United States Patent

Murphey, Jr.

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[45] **Dec. 19, 1972**

[54] **WELL DEVIATION CONTROL SYSTEM**

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[73] Assignee: **Shell Oil Company**, Houston, Tex.

[22] Filed: **Dec. 6, 1971**

[21] Appl. No.: **205,222**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 2,763, Jan. 14, 1970, abandoned.

[52] **U.S. Cl.** **175/320**

[51] **Int. Cl.** **E21b 17/00**

[58] **Field of Search** 175/320, 61, 325

[56] **References Cited**

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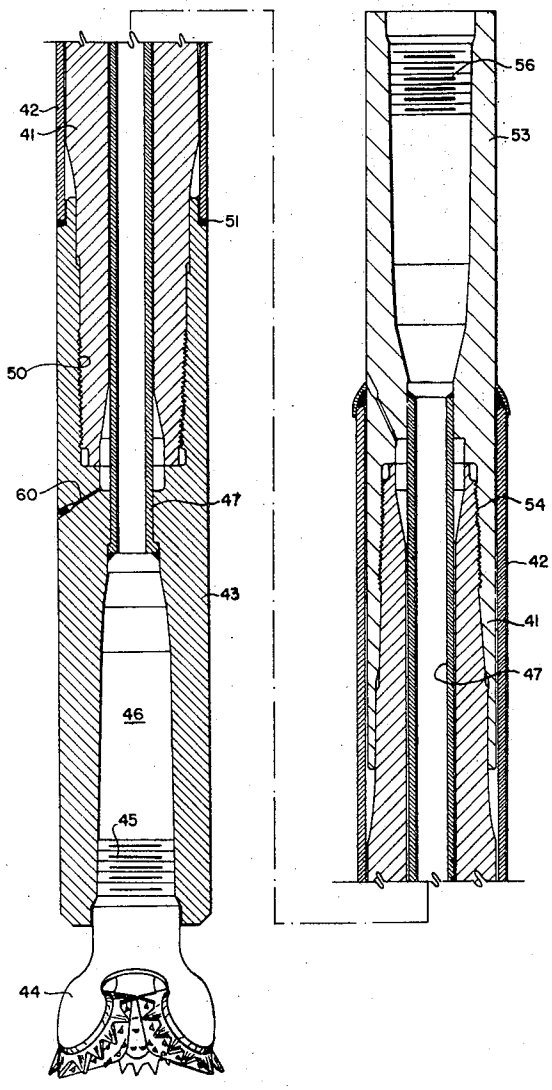
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Primary Examiner—David H. Brown
Attorney—Theodore E. Bieber et al.

[57] **ABSTRACT**

A system for controlling hole deviation through the use of a bit and a composite drill string comprising a heavy drill collar disposed above the bit and conventional steel collars above the heavy metal collar.

