The assembly comprises a bent sub (1411), and optionally a swivel (1480). The bend angle α of the bent sub in relation to the central axis of the assembly can be adjusted by rotating lower bend member (1431) relative to upper bend member (1430), which is non-rotatably attached to downhole motor (1460), using harmonic drive (1413) arranged between lower and upper bend members. In order to adjust the rotational orientation of the bent sub (1411), a swivel (1480) is provided having upper and lower swivel members (1432, 1433). Upper swivel member can be rotated relative to lower member, which is non-rotatably attached to the downhole motor, using a second harmonic drive (1423) arranged between lower and upper swivel members.
DOWNHOLE DIRECTIONAL DRILLING ASSEMBLY

[0001] The present invention relates to the field of oil and gas exploration, and in particular downhole activities, such as, for example, drilling, logging, fishing, completions, etc. More specifically, the present invention is a drive arrangement suitable for various uses, such as, for example, driving a component of a Bottom Hole Assembly (BHA) including, but not limited to, a directional drilling tool.

[0002] When drilling wellbores for oil and gas production, a drill-string is used which includes various components, such as the drill-bit, BHA and, in some cases, a drill-pipe rotatable by a topmotor at surface which in turn rotates the BHA, typically, during straight drilling. In other cases, coiled tubing is used, a continuous length of pipe wound on a spool which, typically, cannot rotate about its own axis. A workstring is used within a completed or nearly completed wellbore and includes a tubing string used to convey a treatment or equipment for well service activities. Components of these and similar arrangements for downhole activities may be required to rotate around a central axis. The drill-bit, for example, must usually rotate in order that it abrades the seabed to form the wellbore. The rotation may be the whole of the arrangement or it may be the case, for example, where coiled tubing is used, that the arrangement provides for rotation of only part of the work or a drill-string, or that different sections rotate independently, at different angular velocities and/or with different torques being exerted, or it may be advantageous that only part of the work or a drill-string rotates.

[0003] In directional drilling, the BHA typically includes a bent portion near the drill bit. Such a BHA typically includes a bent portion or a bent sub. The bent portion points in a direction slightly different from the axis of the rest of the drillstring including the drill bit. In order to allow the bit to drill in the direction the bent portion points, the drill bit is rotated, typically, by a downhole motor located within the BHA, while the drillstring above the bit and the bent portion do not rotate. The downhole motor is typically a mud motor, also referred to as a Positive Displacement Motor (PDM), driven by the flow of mud inside the drillstring.

[0004] In drill pipe drilling, where the drill pipe is rotatable by a topmotor at surface, once a particular wellbore direction has been achieved, the entire drillstring, including the drill pipe and the bent portion are rotated as one piece from surface. This allows the drilling to continue along a straight path with greater speed and torque because the rotations of the mud motor and the topmotor add at the drill bit. The rotation of the bent portion results in a slight enlargement of the wellbore diameter. However, since the bend angle between the drillstring axis and the axis of the bent portion typically lies in the region between 0°-3° and the bent portion is located close to the bit, such an enlargement is negligibly small. When a change in direction is required, the drill string can be rotated slowly to point the bent portion in the required direction downhole.

[0005] In conventional coiled tubing directional drilling, the coiled tubing cannot be rotated and thus it is generally not possible to obtain a straight wellbore while drilling with a bent sub. A straight drilling direction is typically achieved by alternately drilling in one direction first, then orienting the bent portion, e.g. by using a mud flow driven actuator, to point in opposite direction and then drilling in the second direction. Such drilling results in a wavy wellbore which generally follows a straight line.

[0006] A number of problems exist related to relative rotation of drillstring or workstring components downhole.

[0007] One problem associated with the use of a bent sub, regardless whether drill pipe or coiled tubing is used, is that adjustment of the angle of the bend, and consequently, the amount of deviation of the drilling direction from a straight path, invariably must be carried out manually at the surface. This means that the drilling process needs to be stopped and the entire drillstring must be pulled out to the surface and then inserted back into the wellbore. In an arrangement described in U.S. Pat. No. 4,836,303, the bend angle can be remotely adjusted downhole, thereby avoiding the need for the drillstring to be recovered to the surface for adjustment of the bend. However, the drilling operation still has to be halted and the drillstring lifted off-bottom in order for the orientation of the bent sub to be adjusted, thereby still involving a significant amount of non-drilling time (NDT) in any drilling operation. Furthermore, starting and stopping the drilling operation can result in a stuck pipe. Moreover, stopping and starting circulation of the drilling fluid, which interrupts the removal of cuttings and the cleaning of the borehole, can increase the risk of stuck pipe occurrence.

[0008] Another problem associated with the use of a bent sub in directional drilling is caused by the fact that that during directional drilling, the drill bit is rotated downhole by the mud motor whereas the drillstring including the bent sub above the bit do not rotate. The drillstring and the bent sub thus slide in the wellbore as the drill bit is advancing in the direction determined by the bent sub. Slide-drilling, along with low rate of penetration, also brings along friction problems between the drillstring and the wellbore walls, including the risk of a stuck drillstring. US 2004/0079552 attempted to address this problem in drill pipe drilling by providing a BHA with an offsetting arrangement to provide a deviation from a straight path and by connecting the drill pipe directly to the bit, dispensing with the need for a mud motor. This allows the drill pipe to rotate during directional drilling, while the BHA housing does not rotate. However, this is achieved at the expense of not being able to drill along a straight path. Furthermore, this arrangement is inherently not suitable for coiled tubing drilling. And yet furthermore, the bend angle still has to be set at surface.

[0009] A further problem in directional drilling, whether using drill pipe or coiled tubing, is caused by reactive torque created by the drillstring fluid hitting against the stator (i.e. typically the motor housing) of the downhole motor. Since the stator constitutes the body of the motor and comprises part of the BHA housing, the reactive torque twists the motor together with the BHA anticlockwise. The reactive torque at the motor housing is equal to the active drilling torque at the bit. Reactive torque causes a problem during directional drilling because the twisting of the BHA caused by reactive torque changes the toolface orientation of the bent sub over time. Reactive torque which exceeds a certain threshold (over torque) is dangerous as the twisting of the drillstring results in stresses which can lead to damage or sticking of the drillstring. Furthermore, sticking of drillstring causes highly variable RPM and drillstring torque transmitted to the BHA. This torque is reacted by the BHA, which can result in difficulty in maintaining drilling direction in directional and horizontal wells.
A still further problem associated with drill pipe drilling is that rotation of the drill pipe can result in drill string components, including the BHA experiencing excessive torque from surface rotation, which can be damaging to the drill string joints and the components of the BHA.

Some further examples of downhole activities where rotating components are involved and where problems exist related to aspects of relative rotation of components of downhole tools include:

- Wellbore cleaning while drilling
- Enhanced Rotary Steerable Systems (RSS)
- Stick slip mitigation
- BHA RPM limiter
- Lower sand screen completions
- Horizontal liners (cemented or non-cemented)
- Slotted or pre-perforated liners
- Gravel pack installations
- TCP gun deployment
- Fishing
- Included in BHA for Firing jars
- Deploying deep set packers
- Multi-lateral completions
- Casing exits

It is an aim of the present invention to obviate or mitigate one or more of the disadvantages associated with existing downhole tools.

Accordingly, the present invention provides a downhole tool assembly, comprising:

- A first body and a second body arranged to rotate one relative to the other about a rotation axis and
- A drive arrangement between the first and the second body for rotating the first and the second body relative to each other, wherein the drive arrangement comprises a harmonic drive comprising a wave generator, a flexible gear and an outer gear, wherein one of the wave generator, flexible gear and outer gear is adapted to function as a rotary input component and another of the wave generator, flexible gear and outer gear is adapted to function as a rotary output component; and wherein the downhole tool assembly comprises one or more motors for rotating a component of the downhole tool assembly, wherein the harmonic drive is arranged in a couplable relationship with the motor so that rotation of the motor results in rotation of the first and the second bodies relative to each other.

Preferably, the remaining one of the wave generator, flexible gear and outer gear is adapted to function as a stationary component of the harmonic drive.

The downhole tool arrangement preferably includes a Bottom Hole Assembly (BHA) wherein at least one of the first and second bodies is included in the BHA. The downhole tool assembly preferably forms part of a drill-string or workstring.

A harmonic drive is a special type of drive and typically comprises a wave generator (typically an elliptical hub or cam sometimes also referred to as an oval bearing), an intermediate gear, aka a flexible gear, and an outer gear, commonly referred to as a circular gear. Typically, in a harmonic drive, when the outer gear is fixed, the wave generator and the flexible gear rotate in opposite directions; when the flexible gear is fixed, the outer gear and the wave generator rotate in the same direction; and when the wave generator is fixed, the outer gear and the flexible gear rotate in the same direction. Arrangements are possible where all the three components of the harmonic drive rotate so that the harmonic drive functions as a differential. Due to its unique principle of construction, a harmonic drive provides very high or very low, depending on what is used as an input, transmission ratios (typical ratios include 100:1, 200:1, 300:1 or vice versa etc.) along with high torque transmission (due to a plurality of teeth meshing at the same time), torque multiplication (or reduction depending on what is used as an input), very compact construction, rotation precision, low vibration and absence of backlash. Since harmonic drives are known, it is not necessary to describe its construction and operation in detail.

Preferably, the first and the second bodies have a common axis of rotation.

The motor preferably comprises a rotor component for driving the component of the downhole tool assembly and a stator component wherein the rotary input component of the harmonic drive is arranged in a couplable relationship with the motor so as to transmit rotation from the motor via the harmonic drive to the rotary output component of the harmonic drive.

In one arrangement, the rotary input component of the harmonic drive is arranged in a couplable relationship with the rotor component of the motor so as to transmit rotation from the motor via the harmonic drive to the rotary output component of the harmonic drive.

