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(54) **THRUSTER RESPONSIVE TO DRILLING PARAMETERS**

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(57) **ABSTRACT**

This invention provides a bottomhole assembly that contains a thruster for applying an axial force on the drill bit during drilling of the wellbore. The bottomhole assembly includes at least one sensor which provides measurements for determining a parameter of interest relating to the drilling of the wellbore. A power unit supplies power to the thruster to move a member toward the drill bit to apply the force on the drill bit. A processor operatively coupled to the thruster controls the magnitude of the force generated by the thruster in response to one or more parameters interest.

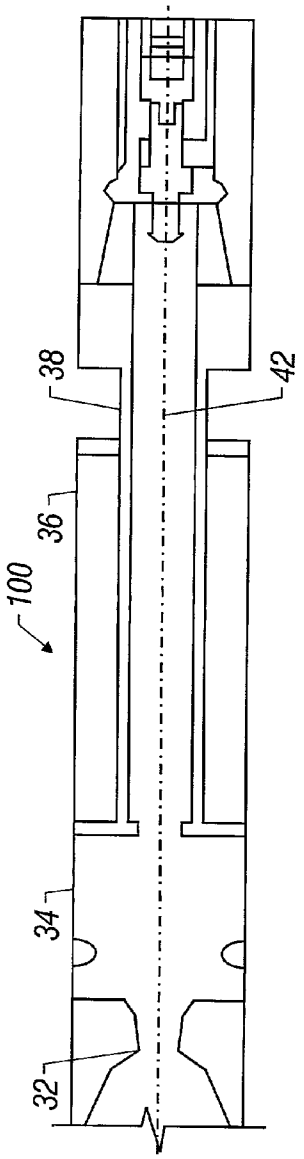


FIG. 1A

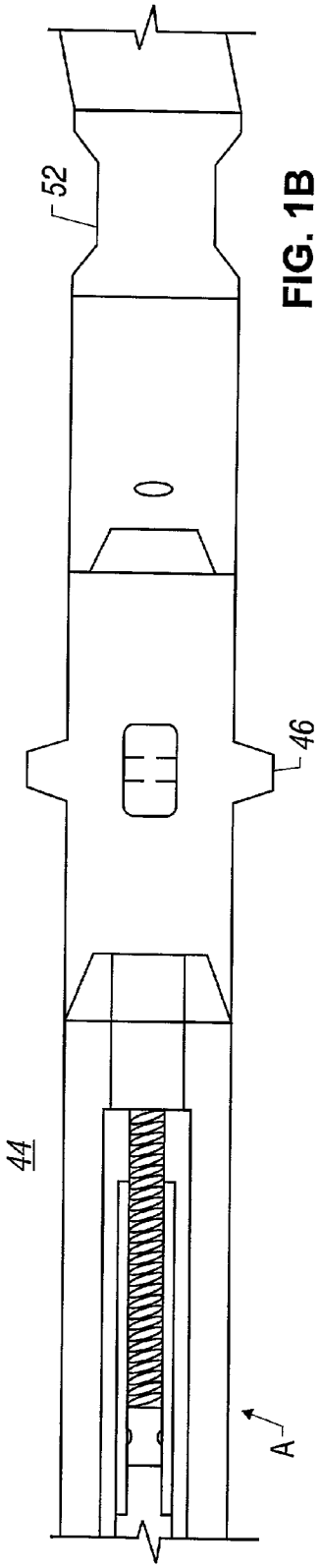


FIG. 1B

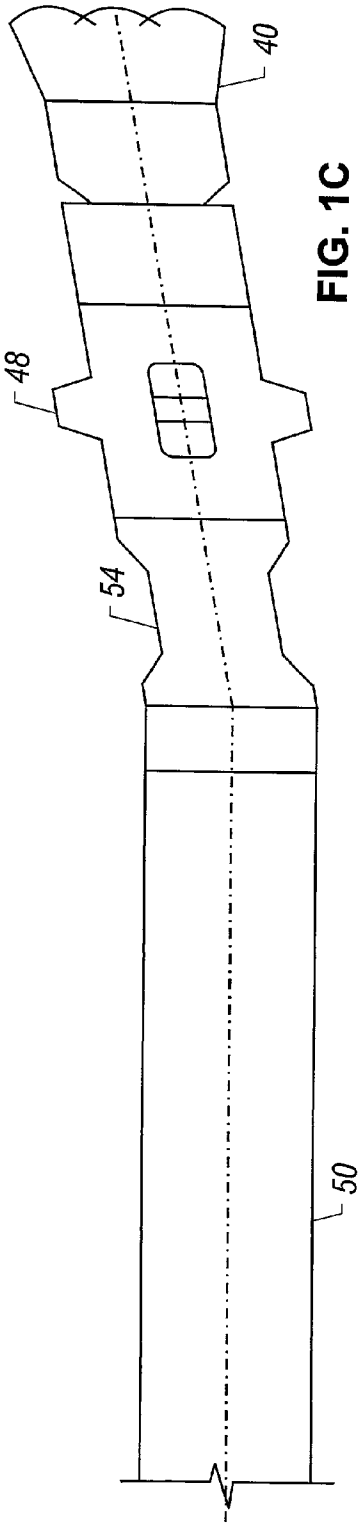


FIG. 1C

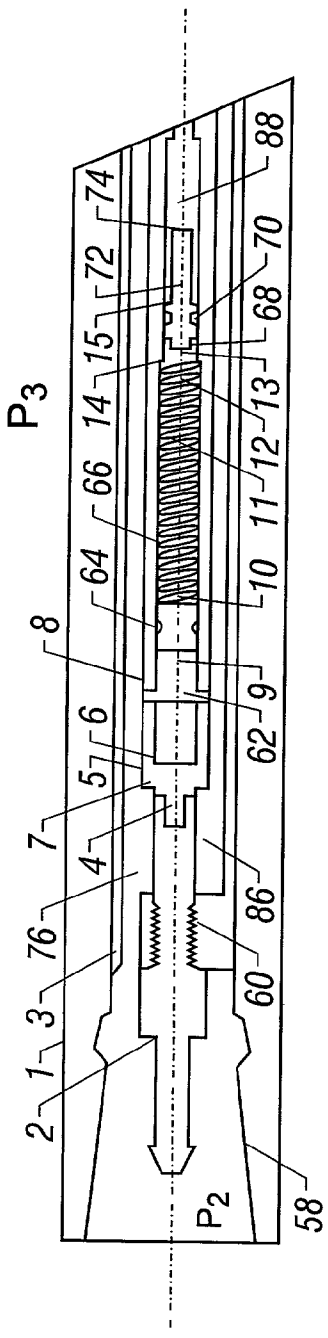

P3
P2
88
74
72
70
68
15
14
13
12
11
10
66
64
8
9
62
6
5
7
4
86
76
60
3
1
2
