A mechanism for adjusting the relative angular orientation of two coaxial components includes a mandrel having a cylindrical central section between upper and lower splined sections, a sleeve rotatably and slidably disposed around the mandrel’s central section, and generally cylindrical upper and lower ratchet members positioned, respectively, about the mandrel’s upper and lower splined sections. The ratchet members have internal grooves which receive the mandrel splines for torsional load transfer while permitting limited rotation relative to the mandrel, but their axial positions relative to the mandrel are fixed. The upper and lower ends of the sleeve have circumferentially-arrayed ratchet teeth engageable, respectively, with corresponding teeth on the upper and lower ratchet members. The central sleeve has torque-transferring external splines slidable within matching grooves on the inner surface of a cylindrical tool housing enclosing the mechanism. The mandrel is rotatable relative to the housing, but its axial position is fixed. The teeth of the sleeve and ratchet members are configured such that movement of the sleeve from a position engaging the upper ratchet member to a position engaging the lower ratchet member, or vice versa, will effect an incremental angular shift of the mandrel relative to the tool housing, while maintaining effective transfer of torsional loads therebetween.

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MECHANISM FOR PROVIDING CONTROLLABLE ANGULAR ORIENTATION WHILE TRANSMITTING TORSIONAL LOAD


FIELD OF THE INVENTION

[0002] The present invention relates in general to mechanisms for providing controllable angular orientation between an outer tubular element and a coaxial inner tubular element while transmitting torsional load between the outer and inner tubular elements. More particularly, the invention is directed to such mechanisms which can be incorporated in a downhole tool coupled within a drill string in a wellbore to provide controllable angular orientation between the sections of the string above and below the tool, while the mechanism is subjected to torsional load.

BACKGROUND OF THE INVENTION

[0003] In drilling a borehole (or wellbore) into the earth, such as for the recovery of hydrocarbons or minerals from a subsurface formation, it is conventional practice to connect a drill bit onto the lower end of a "drill string", then rotate the drill string so that the drill bit progresses downward into the earth to create the desired borehole. A typical drill string is made up from an assembly of drill pipe sections connected end-to-end, plus a "bottomhole assembly" ("BHA") disposed between the bottom of the drill pipe sections and the drill bit. The BHA is typically made up of sub-components such as drill collars, stabilizers, reamers and/or other drilling tools and accessories, selected to suit the particular requirements of the well being drilled.

[0004] In conventional vertical borehole drilling operations, the drill string and bit are rotated by means of either a "rotary table" or a "top drive" associated with a drilling rig erected at the ground surface over the borehole (or in offshore drilling operations, on a seabed-supported drilling platform or suitably-adapted floating vessel). During the drilling process, a drilling fluid (commonly referred to as "drilling mud" or simply "mud") is pumped under pressure downward from the surface through the drill string, out the drill bit into the wellbore, and then upward back to the surface through the annulus between the drill string and the wellbore. The drilling fluid carries borehole cuttings to the surface, cools the drill bit, and forms a protective cake on the borehole wall (to stabilize and seal the borehole wall), in addition to other beneficial functions.
As an alternative to rotation by a rotary table or a top drive, a drill bit can also be rotated using a "mud motor" (alternatively referred to as a "downhole motor") incorporated into the drill string immediately above the drill bit. The mud motor is powered by drilling mud pumped under pressure through the mud motor in accordance with well-known technologies. The technique of drilling by rotating the drill bit with a mud motor without rotating the drill string is commonly referred to as "slide" drilling, because the non-rotating drill string slides downward within the wellbore as the rotating drill bit cuts deeper into the formation. Torque loads from the mud motor are reacted by opposite torsional loadings transferred to the drill string.

Directional drilling operations using a mud motor require means for controlling the orientation of the mud motor relative to earth while the motor is down hole, in order to control the resulting direction of the curved or deflected wellbore. When drilling with a conventional string of drill pipe, mud motor orientation control can be accomplished by rotating the entire pipe string from surface. However, when drilling with coiled tubing, which cannot easily be rotated from surface, orientation control must be accomplished using means capable of controlling the angular orientation of the mud motor relative to the coiled tubing. It is desirable for this relative orientation to be controllable while drilling operations are in progress, to avoid any unexpected and undesired changes in orientation due to the unwinding and recoiling of the coiled tubing that can occur when drilling is interrupted.

The prior art teaches various devices which facilitate relative rotation of upper and lower string components, including the following U.S. patents:

- US 5,215,151 - Method and Apparatus For Drilling Boreholes Under Pressure (Smith et al.)
- US 5,259,467 - Directional Drilling Tool (Schoeffler)
- US 5,311,952 - Apparatus and Method For Directional Drilling With Downhole Motor On Coiled Tubing (Eddison et al.)
- US 5,339,913 - Well Orienting Tool and Method of Use (Rives)
- US 5,450,914 - Fluid Powered Stepping Motor For Rotating a Downhole Assembly Relative To a Supporting Pipe String (Coram)
- US 5,775,444 - Drill String Orienting Motor (Falgout, Sr.)
- US 5,894,896 - Orienting Tool For Coiled Tubing Drilling (Smith et al.)
- US 6,439,321 - Piston Actuator Assembly For An Orienting Device (Gillis et al.)
- US 6,955,231 - Tool For Changing The Drilling Direction While Drilling (Bakke).

These prior art devices typically include an arrangement of lugs and spiral grooves, or an arrangement of lugs and circumferentially-spaced cam bodies, that convert axial motion
of a piston into rotational motion of the lower string components. Such devices are generally very complicated in construction and operation, with large numbers of components. The devices also do not allow orientation to be controlled and adjusted while being subjected to torsional loads (such as under normal drilling conditions).

