Title: APPARATUS AND METHOD FOR LATERAL WELL DRILLING

Abstract: An apparatus, method and downhole tool assembly for cutting laterally into an earthen formation from a wellbore.
APPARATUS AND METHOD FOR LATERAL WELL DRILLING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Application No. 61/743,678 filed on September 10, 2012.

FIELD

[0002] The present invention relates to an apparatus and method for rotating a shaft around a radius using a flexible splined member. In a specific application, the invention relates to an apparatus and method for mechanically cutting earthen formation surrounding a wellbore, and optionally, cutting the casing and/or cement disposed in the wellbore, with the use of said flexible spline member.

BACKGROUND

[0003] A multitude of wellbores have been drilled into earth strata for the extraction of oil, gas, and other material therefrom. In many cases, such wells are found to be initially unproductive, or may decrease in productivity over time, even though it is believed that the surrounding strata still contains extractable oil, gas, water or other material. Such wells are typically vertically extending holes including a production casing, usually of a mild steel pipe, having an outer diameter of a few inches to over 12 inches and used for the transportation of the oil, gas, or other material upwardly to the earth's surface. Commonly employed production casing sizes range from about 4.5” to 9.0” and account for an estimated 97%+ of the wells in the world. In other instances, the wellbore may be uncased at the zone of interest, commonly referred to as an “openhole” completion.

[0004] In an attempt to obtain production from unproductive wells and increase production in under producing wells, methods and devices for forming a hole in a well casing, if present, and forming a lateral passage into the surrounding earth strata are known. For example, a hole in cased wells can be produced by punching a hole in the casing, abrasively cutting a hole in the casing, milling a hole in the casing wall, milling out a vertical section of casing, or thermally or chemically forming a hole in the casing. While more or less efficacious, such methods are generally familiar to those in the art. In openhole wells, the steps to form a hole in the casing are not required, but the methods for forming a lateral passage into the surrounding strata may be virtually identical to those used on a cased well.
[0005] Under both the cased and uncased well scenarios, a type of whipstock having a lower radius is typically incorporated to direct the cutting head out of the wellbore and into the formation. The whipstock is often set on the end of upset tubing (production tubing) and secured in place by a packer or anchor. Certain whipstock configurations are able to direct cutting tools outside of the wellbore while themselves staying within the wellbore; other, typically more complicated systems involve various mechanisms that extend outside of the wellbore.

[0006] In the interest of time and for economic reasons, often the cutting tools are run on the end of coiled tubing. In at least one known conventional horizontal drilling method using coiled tubing, the cutting tool completes its transition to the horizontal direction over a radius of about 100 feet. It is common for horizontal drilling providers to speak of their “build angle”, which commonly range from around 3.5 degrees per foot to about 0.35 degrees per foot. Translating such a system around 90 degrees may thus require between about 25 feet and about 250 feet. The size of this transition radius stems primarily from the length, diameter and effective rigidity of the cutting system’s components that must transition around the radius.

[0007] Other known methods for creating horizontal drainage tunnels are able to transition around short or ultra-short radii (e.g. around 90 degrees within 5.5” casing) by not attempting to pass relatively long and/or large diameter “rigid” tools outside of the wellbore. Many such methods utilize a flexible jetting hose with a specialized, high pressure jetting nozzle. Such methods may be efficacious, but have shown unable to cut certain harder formation or hard inclusions, like chert. Accordingly, these methods may be limited to only very soft formations.

[0008] Other technologies in the art of short radius (e.g. a 90 degree transition in about a foot) and ultra-short radius (e.g. a 90 degree transition in only a few inches) lateral drilling, utilize a series of segmented links in an attempt to transmit torque to a mechanical drilling head. These methods, however, suffer from one or more of the following problems:
- an inability to cut appreciably into the formation due to a lack of supplying cutting fluid to the cutting head, thereby adversely affecting the cutting head bit and, relegating any cuttings to become “stuck” at the front of the cutting head;
- a complex, difficult to build and/or difficult to assemble tensioning system that is prone to failure on account of its multiple tensioning lines becoming entangled in their adjacent, meshing teeth, wherein such a design also unnecessarily weakens the drive section/segment
on account of multiple passageways running through each segment;
- difficulty of the drill-string to transition around a radius of less than about a foot when not rotating and, impossible to transition around such a radius when rotating;
- an inability to keep the drive faces engaged when cutting harder formation or hard inclusions;
- tooth geometry (e.g. simple wide square teeth and obtuse drive angles) that is unable to keep the segmented or sectional drive system meshed together when under torque around a tight radius, allowing for a skipping of the teeth, twisting of a contained hose, and/or possibly resulting in broken teeth and/or a stalled or altogether stuck drill-string;
- an inability to efficiently centralize the drilling head thereby allowing a highly deviated and/or unpredictable borehole to be drilled—including one which can tend downward into subtending water zones, which can ruin an otherwise economic well;
- an inability to efficiently transfer enough weight onto the bit to cut deep into the formation or to cut hard material(s) due to helical buckling of the drive segments in the oversized borehole;
- provisions only for reverse circulation of cuttings out of the wellbore (via the drill-string)- a scenario which can allow orifices on the cutting head to become plugged with debris, in turn negating cuttings removal and allowing loss of circulation as the lateral borehole becomes longer and the zone simply “takes” the drilling fluid;
- an over-complex and failure prone tensioning mechanism which is unable to provide a suitable means of retrieving the drill-string in the event of a hard pull-back;
- a complex mechanism used to direct the drill-string toward the formation and often having to extend beyond the wellbore, which mechanism is catastrophically failure-prone due to contaminants like asphaltene, paraffin and scale, which are endemic to the downhole environment.

[0009] Any one of the aforementioned shortcomings can cause a catastrophic failure in the lateral drilling process; and, the collection of these shortcomings is presumed to explain the lack of commercial success by systems employing such segmented designs.

[0010] In view of the above, it would be desirable to have a reliable cutting tool capable of being run in a wellbore and transitioning sufficient torque around a tight radius to mechanically cut a straight borehole (in even hard formations) and efficiently removing the associated cuttings with fluid, gas or combination thereof.
SUMMARY

[0011] In embodiments, the present invention is an apparatus for cutting laterally into an earthen formation from a wellbore that includes a flexible spline member formed from a series of meshable drive segments, wherein the drive segments collectively form at least one inner passageway. The flexible spline member being sized and configurable such that an attached cutting head assembly, the at least one inner passageway, and a fluid pumping source may be in fluid communication. The flexible spline member further having certain acute angles on the teeth, thereby allowing the segments to remain splined, even while transmitting high torque around a tight radius. Wherein a first flexible spline member end portion is sized and configured to be attachable to a rotation means, such as a motor, and a second flexible spline member end portion operatively coupled to a cutting head assembly such that torque applied to the first flexible spline member end portion by the rotational source may be translated to the cutting head assembly by virtue of the drive segments.

[0012] In an embodiment a method for forming a lateral borehole using a downhole tool assembly operatively connected to a rotational source, the rotational source being coupled to a conduit, such that the conduit, rotational source, and downhole tool assembly are in fluid communication. The method further includes activating the rotational source so that torque applied to the drive segments that form the flexible spline member is thereby translated to the cutting head of the downhole tool assembly, causing the cutting head to rotate.

[0013] In embodiments there is a tubular member disposed within the flexible spline member’s inner passageway (at least one inner passageway); this tubular member being capable of providing a substantially leak-proof fluid conduit between the pumping source and the cutting head assembly. The substantially leak-proof fluid conduit can be created by utilizing a hose, flexible tubing, KEVLAR®, convoluted tubing, interlocking hose or similar conduit. Alternatively there can be an elastomeric sealing material positioned between the series of drive segments for the creation of a substantially leak-proof fluid passageway within the flexible spline member’s inner passageway.

[0014] The apparatus can include a rotational source selected from a downhole fluid-driven or electrical motor, a top-drive motor or some combination thereof.

[0015] In embodiments, the apparatus has an inherent tensioning system that when under a torsional load pulls the segments together on account of the functioning drive angle geometry (i.e. the angles on the drive and driver faces). In embodiments, the apparatus may include
another tensioning means used to hold the drive segments together such as by a tensioning line. The tensioning line may be useful when tripping into the wellbore (i.e. when torsional resistance is usually low) or in the event of a rotational system failure. As such the tension line may serve as a sort of secondary or back-up tensioning means. In embodiments, the apparatus may also include a retrieval means suitable not only for typical retrieval/pulling-out of the drill-string from the borehole, but also suitable for “hard” over-pulls, such as if the system should become firmly stuck. Described more fully, below, the drive segments may be held in tension by the placement of a preload on a wire(s) (tension line) running through the series of drive segments. In embodiments, the same tensioning line used as the secondary or back-up tensioning means may be used for the retrieval of the drill-string.