58

FIG. 2A

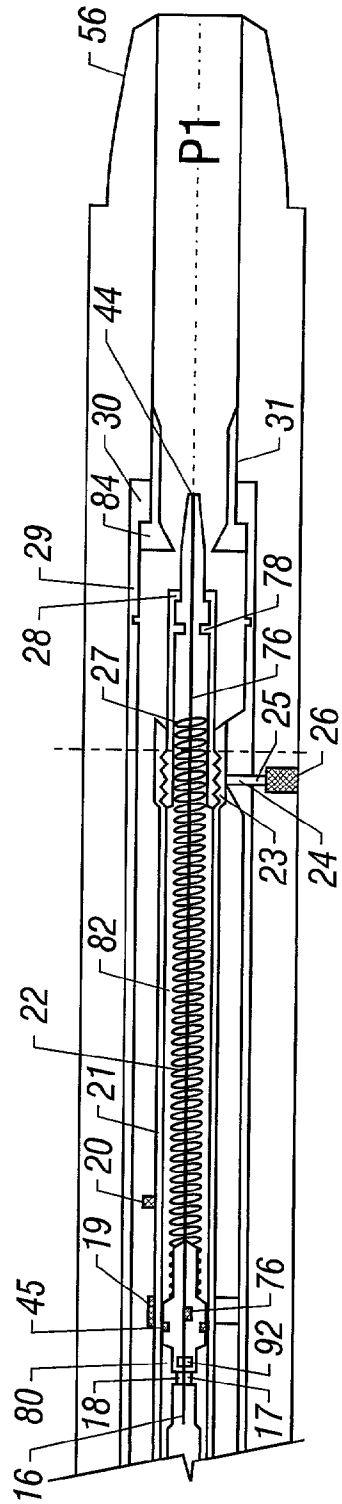

56
P1
44
30
31
84
29
78
28
27
76
25
26
23
24
82
22
21
20
19
45
76
92
80
18
17
16

FIG. 2B

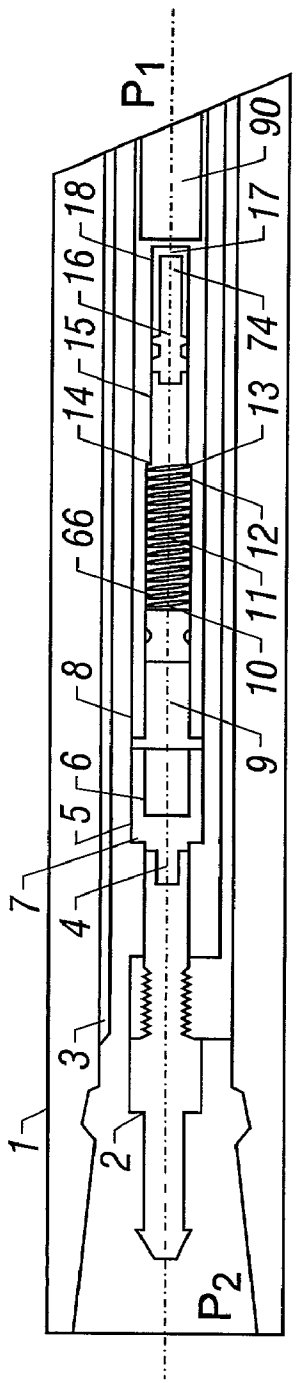

P1
90
18
17
16
74
15
14
13
66
12
11
10
8
9
6
5
7
4
3
1
2
P2

FIG. 3A

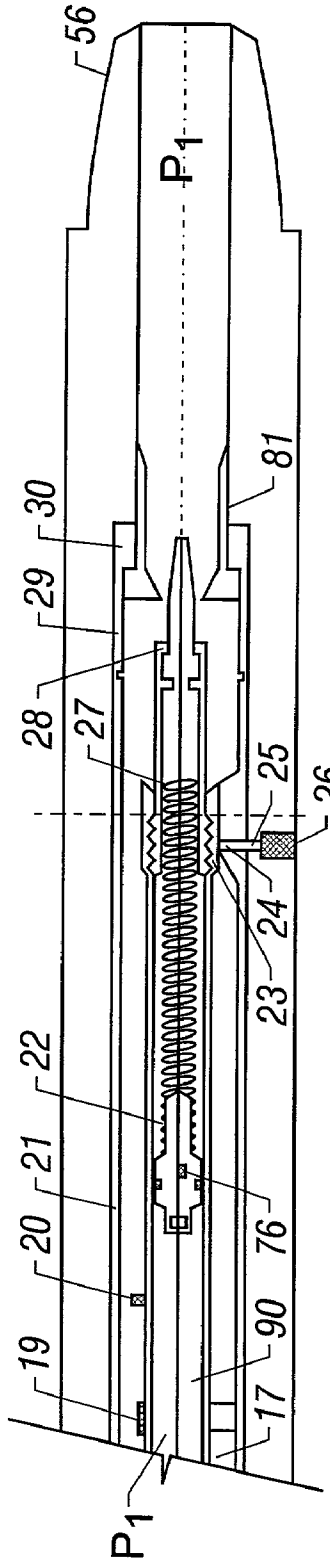

56
P1
81
30
29
28
27
25
26
24
23
22
21
20
76
19
90
17
P1

FIG. 3B

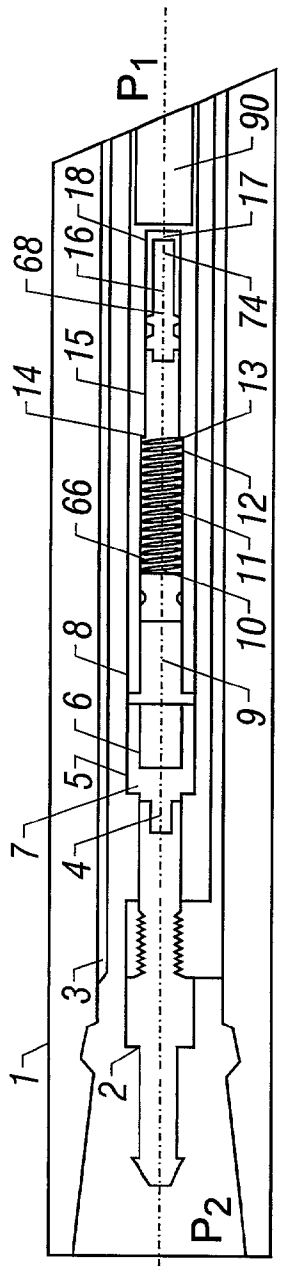

P1
P2
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
66
68
74
90

FIG. 4A

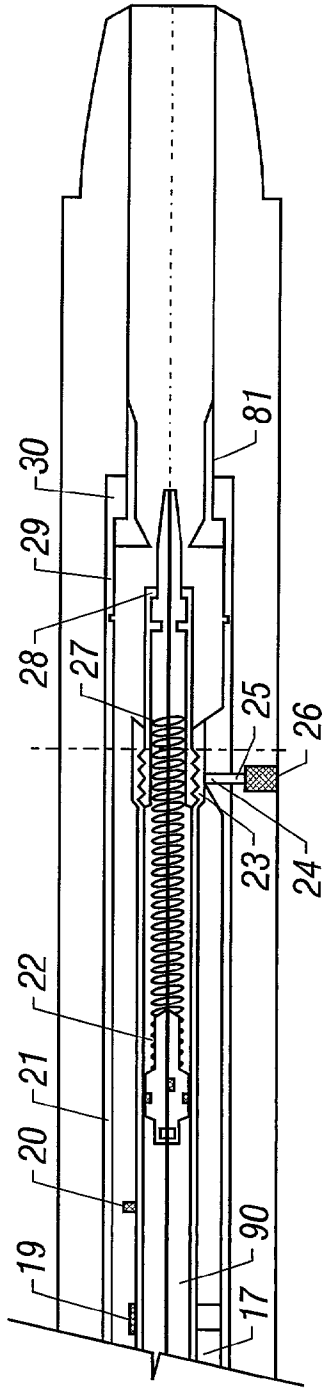

19
20
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28
29
30
81
90
17

FIG. 4B

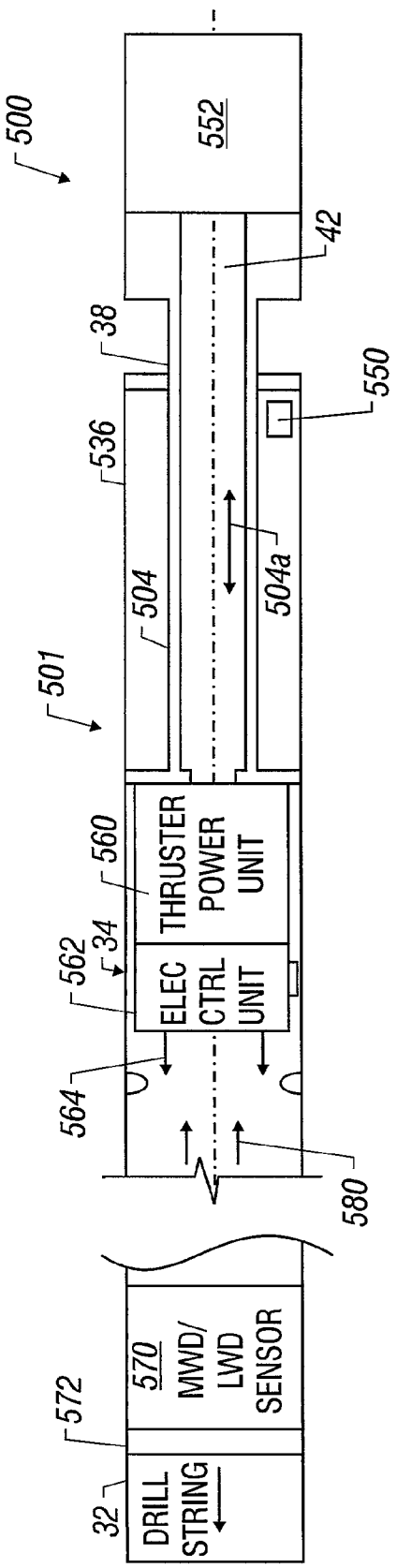

500
552
42
38
550
536
504
504a
501
560
THRUSTER POWER UNIT
562
34
ELEC CTRL UNIT
564
580
572
570 MWD/ LWD SENSOR
32
DRILL STRING

FIG. 5A

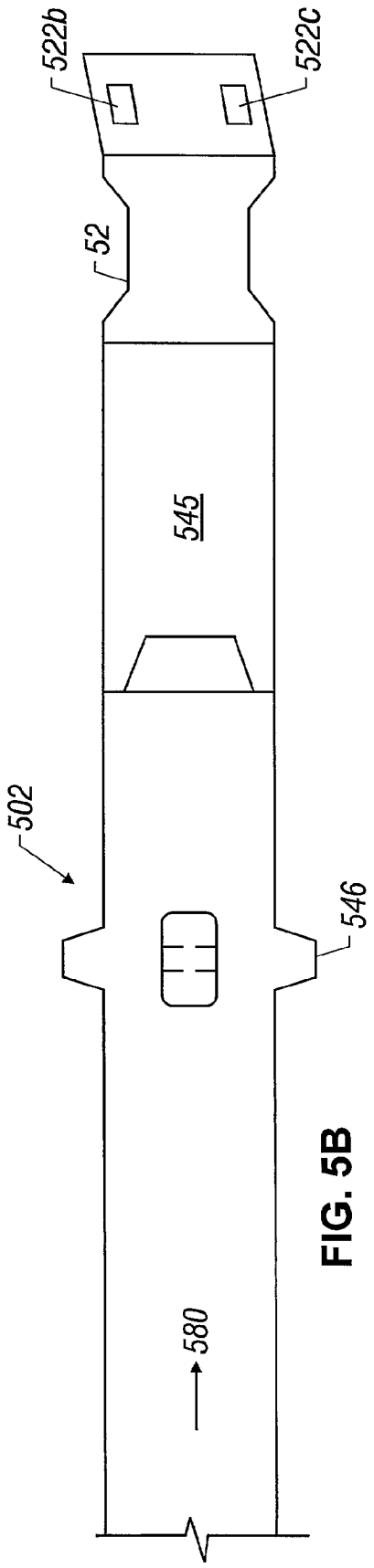

522b
522c
52
545
502
546
580

FIG. 5B

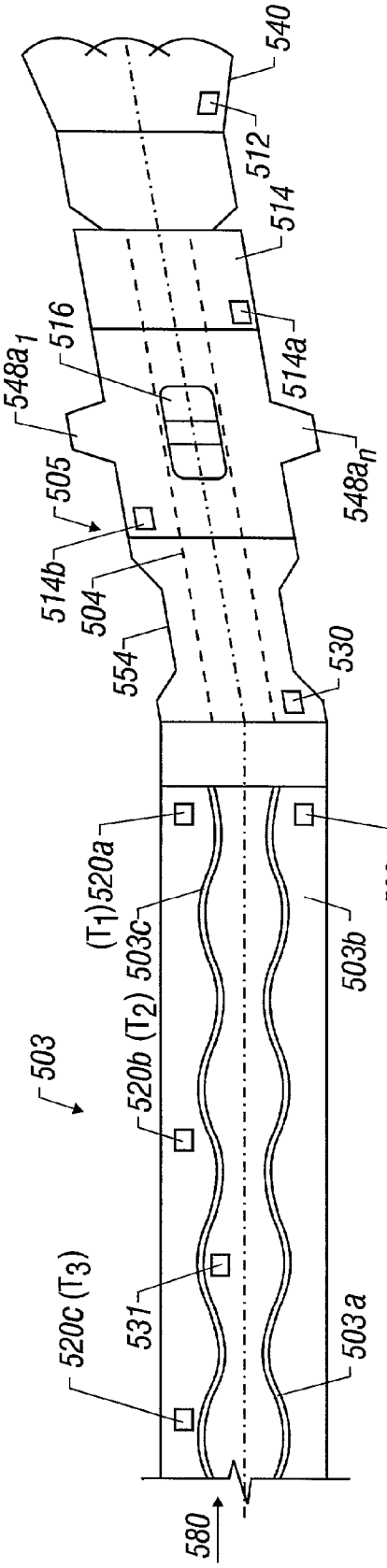

540
512
514
516
548a1
514a
505
548an
514b
504
554
530
(T1)520a
522a
503c
503b
520b (T2)
503
520c (T3)
531
503a
580

