

May 17, 1960

F. WHITTLE
WELL DRILLING SYSTEM

2,937,007

Filed Nov. 21, 1955

9 Sheets-Sheet 1

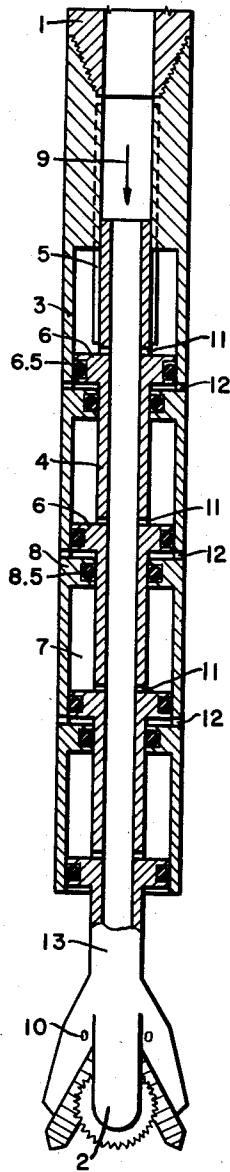


FIG. 1

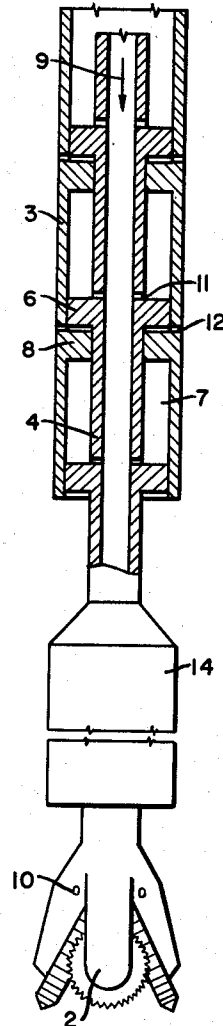


FIG. 2

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9 Sheets-Sheet 2

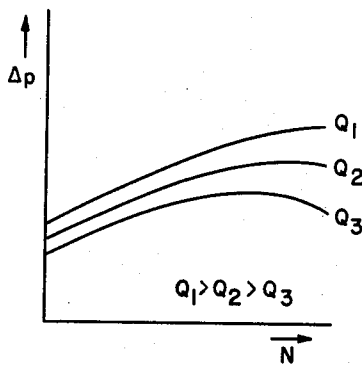


FIG. 3

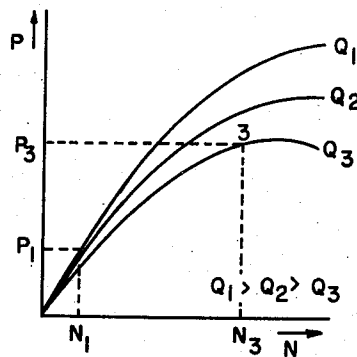


FIG. 5

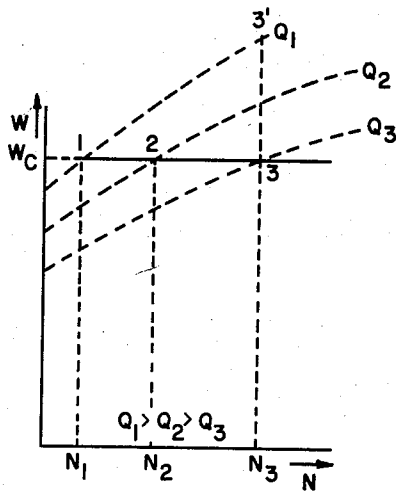


FIG. 4

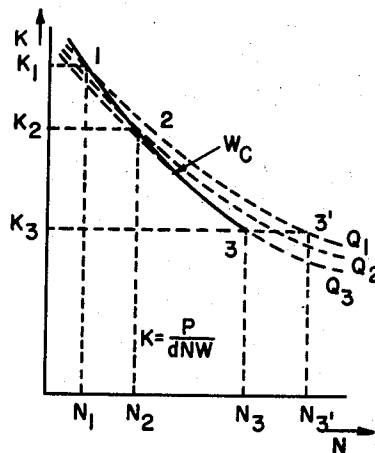


FIG. 6

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9 Sheets-Sheet 3

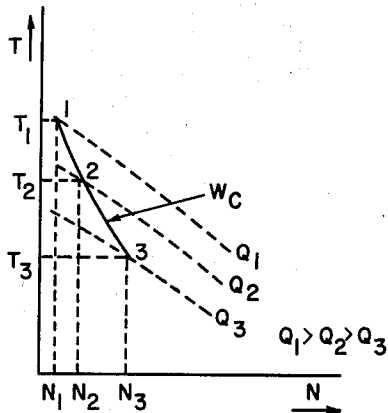


FIG. 6A

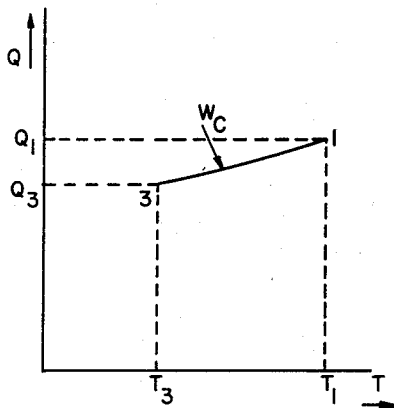


FIG. 6B

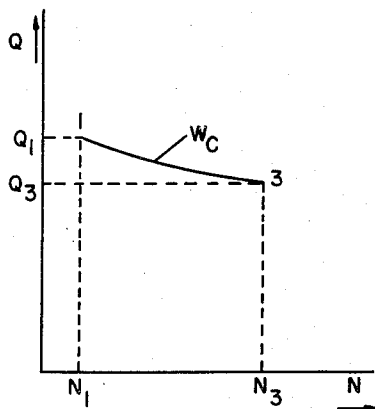


FIG. 6C

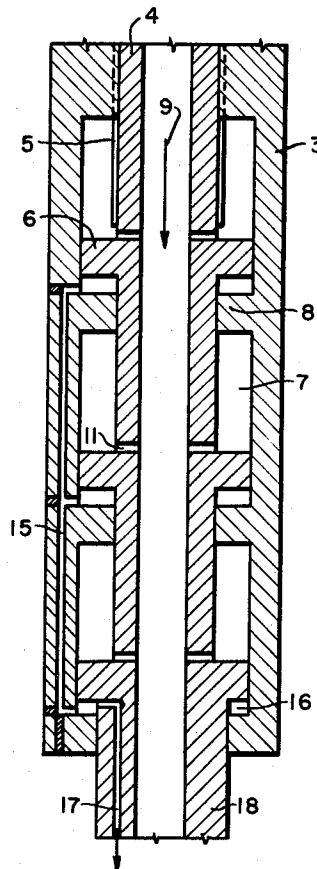


FIG. 7

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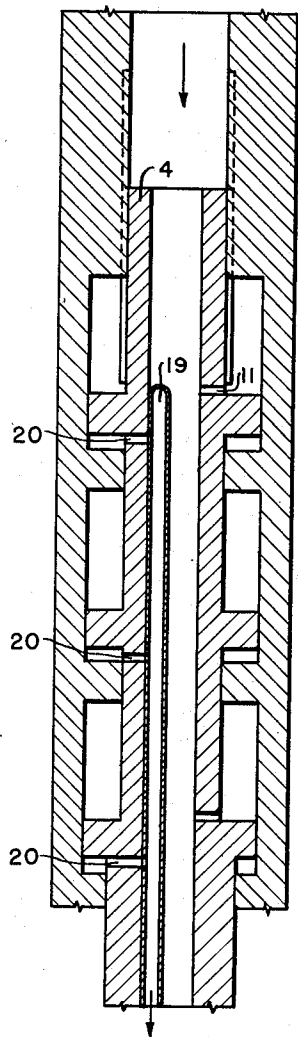


FIG. 8

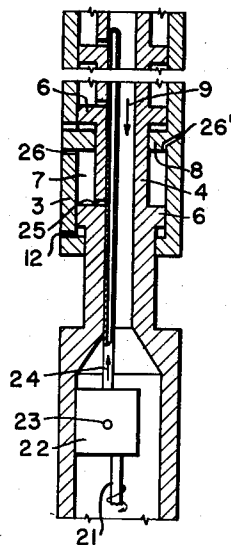


FIG. 9A

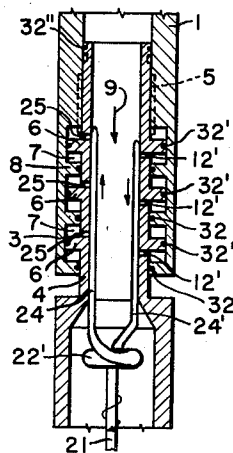


FIG. 9B

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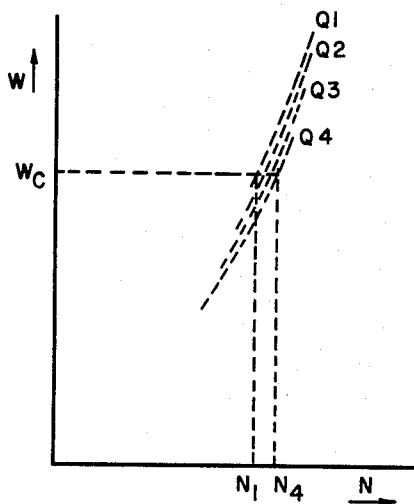