In another arrangement, the rotary input component of the harmonic drive is arranged in a couplable relationship with the stator component of the motor so as to permit the stator component of the motor to rotate under the influence of reactive torque acting on the stator component during rotation of the rotor component of the motor.

In one arrangement, a pair of harmonic drives is provided, wherein in a first harmonic drive the rotary input component is arranged in a couplable relationship with the rotor component of the motor so as to transmit rotation from the motor via the harmonic drive to the rotary output component of the harmonic drive, and wherein the rotary input component of the second harmonic drive is arranged in a couplable relationship with the stator component of the motor so as to permit the stator component of the motor to rotate under the influence of reactive torque acting on the stator component during rotation of the rotor component of the motor and, preferably, wherein the first harmonic drive is incorporated into the rotary output component of the second harmonic drive so that when the rotary output component of the second harmonic drive is rotated, the first harmonic drive rotates as a unit with the rotary output component of the second harmonic drive in the direction opposite to the direction of rotation of the rotary output component of the first harmonic drive. In this arrangement, rotation of the rotary output component of the first harmonic drive in opposite directions is made possible.

In one arrangement, one of the first and second bodies comprises one of the rotor component or the stator component of the motor.

In one arrangement, the motor is a downhole motor for rotating a component of the downhole tool, such as for example a drill bit. The downhole motor is preferably arranged in a power section of the BHA of the downhole tool assembly and wherein the rotor component of the motor comprises a motor shaft extending substantially coaxially with the rotation axis of the first body relative to the second body and the stator component comprises a tubular motor
housing wherein the housing encloses the motor shaft. The down hole motor may comprise a mud motor, but it will be appreciated that alternative types of downhole motor can be utilised, e.g. a turbine motor. The motor shaft is preferably connected to an end component, which can be a drill bit or some other tool.

[0040] In another case, the motor comprises a topmotor at surface wherein the rotor component of the motor comprises a drill pipe extending between the BHA and the topmotor. Preferably, the harmonic drive is coupled to the drill pipe at the rotary input component and to the second body at the rotary output component. Where drill pipe is used, the downhole tool assembly preferably comprises a second motor in the form of a downhole motor.

[0041] The present invention is usable with either drill pipe or coiled tubing. Thus, in one arrangement, the first body comprises a drill pipe rotatable by a topmotor. In another arrangement, the first body comprises non-rotatable coiled tubing. In either of the above arrangements, i.e. where the first body comprises a drill pipe or coiled tubing, the second body preferably comprises a rotatable component of a BHA.

[0042] Thus, in one arrangement, the harmonic drive can be connected between the motor shaft of downhole motor and the rotatable component of the BHA, e.g. a bent portion or a bent sub, so as to utilise the active torque of the downhole motor to rotate the rotatable component of the BHA with considerable reduction, e.g. in order to orient a bent sub. Rotation in opposite direction can be achieved by coupling the harmonic drive to the stator component of the downhole motor and coupling the stator component to the rotatable component of the BHA and utilising the reactive torque acting on the stator component to rotate the rotatable component of the BHA.

[0043] In another arrangement, the harmonic drive is coupled between a drill pipe and a rotatable component of the BHA, e.g. a bent portion or a bent sub, wherein rotation of the drill pipe is transmitted to the rotatable component of the BHA with considerable reduction, e.g. in order to orient a bent sub or to allow the bent sub to rotate constantly but considerably slower than the drill pipe. In the latter case, the drill pipe can thus rotate during directional drilling and thereby slide drilling can be avoided while the bent portion remains non-rotating or rotates so slowly that the effect of this rotation on the drilling direction is negligibly small. Furthermore, the harmonic drive of the present invention can be equipped with a clutch arrangement, as specified in more detail below, for selective interruption of the rotary connection between the drill pipe and the BHA, e.g. in case of excessive torque exerted on the BHA by the drill pipe. The clutch arrangement is also preferably adapted to selectively lock the harmonic drive between the drill pipe and the BHA so that the drill pipe and the BHA rotate as one piece thereby providing for the possibility of drilling straight. The clutch arrangement is also preferably adapted to alter connection sequence between the motor, the wave generator, the flexible gear, the outer gear and the first or the second body of the BHA so that the first or the second body can be rotated in opposite directions.

[0044] In one arrangement, the harmonic drive is coupled between the motor and the first or the second body of the BHA, so that the first or the second body of the BHA is coupled with either the flexible gear or the outer gear so that the first or the second body can be rotated in the desired direction, or a clutch means is provided enabling first or the second body to be selectively coupled with either the outer gear or the flexible gear, so that the first or the second body can be rotated in opposite directions.

[0045] In one arrangement, the outer gear is provided in the form of a stabiliser mounted around an outer circumference of the downhole tool assembly. In one arrangement, the stabiliser is a non-rotating stabiliser.

[0046] In one arrangement, the outer gear is adapted to function as a stationary component in the harmonic drive. Preferably, the outer gear is configured so that it remains stationary in a borehole due to friction between the outer gear and a wall of the borehole while one of the flexible gear or, preferably, the wave generator functions as the rotary input component. However, the friction can be overcome when the outer gear is coupled to the motor to be rotated by the motor and the harmonic drive is locked to rotate as a unit together with the motor. In one arrangement, the outer gear can be provided with a device, e.g. a flywheel, which prevents rotation of the outer gear in the direction opposite to the rotation of the outer gear when it is coupled to the motor and the harmonic drive is locked to rotate as a unit together with the motor, when the outer gear is required to remain stationary during the operation of the harmonic drive, and permits rotation of the outer gear when the outer gear is coupled to the motor and the harmonic drive is locked to rotate as a unit together with the motor. For example, the direction opposite to the rotation of the outer gear when it is coupled to the motor and the harmonic drive is locked to rotate as a unit together with the motor, when the outer gear is required to remain stationary during the operation of the harmonic drive is a direction of reactive torque acting on the outer gear from a stator component of the motor, when the rotary input component of the harmonic drive is arranged in a coupleable relationship with the stator component of the motor so as to permit the stator component of the motor to rotate under the influence of reactive torque acting on the stator component during rotation of the rotor component of the motor.

[0047] In one embodiment, the BHA is an orienting sub in which the relative rotation between the first body and the second body results in the change of orientation of one of the two bodies with regard to the other. This change in the orientation can be angular, i.e. a change in the rotational angle between the first and second bodies due to relative rotation of the first and second bodies about a common axis or longitudinal, i.e. involving a change in the angle between longitudinal axes of the first and the second bodies.

[0048] In a preferred arrangement, the BHA comprises a bent sub or a bent portion wherein the second body of the downhole tool assembly comprises the bent portion. The bent portion has an axis positioned at an angle to a central axis of the downhole tool assembly, wherein rotation of the bent portion around the central axis of the downhole tool assembly results in a change of circumferential orientation of the bent sub, and thus in the eventual direction of advancement of the downhole tool. The bent portion is preferably provided in the form of a bent housing rotatable about the central axis of the downhole tool assembly.

[0049] The bent portion or the bent sub may be arranged so that the bend angle in relation to the central axis of the downhole tool assembly can be adjusted downhole. This is achieved, preferably, by providing a bent portion comprising first and second bend members, wherein the first bend member is co-axial with the central axis of the downhole tool assembly, and the second bend member is rotatably coupled
to the first bend member and rotatable relative thereto about a second axis of rotation which is at a non-zero angle relative to the central axis whereby the relative rotation of the first and second bend members results in the change in the bend angle between the bent portion and the central axis and wherein the first and second bend members are arranged to rotate relative to each other by a harmonic drive according the aspects described above.

[0050] Preferably, the harmonic drive comprises at least one clutch arranged so as to selectively vary the transmission of rotation between the harmonic drive and the motor, so as for example to disable the transmission or enable transmission of rotation with or without reduction and/or so as to change the direction of rotation at the output.

[0051] The clutch may be selected from many suitable types, including conical clutches, freewheels, viscous coupling, Helé-Shaw clutches, fluid drive, wet multi-plate clutch, epicyclic planetary gear system, wet clutch, magnetic inductance and other suitable.

[0052] Preferably, actuating means is provided for actuating the clutch, which can be provided in any suitable form, including a motor actuator, such as, for example, an electric actuator, pressure differential actuator (e.g. a spring), weight-on-bit (WOB) actuation, flow rate or flow pulse operated actuator.

[0053] A clutch may be adapted to selectively alternately cooperate with one or more of the wave generator, the flexible gear and the outer gear so as to enable or restrict rotation of that gear and so as to permit or restrict rotation of another gear, thereby enabling the change in the direction of rotation to occur between the first and the second body. The clutch can be active or passive, i.e. adapted to be activated/deactivated conditionally, e.g. when a certain condition is met. For example, a passive clutch can be provided between the harmonic drive and the BHA, the clutch being operable so that when torque exerted on the BHA from the drill pipe exceeds predetermined value, the clutch is activated and the rotary connection between the drill pipe and the BHA is interrupted so that the drill pipe can continue to rotate without exerting torque on the BHA.

[0054] Each of the first and second bodies preferably comprises a longitudinal axis. In a preferred embodiment, the longitudinal axes are collinear. Also, in a preferred embodiment, the longitudinal axes coincide with the mutual rotational axis of the bodies.

[0055] In a further advantageous variation, the harmonic drive may include one or more additional sets of an wave generator, a flexible gear and an outer gear, wherein the additional set of gears is linked to the existing set of gears so that the transmission ratio of the harmonic drive is a product of the transmission ratios of the existing and the additional sets. The provision of an additional gear set enables the transmission ratio of the harmonic drive to be set within a wide range of ratios, wherein each such ratio provides for a high level of precision in moving the first body in relation to the second body. For example, by providing a high reduction ratio between (such as the order of 1/100 or 1/10000 and so on) it is possible to rotate a rotatable component of a BHA very slowly, sufficiently slow so that the relative positions of the first and second bodies can be adjusted with high level of accuracy, or to make the rotation so slow that it can be regarded as non existent, where it is necessary to restrict the rotation of one of the two bodies while allowing the other body to rotate. In such an arrangement however, output torque is considerably higher than in a single-step harmonic drive and it is thus preferred to provide a torque limiting device at the output of the harmonic drive in order to prevent components of the downhole assembly from becoming damaged due to excessive torque.