FIG. 5C

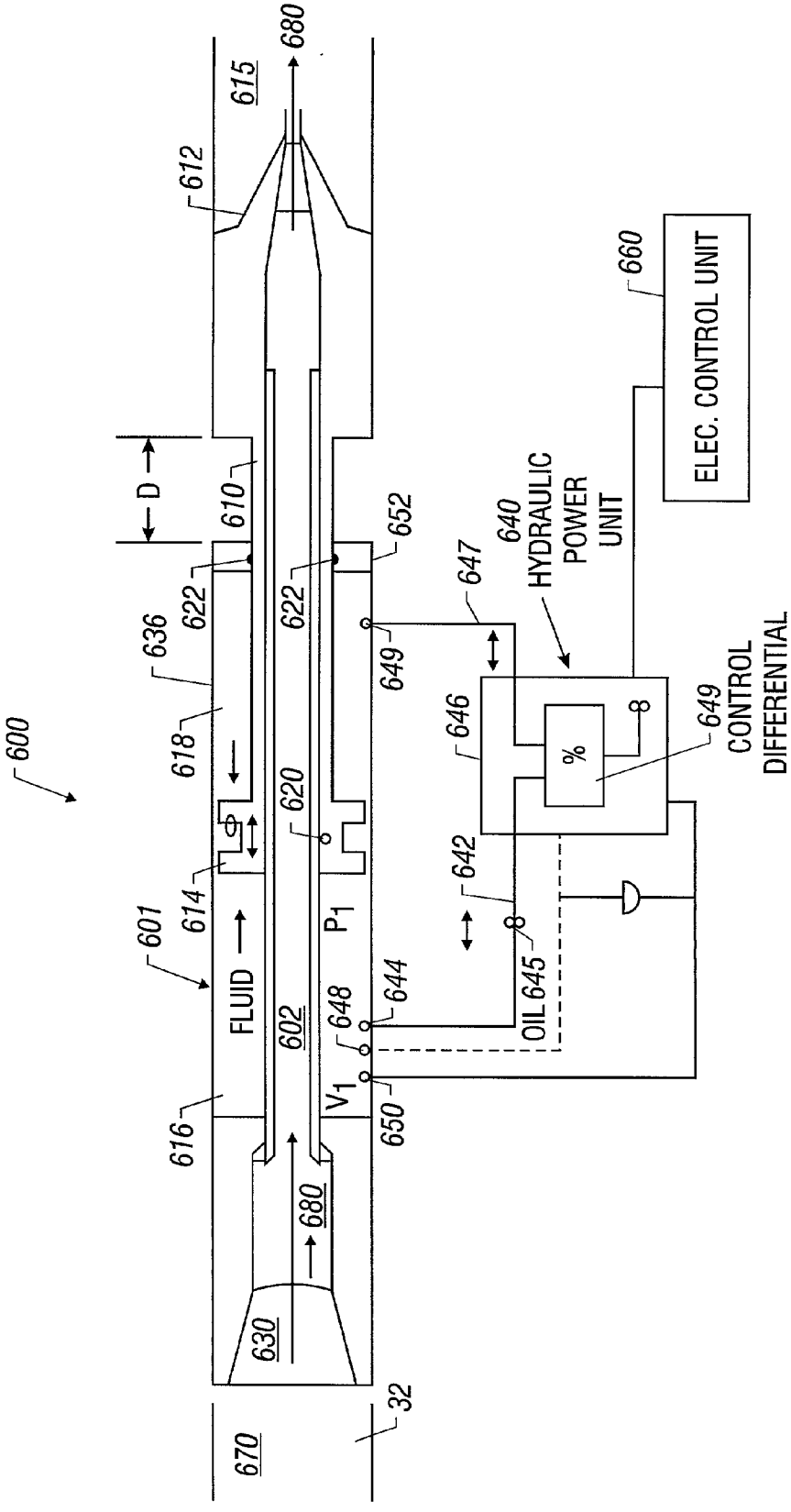

600
601
602
610
612
614
615
616
618
620
622
630
636
640
642
644
645
646
647
648
649
650
652
660
670
680
D
FLUID
P1
V1
OIL
%
HYDRAULIC POWER UNIT
ELEC. CONTROL UNIT
CONTROL DIFFERENTIAL
32