FIG. 10

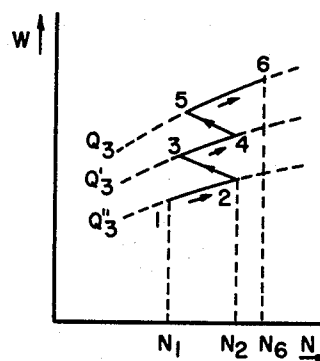


FIG. 14

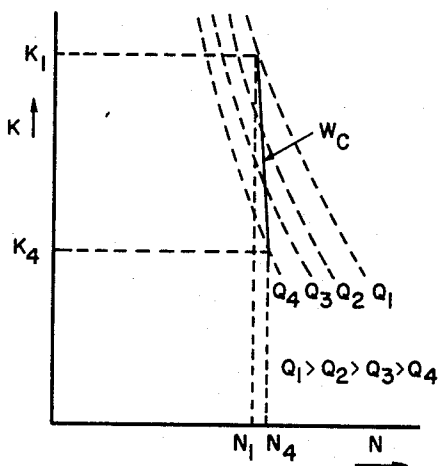


FIG. 11

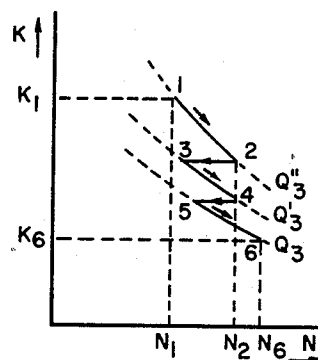


FIG. 15

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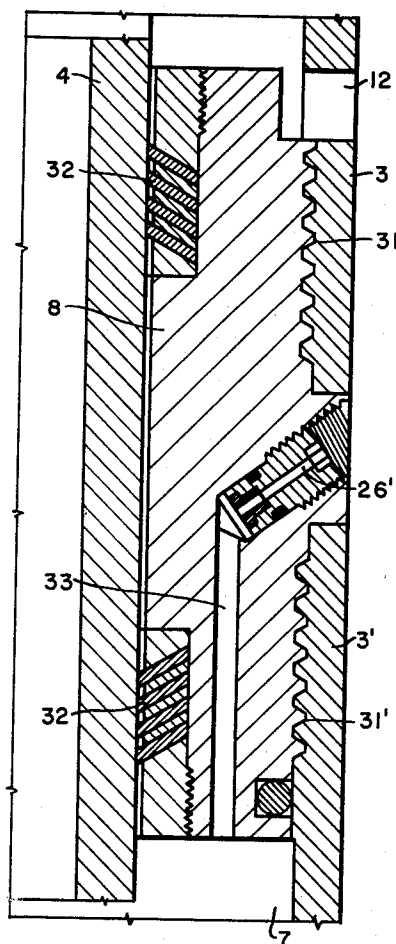


FIG. 13

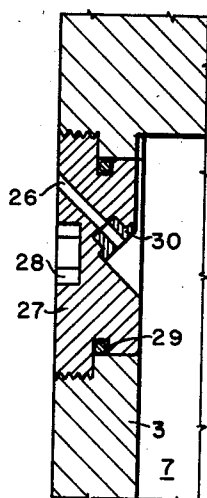


FIG. 12

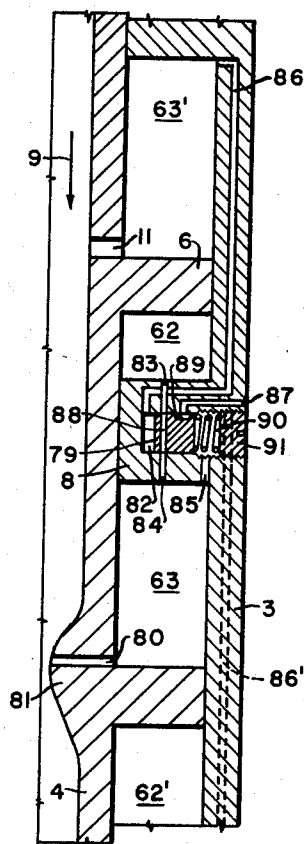


FIG. 29

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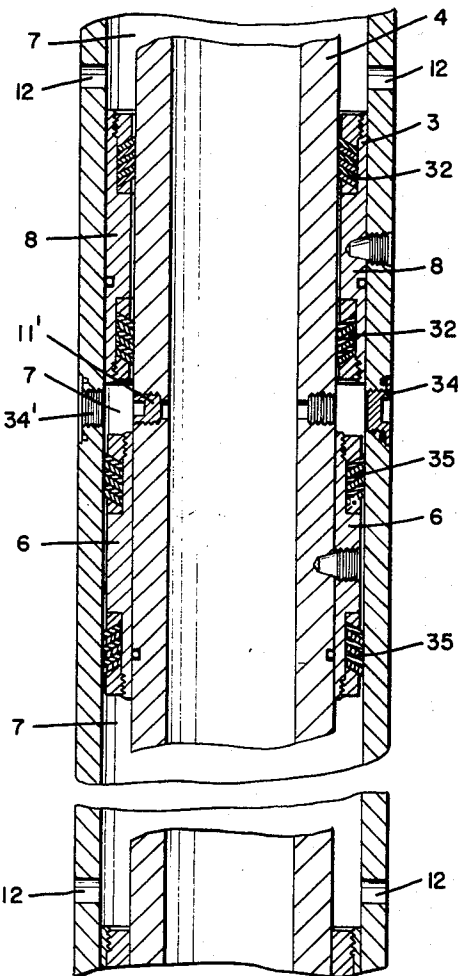


FIG. 16

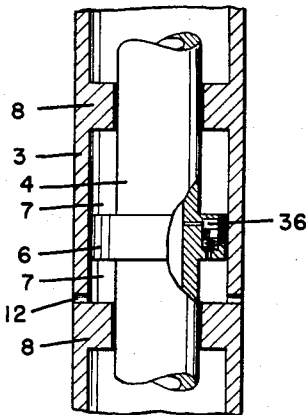


FIG. 17

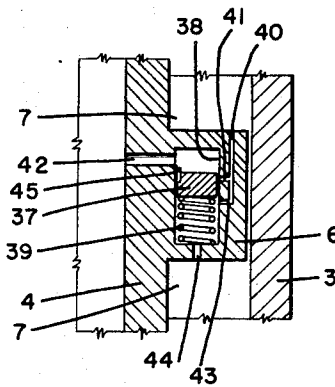


FIG. 18

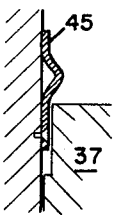


FIG. 19a

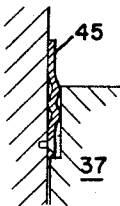


FIG. 19b

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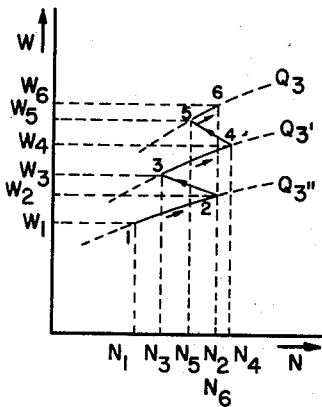


FIG. 20

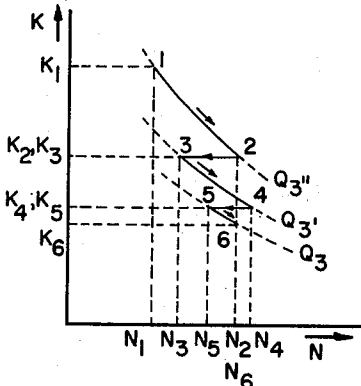


FIG. 21

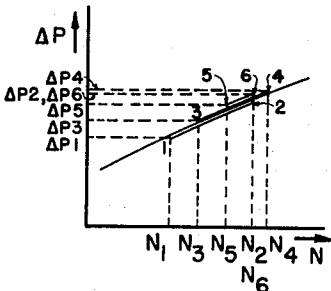


FIG. 22

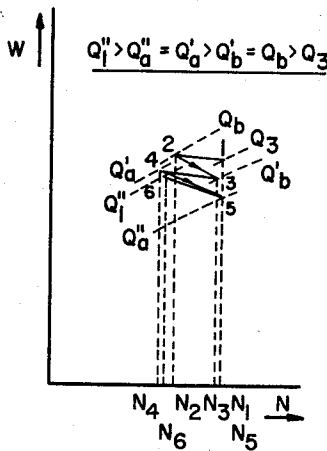


FIG. 25

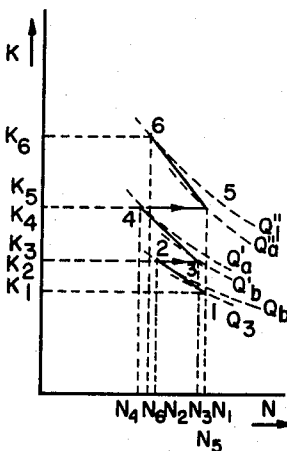


FIG. 26

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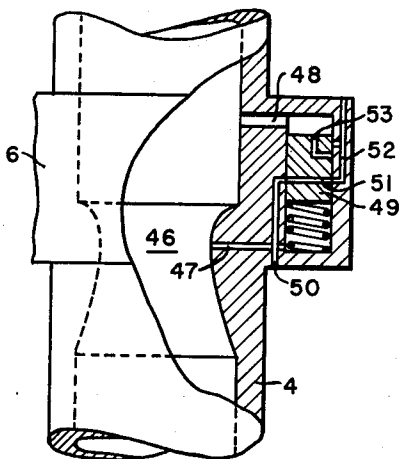