7 Claims, 7 Drawing Figures



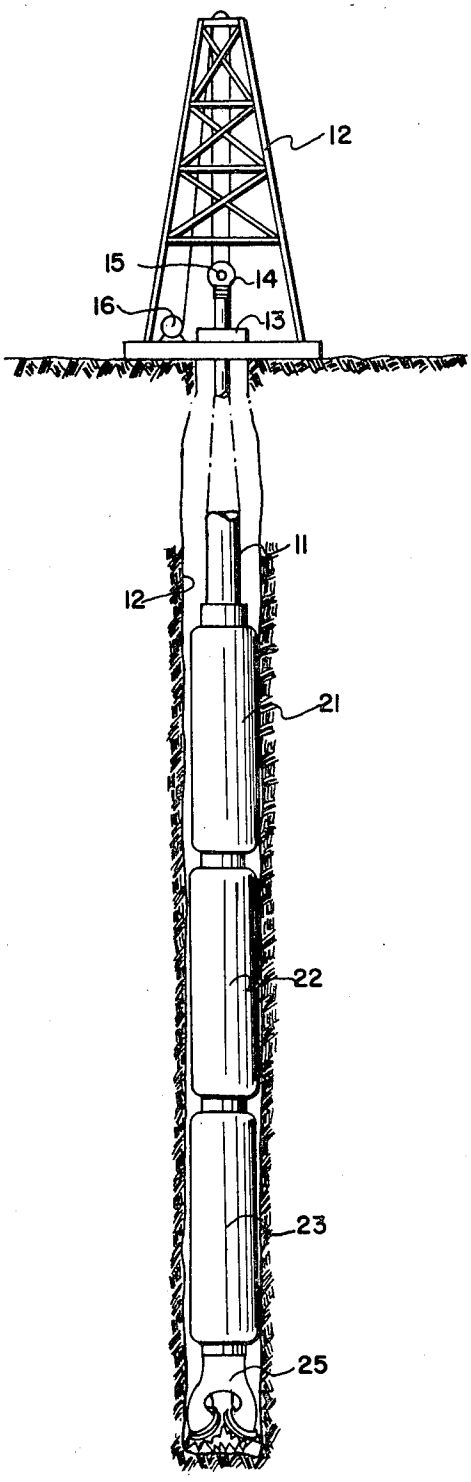


FIG. 1

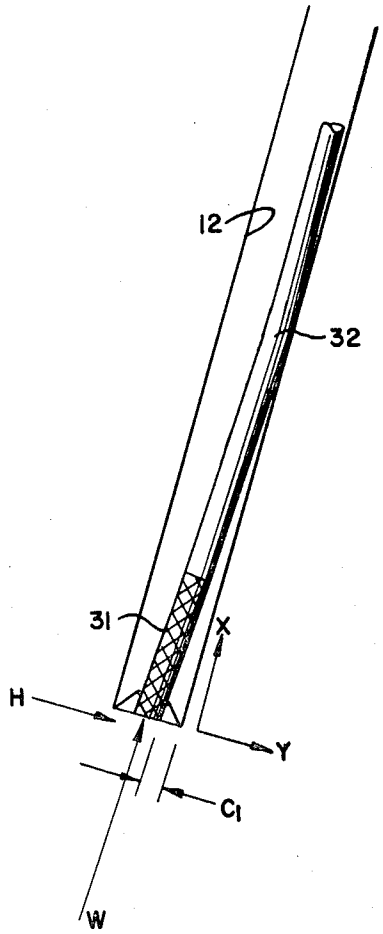


FIG. 2

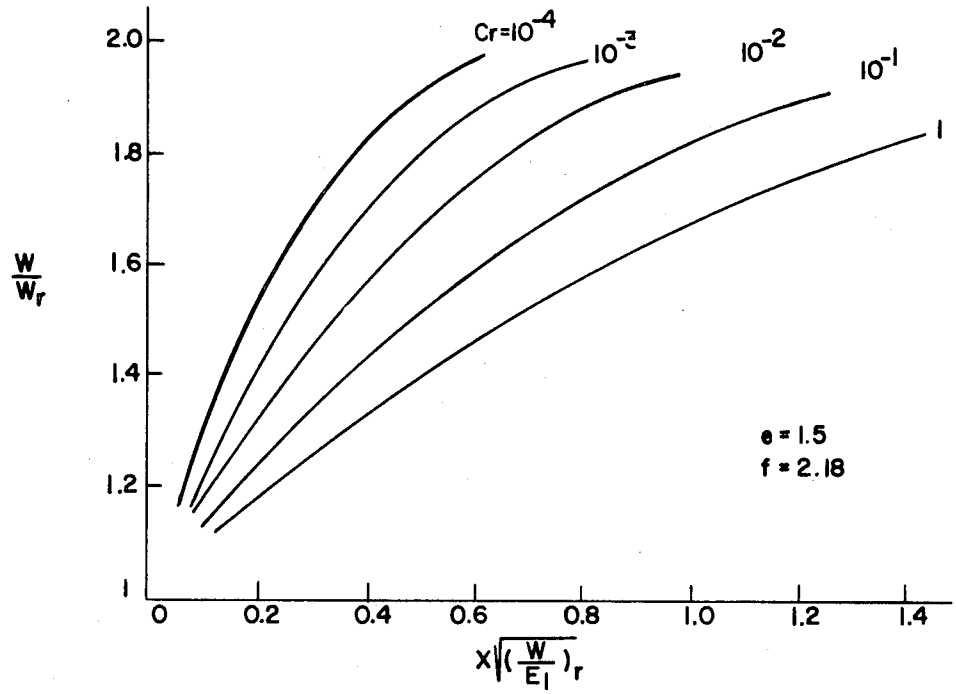

2.0
1.8
1.6
1.4
1.2
1
W/Wr
Cr=10^-4
10^-3
10^-2
10^-1
1
e = 1.5
f = 2.18
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
X√(W/E1)r

FIG. 3

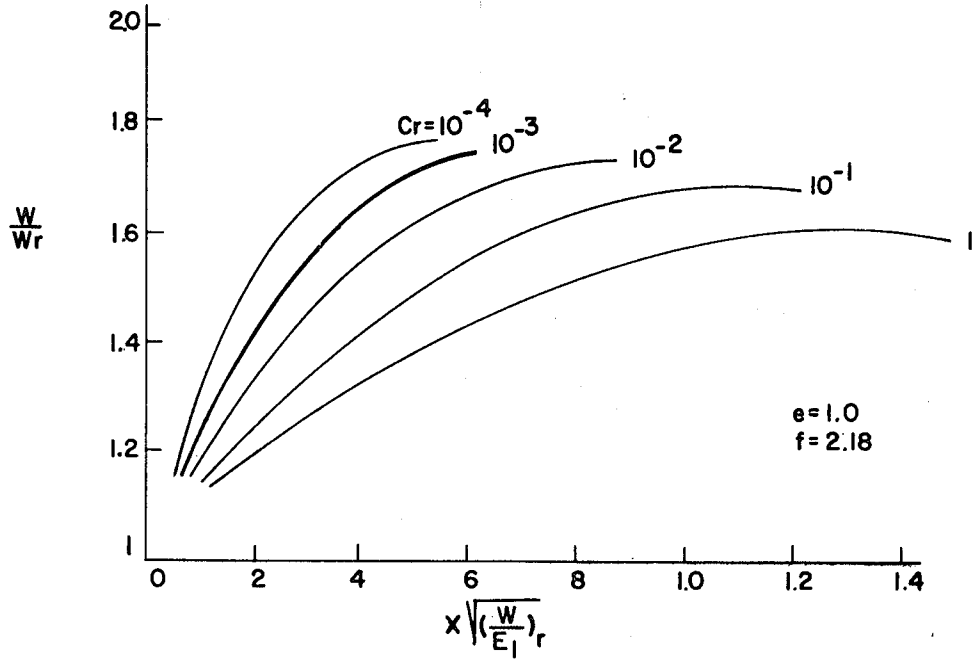

2.0
1.8
1.6
1.4
1.2
1
W/Wr
Cr=10^-4
10^-3
10^-2
10^-1
1
e = 1.0
f = 2.18
0
2
4
6
8
1.0
1.2
1.4
X√(W/E1)r