Accordingly, there remains a need for improved and less complicated apparatus for controlling and adjusting the angular orientation between coaxial tubular elements, particularly while under torsional loading. The present invention is directed to this need.

**BRIEF SUMMARY OF THE INVENTION**

The present invention provides a mechanism which can be incorporated into a tool located between the end of a tubing string and a mud motor, whereby the angular orientation of the mud motor relative to the tubing string can be adjusted without interrupting well-drilling operations, while maintaining effective transfer of torsional loads from the mud motor to the tubing string. In preferred embodiments, the mechanism includes a generally cylindrical mandrel having a central bore throughout its length (for passage of drilling fluid), a cylindrical central section, an upper section above the cylindrical central section, and a lower section below the cylindrical central section. The mandrel is positioned coaxially within a cylindrical tool housing such that the mandrel is rotatable relative to the housing but its axial position relative to the housing is substantially fixed. In a typical well-drilling application of the mechanism, a mud motor will be coupled to the lower end of the mandrel (either directly or through intermediary components).

A cylindrical central sleeve is disposed around the central cylindrical section of the mandrel, with the central sleeve having an internal diameter to provide a close but readily slidable fit with the central cylindrical section of the mandrel. The central sleeve is longitudinally slidable but substantially non-rotatable relative to the housing. In the preferred embodiment, this functionality is facilitated by forming the central sleeve with a plurality of longitudinally-oriented external splines slidingly received within complementary grooves formed in the inner surface of the housing. The upper and lower ends of the central sleeve each have a plurality of circumferentially-arrayed and equally-spaced ratchet teeth. In the preferred embodiment, each ratchet tooth has a first face that is parallel to the longitudinal axis of the mandrel, plus a second face that is angled relative to the first face (hereinafter these first and second faces will be referred to as "vertical faces" and "sloped faces" respectively).

The mechanism also includes generally cylindrical upper and lower ratchet members disposed, respectively, about the upper and lower sections of the mandrel; i.e., on either side of the central sleeve. The upper and lower ratchet members are mounted such that their axial
positions relative to the mandrel are substantially fixed, but also such that they are independently rotatable relative to the mandrel within a limited angular range. In the preferred embodiment of the mechanism, this limited rotational functionality is facilitated by providing the inner cylindrical surfaces of the upper and lower ratchet members with longitudinal grooves configured to receive complementary external splines formed on the upper and lower sections of the mandrel, but with the ratchet member grooves being wider than the corresponding mandrel splines. In preferred embodiments, biasing means (such as bow springs) will be provided to bias the mandrel splines against one side face of the corresponding ratchet member grooves to facilitate torque transfer during drilling.

[0013] The lower end of the upper ratchet member has a plurality of circumferentially-arrayed and equally-spaced ratchet teeth configured for mating engagement with the ratchet teeth on the upper end of the central sleeve. Similarly, the upper end of the lower ratchet member has a plurality of circumferentially-arrayed and equally-spaced ratchet teeth configured for mating engagement with the ratchet teeth on the lower end of the central sleeve. The four pluralities of ratchet teeth have matching numbers of ratchet teeth, and, therefore, the same spacing (or angular interval) between adjacent ratchet teeth.

[0014] The upper and lower ratchet members are axially spaced such that the central sleeve can slide along the mandrel between:

- an upper position in which the central sleeve's upper ratchet teeth are matingly engaged with the ratchet teeth of the upper ratchet member, with the central sleeve's lower ratchet teeth being clear of the ratchet teeth of the lower ratchet member; and
- a lower position in which the central sleeve's lower ratchet teeth are matingly engaged with the ratchet teeth of the lower ratchet member, with the central sleeve's upper ratchet teeth being clear of the ratchet teeth of the upper ratchet member.

[0015] When the central sleeve is in its upper position, its lower ratchet teeth will be offset relative to the ratchet teeth of the lower ratchet member, with the offset preferably being approximately one-half of the typical ratchet tooth spacing (or angular interval). In this configuration, torque from a mud motor connected to the bottom of the mandrel will be transferred from the mandrel to the upper ratchet member via the spline/groove connection therebetween, from the upper ratchet member to the central sleeve via the respective engaged ratchet teeth, and from the central sleeve to the tool housing via the spline/groove connection therebetween.
Similarly, when the central sleeve is in its lower position, its upper ratchet teeth will be offset relative to the ratchet teeth of the upper ratchet member, with the offset preferably being approximately one-half of the typical ratchet tooth spacing (or angular interval). In this configuration, torque from a mud motor connected to the bottom of the mandrel will be transferred from the mandrel to the lower ratchet member via the spline/groove connection therebetween, from the lower ratchet member to the central sleeve via the respective engaged ratchet teeth, and from the central sleeve to the tool housing via the spline/groove connection therebetween.

When the central sleeve is moved from its upper position toward its lower position, the central sleeve's upper ratchet teeth will begin disengaging from the ratchet teeth of the upper ratchet member, but torque transfer between the upper ratchet member and the central sleeve will remain effective until these two sets of ratchet teeth are fully disengaged, because their respective vertical faces will remain in load-transferring contact prior to full disengagement, and until such full disengagement there can be no rotation of the upper ratchet member relative to the sleeve.