[0056] In one arrangement, where a drill pipe is used in combination with a downhole motor and a bent sub, the harmonic drive is located above the downhole motor, but within the BHA and is connected between the drill pipe and a bent portion of the BHA so as to selectively to permit the rotation of the drill pipe from surface above the harmonic drive while minimising or preventing altogether rotation of the bent portion. This is achieved by carefully selecting the reduction ratio of the harmonic drive such that the resulting rotation of the bent sub is negligibly slow compared with the rotation of the drill pipe that it can be regarded as non-existent. Such an arrangement enables directional drilling in the preset direction (i.e. when the orientation of the bent sub is fixed and the bent portion slides as the bit is being rotated) with the drilling action powered by the downhole motor with the BHA and at the same time permits the drill pipe to be rotated by the drill motor above the bent portion. This arrangement eliminates the need to stop surface rotation of the drill pipe during directional drilling thereby minimising considerably friction problems in directional drilling.

[0057] The provision of a harmonic drive for rotating components of a downhole tool eliminates the need for a separate actuator motor. Instead, the harmonic drive uses the power of the primary motor (i.e. a topmotor or a downhole motor) of the downhole tool thereby reducing power consumption. A further effect of this arrangement is that it is not necessary to stop drilling or other downhole activity in order to adjust the tool orientation as the adjustment can now be done simultaneously with the drilling or the other activity while the primary motor is in operation. The considerable reduction ratio provided by the harmonic drive provides for a high precision in the adjustment of the orientation of the tool and requires low torque for functioning or the possibility to slow down the rotation of a bent portion of a bent sub to a negligible level during directional drilling so that the drill pipe upstring the bent sub can rotate at the same speed as the topmotor whereas the bent portion slides thereby setting the required drilling direction for the BHA. Furthermore, a harmonic drive has an inherently compact configuration and fits coaxially around a main longitudinal axis of the tool, thus making it easier to manufacture and assemble the tool compared to a tool with a separate actuator motor which is typically offset from the longitudinal axis of the drilling tool and thus requires asymmetric linkage components to be used to connect a drive shaft of the actuator motor with the rotating components of the sub.

[0058] In one arrangement, the rotatable component of the motor comprises an eccentric drive shaft of a downhole motor and the rotary input component of the harmonic drive is coupled directly to the eccentric drive shaft. The advantage of this arrangement over coupling to the motor shaft of the downhole motor is that this reduces the overall length of the tool.

[0059] According to a second aspect of the present invention there is provided a directional drilling tool, comprising:

[0060] a first end attachable to a drillstring, and a second end attachable to a drill bit;

[0061] a power section located intermediate the first and second ends, and adapted to provide power to the drill bit;
[0062] a swivel section having first and second swivel members non-rotatably attached to the first end and power section respectively, wherein the second swivel member is rotatably coupled to the first swivel member and rotatable relative thereto about a first axis of rotation which is coaxial with a longitudinal axis of the tool; a first harmonic drive adapted to selectively rotate the second swivel member about the first axis of rotation;
[0063] an adjustable bend section having first and second bend members non-rotatably attached to the power section and the second end respectively, wherein the first bend member is coaxial with the longitudinal axis, and the second bend member is rotatably coupled to the first bend member and having a second axis positionable at a non-zero angle relative to the longitudinal axis; and a second harmonic drive adapted to selectively rotate the first and second bend members relative each other so as to vary the angle between the longitudinal axis and the second axis.
[0064] The drilling tool may further comprise a remote control system having an operator control interface which may include a graphical display means indicating the path of the tool.
[0065] Further preferably, the drilling tool comprises a measuring device, for example a measurement while drilling (MWD) tool installed, preferably, below the swivel section and, ideally, above the power section. The MWD tool serves to read and measure drilling parameters. The BHA may also comprise a logging-while-drilling (LWD) tool in place of or in addition to MWD.
[0066] Embodiments of the second aspect of the present invention may comprise one or more features of the first aspect of the present invention and vice versa.
[0067] According to a third aspect of the invention there is provided a directional drilling system, comprising:
[0068] a directional drilling tool according to the second aspect of the invention;
[0069] a drill bit attached to the second end of the tool;
[0070] a measuring device adapted to monitor the orientation and position of the drill bit;
[0071] a remote control system having an operator control interface adapted to receive manual tool control inputs; and
[0072] an electronic controller adapted to selectively activate the first and/or second harmonic drives of the tool in response to signals from the measuring device and/or remote control system.
[0073] Each of the swivel and adjustable bend sections may further comprise one or more positional sensors adapted to communicate the rotational position of the swivel and adjustable bend sections to the controller.
[0074] Embodiments of the third aspect of the present invention may comprise one or more features of the first or second aspect of the present invention and vice versa.
[0075] According to a fourth aspect of the invention, there is provided a downhole tool assembly, comprising:
[0076] a first body and a second body arranged to rotate one relative to the other about a rotation axis and
[0077] a drive arrangement between the first and the second body for rotating the first and the second body relative to each other, wherein the drive arrangement comprises a planetary gearbox comprising a sun, a planet carrier and an annulus, wherein one of the sun, planet carrier and annulus is adapted to function as a rotary input component and another of the sun, planet carrier and annulus is adapted to function as a rotary output component; and wherein the downhole tool assembly comprises a motor for rotating a component of the downhole tool assembly, wherein the planetary gearbox is arranged in a couplable relationship with the motor so that rotation of the motor results in rotation of the first and the second bodies relative to each other.
[0078] Embodiments of the fourth aspect of the present invention may comprise one or more features of the first, second and third aspects of the present invention.
[0079] According to a fifth aspect of the present invention there is provided a directional drilling tool, comprising:
[0080] a first end attachable to a drillstring, and a second end attachable to a drill bit;
[0081] a power section located intermediate the first and second ends, and adapted to provide power to the drill bit;
[0082] a swivel section having first and second swivel members non-rotatably attached to the first end and power section respectively, wherein the second swivel member is rotatably coupled to the first swivel member and rotatable relative thereto about a first axis of rotation which is coaxial with a longitudinal axis of the tool;
[0083] a first planetary box adapted to selectively rotate the second swivel member about the first axis of rotation;
[0084] an adjustable bend section having first and second bend members non-rotatably attached to the power section and the second end respectively, wherein the first bend member is coaxial with the longitudinal axis, and the second bend member is rotatably coupled to the first bend member and having a second axis which is at a non-zero angle relative to the longitudinal axis; and
[0085] a second planetary box adapted to selectively rotate the first and second bend members relative each other so as to vary the angle between the longitudinal axis and the second axis.
[0086] Embodiments of the fifth aspect of the present invention may comprise one or more features of the first, second, third and fourth aspects of the present invention.
[0087] According to a sixth aspect of the invention there is provided a directional drilling system, comprising:
[0088] a directional drilling tool according to the fifth aspect of the invention;
[0089] a drill bit attached to the second end of the tool;
[0090] a measuring device adapted to monitor the orientation and position of the drill bit;
[0091] a remote control system having an operator control interface adapted to receive manual tool control inputs; and
[0092] an electronic controller adapted to selectively activate the first and/or second planetary gearboxes of the tool in response to signals from the measuring device and/or remote control system.
[0093] Embodiments of the sixth aspect of the present invention may comprise one or more features of the first, second, third, fourth and fifth aspects of the present invention.
[0094] One of the advantages of the use of a planetary gear box is that a planetary gearbox has a considerable durability in high shock environments compared to other transmission devices, especially in coaxial transmission.
[0095] The present invention is particularly useful in a directional drilling sub having a bent portion where it is
necessary to be able to rotate the bent portion with respect to the central axis of the drillstring in order to change the rotational orientation of the bent portion and thereby to change the direction of drilling.

[0096] It will be however will be appreciated that the present invention is not limited to the use in a bent sub only and indeed is useful in other applications where it is necessary control relative rotation of at least a pair of components in a downhole tool assembly. Coupling the harmonic drive to a primary motor of a downhole tool assembly, e.g. a topmotor or a downhole motor causes the harmonic drive to use the rotation of the primary motor to induce relative rotation of various parts of a down hole tool assembly which need to be controlled in a desired manner and which cannot be directly rotated by the primary motor. At the same time, and equally importantly, the incorporation of the harmonic drive into a downhole tool assembly of the present invention does not result in the loss of important primary functions of the downhole tool, e.g. the ability to drill or advance straight in the wellbore.

[0097] For example, in drill pipe drilling, the present invention, in one mode of operation, provides for the rotation of the drill pipe during directional drilling while the bent housing is practically not rotating, thereby mitigating the friction problems associated with slide drilling and increasing the rate of penetration during directional drilling compared to the conventional slide drilling. Whereas in another mode of operation, the present invention provides for the rotation of the drillstring and the bent housing as one piece, thereby keeping the ability of the downhole tool assembly to drill straight ahead as opposed to drilling alternately in opposite directions when a generally straight path is required. Furthermore, the present invention allows the rotation of the drill pipe rotated by the topmotor to be used to orient the toolface and/or adjust the bend angle. Also, in drill pipe drilling, the harmonic drive in combination with an active clutch provide for the rotation of the drill pipe together with a BHA as one piece thereby permitting straight drilling. Also in drill pipe drilling, the harmonic drive in combination with a passive clutch provide for overtorque relief by interrupting the rotary connection between the drill pipe and the BHA so that the drill pipe can rotate without imparting torque on the BHA.