FIG. 6

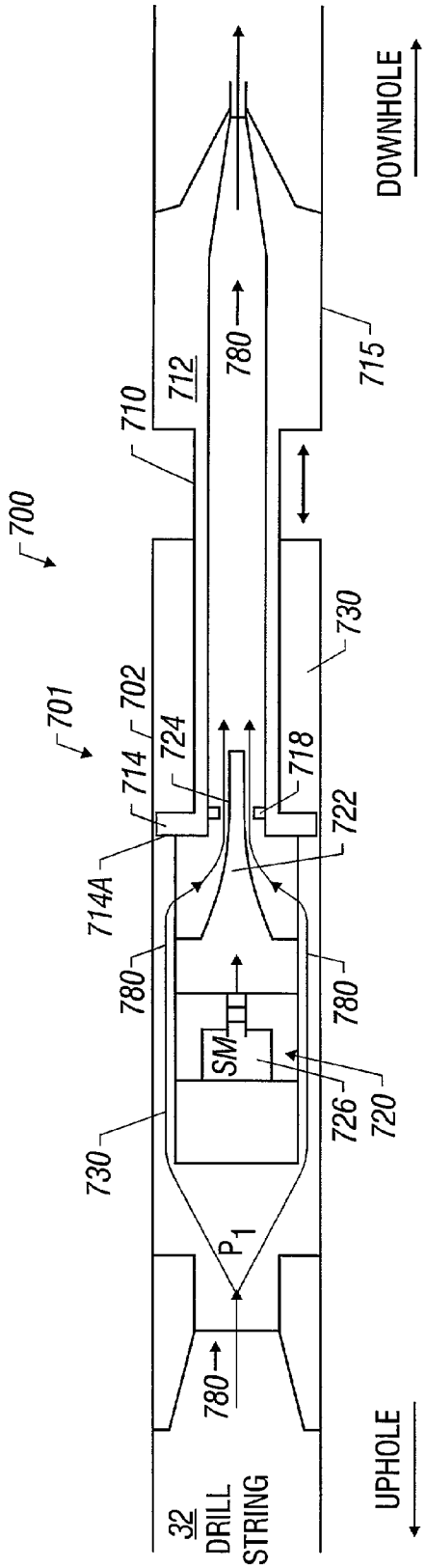

700
701
710
712
780
715
DOWNHOLE
730
702
724
714
718
714A
722
780
780
SM
726
720
730
P1
780
32
DRILL
STRING
UPHOLE

FIG. 7

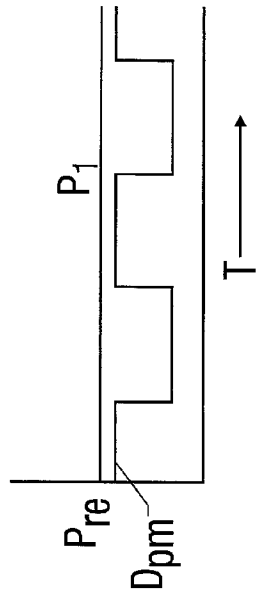

P1
T
Pre
Dpm

FIG. 7A

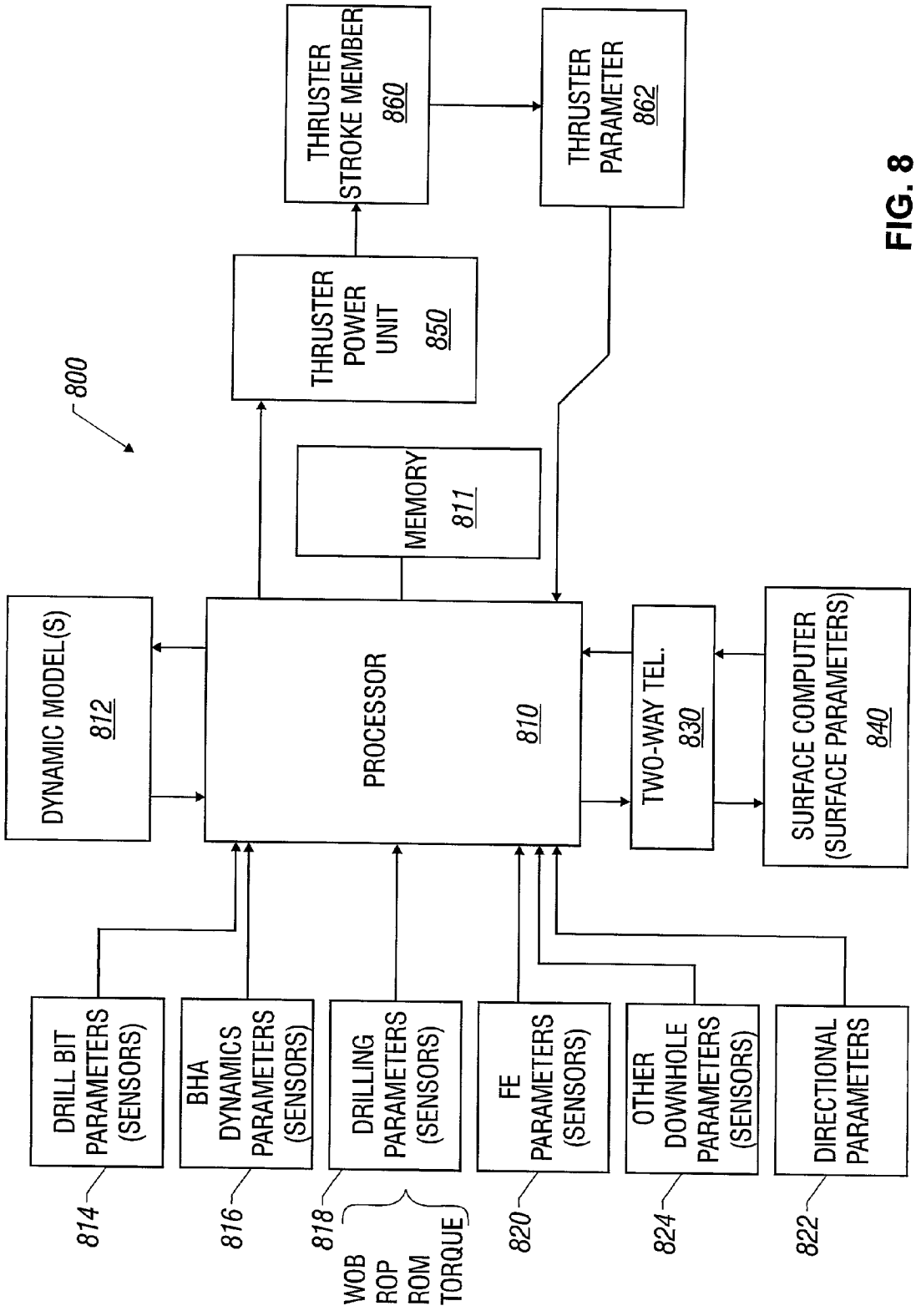

800
THRUSTER STROKE MEMBER 860
THRUSTER PARAMETER 862
THRUSTER POWER UNIT 850
MEMORY 811
DYNAMIC MODEL(S) 812
PROCESSOR 810
TWO-WAY TEL. 830
SURFACE COMPUTER (SURFACE PARAMETERS) 840
DRILL BIT PARAMETERS (SENSORS)
BHA DYNAMICS PARAMETERS (SENSORS)
DRILLING PARAMETERS (SENSORS)
WOB ROP ROM TORQUE
FE PARAMETERS (SENSORS)
OTHER DOWNHOLE PARAMETERS (SENSORS)
DIRECTIONAL PARAMETERS
814
816
818
820
824
822

FIG. 8

THRUSTER RESPONSIVE TO DRILLING PARAMETERS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application takes priority from United States patent application Ser. No. 60/078,733 filed on Mar. 20, 1998.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates generally to drill strings for drilling boreholes for the production of hydrocarbons and more particularly to thrusters to provide force to the drill bit during drilling of the boreholes, especially for drilling deviated and horizontal boreholes with bottomhole assemblies using drilling motors.

[0004] 2. Description of the Related Art

[0005] To obtain hydrocarbons such as oil and gas, boreholes or wellbores are drilled by rotating a drill bit attached to a drill string. A substantial proportion of the current drilling activity involves directional drilling, i.e., drilling deviated and horizontal boreholes, to increase the hydrocarbon production from the earth formations. Modern directional drilling systems generally employ bottomhole assemblies ("BHA") or drilling assemblies that include a drill bit rotated by a drilling motor (commonly referred to as the "mud motor") in the BHA. The BHA is conveyed into the wellbore by a tubing, such as drill pipe or coiled tubing. Drilling fluid (commonly referred to as the "mud") is circulated through the drill string under pressure. The drilling fluid passes through the mud motor, rotating the mud motor and thus the drill bit. A certain amount of weight on bit ("WOB") must be maintained to cause the drill bit to penetrate the formation. Weight on bit cannot be properly applied by the drill string during horizontal drilling or when coiled tubing is used as the tubing. In such applications, a thruster is often utilized to exert axial force (force along the borehole longitudinal axis) on to the drill bit.

[0006] Commonly used thrusters are telescopic tubular arrangements. A thruster is usually disposed in or incorporated into the bottomhole assembly above the drilling motor. A telescopic or stroke member extending from the thruster applies force on the drill bit, causing the drill bit to advance into or penetrate the borehole while the tubing above the thruster is held stationary. When the telescopic member of the thruster has fully extended, it is retracted to its initial or unextended position. Additional length of the tubing is then inserted into the borehole to continue drilling.

[0007] During drilling, pressure across the drilling motor varies as the drilling conditions change. Fluctuations in the pressure drop across the mud motor can impede the function of the thruster. Thrusters have been designed that respond to the changes in the mud motor differential pressure instead of attempting to maintain a constant force on the drill bit and hence a constant weight on bit. The inability of such thrusters to exert relatively constant force, regardless of the amount of work the drilling motor is required to do, reduces the effectiveness of the drilling operations. What occurs is a pressure buildup due to higher load on the mud motor as drilling begins. The higher pressure is sensed at the thruster, causing the telescopic portion to extend further to exert greater force on the bit. This, in turn, increases the weight on bit. Ultimately, with increasing weight on bit, the motor can stall and no longer turn the bit.

[0008] In these types of applications, the weight on bit is a function of the pressure difference between inside and outside the thruster. The greater the difference, the more the force on the bit exerted by the thruster. As a result, assemblies using thrusters with downhole motors have not gained great commercial success.

[0009] In one embodiment, this invention provides a BHA with a thruster and a pressure modulation valve between the thruster and the mud motor to compensate for the flow resistance changes experienced in the mud motor due to changes in the drilling conditions. Such a thruster system is operable efficiently and reliably without the above-noted problems when used in conjunction with the drilling motor. Use of the pressure modulation valve exerts a constant weight on the bit since variations in the pressure drop in the drilling motor do not affect the relative force exerted on the bit. However, this thruster cannot adjust the force on the bit as the drilling conditions change.

[0010] The number of horizontal wellbores drilled has been steadily increasing. The trend seems to be toward drilling an increasing number of relatively complex (extended reach horizontal wellbores and curved wellbores in and around subsurface formations) wellbores. The drilling assemblies used for such wellbores utilize a variety of sensors that provide measurements of various parameters relating the bottomhole assembly, wellbore conditions, drilling operations and the formations being penetrated.

[0011] As noted above, bottomhole assemblies used for drilling such wellbores often use mud motors and thrusters to provide force or the weight on bit. The weight on bit and the mud motor speed (which usually is the drill bit rotational speed), to a large extent, control the rate of penetration ("ROP") of the wellbore or the wellbore drilling rate and the operating life of the drilling assembly. Excessive WOB can wear the drill bit prematurely. The output power of a mud motor is a function of the differential pressure across the motor. The mud motor operates most efficiently in a certain range of the differential pressure. Excessive differential pressure across the mud motor can deteriorate the mud motor performance and damage the motor. Additionally, drilling assembly parameters, such as vibration, whirl, radial and axial displacements of the drive shaft and various other wellbore and drilling assembly parameters can adversely affect the drilling efficiency. It also is desirable to determine the nature of the formation being drilled and adjust the ROP that is most appropriate for such formation and the drilling assembly being utilized. Drilling can be accomplished at higher ROP in soft formations. Weight on bit can influence one or more of the above-noted parameters. Thus, it is desirable to adjust the thruster force to achieve such higher rates without adversely affecting the drilling assembly health. Accordingly, there is a need to provide thrusters for use with drilling assemblies that can adjust the applied force as a function of one or more parameters of interest computed during the drilling of the wellbores.

[0012] The present invention provides thrusters for use in drilling assemblies wherein the force applied on the drill bit can be adjusted as a function of one or more parameters of

interest. The system of the present invention utilizes one or more models which determine the desired thruster force based upon certain parameters computed downhole and/or transmitted to the bottomhole assembly from the surface. Such models are dynamic, in that they may be updated as the downhole conditions change during the drilling of the wellbore.

SUMMARY OF THE INVENTION

[0013] This invention provides a bottomhole assembly that contains a thruster for applying force on the drill bit during drilling of the wellbore. The bottomhole assembly includes at least one sensor which provides measurements for determining a parameter of interest relating to the drilling of the wellbore. A power unit supplies power to the thruster to move a force application member axially toward the drill bit to apply predetermined force on the drill bit. A processor operatively coupled to the thruster controls the magnitude of the axial force generated by the thruster in response to one or more of the parameters of interest.

[0014] The parameters of interest may be selected from (a) weight-on-bit, (b) pressure differential between the pressure in the BHA and an annulus between the BHA and the subsurface formation, (c) pressure at a selected location in the BHA, (d) pressure drop across a mud motor in the BHA, (e) rotational speed of the drill bit, (f) torque, (g) rate of penetration ("ROP") of the drill bit in the subsurface formation, (h) vibration, (i) whirl, (j) bit bounce, (j) stick slip, and (k) one or more characteristics of the formation being penetrated.

[0015] The sensors may include (a) an rpm sensor, (b) a pressure sensor for determining at least one of the pressure in BHA, pressure in an annulus between the BHA and the formation, differential pressure across the drilling motor, (c) a sensor for determining the weight-on-bit, (d) a sensor for determining the rate of penetration of the drill bit in the formation, (e) a temperature sensor, (f) a vibration sensor, (h) a displacement measuring sensor, and (i) a formation evaluation sensor.

[0016] The processor determines the parameter(s) of interest downhole during drilling of the wellbore. One or more dynamic models are provided to the processor. The processor utilizing these models computes the desired force to be applied to the drill bit based on predetermined criteria. The processor controls the magnitude of the axial force exerted by the thruster in response to the determined parameters of interest.

[0017] In one embodiment of the present invention, the thruster includes a stroke member which reciprocates between a first (retracted) position and a second (extended) position. The stroke member applies force on the drill bit when it is moved axially toward the drill bit. A power unit supplies power (hydraulic or electric) to the stroke member to cause the stroke member to move toward the drill bit. A control unit controls the amount of the hydraulic power supplied by the power unit in response to one or more parameters of interest.