FIG. 4

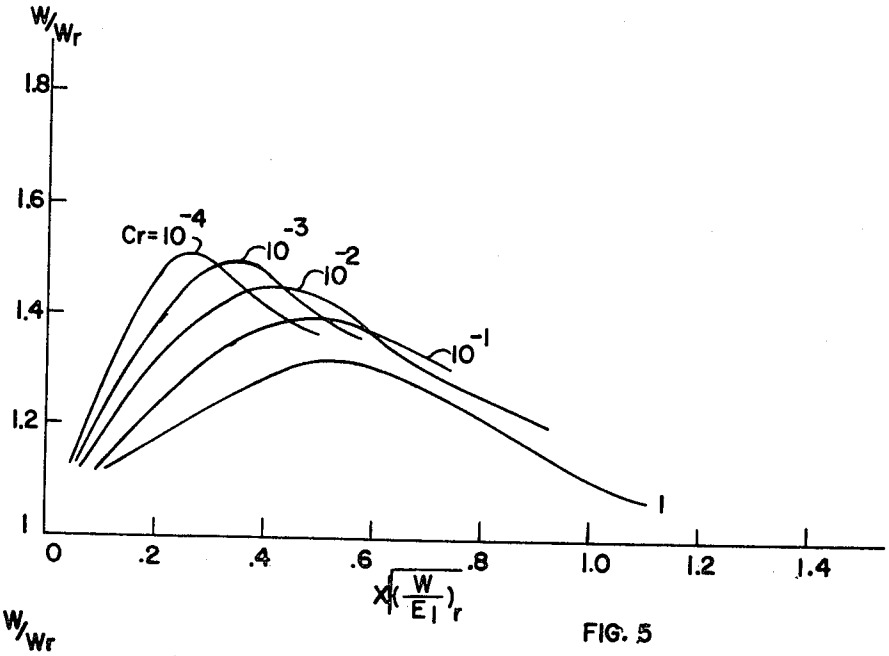

W/Wr
1.8
1.6
1.4
1.2
1
Cr=10^-4
10^-3
10^-2
10^-1
1
0
.2
.4
.6
.8
1.0
1.2
1.4
X √(W/E1)r

FIG. 5

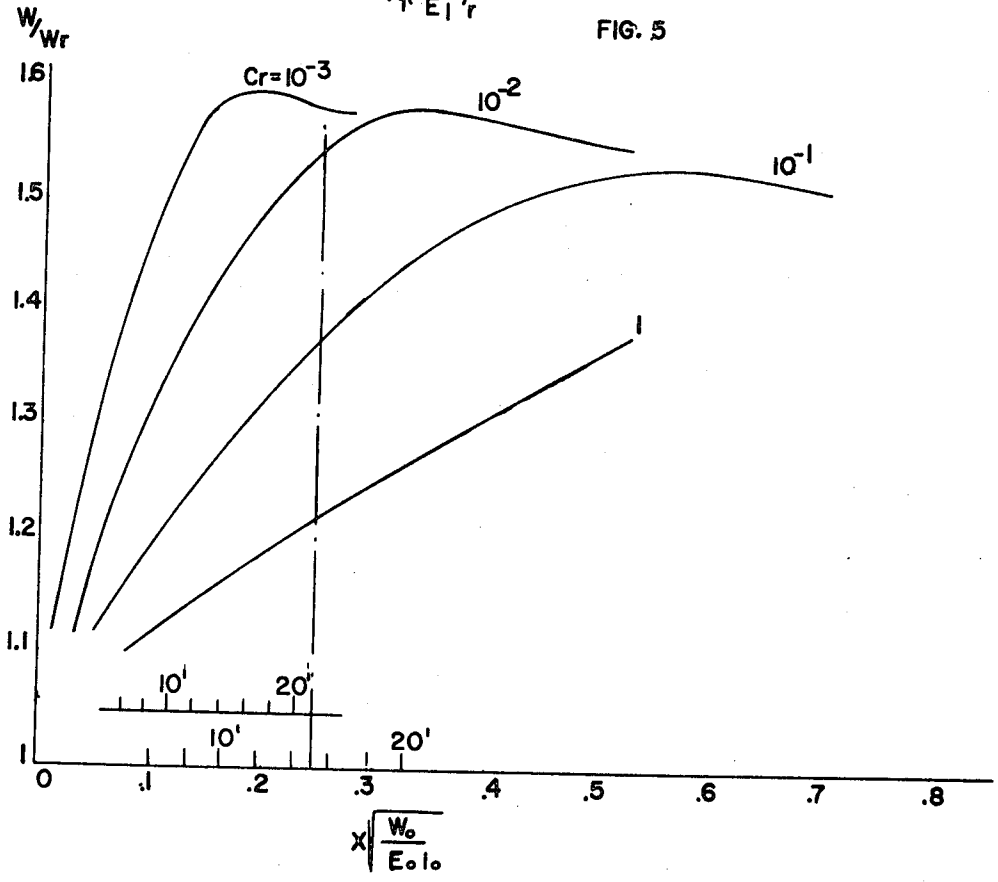

W/Wr
1.6
1.5
1.4
1.3
1.2
1.1
1
Cr=10^-3
10^-2
10^-1
1
10'
20"
10'
20'
0
.1
.2
.3
.4
.5
.6
.7
.8
X √(Wo/Eo lo)