However, as the central sleeve is moved from its upper position toward its lower position, the central sleeve's lower ratchet teeth will begin engaging the ratchet teeth of the lower ratchet member before the central sleeve's upper ratchet teeth are fully disengaged from the upper ratchet member. As well, due to the previously-noted offset between the central sleeve's ratchet teeth and the ratchet teeth of the lower ratchet member, the continued downward movement of the central section's ratchet teeth into the ratchet teeth of the lower ratchet member will force the lower ratchet member to rotate approximately one-half of a ratchet tooth interval relative to the mandrel, due to the tips of the central sleeve's lower ratchet teeth bearing downward against the sloped faces of the ratchet teeth of the lower ratchet member. This limited rotational displacement of the lower ratchet member is possible because, as previously noted, the splines in the lower splined section of the mandrel are narrower than the corresponding grooves in the lower ratchet member. During this limited rotational displacement, any springs or other biasing means associated with the lower ratchet member will be compressed or otherwise stressed as the mandrel splines move in an arcuate path within the lower ratchet member grooves.

As the central sleeve reaches its lower position, and as the central sleeve's upper ratchet teeth become fully disengaged from the upper ratchet member, torsional loads acting on the mandrel (e.g. from a mud motor) will cause a sudden angular displacement of the mandrel relative to the central sleeve, while concurrently relieving stresses induced in the biasing means (if present) during the movement of the central sleeve. The amount of this
angular displacement will correspond to one-half of the ratchet tooth spacing. Because the central sleeve cannot rotate relative to the tool housing by virtue of the spline/groove connection therebetween, the effect of the angular displacement between the mandrel and the central sleeve is to create the same angular displacement between the tool housing and the mandrel - and therefore between the tool housing and any mud motor or other tool or appurtenance coupled to the mandrel.

[0020] In a fashion similar to that described above, upward movement of the central sleeve back to its upper position will induce a similar and additional angular displacement of the mandrel relative to the tool housing.

[0021] In alternative embodiments, the mechanism of the present invention may also be configured to internally drive the relative rotation that occurs during orientation in applications that are not subject to external torsional loads.

[0022] Although the present invention has particularly beneficial applications in association with directional drilling with coiled tubing, persons skilled in the art will appreciate that it may be also be readily adapted for use in other applications where controlled angular orientation between two or more coaxial components is required, with or without the presence of applied torsional load.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] Embodiments of the invention will now be described with reference to the accompanying figures, in which numerical references denote like parts, and in which:

[0024] FIG. 1 is a partial-cutaway elevation of a drill string incorporating an angular orientation mechanism in accordance with one embodiment of the present invention.

[0025] FIG. 1a is an elevation of a mandrel suitable for use in accordance with one embodiment of the invention.

[0026] FIG. 2 is a partial cutaway view of the orientation mechanism in FIG. 1, with the central sleeve in its upper position.

[0027] FIG. 3 is a transverse cross-section through the tool housing, cylindrical piston, upper ratchet member, and mandrel of the orientation mechanism in FIG. 2.

[0028] FIG. 4 is a transverse cross-section through the tool housing, central sleeve, and mandrel of the orientation mechanism in FIG. 2.

[0029] FIG. 5 is a transverse cross-section through the tool housing, lower ratchet member, and mandrel of the orientation mechanism in FIG. 2.

[0030] FIG. 6 is a partial cutaway view of the orientation mechanism in FIG. 2, with the central sleeve displaced slightly downward from its upper position, with its lower ratchet teeth beginning to engage the ratchet teeth of the lower ratchet member.
FIG. 7 is similar to FIG. 6 but with the central sleeve displaced further downward, with its lower ratchet teeth engaging the sloped faces of the ratchet teeth of the lower ratchet member so as to incrementally rotate the lower ratchet member in a counterclockwise direction.

FIG. 8 is a partial cutaway view showing the central sleeve after full downward displacement to its lower position, with its lower ratchet teeth in full mating engagement with the ratchet teeth of the lower ratchet member, and with its upper ratchet teeth fully disengaged from the upper ratchet member.

FIG. 9 is a transverse cross-section through the tool housing, lower ratchet member, and mandrel, as viewed during downward displacement of the central sleeve as in FIG. 7.

FIG. 10 is a transverse cross-section through the tool housing, lower ratchet member, and mandrel, as viewed after full downward displacement of the central sleeve as in FIG. 8.

FIG. 11 is a partial cutaway view of the orientation mechanism in FIG. 2, with the central sleeve displaced slightly upward from its lower position, and with its upper ratchet teeth beginning to engage the ratchet teeth of the upper ratchet member.

FIG. 12 is similar to FIG. 11 but with the central sleeve displaced further upward, with its upper ratchet teeth engaging the sloped faces of the ratchet teeth of the upper ratchet member so as to incrementally rotate the upper ratchet member in a counterclockwise direction.

FIG. 13 is a partial cutaway view showing the central sleeve after full upward displacement back to its upper position, with its upper ratchet teeth in full mating engagement with the ratchet teeth of the upper ratchet member, and with its lower ratchet teeth fully disengaged from the lower ratchet member.

FIG. 14 is a transverse cross-section through the tool housing, cylindrical piston, upper ratchet member, and mandrel, as viewed during upward displacement of the central sleeve as in FIG. 12.

FIG. 15 is a transverse cross-section through the tool housing, cylindrical piston, upper ratchet member, and mandrel, as viewed after full upward displacement of the central sleeve as in FIG. 13.