FIG. 23

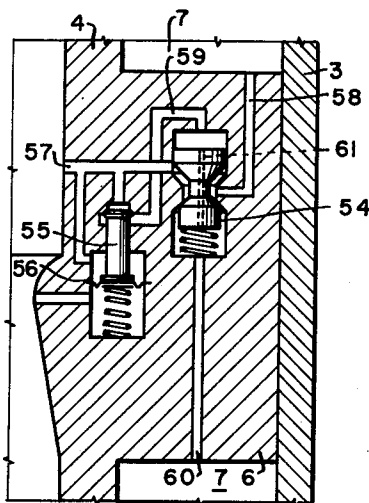


FIG. 24

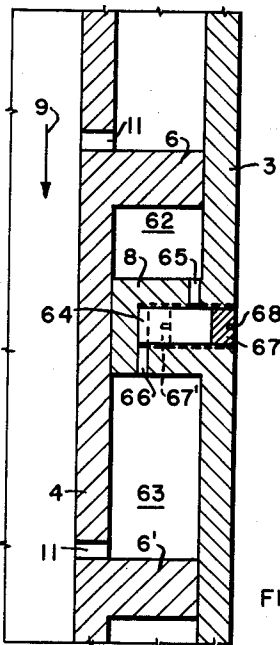


FIG. 27

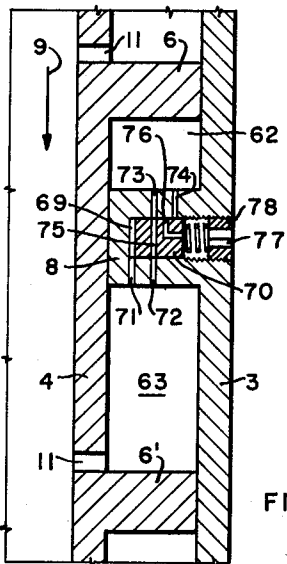


FIG. 28

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WELL DRILLING SYSTEM

Frank Whittle, Dunsford, England

Application November 21, 1955, Serial No. 548,048

Claims priority, application Great Britain
December 10, 1954

16 Claims. (Cl. 255-4)

This invention relates to well drilling systems of the rotary type, which systems comprise a tubular drill string and a rotary drill bit. A well drilling system of this type is frequently used for example when drilling deep bore holes in the earth, with the object of finding water, oil, gas, salt or sulfur, etc.

In a well drilling system of the rotary type, which is often used at present, the rotary drill bit is connected to the drill string, which is actuated by a prime mover located at the top of the bore at the surface of the earth, and a flow of mud flush is sent down through the interior of the drill string to the bottom of the hole. At the lower end of the drill string the mud flush is ejected through openings provided in the drill bit. The mud streams which are ejected from these openings, are directed on to the cutting surfaces of the bit with the object of cooling them and removing the cuttings. This form of rotary well drilling system will be referred to hereinafter as a conventional type of system.

The invention also relates to well drilling systems of the rotary type in which the rotary drill bit is connected to the lower end of the drill string by means of an interposed driving means, such as an electric motor or a hydraulic turbine. In this case, the drill string is either kept stationary or is rotated very slowly so as to prevent it sticking.

When drilling, the weight on the rotating bit has to be adjusted very carefully, in order to control the rate of penetration of the bit through the formation, and to prevent damage to the drill string or the drill bit and to avoid deviation of the direction of the borehole.

An object of the present invention is to provide a device, hereinafter called a ram device, for controlling the weight on the bit, and enabling this weight to be adjusted in a simple and effective manner when the conditions under which the bit is advancing its way through the formation, vary.

According to the present invention, in a well drilling system comprising a tubular drill string and a drill bit provided with mud flush openings, said bit being connected to the drill string, which is rotated by a prime mover located at the top of the bore hole, the connection between the bit and the drill string includes a ram device comprising two hollow telescopic members, the inner one of which provides a channel for the passage of fluid from the drill string to the bit and which members have means for preventing relative rotational movement between them, one of said members being provided with a number of pistons, which co-operate with an equal number of cylinders formed on the other member, each piston dividing the cylinder with which it co-operates into two cylindrical spaces. The ram device also includes means for connecting all the cylindrical spaces located to one side of the pistons to the interior of the inner telescopic member so that the pistons are subjected on that side to the pressure of the fluid in the drill string, and means for connecting all the cylindrical spaces lo-

cated to the other side of the pistons to the exterior of the outer telescopic member so that the pistons are subjected on their other sides to the pressure of the fluid in the bore hole, whereby in operation a downwards force is exerted on the bit.

It will be appreciated that in the combination of a conventional type of drilling system and a ram device as defined above, the bit weight is equal to the force exerted on the pistons due to the pressure difference existing between the spaces to each side of them, this pressure difference being equal at any moment to the pressure drop then prevailing across the bit openings. As this pressure drop is proportional to the square of the circulation rate of the mud flush, the bit weight may be controlled by varying the circulation rate of the mud flush.

Further according to the present invention in a well drilling system comprising a tubular drill string and an electric motor driving a drill bit provided with mud flush openings, the motor being connected to the drill string, which is kept stationary or rotated very slowly, the connection between the bit and the drill string includes a ram device comprising two hollow telescopic members, the inner one of which provides a channel for the passage of fluid from the drill string to the bit and which members have means for preventing relative rotational movement between them, one of said members being provided with a number of pistons, which co-operate with an equal number of cylinders formed on the other member, each piston dividing the cylinder with which it co-operates into two cylindrical spaces, the ram device also comprising means for connecting all the cylindrical spaces located to one side of the pistons to the interior of the inner telescopic member so that the pistons are subjected on that one side to the pressure of the fluid in the drill string, and means for connecting all the cylindrical spaces located to the other side of the pistons to the exterior of the outer telescopic member so that the pistons are subjected on their other sides to the pressure of the fluid in the bore hole. In this case also the bit weight may be controlled, for exactly the same reasons, by varying the circulation rate of the mud flush, whereby in operation a downwards force is exerted on the bit.

Again according to the present invention in a well drilling system comprising a tubular drill string and a hydraulic motor driving a drill bit which is provided with mud flush openings, the motor being connected to the drill string which is kept stationary or rotated very slowly, and the hydraulic motor being actuated by the mud flush pumped down the drill string the connection between the bit and the drill string includes, besides the hydraulic motor, a ram device comprising two hollow telescopic members, the inner one of which provides a channel for the passage of fluid from the drill string to the bit and which members have means for preventing relative rotational movement between them, one of said members being provided with one or more pistons, which co-operate with an equal number of cylinders formed on the other member, each piston dividing the cylinder with which it co-operates into two cylindrical spaces, the ram device also comprising means for connecting the cylindrical spaces located to one side of the pistons to a space in which there is a relatively high fluid pressure in operation, and means for connecting the cylindrical spaces located to the other side of the pistons to a space in which there is a relatively lower fluid pressure in operation, whereby in operation a downwards force is exerted on the bit.

As in the cases of the conventional type of well drilling system and a system comprising an electric motor the ram device may have means connecting the spaces to each side of the pistons respectively to the interior of the inner telescopic member and the exterior of the outer

telescopic member, the pressure difference between the spaces to each side of a piston when thus connected, being equal at any moment to the difference then prevailing between the fluid pressures in the drill string and in the bore hole. This latter difference will be equal to the sum of the pressure drops in the hydraulic motor and across the bit openings. Preferably the hydraulic motor mentioned above is a hydraulic turbine.

A ram device for use in well drilling systems according to the present invention comprises two hollow telescopic members, the inner one of which provides a channel for the passage of fluid from the drill string to the bit and which members have means for preventing relative rotational movement between them, one of said members being provided with a number of pistons, which co-operate with an equal number of cylinders formed on the other member, each piston dividing the cylinder with which it co-operates into two cylindrical spaces, the ram device also comprising means for connecting the cylindrical spaces located to one side of the pistons to a first common space in which there is a relatively high fluid pressure in operation, and means for connecting the cylindrical spaces located to the other side of the pistons to a second common space. The first common space may be the interior of the inner telescopic member and the second common space the exterior of the outer member.

When operating a system including a hydraulic turbine, which is driven by the mud flush pumped down the drill string, which mud flush at the same time actuates the ram device, the bit weight exerted by the ram device influences the load on the turbine and consequently the turbine speed. Furthermore the hardness of the formation has a bearing on the turbine speed and careful consideration therefore has to be given to the interaction between the ram device and the turbine, so as to prevent over-speeding or stalling of the latter in hard or soft formations, respectively. Also the speed at which the turbine operates has to be kept within restricted limits, as the turbine efficiency will be at or near a maximum for the design speed of the turbine. As will be explained, the turbine speed may be kept within the required limits despite varying conditions of the formation being drilled, by correctly adjusting the circulation rate of the mud flush and the effective area of the pistons of the ram device.

A further object of the present invention is to provide means by which, owing to the action of the ram device, the turbine will operate within a relatively small speed range when boring through formations having widely varying formation hardness.