FIG. 6

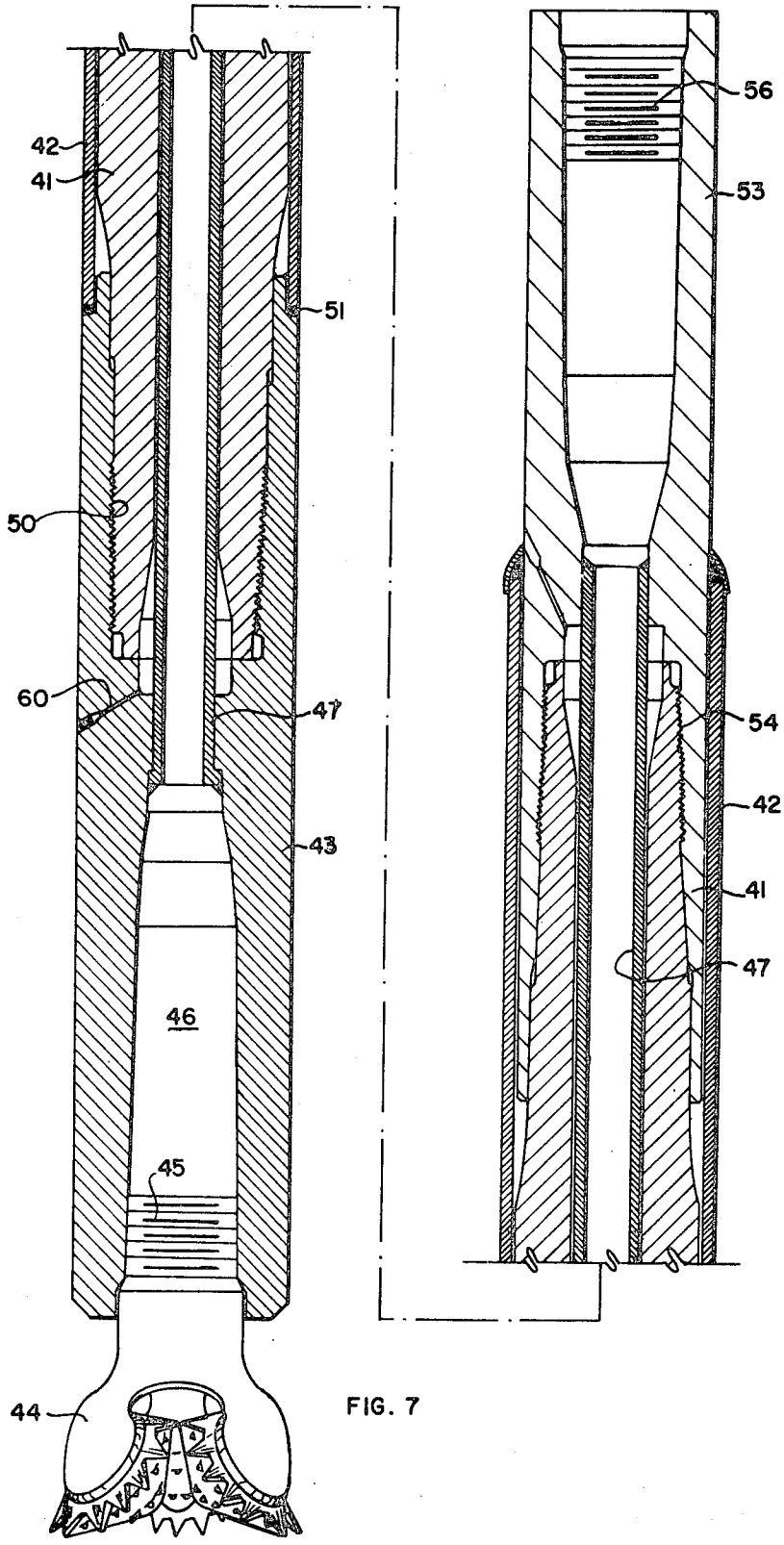


FIG. 7

WELL DEVIATION CONTROL SYSTEM

RELATED PATENT APPLICATION

This application is a continuation-in-part of Ser. No. 2763, entitled "Well Deviation Control System", filed Jan. 14, 1970 for Carey E. Murphey, Jr. and now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a system of borehole drilling control, and, more particularly, a system for reducing or eliminating hole deviation such as may be caused by drilling through dipping, laminated or anisotropic formations or in controlling the borehole deviation in directionally drilled wells. Dipping, laminated or anisotropic formations will hereinafter be referred to as "anisotropic formations."

2. Description of the Prior Art

When utilizing conventional rotary drilling techniques and equipment, problems are often encountered in drilling through anisotropic formations. Reactive forces between the bit, drill string and formation create a force imbalance which causes the string to deviate from its desired direction.

A conventional technique used to control the correct borehole deviation consists of reducing the weight on bit, sometimes by as much as 90 percent of the optimum drilling weight, and maintaining or increasing the rotary speed. This practice accents what is commonly known in the drilling art as the pendulum effect and brings the hole back toward the vertical or other desired drilling direction. An alternative or supplemental approach for the prevention of undesired bit and drill string deviation is to utilize square drilling collars to stiffen the drill string assembly while running lighter bit weights. Both of these prior art approaches are characterized by the fact that much lower drilling rates are obtained with resultant increases in drilling per cost per foot of hole.

Other prior art drill collars have attempted to control hole deviation problems by the concentration of additional weight in the drill string immediately above the drill bit. These devices have contributed to partially solving the problem of hole deviation control while at the same time achieving some reasonably acceptable penetration rate. For instance, U.S. patent to Bruce (No. 3,047,313) discloses using inner and outer tubular members having a cellular spacer means between the inner and outer tubular members. The cellular spacing means have interconnected passageways for receiving a weighting material in a liquid or powder form. Threaded connectors are welded to the inner and outer tubular members at each end of the drill collar. Bruce, by his collar make-up, uses the heavy metal only as a weighting material and does not utilize the heavy metal, as a structural member of his drill collar.

SUMMARY OF THE INVENTION

The applicant has solved the prior art problems through his use of a heavy metal which forms a integral or mechanical link in the drill string contributing both stiffness and weight to the drill string.

The applicant has increased the stiffness from approximately 0.3 where a material is used only as a weighting material as in Bruce to roughly 0.68 when the material forms an integral or mechanical link in the drill string thus allowing considerably more weight to be applied to the drill bit while at the same time maintaining the same deviation but achieving increased rates of penetration. An increase of this magnitude is significant when weight on bit and deviation of the borehole are considered.

It is therefore an object of the present invention to provide a system whereby substantially high weight levels may be maintained on the bit without resulting in deviation of the string and bit even when drilling in anisotropic formations.