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

FIG. 1 illustrates an angular orientation mechanism 100 in accordance with one embodiment of the present invention, incorporated within a string of tubular elements constituting a downhole tool. FIG. 1 depicts one possible orientation of the downhole tool relative to a wellbore, with the tool comprising a cylindrical tool housing 20 (typically made
up from a plurality of tool housing members) having an upper end 20U which may be coupled to the lower end of a pipe string or coiled tubing string (not shown), or to other tools or components that are coupled to the lower end of the string. For convenience, the adjectives "upper" and "lower" are used in this patent specification in reference to various components as if mechanism 100 were at all times vertically oriented as in FIG. 1. It will be appreciated, however, that these terms are used in a relative sense only, as the mechanism may be used in a variety of different orientations (such as during directional drilling operations).

[0041] Mechanism 100 includes a generally cylindrical mandrel member 14 with a central bore 30 to permit passage of drilling fluid (mud). FIG. 1a illustrates one embodiment of a mandrel 14 adapted for use in mechanism 100. Mandrel 14 is axially and radially supported within housing members 20 such that it is coaxially rotatable relative to housing 20 but its axial position relative to housing 20 is substantially fixed. Persons skilled in the art will appreciate that specific means for supporting mandrel 14 within housing 20 as described above may be readily devised, and the present invention is not limited to any particular means of providing such support.

[0042] Mandrel 14 includes a central section 31 having a smooth cylindrical outer surface, an upper splined section 32 above central section 31, and a lower splined section 33 below central section 31. As shown in FIG. 1a, upper splined section 32 defines a plurality of longitudinally-oriented upper splines 141 spaced around the circumference of upper splined section 32 and projecting outward therefrom. Similarly, lower splined section 33 defines a plurality of longitudinally-oriented lower splines 142 spaced around the circumference of lower splined section 33 and projecting outward therefrom.

[0043] The lower end 14L of mandrel 14 may be coupled to a mud motor (not shown) or other tool or other additional lower tubular elements that require controllable angular orientation relative to housing 20 (and relative to a pipe string or tubing string supporting housing 20). Additional or auxiliary elements or appurtenances may be coupled above mandrel 14 (for example, components that provide axial or radial support to mandrel 14, or components involved in controlling the actuation of the mechanism 100). However, such additional elements do not form part of the broadest embodiments of the present invention, and other embodiments of the invention could take alternative forms without departing from the scope of the invention.

[0044] Mechanism 100 as illustrated is not limited to orientation relative to a wellbore as described above. In alternative embodiments, mechanism 100 may be inverted such that mandrel 14 is coupled to the lower end of the pipe string or coiled tubing string, or to other
tools or components that are coupled to the lower end of the string, with housing 20 being coupled to a drilling tool or other additional lower tubular elements requiring angular orientation control.

[0045] In the embodiment illustrated in the FIGS, (and as will be explained in greater detail), torque-transmitting components of mechanism 100 are configured to resist torsional loading applied in the clockwise direction when viewed from above. In alternative embodiments adapted to resist counterclockwise torsional loading, the configurations of torque-transmitting components would be essentially the reverse of the illustrated configurations.

[0046] FIG. 2 is an enlarged detail illustrating the components of mechanism 100 in accordance with the embodiment of FIG. 1. As shown, mechanism 100 includes a generally cylindrical central sleeve 10 with longitudinal external splines 101, plus a generally cylindrical outer housing 11 coupled to the lower end of tool housing 20, and having longitudinal internal grooves 111 configured to receive splines 101 of sleeve 10 in closely-fitting fashion as shown in FIG. 4. The inner diameter of central sleeve 10 is slightly greater than the outer diameter of central section 31 of mandrel 14, such that it may be coaxially disposed around central section 31 as shown in FIG. 4, and will be free to rotate relative to mandrel 14 and free to slide longitudinally relative to mandrel 14. Splines 101 on central sleeve 10 and grooves 111 on housing 11 prevent relative rotation between sleeve 10 and housing 11, while allowing sleeve 10 to travel axially relative to housing 11.

[0047] A generally cylindrical upper ratchet member 12 with internal grooves 122 is coaxially disposed around upper splined section 32 of mandrel 14, such that splines 141 of mandrel 14 are received within grooves 122. Grooves 122 are wider than splines 141 such that when a first vertical face 141a of a given spline 141 is bearing against a first vertical face 122a of the corresponding groove 122, a vertical gap G-I will be formed between the second vertical face 122b of groove 122 and the second vertical face 141b of spline 141, all as shown in FIG. 3. The axial position of upper ratchet member 12 is substantially fixed relative to mandrel 14, but upper ratchet member 12 is free to rotate coaxially relative to mandrel 14, to the extent allowed by gaps G-I.

[0048] Preferred embodiments will include suitable biasing means such that when torque load is not present between upper ratchet member 12 and mandrel 14, first vertical faces 141a of splines 141 will be biased toward and against the corresponding first vertical faces 122a of grooves 122. As shown in FIG. 3, such biasing means may be in the form of bow springs 15 disposed within the gaps G-I between second vertical faces 122b and 141b. However, the present invention is not limited to the use of this or any particular type of biasing means.
Persons skilled in the art will appreciate that various functionally effective biasing means may be devised and provided in accordance with known technologies (e.g., torsion springs coupled between the mandrel and upper and lower ratchet members), without departing from the scope of the present invention, and the biasing means may be omitted in alternative embodiments.