For a better understanding of the behavior of the ram device in this respect, the term "insensibility" is introduced by which is to be understood the ratio between a range of formation hardness and the turbine speed range when drilling through formation of the said range of hardness. The larger the value of the insensibility of a system, the greater the range of formation hardness of the formations which may be drilled through without the turbine speed passing outside predetermined limits.

$$\text{Insensibility} = \frac{\text{Hardness}_{\text{max.}} - \text{Hardness}_{\text{min.}}}{\text{Speed}_{\text{max.}} - \text{Speed}_{\text{min.}}}$$

An increased insensibility of a system including a hydraulic turbine and a ram device may be obtained by any one or more of the following methods:

(1) Connecting the lower pressure side of the pistons to the space at the exhaust of the turbine instead of to the bore hole;

(2) Using a turbine which has a design speed equal to the minimum speed of the desired operational speed range, and a pressure drop across it which increases rapidly for speeds higher than the design speed;

(3) Throttling either the turbine exhaust or the turbine inlet at higher speeds of the turbine by means of a speed-

sensitive throttle valve, so as to increase the pressure drop across the turbine as the speed increases;

(4) By-passing part of the mud flush circulation so that it does not pass through the bit openings whereby the mud flush circulation through the openings remains substantially constant in spite of varying circulation rates of mud flush down the drill string;

(5) Connecting the higher pressure side of the pistons to the outlet of a pump driven by the turbine and (a) connecting the suction side of the pump to the fluid at the inlet of the turbine, or (b) connecting the suction side of the pump to the lower pressure side of the pistons and circulating a servo fluid different from the mud flush through the pump and cylinders;

(6) Putting one or more of the pistons of the ram device out of action by interconnecting adjacent cylindrical spaces, this operation being performed (a) manually, or (b) automatically, for example, each piston being put out of action in response to a predetermined pressure difference between the cylindrical spaces on the two sides of a piston, or in response to a predetermined rate of circulation of the mud flush;

(7) When employing the method (6) above of putting one or more pistons out of action, employing a ram device having pistons of different diameters.

In addition, as will be described, it may be desirable when operating a system according to the invention to employ a method in which the circulation rate of the mud flush through the drill string is varied in accordance either with the bit weight or with the bit speed, or with the torque applied to the bit.

A number of systems in accordance with the present invention will be now described by way of example with reference to the accompanying drawings, in which

Figure 1 is a schematic cross-section of a ram device for use in combination with a conventional rotary drilling system,

Figure 2 is a schematic cross-section of a ram device for use in combination with a hydraulic turbine or an electric motor,

Figures 3, 4, 5 and 6 show graphs representing the pressure drop/turbine speed, bit weight/turbine speed, turbine output/turbine speed and formation coefficient/turbine speed relations respectively for various values of mud flush circulation rate Q in a system as described with reference to Figure 2,

Figure 6A is a graphic representation of the relation between torque T and speed N for various values of the circulation rate Q , and the operation curve W_c over which the bit weight is kept constant,

Figures 6B and 6C show the relation between the circulation rate Q and the torque T (Figure 6B) and the turbine speed N (Figure 6C) when the bit weight W_c is kept constant,

Figures 7 and 8 show alternative constructions of the ram device for increasing the insensibility of the system,

Figures 9A and 9B show a ram device provided with a hydraulic pump driven by the turbine, whilst Figures 10 and 11 show graphs representing the bit weight/turbine speed and formation coefficient/turbine speed relations for a construction as shown in Figure 9A with various mud flush circulation rates Q ,

Figures 12 and 13 are detail views of portions of the apparatus shown in Figure 9A,

Figures 14 and 15 show the bit weight/turbine speed and formation coefficient/turbine speed curves, for the modified ram devices shown in Figures 16 and 27, these devices being provided with means for manually interconnecting adjacent cylindrical spaces,

Figures 17, 18, 19A, 19B and 28 show ram devices in which adjacent cylindrical spaces can be interconnected automatically, the curves illustrating the operation of which are shown in Figures 20, 21 and 22,

Figures 23, 24 and 29 show further ram devices in

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which adjacent cylindrical spaces can be interconnected automatically, the curves illustrating the operation of which are shown in Figures 25 and 26.

Referring now to the drawings, in Figure 1 there is shown a ram device for use in combination with a conventional rotary well drilling system. Here the ram device is shown in its fully open or extended position. Between the lower end of the drill string 1 and the rotary drill bit 2, there are interposed two members 3 and 4 which are telescopically arranged in relation to each other. Torque is transferred from the outer telescopic member 3 to the inner telescopic member 4 by a spline or key arrangement 5 shown at the upper part of the device, but which also could be at the bottom of the ram or at any other convenient place. The inner telescopic member 4 is provided with a number of pistons 6, which are sealed against the inner wall of the member 3 in a suitable manner well known to the art, as by slidable sealing rings or packing 6.5. For cooperation with the pistons 6, there are arranged an equal number of cylinders 7, formed on the outer telescopic member 3, which cylinders are each divided into two cylindrical spaces by the corresponding pistons 6. Abutments 8, separating the cylinders 7, are preferably provided with suitable sealing means 8.5 for sealing the passage between adjacent cylinders.

Although in Figure 1, the inner telescopic member 4 is shown as being coupled to the drill bit 2, and the outer telescopic member 3 is shown as being coupled to the drill string 1, it will be evident that in an alternative arrangement, the outer telescopic member may be coupled to the bit 2, whilst the inner telescopic member is connected to the drill string 1.

The mud flush, pumped down through the drill string 1 in operation to the bottom of the hole, enters the interior of the telescopic member 4 in the direction shown by the arrow 9, and flows through the interior of the member 4 to the drill bit 2, from which it is ejected through the jets or openings 10. The mud jets may be directed onto the cutting surfaces of the bit 2, which are thus cooled, whilst at the same time the cuttings are removed from them. Alternatively, the mud may jet against the bottom of the bore hole.

Openings 11 are provided in the wall of the inner telescopic member 4, through which the cylindrical spaces above the pistons 6 are connected to the interior of the tubular member 4. The cylindrical spaces below the pistons 6 are connected to the exterior of the member 3, i.e. to the bore hole, through the openings 12 provided in its wall.

The openings 11 are located just above the pistons 6 and the openings 12 are located just above the abutments 8, so that the openings 11 always communicate with the spaces above the pistons 6, and the openings 12 always communicate with the spaces below the pistons 6, irrespective of the mutual positions of the telescopic members 3 and 4.

The pressure differential existing between the spaces located above and below the pistons 6 is equal to the pressure differential existing between the static pressure of the mud flush in the interior of the member 4 and the static pressure of the mud flush present in the bore hole. This latter pressure differential depends on the resistance offered to the flow of mud flush by the openings 10 in the bit 2, and is substantially proportional to the square of the mud flush circulation rate. It will be appreciated that by varying the circulation rate of the mud flush and/or by adjusting the size or shape of the jet openings 10, the pressure differential acting on the pistons 6 may be varied at will.

The weight exerted on the bottom of the borehole by the bit 2 (commonly described in the oil field terminology as the "weight on the bit") in this arrangement is substantially equal to the combined weight of the telescopic member 4 and the drill bit 2, increased by the force resulting from the mud flush pressure acting on the upper

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surfaces of the pistons 6 and decreased by the force resulting from the pressure of the mud flush in the bore hole acting on the lower surfaces of the pistons 6. Attention is drawn to the fact that part of the effective piston area is provided by the restricted upper end and the virtually closed end of the inner telescopic member 4, i.e. if the ram pistons did not exist and the member 4 were simply a tube sliding inside another member 3, there would be a force trying to extend the system. Further in the case of jets ejecting downwards, the reaction of the jets gives a force in the opposite direction. In the following, for the sake of simplicity, these forces will not be taken into account.

The bit weight can be determined by means of a weight indicator, as is conventional in rotary-drilling practice, or by measuring the compression force in the stem 13 of the drill bit 2 by suitable means (not shown) and by communicating this intelligence in a suitable way, e.g. as some form of electric signal, to the surface of the earth. Here the information is received by the driller who controls the bit weight by varying the mud flush circulation rate.

When during a drilling operation the bit weight decreases rapidly and cannot be adjusted to the desired value by increasing the circulation rate, this means that the ram has reached the end of its stroke, so that the telescopic members 3 and 4 are in their fully extended position. By lowering the outer telescopic member 3, the ram can then be fully telescoped again.

It will be clear that it is preferable to pay off the drill string 1 continuously at the surface at a rate approximately equal to the rate of penetration of the bit 2. It is then only necessary to adjust the rate of feed at comparatively long intervals when there are indications that the ram is either in the fully open or the fully closed position. For example, if the surface feed were 40 ft./hr. and the bit was actually penetrating at 50 ft./hr., then the ram pistons 6 would be moving downwards in the ram cylinders 7 at the relative rate of 10 ft./hr. A five foot stroke of the ram piston would thus last under these conditions for 30 minutes. When drilling through reasonably uniform formations the driller could probably adjust the surface feed to the penetration rate to avoid adjustments at intervals of less than one hour, whereas if the feed were left entirely to the ram, the driller would have to pay off every few minutes.

Figure 2 shows the lower part of a device identical to the ram device as shown in Figure 1, but in this case used in combination with a rotary drill bit 2 driven by a submerged driving means 14 connected to the lower end of the inner telescopic member 4.

This driving means 14 may be constituted by an electric motor, or by a motor driven by the mud flush, such as a hydraulic turbine. In the latter case, the turbine is driven by the mud flush which is pumped down through the drill string (not shown) and through the interior of the member 4 (vide arrow 9), is then guided to the turbine blading and, after having performed its action therein, flows to the interior of the bit 2 and is ejected through the jet openings 10.

Although in Figure 2, the turbine is shown as being interposed between the bit 2 and the ram device, it will be appreciated that the turbine may also be coupled between the ram device and the drill string.

With the above in mind it will be appreciated that the bit weight, as far as it is related to the mud pressure, depends on the total pressure drop across the turbine and the bit jet openings 10 as well as on the effective area of the ram pistons 6.

It follows that (neglecting certain factors such as reaction forces due to jet nozzles on the bit, as mentioned previously):

$$W = A(\Delta P) = A(\Delta p + kQ^2) \quad (1)$$

where

W=the weight on the bit, i.e., the force exerted by the bit against the bottom of the borehole
 A=the effective piston area of the ram pistons 6
 ΔP =the total pressure difference acting on the pistons 6
 Δp =the pressure drop across the turbine
 kQ^2 =the pressure drop across the bit jet openings 10
 k=a constant for the bit jet openings 10, and
 Q=the circulation rate of the mud flush.