[0018] In another embodiment of the present invention, the thruster includes a stroke member that reciprocates axially along the wellbore between a first (retracted) and a second (extended) position when the drilling fluid under pressure is applied to the stroke member. A fluid flow control valve assembly in the thruster controls the supply of the drilling fluid to the stroke member. The valve is preferably a stepper motor-controlled or a solenoid-controlled. The valve is modulated to compensate for the pressure changes downhole.

[0019] This invention also provides a pressure modulation valve which is used in combination with a downhole drilling motor and a drill string thruster to compensate for changes in pressure drop through the drilling motor which normally occur during drilling. When conditions change during drilling, which in turn changes the pressure drop through the drilling motor, the drill string pressure modulation valve compensates for such changes to minimize the effect of such changes on the operation of the thruster. The modulation valve has a feature which allows it to find automatically a preload condition for the main needle valve each time the rig pumps are turned off and then turned on. The modulation valve is fully self-contained, and is assembled as part of the bottomhole assembly. The device senses the no-load pressure drop in the system and sets itself each time the rig pumps are turned on to compensate for any change in the no-load pressure drop experienced below the device which could be attributable to such things as motor wear, bit nozzle plugging, or changes in the flow rate. Accordingly, the hydraulic thrusting force remains constant over a wide range of drilling environments. As the drilling conditions change and the pressure drop in the downhole motor increases, the needle valve shifts to compensate for such additional pressure drop with a resultant small or no effect on the thruster located upstream.

[0020] Examples of the more important features of the invention thus have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] For detailed understanding of the present invention, references should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals and wherein:

[0022] FIGS. 1A-1C illustrates a bottomhole assembly in sectional and elevational views showing the layout of the components, as well as a possible location for a measurement-while-drilling system which can be used in tandem with the apparatus.

[0023] FIGS. 2A-2B is a sectional view of the drill string pressure modulation valve in the run-in position without the rig pump circulating.

[0024] FIGS. 3A-3B is the view of FIGS. 2A-B with the pumps circulating, but the bit off bottom.

[0025] FIGS. 4A-4B is the view of FIGS. 3A-B with the pumps running and the drill bit on bottom.

[0026] FIGS. 5A-5C is a schematic diagram of a bottomhole assembly with a thruster whose operation is controlled as a function of certain parameters of interest.

[0027] **FIG. 6** shows schematic diagram of a thruster according to one embodiment of the present invention.

[0028] **FIG. 7** shows schematic diagram of a device for controlling the flow of the drilling fluid through the thruster.

[0029] **FIG. 7A** shows a graph depicting a constant pressure applied by the thruster while the mud motor pressure varies.

[0030] **FIG. 8** shows block diagram of an embodiment of an electrical control unit for use with the thrusters shown in FIGS. **5-7**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0031] FIGS. **1A-1C** illustrate a drill string modulation valve for use with a thruster in the bottomhole assembly **100** according to the present invention. A tubing string **32**, which can be rigid or coiled tubing, supports a drill string thruster **34**. The thruster **34** has an outer housing **36** and an internal pipe **38**. The internal pipe **38** is reciprocally mounted within the outer housing **36** and extends as the drill bit **40** advances. The thruster **34** is responsive to the pressure difference between the inside of the bottomhole assembly, referred to as **42**, and an annulus around the assembly, referred to as **44**. The apparatus A is connected to the internal pipe **38**. Below the apparatus A, a measurement while drilling system can be inserted to supply data to the surface regarding formation conditions and/or the orientation of the advancement of the bit **40**. The bottomhole assembly of FIGS. **1A-C** also indicates an upper stabilizer **46** and a lower stabilizer **48** between which is a drilling motor **50**. Optionally, to assist in drilling deviated wellbores, bent subs **52** and **54** can also be employed in the bottomhole assembly.

[0032] This type of a bottomhole assembly is typically used for deviated wellbores. The drilling motor **50** can be a progressive cavity type of a motor which is actuated by circulation from the surface through the drill string **32**. The weight or force on the drill bit **40** is determined by the pressure difference internally to the thruster **34** at point **42** and the annular pressure outside at point **44**. The drilling motor **50** is a variable resistance in this circuit in that the pressure drop across it is variable depending on the load imposed on the motor **50**. For example, as drilling begins, the bit **40** causes an increase in load on the drilling motor **50** which increases the pressure drop between the drilling motor **50** and the annulus **44**. That increase in pressure drop raises the pressure difference across the thruster **34** (if the apparatus A is not used) by raising the pressure at point **42** with respect to the pressure at point **44**. As a result, the thruster **34** adds an incremental force through the drilling motor **50** down to bit **40**. As additional weight is put on the bit **40**, the drilling motor **50** increasingly bogs down to the point where this cycle continues until the drill bit **40** stalls the motor **50** due to the extreme downward pressure that is brought to bear on the bit **40** from the ever increasing internal pressure at point **42** inside the thruster **34**. The thruster **34** instead of feeding out the internal pipe **38** at a lower rate to compensate for the advancement of the bit **40**, is urged by the rise in pressure internally at point **42** to feed out the internal pipe **38** at a greater rate than the advancement of the bit **40**, thus adding the force on bit, which in turn finally stalls the drilling motor **50**. This had been the problem and the apparatus A of the present invention, when inserted in the bottomhole assembly, as shown in **FIG. 1B**, addresses this problem. The apparatus A acts as a compensation device, which, as its objective, keeps the pressure as constant as possible at the internal point **42** of the thruster **34** despite variations in pressure drop that the drilling motor **50** created during drilling.

[0033] Referring now to **FIGS. 2A and B**, the apparatus A has a containment sub **1** which has a lower end **56** which is oriented toward the drilling motor **50**, and an upper end **58**, which is oriented toward the thruster **34**. In order to describe the operation of the apparatus, the pressure adjacent lower end **56** will be referred to as P_1; the pressure adjacent the upper end will be referred to as P_2; and the annulus pressure outside the containment sub **1** will be referred to as P_3. Again, the objective is to keep P_2 as constant as possible.

[0034] The assembly shown in **FIG. 2** starts near the upper end with lifting head **2** which is supported from the containment sub **1** at thread **60**. Attached to the lower end of the lifting head **2** is compressive pad **4**, which in turn is secured to a porous metal filter **7**. Below the porous metal filter **7**, liquid that gets through it flows through mud flow port **6** to a cavity **62** above delay valve piston **9**. Delay valve piston **9** is sealed at its periphery by seal **64** to divide the delay valve tube **8** into cavity **62** and cavity **66**. Delay valve spring **10** resides in cavity **66** and biases the delay valve piston **9** toward the porous metal filter **7**. A delay valve orifice assembly **12** is located at the lower end of the delay valve tube **8**. This is an orifice which, in essence, regulates the displacement of clean fluid in cavity **66** into cavity **68**. Those skilled in the art will appreciate that movement of delay valve piston **9** downhole toward the lower end **56** will result in displacement of clean fluid, generally an oil, from cavity **66** through delay valve orifice block **11** into cavity **68** for ultimate displacement of piston valve **15**. Piston valve **15** is sealed internally in delay valve tube **8** by seal **70**. The piston valve **15** has a receptacle **72**, which includes a seal **74**, which ultimately straddles the low-pressure transfer tube **16**, as shown by comparing **FIG. 2A** to **FIG. 3A**. The low pressure transfer tube **16** extends to compensation tube body **20**. Inside of compensation tube body **20** is compensation spring **22**. Spring **22** bears on compensation piston **76** at one end and on the other end against modulating ram needle **27**. Needle **27** is sealed internally in the compensation tube body **20** by seal **78**. The compensating piston **76** is also sealed within the compensation tube body **20** by seal **80**. Both the compensating piston **76** and the needle **27** are movable within the compensating tube body **20** for reasons which will be described below. In effect, the piston **76** and the needle **27** define a cavity **82** within the compensation tube body **20**. The low pressure transfer tube **16** spans the entire cavity **82**, but is not in fluid communication with that cavity. A vent port **23** is in fluid communication with cavity **82**. The port **23** is in fluid communication with cartridge vent port **24**, which ultimately leads to transfer groove **25**, which in turn leads to the porous metal filter **26**. Accordingly, the pressure P_3 is communicated into the cavity **82**. Port **24** can be sized to make cavity **82** operate as a dampener on the movements of needle **27**. It can be directly connected to P_3 as shown or to an external or internal reservoir. The reservoir can have a floating piston with one side exposed to P_3 through the filter **26**. This layout can reduce potential plugging problems in filter **26**.

[0035] Referring now toward the lower end of the compensation tube body **20**, the needle **27** extends beyond an opening **84** and into the restrictor orifice **31**. The preferred components for the needle **27** and the restrictor orifice **31** is a carbide material. As illustrated in **FIG. 2**B, the pressure at the inlet of the drilling motor **50** (see **FIG. 1B**) is the pressure P1, which is also illustrated in **FIG. 2B**. Normal flow to the motor **50** occurs from upper end **58** through passage **86** down around needle **27** and out lower end **56**.

[0036] In the position shown in **FIG. 2**A, the low pressure transfer tube **16** communicates with cavity **88**, which in turn through openings or ports **17** communicates with cavity **90**. Those skilled in the art will appreciate that as long as the seals **74** do not straddle the top end of the low pressure transfer tube **16**, the pressure P_1 at the lower end **56** communicates through low pressure transfer tube **16** through cavity **88** and into cavity **90** so that the pressure P_1 acts on the area of the compensating piston **76** exposed to cavity **90**. A seal **92** retains the pressure P_1 in cavity **90** while, at the same time, allowing the compensating piston **76** to move with respect to the low pressure transfer tube **16**. The low pressure transfer tube **16** is secured to the needle **27** and is placed in alignment with a longitudinal passage **94** in the needle **27**. A seal **96** separates the pressure P_1, which exists in passage **94** and in low pressure transfer tube **16**, from pressure P_3, which exists in cavity **82**. Seal **78** serves a similar purpose around the periphery of the needle **27**.

