takes account of the movement of a PDC bit (such as rpm and rate of penetration) and then calculates the total forces acting on the bit by summing all of the forces generated by cutters and other bit features. The software may therefore readily be used to produce torque/rpm data, or lateral vibrations/rpm or depth of cut/rpm data, in respect of any proposed design of drill bit.

[0033] A further application of the present invention is to the active design of drill bits, or associated downhole components, to produce the rising torque/rpm characteristic which is now indicated as being desirable to avoid stick-slip.

[0034] One simple method of providing for bit torque to increase with rotary bit speed is to provide the drill bit or an associated downhole component with a simple centrifugal governor. For example, a 100 kg mass rotating at 400 rpm at 8¾ inch radius would provide a torque of 1415 lb ft, and such an arrangement may provide sufficient positive damping to reduce the susceptibility to stick-slip to a useful extent. However more preferred arrangements are those which use other power sources to actuate a braking device. Such power sources may include drilling fluid pressure, stored energy (e.g. electrical energy stored during smooth drilling), or axial motion of the drill string under weight-on-bit.

[0035] The braking device may interact with the cylindrical borehole wall or with the cutting face of the borehole.

[0036] In the case where the braking device act on the borehole or, it may take the form of brake elements spaced apart around the periphery of the drill bit or associated downhole component and arrange to be displaced outwardly into engagement with the borehole wall with increasing rotary bit speed.

[0037] Figures 12-14 show diagrammatically typical forms which such brake elements might take.

[0038] In Figure 12, the device is in the form of a curved pad 10 pivotally mounted at 11 adjacent the periphery 12 of the drill bit, the arrangement being such that the pad 10 trails the pivot 11 with respect to the direction of rotation indicated by the arrow 13.

[0039] In the arrangement of Figure 13 the pad 14 leads the pivot 15 with respect to the direction of rotation of the bit or component. Such arrangement would provide a self-jamming effect and thereby increase the torque.

[0040] Figure 14 shows an arrangement in which a roller 16 is so mounted that it may be forced outwardly by a piston 17 to jam against the borehole wall.

[0041] In each case power means of any of the kinds referred to above are provided to force the brake elements outwardly against the borehole wall in response to increase in rotary speed of the drill bit. Figure 15 shows diagrammatically one type of arrangement which makes use of the hydraulic pressure of the drilling fluid which is normally supplied under pressure to the drill bit during drilling.

[0042] Referring to Figure 15: in conventional manner drilling fluid is pumped under pressure down the drill string 18 and is delivered to nozzles 19 in the leading face of the drill bit which cause the drilling fluid to flow outwardly across the leading face of the bit to cool and clean the cutters and to carry the cuttings upwardly past the gauge section of the bit to the surface through the annulus between the drill string and the wall of the borehole, such annulus being indicated diagrammatically at 20 in Figure 15.

[0043] For the purpose of powering the brake devices, for example of the kind shown in Figures 12-14, a passage 21 for drilling fluid leads to a control valve 22 which may selectively deliver drilling fluid through a passage 23 to the nozzles 19 or through a passage 24 to an hydraulic actuator 25, such as a piston and cylinder arrangement, for energising the brake pads 10, 14, 16 of Figures 12-14.

[0044] The control valve 22 is arranged to divert a proportion of the drilling fluid from the nozzles 19 to the actuators 25 upon increase in the rotary speed of the drill bit or other component of the bottom assembly on which the brake devices may be mounted. The power for such a control valve could be generated from the flow of drilling fluid, using technologies well established, for example in mud pulse telemetry.

[0045] The control unit for the valve 22 is preferably "strapped down" (i.e. attached to the drill string) and is activated by rate of change of rotary speed. Slip-stick typically operates over a period of around 10-20 seconds, so a rate of change corresponding to doubling rpm in 2.5-5 seconds would indicate the occurrence of stick-slip.

[0046] Bit torque may also be varied by modifying the bits' "aggressivity", defined as its torque/WOB. Torque can be increased by, for example, reducing the back rake of PDC cutters mounted on the drill bit and reduced by, for example, engaging a depth of cut limiter. Conversely, therefore, torque may be increased by allowing the depth of cut to be increased. The power to operate such mechanisms is again preferably hydraulic.

[0047] Another approach is to vary the bit torque by varying the effective cutting diameter of the drill bit. This may achieved by using an expanding bit which is enlarged above nominal size. Devices similar to the brake shoes described above could carry PDC or other cutters on an outwardly movable arm. Alternatively, cutters could be mounted on an hydraulically actuated piston member, such as indicated at 26 in Figure 16 and 27 in Figure 17, which slides along an inclined ramp into engagement with the surrounding wall of the borehole. A similar arrangement might also be used for outward movement of brake shoes for the arrangement previously described.

[0048] The piston members 26 and 27 may be hydraulically actuated, for example by using a drilling fluid system of the kind shown in Figure 15.