[0016] The cutting head assembly has at least one cutting surface and is configured to mechanically cut into the earthen formation. The cutting head assembly has at least one orifice for the ejection of fluid thereof and is capable of being in fluid communication with the fluid pumping source. Ejecting of the fluid from on or near the cutting head has one or more of the following purposes: to keep the cutting head clean for effective cutting, keep the cutting head cool to protect coatings, bonding-agents and/or PDC inserts, emitting chemicals for treating the formation or pre-disposing the formation to more efficient cutting, and emitting fluid to provide a suitable medium to carry formation cuttings back toward the wellbore.

[0017] Besides facilitating cutting removal by fluid circulation, in embodiments, the drive segments have grooves or flats about their exterior. Such designs assure the removal of cuttings by providing a “wide” fluid and cuttings return flow path around the exterior of the drive segments.

[0018] The series of drive segments (two or more) have an outer profile that is generally cylindrical or barrel-shaped (wider in the middle than at the ends). A barrel shape outer profile (that at its maximum is of the same diameter as the cutting head) used in conjunction with flats on the webbing (described below), yields a highly efficient cuttings return path while also mitigating helical buckling.

[0019] In embodiments, each drive segment has a base plane situated perpendicular to the axis of rotation of that drive segment; said base plane being situated at or near the center of said drive segment. Each drive segment has at least one tooth or projection (male) positioned on each side of this base plane and has at least one socket (female) positioned on each side of
the base plane. The at least one tooth on one side of the base plane being distinct from the at least one tooth (or projection) on the other side of the base plane; and, the at least one socket on one side of the base plane being distinct from the at least one socket on the other side of the base plane. The at least one tooth on one side of the base plane of a drive segment mesh into at least one mating socket on an adjacent drive segment. In operation (e.g. rotating while articulated), a given tooth will mesh into and out of a socket-- hence the drive segments of this disclosure is a sort of gear (which have meshing teeth and sockets). However, operationally, this disclosure is also like a spline in that torque is transmitted from the same tooth to the same socket. On account of these features the devices is sometimes herein referred to as flexible spline member.

[0020] The apparatus can include a whipstock, optionally positioned on the end of upset tubing, and used to guide the drive segments around a radius. The whipstock can include a passageway through which formation cuttings can pass to a location below the whipstock.

[0021] An embodiment of the present invention is a method for cutting laterally, or generally perpendicular, into an earthen formation from a wellbore utilizing the apparatus described above. An embodiment of the present invention is a method for cutting laterally into an earthen formation from a wellbore by guiding a downhole tool assembly having a series of drive segments, defining at least one inner passageway, through a channel defined by a guide assembly and positioning the downhole tool assembly so that the downhole tool assembly contacts a portion of the earthen formation to be laterally cut. The downhole tool assembly is coupled to a conduit, such that the conduit and downhole tool assembly are in fluid communication. The method further includes pumping one or more fluids through the conduit and into the downhole tool assembly, rotating a cutting head of the downhole assembly and cutting a borehole into the earthen formation with the cutting head in a direction lateral to the wellbore.

[0022] In the method the downhole tool assembly can be operatively connected to a rotational source and the rotational source is coupled to a conduit, such that the conduit, rotational source, and downhole tool assembly are in fluid communication. The method further can include activating the rotational source, wherein a torque is applied to the drive segments comprising a flexible tubular member and translating the torque to a cutting head of the downhole tool assembly, wherein the torque causes the cutting head to rotate. The rotational source can be activated by the fluid flow through the conduit into the rotational source.
[0023] The drive segments collectively define at least one inner passageway, and the
downhole tool assembly further includes one or more orifices in fluid communication with at
least a portion of a tubular member disposed within the inner passageway, wherein the
method further includes pumping one or more fluids through the tubular member and
emitting the pumped fluid from the one or more orifice, whereby the fluid contacts the cutting
head.

[0024] As described more fully below, the system may be deployed by a variety of oilfield
work-over units including: Coiled Tubing, E-Line or Slick-Line, or via a Top-Drive.

BRIEF DESCRIPTION OF DRAWINGS

[0025] Figure 1 illustrates a cross-sectional view of a cased wellbore containing a whipstock,
wherein an embodiment of the present invention is deployed in the wellbore, guided through
a guide channel in the whipstock, and has created a lateral borehole through the casing and
cement and is proceeding into an earthen formation.

[0026] Figure 2 illustrates a cross-sectional view of a cased wellbore containing a
whipstock, wherein an embodiment of the present invention is deployed in the wellbore,
guided through a guide channel in the whipstock, and has created a lateral borehole through
the casing and into the cement and is approaching an earthen formation.

[0027] Figure 3 illustrates a cross-sectional view of an openhole completed wellbore
containing a whipstock prior to the use of the whipstock in conjunction with an embodiment
of the present invention.

[0028] Figures 4a – 4d illustrate various views of a drive segment consistent with an
embodiment of the present invention.

[0029] Figures 5a – 5d illustrate various views of a drive segment consistent with an
embodiment of the present invention.

[0030] Figure 6 illustrates a laid open side view of a drive segment consistent with an
embodiment of the present invention.

[0031] Figure 7 illustrates a laid open side view of a drive segment consistent with an
embodiment of the present invention.
[0032] Figures 8a – 8b illustrate various views of a drive segment consistent with an embodiment of the present invention.

**DETAILED DESCRIPTION**

[0033] In an aspect of the current invention, an apparatus for cutting laterally from a wellbore is provided. As used herein, the term “lateral” or “laterally” refers to a borehole deviating from a wellbore and/or a direction deviating from the orientation of the longitudinal axis of the wellbore. However, it should be understood that the orientation of the longitudinal axis of the wellbore may vary as the depth of the well increases, and/or specific formations are targeted and as wells are varied from vertical to deviated wells and to substantially horizontal wells. As used herein, the term “strata” refers to the subterranean formation also referred to as “earthen formation.” A particular earthen formation is typically chosen due to the properties of the formation relating to hydrocarbons; such a formation may be referred to as an “earthen formation of interest”.

[0034] The present invention relates to an apparatus, system, and method for cutting laterally into an earthen formation. Optionally, the apparatus may be used for cutting laterally into casing and/or cement disposed within a wellbore. Optionally, the apparatus may be used to cut laterally through the casing, cement and earthen formation, which is advantageous in that the number of required downhole trips can be significantly reduced. The apparatus may be used either in cased wellbores or in openhole wellbores. The apparatus may be used in wellbores wherein one or more holes have already been created through the casing and/or cement.

[0035] In a general configuration the apparatus is a flexible, segmented spline tool capable of providing torque around a tight radius. In its most general lateral drilling configuration, the apparatus is a downhole tool comprising a cutting head assembly and the above “flexible spline member” attached to a means of rotation and in fluid communication with a pumping source.

[0036] In embodiments, one end portion, or first end portion, of a conduit (e.g. a pipe, hose or tubing) run into the wellbore is coupled to a fluid pumping source; and, the second end portion of the conduit is coupled to the first end portion of the flexible spline member, such that the fluid pumping source is in fluid communication with the flexible spline member and attached cutting head assembly. The fluid pumping source can be any conventional fluid
pump capable of providing fluid pressures to the downhole tool assembly such that the
downhole tool assembly is able to emit fluid from near or on the cutting head. Optionally,
the fluid may be emitted at a pressure from about 100 to 5000 psi. In certain other
applications, the fluid may be pumped at a pressure from about 5,000 to about 10,000 psi. In
embodiments, suitable flow rate for the fluid may range from an equivalent of about 3 to
about 12 gallons per minute (gpm), while in other embodiments, the operating flow may
range from about 10 to about 25 gpm; while in yet other applications (typically larger
diameter and/or longer borehole drilling applications), the operating flow range may exceed
25gpm. Non-limiting examples of the fluid pumped from the fluid pumping source include
nitrogen, nitrogen-fluid mixture, air, foam, diesel, hydrochloric acid, water, formation brine,
biocides, wettability modifiers, surfactants, and the like. Among other purposes, fluid
pumped through orifices on or near the cutting head assembly can be used to eject chemicals
from the drill-string to better pre-dispose the formation to mechanical cutting and/or to
diffuse a chemical treatment(s) into the formation adjacent to the lateral borehole (e.g.
biocides, inhibitors, wettability modifiers, etc.).

[0037] In an embodiment, the second end portion of the conduit is coupled to a rotational
source, such as a fluid motor sized and configured to be run into the wellbore and capable of
operating at the depth and conditions desired by the well operator. A non-limiting example
of such a motor is Roper Pumps model 175R5640 procurable through Power Hydraulics
(www.power-hydraulics.com), which motor is readily capable of producing in excess of 20
ft-lbs of torque under most operating conditions. In embodiments, the motor can be
operatively coupled to a first end portion of the flexible spline member such that a torque
generated by the motor is applied to the flexible spline member, thereby causing the flexible
spline member to rotate. In embodiments, the motor may be configured such that the fluid
pumping source may be in fluid communication with the first end portion of the flexible
spline member by virtue of an upper cross-over member. In embodiments, the upper cross-
over member not only transmits torque but also allows for the concurrent transmission of
fluid into the flexible spline member. In a different embodiment, the rotation source may be
a surface-based rotational source, such as a power swivel. In yet other embodiments, the
rotational source connected to the downhole tool may be a DC motor.