[0037] The significant components of the apparatus now having been described, its operation will be reviewed in more detail. FIGS. **2**A-B reflect the apparatus A in the condition with the surface pumps turned off. In that condition, the spring **22** pushes the compensation piston **76** against delay valve tube **8** and, at the same time, pushes the needle **27** against the ledge formed by opening **84**. At the same time the delay valve spring **10** pushes the delay valve piston **9** against hydrostatic pressures applied through the upper end **58** through the porous metal filter **7** and mud flow port **6**. At this point with no flow, $P_1=P_2$ and the delay valve piston **9** is in fluid pressure balance.

[0038] When the surface pumps are turned on, the first objective of the apparatus A of the present invention is to obtain a preload force on the needle **27** which actually compensates for the mechanical condition of the motor **50** and any other variables downhole which have affected the pressure drop experienced in the region of the drilling motor **50** and the assembly since the last time the pumps were operated from the surface. The desired preload acts to put a force on the needle **27** which will prevent it from rising on increasing pressure P_1 until a predetermined level is exceeded. Stated in general terms, the pressure P_2 is maintained as close as possible to a desirable level by modulation of the position of needle **27** in response to fluctuations in the pressure P_1. Variations in pressure P_1 will occur as a result of the drilling activity being conducted with bit **40**. Accordingly, with the surface pumps turned on and the bit **40** off of bottom, meaning that there is no drilling going on, the pressure P_2 increases with respect to pressure P_3 as circulation is established. When this occurs, the pressure P_1 also increases with respect to pressure P_3. As previously stated, cavity **82** communicates with pressure P_3 through the porous metal filter **26**. By proper configuration of the compensating piston **76**, the pressure P_1, which exceeds the pressure P_3, communicates through the low pressure transfer tube **16** into cavity **88** through ports **17** and into cavity **90**, and onto the top of compensating piston **76**. Ultimately, an imbalance of forces occurs on compensating piston **76** due to pressure P_1 in cavity **90** and P_3 in cavity **82** which causes piston **76** to compress the compensation spring **22**. The compensating piston **76** is designed to complete its movement and reach an equilibrium position before the piston valve **15** moves downward sufficiently to bring the seal **74** over the upper end of the low pressure transfer tube **16**. **FIGS. 3A and B** show the conclusion of all the movements when the pumps on the surface are turned on and the bit **40** is off of bottom. However, the movement occurs sequentially so that the piston **76** finds its preload position, shown in **FIG. 3**B, before movement of piston valve **15** occurs. Movement of piston valve **15** occurs as the pressure P_2 ultimately communicates with cavity **62**, as described previously. The fluids in the well, which have been passed through the porous metal filter **7** push on the delay valve piston **9** and ultimately the delay valve spring **10** is compressed. As previously stated, the cavity **66** is filled with a clean oil which is ultimately forced through the orifice assembly **12** into cavity **68** by movement of delay valve piston **9**. The orifice assembly **12** is designed to provide a sufficient time delay, generally 1 to 2 minutes, so that the compensating piston **76** can find its steady state position. Those skilled in the art will appreciate that when the surface pumps are turned on and flow is initiated, it takes a little time for the circulating system to stabilize. Thus, one of the desirable functions of the apparatus A is that the low pressure transfer tube **16** is not capped by the piston valve **15** by virtue of seal **74** until the compensating piston **76** has found its desirable position shown in **FIG. 3B**. In the position shown in **FIG. 3**B, the forces on the compensating piston **76** have reached equilibrium. Thus, the pressure P_3 acting on the bottom of compensating piston **76** in conjunction with the force of compensation spring **22** becomes balanced with the pressure P_1 that is acting in the now enlarged cavity **90**. Ultimately, enough clean fluid passes through the delay valve orifice assembly **12** to urge the piston valve **15** downward to the position shown in **FIG. 3A** such that the seal **74** straddles the low pressure transfer tube **16**. As soon as this occurs, the compensation piston **76** is in effect isolated from further fluctuations of the pressure P_1. In effect, the pressure at the lower end **56** can no longer communicate with the top end of the compensating piston **76** because the piston valve **15** has cutoff the access to cavity **90** by capping off the low pressure transfer tube **16**.

[0039] After having attained the position shown in **FIGS. 3A and B**, the drilling with bit **40** begins. This puts an additional load on the motor **50** which in turn raises the pressure P_1. As the pressure P_1 rises, the needle **27** has a profile, which in turn decreases the pressure drop across the restrictor orifice **31** as the needle **27** moves upwardly. Due to the profiles of needle **27** as the needle moves up the pressure drop change per unit of linear movement is increased. The spring **22** resists upward movement of the modulation ram needle **27**. At this point in time when the bit **40** contacts the bottom of the hole, the compensating piston **76** is immobilized against upward movement because the piston valve **15** has capped off the pressure P_1 from communicating with cavity **90**. Since P_2 is always greater than P_1 due to frictional losses and the pressure drop across the orifice **31**, the pressure in cavity **68**, which is P_2 keeps the piston valve **15** firmly bottomed in the delay valve tube **8**. As

previously stated, the seal **70** prevents the pressure P_2, which is in cavity **68** in **FIG. 4A** from getting into cavity **90**. Accordingly, the compensating piston **76** now is in a position where it supports the spring **22** with a given preload force on the needle **27**. As the motor **50** takes a greater pressure drop, which tends to increase P_1, the upward forces on needle **27** eventually exceed the downward forces on needle **27**. The downward forces on needle **27** comprise the pressure P_3 acting on top of the needle **27** in cavity **82** in combination with the preload force from spring **22**. Thus, an increase in the pressure P_1 which exceeds P_3 backs the needle **27** out of the orifice **31** removing some of the pressure losses that had been previously taken across the orifice **31**. Thus, the increase in pressure drop at the motor **50** is compensated for by a decrease in pressure drop at the orifice **31** with the net result being that very little, if any, pressure change occurs as P_2 remains nearly steady. In other words, the system pressure drops upstream of the upper end **58** remains steady and all that desirably occurs is an increase in pressure drop through the motor **50** compensated for by a corresponding decrease in pressure drop across the restrictor orifice **31** with the net result that the thruster **34** sees little, if any, pressure change as indicated by the symbol P_2.

[**0040**] When the pumps are again turned off at the surface, the apparatus A quickly resets itself. As the pumps are turned off at the surface P_2 decreases, thus reducing the pressure in cavity **62**. A check valve **13** allows flow into cavity **66** from cavity **68**. Accordingly, when the spring **10** pushes the piston **9** upwardly, it draws fluid through the check valve **13**, which in turn draws fluid out of cavity **68**. The drawing of fluid out of cavity **68** brings up the piston valve **15** and ultimately takes the seal **74** off of the top of the low pressure transfer tube **16**. When this occurs, P_1 can then communicate through the low pressure transfer tube **16** and into cavity **90** as previously described. Ultimately, with no fluid circulating, P_3 will be equal to P_1 and the spring **22** will bias the compensating piston **76** back to its original position shown in **FIG. 2B**. Therefore, the next time the surface pumps are started, the process will repeat itself as the compensating piston **76** seeks a new equilibrium position fully compensating for any changes in condition in the circulating system from the drilling motor **50** down to the bit **40**.

[**0041**] Those skilled in the art will appreciate that the configuration of the compensating piston **76** is selected in combination with a particular spring rate for the compensating spring **22** to deliver a preload force on the needle **27** within a limited range. Too little preload is undesirable in the sense that minor pressure fluctuations in P_1 during drilling will cause undue oscillation of the needle **27**. On the other hand, if the preload force is too great, the system becomes too insensitive to changes in P_1, thus adversely affecting the operation of the thruster **34** and if extreme enough causing the thruster **34** to load the bit **40** to the extent that the motor **50** will bog down and stall. Thus, depending on the parameters of the drilling motor **50** and the bit **40**, the configurations of the compensating piston **76** and spring **22**, as well as the profile of the needle **27** can be varied to obtain the desired performance characteristics. Similarly, the orifice assembly **12** can be designed to provide the necessary delay in the capping of the low pressure transfer tube **16** to allow the system to stabilize before the low pressure transfer tube **16** is capped. This, in turn, allows the compensating piston **76** to seek its neutral or steady state position before its position is immobilized as the piston valve **15** caps off the low pressure transfer tube **16**. In essence, what is created is a combination spring and damper acting on the needle **27**. The spring is the compensation spring **22**, while the damper is the cavity **82** which varies in volume as fluid is either pushed out or is sucked in through port **24** or the porous metal filter **26** which can act as an orifice in the damper system.

[**0042**] Those skilled in the art will now appreciate that the apparatus A provides several important benefits. It is self-contained and it is a portion of the assembly. Each time the surface pumps are turned on the compensating feature adjusts the preload on the needle **27** to account for variations within the circulating system. Once in operation during drilling, the system acts to smooth out pressure fluctuations caused by changes in the drilling activity so that the pressure fluctuations are isolated as much as possible from the thruster **34**. With these features in place, drilling can occur using a downhole motor. Downhole motors are desirable when using coiled tubing or when the string, even though it is rigid tubing, is sufficiently long and flexible to the extent that a downhole motor becomes advantageous. The system using the apparatus A resets quickly using the check valve feature and stands ready for a repetition of the process the next time the surface pumps are turned on.

[**0043**] It should be noted that the normal pressure drop across the orifice **31** with the bit **40** off of bottom is approximately 400 or 500 psi in the preferred embodiment. That pressure drop is reduced during operation as the drilling motor **50** resistance increases which causes the needle **27** to compensate by backing out of the orifice **31**, thus reducing the pressure drop. It should also be noted that the amount of preload provided by the compensation spring **22** needs to be moderated so as not to be excessive. Excessive preload on the needle **27** reduces the sensitivity of the apparatus A in that it requires the pressure P_1 to rise to a higher level prior to the apparatus reacting by moving the needle **27** against the spring **22**. Thus, a higher preload on spring **22** also reduces sensitivity. Those skilled in the art can use known techniques for adjusting the variables of preload and needle profile within an orifice **31** to obtain not only the desired pressure compensation result but the appropriate first, second, and higher order responses of the control system so that a stable operation of the modulation ram needle **27** in orifice **31** is achieved.