[0049] In the case of enlargement of the affecting cutting diameter of the drill bit, a short section of borehole would be oversize. Preferably, therefore, the maximum effective cutting diameter of the drill bit would be equivalent to the nominal diameter of the bit so that the moving pads would withdraw as the rotary speed drops, to reduce the borehole size, and expand to the nominal bit size as the rotary speed increases during slip. In this case a short undergauge portion of borehole would result. It is anticipated that a reaming device higher in the borehole (not necessarily integral with the drill bit) would correct this.

Claims

1. The combination with a rotary drag-type drill bit of a device, and **characterised in that** the device (10) is responsive to rotary bit speed and adapted to increase the bit torque with increase in bit speed, the rotary bit speed responsive device (10) being provided either on the drill bit itself, or on an additional downhole component which, in use, rotates with the drill bit

2. The combination according to Claim 1, wherein the rotary bit speed responsive device (10) includes brake means (10) adapted, in use, to bear on the formation being drilled with a force which increases with increase in rotary bit speed.

3. The combination according to Claim 2, wherein the brake means (10) include elements which are displaced outwardly, with respect to the axis of rotation, to bear on the surrounding wall of the borehole in the formation being drilled.

4. The combination according to Claim 3, wherein the brake means (10) comprise a number of formation-engaging elements (10) which are displaceable outwardly under the action of power means selected

from: hydraulic pressure of drilling fluid supplied to the drill bit during drilling; a source of electrical power; axial motion of the drill bit under weight-on-bit.

5. The combination according to Claim 1, wherein the rotary bit speed responsive device comprises means to modify the orientation of a number of cutters mounted on the drill bit.

6. The combination according to Claim 5, wherein the rotary speed responsive device is adapted to reduce the back-rake of cutters mounted on the drill bit with increasing rotary bit speed.

7. The combination according to Claim 5, wherein the rotary speed responsive device is adapted to increase the depth of cut of cutters mounted on the drill bit with increasing rotary bit speed.

8. The combination according to Claim 1, wherein the rotary bit speed responsive device comprises means (26, 27) to increase the effective cutting diameter of the drill bit with increasing rotary bit speed.

9. The combination according to Claim 8, wherein the nominal diameter of the drill bit is the maximum effective cutting diameter permitted by the rotary bit speed responsive device.

10. The combination according to Claim 8 or Claim 9, wherein the drill bit includes a number of cutters or abrasion elements mounted on the bit body for movement inwardly and outwardly relative to the axis of rotation of the bit, the cutters or abrasion elements being moved outwardly in response to increasing rotary bit speed.

11. The combination according to Claim 1, wherein the device responsive to rotary bit speed in order to increase the bit torque with increase in bit speed comprises an additional mass rotatable with the bit and located outwardly of the axis of rotation of the bit.

12. The combination according to Claim 11, wherein the additional mass is mounted in the bit body itself or in a further downhole component which is rotatable with the bit.

Patentansprüche

1. Verbindung einer Vorrichtung mit einem Rotary-Blattbohrmeißel und **dadurch gekennzeichnet, daß** die Vorrichtung (10) auf die Rotary-Meißelgeschwindigkeit anspricht und dafür geeignet ist, bei einer Steigerung der Meißelgeschwindigkeit das Meißeldrehmoment zu steigern, wobei die auf die Rotary-Meißelgeschwindigkeit ansprechende Vorrichtung (10) entweder am Bohrmeißel selbst oder an einer zusätzlichen Bohrlochkomponente bereitgestellt wird, die sich bei Anwendung mit dem Bohrmeißel dreht.

2. Verbindung nach Anspruch 1, bei der die auf die Rotary-Meißelgeschwindigkeit ansprechende Vorrichtung (10) Bremsmittel (10) einschließt, dafür geeignet, bei Anwendung mit einer Kraft, die sich bei einer Steigerung der Rotary-Meißelgeschwindigkeit steigert, auf die gerade gebohrte Formation zu wirken.

3. Verbindung nach Anspruch 2, bei der die Bremsmittel (10) Elemente einschließen, die im Verhältnis zur Rotationsachse nach außen verschoben werden, um auf die Wand des Bohrlochs in der gerade gebohrten Formation zu wirken.

4. Verbindung nach Anspruch 3, bei der die Bremsmittel (10) eine Zahl von Formationseingriffselementen (10) umfassen, die nach außen verschoben werden können unter der Wirkung von Antriebsmitteln, ausgewählt aus: hydrostatischem Druck des dem Bohrmeißel während des Bohrens zugeführten Spülschlamms, einer Quelle elektrischer Leistung, der Bewegung des Bohrmeißels in Axialrichtung unter Bohrmeißelauflast.

5. Verbindung nach Anspruch 1, bei der die auf die Rotary-Meißelgeschwindigkeit ansprechende Vorrichtung Mittel zum Modifizieren der Ausrichtung einer Zahl von am Bohrmeißel angebrachten Schneiden umfaßt.

6. Verbindung nach Anspruch 5, bei der die auf die Rotary-Meißelgeschwindigkeit ansprechende Vorrichtung dafür geeignet ist, bei zunehmender Rotary-Meißelgeschwindigkeit den Spitzenanschnittwinkel von am Bohrmeißel angebrachten Schneiden zu verringern.