A generally cylindrical lower ratchet member 13 with internal grooves 132 is coaxially disposed around lower splined section 33 of mandrel 14, such that splines 142 of mandrel 14 are received within grooves 132. Grooves 132 are wider than splines 142 such that when a first vertical face 142a of a given spline 142 is bearing against a first vertical face 132a of the corresponding groove 132, a vertical gap G-2 will be formed between the second vertical face 132b of groove 132 and the second vertical face 142b of spline 142, all as shown in FIG. 5. The axial position of lower ratchet member 13 is substantially fixed relative to mandrel 14, but lower ratchet member 13 is free to rotate coaxially relative to mandrel 14, to the extent allowed by gaps G-2. Preferred embodiments will include suitable biasing means such that when torque load is not present between lower ratchet member 13 and mandrel 14, first vertical faces 142a of splines 142 will be biased toward and against the corresponding first vertical faces 132a of grooves 132. As shown in FIG. 5, such biasing means may be in the form of bow springs 21 disposed within the gaps G-2 between second vertical faces 132b and 142b.

The lower end of upper ratchet member 12 has a circumferentially-arrayed plurality of ratchet teeth 121, each having a vertical face 121a and a sloped face 121b. The upper end of lower ratchet member 13 has a similar plurality of ratchet teeth 131, each having a vertical face 131a and a sloped face 131b. The upper end of central sleeve 10 has a plurality of ratchet teeth 102, each having a vertical face 102a and a sloped face 102b, and configured to mate with ratchet teeth 121 on upper ratchet member 12. Similarly, the lower end of central sleeve 10 has a plurality of ratchet teeth 103, each having a vertical face 103a and a sloped face 103b, and configured to mate with ratchet teeth 131 on lower ratchet member 13.

Upper ratchet member 12 and lower ratchet member 13 are positioned on mandrel 14 to permit a certain amount of axial movement of central sleeve 10 along mandrel 14, such that when ratchet teeth 102 of central sleeve 10 are matingly engaged with ratchet teeth 121 of upper ratchet member 12, ratchet teeth 103 of central sleeve 10 will be clear of ratchet teeth 131 of lower ratchet member 13. Torque may thus be transmitted between central sleeve 10 and upper ratchet member 12 (i.e., by engagement of ratchet teeth 102 and 121) or between central sleeve 10 and lower ratchet member 13 (i.e., by engagement of ratchet teeth
103 and 131), depending on the axial position of central sleeve 10 during operation of mechanism 100, as will be further explained below.

[0052] The incremental angular displacement that occurs during one index cycle is determined by the angular spacing between adjacent ratchet teeth, which is determined by the total number of ratchet teeth of each plurality of ratchet teeth. The tool may be configured with the required number of ratchet teeth per ratchet plurality to achieve a selected incremental angular displacement for each cycle. For example, a ratchet plurality comprising 24 teeth would result in an incremental angular rotation of 15 per index cycle.

[0053] The operation and function of mechanism 100 may be clearly understood with reference to the FIGS. and the foregoing description. FIG. 2 illustrates an embodiment of mechanism 100 with central sleeve 10 in its upper position (as previously defined), with ratchet teeth 102 of central sleeve 10 in mating engagement with ratchet teeth 121 of upper ratchet member 12, and with ratchet teeth 103 of central sleeve 10 axially separated from ratchet teeth 131 of lower ratchet member 13. Any torsional load (for example, due to drilling using a mud motor coupled to mandrel 14) is transmitted from mandrel 14 to housing 11 through splines 141 and grooves 122, ratchet teeth 102 and 121, and splines 101 and grooves 111.

[0054] When adjustment is required with respect to the angular orientation of mandrel 14 relative to housing 11, an index cycle is initiated by forcing central sleeve 10 downward toward its lower position (previously defined) using suitable central sleeve actuation means capable of providing sufficient force to overcome the friction between sliding or otherwise mechanically-engaged components (e.g., spline/groove arrangements; mating ratchet teeth) during indexing. In the illustrated embodiment, the central sleeve actuation means comprises:

- a generally cylindrical piston 19 which is disposed above central sleeve 10 and is axially movable within an annular space between housing 11 and upper ratchet member 12;
- a cylindrical drive sleeve 17 which is disposed below central sleeve 10 and is axially movable within an annular space between housing 11 and lower ratchet member 13; and
- a helical return spring 16 disposed below and reacting against drive sleeve 17 in association with a drive sleeve retention ring 18.

[0055] In this embodiment, piston 19 is actuated by exposure to fluid pressure (either liquid or gaseous) sufficient to force central sleeve 10 downward against drive sleeve 17 so as to
compress return spring 16. As return spring 16 is compressed, central sleeve 10 begins to travel axially along central section 31 of mandrel 14, while ratchet teeth 102 of central sleeve 10 begin to move downward relative to ratchet teeth 121 of upper ratchet member 12. During this phase of the indexing operation, however, vertical faces 102a of ratchet teeth 102 remain in sliding contact with opposing vertical faces 121a of ratchet teeth 121 (as may be seen in FIGS. 6 and 7), and thus remain capable of transmitting torsional load.