[**0044**] FIGS. **5A-5C** is a schematic diagram of a bottomhole assembly **500** with a thruster whose operation is controlled as a function of one or more parameters of interest determined downhole and/or provided from the surface during drilling of a wellbore according to one embodiment of the present invention. The bottomhole assembly **500** includes a thruster **501** (a force application device) that applies force to a lower section **502** of the bottomhole assembly **500**. The lower section **502** includes a mud motor **503** that contains a lobed rotor **503***a* that rotates inside a lobed elastomeric stator **503***b* when drilling fluid **580** passes through progressive cavities **503***c* formed between the rotor **503***a* and stator **503***b*. The rotor **503***a* is coupled to the drill bit **540** via a drill shaft **504** that passes through a bearing assembly **505**. Drilling motors and bearing assemblies are known in the art and are not described in detail herein, except for the placement of certain sensors for use in the present invention. A bent sub **554** between the mud motor **503** and the bearing assembly **505** allows the BHA **500** to

drill curved wellbores. A stabilizer **548***a*, preferably having a plurality of adjustable pads or ribs **548***a*$_1$-**548***a*$_n$ is disposed on the bearing assembly **505** to provide lateral stability to the bottomhole assembly **500** near the drill bit **540** and to provide a certain degree of steering of the drill bit **540**. Additional stabilizers, such as stabilizer **546**, may be provided above the mud motor **503** to provide lateral stability to the bottomhole assembly **500** during drilling. An adjustable bend **552** may also be provided to drill shorter radius boreholes.

[**0045**] One or more sensors **512** are included in the drill bit **540** to provide measurements for certain drill bit parameters, including pressure at the drill bit bottom and wear of the drill bit **540**. A module **514** containing a plurality of sensors **514***a* provides measurements of various BHA physical or dynamics parameters. The module **514** is preferably provided near the drill bit **540**. The BHA dynamic parameters include weight on bit, torque on bit, whirl, vibration, bit bounce and stick-slip. The BHA dynamic parameter sensors may be located at any other suitable locations in the bottomhole assembly **500**. For example, a group of BHA dynamic parameter sensors **545** may be located above the mud motor **503** to provide measurements for the desired BHA dynamic parameters. Sensors **514***b* disposed in the bearing assembly **505** measure the radial and axial displacement of the drill shaft **504** and other desired physical bearing assembly parameters (e.g. leakage, oil level for sealed bearings, etc.).

[**0046**] A set of temperature sensors **520***a*-**520***c*, respectively measure temperatures T_1-T_3 of the elastomeric stator along its length while pressure sensors **522***a* below the mud motor **503** and **522***b* above the mud motor **503** provide differential pressure across the mud motor **503**. A differential pressure sensor **522***c* instead may be used to determine the differential pressure across the mud motor **503**. Sensors **530** provide measurement for the rotational speed (rpm) of the mud motor **503**. Additional sensors **531** in the mud motor **503** provide pressure of the drilling fluid **580** in the mud motor **503** and the annulus pressure.

[**0047**] The thruster **501** has a force application member **504** which strokes or reciprocates in an outer housing **536** between a retracted position and an extended position. When the member **504** extends, it moves toward the drill bit **540**, thereby moving the lower section **502** of the bottomhole assembly **500**. The drill string **32** above the thruster **501** is held stationary or anchored in the wellbore by any suitable device, such as a retractable anchor or a packer (not shown) to cause the force application member **504** to exert force on the drill bit **540**. A thruster power unit **560** causes the member **504** to move downhole to exert the desired force on the drill bit **540**. The power unit **560** may be an electric motor, a hydraulic power unit, a pneumatic power unit or a combination thereof. The power unit **560** is adapted to cause the stroke member **504** to move in both the downhole and uphole directions as shown by the double arrow **504***a*. A position sensor or a displacement sensor **550** measures the displacement of the stroke member **504**, which provides the rate of penetration ("ROP") of the drill bit **540**. An electrical control circuit or unit **562** in the BHA controls the operation of the thruster power unit **560** as more fully described below in reference to **FIG. 8**.

[**0048**] Appropriate fluid paths (not shown) through the thruster assembly **501** are provided to allow the drilling fluid **580** to flow downhole to the mud motor **503**. Commonly utilized measurement-while-drilling ("MWD") or logging-while-drilling ("LWD") sensors **570** are provided at suitable location(s) in the bottomhole assembly **500**. The MWD/LWD sensors are known in the art and may include resistivity sensors, sensors for determining the formation porosity, formation density measuring sensors, and nuclear magnetic resonance sensors. Sensors for determining the position, azimuth and orientation (collectively represented by numeral **514***b*) are preferably located below the mud motor **503**. Accelerometers, magnetometers and gyroscopic devices are utilized as position/direction sensors. A two-way telemetry **572** enables the bottomhole assembly **500** to communicate with the surface unit (not shown).

[**0049**] The control unit **562** contains one or more microprocessors, one or memory devices and other electronic control circuits. The circuitry for such control units is known in the art and is not described in detail herein. The operation and function of the control unit **562** as it applies to the present invention, however, is described below in reference to **FIG. 8**. The sensors described above provide measurements to the control unit **562**. For simplicity, only one electrical control unit **562** is shown. The functions of the control unit described herein, however, may be distributed among more than one processor or circuits. Such methods are known in the art and are not described in detail herein.

[**0050**] Signals from the various sensors are processed to compute the values of the various parameters of interest, which, as described above, may include the drill bit parameters (drill bit wear, pressure at the drill bit bottom, etc.), drilling assembly physical parameters or BHA dynamic parameters (vibration, pressures, temperature, radial and axial displacement, whirl, stick slip, bit bounce, etc.), mud motor parameters (differential pressure or pressure drop across the mud motor, stator wear condition, pressure differential between the mud motor and the annulus pressure, fluid flow rate through the motor, motor rpm, etc.), and thruster parameters (displacement, applied force one the drill bit, pressures and temperatures). The drilling parameters such as the weight on bit ("WOB"), rate of penetration ("ROP"), hook load, and the drilling fluid flow rate are determined from the measurements of the appropriate sensors in the bottomhole assembly **500** or at the surface. The drilling fluid **580** is pumped through the drill string **32** from the surface. The flow rate and the pressure at the surface may also be communicated to the control unit **562**. The formation evaluation or MWD sensors determine various characteristics (formation evaluation parameters) of the formation penetrated by the wellbore. The formation evaluation parameters include, formation resistivity, formation porosity, density, permeability, water saturation and the rock matrix type. Information, such as the type of formation (rock matrix) being drilled, which may be relevant to the determination of the force to be generated by the thruster **501** is also provided to the control unit **562**.

[**0051**] As more fully described below in reference to **FIG. 8**, the control unit **562** determines the desired amount of the force to be applied to the drill bit **540** as a function of one or more parameters of interest that will provide enhanced drilling and extended life of the bottomhole assembly **500**. The control unit **562** then causes the power unit **560** to adjust the applied force accordingly. Thus, the thruster **501** automatically adjusts the weight on bit as the drilling conditions

change to achieve higher drilling efficiency, which is usually considered to be the higher drilling rate over a given time period. It should be noted that it is possible to achieve higher drilling rates over relatively short periods of time at the expense of the health of one or more components of the bottomhole assembly **500**. For example, higher penetration rate may wear out the drill bit **500** rapidly or cause damage to the mud motor **503**. Such drilling rates, though higher, would require tripping out the drill string **32** to replace the damaged or worn components, which can be very time consuming, expensive and may reduce the overall drilling efficiency. Greater drilling efficiency can be obtained by adjusting the drilling parameters, including the WOB, in a manner that will simultaneously maintain a number of parameters within their respective desired limits. The thruster **501** of the present invention enables drilling of the wellbores by maintaining the desired parameters of interest within their limits. In the present invention, the WOB may be continuously or periodically determined by models and programs provided to the BHA.

[**0052**] **FIG. 6** shows an embodiment of a thruster **601** that utilizes a hydraulic power unit controlled by an electrical control unit **660** for use with a bottomhole assembly **600**. The thruster **601** includes a stroke member or reciprocating force member **610** (also referred to herein as a "force application member") that reciprocates in a housing **636**. The lower end **612** of the stroke member **610** is coupled to the lower section **615** of the bottomhole assembly **600**, while the upper end terminates in a piston **614**. The piston **614** reciprocates in upper and lower fluid chambers **616** and **618**. Seals **622** provide seals between the stroke member **610** and fluid chambers **616** and **618**. The upper end **630** of the thruster **601** is connected to the uphole section **670** of the drill string **32**. Drilling fluid **680** passes downhole to the mud motor (**FIG. 5**) via a through passageway **602** in the stroke member **610**. A hydraulic power unit **640** provides power to the reciprocating member **610**. The power unit **640** supplies fluid, such as oil, under pressure from a source thereof **646** to the upper chamber **616** via a line **642** and a port **644**. A fluid control valve **645** in the line **642** may be modulated to modulate the fluid supply to the upper chamber **616**. Fluid from the source **646** may also be provided to the lower chamber via line **647** and port **649**. Suitable fluid return paths (not shown) from the chambers **616** and **618** to the source **646** are provided to bleed off the pressure. The power unit **640** may also be designed to maintain desired differential pressure between the two chambers **616** and **618**.

[**0053**] Pressure sensor **648** and volumetric sensor **650** respectively provide pressure P_1, in and volume V_1 of the upper chamber **616**. Similar sensors may be used for the lower chamber **618**. A displacement sensor **652** measures the displacement of the stroke member **610** from an initial or retracted position, which allows the operator or system to determine when to retract the stroke member **610** to repeat the cycle. It also provides a relatively precise measure of the rate of penetration. A control unit **660**, similar to the control unit **560** described above (**FIG. 5A**), utilizes the pressure sensor, volumetric sensor and displacement sensor measurements and controls the operation of the hydraulics power unit **640** to maintain the desired force on the drill bit **540** (**FIG. 5**). The pressure P_1, in the upper chamber **616** controls the force (weight on bit) on the drill bit **540** while the fluid volume V_1 in the upper chamber **616** controls the axial displacement ("D") of the thruster **601**. The control unit **640** controls the thruster **601** as a function of selected parameters of interest, as more fully described below in reference to **FIG. 8**.