This and other objects have been attained in the present invention by providing a system for drilling through anisotropic formations wherein drilling pressure is applied to the drill bit by subjecting it to the weight of a composite heavy metal drill collar assembly that is substantially as long as the pendulum length for the borehole being drilled and contains a high-density collar section that is located between the bit and a section of drill collars of conventional weight and stiffness. The high density collar section is composed of metal having at least about twice the density of steel in a configuration that provides a collar having a stiffness of at least one half of that of a steel collar.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a view taken in longitudinal projection illustrating the arrangement according to the present invention located "in hole" and in operative association with a drilling derrick;

FIG. 2 is a schematic view taken on longitudinal projection of a composite drill collar assembly adapted to penetrate an anisotropic formation which serves to illustrate the principles underlying the present invention;

FIGS. 3, 4, 5 and 6 are graphs illustrating certain performance characteristics of composite heavy metal drill collars; and

FIG. 7 is an enlarged detail cross sectional view of a heavy metal drill collar unit constructed in accordance with the present invention in operative association with a rotary drilling bit.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, a "drill string" is shown as depending from a derrick 61 into a well borehole 12. Associated with the derrick is conventional drilling equipment including rotary table 13, swivel joint 14 and a travelling block 15 operatively associated with a winch 16 in the conventional manner. At the lower end of the string a plurality of drill collars 21, 22 and 23 are end connected in the conventional manner. As will be pointed out in greater detail below at least the lowermost collar 23 which is connected to rotary bit 25 is of a special heavy metal construction.

For the proper understanding of the invention, the basic principles upon which it is founded will first be discussed. Briefly, the basic theory underlying this invention states that the composite drill collar assembly according to the present invention will reduce hole deviation problems by increasing the "pendulum" force, induced by the assembly, that acts on the bit. This in turn allows more weight on bit to be run while

maintaining a constant hole angle, or a reduction in hole angle. The additional weight on bit results in faster penetration and more economical drilling conditions.

The detailed analysis utilized in developing the subject invention will now be set forth. It should be noted that the bending and column action of the drill collars is treated with conventional engineering beam theory. In carrying out the detailed analysis the following symbols are used:

SYMBOLS

E — modulus of elasticity
I — moment of inertia
Y — deflection of drill collar
W — axial component of weight on bit
X — axial coordinate measured upwards from the bit
P — weight per unit length of the drill collars
α — angle of inclination of borehole
H — side force acting on bit

In the solution, the measure of performance used is the percent increase in weight on bit with no increase in borehole inclination which can be obtained with a composite heavy metal drill collar string. The reference value of weight on bit is that for an all steel drill collar string. When a heavier, stiffer drill collar is substituted just behind the bit for the steel drill collar, more weight on bit at constant inclination can be run, thus increasing the penetration rate. The percentage increase in weight on bit depends on the length, weight, stiffness, and diameter of the heavier drill collar and on the reference drilling conditions. The reference drilling conditions consist of the reference drill collar size, clearance, inclination angle, and reference weight on bit. In the analysis the drill collar is made up of short lengths having uniform diameter and material properties. The length, diameter, and uniform material properties of each uniform section can be varied arbitrarily. The transfer matrix concept is used to simplify as much as possible the algebra with continuity and boundary conditions.

The differential equation governing bending and column action of a uniform section of drill collar is:

$$EIY''' + (W - Xp\cos\alpha)\,Y' = Ho + p\sin\alpha\,(X - Xo)$$

The physical system is shown in schematic form in FIG. 2 wherein the reference numeral **31** designates a stiff heavy metal section and part **32** represents one or more conventional steel collars. Use of this equation implies the usual assumptions of deviation analysis. Only static deflection from initial straight line is considered. All forces and deflection lie in a vertical plane. We neglect the variation in compressive load in the drill collars relative to the weight on bit so that the simplified differential equation is:

$$EIY''' + WY' = Ho + p\sin\alpha\,(X - Xo)$$ The differential equation can be integrated once to obtain

$$EIY'' + WY = WYo + Mo + Ho\,(X - Xo) + \tfrac{1}{2}p\sin\alpha\,(X - Xo)$$

This differential equation must be satisfied within every section. The bending stiffness, EI and weight per unit length p may vary from section to section. When two sections are joined together, the following continuity conditions must be satisfied at the interface.

$$Y(X-) = Y(X+)$$

$$Y'(X-) = Y'(X+)$$

$$M(X-) = EIY'' = M(X+)$$

$$H(X-) = EIY''' + WY' = (X+)$$

Introducing dimensionless parameters

$$Y = \frac{(EIp)r\,\mathrm{Sin}\,\alpha}{W^2}\,y \qquad X = \sqrt{\frac{\overline{EI}_r}{W}}\,X$$

$$M = \frac{(EIp)r\,\mathrm{Sin}\,\alpha}{W}\,m \qquad H = \frac{(\sqrt{EIp})_r\,\mathrm{Sin}\,\alpha}{\sqrt{W}}\,h$$

$$e = EI/(EI)r$$

$$f = p/pr$$

the differential equation becomes

$$ey'' + y = yo + mo + ho\,(X - Xo) + \tfrac{1}{2}f(X - Xo)^2$$

and the continuity equations are

$$y(X-) = y(X+)$$
$$m(X-) = ey'' = m(X+)$$
$$y'(X-) = y'(X+)$$
$$h(X-) = ey''' + y' = h(X+)$$

From the differential equation force continuity condition can be simplified to

$$h(X-) = ho + f(X - Xo) = h(X+)$$

The solution of the differential equation is

$$y(X) = A\sin(X/\sqrt{e}) + B\cos(X/\sqrt{e}) - ef + yo + mo + ho\,(X - Xo) + \tfrac{1}{2}f(X - Xo)^2$$

The two arbitrary constants in the homogeneous solution can be evaluated using

$$y(Xo) + yo$$

$$ey''(Xo) = mo$$

and with trigonometric identities the solution written as

$$y(X) = yo \mp yo'\sqrt{e}\sin X - Xo/\sqrt{e} + mo\,(1 - \cos(X - Xo/\sqrt{e})) + ho\,(X - Xo - \sqrt{e}\,\mathrm{Sin}\,(X - Xo/\sqrt{e}) - ef(1 - \cos(X - Xo/\sqrt{e})) + \tfrac{1}{2}f(X - Xo)$$

