A shock-absorber subassembly for a subsurface drilling assembly is disclosed. The shock-absorber subassembly comprises a mandrel, a body assembly, and at least one torsional spring assembly. The mandrel has a bore extending therethrough and has one end connectable to a portion of the subsurface drilling assembly. The body assembly has a bore extending therethrough and one end connectable to another portion of the subsurface drilling assembly. The body assembly is coupled to the mandrel to establish fluid communication between the bore of the mandrel and the bore of the body assembly and to permit planar rotational movement of the mandrel relative to the body assembly. The at least one torsional spring assembly engages the mandrel and the body assembly to absorb torsional shocks and vibrations between the mandrel and the body assembly and to limit the degree of planar rotational movement. In a second embodiment, the body assembly is coupled to the mandrel to permit axial movement as well as planar rotational movement. In this second embodiment, the shock-absorber subassembly further comprises at least one axial spring assembly engaging the mandrel and the body assembly to absorb axial shocks and vibrations between the mandrel and the body assembly.
DOWNHOLE SHOCK ABSORBER FOR TORSIONAL AND AXIAL LOADS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a vibration-dampening and shock-absorbing device, and more particularly, but not by way of limitation, to a shock-absorber subassembly adapted to engage a subsurface drilling assembly above the drill bit, the shock-absorber subassembly provided with at least one resilient shock absorber for absorbing torsional vibrations, shocks, and impact loads to prevent and reduce wear on drilling components.

2. Brief Description of Related Art

During the drilling of an oil or gas well, a drill string is rotated from the surface causing a drill bit to cut and crush rock formations with the weight of drill collars assisting in driving the drill bit downward into contact with the underlying rock. Drill collars also act as conduits for the drilling fluids or “mud” used to lubricate the drill bit and carry cuttings back to the surface. Mud motors and turbines are sometimes employed down-hole to aid the drill bit rotation.

The drilling of oil and gas wells often takes place in rock formations. These rock formations are often porous and have layers of varying hardness. In drilling through such formations, the drill bit may generate significant vibrations, shocks, and impact loads. If transmitted to the drill string, the vibrations, shocks, and impact loads will eventually cause metal fatigue which could result in cracking and ultimate failure of joints between drill string segments, as well as entire drill string components. The direct transfer of these loads from the drill bit to the drill string reduces the useful life of the drill bit. Additionally, the efficiency may be reduced because the shocks and impact loads may cause the drill bit to “jump” or lose contact with the surface being drilled.

Vibrations, shocks, and impact loads may also have an adverse affect on sensors and electronics located within the drill string. At various points during the drilling process, specialized measurement and telemetry tools can also be employed to assess downhole conditions. Methods known in the art include measurement-while-drilling (MWD) and logging-while-drilling (LWD); such methods employ a diverse and evolving range of sensors. These sensors are usually located in the drill string near the drill bit and measure data such as resistivity, gravity, magnetic and nuclear magnetic resonance. The sensors then store the data in down-hole memory or transmit the data to the surface.

While such sensors provide highly useful information about the down-hole drilling environment, vibration due to the drilling process can damage the sensors. An axial load is applied to the drill bit during drilling into underlying formations, and this produces vibrations in the overlying drill string, and vibration can occur due to drill string rotation in a deviated or directional well bore. While most of these sensors are sufficiently robust to address the vibrations of normal drilling conditions, extended vibrations, and especially heavy shocks or impact loads may have adverse affects on the data measured by the sensors, and may eventually lead to sensor damage and failure.

A number of attempts have been made in the prior art to provide a shock absorber between the drill bit and the rest of the drill string so as to reduce the vibrations and shocks that are transmitted to the drill string. Several attempts have been made in the prior art to reduce axial loads with shock absorbers that rely on helical springs, Belleville springs, and wire mesh springs. In addition, several attempts have been made in the prior art to reduce both axial and torsional loads with shock absorbers that rely on helical springs or helical grooves. The use of helical geometry to reduce both axial and torsional loads makes the reduction of one of the axial or torsional loads interdependent on the other. That is, if the shock absorbing structure fails, neither axial nor torsional loads will be reduced. Additionally, the interdependence of the geometry may reduce the effectiveness of the shock absorber with respect to both axial and torsional loads.