[**0054**] **FIG. 7** shows a schematic diagram of an alternative embodiment of a thruster **701** of a bottomhole assembly **700** which utilizes drilling fluid **780** to exert the desired force on the drill bit **540** (**FIG. 5**). The thruster **701** includes a stroke member **710** that reciprocates or strokes in an outer housing **702**. The lower end **712** of the stroke member **710** is coupled to the lower portion **715** of the bottomhole assembly **700**. Drill bit is attached to the bottomhole end of the lower section **715**. The upper end **714** of the stroke member **710** has a valve opening or seat **718** that allows the drilling fluid **780** to pass through the thruster **701**. The drilling fluid **780** flows through the stroke member **710** via an opening **716**. The flow of the fluid through the opening **716** is controlled by a valve assembly **720** that includes a conical member or spear **722** which can open and close the opening **716**. The pressure of the drilling fluid **780** is applied to the upper end **714**A of the stroke member **710** at the flange **714***a*. The opening **724** between the spear **722** and the seat **718** defines the fluid flow path through the stroke member **710**. Closing the valve **718** will exert the maximum force on the stroke member **710**. Bypass fluid flow paths through the thruster **701** to section **715** of the bottomhole assembly (not shown) may be provided to ensure uninterrupted fluid flow to the drill bit. Completely opening of the valve **718** will equalize the pressure on both sides of the opening **718**. The spear **722** may be operated by a suitable device **726** such as a stepper motor or a solenoid-controlled valve.

[**0055**] Still referring to **FIG. 7**, an electrical control unit **730** controls the operation of the spear **722**. To maintain a desired force on the drill bit, the control valve **720** is modulated to compensate for the affects of the pressure changes in the mud motor and changes in the downhole conditions, which allows maintaining the thruster force to any desired value while compensating for the downhole pressure changes. As an example, the graph of **FIG. 7A** shows that the pressure P exerted by the thruster **701** remains constant at P_1 over time T even when the mud motor differential pressure P_m changes. Suitable sensors measure pressure P_3 applied to the bottomhole assembly section **715** and the pressure P_4 above the thruster **701**. The electrical control unit **730** includes a processor and other desired circuit to control the action of the valve member **722** to maintain P_3 at the desired valve during drilling of the wellbore. The length of the cylinder **730** between the flange **714** and the housing **702** defines the length of the stroke or travel for the thruster **701**.

[**0056**] **FIG. 8** is a functional block diagram of an electrical control unit **800** for use in the present invention. The control unit **800** includes one or more micro-processors **810**, associated memory units **811** and other electrical circuits (not shown). The processor **810** receives signals from the various downhole sensors in the bottomhole assembly described above. The sensor data includes signals for drill bit parameters **814**, bottomhole assembly dynamic parameters **816**, drilling parameters **818**, formation evaluation ("FE") parameters **820**, directional parameters **822** and other downhole parameters **824**. Data and signals (surface parameters) may also be communicated to the processor **810** from a surface computer **840** via a two-way telemetry **830**. Such data may include the surface fluid pressure, drilling fluid

flow rate, drilling fluid properties, such as the density and viscosity, effective circulating density, rock matrix type, hook load, etc. The processor **810** preferably is provided with one or models **812** that utilize data from the sensors and the surface supplied parameters **840** to determine the force to be applied by the thruster power unit **850**.

[**0057**] The processor **810** then controls the power unit **850** to apply the required power on the thruster stroke member **860**. The actual values of the thruster parameters **862**, such as the magnitude of the force and the thruster displacement are fed back to the processor **810**. The processor **810** continues to cause the thruster power unit **850** to adjust the applied force so as to maintain selected parameters within their desired limits. The processor **810** may also be programmed to cause the thruster to apply constant force on the bit. In one aspect of the invention, the models **812** provide the ranges or values of the selected parameters, such as the weight on bit, differential pressure across the mud motor, vibration, etc. The processor **810** adjusts the thruster force so as to maintain these parameters at their desired values. Thus, if the mud motor pressure differential is outside the allowed limits, the thruster force is adjusted (within its own limits) until the mud motor pressure is within the allowed limits. Similarly, if the vibrations are excessive, perhaps due to bit bounce, the thruster increases the weight on the bit to reduce the vibrations. If the thruster adjustments cannot maintain the selected parameters within or at their respective desired values, the processor **810** may be programmed to transmit signals to the surface to provide warning to the drilling operator or to utilize alternative models. The processor **810** is preferably programmed to upgrade the models **812** as the drilling conditions and the formation being penetrated change, making the models **812** dynamic.

[**0058**] The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing from the scope and the spirit of the invention. It is intended that the following claims be interpreted to embrace all such modifications and changes.

What is claimed is:

1. A bottom hole assembly ("BHA") for use in drilling a wellbore in a subsurface formation, said BHA comprising:

(a) a drill bit at an end of the BHA;

(b) a force application device in the BHA applying force having a magnitude on the drill bit during drilling of the wellbore;

(c) a sensor in the BHA providing measurements of a parameter of interest relating to the drilling of the wellbore; and

(d) a processor determining the magnitude of the force in response to said parameter of interest and causing the force application device to apply said force having said magnitude on the drill bit during drilling of the wellbore.

2. The BHA of claim 1, wherein the force application device further comprises a force application member that extends toward the drill bit relative to a stationary section of the force application device to exert the force on the drill bit.

3. The BHA of claim 2 further comprising a sensor for determining the magnitude of the force actually applied by the force application device on the drill bit.

4. The BHA of claim 3, wherein the sensor is selected from a group consisting of (i) a sensor measuring displacement of said force application member from an initial position, and (ii) a pressure sensor.

5. The BHA of claim 1, wherein the processor causes the thruster to adjust the application of the force on the drill bit to maintain the parameter of interest within a predetermined range.

6. The BHA of claim 1, wherein the processor determines the parameter of interest downhole during drilling of the wellbore.

7. The BHA of claim 1 further comprising at least one model utilized by said processor to compute the parameter of interest and the magnitude of the force to be applied to the drill bit.

8. The BHA of claim 1, wherein the processor adjusts the magnitude of the axial force exerted by the force application member in response to the measurement of the parameter of interest.

9. The BHA of claim 1, wherein the force application device is one of a hydraulically-operated device, mechanically-operated device and an electro-mechanical device.

10. The BHA of claim 1, wherein the parameter of interest is selected from a group consisting of (i) rotational speed of the drill bit, (ii) rotational speed of a drill collar rotating said drill bit from a surface location, (iii) weight-on-bit, (iv) pressure differential between the pressure in the BHA and an annulus between the BHA and the wellbore, (v) pressure at a selected location in the BHA, (vi) drop differentially across a mud motor in the BHA, rotating said drill bit, (vii) torque, (viii) rate of penetration ("ROP") of the drill bit in the subsurface formation, (viii) vibration, (ix) whirl, (x) bit bounce, (xi) stick slip, (xii) rock matrix of the formation, (xiii) a formation characteristic; rotational speed of the drill bit.

11. The BHA of claim 1, wherein the sensor is selected from a group consisting of (a) an rpm sensor, (b) a pressure sensor for determining at least one of, the pressure in the BHA, pressure in an annulus between the BHA and the formation, differential pressure across a drilling motor associated with the BHA, (c) a sensor for determining the weight-on-bit, (d) a sensor for determining the rate of penetration of the drill bit in the formation, (e) a temperature sensor, (f) a vibration sensor, (h) a displacement measuring sensor, and (i) a formation evaluation sensor.

12. A force application device for applying force to a drill bit coupled thereto during the drilling of a wellbore, said force application device comprising:

(a) a stroke member movable between a first position and a second position, said stroke member adapted to apply a predetermined force on the drill bit when said stroke member is moved from the first position toward the second position;

(b) a power unit supplying power to the stroke member to cause the stroke member to move from the first position to the second position to apply the predetermined force on the drill bit; and

(c) a control unit controlling the operation of the power unit in response to a parameter of interest determined at least in part based on a measurement made in the

wellbore during drilling of the wellbore to maintain the force on the drill bit within a predetermined range.

13. The force application device of claim 12, wherein the stroke member reciprocates in a chamber and the power unit supplies a fluid under pressure to the chamber to cause the stroke member to move from the first position to the second position.

14. The force application device of claim 13, wherein the power unit supplies fluid under pressure to the chamber in a reverse direction to move the stroke member from the second position to the first position.

15. The force application device of claim 13, wherein the parameter of interest is selected from a group consisting of (i) rotational speed of the drill bit, (ii) rotational speed of a drill collar rotating said drill bit from a surface location, (iii) weight-on-bit, (iv) pressure differential between the pressure in the BHA and an annulus between the BHA and the wellbore, (v) pressure at a selected location in the BHA, (vi) drop differentially across a mud motor in the BHA, rotating said drill bit, (vii) torque, (viii) rate of penetration ("ROP") of the drill bit in the subsurface formation, (viii) vibration, (ix) whirl, (x) bit bounce, (xi) stick slip, (xii) rock matrix of the formation, (xiii) a formation characteristic; rotational speed of the drill bit.

16. The force application device of claim 12, wherein the force application member has a through opening allowing fluid flow therethrough and the force applied on the drill bit being responsive to the pressure of the fluid on the force application member.

17. The force application device of claim 16 further comprising a valve for controlling the flow of the fluid through the stroke member, thereby controlling the pressure on the force application member.

18. The force application device of claim 17, wherein the control unit modulates the valve to control the force exerted by the stroke member on the drill bit.

19. The force application device of claim 18, wherein the valve is operated by a device selected from a group consisting of (i) a stepper motor, and (ii) a solenoid.

20. A method of drilling a wellbore in a subsurface formation by a drilling assembly that includes a drill bit and a thruster which exerts force on the drill bit during drilling of the wellbore, said method, comprising:

(a) conveying the drilling assembly into the wellbore;

(b) rotating the drill bit to cause the drill bit to penetrate the formation;

(c) operating the thruster to apply a predetermined force on the drill bit;

(d) determining at least periodically at least one parameter of interest downhole during drilling of the wellbore relating to the drilling of the wellbore; and

(e) altering the force applied by the thruster in response to the determined at least one parameter of interest.

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