[0056] As illustrated in FIG. 6, representative ratchet tooth 102-1 is initially located between adjacent ratchet teeth 121-1 and 121-2. As central sleeve 10 continues to travel downward, sloped faces 103b of ratchet teeth 103 begin to contact sloped faces 131b of ratchet teeth 131, as shown in FIG. 7. Due to the angular inclination of sloped faces 103b and 131b, lower ratchet member 13 is thus forced to rotate relative to mandrel 14 opposite to the direction of torsional load (i.e., counterclockwise in the illustrated embodiment), while bow springs 21 compress and vertical faces 132a of grooves 132 separate from vertical faces 142a of splines 142, as shown in FIG. 9. Ratchet teeth 102 continue to separate from ratchet teeth 121 until they fully disengage. At this point, there is a sudden relative rotation between mandrel 14 and central sleeve 10 in the direction of torsional load. Concurrently, ratchet teeth 103 become fully engaged with ratchet teeth 131 as central sleeve 10 reaches its lower position, as shown in FIG. 8. Rotation between mandrel 14 and central sleeve 10 continues until vertical faces 142a of splines 142 contact vertical faces 132a of grooves 132, as shown in FIG. 10. At this point of the index cycle, angular displacement between mandrel 14 and central sleeve 10 is approximately one-half of the total angular displacement of one full index cycle. In this position, ratchet teeth 102 and 121 are separated, and torsional load is transmitted from mandrel 14 to housing 11 through splines 142 and grooves 132, ratchet teeth 103 and 131, and splines 101 and grooves 111.

[0057] To complete the index cycle, fluid pressure acting on piston 19 is sufficiently decreased such that return spring 16 forces central sleeve 10 to travel axially along mandrel 14 to return to its upper position. Ratchet teeth 103 begin to separate from ratchet teeth 131 while remaining torsionally engaged and capable of transmitting torsional load, with vertical faces 103a of ratchet teeth 103 remaining in sliding contact with opposing vertical faces 131a of ratchet teeth 131 as seen in FIGS. 11 and 12. Because of the angular displacement between central sleeve 10 and mandrel 14, as ratchet teeth 102 and 121 begin to reengage, ratchet tooth 102-1 is now located between ratchet teeth 121-2 and 121-3. Contact between sloped faces 102b of ratchet teeth 102 and sloped faces 121b of ratchet teeth 121, as shown in FIG. 12, causes upper ratchet member 12 to rotate relative to mandrel 14 opposite to the direction of torsional load, while bow springs 15 compress and vertical faces 122a of grooves
122 separate from vertical faces 141a of splines 141, as shown in FIG. 14. Travel of central sleeve 10 continues until ratchet teeth 103 disengage from ratchet teeth 131, and torsional load causes mandrel 14 to rotate relative to central sleeve 10. Vertical faces 102a of ratchet teeth 102 engage with vertical faces 121a of ratchet teeth 121, and vertical faces 141a of splines 141 contact faces 122a of grooves 122, as shown in FIGS. 13 and 15. Mechanism 100 has now returned to the initial position shown in FIG. 2, but with ratchet teeth 102 and 121 having indexed one incremental amount, determined by the angular distance between adjacent teeth, and with mandrel 14 having rotated by this same amount relative to housing 11. The index cycle is repeated until the desired orientation between elements above and below the tool is achieved.

[0058] Persons skilled in the art will appreciate that any of various means or mechanisms could be used to actuate piston 19, and the present invention is not limited or restricted to the use of any particular means of actuating piston 19. In alternative embodiments, piston 19 could be actuated by functionally effective means other than fluid pressure, without departing from the scope of the present invention. Furthermore, the invention is not limited or restricted to use of the central sleeve actuation means described and illustrated herein, or any other particular central sleeve actuation means. Persons skilled in the art will recognize that other functionally effective central sleeve actuation means can be readily devised and provided in accordance with known technologies, without departing from the scope of the invention.

[0059] In accordance with embodiments of the present invention as described above, applied torsional load drives the relative angular rotation that occurs during an index cycle. Mechanism 100 could alternatively be configured such that the relative angular rotation is internally driven. One way to achieve this would be to have strong enough biasing means between upper ratchet member 12 and mandrel 14, and between lower ratchet member 13 and mandrel 14, to induce enough torque to effect the relative rotation of mandrel 14 during the index cycle.

[0060] Another method would be to have upper ratchet member 12 and lower ratchet member 13 rotationally fixed to mandrel 14. In that configuration, as central sleeve 10 translates axially on the downstroke or upstroke, contact between sloped faces 103b and sloped faces 131b, or between sloped faces 102b and sloped faces 121b, would provide the driving force to rotate mandrel 14 relative to housing 11, so that indexing could be accomplished in the absence of an applied torsional load.

[0061] It will be readily appreciated by those skilled in the art that various modifications of the present invention may be devised without departing from the essential concept of the
invention, and all such modifications are intended to come within the scope of the present invention. It is to be especially understood that the invention is not intended to be limited to illustrated embodiments, and that the substitution of a variant of a claimed element or feature, without any substantial resultant change in the working of the invention, will not constitute a departure from the scope of the invention. To provide one particular non-limiting example, the central sleeve actuation means could be provided in a variety of alternative forms, such as upper and lower gas-actuated or hydraulically-actuated pistons above and below the central sleeve, without a return spring being required.

[0062] In this patent document, the term "ratchet teeth" is not to be interpreted as being limited solely to ratchet teeth of form or configuration specifically as described and illustrated herein, but is also intended to encompass alternative means of torque-transferring engagement between the central sleeve and the upper and lower ratchet members in accordance with the described operative principles of the present invention. Similarly, the term "ratchet member" is to be understood as referring to a member incorporating means for torque-transferring engagement with the central sleeve, and such engagement means may but will not necessarily comprise ratchet teeth as such. Persons skilled in the art will recognize that alternative torque-transfer engagement means may be devised using known technologies without departing from the scope of the invention. To provide only one non-limiting example, the torque-transfer engagement means in an alternative embodiment of the present invention could comprise a series of circumferentially-spaced lugs on either end of the central sleeve, with each lug being operatively engageable with a ratchet-shaped slot along the circumference each of the upper and lower ratchet members.