[0038] In embodiments, the downhole tool assembly of this disclosure includes a flexible
spline member comprising a series of splined drive segments, or simply “drive segments”,
used to transmit torque around a radius. Interestingly, these drive segments are able to
transfer torque without the need for or benefit of a shaft or fixed axis of rotation—something atypical to conventional gears and splines.

[0039] In embodiments of the apparatus, the flexible spline member includes a first end portion and a second end portion wherein the first end portion can be coupled to a rotational source and the second end portion can be coupled to a lower cross-over member or cutting head assembly. In certain embodiments, the flexible spline member is capable of transitioning through and transmitting torque around an arc of 90 degree and having a radius of less than 12 inches, such as might be done on a wellbore having a 5.5 inch casing. In other embodiments, the flexible spline member may allow torque to be transitioned around an arc with a radius of about 12 inches. The series of drive segments of the apparatus are sized and configured such that each drive segment engages at least one other drive segment such that torque is transmitted from drive segment to drive segment. While the drive segments can transition torque from one to another by meshing of mating drive teeth, technically the series of drive segments are not interlocked or interconnected to one another.

[0040] In embodiments, the series of drive segments (i.e. 2 or more) transmit torque through one or more projections (or teeth) on each side of a given drive segment and a respective mating socket(s) on an adjacent drive segment. In embodiments, each drive segment is configured with both a male projection or “tooth” and a female recess or “socket” on each side of the drive segment. In embodiments, each drive segment is configured with one or more tooth predominately or wholly on one side of the drive segment (i.e. on the one side of the base plane of the segment) that is distinct from the one or more tooth predominately or wholly on the other side of the drive segment; and, wherein one or more sockets predominately or wholly on the one side of the drive segment is/are distinct from the one or more sockets predominately or wholly on the other side of that drive segment. Again, the qualification that a given tooth and/or sockets is predominately on the one or the other sides stems from the fact that a given tooth or socket may cross over the base plane, such as may be possible if the two sides of the drive segment are suitably clocked or phased.

[0041] In at least one embodiment, there are three male projections or teeth and three female sockets on each side of the drive segments. In other embodiments there are 4 teeth and 4 sockets on each side of a drive segment, while in still other embodiments there are 6 teeth and 6 sockets on each side. Moreover, while not preferred, there is no necessity that both sides of a given drive segment have the same number of teeth and sockets. For example,
one side of a given drive segment might have 4 teeth and 4 sockets, while the other side of that same drive segment has 5 teeth and 5 sockets.

[0042] In embodiments of the flexible spline member, the first end portion of the series of drive segments is operably connected to an upper cross-over member comprising a partial drive segment (e.g. a “one-sided” drive segment) that mates with an upper drive segment so as to allow the transmission of torque and fluid. Similarly, the second end portion of the series of drive segments is operably connected to a lower cross-over member comprising a partial drive segment (e.g. a “one-sided” drive segment) that mates with an lower drive segment so as to allow the transmission of torque and fluid to the lower cross-over member and/or the cutting head assembly. The flexible spline member and series of drive segments are further sized and configured to transmit torque applied from the rotational source to the cutting head assembly such that the cutting head assembly is supplied with sufficient torque to cut the intended earthen formation.

[0043] In embodiments, the flexible spline member may define at least one hollow cavity or inner passageway comprising at least one opening in each drive segment. In at least one embodiment, a tubular member (e.g. a hose), itself defining another interior passageway, may be disposed within the inner passageway of the flexible spine member and in fluid communication with both pumping equipment and the cutting head assembly. In an embodiment used with a sealing mechanism, the first end portion of the flexible spline member allows for external to internal porting whereby fluid may enter into the inside of the flexible spline member and optional tubular member so as to be directed to the cutting head assembly.

[0044] Optionally, the maximum diameter of the drive segment portion of the downhole tool is the same or nearly the same as the diameter cut by the drilling head. This can pre-empt the flexible spline member from appreciably deviating or helically buckling in the borehole being drilled. Normally, such a situation would create a scenario where the cuttings would have no return path to the wellbore and/or where the downhole tool were highly prone to becoming stuck. To negate this problem, optionally, the series of drive segments may have one or more flats, grooves or flutes along their exterior edge. In embodiments, the one or more flats, grooves or flutes are positioned along the webbing that is situated between adjacent teeth of a given drive segment. Furthermore, in some embodiments, a series of drive segments could have a barrel-shaped outer profile (wider at the center than at the ends) and flats along the webbing outer faces so as to provide a large cross-sectional area through which cutting may
flow back to the wellbore. In some embodiments, the difference between the maximum drilling head diameter and the maximum drive segment diameter may range to about 0.00” to about 0.025”, while in other embodiments (typical to larger diameter drive segments) the difference may range to or exceed about 0.25”. The distinct advantage of having the aforementioned diameters being identical or nearly identical is that by this method one can insure that a very straight borehole is drilled since the drilled borehole (whose size is dictated by the diameter of the cutting head) is not larger or appreciably larger than the drill-string itself. Again, a trailing drill-string cannot appreciably helically buckle in a borehole of essentially its same diameter. Furthermore, the drill head itself cannot meaningfully deviate from a straight-line trajectory on account of the fact that its attached, tightly constrained drill-string acts like a virtually rigid axis about which the drill-head rotates.

[0045] In certain embodiments, the utilization of one or more unique drive segment designs cause each drive segment to center-up on its adjacent drive segment(s), when under torsional load. In fact, in such embodiments, the greater the acting torsional load on a series of drive segments, the more that series of drive segments try to line-up or self-center along a single, straight axis so as to drill a straight lateral borehole. Yet a further noteworthy benefit to the system described herein is that weight applied to the top of the drill-string can be substantively and more effectively translated to the drilling head since the weight (i.e. force) is not being forfeited to helical buckling—a well-known limitation and problem in conventional horizontal drilling and a virtually unaddressed phenomenon in the art of short and ultra-short radius lateral drilling. More to the point, this improved weight transference capability can allow one to not only drill a given rock faster (due to increased weight on bit) and to drill further (due to minimized helical buckling), but also to drill harder rock than might otherwise be possible. This combination of benefits should make some otherwise impractical or uneconomical lateral well work-overs, feasible and potentially profitable. These features also tend to mitigate the very real and problematic risk of an errant/astray lateral borehole drilling into a subtending water zones, which scenario can readily render an otherwise commercially lucrative well uneconomical (due to high water disposal costs and/or reduced hydrocarbon production).

[0046] Certain embodiments of the present invention may include an upper cross over member composed of an upper and lower threaded body housing a large interior space. In embodiments the upper cross-over member can transmit both torque and fluid to the first end of the series of drive segments. In at least one embodiment, the upper cross-over member
directs fluid into a tubular member positioned inside of the series of drive segments. In embodiments, the upper cross-over member is coupled to a motor on its one end and on its other end to a partial, one-sided drive segment that is situated at a first end of the series of drive segments, so as to thereby allowing torque to be transmitted from the upper cross-over to the series of drive segments. In embodiments, the upper cross-over member directs fluid into a tubular member positioned inside of the inner passageway of the drive segments by way of a ported washer through which an optional tensioning line may pass. In a few embodiments, the upper cross-over member may allow for fluid to be diverted from upset tubing into the flexible spline member by virtue of a sealing mechanism positioned between the upper cross-over member and optional upset tubing or other circumscribing conduit. As described elsewhere in more detail, in embodiments, the upper cross-over member may function as part of a tensioning system capable of keeping the series of drive segments engaged with one another in certain circumstances, such as when not under torsional load and/or in a hard pull-back scenario.

[0047] As noted above, each drive segment may define one or more drive segment openings, which as a whole form at least one inner passageway. Optionally, a tubular member, such as flexible hose or tubing, may be disposed within the at least one inner passageway. Non-limiting examples of the tubular member are hose or braided hose, Kevlar®, convoluted tubing, interlocking hose, semi-rigid tubing, and the like. In embodiments, the tubular member is in fluid communication with the fluid pumping source and the cutting head assembly. Optionally, the tubular member itself can be part of or it can circumscribe a separate, optional tensioning system, such as is discussed in a preferred embodiment, below. In embodiments, the tubular member within the flexible spline member can be fed, or transitioned, through a whipstock and into the earthen formation with the flexible spline member.