Repeated differentiation obtains the transfer matrix relating conditions at opposite ends of the length of uniform bar.

$$\begin{bmatrix} y(X) \\ y'(X) \\ m(X) \\ h(X) \\ 1 \end{bmatrix} = \begin{bmatrix} \quad \end{bmatrix} \begin{bmatrix} yo \\ y'o \\ mo \\ ho \\ 1 \end{bmatrix}$$

where T=

$$\begin{bmatrix} 1\sqrt{e}\,\text{Sin}\,\frac{X-Xo}{\sqrt{e}} & 1-\text{Cos}\,\frac{X-Xo}{\sqrt{e}} & X-Xo\sqrt{e}\,\text{Sin}\,\frac{X-Xo}{\sqrt{e}} & -ef\left(1-\text{Cos}\,\frac{X-Xo}{\sqrt{e}}\right)+1/2f(X-Xo)^2 \\ 0\ \cos\frac{X-Xo}{\sqrt{e}} & \frac{1}{\sqrt{e}}\sin\frac{X-Xo}{\sqrt{e}} & 1-\cos\frac{X-Xo}{\sqrt{e}} & -\sqrt{e}f\sin\frac{X-Xo}{\sqrt{e}}+f(X-Xo) \\ 0 & -\sqrt{e}\sin\frac{X-Xo}{\sqrt{e}} & \cos\frac{X-Xo}{\sqrt{e}} & \sqrt{e}\sin\frac{X-Xo}{\sqrt{e}} \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{matrix} ef\left(1-\cos\frac{X-Xo}{\sqrt{e}}\right) \\ f(x-Xo) \\ \\ 1 \end{matrix}$$

Note that this transfer matrix depends only on the stiffness ratio, density ratio, and length of the uniform section.

If two bars are connected together, the transfer matrix of the combination is obtained by matrix multiplication of the individual transfer matrices. If bar B is connected to the end of bar A whose length is L_a, the transfer matrix relating conditions at the end of bar A any point in bar B is

$$[T(e_b, F_b, X-l_a)]\,[T(e_a, f_a, l_a)]$$

where $Xo = o$ for bar A and $Xo = l_a$ for bar B In the process of matrix multiplication the continuity equations are automatically satisfied. This, of course, is the primary motivation for using the transfer matrix concept. For a drill collar made up in uniform sections the over-all transfer matrix is obtained by matrix multiplication of the individual transfer matrices.

$$u=[T(N)]\,[T(N-l)]\ldots.[T(2)]\,[T(1)]$$

The foregoing applies to drill collars and beam columns with any boundary conditions. For a drill collar at its equilibrium angle in a straight hole with no stabilizer, the following boundary conditions apply at the bit.

$$\begin{matrix} Y(o)=-C \\ Y'(o)=S \\ M(o)=O \\ H(o)=Ho \end{matrix} \qquad \begin{matrix} y(o)=-c \\ y'(o)=s \\ m(o)=o \\ h(o)=ho \end{matrix}$$

At the point of tangency of the drill collars to the low side of the borehole

$$\begin{matrix} Y(L)=O \\ Y'(L)=O \\ M(L)=O \\ H(L)=H_1 \end{matrix} \qquad \begin{matrix} y(l)=o \\ y'(l)=o \\ m(l)=o \\ h(l)=h_1 \end{matrix}$$

The boundary conditions are written in terms of both physical variables and dimensionless variables. Using the over-all transfer matrix, these boundary conditions require

$$\begin{bmatrix} 0 \\ 0 \\ o \\ h_1 \\ 1 \end{bmatrix} = \begin{bmatrix} \\ u \\ \\ \\ \\ \end{bmatrix} \begin{bmatrix} -c \\ s \\ 0 \\ h_o \\ 1 \end{bmatrix}$$

where

$$U=U(e_2, f_2, l-x_1, e_1, f_1, x_1)$$

This matrix equation is equivalent to five simultaneous equations. The fifth equation is trivial while the fourth equation determines the side force on the drill collars at the point of tangency. This side force does not enter into further deviation calculations so the fourth equation can be ignored. The remaining three equations relate the dimensionless side force, slope, and clearance at the bit.

The percentage change in weight on bit at constant hole angle is calculated when a short length of heavy drill collar is substituted for a steel collar just behind the bit. If the borehole inclination angle and the formation being drilled do not change, the ratio of side force to weight on bit is constant. The dimensionless groups in previous equations then can be written as

$$h=\left(\frac{H}{W}\right)\frac{W3/2}{(\sqrt{EIp})r\,\text{Sin}\,\alpha} \qquad \frac{H}{W}=\text{constant}$$

$$c=\frac{W^2C}{(EIp)r\,\text{Sin}\,\alpha}$$

$$1=\sqrt{\frac{W}{(EI)r}}\,L$$

$$x=\sqrt{\frac{W}{(EI)r}}\,X$$

The ratio of the dimensionless groups to their reference values can be written as

$$\left(\frac{c}{cr}\right)=\left(\frac{W}{Wr}\right)^2\left(\frac{h}{hr}\right)=\left(\frac{W}{Wr}\right)^{3/2}$$

Eliminating the weight on bit ratio

$$\left(\frac{c}{cr}\right)^{1/2}=\frac{W}{Wr}=\left(\frac{h}{hr}\right)^{2/3}$$

the dimensionless side force at the bit and the dimensionless clearance must be related by

$$c/cr=(h/hr)\,4/3$$

This equation and the three simultaneous equations obtained from the matrix equation provide the analytical basis for computing deviation performance. To solve these four equations, the known parameters are e_2, f_2, e_1, f_1, c_r, and h_r

while the unknowns are l, c, and h.

By assuring a trial value of the dimensionless pendulum length, l, the three simultaneous equations can be solved for c and h. These values can be substituted in the fourth equation. If equality is not obtained, Newton's method is used to iterate on l until a solution is obtained.