7. Verbindung nach Anspruch 5, bei der die auf die Rotary-Meißelgeschwindigkeit ansprechende Vorrichtung dafür geeignet ist, bei zunehmender Rotary-Meißelgeschwindigkeit die Schneidtiefe von am Bohrmeißel angebrachten Schneiden zu steigern.

8. Verbindung nach Anspruch 1, bei der die auf die Rotary-Meißelgeschwindigkeit ansprechende Vorrichtung Mittel (26, 27) umfaßt, um bei zunehmender Rotary-Meißelgeschwindigkeit den wirksamen Schneiddurchmesser des Bohrmeißels zu steigern.

9. Verbindung nach Anspruch 8, bei welcher der Nenndurchmesser des Bohrmeißels der maximale durch die auf die Rotary-Meißelgeschwindigkeit ansprechende Vorrichtung ermöglichte wirksame Schneiddurchmesser ist.

10. Verbindung nach Anspruch 8 oder Anspruch 9, bei welcher der Bohrmeißel eine Zahl von Schneiden oder Schleifelementen einschließt, die für eine Bewegung nach innen und nach außen in Verhältnis zur Rotationsachse des Meißels am Meißelkörper angebracht werden, wobei die Schneiden oder Schleifelemente als Reaktion auf eine zunehmende Rotary-Meißelgeschwindigkeit nach außen bewegt werden.

11. Verbindung nach Anspruch 1, bei der die auf die Rotary-Meißelgeschwindigkeit ansprechende Vorrichtung eine zusätzliche, mit dem Meißel drehbare und von der Rotationsachse des Meißels nach außen angeordnete, Masse umfaßt, um bei einer Steigerung der Meißelgeschwindigkeit das Meißeldrehmoment zu steigern.

12. Verbindung nach Anspruch 11, bei der die zusätzliche Masse im Meißelkörper selbst oder in einer weiteren Bohrlochkomponente angebracht wird, die mit dem Bohrmeißel gedreht werden kann.

Revendications

1. Combinaison d'un trépan de forage rotatif du type à lames et d'un dispositif, **caractérisée en ce que** le dispositif (10) réagit à la vitesse de rotation du trépan et est destiné à accroître le couple appliqué au trépan en fonction d'un accroissement de la vitesse du trépan, le dispositif réagissant à la vitesse de rotation du trépan (10) étant agencé sur le trépan de forage même ou sur un composant de fond additionnel, tournant en service avec le trépan de forage.

2. Combinaison selon la revendication 1, dans laquelle le dispositif réagissant à la vitesse de rotation du trépan de forage (10) englobe des moyens de frein (10), destinés à peser en service sur la formation en cours de forage avec une force accrue en fonction d'un accroissement de la vitesse de rotation du trépan.

3. Combinaison selon la revendication 2, dans laquelle les moyens de frein (10) englobent des éléments déplacés vers l'extérieur, par rapport à l'axe de rotation, pour peser sur la paroi environnante du trou de forage dans la formation en cours de forage.

4. Combinaison selon la revendication 3, dans laquelle les moyens de frein (10) comprennent plusieurs éléments s'engageant dans la formation (10), pouvant être déplacés vers l'extérieur sous l'action d'un moyen d'alimentation d'énergie, sélectionné dans le groupe constitué de: la pression hydraulique du fluide de forage amené vers le trépan de forage au cours du forage; une source d'énergie électrique; le déplacement axial du trépan de forage en présence d'un couple appliqué au trépan.

5. Combinaison selon la revendication 1, dans laquelle le dispositif réagissant à la vitesse de rotation du trépan comprend un moyen destiné à modifier l'orientation de plusieurs éléments de coupe montés sur le trépan de forage.

6. Combinaison selon la revendication 5, dans laquelle le dispositif réagissant à la vitesse de rotation est destiné à réduire l'inclinaison arrière des éléments de coupe montés sur le trépan de forage en fonction d'un accroissement de la vitesse de rotation du trépan.

7. Combinaison selon la revendication 5, dans laquelle le dispositif réagissant à la vitesse de rotation est destiné à accroître la profondeur de coupe des éléments de coupe montés sur le trépan de forage en fonction d'un accroissement de la vitesse de rotation du trépan.

8. Combinaison selon la revendication 1, dans laquelle le dispositif réagissant à la vitesse de rotation du trépan comprend un moyen (26, 27) destiné à accroître le diamètre de coupe effectif du trépan de forage en fonction d'un accroissement de la vitesse de rotation du trépan.

9. Combinaison selon la revendication 8, dans laquelle le diamètre nominal du trépan de forage correspond au diamètre de coupe effectif maximal permis par le dispositif réagissant à la vitesse de rotation du trépan.

10. Combinaison selon les revendication 8 ou 9, dans laquelle le trépan de forage englobe plusieurs éléments de coupe ou éléments d'abrasion montés sur le corps du trépan en vue d'un déplacement vers l'intérieur et vers l'extérieur par rapport à l'axe de rotation du trépan, les éléments de coupe ou d'abrasion étant déplacés vers l'extérieur en réponse à un accroissement de la vitesse de rotation.