[0048] In other embodiments wherein the flexible spline member is used without a tubular member, seals positioned between the drive segments can be used to produce fluid communication between the opposite ends of the flexible spline member. In such embodiments, fluid communication can be established between the first end of the flexible spline member end and the second end of the flexible spline member end, without usage of a hose or similar single continuous conduit. In such embodiments, the sealing mechanism consists of elastomeric seals that are adhesively or mechanically bonded to adjacent drive segments.
[0049] In embodiments, the flexible spline member comprises a lower cross-over member capable of mating the second end portion of the series of drive segments to the cutting head assembly by virtue of a “one-sided” drive segment. In embodiments, the other end of the lower cross-over member is then securely fastened to the cutting head assembly, such as by threading, welding or similar means. In embodiments, a tubular member contained in the inner passageway of the flexible spline member (i.e. within the series of drive segments) terminates at or in the lower cross-over member by such means as a hose crimp, another side of which can be securely fastened to the lower cross-over member, such as by threading. In embodiments, the lower cross-over member has one or more internal passageways allowing for fluid exiting the aforementioned tubular member to be passed to the cutting head assembly. In yet other embodiments utilizing an optional tensioning line, the lower cross-over member may have a ported washer and associated lower rest through which an optional tensioning line may pass. Described more fully elsewhere herein, this lower rest may allow tension to be pulled on the optional tensioning line and hence on the series of drive segments, as a whole. Moreover, as the aforementioned lower washer may have multiple ports or grooves, fluid can freely flow through or around this washer; and hence to the cutting head. Thus, in embodiments, the lower cross-over member is designed to transmit torque, transmitting fluid and providing a steady rest for an optional tensioning line.

[0050] In at least one embodiment, the drive segments of the flexible spline member may be held in tension with one another by a distinct tensioning system, separate from the induced tension that may arise from the dynamic operation of the drive segments themselves. In embodiments, this optional tensioning system may be comprised of a tensioning line running from and affixed to the upper cross-over member on the one end and to the lower cross-over member (or the cutting head assembly) on the other end. As described above, the optional tensioning line has an upper end, which generally terminate in the upper cross-over member; and, a lower end, which generally terminates in the lower cross-over member. Optionally, this tensioning line may be comprised of one or more hose(s) or cables(s), but it is preferable a single wire rope.

[0051] In some embodiments, the optional tensioning line is crimped or swaged on its lower end via a lower crimp, which is positioned so as to rest on the lower end of the lower washer (i.e. the washer housed in the lower cross-over member). This arrangement provides the tensioning system a lower “rest” against which tension can be pulled. In embodiments, the upper end of the tensioning line terminates in the upper cross-over member by means of
an upper crimp (or swedge fitting) that is crimped to the tensioning line. Like the lower
tensioning crimp, the upper crimp can be brought to rest (or even pull) against one side of a
washer (i.e. an "upper washer")—and, more specifically, against the uppermost side of the
upper washer. To conveniently allow for varying and/or dynamic amounts of tension to be
pulled on the optional tensioning line, the bottom side of the upper washer can rest on a
compression spring whose lower side in turn lands or is seat into the upper cross-over
member. In embodiments, the upper crimp (which secures the tensioning line) itself
terminates on its opposite end in a threaded extension, which is sized and then positioned so
as to freely slip through an opening or slot running through the upper washer. A nut can then
be tightened onto this threaded connection so as pull tension on the upper crimp and the
attached tension line (the opposite end of which is secured in the lower cross-over member).
Moreover, by resting the upper wash on a spring, one can easily and conveniently adjust the
amount of tension on the optional tensioning cable, such as to match appropriate tension on
the flexible drive member to the particular radius of a given whipstock, simply by tightening
or loosening the nut sitting atop the upper washer. While any number of other optional
tensioning embodiments are possible the simplicity of this series of concentric strings is
noteworthy for its robustness, easy of assembly and ease of adjustability capabilities (e.g.
tensioning nut and spring located in the top cross-over member).

[0052] To reiterate, while this disclosure discusses an optional, distinct tensioning means
(i.e. a tension line), certain embodiments herein have their own form of dynamic tension
which arises under rotation on account of the geometry of the mating teeth. Thus, the
optional distinct tensioning system may be viewed as a sort back-up tensioning system.

[0053] In an embodiment, the cutting head assembly includes a cutting head, wherein the
cutting head can be detachably attached to the cutting head assembly and further configured
to be rotatable and to cut laterally through casing and/or cement and/or earthen formation.
Besides comprising one or more cutting surfaces or faces, the cutting head assembly may be
configured such that one or more orifices on or near the cutting head assembly are able to
eject fluid near the cutting surface(s) or face(s). Fluid flow out of orifices on or near the
cutting head assembly can be used to keep the cutting head cool and debris free so as to allow
efficient cutting operations; residually this flow can also be used to facilitate the removal of
cuttings from the borehole. In an embodiment, the cutting head assembly may circumscribe a
rotatable nozzle. In embodiments, the cutting face(s) can be formed from a hard material like
carbide, poly-diamond crystals (PDC) or tool steel with specialized coatings. Finally, is
should be noted that in various embodiments, the lower cross-over member and the cutting head assembly are essentially indistinguishable assemblies—i.e. they are one and the same member.

[0054] Having described above the system, generally, and the flexible spline member in some detail, we now move on to key aspects of the drive segments themselves. For purposes of clarity and to perhaps better convey aspects of the drive segments, certain gear/spline terminology is used herein.

[0055] Each drive segment has an axis of rotation. Perpendicular to this axis of rotation is a base plane situated toward or at the center of the drive segment and dividing the drive segment into a first end and a second end. In certain embodiments, the first and second ends are symmetrical to one another, while in other embodiments, they are asymmetrical to one another. Further, in various embodiments, the clocking of the two sides may be identical to one another or out of phase with each other. Each drive segment also has an overall height and maximum diameter, wide combinations of which may be employed. In various embodiments, the maximum diameter of a drive segment may range from about 0.75” to about 3.5”. To transition adequate torque around a short or ultra-short radius for lateral drilling, the height of a drive segment will almost always be less than its width. Generally, the tighter the radius that must be transitioned by a drive segment, the smaller must be its height and diameter.

[0056] In embodiments where the drive segments have an inner passageway, a surface defines this passageway. In certain embodiments this surface is a fixed distance (e.g. a “first radius”) away from the axis of rotation, in which case the inner surface of the segment essentially forms a cylinder. In other embodiments, the surface forms an inverted barrel shape, such as if a small arc with its apex located nearest an axis is rotated about that axis to form a surface; obviously, the contour of possible inner surfaces may vary widely.

[0057] In embodiments, each drive segment is comprised of one or more teeth on each side of the base plane and of one or more sockets on each side of the base plane. The teeth of the drive segments each have drive faces which, depending upon the direction of rotation of the flexible spline member, can be viewed as either driving or being driven. Thus a driving face on one drive segment tooth forces - or drives - a driven face on a mating drive segment. Furthermore, when under rotation, a given drive segment essentially has one side about the base plane that is driven and another side about the base plane that is driving. As will
become evident, a tooth drive face may be planar or curvilinear. A given tooth has not only a drive face, but also a leeward face or flank. The flank is the surface that is opposite the drive face of a given tooth; and, one may rightly consider the flank to be the "backside" of its respective tooth.

[0058] On the top of a tooth is a top land, which surface may be planar or curvilinear. Similarly, in embodiments, at the bottom of a socket is a bottom land, which surface may also be planar or curvilinear. In embodiments, when a portion of the series of drive segments is rotated around a radius, the top land of one tooth lands into the bottom land of its mating socket. Both the top and the bottom land may be parallel, angled or skewed with respect to their base plane and/or each other. Discussed more fully, below, the shape of the top land and bottom land can be used to mitigate certain problems encountered by prior art employing segmented teeth.

[0059] Situated between and connecting the adjacent teeth of a given drive segment is a webbing. This webbing has an inner and an outer surface and a first side and a second side. In certain embodiments, this webbing has an inner and outer surface that each co-terminates with part of the inner surface and outer surface, respectively, of that drive segment. A webbing's first side serves as the bottom land of a socket on a first side of the drive segment; while that webbing's second side serve as the bottom land of another socket on a second side of said segment. The webbing is readily identifiable as it sits at or near the base plane of a drive segment and is generally positioned between adjacent teeth.

[0060] Defining certain edges of the apparatus may also prove useful. A top drive edge is the edge formed by a drive face and its adjoining top land; a bottom drive edge is the edge formed by a drive face and its adjoining bottom land; a top flank edge is the edge formed by a top land and its adjoining flank; a bottom flank edge is the edge formed by a bottom land and its adjoining flank.

[0061] Having established certain key features of the drive segments we now proceed to further discuss the critical angles, planes and surfaces which make the disclosure unique; and, which are generally based on Euclidean geometry. These defining characteristics are not known to be disclosed in prior art and are not generally employed in spline applications.

[0062] In some embodiments, a drive face is perpendicular to its adjoining bottom land. In other embodiments, a drive face is acutely angled with respect to its adjoining bottom land. In embodiments, the angle between the drive face and its adjoining bottom land may range
from about 88 degrees to about 70 degrees, while in other embodiments it may range from about 75 to about 60 degrees; while in still other embodiments it may be less than 60 degrees.