Now Δp is a function of the turbine rotation speed N and the circulation rate Q. This is shown graphically in Figure 3 in which Δp is plotted against N for various Q's (Q_1 being greater than Q_2 and Q_2 being greater than Q_3), and can be represented by the following equation:

$$\Delta p = F(Q, N) \quad (2)$$

From (1) and (2) there is derived.

$$W = A[F(Q, N) + kQ^2] \quad (3)$$

and this is the basis of the curves shown in Figure 4.

Tests indicate that the power required when drilling through a certain formation, is dependent on a coefficient representative of the hardness of the formation, the bit diameter, the bit speed and the bit weight and that the relationship may be represented by the following equation:

$$P = KdNW \quad (4)$$

where

P=the H.P. required to be delivered by the turbine
 K=the formation coefficient, depending on the hardness of the formation and varying from 0.0004 for hard rock to 0.001 for soft rock
 d=the diameter in inches of a given bit
 N=the number of rotations per minute of the bit
 W=the weight on the bit given in thousands of pounds.

(Although it is not certain that this Equation 4 is correct under all circumstances, it will be used as a basis for the following consideration of the problem.)

For a given bit d is a constant, whilst in the Formula 4 both W and P are functions of N for various circulation rates Q. Thus we have:

$$W = A[F(Q, N) + kQ^2] \quad (3)$$

as shown in Figure 4, and

$$P = F'(Q, N) \quad (5)$$

as shown in Figure 5. So, it is possible, as has been done in Figure 6, to draw curves (for various Q's) showing the relationship between the bit speed N and the formation coefficient K, which relationship may be derived from Equations 4, 3 and 5 as follows.

$$K = \frac{P}{dNW} = \frac{F'(Q, N)}{d.N.A.[F(Q, N) + kQ^2]} = F''(Q, N)$$

From these curves it can be seen that when drilling, for example, in a soft formation having a high formation coefficient K_1 with a circulation rate Q_1 , the speed will be N_1 , whereas in a hard formation with coefficient K_3 the speed with the same circulation rate Q_1 will have a much greater value N_3 . Further it will be seen that for a given formation coefficient, e.g. K_3 , the speed decreases from N_3' to N_3 when the circulation rate is decreased from Q_1 to Q_3 .

As has been said previously, it is desirable to keep the speed variations of the turbine within restricted limits when drilling through formations having widely varying formation coefficients. It will be clear from Figure 6 that this may be effected by varying the circulation rate, preferably in a continuous manner, in dependence on the speed. Thus, a curve W_c may be drawn between the points 1, 2 and 3 lying on the circulation curves Q_1 , Q_2 and Q_3 , which curve W_c may represent, if the points 1, 2 and 3 are correctly chosen, an operating curve over

which the bit weight W is kept constant (vide Figure 4). From Figure 6 the insensibility

$$\frac{K_1 - K_3}{N_3 - N_1}$$

of this arrangement can be derived.

It will be clear that the operating curve W_c in Figure 6 will be followed when the driller controls the circulation rate Q in such a way that the bit weight W is kept constant at a value W_c . When the bit weight W_c decreases the circulation has to be increased and vice versa. The control may be performed either automatically, or manually by the driller. As has already been stated, the bit weight W can be determined by means of a convenient weight indicator or by measuring the compression force in the shank of the drill bit 2, and sending this intelligence to the surface of the earth by suitable means, e.g. as an electric signal.

Another system of control may respond to changes in the torque, measured in the shank just above the drill bit 2. The torque/speed (T/N) curves of a hydraulic turbine for various Q's are shown in Figure 6A. An operating curve for constant bit weight W_c can be drawn by means of the values of Q and N corresponding to the points 1, 2 and 3, shown in Figure 4. By manually adjusting the circulation rate Q under varying torque conditions according to the curve shown in Figure 6B, the driller may thus keep the bit weight W_c constant. This control may also be performed automatically.

A further system of keeping the bit weight constant under changing drilling conditions, may be realized by measuring the speed of the turbine, transmitting this intelligence to the surface of the earth (e.g. as an electric signal) and adjusting the circulation rate Q according to the curve shown in Figure 6C. This curve is obtained from the curves of Figure 4. Here, too, the control may be effected automatically or manually.

A greater increase of insensibility than may be obtained by keeping the bit weight constant can be obtained by arranging that the turbine speed is kept within narrow limits. One way of obtaining a relatively small turbine speed range for a wide range of formation coefficients, i.e. a high insensibility, is illustrated in Figures 7 and 8. The pistons 6 of the ram device shown therein, are subjected only to the pressure drop across the turbine, instead of to the total pressure drop between the inside and the outside of the drill string which is equal to the sum of the pressure drop across the turbine and the pressure drop across the bit jet openings 10.

To this end, in Figure 7, the cylindrical spaces located below the pistons 6, are connected to the fluid space at the exhaust of the turbine (not shown) via the conduit 15 provided in the telescopic member 3, the lower-most cylindrical space 16 and the duct 17 located in the extension 18 of the telescopic member 4.

Figure 8 shows an alternative construction. Here the cylindrical spaces located below the pistons 6 are connected directly to the fluid space at the turbine exhaust by means of a conduit 19 located in the interior of the telescopic member 4 and communicating at one end with the openings 20, and at the other end with the turbine exhaust space (not shown).

When comparing the action of the ram device arranged as shown in Figure 2 with these arrangements shown in Figures 7 and 8, it will be seen that the bit weight W is affected to a much greater extent in the former case than the latter by changes of the pressure drop kQ^2 across the bit jet openings, the influence of which was greatest at the highest mud circulation rate Q_1 , i.e. at the lowest turbine speed N_1 . This results in the latter case in the points 1 and 3 (Figure 4) both shifting to the right on the line $W_c = \text{constant}$, whilst at the same time the distance between these points 1 and 3 (this distance being proportional to the speed range $(N_3 - N_1)$) is reduced. It will be appreciated that this results in a

steeper operating curve W_c in Figure 5, and thus in an increased insensibility.

Another way of increasing the insensibility of the system is to maintain the pressure drop across the bit jet openings substantially constant irrespective of the circulation rate. This can be arranged by designing the jet openings to give the minimum desired jet velocity at the minimum circulation rate likely to be used, and having a pressure relief valve between the turbine exhaust and the bit which allows some of the fluid to by-pass the bit openings at circulation rates above the minimum. An alternative arrangement may be provided by using relief valves in the bit openings.

In general, a steeper operating curve, such as the curve W_c in Figure 6, and thus a greater insensibility of the system will be obtained when the pressure differential applied to the pistons 6 of the ram device increases at higher turbine speeds to a greater extent than shown in Figure 3.

This can be achieved, for example, by using a turbine having a design speed equal to the minimum speed of the desired speed range when drilling through formations, and having a rapidly increasing pressure drop across it for speeds higher than the design speed as a result of decreased efficiency at such higher speeds.

In a similar way the desired steeper curves in Figures 3 and 6 can be obtained by artificially increasing the pressure drop across the turbine at higher speeds thereof by throttling the turbine outlet (or the turbine inlet) at the said speeds. This can be achieved by means of a speed sensitive throttle valve of suitable design located in the outlet conduit (or the inlet conduit) of the turbine.

The insensibility of the system may also be increased by controlling the pressure differential applied to the pistons 6 by a pump, driven by the turbine, as shown in Figures 9A and 9B. In Figure 9A, the pump shaft 21 of the pump 22, which is preferably a positive displacement type of pump such as a gear pump, is driven by the turbine (not shown). A small part of the mud flush flowing in the direction 9 through the interior of the inner telescopic member 4 is sucked through the inlet opening 23 of the pump 22, and pumped under increased pressure via the conduit 24 and openings 25 to the cylindrical spaces 7 located above the piston 6. The pressure increase will be a function of the turbine speed N , increasing as N increases.

The bit weight/speed ratio (W/N) curves for various circulation rates in the arrangement shown in Figure 9A, are shown in Figure 10.

On comparing the W/N curves thus obtained (Figure 10) with the W/N curves as shown in Figure 4, it will be seen that the former are considerably steeper than the latter due to the additional effect of the increased pressure from the pump, itself increasing with N . The corresponding formation coefficient/speed (K/N) curves shown in Figure 11 will consequently be steeper than the corresponding curves in Figure 6.

This results, when drilling through the whole range of formation hardnesses K_1-K_4 at a constant bit weight W_c , in a very steep operating curve W_c (Figure 11), so that when reducing the circulation rate Q from Q_1 to Q_4 as the formation grows harder, only a very small range of speed variations (N_4-N_1) will be covered. This, as already mentioned, is a highly desirable feature from the point of view of turbine operation.

Returning to Figure 9A, there are shown small venting orifices 26 and 26', details of the construction of which are shown in Figures 12 and 13, respectively. The venting orifices 26 and 26', venting the cylindrical spaces 7 located above the pistons 6 to the bore hole, are required to pass the circulation of fluid from the pump 22, in such a way that the required pressure can be established in the cylindrical space 7.

In the construction shown in Figure 12, a screw plug

and is sealed by an O-ring 29. A hexagonal recess 28 is provided to facilitate the insertion and removal of the plug 27. The venting orifice 26 is located in the plug 27, and a hard metal nozzle 30 is adopted so as to prevent excessive wear by the mud flowing through the orifice 26. The plug 27 is quickly interchangeable for a new one when the nozzle is worn out, or for a plug having a nozzle 30 of a greater or smaller diameter which may be required under certain circumstances.