11. Combinaison selon la revendication 1, dans laquelle le dispositif réagissant à la vitesse de rotation du trépan pour accroître le couple appliqué au trépan en réponse à un accroissement de la vitesse du trépan comprend une masse additionnelle pouvant tourner avec le trépan et agencée vers l'extérieur de l'axe de rotation du trépan.

12. Combinaison selon la revendication 11, dans laquelle la masse additionnelle est montée dans le corps du trépan même ou dans un composant de fond additionnel pouvant tourner avec le trépan.

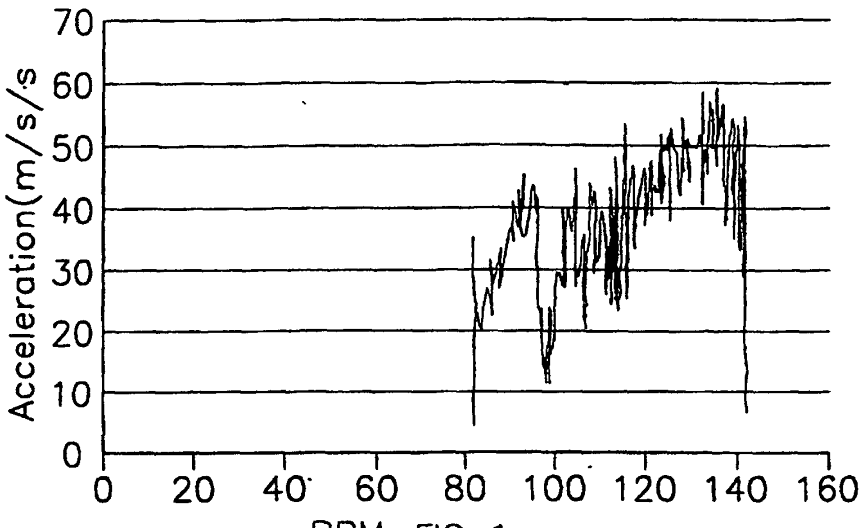


FIG 1

210 RPM

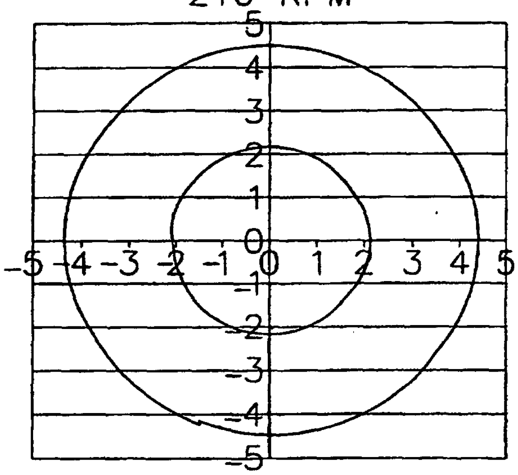


FIG 2

240 RPM

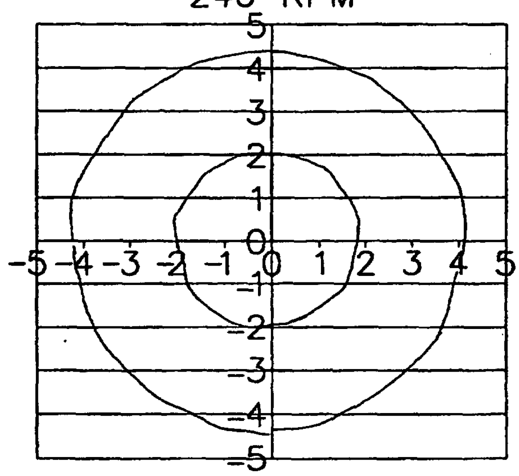


FIG 3

270 RPM

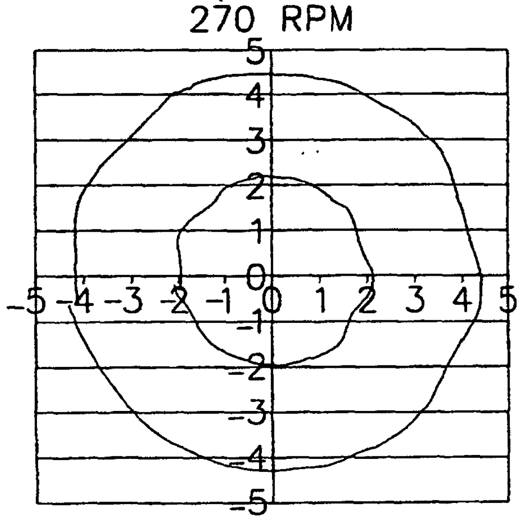


FIG 4

300 RPM

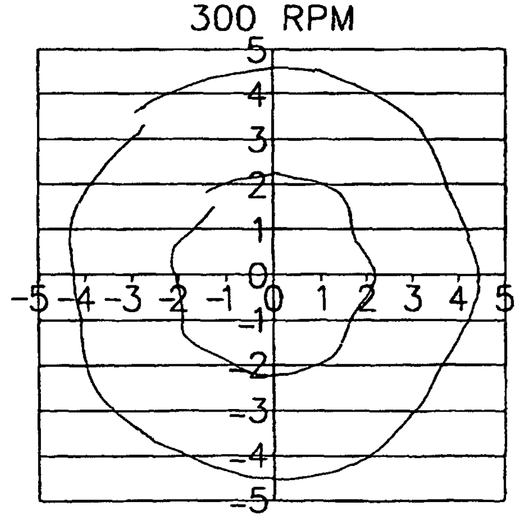
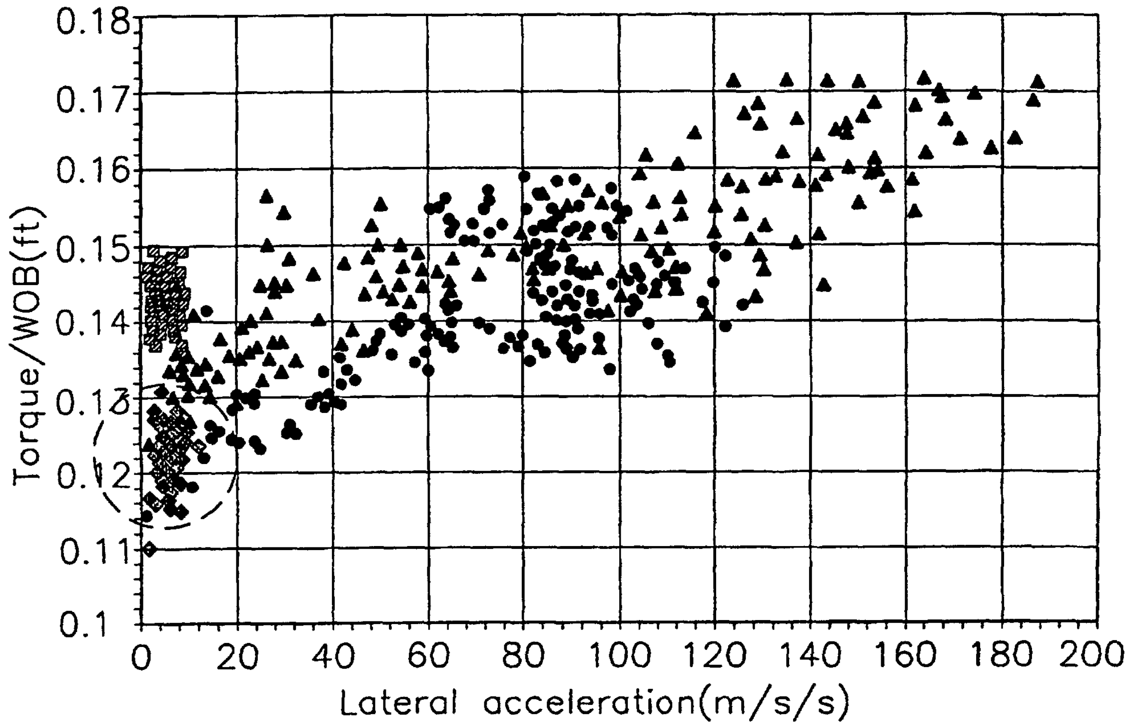
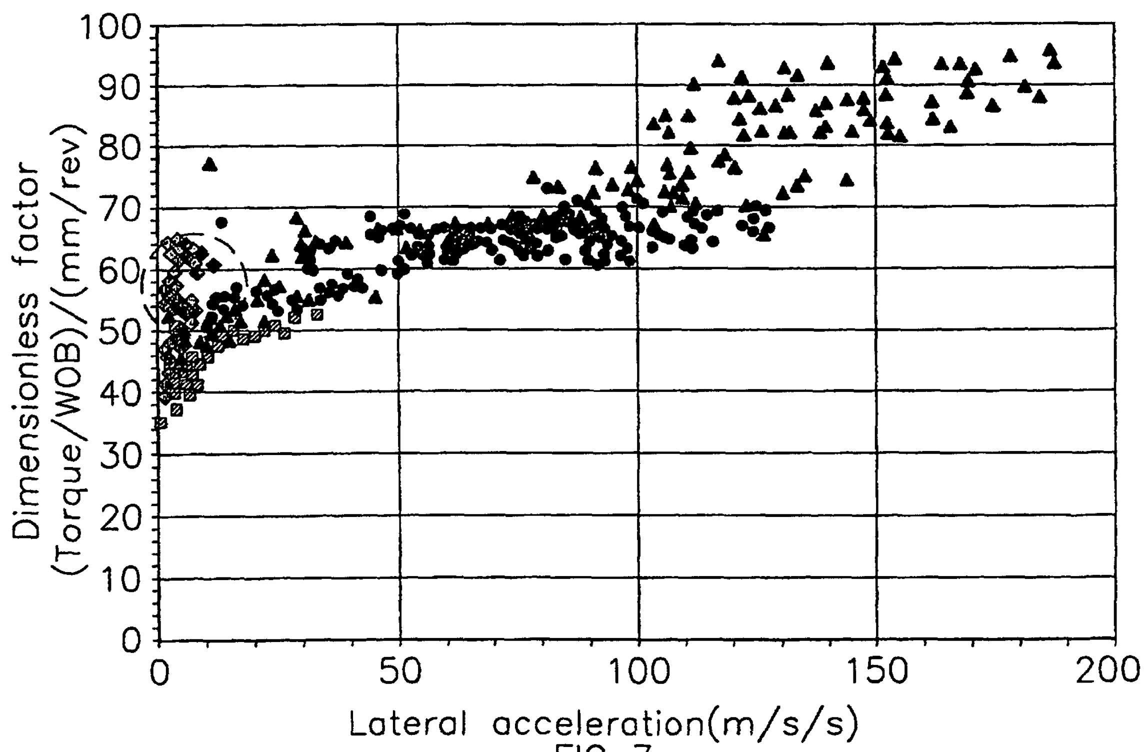