To this end, a need exists for an improved shock absorber with independent means for reducing the transmission of axial loads and independent means for reducing the transmission of torsional loads. In addition, due to the current use of shock absorbers that are directed solely to reducing the transmission of axial loads, a need exists for an improved torsional shock-absorber that may be implemented in conjunction with an axial shock-absorber. It is to such an apparatus that the present invention is directed.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. 1 is a schematic view of a drilling assembly. FIG. 2 is an exploded perspective view of a shock-absorber subassembly constructed in accordance with the present invention. FIG. 3 is a cross-sectional view of the shock-absorber subassembly. FIG. 4 is an enlarged cross-sectional view of the shock-absorber subassembly illustrating a torsional spring assembly constructed in accordance with the present invention. FIG. 5 is a perspective view of the torsional spring assembly constructed in accordance with the present invention. FIG. 6 is a cross-sectional view of one embodiment of the shock-absorber subassembly taken along line 6-6 of FIG. 4.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, and more particularly to FIG. 1, a subsurface drilling assembly is depicted as an example of one context for the use of the present invention. The depiction is purely illustrative and exemplary, and is not intended to be limiting in any way. Specifically, a drill string 10 is shown suspended in a wellbore 14 and supported at the surface 18 by a drilling rig 22. The drill string 10 includes multiple joints of drill pipe 26 coupled to a downhole tool assembly 30. The downhole tool assembly 30 includes multiple drill collars 34, an instrumented drill pipe 38, a mud motor 42, and a drill bit 46. The drill string 10 also preferably comprises a shock-absorber subassembly 50. The shock-absorber subassembly is most preferably disposed immediately above the mud motor 42, but may also be disposed between the mud motor 42 and the drill bit 46, or otherwise disposed further up the drill string 10 from the mud motor 42.

The drill bit 46 is rotated by the mud motor 42 which responds to the flow of drilling fluid, or mud, which is pumped from a mud tank (not shown) through a central passageway or mud channel through the drill pipe 26, drill collars 34, the instrumented drill pipe 38, the shock-absorber subassembly 50, and then to the mud motor 42. The pumped drill-
ing fluid jets out of the drill bit 46 and flows back to the surface through an annulus formed between the drill string 10 and the wellbore 14. The drilling fluid carries debris away from the drill bit 46 as the drilling fluid flows back to the surface. The drill collars 34 provide a means to provide weight on the drill bit 46 while maintaining the drill pipe 26 in tension, enabling the drill bit 46 to crush and cut the formations as the mud motor 42 rotates the drill bit 46.

[0018] As drilling progresses, it is desirable to monitor a variety of downhole conditions. To accomplish this, an elongated portion of the drill pipe 38 is used to measure downhole parameters and formation characteristics. The data can be transmitted in real time utilizing mud pulse and electromagnetic telemetry or recorded in downhole memory and retrieved after the tool returns to the surface.

[0019] Similarly, to help ensure consistent and efficient drilling, it is desirable to have one or more shock-absorber assemblies 50 disposed above the drill bit 46 in the drill string 10. The shock-absorber subassembly 50 preferably reduces the transfer of torsional and/or axial shocks and vibrations between the drill bit and the drill string 10. The present invention is directed to several embodiments of an improved version of a shock-absorber subassembly 50.

[0020] Referring now to FIG. 2, an exploded perspective view of one embodiment of the shock-absorber subassembly 50 is shown. Shock-absorber subassemblies have been used for some time in the art and thus not all elements will be described in as much detail. The present invention is particularly directed to the incorporation of a torsional shock-absorbing element into a shock-absorber subassembly 50. Thus, the torsional shock-absorber elements are described in the most detail, while other elements are described with enough particularity that one skilled in the art will understand the context within which the torsional shock-absorber elements may be implemented. Thus, it should be understood that the disclosure will enable one skilled in the art to implement the torsional shock-absorber elements described herein either alone or in a variety of shock-absorber subassembly configurations. Similarly, the materials used in such subassemblies are well known in the art and any suitable materials may be used for a given application. For example, when the shock-absorber subassembly 50 is disposed near the instrumented drill pipe 38 (FIG. 1), it may be desirable to construct the shock-absorber subassembly 50 out of non-magnetic alloys. Similarly, seal and spring materials are well known in the art, and may be constructed from natural or synthetic rubber, polyurethane, or other suitable polymers.