[0063] In this patent document, any form of the word "comprise" is to be understood in its non-limiting sense to mean that any item following such word is included, but items not specifically mentioned are not excluded. A reference to an element by the indefinite article "a" does not exclude the possibility that more than one of the element is present, unless the context clearly requires that there be one and only one such element.

[0064] Any use of any form of the terms "connect", "engage", "couple", "attach", or any other term describing an interaction between elements is not meant to limit the interaction to direct interaction between the subject elements, and may also include indirect interaction between the elements such as through secondary or intermediary structure. Relational terms (such as but not limited to) "parallel", "perpendicular", "coaxial", "coincident", "intersecting", and "equidistant" are not intended to denote or require absolute mathematical or geometrical precision. Accordingly, such terms are to be understood as denoting or
requiring substantial precision (e.g., "substantially parallel") unless the context clearly requires otherwise.
CLAIMS

What is claimed is:

1. A mechanism for adjusting the relative angular orientation between two coaxial components, said mechanism comprising:
   (a) a cylindrical housing;
   (b) a generally cylindrical mandrel coaxially mounted within the housing so as to be rotatable relative thereto but with its axial position relative thereto being substantially fixed, said mandrel having a central section, an upper section above the central section, and a lower section below the central section;
   (c) a generally cylindrical central sleeve coaxially disposed around the central section of the mandrel so as to be rotatable and longitudinally slidable relative thereto, said central sleeve being engaged with the housing so as to be is longitudinally slidable but substantially non-rotatable relative thereto;
   (d) a generally cylindrical upper ratchet member coaxially disposed around the upper section of the mandrel such that the axial position of said upper ratchet member relative to the mandrel is substantially fixed but said upper ratchet member is rotatable relative to the mandrel within a limited angular range while being adapted for torsional load transfer between the upper ratchet member and the mandrel in response to application of torsional load in a first angular direction;
   (e) a generally cylindrical lower ratchet member coaxially disposed around the lower section of the mandrel such that the axial position of said lower ratchet member relative to the mandrel is substantially fixed but said lower ratchet member is rotatable relative to the mandrel within a limited angular range while being adapted for torsional load transfer between the lower ratchet member and the mandrel in response to application of torsional load in said first angular direction;

wherein:

   (f) the upper end of the central sleeve defines a first plurality of circumferentially-arrayed ratchet teeth;
   (g) the lower end of the central sleeve defines a second plurality of circumferentially-arrayed ratchet teeth;
   (h) the lower end of the upper ratchet member defines a third plurality of circumferentially-arrayed ratchet teeth configured for mating engagement with the first plurality of ratchet teeth such that torsional loads in said first direction
can be transferred from the central sleeve to the upper ratchet member when said first and third pluralities of ratchet teeth are at least partially engaged;

(i) the upper end of the lower ratchet member defines a fourth plurality of circumferentially-arrayed ratchet teeth configured for mating engagement with the second plurality of ratchet teeth such that torsional loads in said first direction can be transferred from the central sleeve to the lower ratchet member when said second and fourth pluralities of ratchet teeth are at least partially engaged; and

(j) the upper and lower ratchet members are axially positioned on the mandrel such that the central sleeve is movable between:

j.1 an upper position in which the first plurality of ratchet teeth are matingly engaged with the third plurality of ratchet teeth, while the second plurality of ratchet teeth are fully separated from and angularly offset from the fourth plurality of ratchet teeth; and

j.2 a lower position in which the second plurality of ratchet teeth are matingly engaged with the fourth plurality of ratchet teeth, while the first plurality of ratchet teeth are fully separated from and angularly offset from the third plurality of ratchet teeth; and

(k) the mechanism further comprises central sleeve actuation means for selectively moving the central sleeve between said upper and lower positions.

2. The angular orientation mechanism of Claim 1 wherein the central sleeve actuation means comprises:

(a) a cylindrical piston disposed above the central sleeve and axially movable within an annular space between the housing and the upper ratchet member;

(b) a cylindrical drive sleeve disposed below the central sleeve and axially movable within an annular space between the housing and the lower ratchet member; and

(c) a helical return spring disposed below the drive sleeve.

3. The angular orientation mechanism of Claim 1, further comprising biasing means for biasing the upper and lower ratchet members toward torque-transferring positions relative to the mandrel.

4. The angular orientation mechanism of Claim 3 wherein the biasing means comprises a spring.
5. The angular orientation mechanism of Claim 1 wherein the housing has a plurality of longitudinally-oriented internal grooves and the central sleeve has a plurality of longitudinally-oriented external splines disposed within the internal grooves of the housing.

6. The angular orientation mechanism of Claim 1 wherein:
   (a) each of said upper and lower ratchet members has a plurality of longitudinally-oriented internal grooves;
   (b) each of said upper and lower sections of the mandrel has a plurality of longitudinally-oriented external splines;
   (c) the grooves of the upper and lower ratchet members are wider, respectively, than the splines of the upper and lower sections of the mandrel; and
   (d) the splines of the upper and lower sections of the mandrel are disposed within the grooves of the upper and lower ratchet members, respectively.

7. The angular orientation mechanism of Claim 6, further comprising biasing means for biasing the splines of the upper and lower sections of the mandrel toward torque-transferring contact with vertical faces of the corresponding grooves in the upper and lower ratchet members, respectively.

8. The angular orientation mechanism of Claim 7 wherein the biasing means comprises a bow spring disposed within one of the grooves in the upper ratchet member, and a bow spring disposed within one of the grooves in the lower ratchet member.