FIG 5



Torque/WOB(ft)
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0
20
40
60
80
100
120
140
160
180
200
Lateral acceleration(m/s/s)

FIG 6



Dimensionless factor
(Torque/WOB)/(mm/rev)
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
Lateral acceleration(m/s/s)

FIG 7

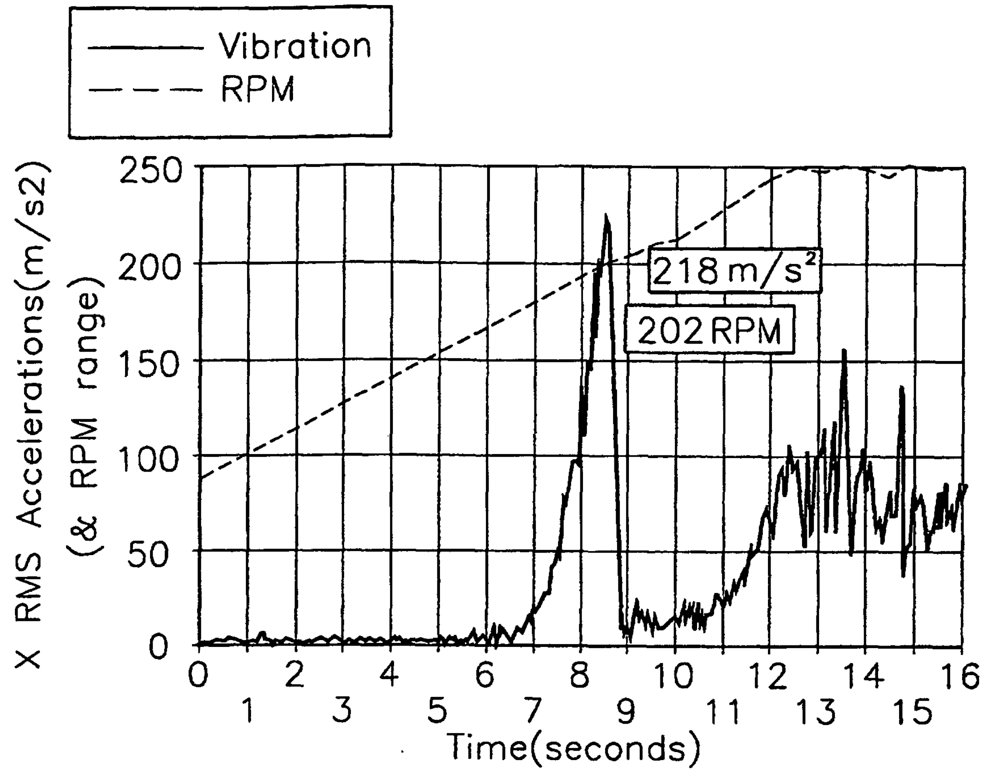

Vibration
RPM
X RMS Accelerations(m/s2)
(& RPM range)
250
200
150
100
50
0
218 m/s²
202 RPM
0
2
4
6
8
10
12
14
16
1
3
5
7
9
11
13
15
Time(seconds)