[0021] In one embodiment, the shock-absorber subassembly 50 comprises a mandrel assembly 54 and a body assembly 58 rotatably mounted about the mandrel assembly 54. For simplicity and clarity, the mandrel assembly 54 may also be referred to as the mandrel herein and in the attached claims. The mandrel assembly 54 preferably comprises a mandrel body 62, a washpipe 66, and a sleeve 70. Additionally, the mandrel assembly 54 is provided with bore 72 extending through the mandrel body 62 and the washpipe 66, and, as necessary for other embodiments, the sleeve 70. The mandrel body 62 is preferably cylindrically-shaped and is formed with a base portion 74, a compression portion 78, a spindle portion 82, and a connection portion 86. The base portion 74 is adapted to engage one of the drill bit 46 (FIG. 1) or another portion of the drill string 10 (FIG. 1). As will be appreciated by those skilled in the art, the base portion 74 can be either internally or externally threaded, that is, provided with male or female threads, to permit the mandrel 50 to be connected to one of the drill bit 46 (FIG. 1) or another portion of the drill string 10 (FIG. 1).

[0022] The compression portion 78 is preferably formed with a smaller diameter than that of the base portion 74 so as to form a seal shoulder 94 between the compression portion 78 and the base portion 74. The spindle portion 82 is formed with a smaller diameter than that of the compression portion 78 so as to form a seal shoulder 98 between the spindle portion 82 and the compression portion 78. The spindle portion 82 is also formed with at least one torsional spring recess 102 sized to receive a torsional spring assembly 106. More preferably, the spindle portion 108 is provided with a plurality of spring recesses 102 equally spaced about the circumference of the spindle portion 82. As shown, the connection portion 86 is preferably formed with internal, or female, threads for receiving the washpipe 66, and with external, or male, threads for engaging the sleeve 70.

[0023] The washpipe 66 is formed with an elongated, cylindrical shape and has a threaded end 110 sized to engage the female threads of the connection portion 86 of the mandrel body 62. The sleeve 70 is preferably formed with a hollow, cylindrical extension portion 114 and a flange portion 118. The extension portion is sized to fit snugly about the washpipe 66 and the flange portion 118 is provided with internal threads sized to engage the external threads of the connection portion 86 of the mandrel body 62.

[0024] The body assembly 58 includes a top packing sub 200, a seal assembly 204, an axial spring assembly 208, an axial spring sub 212, a torsional spring sub 216, and a bottom packing sub 220. The body assembly 58 is provided with a bore 238 extending through the top packing sub 200, and, as necessary for other embodiments, the axial sub 212, torsional sub 216, and lower packing sub 220. When the shock-absorber subassembly 50 is assembled, as described below, the bore 238 through the body assembly 58 axially aligns with the bore 72 through the mandrel assembly 54 such that the bores 238 and 72 are in fluid communication and cooperate to form a mud channel through the entire shock-absorber subassembly 50.

[0025] The top packing sub 200 is preferably cylindrically-shaped and is formed with a distal end 224. The distal end 224 is adapted to engage one of the drill bit 46 (FIG. 1) or another portion of the drill string 10 (FIG. 1). As will be appreciated by those skilled in the art, the distal end 224 can be either internally or externally threaded, that is, provided with male or female threads, to permit the mandrel body assembly 58 to be connected to one of the drill bit 46 (FIG. 1) or another portion of the drill string 10 (FIG. 1). Each of the top packing sub 200, axial spring sub 212, torsional spring sub 216, and bottom packing sub 220 are formed with correspondingly-threaded ends 228 such that they can be sequentially connected as shown. The threaded ends 228 may be formed as male or female threads in any suitable size or thread pitch, so long as adjacent ends of adjacent pieces correspond to one another, i.e., can be threaded together as shown to form a firm connection. The torsional spring sub 216 is provided with at least one spring recess 232 (FIG. 3) to correspond to each spring recess 106 in the spindle portion 82 of the mandrel body 62. The bottom packing sub 220 is further formed with an internally-smooth distal end 236 such that relative axial displacement may be permitted between the body assembly 58 and the mandrel assembly 54 during assembled operation.
The body assembly 58 further includes a number of set screws 240, filler plugs 244, o-rings 248, and relief valves 252. The uses of such elements are well known in the art and no further description thereof is deemed necessary to enable one skilled in the art to implement the present invention. Similarly, the position of these elements is exemplary, and may be adjusted as necessary for different configurations of shock-absorber subassemblies 50. The shock-absorber subassembly 50 further comprises a wear bushing 256, a floating seal 260, and a seal stop 264; all of which are formed with an internal radius such that they will fit closely over the spindle portion 82 of the mandrel body 62. The respective functions of the wear bushing 256, floating seal 260, and seal stop 264 will be described in more detail below with reference to FIG. 3.