In Figure 13, the abutment 8 of the outer telescopic member 3 is provided with upper and lower screw threads 31 and 31' respectively, engaging the screw threads of the upper and lower parts 3 and 3' respectively of the outer telescopic member 3. The adjacent cylindrical spaces 7 located above and below the abutment 8 are sealed at the surface of the inner telescopic member 4 by sealing member 32. The venting orifice 26' communicates through the conduit 33 with the cylindrical space 7 located below the abutment 8, the conduit 33 opening into the space 7 from the lower surface of the abutment 8. The construction of the plug in which the orifice 26' is located is similar to the one shown in Figure 12.

Referring now to Fig. 9B, there is shown an alternative arrangement in which a pump driven by the turbine is used. The pump 22' in this case is a gear pump and is connected by an extension of its shaft 21 to the upper end of the turbine rotor shaft (not shown). The outlet end of the pump 22' communicates through the conduit 24 and the openings 25 with the cylindrical spaces 7 located above the pistons 6. The intake of the pump 22' communicates through the conduit 24' and the openings 12' with the cylindrical spaces 7 located below the pistons 6. Venting orifices similar to those indicated in Figure 9A are provided, connecting the upper and lower surfaces of the pistons 6. The pump pressure P_p is therefore applied to all the pistons 6, that pressure being a function of the turbine speed. For the various circulation rates Q , at which the turbine is operated, there are obtained with this arrangement W/N and K/N relations similar to those shown in Figures 10 and 11. The advantage of this arrangement over the arrangement shown in Figure 9A, resides in the fact that a separate servo fluid can be used for operating the pistons 6. Thus, interruption of drilling due to fouling or clogging of the venting orifices 26, 26' or of the ports 25 (vide Figure 9A) is avoided. The pistons 6 are sealed to the cylinder walls by sealing means 32', whilst the abutments 8 are sealed to the inner telescopic member 4 by sealing means 32. Particular attention has to be paid to the upper sealing means 32' provided on the extension of the inner telescopic member 4, and the lowest one of the sealing means 32, as these two particular sealing means separate zones containing mud flush and servo-fluid.

The range of turbine speeds can be restricted in another manner by interconnecting the cylindrical spaces 7 on the opposite sides of one or more of the pistons 6 of the ram device, thus putting the pistons 6 so treated out of action. At the same time it is necessary to close either the passage existing between one of the said spaces 7 and the interior of the inner telescopic member 4, or the passage existing between the other of the said spaces 7 and the exterior of the outer telescopic member 3, to prevent direct communication between the mud flush inside the member 4 and in the bore hole outside the member 3.

The result of including these arrangements is shown in Figure 14, in which the bit weight/turbine speed (W/N) curves are drawn for circulation rates Q_3 , Q_3' and Q_3'' . The quantities of mud circulation Q_3 , Q_3' and Q_3'' are equal to each other, the only difference being that the curve Q_3 represents the W/N relation with all the pistons in action (compare Q_3 in Figure 4), whilst the curve Q_3' represents the W/N variation with one piston out of action and Q_3'' with two pistons out of action.

Figure 15 shows the formation coefficient/speed (K/N) curves drawn for circulation rates Q_3 , Q_3' and Q_3'' . It can be seen from Figure 15 that, when starting drilling in a formation having a coefficient K_1 with a ram device having two pistons out of action, which coefficient gradually decreases, the turbine speed will increase from N_1 to N_2 . At the point 2 on the curve Q_3'' , one more piston is put into action and drilling proceeds from point 3 to point 4 on the curve Q_3' , with only one piston out of action. At the point 4, the remaining piston is put into action and drilling proceeds from point 5 to point 6 along the curve Q_3 . From Figure 14 it can be seen that the bit weight W gradually increases as the drilling operation proceeds in the manner indicated by the path between points 1—6 on Figures 14 and 15.

This can be changed however to make it possible to drill under a constant bit weight within each step 1—2, 3—4 and 5—6, by varying the circulation rate Q , in the manner described with reference to Figures 4 and 6.

The pistons may be put out of action manually when the ram device is lifted out of the bore hole. To this end, there may be provided screw-threaded openings 11 in the wall of the inner telescopic member 4 (see Figure 16) and screw-threaded openings 34' in the wall of the outer telescopic member 3, the openings 34' being located just below the abutments 8 (provided with sealing means 32) and the openings 11 being located just above the pistons 6 (being provided with sealing means 35). Each opening 34' is in alignment with a corresponding opening 11 when the ram device is in its fully retracted position, and has a diameter greater than the diameter of the opening 11, such that a screw plug 11' (see the left hand side of Figure 16) can be inserted into the corresponding screw-threaded opening 11 from the exterior of the member 3 through the opening 34'. In this way, as shown at the left hand side of Figure 16, the piston 6 is put out of action because the opening 34' is in communication with the cylindrical space 7 located above the piston 6, and the opening 12, in communication with the cylindrical space below the piston 6, connect both said spaces with the exterior of the outer telescopic member 3, i.e. the bore hole.

If the plug 11' is removed and the plug 34 is inserted into the opening 34', the situation as shown at the right hand side of Figure 16 is obtained. Here the cylindrical space 7 below the piston 6 is still in communication with the bore hole, but the upper cylindrical space 7 is now in communication with the interior of the inner cylindrical member 4, and the pressure differential existing across the turbine and bit jet openings will be applied to the piston 6 thus contributing to the weight on the bit.

The screw plugs 11' may also be inserted or removed when the ram device is in its fully extended position. To this end, there are provided in the wall of the outer telescopic member 3 a number of ports (not shown) having a diameter greater than the diameter of the openings 11, which ports are in alignment with the openings 11 when the ram device is in its extended position. These ports are closed by screw plugs except when the plugs 11' are being inserted or removed through them.

These operations for putting the pistons 6 into and out of action have to take place at the surface of the earth. Usually this is no drawback, as the bit and/or the turbine bearings or blades have to be inspected or replaced periodically, and the number of active pistons 6 can at the same time be adjusted in accordance with the requirements set by the hardness of the formation to be drilled when drilling recommences.

However, under certain conditions, for example when boring through a formation having a quickly varying formation coefficient, it may be desirable to adjust the number of active pistons automatically when the ram device is at the bottom of the hole.

Two alternative arrangements by which this control can be performed are described.

The first arrangement comprises a system of spring-loaded valves within the pistons 6 of the ram device so arranged as to increase the number of pistons 6 in action as the pressure differential applied to the pistons 6 increases. In the second arrangement the pistons 6 are put into action by spring-loaded valves operated by changes in the circulation rate of the mud flush.

Returning to the first arrangement which is shown in Figure 17, there is shown only one piston 6 out of the number of pistons of the ram device, said piston being provided on the inner telescopic member 4 and being able to slide between the abutments 8 on the outer telescopic member 3, said abutments 8 bounding the cylindrical space 7, which is divided by the piston 6 into a lower cylindrical space which is in communication with the bore hole (i.e. the exterior of the member 3) and an upper cylindrical space which has to communicate either with the interior of the member 4 or with the lower cylindrical space, depending on whether the piston 6 is to be in or out of action respectively.

In the piston 6 there is provided a pressure-sensitive valve 36, an enlarged view of which is shown in Figure 18 in its fully extended position wherein the pressure difference existing is not sufficient to compress the spring 39. The valve consists of a cylindrical valve member 37 which slides in a cylinder 38. Two forces act on the valve member 37, to wit the force exerted by a compressed spring 39 and the force resulting from the pressure differential between the pressure of the mud flowing through the inner telescopic member 4, and the fluid pressure in the bore hole. When this pressure differential increases, the valve member 37 is depressed, and the cylindrical space 7 located above the piston 6 is connected through the conduits 40, 41 and 42 with the interior of the inner telescopic member 4. At the same time, the connection between the cylindrical spaces 7 above and below the piston 6 through the conduits 40, 43 and 44 is broken blocked by the member 37, and thus the piston 6 is put into operation by an increase of the pressure differential.

By setting the valves of the various pistons 6 to operate at various pressure differentials, the action indicated by the curves in Figures 20, 21 and 22 may be obtained.

When advancing through a soft formation which gradually grows harder, the formation coefficient K (see Figure 21) will decrease from K_1 to K_6 . The circulation rate $Q_3=Q_3'=Q_3''$ is kept constant. The curve Q_3 represents the K/N relation with all the pistons in operation (compare Q_3 in Figure 6), whilst the curve Q_3' represents the K/N relation for one piston out of action and the curve Q_3'' for two pistons out of action.

Now the valves 36 (only one of which is shown in Figure 17) are adjusted at the surface of the earth to operate at the pressure differentials existing with the flow rate anticipated, i.e. Q_3 . Let us assume that the drilling operation starts under conditions corresponding to the point 1 on the curve Q_3'' (Figure 21) in a formation having a hardness coefficient K_1 . The formation gradually grows harder, and between the points 1 and 2 on the curve Q_3'' (two pistons out of action) the turbine speed gradually increases from N_1 to N_2 . It can be seen in Figure 20 that over the speed range N_1 — N_2 with the circulation rate Q_3'' , the bit weight increases from W_1 to W_2 , and at the same time the pressure drop ΔP across the turbine and bit openings increases from ΔP_1 to ΔP_2 (see Figure 22 and compare this diagram with the diagram shown in Figure 3). At the pressure ΔP_2 , the valve 36 of one of the two pistons 6 which are out of action, operates bringing the piston 6 with which it is associated into action. This one of the valves 36 is set to operate at a pressure differential ΔP_2 . Returning to Figure 21 it will be seen that the drilling operation is then continued along the curve Q_3' , which represents the K/N relation

for the same circulation rate, but with only one piston out of action. At the starting point 3 on this curve, the turbine rotates at a speed N_3 , which is considerably lower than N_2 . Between the points 3 and 4 on the curve Q_3 , the formation is still growing harder, the hardness coefficient decreasing from K_3 to K_4 , and the speed increases from N_3 to N_4 , which increase corresponds to an increase in bit weight from W_3 to W_4 (see Figure 20). At the point 4, a pressure differential ΔP_4 is reached (which is greater than ΔP_2) and the remaining piston is brought into action. Consequently, the speed drops to N_5 (see Figure 21), the bit weight jumps to W_5 , and a final drilling operation following the curve Q_3 (Figure 20) between the points 5 and 6 is undertaken, the formation having a hardness coefficient ranging from K_5 to K_6 and the turbine speed varying from N_5 to N_6 .