[0098] In both coiled tubing drilling and drill pipe drilling, the present invention allows the rotation of the downhole motor to be used to orient the toolface and/or adjust the bend angle.

[0099] In both coiled tubing drilling and drill pipe drilling, the present invention allows the reactive torque acting on the stator component of the downhole motor to be utilised to orient the rotatable component of the BHA, such as the bent portion, as well as to correct the toolface which tends to be displaced due to the reactive torque during directional drilling. The use of both the active and reactive torques of a downhole motor permits the rotation of the rotatable component in opposite directions.

[0100] Thus, advantages of the present invention include the ability for the upper string to be rotated independently of any downhole apparatus that is run below without imparting any torque or rotation to the apparatus being deployed and/or allowing the upper string to be rotated faster than the apparatus being deployed with a reduction in torque transmitted from the work-string to the said apparatus.

[0101] Further still, it may allow a predetermined torque to be held on the downhole tool without rotation of said downhole tool being deployed by maintaining a predetermined rotational speed in the work string above.

[0102] Further still, it may allow a predetermined torque limit to be set to avoid excess torque being transmitted into downhole tool and/or it may allow multiple tools to be run and functioned independently in the same work string so as to allow a combination of variable speed and torque to be conveyed to many parts of the same work string.

[0103] Moreover, it may allow multiple tools to be run and functioned independently in the same work string so as to allow a combination of variable speed and torque and tool lock out to be conveyed to many parts of the same work string and/or it may allow tools to be locked to provide full one to one drive from work string to the downhole tool that is being deployed.

[0104] Further still, it may allow the upper string to be rotated slower than the apparatus being deployed with a considerable reduction in torque transmitted from the work-string to the said apparatus and/or it may allow the upper string to be rotated faster than the apparatus being deployed with an increase in torque transmitted from the work-string to the said apparatus.

[0105] The present invention may find application in several applications, including:

[0106] Wellbore cleaning while drilling
[0107] Slide drilling
[0108] Enhanced RSS
[0109] Stick slip mitigation
[0110] BHA RPM limiter
[0111] Torque reduction
[0112] Lower sand screen completions
[0113] Horizontal liners (cemented or non-cemented)
[0114] Slotted or pre-perforated liners
[0115] Gravel pack installations
[0116] TCP gun deployment
[0117] Fishing
[0118] Included in BHA for firing jars
[0119] Deploying deep set packers
[0120] Multi-lateral completions
[0121] Casing exits

[0122] Embodiments of the present invention will now be described by way of example only, with reference to the accompanying drawings in which:

[0123] FIGS. 1 to 3 and 5 to 8a and 9 to 11 are schematic illustrations of longitudinal cross-sectional partial views of respective first, second, third, fourth, fifth, sixth, seventh, eighth, ninth and tenth embodiments of a downhole tool of the invention;

[0124] FIG. 4 is a schematic illustration of a longitudinal cross-sectional view of the embodiment of FIG. 3;

[0125] FIG. 8b is a transverse cross-section of an outer gear having a device permitting rotation of the outer gear in one direction and preventing rotation in the opposite direction;

[0126] FIGS. 12 and 13 are schematic partially cross-sectional side views of variations of a downhole assembly of the invention having a bent section for directional drilling;

[0127] FIG. 14 is a further variation of a downhole assembly of the invention having an adjustable bend section and a swivel section;

[0128] FIGS. 15 and 16 are cross-sectional partial side views showing an adjustable bend section in more detail.

[0129] In the presently described embodiments the downhole tool assembly of the invention is described in the form of a directional drilling tool, as will be described in more detail.
below, comprising a BHA having a bent portion having a bent axis wherein the orientation of the bent axis in relation to a central axis of the BHA can be adjusted downhole. It will be appreciated that embodiments of the invention as described below, suitably adapted as would be readily apparent to a person skilled in the art, can be used in other downhole tools, such as for example logging, fishing, completions etc. where it is required to rotate a first body relative to a second body about a rotation axis.

[0130] Initially, referring to FIGS. 1 to 8a and 9 to 11, the general principles of the invention will be described. For brevity, some features common for some or all the Figures have been denoted using common reference numerals.

[0131] A downhole tool assembly 1, 2, 3, 4, 5, 5a, 6, 7, 8, 9, 5000 according to the first aspect of the present invention comprises a BHA 10, 20, 30, 40, 50, 50a, 60, 70, 80, 90, 5050 comprising a bent portion (not shown). The downhole tool assembly 1, 2, 3, 4, 5, 5a, 6, 7, 8, 9, 5000 comprises a first body 11, 21, 31, 41, 51, 51a, 61, 71, 81, 91, 5051 and a second body 12, 22, 32, 42, 52, 52a, 62, 72, 82, 92, 5052 arranged to rotate one relative to the other about a rotation axis 1000 which is also a common axis of the first and second bodies. In the presently described embodiments, the downhole tool assembly 1, 2, 3, 4, 5, 5a, 6, 7, 8, 9, 5000 forms part of a drill string, but it will be appreciated that the present invention can be incorporated into other workstrings. At least one of the first or second bodies belongs to the BHA 10, 20, 30, 40, 50, 50a, 60, 70, 80, 90, 5050.

[0132] In the presently described embodiments, in the BHA 10, 20, 30, 40, 50, 50a, 60, 70, 80, 90, 5050 rotation of the first body 11, 21, 31, 41, 51, 51a, 61, 71, 81, 91, 5051 relative to the second body 12, 22, 32, 42, 52, 52a, 62, 72, 82, 92, 5052 results in the change of orientation of one of the two bodies with regard to the other. The change in the orientation can be angular, i.e. involve a change in the relative rotational disposition of the first and second bodies or longitudinal, i.e. involving a change in the angle between longitudinal axes of the first and second bodies or both.

[0133] The downhole tool assembly 1, 2, 3, 4, 5, 5a, 6, 7, 8, 9, 5000 comprises a drive arrangement 1001 for rotating the first and the second bodies relative to each other. The drive arrangement comprises a harmonic drive 13, 23, 33, 43, 53, 53a, 63, 73, 83, 93, 5053 comprising a wave generator 14, 24, 34, 44, 54, 64, 74, 84, 94, 5054 a flexible gear 15, 25, 35, 45, 55, 65, 75, 85, 95, 5055 and an outer gear 16, 26, 36, 46, 56, 66, 76, 86, 96, 5056. As will become more apparent from the following description, one of the wave generator, flexible gear and outer gear is adapted to function as a rotary input component and another of the wave generator, flexible gear and outer gear is adapted to function as a rotary output component.

[0134] Still referring to FIGS. 1 to 8a and 9 to 11, the downhole tool comprises a motor (not shown) for rotating a component of the downhole tool assembly 1, 2, 3, 4, 5, 5a, 6, 7, 8, 9, 5000. The harmonic drive 13, 23, 33, 43, 53, 63, 73, 83, 93, 5053 is arranged in a couplable relationship with the motor so that rotation of the motor results in rotation of the first and the second bodies relative to each other.

[0135] The motor comprises a rotor component 17, 47, 57, 57a, 67, 77, 87, 97, 5057 (FIGS. 1, 5 to 8a and 9 to 11), for driving a component the down-hole assembly, e.g. a drill bit and a stator component 28, 38 (FIGS. 2 to 4). In the embodiments of FIGS. 2 to 4, the stator component 28, 38 is a housing of a downhole motor, as will be discussed below. The rotary input component of the harmonic drive 13, 23, 33, 43, 53, 53a, 63, 73, 83, 93, 5053 is arranged in a couplable relationship with the motor so as to transmit rotation from the motor via the harmonic drive 13, 23, 33, 43, 53, 53a, 63, 73, 83, 93, 5053 to the rotary output component of the harmonic drive 13, 23, 33, 43, 53a, 63, 73, 83, 93, 5053.

[0136] In the embodiments shown in FIGS. 1 to 8a and 9 to 11, the rotary input component of the harmonic drive 13, 23, 33, 43, 53, 53a, 63, 73, 83, 93, 5053 is arranged in a couplable relationship with the rotor component 17, 47, 57, 57a, 67, 77, 87, 97, 5057 of the motor so as to transmit rotation of the rotor component 17, 47, 57, 57a, 67, 77, 87, 97, 5057 via the harmonic drive 13, 43, 53, 53a, 63, 73, 83, 93, 5053 to the rotary output component of the harmonic drive 13, 43, 53, 53a, 63, 73, 83, 93, 5053. In FIGS. 1, 5 to 8a and 9 to 11, the rotary input component is the wave generator 14, 44, 54, 54a, 64, 64a, 74, 84, 94, 5054 and the rotary output component is the flexible gear 15, 45, 55, 65, 75, 85, 95, 5055. Additionally, in FIGS. 9 and 10, the outer gears 86, 96 can function as the rotary output components as will be specified below.

[0137] In the embodiments shown in FIGS. 2 to 4, the rotary input component of the harmonic drive 23, 33 is arranged in a couplable relationship with the stator component (housing) 28, 38 of the motor so as to permit, when required, the stator component 28, 38 of the motor to rotate under the influence of a reactive torque acting on the stator component 28, 38 during rotation of the rotor component of the motor. In FIGS. 2 to 4, the rotary input component, in this case the flexible gear 25, 35 of the harmonic drive 23, 33 is coupled to the stator component (housing) 28, 38 to enable transmission of rotation via the harmonic drive 23, 33 using the reactive torque of the stator component (housing) 28, 38. In this embodiment, although the rotary output component is the wave generator 24, 34, the rotation at the output is idle, i.e. the wave generator rotates without transmitting the rotation anywhere, whereas the reactive rotation of the stator component (housing) 28, 38 achieved by the provision of the harmonic drive 23, 33 is the actual useful output. The outer gear 26, 36 functions as a stationary component of the harmonic drive when the harmonic drive is open for transmission.