[0063] In some embodiments, a drive face is perpendicular to its base plane. In some embodiments, a drive angle is acute—that is, the drive face is acutely angled to its base plane. That is, a drive face and its base plane form an angle of less than 90 degrees. In certain embodiments, this angle may range from about 88 to about 70 degrees, while in other embodiments it may range from about 75 to below about 55 degrees. In some embodiments a drive face is acutely angled both with respect to its base plane and its adjoining bottom land. In applicable prior art, there is no known instance of a drive face being acutely angled to its corresponding base plane. Notably, such acutely angled drive faces have the noteworthy advantage of pulling adjoining drive segments together when in rotation; this can be a particularly helpful feature for keeping drive teeth splined together while transmitting torque around a radius. Again, acutely angled drive teeth on mating drive segments can mitigate skipping or jacking apart of the drive segments - a problem which can have such catastrophic results as: chipped or broken teeth; a stalled and/or stuck drilling tool, and/or a tubular member (e.g. hose or other conduit) which becomes twisted up and/or otherwise fails. It should be further noted that in embodiments of acutely angled drive teeth, the more torque that is applied, the more that the associated drive segments pull into one another; thus, by this fashion and without a separate tensioning means (e.g. wire rope), such a series of drive segments may be held in tension.

[0064] Determining an angle between a given drive face and its adjoining bottom land may be easily accomplished by intersecting the two surfaces with a plane perpendicular to the base plane. However, determining the angle between a drive face and its base plane may not be so obvious on account of the fact that the two surfaces may not directly intersect one another. To determine the angle in such a case, one can simply project or “extend out” that drive face surface until it intersects its base plane; one can then intersect the aforementioned two surfaces with a plane perpendicular to the base plane to determine the nature of the angle formed thereby. Since our concern here is about the angle formed by the drive face and its base plane on the “drive side” of the tooth (rather than the angle forward of the flank side), if the angle formed by the intersections of these respective surfaces and measured on the drive side is acute, then that drive face is to be judged acute or acutely angled with respect to its base plane. Needless to say, determining the angles of other surface relations discussed herein may be accomplished by a similar means—namely an extending or projecting of the
two surfaces (if necessary) to determine if those surfaces are parallel to or intersect one another; and then, if intersecting, whether acutely or obtusely.

[0065] In embodiments, a top land is acute with respect to its drive face. In embodiments, an angle formed by a top land and a drive face is from about 88 degrees to about 65 degrees, while in other embodiments, the angle is from about 65 degrees to about 50 degrees; while in still other embodiments, the angle may be less than about 40 degrees.

[0066] In certain embodiments, a given top land and its respective base plane may be said to be acutely angled toward one another. Again, if one projects out a given top land and that projection intersects its corresponding base plane, then the two surfaces are obviously not parallel to one another. To now determine if such surfaces are “acutely” angled or “obtusely” angled with respect to one another, one needs a reference point or side. For purposes herein, that reference point is the given drive segment’s axis of rotation. Thus, if an angle formed by the intersection of an extended top land and base plane is acute and “opens toward” the axis of rotation, then that top land and base plane are said to be acutely angled toward one another. As a given top land surface (or, for that matter, drive face, bottom land or flank surface) may be curvilinear, it may prove helpful here to discuss how one may determine the angle/orientation of such a surface of a drive segment to another surface or reference. In such instances, one may simply take the “mean” or “average” surface of that curvilinear surface and then project out this “representative” plane. In embodiments, a top land may form an acute angle with its base plane (and opening towards the axis of rotation) of between about 1 and about 10 degrees, while in still other embodiments, it may form an angle of about 8 to about 18 degrees, while in still other embodiments this angle may exceed 20 degrees. Obviously, a multitude of acute angles defining the relation of a top land to its respective base plane are possible, and these are intended to be within the scope and intent of this disclosure.

[0067] In some embodiments of this disclosure, a bottom land of a drive segment is acutely angled with respect to its base plane. As in the technique employed above, we use the axis of rotation as the point of reference by which to judge whether or not a “non-parallel” bottom land and its corresponding base plane are “acute” or “obtuse” with respect to the base plane. As used herein, a bottom land and its base plane are judged to be acutely angled or acute with respect to one another when a plane perpendicular to said base plane intersects projections or extension of the bottom land and said base plane and thereby form an angle “opening towards” that drive segment’s axis of rotation. In other words a point on an
inner edge of the bottom land will be a further distance from the base plane as a point on an outer edge of the bottom land if the points are located on a line extending through the axis of rotation. In embodiments, a bottom land may form an acute angle with its base plane of between about 2 and about 10 degrees, while in still other embodiments, it may form an angle of about 10 and about 20 degrees, while in still other embodiments this angle may exceed 20 degrees. Obviously a wide array of acute angles between a bottom land and its respective base plane are possible.

[0068] In embodiments, a top land and a bottom land of a given drive segment may be parallel or angled with respect to each other. In another aspect, a webbing adjoining top land and bottom land may be parallel or angled to one another. In embodiments, projections of a webbing adjoining top land and bottom land may both form acute angles (with the base land) and open toward the axis of rotation. In embodiments, the measure of an acutely angled top land to its base plane is different than the measure of an acutely angled bottom land to that same base plane, even though both said top and bottom land are on the same drive segment. Embodiments with acutely angled top and/or bottom lands to their respective base plane allow better “nesting” of their respective series of drive segments when articulated and rotating. Again, while not known in prior art, embodiments with this configuration may allow improved contact between mating drive teeth faces and hence insure that said drive teeth remain reliably meshed when articulated and under torque.

[0069] As defined herein the flank of a tooth is a sort of by-product of the sizing and geometry of its adjoining top land and bottom land. In a sense, it is the surface that arises out of joining a trailing edge of a top land (i.e. the non-drive face side of a top land) and a leeward edge of an adjacent bottom land (i.e. the side of the bottom land that is opposite the drive face). Needless to say, the size, angles and surface profile of flanks can vary widely. For example, a flank may be shorter, equal to or taller than its conjoined drive face height (i.e. the face on the other side of the tooth). A drive segment of this disclosure wherein a flank height is taller than its conjoined drive face is likely to present splining challenges and inefficiencies, but in certain scenarios (and on account of other features) may allow adequate transmission of torque around a radius. In other, generally more preferred embodiments, however, the height of a flank is equal to or less than that of its associated drive tooth. Like the height of the flank, the flank angle (i.e. the angle a flank surface forms with its adjoining bottom land) can also vary. While it is possible to design a drive segment with an acute flank angle, it presents incredible re-meshing challenges and is of practically no value in short and
ultra short radius lateral drilling. In some embodiments, the flank angle is right, but in most preferred embodiments the angle is obtuse. An obtuse flank angle allows for the easiest re-meshing of respective sets of teeth and mating sockets (on adjoining drive segments) when articulated and rotating around a radius. In embodiments, an angle that a flank and its adjoining bottom land form is between about 95 and about 120 degrees; while in other embodiments, it ranges from about 115 to about 135 degrees; while in still other embodiments it is between about 130 to about 155 degrees. In certain embodiments, the flank angle and the drive angle are complimentary angles; that is, in some embodiments, the drive face and flank surfaces are parallel to one another.

[0070] The allowance of clearance, often referred to as lash, in between a socket and its mating tooth allows articulation of the series of drive segments around a radius. In embodiments, the lash between a tooth and socket is from about .005” to about .025”, while in other embodiments it is from about .020” to about .045” and in yet other embodiments, it is well over 0.050”.

[0071] A further distinguishing characteristic of certain embodiments of this disclosure is a sort of “self-centering” geometry. That is, drive face geometry that causes the series of drive segments try to center-up along a single axis during operation, especially when rotating under high torsional resistance. In embodiments, this may be accomplished by defining helical surfaces on the drive face of the segments. Under rotation a drive segment having helical drive faces may not only be encouraged to rotate its adjoining segment (e.g. clockwise), but also to force itself into (or along) the same axis of rotation as that adjoining drive segment. As will perhaps be more evident in the figures, under rotation and in the presence of torque, a helical drive segment drive faces such that adjoining and mating drive faces pull into one another and toward a single, common center-line with each other.

[0072] In embodiments any or all the defining edges of the apparatus may have a radius, chamfer or other form of “edge break”.