From a series of such calculations one can obtain a dimensionless performance plot of

$$\left(\frac{W}{Wr}\right)=\left(\frac{c}{cr}\right)^{1/2} \text{ versus } \sqrt{\frac{Wr}{ErIr}}\,X_1=\left(\frac{c}{cr}\right)^{1/4}X_1$$

INTERPRETATION OF ANALYTICAL RESULTS

The results of the analytical analysis are expressed in terms of the dimensionless groups W/W_r and $x\sqrt{W_r/E_rI_r}$ for various values of

$$c_r = (W_r^2 C/E_r I_r p_r \sin\alpha)$$

The dimensionless ratio c_r is a variable in the solution and represents the severity of the natural hole deviation problem that exists using standard steel collars. Values of c_r of 0.001 or less represent "severe" deviation conditions, values of c_r of 0.01 to 0.1 represent "moderate" conditions and for c_r less than 0.1 the severity of the deviation problem is only "slight."

The ratio W/W_r represents the performance of the heavy metal collar relative to the standard collar. W_r is the weight on bit that can be run while maintaining a constant hole angle using standard weight collars while W represents the weight on bit that can be run while maintaining the same hole angle using the heavy metal collar.

The group $x\sqrt{W_r/E_rI_r}$ represents the dimensionless length ratio for the heavy metal collar. x is the actual length of the collar and E_rI_r is the stiffness function of the reference standard weight collars.

To compute the performance of a given diametrical size of heavy metal collar composed of a specific metal, an analysis must be made for each size of standard collar that one wishes to compare to the heavy metal collar.

FIGS. 3, 4, and 5 illustrate the performance curves for a composite heavy metal drill collar string composed of a tungsten collar and regular 8 inch outside diameter by 2 inch inside diameter steel collar. Tungsten has a specific gravity of 17.0 and a modulus of elasticity of 45×10^6 psi as compared to values of 7.8 and 30×10^6 psi respectively for steel. These three figures illustrate the advantageous of heavy metal composite drill collar string design over standard drill collar string and point out the importance of stiffness in the design of a composite metal drill collar as related to improving the performance of drilling in naturally deviated wells.

To determine the performance of the heavy metal collar the value of c_r must be computed from the reference drilling condition determined while drilling with standard drill collars. Next the dimensionless length $x\sqrt{W/EI)_r}$ must be computed using the reference conditions and the length of the heavy metal collar. Once these two values are known the performance of the heavy metal collar can be evaluated.

The following is a typical example:

Hole diameter = 9 ⅞inch
Equilibrium drilling
weight to maintain
constant hole angle
using steel collars (W_r) = 10,000 pounds
Hole angle = **6.75°**
Collar size = 8 inch O.D − 2 inch ID.
$E_rI_r = 60 \times 10^8$ lb − in^2
$p_r = 13.3$ lb/in

$$c_r = \frac{W_r^2 C}{E_r I_r p_r \sin\alpha} = \frac{(10{,}000)^2(0.9375)}{(60\times10^8)(13.3)(0.1175)} = 10^{-2}$$

For a 30 foot tungsten collar the dimensionless length is

$$x\frac{W_r}{E_rI_r} = (30)(12)\frac{10{,}000}{60\times10^8} = 0.464$$

From FIG. 3, using $c_r = 10^{-2}$ and $x(W_r/E_rI_r) = 0.464$ a performance ratio of 1.64 is determined for this particular example. The performance ratio indicates that 16,400 pounds weight on bit could be run while still maintaining a constant hole angle. In many drilling areas there is a one to one correspondence between weight on bit and drilling rate. In such a case, the use of the 30 foot collar in the above example would have resulted in a 64 percent increase in drilling rate and a corresponding decrease in the drilling cost per foot of hole.

The performance curves illustrated in FIG. 3 are for tungsten collars design so as to take full advantage of tungsten's greater modulus of elasticity (E) as compared to steel. The curves correspond to a design whereas the tungsten collar is the same size as the reference steel collars and is connected directly to reference steel collar.

The performance curves illustrated in FIGS. 4 and 5 correspond to designs whereas the stiffness ratio (EI/E_rI_r) has been reduced to values of 1 and 0.4 respectively. These curves illustrate the importance of stiffness in the performance of a composite heavy metal collar. Consider the above example case. The performance ratio for a stiffness ratio of 1.5 (from FIG. 3) is 1.64. This compares to a performance ratio value of 1.6 for a stiffness ratio of 1 and a performance ratio of 1.44 for a stiffness ratio of 0.4. For the last case, this represents a decrease of 20 percent in the allowable weight on bit that could be run while maintaining a constant hole angle of 6.75° in the previous example. A stiffness ratio of 0.4 corresponds to a design wherein the tungsten acts only as an additional weighting material and is encased in a thick steel shell that composes the structural element of the heavy metal collar.

In FIG. 6 the performance curves for a heavy metal drill collar fabricated from a depleted uranium alloy having a specific gravity of 18.4 and a modulus of elasticity of 20×10^6 psi are shown. These curves serve to illustrate the value of a composite heavy metal drill collar string design. Note the maximums in the performance curves for values of c_4 of 10^{-3}, 10^{-2}, and 10^{-1}. These maximum values indicate that for a specific drilling situation when W_r, E_r and I_r are known, there is an optimum value for the length of the heavy metal collar to be used just above the bit.

The specific optimum length of the heavy metal section of the composite string is a variable that is a function of c_r and W_r, for a given E_r and I_r. However, in practice a preferable length of the heavy metal collar can be determined by considering the performance curve for the severe deviation problem, that is for $c_r = 10^{-3}$. From field experience we know that for severe deviation cases, W_r often falls in the region of 5,000 to 10,000 pounds. Note in FIG. 6 that for these two values of W_r the performance of a 15 foot heavy metal collar brackets the optimum performance ratio value of $c_r = 10^{-3}$. Thus for an 8 inch diameter depleted uranium collar to be used in a composite string with 8 inch diameter steel collars, a length of 15 feet is most suitable. A longer heavy metal collar would result in diminishing performance in a string without stabilizers.