[0138] In FIGS. 1 to 6, the motor is a downhole motor, e.g. a mud motor, for rotating a component of the downhole tool assembly, such as for example a drill bit. The downhole motor is normally arranged in or power section of rotation of the downhole tool assembly and the rotor component of the motor comprises a motor shaft 17, 87, 97 shown extending substantially coaxially with the rotation axis 1000. The embodiments of FIGS. 2, 3 and 4 also include motor shaft which is not visible in the drawings because the harmonic drive 23, 33 is positioned above the power section in these embodiments.

[0139] In the embodiments of FIGS. 1 to 6, the downhole motor comprises a tubular housing 18, 28, 38, 88, 98, which encloses the motor shaft and constitutes a reactive component of the motor. The BHA of FIGS. 1 to 6 is coupled to non-rotatable coiled tubing upstring (left-hand side of the drawings).

[0140] Thus, in FIGS. 1, 5 and 6, the harmonic drive 13, 83, 93 is connected between the motor shaft 17, 87, 97 of downhole motor and the rotatable component 12, 82, 92 of the BHA, e.g. a bent portion or a bent sub, so as to utilise the active torque of the downhole motor to rotate the rotatable component 12, 82, 92 of the BHA, e.g. to orient the bent sub. Rotation in the opposite direction can be achieved by coupling a harmonic drive 22, 32 to the stator component (hous-
ing) 28, 38 of the downhole motor and utilising the reactive torque of the stator component as illustrated in FIGS. 2 to 4. Thus, although not shown in FIGS. 1, 5 and 6, a pair of harmonic drives can be included in a BHA, one coupled to motor shaft 17 as shown in FIGS. 1, 5 and 6 and the other coupled to motor housing 18 above the power section as shown in FIGS. 2 to 4. In FIGS. 1, 5 and 6, the outer gear 16, 86, 96 normally functions as a stationary component of the harmonic drive 13, 83, 93 when the harmonic drive is open for transmissions except FIG. 5, where the outer gear 86 can operate as a rotary output component in a specific mode of operation of the harmonic drive 83, as will be described below.

[0141] In FIGS. 7 to 8a, and 9 to 11, the motor is a topmotor at surface and the rotor component of the motor comprises a drill pipe extending between the BHA and the topmotor. In FIGS. 7 to 8a, and 9 to 11, housing 48, 58, 58a, 68, 78, 5058 of the BHA is coupled to a drill pipe so as to be rotated by the drill pipe which functions as a rotor component 47, 57, 57a, 67, 77, 5057. Additionally (although not shown in the drawings), the downhole tool assembly of FIGS. 7 to 8a, and 9 to 11 preferably comprises downhole motor as a second additional motor, e.g. for drilling straight ahead.

[0142] In FIGS. 7 to 8a, and 9 to 11, the harmonic drive 43, 53, 53a, 63, 73, 5053 is coupled between the drill pipe and the rotatable component 42, 52, 52a, 62, 72, 5052 of the BHA, so that rotation of the drill pipe is transmitted to the rotatable component 42, 52, 52a, 62, 72, 5052 coupled to the BHA, e.g. to orient the bent sub or make it rotate considerably slower than the drill pipe. The latter possibility allows the drill pipe to rotate during directional drilling while the bent portion remains non-rotating or rotates so slowly that the effect of this rotation on the drilling direction is negligibly small. Thus, slide drilling and friction problems associated with it can be avoided. In FIGS. 7 to 8a, and 9 to 11, the outer gear 46, 56, 56a, 66, 76, 5056 is normally non-rotatable in the borehole due to friction with the borehole walls and thus normally serves as the stationary component of the harmonic drive 45, 55, 55a, 65, 75, 5055 with some exceptions as will be described below.

[0143] FIGS. 12 and 13 illustrate examples of downhole assemblies in which the present invention can be incorporated. In FIGS. 12 and 13, the downhole assemblies comprise drilling BHAs 1210, 1310, respectively. BHA 1210, 1310 comprises a bent portion 1211, 1311 and the bent portion 1211, 1311 comprises the body of the downhole tool assembly of the present invention. The bent portion 1211, 1311 has an axis positioned at an angle to the central axis 1000 of the downhole tool assembly. Rotation of the bent portion 1211, 1311 around the central axis 1000 of the downhole tool assembly results in a change of rotational orientation of the bent portion 1211, 1311 in relation to the rest of the drill string and thus in the eventual direction of drilling. The bent portion 1211, 1311 can also be configured so that its bend angle in relation to the central axis 1000 of the downhole tool assembly can be adjusted downhole as will be described below.

[0144] FIG. 12 illustrates a BHA 1210 having a harmonic drive 1213 arranged in the BHA 1210 similar to the arrangements of FIGS. 1, 5 and 6, i.e. the harmonic drive 1213 is connected between a motor shaft 1217 of a downhole motor 1260 and the bent portion 1211 so as to utilise the active torque of the downhole motor shaft 1217 to rotate the bent sub 1211 and thus to change drilling direction. In the BHA 1210, the motor shaft 1217 is coupled to a wave generator 1214, which drives a flexible gear 1215 in order to rotate the bent portion 1211 while an outer gear 1216 coupled to motor housing 1218, which in turn is coupled to non-rotatable coiled tubing sting 1240, remains stationary.

[0145] FIG. 13 illustrates a BHA 1310 having a harmonic drive 1313 arranged in the BHA 1310 similar to the arrangements of FIGS. 7 to 8a and 9 to 11, i.e. the harmonic drive 1313 is coupled between a drill pipe 1340 rotatable from surface and the bent portion 1311, but above a downhole motor 1360, so that rotation of the drill pipe 1340 is transmitted to the entire BHA 1310 and the BHA 1310 is thus rotated as a unit with the downhole motor 1360 in order to orient the bent portion 1311 or make it rotate considerably slower than the drill pipe during directional drilling. The latter possibility allows the drill pipe 1340 to rotate during directional drilling while the bent portion 1311 remains non-rotating or rotates so slowly that the effect of this rotation on the drilling direction is negligibly small. Thus, slide drilling and friction problems associated with it can be avoided. In the BHA 1310, an outer gear 1316 of the harmonic drive 1313 is normally non-rotatable in the borehole due to friction with the borehole walls and thus normally serves as the stationary component of the harmonic drive 1313 whereas the drill pipe 1340 rotates a wave generator 1314, which drives a flexible gear 1315 in order to rotate the BHA 1310 as a whole.

[0146] Often, a downhole assembly comprises a measuring device, for example a measurement while drilling (MWD) tool to read and measure drilling parameters. As shown in FIGS. 12 and 13, an MWD tool 1290, 1390 respectively installed above the downhole motor 1260, 1360.

[0147] FIG. 14 shows a BHA 1410 having an adjustable bend portion 1411, similar to the bent portions 1211, 1311, but in which the bend angle \( \alpha \) of the bent portion 1411 in relation to the central axis 1000 of the BHA 1410 can be adjusted. This is achieved by providing the bent portion 1411 with first and second bend members 1430, 1431, wherein the first bend member 1431 is co-axial with the central axis 1000 of the BHA 1410 and is non-rotatably attached to housing 1418 of downhole motor 1460 below the motor 1460, and the second bend member 1431 is rotatably coupled to the first bend member 1430 and has a second axis 1010. The angle \( \alpha \) between the second axis and the central axis 1000 can be changed between zero and \( \alpha_{\text{max}} \) degrees. A joint is provided between the first and second bend members 1430, 1431 such that the relative rotation of the first and second bend members 1430, 1431 via the joint results in the change in the value of bend angle \( \alpha \) between the axis 1010 of bent portion 1411 and the central axis 1000. A harmonic drive 1413 is provided between the first and second bend members 1430, 1431 to rotate the first and second bend members 1430, 1431 relative to each other in the same manner as described above in relation to FIG. 12. In the embodiment of FIG. 14, in order to adjust the rotational orientation of the bent portion 1411 a swivel section 1480 is provided having first and second swivel members 1432, 1433. The first swivel member 1432 is non-rotatably attached to a drill string 1440 and the second swivel member 1433 is non-rotatably attached to the housing 1418 of the downhole motor 1460 above the motor 1460. The first and second swivel members 1432, 1433 are rotatably coupled to each other and rotatable relative to each other about an axis 1011 of rotation which is co-axial with the central axis 1000. A harmonic drive 1423 is provided between the first and second bend members 1432, 1433 to rotate the
first and second swivel members 1432, 1433 relative to each other in the same manner as described above in relation to FIG. 13.

[0148] FIGS. 15 and 16 illustrate a joint 1480 between the first and second bend members 1430, 1431 which allows the angle between the second axis 1010 and the central axis 1000 can be varied. The joint 1480 is provided by a spherical spline member 1481 which engages a bend adjustment coupling 1482. The spherical spline member 1481 is non-rotatably connected with one end of a bend adjustment sleeve 1445. The bend adjustment sleeve 1445 is coupled to a harmonic drive 1413 at the other end of the bend adjustment sleeve 1445. The bend adjustment coupling 1482 is non-rotatably coupled with the second bend member 1431. The bend adjustment coupling 1482 has a longitudinal rotation axis 1020 which is oriented at an angle $\beta - \alpha_{\text{max}}/2$ to the central axis 1000 and the second axis 1010. The bend adjustment coupling 1482 is rotated by a harmonic drive 1413 in a manner similar to that described with reference to FIG. 12. Specifically, motor shaft 1417 of a downhole motor (not shown) rotates a wave generator 1414 via a clutch 1419 controlled by actuator 1499 in a similar manner as described with reference to FIG. 1. The wave generator 1414 drives a flexible gear 1415 in order to rotate the bend adjustment sleeve 1445 together with the spherical spline member 1481, which in turn causes rotation of the bend adjustment coupling 1482 about the rotation axis 1020 through 180 degrees. An outer gear 1416 coupled to the first bend member 1430 which in turn is non-rotatably coupled to motor housing (not shown) remains stationary. The rotation of the bend adjustment coupling 1482 about the rotation axis 1020 through 180 degrees causes the rotation of the second bend member 1431 about rotation axis 1020 during which the angle $\beta$ and a angle between the rotation axis 1020 and the second axis 1010 either add up or subtract resulting in the change of the angle $\alpha$ between the second axis 1010 and the central axis 1000 between zero and $\alpha_{\text{max}}$ degrees. In FIG. 15 the bend member 1431 is shown fully bent at an angle $\alpha_{\text{max}}$ to the central axis 1000, whereas in FIG. 16 the axis 1010 of second bend member 1431 is aligned at zero degrees with the central axis 1000. The motor shaft 1417 has universal joints which allow the motor shaft to comply with the change of the angle between the second axis 1010 and the central axis 1000.