[0073] In sum, in the art of short and ultra-short radius mechanical drilling, the drive segments of this disclosure are unlike those in known prior art. Moreover, they address a host of noteworthy and potentially catastrophic short-coming of prior art. In somewhat simplistic terms (though better defined elsewhere herein), a drive segment apparatus of this disclosure is one wherein one or more: drive face, top land or bottom land, is acutely angled with respect to its corresponding base plane and/or axis of rotation. Similarly, a highly
simplified and reliable method for providing tension along and fluid through a series of drive segments for short and ultra-short radius lateral drilling is provided. Variants of these designs, which rely upon their principles of design, are intended to be within the scope and intent of this disclosure. Turning now to a system and method for cutting laterally into an earthen formation from a wellbore, a whipstock is employed in at least one embodiment of the present invention. As used herein, the term “whipstock” refers to any downhole device capable of positioning the cutting head assembly toward the earthen formation desired for lateral cutting. The whipstock defines a guide channel sized and configured to receive and guide the cutting head assembly and at least a portion of the flexible spline member through the whipstock and toward the earthen formation of interest. In at least one embodiment, the whipstock may guide the cutting head assembly into a substantially horizontal direction from a vertical wellbore such that the cutting head assembly is disposed approximately 90 degrees from the longitudinal axis of the wellbore. The whipstock may be disposed in the casing prior to the running of the downhole tool assembly. Optionally, the whipstock may be set with a coil tubing unit, on the end of production tubing or it may be set by a wireline unit.

[0074] Optionally, the whipstock assembly may have one or more passageways extending from the guide path to below the whipstock to allow cuttings to freely fall toward the bottom of the wellbore. Optionally, to facilitate the removal of cuttings from in and near the whipstock and thereby insure a cutting-free/hassle free procedure, one can keep as positive flow of fluid out of the whipstock. Optionally, the bottom hole assembly may define one or more circulation passageways traversing through or around the whipstock, to allow for cleanout of the wellbore. The passageway(s) may serve as a circulation path for fluid that is circulated through the wellbore for the removal of cuttings, sand, paraffin and other materials that may have accumulated in the wellbore below the whipstock. For example, it may be necessary to remove cuttings from below the whipstock in order to allow the bottom hole assembly to be repositioned to a lower zone of interest for the creation of another lateral. Additionally, cleaning out any cutting in the wellbore maybe necessary for the proper operation of a tubing anchor. Pumping of fluid to circulate the wellbore through these opening(s) may be done initially, periodically or continuously. Cleaning out the wellbore and unloading the well may be accomplished by pumping fluid or gas at sufficiently high pressure and volumes through one or more of the circulation passageways.

[0075] Having described the apparatus of the present disclosure, we now turn to describe various embodiments and methods of deployment. Generally, the method for cutting laterally
from a wellbore is accomplished by feeding a portion of the flexible spline member and attached cutting head assembly through a whipstock pre-positioned downhole, while rotating said flexible spline member and ejecting fluid out the cutting head assembly.

[0076] In certain embodiments, a coiled tubing and pumping equipment can be operatively connected to a downhole fluid motor in turn operatively connected to the upper end of the flexible spline member such that fluid pumped through the coiled tubing causes the mud motor to turn the flexible spline member and attached cutting head assembly, while at least some of said fluid is conveyed to and pumped through the flexible spline member and out the attached cutting head. Now under rotation and by vertically manipulating the coiled tubing, the flexible spline member can be directed out of the wellbore through the pre-positioned whipstock, whereby the cutting head may cut a lateral borehole in the surrounding earthen formation. Optionally, a tubular member disposed within the flexible spline member and in fluid communication with the fluid pumping source and the cutting head assembly, may be used as a conduit to provide fluid to the cutting head while drilling. Optionally, the flexible spline member and attached cutting head may be used to cut through the casing and/or cement, if present, and proceed to cut into the surrounding earthen formation.

[0077] In other embodiments, wherein the whipstock is disposed in a wellbore and is coupled to a section of upset tubing an e-line unit, such as familiar to those in the industry, can be used to position and control the up-down travel of the downhole tool assembly. In some such embodiments, an electrically driven motor can be connected to the end of the e-line cable on the one end and to the flexible spline member and attached cutting head assembly on the other. This system can include one or more elastomeric sealing mechanisms positioned on or above the motor or upper cross-over member; the elastomeric mechanisms forming a relatively complete seal with the optional upset tubing. The sealing mechanism can be used to divert fluid flow through the upset tubing into the flexible spline member (such as via the upper cross-over member), where it may proceed to exit out the cutting head. Optionally, a tubular member disposed within the flexible spline member and in fluid communication with the fluid pumping source and the cutting head assembly, is used as a conduit to provide the fluid to the cutting head while drilling. Now rotating, the tool string can be lowered so as to traverse around the pre-positioned whipstock and thereby allow the cutting head to cut into the adjacent casing, cement and/or formation.

[0078] In still other embodiments, a wireline or e-line unit can be utilized to control the vertical motion of the toolstring by controlling the motion of a downhole mud motor which is
attached to the flexible spline member. In this embodiment when fluid is pumped into the optional upset tubing a sealing mechanism with the optional upset tubing diverts the flow into the upper cross-over member which is attached to and impels the flexible spine member and attached cutting head to rotate. Optionally, a tubular member disposed within the flexible spline member and in fluid communication with the fluid pumping source and the cutting head assembly, is used as a conduit to provide fluid to the cutting head while drilling. Transitioned through the whipstock, the rotating flexible spine member and attached cutting head can cut into the adjacent casing, cement and/or formation.

[0079] In other embodiments pumping equipment and jointed tubing, positioned by drilling or work-over equipment, can be connected to a downhole fluid motor, which is in turn operably connected to the upper end of the flexible spline member. In this manner fluid pumped through the jointed tubing can cause the fluid motor to rotate, in-turn rotating the attached flexible spline member and cutting head assembly. Optionally, a tubular member disposed within the flexible spline member and in fluid communication with the fluid pumping source and the cutting head assembly is used as a conduit to provide fluid to the cutting head while drilling. Now under rotation, the flexible spline member and attached cutting head can be directed out of the wellbore by the jointed-tubing and pre-positioned whipstock so as to cut a lateral borehole in the surrounding earthen formation. Optionally, the flexible spline member and attached cutting head may be used to through the casing and cement, if present, and proceed to cut into the adjacent casing, cement and/or formation.

[0080] In still other embodiments pumping equipment in communication with jointed tubing and drilling or work-over equipment is connected to a top-drive mechanism capable of rotating a jointed tubing string, which is in turn operably connected to the flexible spline member. In this manner fluid pumped through the jointed tubing can cause the attached flexible spline member and cutting head assembly to also rotate. Now under rotation, the flexible spline member and attached cutting head can be directed out of the wellbore by lowering the jointed-tubing and transitioning the flexible spline member around the pre-positioned whipstock so as to cut a lateral borehole in the surrounding earthen formation. Optionally, a tubular member disposed within the flexible spline member and in fluid communication with the fluid pumping source and the cutting head assembly, is used as a conduit to provide fluid to the cutting head while drilling. Optionally, the flexible spline member and attached cutting head may be used to through the casing and cement, if present, and proceed to cut into the adjacent casing, cement and/or formation.
Looking now at Figure 1, consistent with an embodiment of the present invention shows a cross-sectional view of a portion of the flexible spline member (25) that has been guided through the incline (67) and guide channel (55) defined by a whipstock (54) positioned on tubing (60) in a wellbore (57). The cutting head (50) is shown extending though a portion of casing (62) and a sheath of cement (61) and into the earthen formation (56).

Figure 2 is a cross-sectional view of an embodiment of the present invention showing the flexible spline member (25) connected to a drive mechanism (53) by means of an upper cross-over member (86). The flexible spline member (25) has been guided through an incline (109) in the tubing (60) and into the guide channel (55) defined by a whipstock (54). The downhole tool assembly (63) includes a lower cross-over (85) connecting the flexible spline member (25) to a cutting head (50). The cutting head (50) is shown extending though a predefined opening (65) through the casing (62) and cement (61) and approaching the earthen formation (56). The whipstock (54) is positioned on tubing (60), optionally the whipstock (54) can be positioned on a packer (64) set within the cased wellbore (57). The cutting head (50) is shown extending though a portion of the casing (62) proximate the cement (51) and into the earthen formation (56).

In an embodiment Figure 3 illustrates an openhole completed wellbore (80) containing an orienting device (54), illustrated as a whipstock, coupled to a section of tubing (60). The whipstock (54) has a channel (71) that can enable cuttings to exit out the whipstock (54) and fall to the bottom of the wellbore (91). sized and configured to guide at least a portion of the flexible spline member (25) of this disclosure to a position proximate the earthen formation (56). The wellbore (57) includes a layer of cement (61) disposed between the casing (62) and earthen formation (56). The cutting head (50) is connected to the flexible spline member (25) which is connected to a drive mechanism (53) by an upper cross-over member (86). A service vehicle (52) such as a coiled tubing unit is shown extending coiled tubing (66) into the tubing (60) and directing the cutting head (50), flexible spline member (25) and a drive mechanism (53) such as a mud motor to the whipstock (54). The drive mechanism (53) can convert fluid flow, such as flow through the coiled tubing (66) into rotational movement of the flexible spline member (25) and the cutting head (50).