In one embodiment, assembly of the shock-absorber subassembly 50 may be achieved by the following steps. The seal stop 264 and the floating seal 260 are first sequentially placed over the spindle portion 82 of the mandrel body 62 such that the seal stop 264 is adjacent to the seal shoulder 98. The bottom packing sub 220 is then placed over the spindle portion 82 and the wear bushing 256 is inserted between the spindle portion 82 and the bottom packing sub 220. The torsional spring assemblies 206 (FIG. 3) are then placed within the spring recesses 102 and the torsional spring sub 216 is placed over the spindle portion 82 such that the spring recesses 232 of the torsional spring sub 216 align with the spring recesses 102 of the mandrel body 62 and the torsional spring assemblies 106 (FIG. 3) are within the spring recesses 102 and 232. The correspondingly-threaded portions 228 of the torsional spring sub 216 and the bottom packing sub 220 are then screwed together to connect the two pieces.

Next, the threaded end 110 of the washpipe 66 is threaded into the internal threads of the connection portion 86 of mandrel body 62. The sleeve 70 is then placed over the washpipe 66, inserted within torsional spring sub 216, and the flange 118 can be threaded onto the external threads of the connection portion 86 of the mandrel body 62. The axial spring sub 212 is then placed over the extension portion 114 of the sleeve 70 and the threaded end 228 of the axial spring sub 212 screwed into the threaded end 228 of the torsional spring sub 216. The axial spring assembly 208 is then placed over the washpipe 66 within the axial spring sub 212. Although the axial spring assembly 208 is shown as a stack of Belleville washers, alternate embodiments may use any suitable springs. For example, the axial spring assembly 208 may comprise helical springs, solid springs of rubber or other elastomeric materials, or the like.

The seal assembly 204 is then placed over the washpipe 66 and the top packing sub 200 placed over the seal assembly 204 and the washpipe 66. As shown, the threaded end 228 of the top packing sub 200 is then threaded into the threaded end 228 of the axial spring sub 212 so as to form a firm connection therebetween. The assembled shock-absorber subassembly 50 is depicted in FIG. 3 and the internal features and functions will be described in more detail with reference thereto.

Referring now to FIG. 3, a cross-sectional view of an assembled shock-absorber subassembly 50 is shown. As mentioned above, and best depicted here, the body assembly 58 comprises the top packing sub 200, the seal assembly 204, the axial spring assembly 208, the axial spring sub 212, the torsional spring sub 216, and the bottom packing sub 220. The mandrel assembly 54 comprises the mandrel body 62, the washpipe 66, and the sleeve 70. When the shock-absorber subassembly 50 is assembled, the body assembly 58 and mandrel assembly 54 are permitted to move both axially and rotationally, relative to one another and within a predetermined range. As will be appreciated, the axial spring assembly 208 absorbs some of the energy imparted by axial loads to reduce the transfer of axial shocks and vibrations between the body assembly 58 and the mandrel assembly 54, and the torsional spring assembly 106 absorbs some of the energy imparted by torsional loads to reduce the transfer of torsional shocks and vibrations between the body assembly 58 and the mandrel assembly 54.

Several interior features of the various parts contribute to this functionality and should be specifically noted here. The floating seal 260 maintains a seal between the bottom packing sub and the spindle portion 82 of the mandrel body 62. The seal stop 264 abuts the seal shoulder 98 of the mandrel body 64 so as to prevent the floating seal 260 from being pushed over the seal shoulder 98 as the body assembly 58 moves axially relative to the mandrel assembly 54. As will also be appreciated from the drawing, the shoulder 94 of the mandrel body 62 provides an absolute limit to the amount of axial travel permitted. Specifically, because the base portion 74 of the mandrel body 62 is larger than the bottom packing sub 220, the distal end 236 of the bottom packing sub 220 cannot travel beyond the shoulder 94 of the mandrel body 62.

The bottom packing sub 220 is also further provided with an internal tab 300 to maintain the wear bushing 256 in a fixed position relative to the bottom packing sub 220. Additionally, to facilitate the relative axial travel between body assembly 58 and the mandrel assembly 54, the spring recesses 102 and 132 are preferably longer than the torsional spring assembly 106 such that the torsional spring assembly is permitted to slide within the spring recesses 102 and 132. As shown, the axial spring sub 212 is provided with an enlarged spring chamber 304 to receive the axial spring assembly 208. The axial spring assembly 208 is preferably formed with a central opening large enough about the washpipe 66, but small enough so as not to fit about the extension portion 114 of the sleeve 70. This permits the extension portion 114 of the sleeve 70 to contact, and thereby transmit axial loads to, the axial spring assembly 208.