FIG 8

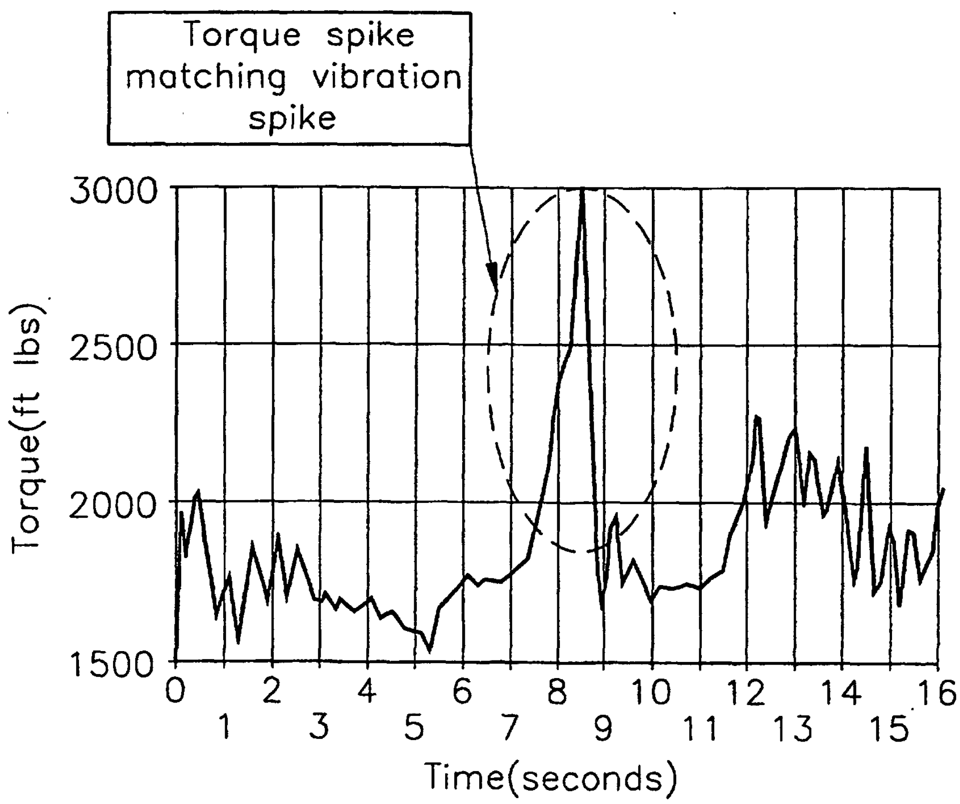

Torque spike
matching vibration
spike
Torque(ft lbs)
3000
2500
2000
1500
0
2
4
6
8
10
12
14
16
1
3
5
7
9
11
13
15
Time(seconds)

FIG 9

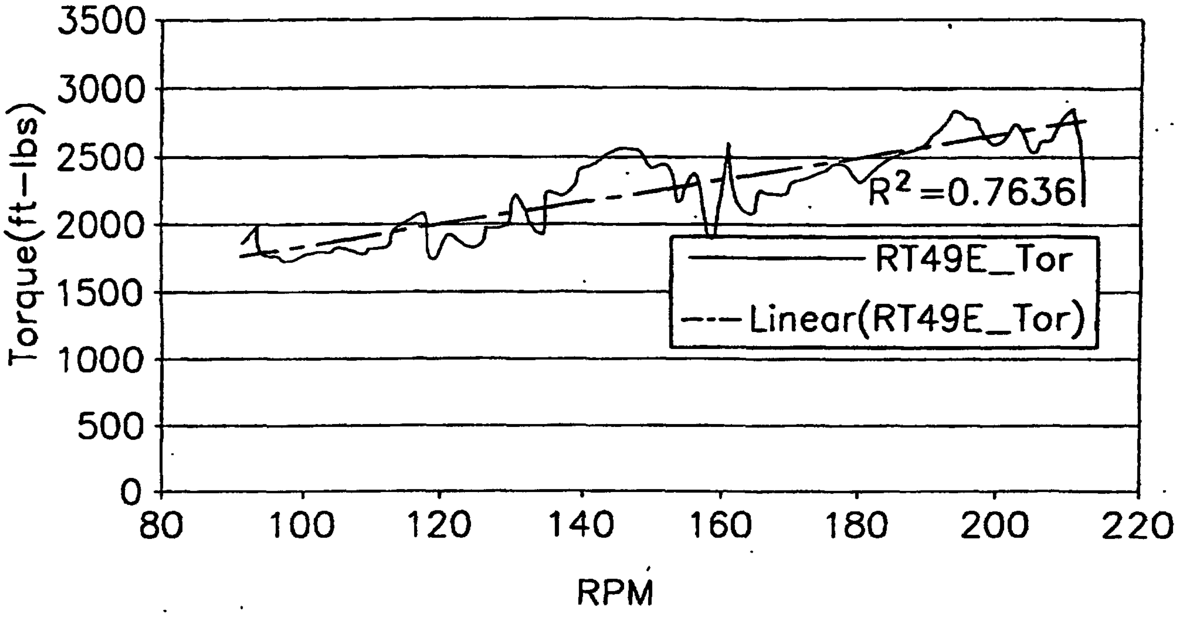

3500
3000
2500
2000
1500
1000
500
0
Torque(ft−lbs)
80
100
120
140
160
180
200
220
RPM
R^2=0.7636
RT49E_Tor
Linear(RT49E_Tor)