Figures 4a-4d illustrate examples of certain geometric construction lines of the disclosure. Fig 4a depicts a top view of a geometrical construction used to partially define what will become a drive face (13) intended for use in clockwise (CW) rotation. Situated on
a base plane (2) a given outer circle (98) will become the outer surface (18) of the drive segment (1c) and a concentric, smaller circle (97) will become the inner surface (17) of that drive segment (1c). The shared center point (O) of the two concentric circles (97 and 98) will ultimately lie along the axis of rotation (not shown) of this drive segment (1c). The line segment (P) which is the difference between the radii of circles (97 and 98), will be used to define a leading edge or top drive edge (22). Line Segment Q, clocked at some offset angle (R), in this case about 25 degrees, from line segment (P) will be used to help define a bottom drive face edge (21). Fig 4b, depicts a view from point (O) of Fig 4a, as if looking outward from the center (O) of the drive segment (1c), as if looking outwards towards the interior surface (17) of drive segment (1c). By virtue of this “center-point” view, certain lines in Fig 4a now appear as points and certain planes as lines. From this view, the base plane (2) becomes a line (shown here as a dotted line) subtending the bottom land (11) of the tooth (9). The drive face (13) is seen “underneath” the top drive edge (22). Shown from this perspective as a point, feature (Q) is really the line segment (Q) and feature (P) is really the line segment (P) in Fig. 4a, above. That is, feature (Q) represents the drive face base edge (21) (or “bottom drive edge”) and feature (P) represents the top drive face edge or top drive edge (22) of drive segment (1c). The drive face (13) can be seen forming an acute angle (A) with its bottom land (12). Thus, by Figs 4a and 4b, one can see how a surface bounded by a top drive edge (22) and bottom drive edge (21) can be used to constructed a drive face (13). By repeating the procedure above at different angles on drive segment (1c), one can further construct other drive faces (not shown). Fig 4c depicts another geometric construction of a drive face (13) on a drive segment (1c) intended for clockwise rotation (CW). Defined similar to line segment P, above, line segment P2 in this figure will also serves as a top drive edge (22). In this case, however, the line segment Q2, namely, what will become the bottom drive edge (21) of our drive face (13) is defined as a line parallel but offset to line segment P2. Obviously, when fully constructed, line segment Q2 and hence the bottom drive edge (21) will also be closer to the base plane (2) than line segment P2, which defines the top drive edge (22). A drive face (13) can now be created by a surface spanning between line segments P2 and Q2. In Fig 4d another geometric construction of a drive face (13) is presented. In this case, line segment P3 does not define the top drive edge (22); instead, the top drive edge (22) is constructed by a line segment (T) that deviates from line segment P3 by and acute angle (R2), opposite the direction of rotation (CW). The line segment (Q3), defining the face base edge (21), is clocked “still further along” than line segment (T), when the drive segment (1c) is under clockwise (CW) rotation. The eventual drive face (13) surface spanning between
line segments (T) and (Q3) (which are on different planes than one another) is an example of a curvilinear drive face (13), which, in this case will also be helical.

[0085] Figures 5a illustrates a top view of an embodiment of a drive segment of the flexible spline member (25). The drive segment includes an axis of rotation (3), an inner surface (6) that forms an inner passageway (8), an outer surface (7), a plurality of teeth (9) and a plurality of webbing sections (10). In this case, the overall profile of the drive segment is generally cylindrical in shape but can include flattened sides (31), which can enable greater fluid flow around the drive segment. A bottom land (11) associated with the webbing sections (10) and a top land (12) associated with the teeth (9) are shown, is a top drive edge (22). A flank (15) is shown as a portion of a tooth (9) that is connected to the webbing section (10) at a flank base edge (26). The teeth (9) connect with the webbing sections (10) at a flank base edge (26). An inner bottom land edge (11a) and outer bottom land edge (11b) can be seen. In an aspect the volume between adjacent teeth (9) define a socket (16).

[0086] Figure 5b shows a side view of the drive segment (1). Evident in the figure is the base plane (2) of a drive segment (1) that is perpendicular to the axis of rotation (3) shown in Figure 5a. The outer surface (7) is shown having flattened side (31) portions. Drive faces (13) and flank (15) surfaces are shown in addition to the webbing (10). The angle (M) of the drive face (13) relative to the base plane (2) is shown as acute or less than 90 degrees.

[0087] Figure 5c shows a side view of a series of drive segments (110) that are engaged together in a manner that can transmit torque and that can be articulated relative to each other. The axis of rotation (3), webbing sections (10), bottom land (11), top land (12), drive face (13) and flank (15) are shown. Additionally, one can see the flats (31) on the teeth (9) and webbing (10). Figure 5d shows a laid-open side view of a drive segment (1) with its base plane (2) and axis of rotation (3) shown. The teeth (9), webbing section (10) and flattened sides (31) are facing the viewer while the bottom land (11), top land (12) drive face (13), flank (15) face base edge (21) and leading edge (22) distinguish the profile. The angle (A) between the drive face (13) and the bottom land (11) is less than a 90 degree angle, while angle (C) between the flank (15) and the bottom land (11) is greater than a 90 degree angle. In this embodiment the flank (15) and drive face (13) have complimentary angles; that is, angle (A) and angle (C) sum to 180 degrees. The dimension (l) gives the distance of the bottom land (11) from the base plane (2), in this particular embodiment the bottom land (11) is parallel to the base plane (2).
[0088] Figure 6 shows a laid-open side view of a drive segment (1) with its base plane (2) and axis of rotation (3) in the interior. Outer surface (7) of the teeth (9) and webbing sections (10) are facing the viewer while the bottom land (11), top land (12) drive face (13), flank (15) face base edge (21), leading edge (22) and flank base edge (26) distinguish the profile. The spaces between the teeth (9) can be referred to as female socket (16) into which teeth (9) of adjacent drive segments (1) can engage. The angle (A) between the drive face (13) and the bottom land (11) is less than a 90 degree angle, while angle (C) between the flank (15) and the bottom land (11) is greater than a 90 degree angle. The embodiment shown in Figure 6 illustrates a more aggressive profile in that the top land (12) has a greater slope relative to the base plane (2) than the embodiment shown in Figure 5d. In this embodiment the flank (15) extends less from the base plane (2) than does the drive face (13), thereby imparting a slope to the top land (12) relative to the base plane (2), a slope that forms angle (K). The angle (J) is formed by the slope of the bottom land (11) relative to the base plane (2). Flats (31) can be seen on the webbing (10).

[0089] Figure 7 shows a laid-open side view of an embodiment of a drive segment (1) with its base plane (2) and axis of rotation (3) shown. The teeth (9), webbing section (10) and outer surface (7) are facing the viewer while the bottom land (11), top land (12) drive face (13), flank (15) and leading edge (22) distinguish the profile. The bottom land (11) has an inside edge (11A) with a dimension (HI) that is greater than an outside edge (11B) with a dimension (HO) so that the bottom land (11) has a slope towards the base plane (2) on moving from the inside (11A) to the outside (11B). In this embodiment the top land (12) is parallel to the base plane (2).

[0090] Figures 8a illustrates a top view of an embodiment of a drive segment (1) of the flexible spline member (25). The drive segment (1) has a base plane (2) and axis of rotation (3), an inner passageway (8), an outer surface (7), a plurality of teeth (9), a plurality of webbing sections (10) and a plurality of sockets (16). In this case, the overall profile of the drive segment (1) is generally barrel shaped (33) but includes flattened sides (31), which can enable greater fluid flow around the drive segment (1). In the embodiment shown there is four flattened sides (31) and adjacent sides are perpendicular to each other as shown by the dashed lines forming a 90-degree angle (G). The flattened sides (31) are shown as associated with the webbing sections (10) while the more cylindrical sides (7) are associated with the teeth (9). A bottom land (11) associated with the webbing sections (10) and a top land (12) associated with the teeth (9) are shown as exposed portions of an end of the drive segment
(1). A flank (15) is shown as a portion of a tooth (9) that is connected to the webbing section (10) at a flank base edge (26).

[0091] Figure 8b shows a side view of a series of drive segments (110) that are articulated relative to each other and that are engage together in a manner that transmits torque around radius or curvature (3R) in the clock-wise (CW) direction. The drive segments (1), teeth (9), webbing sections (10), flats (31), bottom land (11), top land (12), drive face (13), flank (15), leading edge (22) and barrel shaped (33) outer profile (7) are shown. Angle (A) shows the angle formed between the drive face (13) and the bottom land (11).

[0092] As used herein, the term “hose” refers to elastomeric hose, single or multi-braided hose, sheathed hose, Kevlar® hose and comparable means of providing a fluid conduit.

[0093] As used herein, the terms “wire” or “cable” refers to wire and cable whether single or multi-stranded, wire rope and similar means for securing or providing tension between two ends.

[0094] As used herein, the term “fluid” refers to liquids, gases or combinations thereof.

[0095] Use of the term “optionally” with respect to any element of a claim is intended to mean that the subject element is required, or alternatively, is not required. Both alternatives are intended to be within the scope of the claim. Use of broader terms such as comprises, includes, having, etc. should be understood to provide support for narrower terms such as consisting of, consisting essentially of, comprised substantially of, etc.