[0149] The harmonic drive 13, 53, 53a, 63, 73, 83, 93 comprises a clutch or clutches arranged so as to selectively vary the transmission of rotation between the harmonic drive and the motor or to selectively alterate the direction of rotation of a gear and so as to permit or restrict rotation of another gear, thereby enabling the change in the direction of rotation between the first and the second body, or to selectively interrupt the rotary connection between the drill pipe and the BHA, e.g. in case of too high torque exerted on the BHA by the drill pipe. The clutch can be a passive clutch, i.e. adapted to be activated/deactivated conditionally, e.g. when a certain condition is met, e.g. when torque exerted on the BHA from the drill pipe exceeds predetermined value, the clutch is activated and the rotary connection between the drill pipe and the BHA is disconnected, or an active clutch, i.e. activatable by a positive control signal, such as operator's signal from surface.

[0150] In FIG. 1, clutch 19 is movably mounted on the shaft 17 to engage or disengage the wave generator 14 so as to respectively enable or disable transmission through the harmonic drive 13. Clutch 19 is driven by an actuator 199. Specifically, when the clutch 19 is engaged with the wave generator 14, rotation from the motor shaft 17 is transmitted by the wave generator 14 to the flexible gear 15 which rotates the second body 12, which can be e.g. a bent sub, in the direction opposite to the direction of rotation of the motor shaft 17. When the clutch 19 is disengaged from the wave generator 14, the motor shaft 17 rotates freely without transmitting rotation to the wave generator 14. The outer gear 16 is non-rotatably mounted on the first body 11, i.e. the motor housing 18 which is normally stationary and thus serves as the stationary component in the harmonic drive 13.

[0151] In FIG. 2, clutch 29 is movably mounted on the inner side of the first body 21 to engage or disengage the wave generator 24. When the clutch 29 is disengaged, the housing 28 (together with the flexible gear 25) are able to rotate under the influence of a reactive torque acting on the motor housing 28 from the motor shaft and the rotation is transmitted to the wave generator 24 which rotates freely, as described above, without transmitting the rotation further, the resulting useful output rotation being the rotation of the housing 28. The outer gear 26 is non-rotatably mounted on the first body 11, i.e. a portion of non-rotational coiled tubing, and thus serves as the stationary component in the harmonic drive 23. When the clutch 29 is engaged with the wave generator 24, the wave generator becomes locked to the coiled tubing so that no rotation is possible within the harmonic drive 23. Thus, the coiled tubing, the harmonic drive 23 and the motor housing 22 become a stationary unit. Clutch 29 is driven by an actuator 299.

[0152] In FIGS. 3 and 4, when clutch 39 is disengaged, the housing 38 together with the flexible gear 3 are able to rotate under the influence of a reactive torque acting on the motor housing 38 from the motor shaft and the rotation is transmitted to the wave generator 34 which rotates freely together with the clutch 39, as described above, without transmitting the rotation further, the resulting useful output rotation being the rotation of the housing 38. The outer gear 36 is non-rotatably mounted on the first body 31, i.e. a portion of non-rotational coiled tubing, and thus serves as the stationary component in the harmonic drive 33. When the clutch 39 engages the housing 38 (and the flexible gear 35), the flexible gear 35 together with the housing 38 become locked to the coiled tubing (first body 31) via the clutch 39 so that no rotation is possible within the harmonic drive 33. Thus, the coiled tubing, the harmonic drive 33 and the motor housing 32 become a stationary unit. This arrangement prevents the reactive torque acting on the housing 38 from acting on the components of the harmonic drive 33, especially the flexible gear, when the harmonic drive 33 is locked. Instead, the reactive torque acts on the clutch 39. Clutch 39 is driven by an actuator 399.

[0153] In FIG. 5, the wave generator 84 acts as the rotary input component and is rotated by the motor shaft 87. When clutch 89 is moved fully to the right along arrow B, the left portion 85a of the flexible gear 85 engages surface A1 of the first body 81, i.e. the motor housing 88, whereas the right portion of the outer gear 86 engages surface A2 of the second body 82, e.g. a bent sub housing, and splines 891 of the outer gear 86 disengage. In this position, the outer gear 86 rotates at the output in the same direction as the shaft 87 and thus rotates the second body 82 whereas the flexible gear 85 is locked to the motor housing 88, which is normally stationary, and thus the flexible gear 85 also remains stationary. When the clutch
89 is moved fully to the left along arrow B, the right portion 85b of the flexible gear 85 engages surface B1 of the second body 82, whereas the left portion of the outer gear 86 engages surface B2 of the second body 82 and splines 891 of the outer gear 86 disengage. In this position, the flexible gear 85 rotates at the output in the direction opposite to the direction of rotation of the shaft 87 and thus rotates the second body 82 whereas the outer gear 86 is locked to the motor housing 88 and remains stationary. When the clutch 89 is in an intermediate position, splines 891 lock the outer gear 86 to each of the first and second bodies, 81, 82 thereby locking the harmonic drive 83 altogether. Actuator 899 is provided for operating the clutch 89.

[0154] In FIG. 6, clutch 991 is movable by actuator 999 right or left along arrow C and clutch 992 is spring actuated and is movable along arrow D also by actuator 999. When the clutch 991 is in the fully left position, the clutch 991 engages the flexible gear 95 so that the flexible gear 95 is locked to the first body 91, i.e. the motor housing 98 which is normally stationary, and thus the flexible gear 95 also remains stationary. At the same time, the clutch 992 engages shaft 97 and the wave generator 94 so that the wave generator 94 is rotated by the shaft 97. The output rotation is provided by the outer gear 96 which rotates in the same direction as the shaft 97 and thus rotates the second body 92, e.g. a bent sub housing, via a first freewheel 994 which allows rotation only in one direction, presently clockwise. When the clutch 991 is in an intermediate position, the clutch 991 engages the outer gear 96 so that the outer gear 96 is locked to the motor housing 98 which is normally stationary, and thus the outer gear 96 also remains stationary. At the same time, the clutch 992 engages shaft 97 and the wave generator 94 so that the wave generator 94 is rotated by the shaft 97. The output rotation is provided by the flexible gear 95 which rotates in the direction opposite to the direction of rotation of the shaft 97 and thus rotates the second body 92, e.g. a bent sub housing, via a first freewheel 995 which allows rotation only in one direction, presently counterclockwise. When the clutch 991 is in the fully right position, the clutch 991 is engaged with the outer gear 96 so that the outer gear 96 is locked to the motor housing 98 which is normally stationary, and thus the outer gear 96 also remains stationary whereas the clutch 992 disengages the wave generator 94 and engages the flexible gear 95 which thus also becomes locked to the motor housing 98. In this position, no rotation is transferred from the shaft 97 to the wave generator 94 whereas the harmonic drive 93 is locked and cannot transmit rotation.

[0155] Although not illustrated, in the arrangement of FIG. 7, a safety clutch can be provided between the harmonic drive 43 and the drill-string above the BHA. Such a clutch can be sensitive to the torque exerted on the BHA and if the torque exceeds a certain predetermined value, the clutch disconnects the BHA from the upper string and the overtorque is borne by the clutch instead of the BHA thereby mitigating any potential damage to the BHA and other parts of the drill-string. Otherwise, in the embodiment of FIG. 7, rotation by a drill pipe of the BHA housing 48 is transmitted to the wave generator 44 first, then to the flexible gear 45 which rotates the second body 42, e.g. a bent sub, in the direction opposite to the direction of rotation of the drill pipe, while the outer gear 46 remains non-rotational due to friction with the borehole walls.

[0156] In FIGS. 8 and 9, spring action clutches 59, 69 are provided to lock the rotating BHA housing 58, 68 to the outer gears 56, 66 causing the normally stationary, non-rotatable, due to friction with the borehole walls, outer gears 56, to rotate as a unit with the housing 58, 68 and locking the harmonic drive 53, 63 so that the second rotating body 52, 62 also rotates as a unit with the housing 58, 68 without reduction. Clutches 59, 69 are spring activated via weight-on-bit (WOB) actuation, as indicated by arrows X in FIGS. 8 and 9. When the clutches 59, 69 are disengaged, rotation by a drill pipe of the BHA housing 58, 68 is transmitted to the wave generator 54, 64 first, then to the flexible gear 55, 65 which rotates the second body 52, 62, e.g. a bent sub, in the direction opposite to the direction of rotation of the drill pipe, while the outer gear 56, 66 remains non-rotational due to friction with the borehole walls.