9. The angular orientation mechanism of Claim 7 wherein the biasing means comprises a first torsion spring coupled between the mandrel and the upper ratchet member, and a second torsion spring coupled between the mandrel and the lower ratchet member.

10. The angular orientation mechanism of Claim 1 wherein each ratchet tooth has a vertical side and a sloped side.

11. A mechanism for adjusting the relative angular orientation between two coaxial components, said mechanism comprising:
    (a) a cylindrical housing with a central portion having a plurality of longitudinally-oriented internal grooves;
    (b) a generally cylindrical mandrel coaxially mounted within the housing so as to be rotatable relative thereto but with its axial position relative thereto being substantially fixed, said mandrel having a central section, an upper section above the central section, and a lower section below the central section, with each of said upper and lower sections having a plurality of longitudinally-oriented external splines;
(c) a generally cylindrical central sleeve coaxially disposed around the central section of the mandrel so as to be rotatable and longitudinally slidable relative thereto, said central sleeve having a plurality of longitudinally-oriented external splines disposed within the internal grooves of the central portion of the housing such that the central sleeve is longitudinally slidable but substantially non-rotatable relative to the housing;

(d) a generally cylindrical upper ratchet member having a plurality of longitudinally-oriented internal grooves, said grooves being wider than the splines of the upper section of the mandrel, said upper ratchet member being coaxially disposed around the upper section of the mandrel with the splines of the upper section of the mandrel being disposed within the internal grooves of the upper ratchet member such that the upper ratchet member is rotatable relative to the mandrel within a limited angular range;

(e) a generally cylindrical lower ratchet member having a plurality of longitudinally-oriented internal grooves, said grooves being wider than the splines of the lower section of the mandrel, said lower ratchet member being coaxially disposed around the lower section of the mandrel with the splines of the lower section of the mandrel being disposed within the internal grooves of the lower ratchet member such that the lower ratchet member is rotatable relative to the mandrel within a limited angular range;

wherein:

(f) the upper end of the central sleeve defines a first plurality of circumferentially-arrayed ratchet teeth, each ratchet tooth having a vertical side and a sloped side;

(g) the lower end of the central sleeve defines a second plurality of circumferentially-arrayed ratchet teeth, each ratchet tooth having a vertical side and a sloped side;

(h) the lower end of the upper ratchet member defines a third plurality of circumferentially-arrayed ratchet teeth, each ratchet tooth having a vertical side and a sloped side, said third plurality of ratchet teeth being configured for engagement with the first plurality of ratchet teeth such that the vertical sides of the first and third pluralities of ratchet teeth are in torque-transferring contact;

(i) the upper end of the lower ratchet member defines a fourth plurality of circumferentially-arrayed ratchet teeth, each ratchet tooth having a vertical
side and a sloped side, said fourth plurality of ratchet teeth being configured for engagement with the second plurality of ratchet teeth such that the vertical sides of the second and fourth pluralities of ratchet teeth are in torque-transferring contact; and

(j) the upper and lower ratchet members are axially positioned on the mandrel such that the central sleeve is movable between:

j.1 an upper position in which the first plurality of ratchet teeth are matingly engaged with the third plurality of ratchet teeth, while the second plurality of ratchet teeth are fully separated from and angularly offset from the fourth plurality of ratchet teeth; and

j.2 a lower position in which the second plurality of ratchet teeth are matingly engaged with the fourth plurality of ratchet teeth, while the first plurality of ratchet teeth are fully separated from and angularly offset from the third plurality of ratchet teeth; and

(k) the mechanism further comprises central sleeve actuation means for selectively moving the central sleeve between said upper and lower positions.

12. The angular orientation mechanism of Claim 11 wherein the central sleeve actuation means comprises:

(a) a cylindrical piston disposed above the central sleeve and axially movable within an annular space between the housing and the upper ratchet member;

(b) a cylindrical drive sleeve disposed below the central sleeve and axially movable within an annular space between the housing and the lower ratchet member; and

(c) a helical return spring disposed below the drive sleeve.

13. The angular orientation mechanism of Claim 11, further comprising biasing means for biasing the splines of the upper and lower sections of the mandrel toward torque-transferring contact with vertical faces of the corresponding grooves in the upper and lower ratchet members, respectively.

14. The angular orientation mechanism of Claim 13 wherein the biasing means comprises a bow spring disposed within one of the grooves in the upper ratchet member, and a bow spring disposed within one of the grooves in the lower ratchet member.

15. The angular orientation mechanism of Claim 13 wherein the biasing means comprises a first torsion spring coupled between the mandrel and the upper ratchet member, and a second torsion spring coupled between the mandrel and the lower ratchet member.
A. CLASSIFICATION OF SUBJECT MATTER

E21B 7/08(2006.01)1, E21B 17/07(2006.01)1, E21B 23/12(2006.01)1

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)

IPC E21B 7/08 and E21B 17/07

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 since 1975

Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS (KIPO internal) & Keywords control, angular orientation, cylindrical mandrel, cylindrical sleeve, cylindrical ratchet member and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C

See patent family annex

Date of the actual completion of the international search

30 SEPTEMBER 2009 (30 09 2009)

Date of mailing of the international search report

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Name and mailing address of the ISA/KR

Korean Intellectual Property Office
Government Complex-Daejeon, 139 Seonsa-ro, Seogu, Daejeon 302-701, Republic of Korea

Facsimile No 82-42-472-7140

Authorized officer

KIM, Seong Kon

Telephone No 82-42-481-5526

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