The sudden increase of bit weight, when a piston has been brought into action, causes the turbine to slow down and thereby drop the pressure again, so that there may be a tendency for the relevant valve 36 to return to its original position and to put the piston back into action again, i.e. the system would hunt. One way of preventing this is to incorporate a ratchet, trigger device or compression holding spring 45 (see Figures 18 and 19a, b), which, once the valve member 37 has been forced into the lower position, holds the valve member 37 in that position until the pressure differential drops to a predetermined amount below that which operates the valve 36.

Further arrangements for operating piston valves when the ram device is down the hole are shown in Figures 23 and 24, the curves representing the operation of systems incorporating these arrangements being shown in Figures 25 and 26. In these arrangements the piston valves are controlled by changes in circulation rate, in such a way that, when the circulation rate becomes lower than a predetermined value, the piston valve set at this value brings the piston with which it is associated into operation.

In the arrangement shown in Figure 23, a venturi construction 46 creates a pressure differential between two ducts 47 and 48 which communicate with the lower and upper sides respectively of a valve member 49. The valve member 49 is shown in the position in which it would render the ram piston 6 inoperative, the pressure on the upper side of the piston 6 being the same as that on the lower side, by reason of the interconnection through the ducts 50, 51 and 52. When the circulation rate is reduced, the pressure differential between the ducts 47 and 48 decreases, and the valve member 49 rises to block the connection between the duct 52 and the duct 50 and to connect the duct 52 to the upper side of the valve member 49 through a further duct 53, thus bringing the upper side of the ram piston 6 into communication with the interior of the inner telescopic member 4.

In Figure 24, there is shown a similar arrangement having an improved mechanism for operating the valves controlling the pistons 6. The main valve 54 is controlled by an auxiliary valve 55, which is operated by the pressure differential applied to a flexible diaphragm 56. This pressure differential is a function of the rate of the mud circulation through the inner telescopic member 4. The arrangement is shown with the valve 54 in the position such that the piston 6 is in operation. When the circulation rate increases above a predetermined value, the pressure differential increases and the auxiliary valve 55 moves down connecting the duct 57 to the upper side of the valve 54 through the duct 59. The valve 54 then moves down and connects the space 7 on the upper side of the piston 6 to the space 7 on the lower side of the piston 6 through the ducts 58 and 60. At the same time the connection between the interior of the inner telescopic member 4 and the space 7 on the upper side of the piston 6 through the ducts

57 and 58 is cut off, and the piston is thus put out of operation. A small venting duct 61 is provided through the valve 54, so as to facilitate its upward movement.

The bit weight/speed (W/N) and formation coefficient/speed (K/N) curves shown in Figures 25 and 26 show the sequence of operation when starting the drilling action in a hard formation (formation coefficient K_1) and advancing through a formation which gradually grows softer (K_6). In Figure 26 the outlines of three groups of circulation curves are given.

In Figure 26 the group bounded by the curves Q_3 and Q_b (Q_3 being smaller than Q_b) represents the K/N relation for the various values of circulation rate lying between Q_3 and Q_b when all the pistons are in action (compare Figure 6). The group bounded by the curves Q_b' and Q_a' (Q_b' being equal to Q_b but smaller than Q_a') represents the K/N relation for the various values of circulation rate lying between Q_b' and Q_a' , when one piston of the ram device is out of action. Finally, the group bounded by the curves Q_a'' and Q_1'' (Q_a'' being equal to Q_a' but smaller than Q_1'') represents the K/N relation for the various values of circulation rate lying between Q_a'' and Q_1'' , when two pistons are out of action.

When starting under conditions represented by the point 1 in a formation of hardness K_1 , the driller will control the circulation rate from Q_3 to Q_b in accordance with the bit weight W , so that, in Figure 25, the curve joining points 1 and 2 is followed as the formation coefficient gradually increases from K_1 to K_2 . When the circulation rate has risen to Q_b , the valve set to operate at this value will be actuated and the piston with which it is associated, is put out of action. It can be seen from Figure 26 that the speed of the turbine which was reduced from N_1 to N_2 , now increases to N_3 . Over the formation hardness range K_3 to K_4 , the curve joining points 3 and 4 in Figure 25 is followed by the driller, who adjusts the circulation rate accordingly. At the point 4, the circulation rate has risen to Q_a' , with the result that a further valve operates putting one more piston 6 of the ram device out of action. Consequently, the turbine speed N_4 is increased to N_5 (see Figure 26) and the bit weight is reduced from W_4 to W_5 . The curve 5-6 is then followed in the same way as the other curves.

Contrary to the first arrangement described with reference to Figures 17-22, in which the pistons 6 are controlled by pressure-sensitive valves and in which over the whole range of formation co-efficients the circulation rate is kept constant (vide Figures 20, 21 and 22), this latter arrangement requires a continuous adjustment of the circulation rate in accordance with the measured bit weight. This adjustment may be performed either manually or automatically.

Other arrangements for putting the pistons 6 out of action are shown in Figures 27, 28 and 29. In these, a piston 6 is put out of action by interconnecting the two adjacent cylindrical spaces 7 located one below and one above the abutment 8 separating two adjacent cylinders.

Figure 27 shows, by way of example, an arrangement in which the interconnection is effected manually by the driller when the ram device is lifted out of the bore hole. For this purpose the abutment 8, which divides the space between the pistons 6 and 6' into an upper cylindrical space 62 and a lower cylindrical space 63, is provided with a radial bore 64 having a screw thread over its whole length. The bore 64 is connected to the cylindrical space 62 through a port 65, and to the cylindrical space 63 through a port 66. Its outer end opens to the exterior of the outer telescopic member 3, i.e. to the bore hole. A screw plug 67, having an insert 68 for facilitating the mounting and adjustment thereof, is fitted into the outer end of the bore 64. When the plug 67 is in the position shown, the spaces 62 and 63 are connected to each other through the ports 65 and 66 and the bore 64. Since the

space 63 is at the same pressure as the space above the piston 6, this connection puts the piston 6 out of action. By screwing the plug 67 into the bore 64 to the position as indicated in dotted outline 67', the connection between the spaces 62 and 63 is broken, whilst at the same time the space 62 is connected to the bore hole, thus restoring normal action of the piston 6. It will be evident that this could be effected by means of a three-way cock located in the abutment 8.

Figure 28 shows an arrangement similar to the pressure-sensitive control system described with reference to Figures 17-22.

The abutment 8 located between the cylindrical spaces 62 and 63, is provided with a cylindrical bore 69 in which the cylindrical valve member 70 may slide. The space 63 is connected to the bore 69 by the ports 71 and 72, whilst the space 62 is connected to the bore 69 by the ports 73 and 74. The valve member 70 is provided with a radial conduit 75 which, in the one extreme position of the valve member 70, connects the ports 73 and 72 (as shown in the drawing). In the other extreme position of the valve member 70, the port 74 is connected through a further conduit 76 in the member 70 with the bore 69 and thence through the opening 77 in the plug 78 with the exterior of the outer telescopic member 3, i.e. the bore hole.

In the position of the valve member 70 shown, the spaces 62 and 63 are interconnected and the piston 6 is out of action, the pressure differential between the interior of the inner telescopic member 4 and the exterior of the outer telescopic member 3 being below the value member 70 operates, i.e., below the value at which the valve No. 70 is forced to the right against the valve spring.

When the pressure differential increases, as a result of varying drilling conditions, the valve member 70 moves to the right, the connection between the spaces 62 and 63 is broken, and the space 62 is connected to the bore hole through the port 74, the conduit 76, the bore 69 and the opening 77 in the plug 78. In this way the piston 6 is brought into action again.

Figure 29 shows an arrangement similar to the flow-sensitive control system as described with reference to Figures 23-26.

The abutment 8 forming the boundary between the two cylindrical spaces 62 and 63, is provided with a cylinder 82 in which may slide the valve member 79 of a flow-sensitive valve, which is operated by the pressure differential created between the openings 11 and 80 by the flow over the venturi member 81. The space 62 is connected to the cylinder 82 by the port 83, whilst the space 63 is connected to the cylinder 82 by the ports 84 and 85. Further the cylinder 82 is connected to the upper end of the cylindrical space 63' by the conduit 86, and to the exterior of the telescopic member 3 by the conduit 87. The valve member 79 is provided with a radial port 88, which in the one extreme position of the valve member 79 connects the ports 83 and 84, and with a depression 89 which connects the conduits 83 and 87 in the other extreme position of the valve member 79.

In the position as shown in the drawing, the flow in the direction 9 through the interior of the inner telescopic member 4 has reached such a value that the pressure differential existing between the openings 11 and 80, which differential also acts across the ends of the valve member 79, has moved the valve member 79 to its extreme to the right position against the action of the spring 90, which spring is provided between the valve member 79 and the plug 91 closing the cylinder 82. The spaces 62 and 63 are now interconnected by the ports 83 and 84 and the conduit 88 and the piston 6 is inoperative. If the flow is reduced, the pressure differential decreases and the valve member 79 is moved to the left by the action of spring 90. Now the connection between the spaces 62 and 63 is broken, and at the same time the

space 62 is connected to the bore hole through the port 83, the depression 89 and the conduit 87.