[0157] In the embodiments described with reference to FIGS. 7 and 8 above and FIGS. 9 and 10 below, the outer gear 46, 56, 66, 76 is required to be non-rotating, because it serves both as a stationary component of harmonic drive 43, 53, 63, 73 and a sliding stabiliser, e.g. in directional drilling, and is thus designed to have high friction qualities to engage the borehole walls without rotation. However, the outer gear 46, 56, 66, 76 experiences a reactive torque from a motor shaft rotating downstream of the outer gear 46, 56, 66, 76. This reactive torque attempts to rotate the outer gear 46, 56, 66, 76 in the opposite direction, typically counterclockwise. On the other hand, the outer gear 56, 66, 76 of FIGS. 8, 9 and 10 is required to rotate when the clutch 59, 69, 79 locks the harmonic drive 53, 63, 73 and thus can experience excessive friction which can be damaging to the outer gear 56, 66, 76. FIGS. 8a and 8b depict arrangements addressing this issue.

[0158] An embodiment shown in FIG. 8a is similar to the embodiment of FIG. 8 and therefore numerals which indicate the same features as those of FIG. 8 have been used in FIG. 8a with the addition of “a” at each reference numeral. As shown in FIG. 8a, flywheels 560a are provided between the outer gear 56a and each of the housing 58a and the second body 52a, which can be e.g. a bent sub. The flywheels 560a only allow rotation in one direction (arrow W) which is the same as the direction of rotation of the housing 58a. Thus, when the clutch 59a is disengaged, the outer gear 56a remains non-rotational because the flywheels 560a prevent the outer gear 56a from rotating in the direction opposite to the one indicated by arrow W under the influence of a reactive torque. On the contrary, when the clutch 59a is engaged, the flywheels 560a allow the outer gear 56a to rotate in the same direction as the housing 58a (arrow Y). In FIG. 8b an alternative to providing flywheels 560a of FIG. 8a is shown in the form an outer gear 56b which itself is formed as a flywheel 560b with engaging members 561b which engage the borehole wall to prevent rotation in one direction and release when rotation is attempted in the opposite direction. It is beneficial to include flywheels 560a or 560b into the embodiments of FIGS. 7, 8, 9 and 11.

[0159] The embodiment of FIG. 9 is similar to that of FIG. 8. Additionally in FIG. 9, the harmonic drive 63 includes an additional set of components comprising a wave generator 64a, a flexible gear 65 and an outer gear 66 wherein the wave generator 64a is linked with the flexible gear 65. In this arrangement, the transmission ratio of the harmonic drive 63 is a product of the transmission ratio between wave generator 64 and the flexible gear 65 and the transmission ratio between the wave generator 64 and the flexible gear 65. The provision of an additional set of components dramatically increases the reduction ratio of the harmonic drive 66 and thus provides for a high level of precision in moving the first body 61 in relation
to the second body 62 or slows down the rotation of the second body to a negligible level, so that the first body (drill pipe) 61 can rotate while the second body (bent portion) 62 remains virtually non-rotating, thereby eliminating friction problems caused by the sliding of the drill pipe and the bent portion during conventional drill sliding.

[0160] In FIG. 10, the function of the BHA 70 and the function of the clutch 79 in the BHA 70 are similar to the function of the BHAs 50 and 60 and clutches 59, 69 of FIG. 8, 9 with the difference that the clutch 79 is arranged to selectively lock the rotating BHA housing 78 to the second body 72 (e.g., a bent sub) rather than to the outer gear 76 with the same effect of causing the normally stationary outer gear 76, to rotate as a unit with the housing 78 and locking the harmonic drive 73. Furthermore, the clutch 79 is activated by fluid pressure differential created in a restricted area 799. When the clutch 79 is disengaged, the BHA 70 functions in the same manner as described above in connection with FIGS. 8 and 9.

[0161] In FIG. 11, the function of the BHA 5050 and the function of the clutch 5059 in the BHA 5050 are similar to the function of the BHAs 50 and 60 and clutches 59, 69 of FIG. 8, 9 with the difference that the clutch 5059 is arranged to selectively lock the rotating BHA housing 5058 to the outer gear 5056 without moving the wave generator 5054 axially with respect to the flexible gear 5055 and thus preventing the wave generator 5054 and the flexible gear 5055 from damage. More specifically, in order to engage the wave generator 5054 to lock the harmonic drive 5053, the clutch 5059 is arranged to slide axially with respect to both the wave generator 5054 and the outer gear 5056 by, for example, providing spring loaded thrust bearings 5200, 5201, respectively between the clutch 5059 and each of the outer gear 5056 and the wave generator 5054. The outer gear 5053, the wave generator 5054 and the flexible gear 5055 remain stationary in the axial direction, by providing a suitable stop means, for example thrust bearings 5300, 5400, respectively between the wave generator 5054 and the outer gear 5056 and the second body 5052 mounting the flexible gear 5055 and between the outer gear 5056 and the second body 5052. When the clutch 5059 engages the wave generator 5054, the clutch is allowed to slide axially relative to the outer gear 5056 and the wave generator 5054 as the spring of the thrust bearing 5201 is compressed and the spring of the thrust bearing 5200 is extended.

[0162] The clutches may be selected from many suitable types, including conical clutches, freewheels, viscous coupling, Heli-Show clutches, fluid drive, wet multi-plate clutch, epicyclic planetary gear system, wet clutch, magnetic inductance and other suitable.

[0163] Although not illustrated, a planetary gearbox can be used in place of a harmonic drive. Such a planetary box comprises a sun, a planet carrier and an annulus, wherein one of the sun, planet carrier and annulus is adapted to function as a rotary input component and another of the sun, planet carrier and annulus is adapted to function as a rotary output component in the downhole assembly of the invention.

[0164] These and other modifications and improvements may be incorporated without departing from the scope of the present invention.

1. A downhole tool assembly, comprising:
   a first body and a second body arranged to rotate one relative to the other about a rotation axis and
   a drive arrangement between the first and the second body for rotating the first and the second body relative to each other, wherein the drive arrangement comprises a harmonic drive comprising a wave generator, a flexible gear and an outer gear, wherein one of the wave generator, flexible gear and outer gear is adapted to function as a rotary input component and another of the wave generator, flexible gear and outer gear is adapted to function as a rotary output component; and wherein the downhole tool assembly comprises at least one motor for rotating a component of the downhole tool assembly, wherein the harmonic drive is arranged in a couplable relationship with the motor so that rotation of the motor results in rotation of the first and the second bodies relative to each other.

2. A downhole tool assembly as claimed in claim 1, wherein the remaining one of the wave generator, flexible gear and outer gear is adapted to function as a stationary component of the harmonic drive.

3. A downhole tool assembly as claimed in claim 1, wherein the downhole tool arrangement comprises a Bottom Hole Assembly (BHA) wherein at least one of the first and second bodies is included in the BHA.

4. A downhole tool assembly as claimed in claim 3, wherein the first and the second bodies have a common axis of rotation.

5. A downhole tool assembly as claimed in claim 4, wherein the motor comprises a rotor component for driving the component of the downhole tool assembly and a stator component wherein the rotary input component of the harmonic drive is arranged in a couplable relationship with the motor so as to transmit rotation from the motor via the harmonic drive to the rotary output component of the harmonic drive.

6. A downhole tool assembly as claimed in claim 5, wherein the rotary input component of the harmonic drive is arranged in a couplable relationship with the rotor component of the motor so as to transmit rotation from the component of the motor via the harmonic drive to the rotary output component of the harmonic drive.

7. A downhole tool assembly as claimed in claim 5, wherein the rotary input component of the harmonic drive is arranged in a couplable relationship with the stator component of the motor so as to permit the stator component of the motor to rotate under the influence of reactive torque acting on the stator component during rotation of the rotor component of the motor.

8. A downhole tool assembly as claimed in claim 5, wherein a pair of harmonic drives is provided, wherein in a first harmonic drive the rotary input component is arranged in a couplable relationship with the rotor component of the motor so as to transmit rotation of the rotor component of the motor via the harmonic drive to the rotary output component of the harmonic drive, and wherein the rotary input component of the second harmonic drive is arranged in a couplable relationship with the stator component of the motor so as to permit the stator component of the motor to rotate under the influence of reactive torque acting on the stator component during rotation of the rotor component of the motor and, wherein the first harmonic drive is incorporated into the rotary output component of the second harmonic drive so that when the rotary output component of the second harmonic drive is rotated, the first harmonic drive rotates as a unit with the rotary output component of the second harmonic drive in the direction opposite to the direction of rotation of the rotary output component of the first harmonic drive, thereby
enabling rotation of the rotary output component of the first harmonic drive in opposite directions.

9. A downhole tool assembly as claimed in claim 8, wherein one of the first and second bodies comprises one of the rotor component or the stator component of the motor.

10. A downhole tool assembly as claimed in claim 9, wherein the motor is a downhole motor for rotating a component of the downhole tool, the downhole motor being arranged in a power section of the Bottom Hole Assembly (BHA) and wherein the rotor component of the motor comprises a motor shaft extending substantially coaxially with the rotation axis of the first body relative to the second body and the stator component comprises a tubular motor housing wherein the housing encloses the motor shaft.

11. A downhole tool assembly as claimed in claim 10, wherein the motor comprises a topmotor at surface wherein the rotor component of the motor comprises a drill pipe extending between the Bottom Hole Assembly (BHA) and the topmotor, wherein the harmonic drive is coupled to the drill pipe at the rotary input component and to the second body at the rotary output component.

12. A downhole tool assembly as claimed in claim 11, wherein the first body comprises a drill pipe rotatable by a topmotor.

13. A downhole tool assembly as claimed in claim 12 wherein the first body comprises non-rotatable coiled tubing.

14. A downhole tool assembly as claimed in claim 13, wherein the second body comprises a rotatable component of the BHA.

15. A downhole tool assembly as claimed in claim 14, wherein the harmonic drive is connected between the motor shaft of downhole motor and the rotatable component of the BHA, so as to utilise the active torque of the downhole motor to rotate the rotatable component of the BHA with reduction.