The torsional spring sub 216 is provided with sufficient length to form an open space 308 to permit axial motion between the body assembly 58 and the mandrel assembly 54. Similarly, the top packing sub 200 is provided with a seal shoulder 312 and an enlarged chamber 316. The seal shoulder 312 maintains the seal assembly 204 in a fixed position relative to the top packing sub 200 so as to permit the washpipe 66 to slide through the seal assembly 204 and into the enlarged chamber 316 as the body assembly 58 travels axially relative to the mandrel assembly 54.

Referring now to FIGS. 4, 5, and 6, the torsional-shock-absorbing elements and function of the present invention will be described in more detail. FIG. 4 depicts a close-up cross-sectional view of the torsional shock-absorber elements of the shock-absorber subassembly 50. FIG. 5 depicts a perspective view of the torsional spring assembly 106 disposed within the spring recess 102 of the spindle portion 82 of the mandrel body 62. FIG. 6 depicts a cross-sectional view of the torsional spring assembly 106, taken along the line 6-6 of FIG. 4. As best shown in FIG. 5, the torsional spring assembly 106 preferably comprises a drive key 400 and a pair of springs 404, one each on either side of the drive key 400. In some
embodiments, the springs 404 may be affixed to the drive key 400, such as by adhesive, rivets, screws, or any other suitable fastening means. The spring assembly 106 may also be provided with any suitable number of springs, for example, three, four, or the like. The springs 404 are preferably formed as flat springs, as shown, having a at least two arcuate portions 408. In other embodiments, the springs may have any suitable number of arcuate portions 408, for example, one, three, four, or the like. In yet further embodiments, the springs 404 may be formed in any suitable shape, for example, helical springs disposed perpendicular to the drive key, solid rubber or elastomeric springs, leaf springs, or any other suitable spring type or shape.

[0036] As best shown in FIG. 6, the spring 404 absorbs a portion of torsional loads imparted so as to reduce the transfer of torsional shocks and vibration between the torsional spring sub 216 and the spindle portion 82 of the mandrel body 62. The spring assembly 106 thereby reduces the transfer of torsional shocks and vibration between the body assembly 58 and the mandrel assembly 54, while still being capable of transferring rotary motion, and permitting relative axial movement, between the body assembly 58 and the mandrel assembly 54. Additionally, even in the event that the springs 404 fail, the solid drive key 404 limits the relative rotation permitted between the spindle portion 82 of the mandrel body 62 and the torsional spring sub 216 to a predetermined range. Additionally, because the torsional spring assembly 106 is independent of the axial spring assembly 208, planar rotation of the body assembly 58 is permitted relative to the mandrel assembly 54 without requiring any axial motion therebetween. Thus, each spring assembly 106 and 208 can most efficiently absorb the loads, torsional and axial respectively, they are designed to address. It should also be appreciated that the size of the spring recesses can be increased or decreased to increase the permitted range of relative rotation between body assembly 58 and the mandrel assembly 54.

[0037] As best shown in FIG. 4, in one embodiment, the spring recesses 102 and 232 are formed with a length greater than that of the torsional spring assembly 106 so as to permit the body assembly 58 to move axially relative to the mandrel assembly 54, and independently of any rotation. The wear bushing 256 cooperates with the torsional spring sub 216 to define the spring recess 232. As the body assembly 58 moves axially relative to the mandrel assembly 54, the torsional spring assembly 106 is permitted to move axially within the spring recesses 102 and 232, which cooperate to limit the travel of the torsional spring assembly 106. Thus, when an axial shock is applied to one of the body assembly 58 or the mandrel assembly 54, relative axial motion is permitted between the body assembly 58 and the mandrel assembly 54, as the axial spring assembly 204 absorbs a portion of the axial shock, without forcing rotation between the body assembly 58 and the mandrel assembly 54.

[0038] It should be appreciated that the torsional shock absorbing elements of the present invention may also be implemented alone in a shock absorbing subassembly 50. For example, a shock absorbing subassembly 50 may be constructed to include only torsional shock absorbing elements. Such a configuration would be useful, for example, in conjunction with axial shock absorbing subassemblies already in use, to provide axial and torsional shock absorption without having to replace a functional axial shock absorber. Similarly, such a configuration would be useful, for example, when axial displacement is undesirable, such as in softer rock formations, or where more precision is desirable.