[0096] Depending on the context, all references herein to the “invention” may in some cases refer to certain specific embodiments only. In other cases it may refer to subject matter recited in one or more, but not necessarily all, of the claims. While the foregoing is directed to embodiments, versions and examples of the present invention, which are included to enable a person of ordinary skill in the art to make and use the inventions when the information in this patent is combined with available information and technology, the inventions are not limited to only these particular embodiments, versions and examples. Other and further embodiments, versions and examples of the invention may be devised without departing from the basic scope thereof and the scope thereof is determined by the claims that follow.
CLAIMS

What is claimed is:

1. A drive segment comprising:

   an axis of rotation and a base plane extending perpendicular from the axis of rotation through the center of said drive segment, a first end and a second end;

   at least two teeth positioned on each side of the base plane and forming a portion of the first end and second end, each tooth comprising a drive face, a top land and a flank;

   at least two webbing sections connecting the at least two teeth, each webbing section comprising a bottom land and forming a portion of the first end and second end, each bottom land adjacent to a tooth drive face;

   wherein an angle formed by a drive face and the base plane form an angle of less than 90 degrees;

   wherein a series of connected drive segments form a flexible spline member wherein the adjacent drive segments permit articulation and transference of torque of the flexible spline member around a radius.

2. A drive segment comprising:

   an axis of rotation and a base plane extending perpendicular from the axis of rotation through the center of said drive segment, a first end and a second end;

   at least two teeth positioned on each side of the base plane and forming a portion of the first end and second end, each tooth comprising a drive face, a top land and a flank;

   at least two webbing sections connecting the at least two teeth, each webbing section comprising a bottom land and forming a portion of the first end and second end, each bottom land adjacent to a tooth drive face;

   wherein an angle formed by a drive face and its adjoining bottom land form an angle of less than 90 degrees;
wherein a series of connected drive segments form a flexible spline member wherein the adjacent drive segments permit articulation and transference of torque of the flexible spline member around a radius.

3. A drive segment comprising:

an axis of rotation and a base plane extending perpendicular from the axis of rotation through the center of said drive segment, a first end and a second end;

at least two teeth positioned on each side of the base plane and forming a portion of the first end and second end, each tooth comprising a drive face, a top land and a flank;

at least two webbing sections connecting the at least two teeth, each webbing section comprising a bottom land and forming a portion of the first end and second end, each bottom land adjacent to a tooth drive face;

wherein an angle formed by a drive face and its adjoining top land form an angle of less than 90 degrees;

wherein a series of connected drive segments form a flexible spline member wherein the adjacent drive segments permit articulation and transference of torque of the flexible spline member around a radius.

4. A drive segment comprising:

an axis of rotation and a base plane extending perpendicular from the axis of rotation through the center of said drive segment, a first end and a second end;

at least two teeth positioned on each side of the base plane and forming a portion of the first end and second end, each tooth comprising a drive face, a top land and a flank;

at least two webbing sections connecting the at least two teeth, each webbing section comprising a bottom land and forming a portion of the first end and second end, each bottom land adjacent to a tooth drive face;

wherein an angle formed by a top land and the base plane form an angle opening towards the axis of rotation of less than 90 degrees;
wherein a series of connected drive segments form a flexible spline member wherein the adjacent drive segments permit articulation and transference of torque of the flexible spline member around a radius.

5. A drive segment comprising:

an axis of rotation and a base plane extending perpendicular from the axis of rotation through the center of said drive segment, a first end and a second end;

at least two teeth positioned on each side of the base plane and forming a portion of the first end and second end, each tooth comprising a drive face, a top land and a flank;

at least two webbing sections connecting the at least two teeth, each webbing section comprising a bottom land and forming a portion of the first end and second end, each bottom land adjacent to a tooth drive face;

wherein an angle formed by a bottom land and the base plane form an angle opening towards the axis of rotation of less than 90 degrees;

wherein a series of connected drive segments form a flexible spline member wherein the adjacent drive segments permit articulation and transference of torque of the flexible spline member around a radius.

6. The drive segment of any one of claims 2-5, wherein an angle formed by a drive face and the base plane form an angle of less than 90 degrees.

7. The drive segment of any one of claims 1 or 3-5, wherein an angle formed by a drive face and its adjoining bottom land form an angle of less than 90 degrees.

8. The drive segment of any one of claims 1, 2, 4 or 5, wherein an angle formed by a drive face and its adjoining top land form an angle of less than 90 degrees.
9. The drive segment of any one of claims 1-3 or 5, wherein an angle formed by a top land and the base plane form an angle opening towards the axis of rotation of less than 90 degrees.

10. The drive segment of any one of claims 1-4, wherein an angle formed by a bottom land and the base plane form an angle opening towards the axis of rotation of less than 90 degrees.

11. The drive segment of any one of claims 3-5, wherein an angle formed by a drive face and the base plane form an angle of less than 90 degrees and wherein an angle formed by a drive face and its adjoining bottom land form an angle of less than 90 degrees.

12. The drive segment of any one of claims 1-5, wherein when torque is applied to a series of connected drive segments the drive segments exert force to self-center and align along the axis of rotation.

13. The drive segment of any one of claims 1-5, wherein when two drive segments are connected a top land of the first drive segment is adjacent to a bottom land of the second drive segment, a drive face of the first drive segment is adjacent to a drive face of the second drive segment, and a flank of the first drive segment is adjacent to the flank of the second drive segment.

14. The drive segment of any one of claims 1-5, wherein the intersection of a drive face and an adjacent bottom land define a face base edge wherein a projection of the face base edge intersects with the axis of rotation.

15. The drive segment of any one of claims 1-5, wherein the intersection of a drive face and top land on a tooth defines a leading edge and wherein the leading edge is parallel with the face base edge.
16. The drive segment of any one of claims 1-5, wherein the intersection of a drive face and top land on a tooth defines a leading edge and wherein a projection of the leading edge defines an offset angle away from the axis of rotation wherein the offset angle ranges from 0 to 5 degrees.

17. An apparatus for cutting laterally into an earthen formation from a wellbore comprising:

   a flexible spline member formed from a series of interconnectable drive segments, wherein the interconnectable drive segments collectively form at least one inner passageway and a series of interconnectable drive segments permit the articulation and transference of torque of the flexible spline member around a radius;

   the flexible spline member being sized and configurable such that an attached cutting head assembly, the at least one inner passageway, and a fluid pumping source may be in fluid communication,

   drive segments comprised of any one of claims 1-5;

   wherein a first flexible spline member end portion is sized and configured to be attachable to a rotation means and a second flexible spline member end portion operatively coupled to the cutting head assembly such that torque applied to the first flexible spline member end portion by the rotational source may be translated to the cutting head assembly.

18. The apparatus of claim 17 wherein when torque is applied to a series of connected drive segments the drive segments exert force to self-center and align along the axis of rotation.

19. The apparatus of claim 17, further comprising one or more secondary tubular member disposed within the at least one flexible spline member inner passageway and capable of providing a substantially leak-proof fluid conduit between the pumping source and the cutting head assembly.
20. The apparatus of claim 17, further comprising a whipstock to guide the interconnectable drive segments.

21. A method for cutting laterally into an earthen formation from a wellbore comprising:

guiding a downhole tool assembly comprising the apparatus of claim 17 through a channel defined by a guide assembly and positioning the downhole tool assembly so that the downhole tool assembly contacts a portion of the earthen formation to be laterally cut, wherein the downhole tool assembly is coupled to a conduit, such that the conduit and downhole tool assembly are in fluid communication;

pumping one or more fluids through the conduit and into the downhole tool assembly;

rotating a cutting head of the downhole assembly; and

cutting a borehole into the earthen formation with the cutting head in a direction lateral to the wellbore.

22. The method of claim 21, wherein the downhole tool assembly is operatively connected to a rotational source and the rotational source is coupled to a conduit, such that the conduit, rotational source, and downhole tool assembly are in fluid communication;

activating the rotational source, wherein a torque is applied to the interconnected drive segments forming a flexible tubular member; and

translating the torque to a cutting head of the downhole tool assembly, wherein the torque causes the cutting head to rotate.
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/000209

A. CLASSIFICATION OF SUBJECT MATTER
E21B 7/08(2006.01)i, E21B 17/20(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
E21B 7/08; B24F 45/06; E21B 10/26; E21B 7/04; E21B 17/20

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
eKOMPASS(KIPO internal) & Keywords: lateral drilling, flexible spline member, drive segment, tooth, webbing section, and whipstock

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>US 2012-0067640 A1 (SAVAGE, JAMES M.) 22 March 2012 See paragraphs [0011], [0073]-[0074], [0078]-[0082], [0086] and figures 2-3, 5A-5C, 03, 8.</td>
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<td>US 6236224 B1 (COSINS, JAMES E. et al.) 25 February 2003 See column 5, line 3 - column 6, line 43 and figures 1-5.</td>
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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search

Date of mailing of the international search report

Authorized officer
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