FIG 10

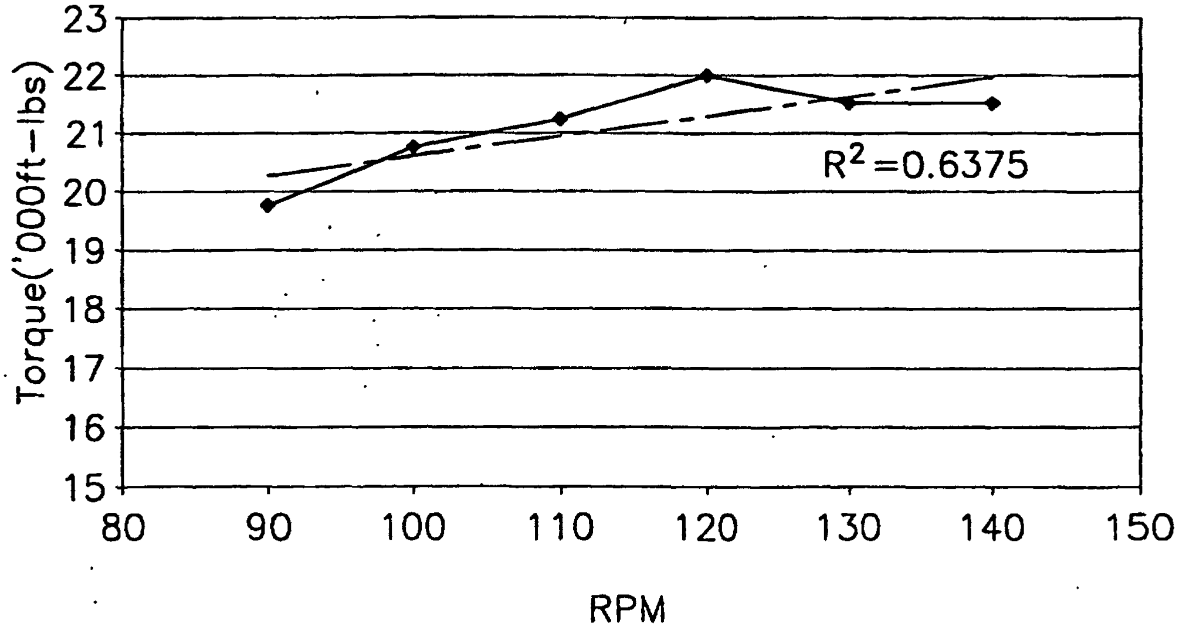

23
22
21
20
19
18
17
16
15
Torque('000ft−lbs)
80
90
100
110
120
130
140
150
RPM
R^2=0.6375

FIG 11

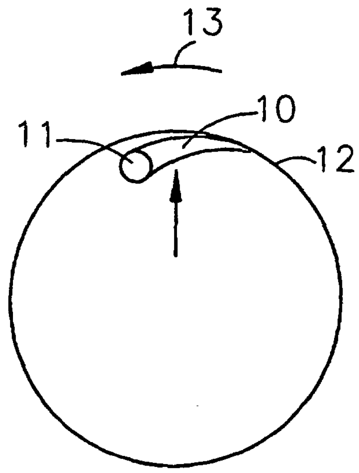


FIG 12

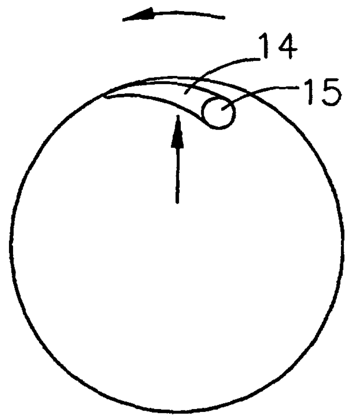


FIG 13

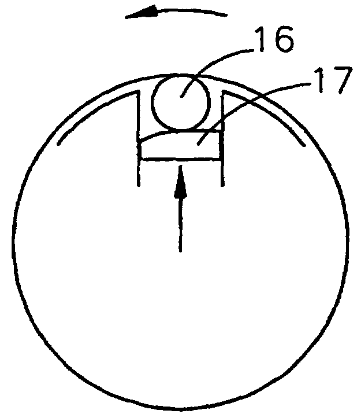


FIG 14

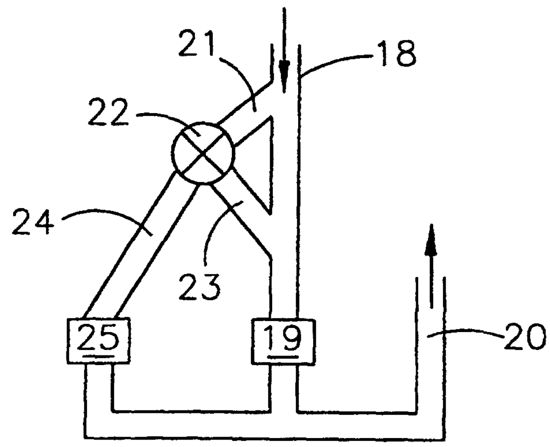


FIG 15

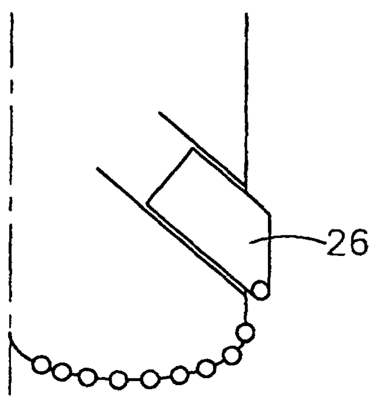


FIG 16

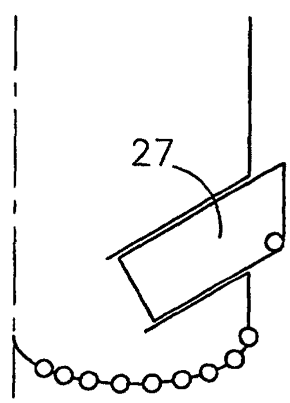


FIG 17