[0039] From the above description, it is clear that the present invention is well adapted to carry out the objects and to attain the advantages mentioned herein, as well as those inherent in the invention. While presently preferred embodiments of the invention have been described for purposes of this disclosure, it will be understood that numerous changes may be made which will readily suggest themselves to those skilled in the art and which are accomplished within the spirit of the invention disclosed and as defined in the appended claims.

What is claimed is:
1. A shock-absorber subassembly for a subsurface drilling assembly, the shock-absorber subassembly comprising:
   a mandrel having a bore extending therethrough and having one end connectable to a portion of the subsurface drilling assembly;
   a body assembly having a bore extending therethrough and one end connectable to another portion of the subsurface drilling assembly, the body assembly coupled to the mandrel to establish fluid communication between the bore of the mandrel and the bore of the body assembly and to permit planar rotational movement of the mandrel relative to the body assembly;
   and at least one torsional spring assembly engaging the mandrel and the body assembly to absorb torsional shocks and vibrations between the mandrel and the body assembly and to limit the degree of planar rotation between the mandrel and the body assembly.

2. The shock-absorber subassembly of claim 1, wherein the torsional spring assembly comprises:
a rigid drive key; and
at least one spring engaging the drive key.

3. The shock-absorber subassembly of claim 2, wherein the at least one spring comprises two springs engaging the drive key and each spring opposingly-disposed on opposite sides of the drive key.

4. The shock-absorber subassembly of claim 3, wherein each spring is a flat spring having at least one arcuate portion.

5. The shock-absorber subassembly of claim 1, wherein an outer surface of the mandrel has at least one spring recess defined therein, and wherein an inner surface of the body assembly has at least one spring recess defined therein, the at least one spring recess of the mandrel and the at least one spring recess of the body assembly cooperating to form at least one spring chamber therebetween, the torsional spring assembly positioned in the spring chamber.

6. The shock-absorber subassembly of claim 5, wherein the torsional spring assembly comprises:
a rigid drive key; and
at least one spring engaging the drive key and at least one of the mandrel or the body assembly.

7. The shock-absorber subassembly of claim 6, wherein the at least one spring comprises two springs engaging the drive key and each spring opposingly-disposed on opposite sides of the drive key.

8. The shock-absorber subassembly of claim 7, wherein each spring is a flat spring having at least one arcuate portion.

9. A shock-absorber subassembly for a subsurface drilling assembly, the shock-absorber subassembly comprising:
a mandrel having a bore extending therethrough and having one end connectable to a portion of the subsurface drilling assembly;
a body assembly having a bore extending therethrough and one end connectable to another portion of the subsurface drilling assembly, the body assembly coupled to the mandrel to establish fluid communication between the bore of the mandrel and the bore of the body assembly and to permit planar rotational movement and axial movement of the mandrel relative to the body assembly; at least one torsional spring assembly engaging the mandrel and the body assembly to absorb torsional shocks and vibrations between the mandrel and the body assembly and to limit the degree of planar rotation between the mandrel and the body assembly; and,
at least one axial spring assembly engaging the mandrel and the body assembly to absorb axial shocks and vibrations between the mandrel and the body assembly.

10. The shock-absorber subassembly of claim 9, wherein the torsional spring assembly comprises:
a rigid drive key; and
at least one spring engaging the drive key.

11. The shock-absorber subassembly of claim 10, wherein the at least one spring comprises two springs engaging the drive key and each spring opposingly-disposed on opposite sides of the drive key.

12. The shock-absorber subassembly of claim 11, wherein each spring is a flat spring having at least one arcuate portion.

13. The shock-absorber subassembly of claim 12, wherein an outer surface of the mandrel has at least one spring recess defined therein, and wherein an inner surface of the body assembly has at least one spring recess defined therein, the at least one spring recess of the mandrel and the at least one spring recess of the body assembly cooperating to form at least one spring chamber therebetween, the torsional spring assembly positioned in the spring chamber.

14. The shock-absorber subassembly of claim 13, wherein the spring recesses in the mandrel and the body assembly have a length greater than the length of the torsional spring assembly to permit axial movement of the torsional spring assembly within the spring chamber during axial movement of the body assembly relative to the mandrel.

15. The shock-absorber subassembly of claim 14, wherein the torsional spring assembly comprises:
a rigid drive key; and
at least one spring engaging the drive key and at least one of the mandrel or the body assembly.

16. The shock-absorber subassembly of claim 15, wherein the at least one spring comprises two springs engaging the drive key and each spring opposingly-disposed on opposite sides of the drive key.

17. The shock-absorber subassembly of claim 16, wherein each spring is a flat spring having at least one arcuate portion.