A depleted uranium drill collar unit adapted for use in accordance with the teachings of the present inven-

tion is illustrated in FIG. 7. The main body of the depleted uranium collar 41 is preferably formed by extruding or otherwise forming a billet into a long solid cylindrical shape. The collar 41 is then rough machined on its outer diameter. The inner bore of the collar 41 is then formed by trepanning or other means for piercing. Final machining of the collar 41 is then completed. The material properties of the finished uranium 41 has a maximum tensile strength of approximately 127,000 psi, a yield strength of roughly 79,500 psi, an elongation of 16 percent, modulus of elasticity of 20×10^6 psi and a fatigue strength in excess of 48,000 psi at 5×10^6 cycles. The unit includes a depleted uranium collar 41 which is surrounded over substantially the full extent of its length by an outer steel sleeve 42, said sleeve 42 being secured at its lower end by means of welding or other suitable securing means to bit connector 43. A conventional rotary bit 44 is illustrated as being secured to connector 43 by means of screw threads 45 in the usual manner. The inner steel sleeve 47 which extends through the uranium collar 41 as shown is welded to bit connector 43 as at 46 protecting collar 41 from internal corrosion. It may thus be seen that uranium collar 41 is protected both internally and externally by steel sleeves 47 and 42 respectively. Although these sleeves contribute to the strength and rigidity of the unit as a whole, their primary function is for corrosion and erosion protection of the uranium alloy collar. If a suitable anti-corrosion alloy of uranium was found, these sleeves could be eliminated resulting in a collar having improved performance for any given finished size.

Preferably, the finished collar is sufficiently nonmagnetic to allow surveys to be run in the collar saving large sums of money by allowing logging to be completed without pulling the drill string from the borehole.

Bit connector 43 is internally threaded at its upper end as at 50 to cooperate with threads on uranium collar 41. The bit connector is also welded to the bottom of outer sleeve 42 as at 51 protecting collar 41 from possible corrosion by external substances encountered during the drilling operation.

An upper connector unit 53 is threadedly secured to the top of uranium collar 41 as at 54. Inner and outer steel sleeves 47 and 42 are welded or otherwise secured to upper connector unit 53. It may thus be seen that uranium collar 41 serves as a mechanical link and structural member of the heavy metal drill collar unit. Threads 56 are provided at the top of upper connector 53 to enable additional conventional collars to be added to the string in a conventional manner.

Thus, the combination of threaded connections 50 and 54 and connectors 43 and 53 provide a mechanical coupling means between the uranium collar 41, the drill bit 44 and "drill string."

Small void spaces may exist between the inner and outer protective sleeves and the collar 41 after the unit is fabricated. For this reason tapped holes may be provided at strategic locations (as at location 60, for example) so these areas may be filled with an epoxy resin. Epoxy (not shown) is also preferably forced down the length of the collar to effect a physical bond between the uranium and the protective inner and outer sleeves. This is done for corrosion protection of the heavy metal rather than for strength purposes.

The upper connector unit 53 and the lower connector unit 43 are both of sufficient length such that the threaded ends 45 and 56 may be cut off to a shorter length and new threads may be cut at each end increasing the useful life of each end connector. End connectors 43 and 53 may be replaced if required by machining their outer diameter until the wall thickness is fairly thin. This would be required since end connectors 43 and 53 are each mated with depleted uranium collar 41 by first heating end connectors 43 and 53 to an elevated temperature and then allowed to cool after being mated with depleted uranium collar 41 such that a shrink fit is effected. The applicant by using a uranium collar 41 threaded at each end and expendable threaded end connectors at each end has provided a drill collar possessing both increased weight while at the same time using the weighting material in a structural capacity which has not heretofore been accomplished.

I claim as my invention:

1. Apparatus for controlling borehole deviation when drilling a borehole, said apparatus comprising:
   - a drill bit; and
   - a heavy metal drill collar unit having substantially twice the density of steel, said heavy metal drill collar unit being a load carrying member, and having first coupling means disposed at the lower end of said heavy metal drill collar for coupling said drill bit to said heavy metal drill collar unit, and having second coupling means disposed at the upper end of said heavy metal drill collar for coupling a collar section to said heavy metal drill collar unit whereby said heavy metal drill collar acts as a structural member for transmitting a substantial portion of the load to said drill bit.

2. The apparatus of claim 1 wherein said heavy metal drill collar unit comprises:
   - an upper connector;
   - a lower connector; and
   - a heavy metal having substantially twice the density of steel, said heavy metal being connected at its upper and lower ends to said upper and lower connector whereby said heavy metal acts as a structural member of said heavy metal drill collar unit.

3. The heavy metal drill collar unit of claim 2 wherein said heavy metal is threadably connected to said upper and lower connector.

4. The heavy metal drill collar unit of claim 2 wherein said heavy metal is depleted uranium alloy.

5. The heavy metal drill collar unit of claim 2 wherein said heavy metal is tungsten.

6. The heavy metal drill collar unit of claim 2 wherein said heavy metal drill collar unit further includes inner and outer sleeve means substantially surrounding said heavy metal thereby providing corrosion protection to said heavy metal.

7. A heavy metal drill collar having a stiffness of at least one half that of a steel drill collar, said heavy metal drill collar comprising:
   - an upper connector;
   - a lower connector;
   - a depleted uranium collar said collar having an inner bore therethrough, said collar being threadably connected to said upper and lower connectors at its ends, said upper and lower connectors being

connected to said depleted uranium collar such that a shrink fit results;

an inner sleeve extending through the inner bore of said collar, said inner sleeve being suitably connected at its ends to said upper and lower connector; and

an outer sleeve surrounding said depleted uranium collar, said outer sleeve being suitably connected at its ends to said upper and lower connectors.

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