The conduit 86 may have a branch conduit 86', which is connected to the cylinder of a control system provided in an abutment 8 bounded at its upper end by the space 62'.

The arrangements shown in Figures 28 and 29 have the advantage over the arrangements shown in Figures 17, 23 and 24 that the adjustment of the control valves, which has to be done when the ram device is lifted out of the hole, can be performed without having to dismantle the telescopic members 3 and 4, since in the former arrangements the valves are accessible from the exterior of the outer telescopic member 3.

In the same way an easier manual control of the number of pistons in action is obtained in the arrangement shown in Figure 27, as compared to the manipulations which are involved when the construction shown in Figure 16 is used.

Normally it is possible with the ram devices shown in Figures 16, 17, 23, 24, 27, 28 and 29 to put all the pistons but one out of action. Then the smallest possible bit weight (when drilling through a soft formation) will be obtained.

When drilling in a very soft formation, the minimum bit weight required is very small. This could be arranged by having a larger number of small pistons 6. This, however, will increase the length of the ram device to an undesired extent.

It has been found that another way of decreasing W_{min} , without altering the length of the ram device, is to keep the number of pistons constant but to arrange that the one piston 6 which is not put out of action has a much smaller area than the others.

It will be clear that several of the features described individually with reference to Figures 7, 8, 9A, 9B, 16, 17-19, 23, 24, 27, 28 and 29, may be combined in a single system.

I claim as my invention:

1. A well drilling apparatus comprising a tubular drill string, a drill bit, advancing-type down-hole motor means, a ram device, said motor means and said ram device being connected in axial alignment in said drill string and forming connecting means between the drill string and the drill bit, said ram device comprising two hollow telescopic members one of which is downwardly extensible, the inner one of which provides a channel for passage of fluid from the drill string to the bit, there being an elongated annular chamber formed between said telescopic members, cooperating means carried by said members for preventing relative rotational movement between them, one of said members being provided with a plurality of abutments forming a number of pistons, at least an equal number of abutments fixedly carried on the other member forming piston chambers between the telescopic members, each piston being positioned in a piston chamber and dividing the piston chamber with which it cooperates into two annular spaces, conduit means carried by said inner telescopic member connecting all the annular spaces located above the abutments of the downwardly extensible member to the interior of the inner telescopic member so that these abutments are subjected on that one side to the pressure of the fluid in the drill string, and conduit means carried by said outer telescopic member connecting all the annular spaces located on the other side of the abutments of the downwardly extensible member to the exterior of the outer telescopic member so that these abutments are subjected on their other side to the pressure of the fluid outside the drilling apparatus, whereby in operation of said drilling system a downward force is exerted on the bit when a drilling fluid is circulated therethrough.

2. A well drilling apparatus comprising a tubular drill string, a drill bit, advancing-type down-hole electric motor means, a ram device, said motor means and said ram

device being connected in axial alignment in said drill string and forming connecting means between the drill string and the drill bit, said ram device comprising two hollow telescopic members one of which is downwardly extensible, the inner one of which provides a channel for passage of fluid from the drill string to the bit, there being an elongated annular chamber formed between said telescopic members, cooperating means carried by said members for preventing relative rotational movement between them, one of said members being provided with a plurality of abutments forming a number of pistons, at least an equal number of abutments fixedly carried on the other member forming piston chambers between the telescopic members, each piston being positioned in a piston chamber and dividing the piston chamber with which it cooperates into two annular spaces, conduit means carried by said inner telescopic member connecting all the annular spaces located above the abutments of the downwardly extensible member to the interior of the inner telescopic member so that these abutments are subjected on that one side to the pressure of the fluid in the drill string, and conduit means carried by said outer telescopic member connecting all the annular spaces located on the other side of the abutments of the downwardly extensible member to the exterior of the outer telescopic member so that these abutments are subjected on their other side to the pressure of the fluid outside the drilling apparatus, whereby in operation of said drilling system a downward force is exerted on the bit when a drilling fluid is circulated therethrough.

3. A well drilling apparatus comprising a tubular drill string, a drill bit, advancing-type down-hole hydraulic motor means, a ram device, said motor means and said ram device being connected in axial alignment in said drill string and forming connecting means between the drill string and the drill bit, said ram device comprising two hollow telescopic members one of which is downwardly extensible, the inner one of which provides a channel for passage of fluid from the drill string to the bit, there being an elongated annular chamber formed between said telescopic members, cooperating means carried by said members for preventing relative rotational movement between them, one of said members being provided with a plurality of abutments forming a number of pistons, at least an equal number of abutments fixedly carried on the other member forming piston chambers between the telescopic members, each piston being positioned in a piston chamber and dividing the piston chamber with which it cooperates into two annular spaces, conduit means carried by said inner telescopic member connecting all the annular spaces located above the abutments of the downwardly extensible member to the interior of the inner telescopic member so that these abutments are subjected on that one side to the pressure of the fluid in the drill string, and conduit means carried by said outer telescopic member connecting all the annular spaces located on the other side of the abutments of the downwardly extensible member to the exterior of the outer telescopic member so that these abutments are subjected on their other side to the pressure of the fluid outside the drilling apparatus, whereby in operation of said drilling system a downward force is exerted on the bit when a drilling fluid is circulated therethrough.

4. A well drilling system according to claim 1, in which the hydraulic motor is a hydraulic turbine.

5. A well drilling system according to claim 4, including a pump positioned between said ram device and said turbine, a shaft connecting said turbine with said pump, conduit means in communication between the outlet of the pump and the space on one side of said pistons where there is a relatively high fluid pressure, the annular spaces to which it is connected being provided with throttle passages to permit the escape of fluid without substantial loss of pressure.

6. A well drilling system according to claim 4, in

which there is provided a pump positioned between said ram device and said turbine and being driven by the turbine, conduit means in communication between the outlet of said pump and the space in which there is a relatively high fluid pressure, conduit means in communication between the intake of the pump and the space on the other side of said pistons where there is a relatively low pressure, and throttle passages interconnecting the spaces to permit circulation of fluid without substantial loss of pressure.

7. A well drilling system according to claim 1, in which the ram device also including by-pass conduit means together with conduit closure means for enabling at least one of the pistons to be put out of action.

8. A well drilling system according to claim 7, in which the pistons are mounted on the inner telescopic member, the spaces of relatively high and low fluid pressure are respectively the interior of the inner telescopic member and the exterior of the outer telescopic member, and, in the case of each piston which can be put out of action, said by-pass conduit means connecting the annular space on the said one side of the piston to the interior of the inner telescopic member comprises at least one radial passage through the inner telescopic member at a point a short distance above the piston, a like number of radial passages through the outer telescopic member at positions such that they are in register with the radial passages through the inner telescopic member when the telescopic members are fully collapsed, and plug valve means adapted to be positioned in one of the radial passages, whereby on blocking only the radial passages in the inner telescopic member the piston is put out of action and on blocking only the radial passages in the other telescopic member the piston can operate normally.

9. A well drilling system according to claim 8, in which the radial passages are all screw-threaded and the said blocking means are correspondingly screw-threaded inserts, the diameter of the bore of the radial passages in the outer telescopic members being such that the blocking means can be removed from the radial passages in the inner telescopic member through the passages in the outer telescopic member, when the passages through the two members are in register.

10. A well drilling system according to claim 7, in which the pistons are mounted on the inner telescopic member and the space of relatively low fluid pressure is the exterior of the outer telescopic member and, in the case of each piston which can be put out of action, there is provided in an abutment at the end of the annular space normally in communication with the said space of relatively low fluid pressure, a radial screw-threaded bore open to the exterior of the outer telescopic member, a first passage joining said annular space to the bore and a second passage joining the annular space on the other side of the abutment to the bore at a point along its length further from the exterior of the outer telescopic member than that at which the first passage joins, a correspondingly screw-threaded insert plug adapted to be positioned in said radial bore to allow said first passage to be in communication selectively with said second passage and the exterior of the outer telescopic member.

11. A well drilling system according to claim 7, in which each said by-pass conduit means comprises in addition to said high pressure conduit means normally communicating with the annular space on one side of the piston, additional conduit means in communication between opposite sides of said piston, and valve means positioned in both said conduit means, said valve means having two operative positions so as to block selectively one of said conduit means at all times.

12. A well drilling system according to claim 11, in which the additional conduit means in communication between opposite sides of the piston and the valve means are positioned in the piston itself.

13. A well drilling system according to claim 11, in

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which the by-pass conduit means is incorporated in the abutment separating two annular spaces in said ram device.

14. A well drilling system according to claim 11, in which by-pass conduit means are provided for each of said pistons, and spring means mounted inside said valve means for adjusting each of the valve means in said by-pass conduit means to operate successively whereby the pistons with which said valve means are associated are put out of action successively by a continuing pressure drop in said drilling system during drilling operations.

15. A well drilling system according to claim 11, including a Venturi construction in the channel for mud flush through the inner telescopic member of said ram device, conduit means in communication between said Venturi and said valve means of said by-pass conduit means, said valve means being actuated by a pressure difference derived from this Venturi construction, the valve means in each said valved by-pass conduit means being arranged to put the piston with which it is associated, out of action when this pressure drop is at least equal to the value corresponding to the predetermined value of the mud flush circulation rate.

16. A well drilling system according to claim 15, in which each of the valve means comprises a main valve

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and an auxiliary valve, the main valve controlling the operation of the piston and being biased to its position for normal operation of the piston, and the pressure drop being applied to the auxiliary valve, which, when the pressure drop reaches the predetermined value, operates to apply fluid under pressure to the main valve to overcome the bias and move the main valve to a position in which the piston is put out of action.

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