16. A downhole tool assembly as claimed in claim 15, wherein the harmonic drive is coupled to the stator component of the downhole motor and the stator component is coupled to the rotatable component of the BHA so as to utilise the reactive torque acting on the stator component to rotate the rotatable component of the BHA.

17. A downhole tool assembly as claimed in claim 14, wherein the harmonic drive is coupled between a drill pipe and the rotatable component of the BHA, wherein rotation of the drill pipe is transmitted to the rotatable component of the BHA with reduction in order to orient a bent portion of the BHA or to allow the bent portion to rotate constantly but considerably slower than the drill pipe.

18. A downhole tool assembly as claimed in claim 17, wherein the harmonic drive is equipped with a clutch arrangement adapted for selective interruption of the rotary connection between the drill pipe and the BHA and/or for selectively locking the harmonic drive between the drill pipe and the BHA so that the drill pipe and the BHA rotate as one piece, and/or for altering connection sequence between the motor, the wave generator, the flexible gear, the outer gear and the first or the second body of the BHA so that the first or the second body can be rotated in opposite directions.

19. A downhole tool assembly as claimed in claim 18, wherein the harmonic drive is coupled between the motor and the first or the second body of the BHA, so that the first or the second body of the BHA is coupled with either the flexible gear or the outer gear so that the first or the second body can be rotated in the desired direction, or a clutch means is provided enabling first or the second body to be selectively coupled with either the outer gear or the flexible gear, so that the first or the second body can be rotated in opposite directions.

20. A downhole tool assembly as claimed in claim 19, wherein the outer gear is provided in the form of a stabiliser mounted around an outer circumference of the downhole tool assembly.

21. A downhole tool assembly as claimed in claim 20, wherein the stabiliser is a non-rotating stabiliser.

22. A downhole tool assembly as claimed in claim 21, wherein the outer gear is adapted to function as a stationary component in the harmonic drive.

23. A downhole tool assembly as claimed in claim 22, wherein the outer gear is configured so that it remains stationary in a borehole due to friction between the outer gear and a wall of the borehole while one of the flexible gear or the wave generator functions as the rotary input component.

24. A downhole tool assembly as claimed in claim 23, wherein the outer gear is configured so that the friction can be overcome when the outer gear is coupled to the motor to be rotated by the motor and the harmonic drive is locked to rotate as a unit together with the motor.

25. A downhole tool assembly as claimed in claim 24, wherein the outer gear is provided with a device which is configured to prevent rotation of the outer gear in the direction opposite to the rotation of the outer gear when it is coupled to the motor and the harmonic drive is locked to rotate as a unit together with the motor, when the outer gear is required to remain stationary during the operation of the harmonic drive, and permits rotation of the outer gear when the outer gear is coupled to the motor and the harmonic drive is locked to rotate as a unit together with the motor.

26. A downhole tool assembly as claimed in claim 25, wherein the BHA is an orienting sub in which the relative rotation between the first body and the second body results in the change of orientation of one of the two bodies with regard to the other, wherein the change in the orientation is angular, i.e. a change in the rotational angle between the first and second bodies due to relative rotation of the first and second bodies about a common axis or longitudinal, i.e. involving a change in the angle between longitudinal axes of the first and the second bodies.

27. A downhole tool assembly as claimed in claim 26, wherein the BHA comprises a bent sub or a bent portion wherein the second body of the downhole tool assembly comprises a bent portion, wherein the bent portion has an axis positioned at an angle to a central axis of the downhole tool assembly, wherein rotation of the bent portion around the central axis of the downhole tool assembly results in a change of circumferential orientation of the bent sub.

28. A downhole tool assembly as claimed in claim 27, wherein the bent portion or the bent sub is arranged so that the bend angle in relation to the central axis of the downhole tool assembly can be adjusted downhole, wherein the bent portion comprises first and second bend members, wherein the first bend member is coaxial with the central axis of the downhole tool assembly, and the second bend member is rotatably coupled to the first bend member and rotatable relative thereto about a second axis of rotation which is at a non-zero angle relative to the central axis whereby the relative rotation of the first and second bend members results in the change in the bend angle between the bent portion and the central axis.

29. A downhole tool assembly as claimed in claim 28, wherein the harmonic drive comprises at least one clutch.
arranged so as to selectively vary the transmission of rotation between the harmonic drive and the motor, so as to disable the transmission or enable transmission of rotation with or without reduction and/or so as to change the direction of rotation at the output.

30. A downhole tool assembly as claimed in claim 29, wherein actuating means is provided for selectively actuating the clutch.

31. A downhole tool assembly as claimed in claim 30, wherein the clutch is adapted to selectively alternately cooperate with one or more of the wave generator, the flexible gear and the outer gear so as to enable or restrict rotation of that gear and so as to permit or restrict rotation of another gear, thereby enabling the change in the direction of rotation to occur between the first and the second body.

32. A downhole tool assembly as claimed in claim 31, wherein the harmonic drive includes one or more additional sets of an wave generator, a flexible gear and an outer gear, wherein the additional set of gears is linked to the existing set of gears so that the transmission ratio of the harmonic drive is a product of the transmission ratios of the existing and the additional sets.

33. A downhole tool assembly as claimed in claim 32, wherein a torque limiting device is provided at the output of the harmonic drive in order to prevent components of the downhole assembly from becoming damaged due to excessive torque.

34. A downhole tool assembly as claimed in claim 10, wherein the harmonic drive is located above the downhole motor, but within the BHA and is connected between the drill pipe and a bent portion of the BHA so as to selectively permit the rotation of the drill pipe from surface above the harmonic drive while minimising or preventing altogether rotation of the bent portion, wherein the reduction ratio of the harmonic drive is such that the resulting rotation of the bent sub is negligibly slow compared with the rotation of the drill pipe that it can be regarded as non-existent.

35. A downhole tool assembly as claimed in claim 34, wherein the rotatable component of the motor comprises an eccentric drive shaft of a downhole motor and the rotary input component of the harmonic drive is coupled directly to the eccentric drive shaft.

36. A downhole tool assembly as claimed in claim 35, wherein the downhole tool assembly forms part of a drill-string or work-string.

37. A directional drilling tool, comprising:
a first end attachable to a drillstring, and a second end attachable to a drill bit;
a power section located intermediate the first and second ends, and adapted to provide power to the drill bit;
a swivel section having first and second swivel members non-rotatably attached to the first end and power section respectively, wherein the second swivel member is rotatably coupled to the first swivel member and rotatable relative thereto about a first axis of rotation which is co-axial with a longitudinal axis of the tool;
a first harmonic drive adapted to selectively rotate the second swivel member about the first axis of rotation; an adjustable bend section having first and second bend members non-rotatably attached to the power section and the second end respectively, wherein the first bend member is co-axial with the longitudinal axis, and the second bend member is rotatably coupled to the first bend member and having a second axis positionable at a non-zero angle relative to the longitudinal axis; and

a second harmonic drive adapted to selectively rotate the first and second bend members relative each other so as to vary the angle between the longitudinal axis and the second axis.

38. A directional drilling tool as claimed in claim 37, wherein the drilling tool comprises a measurement while drilling (MWD) tool for reading and measuring drilling parameters installed below the swivel section and above the power section.

39. A directional drilling system, comprising:
a directional drilling tool of claim 37;
a drill bit attached to the second end of the tool;
a measuring device adapted to monitor the orientation and position of the drill bit;
a remote control system having an operator control interface adapted to receive manual tool control inputs; and
an electronic controller adapted to selectively activate the first and/or second harmonic drives of the tool in response to signals from the measuring device and/or remote control system.

40. A directional drilling system, as claimed in claim 39 wherein each of the swivel and adjustable bend sections comprise one or more positional sensors adopted to communicate the rotational position of the swivel and adjustable bend sections to the controller.

41. A downhole tool assembly, comprising:
a first body and a second body arranged to rotate one relative to the other about a rotation axis and a drive arrangement between the first and the second body for rotating the first and the second body relative to each other, wherein the drive arrangement comprises a planetary gearbox comprising a sun, a planet carrier and an annulus, wherein one of the sun, planet carrier and annulus is adapted to function as a rotary input component and another of the sun, planet carrier and annulus is adapted to function as a rotary output component; and
wherein the downhole tool assembly comprises a motor for rotating a component of the downhole tool assembly, wherein the planetary gearbox is arranged in a couplable relationship with the motor so that rotation of the motor results in rotation of the first and the second bodies relative to each other.

42. A directional drilling tool, comprising:
a first end attachable to a drillstring, and a second end attachable to a drill bit;
a power section located intermediate the first and second ends, and adapted to provide power to the drill bit;
a swivel section having first and second swivel members non-rotatably attached to the first end and power section respectively, wherein the second swivel member is rotatably coupled to the first swivel member and rotatable relative thereto about a first axis of rotation which is co-axial with a longitudinal axis of the tool;
a first planetary box adapted to selectively rotate the second swivel member about the first axis of rotation;
an adjustable bend section having first and second bend members non-rotatably attached to the power section and the second end respectively, wherein the first bend member is co-axial with the longitudinal axis, and the second bend member is rotatably coupled to the first bend member and having a second axis which is at a non-zero angle relative to the longitudinal axis; and
a second planetary box adapted to selectively rotate the first and second bend members relative each other so as to vary the angle between the longitudinal axis and the second axis.

43. A directional drilling system, comprising:
a directional drilling tool according to claim 42;
a drill bit attached to the second end of the tool;
a measuring device adapted to monitor the orientation and position of the drill bit;
a remote control system having an operator control interface adapted to receive manual tool control inputs; and an electronic controller adapted to selectively activate the first and/or second planetary gearboxes of the tool in response to signals from the measuring device and/or remote control system.

44.-46. (canceled)

* * * * *