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Dillard

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[54] **WELL BORE PERFORATING APPARATUS**

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[52] **U.S. Cl.** **175/4.55;** 285/54; 285/235

[51] **Int. Cl.**^{2} **E21B 43/11**

[58] **Field of Search** .... 166/55, 55.1; 175/4.5–4.6; 174/85, 138 D; 64/11 R, 13; 403/220, 291, 225; 285/49, 114, 223, 224, 235, 370, 371, 397, 398, 302, 54, 47, DIG. 14

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[57] **ABSTRACT**

In the representative embodiment of the present invention disclosed herein, new and improved selectively-operated perforating apparatus is arranged to include two or more enclosed thin-walled tubular carriers carrying a corresponding number of sets of shaped explosive charges which are to be independently actuated for successively perforating a cased well bore at selected depth intervals. To effectively protect the charges in the yet-unfired carriers during the sequential operation of the perforating apparatus, the carriers are tandemly joined by a unique shock-isolating intercarrier coupler cooperatively arranged for carrying interconnecting wires between the carriers as well as for at least substantially absorbing the longitudinally directed and laterally directed explosive shocks or impacts which are inherently developed by such sequential firing operations.

11 Claims, 4 Drawing Figures

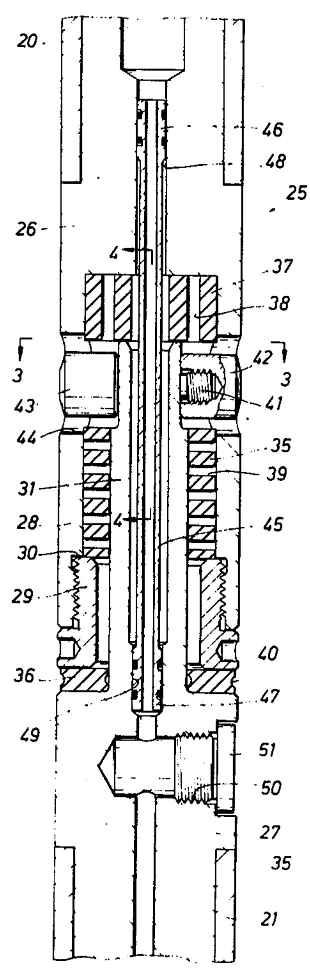


FIG. 1

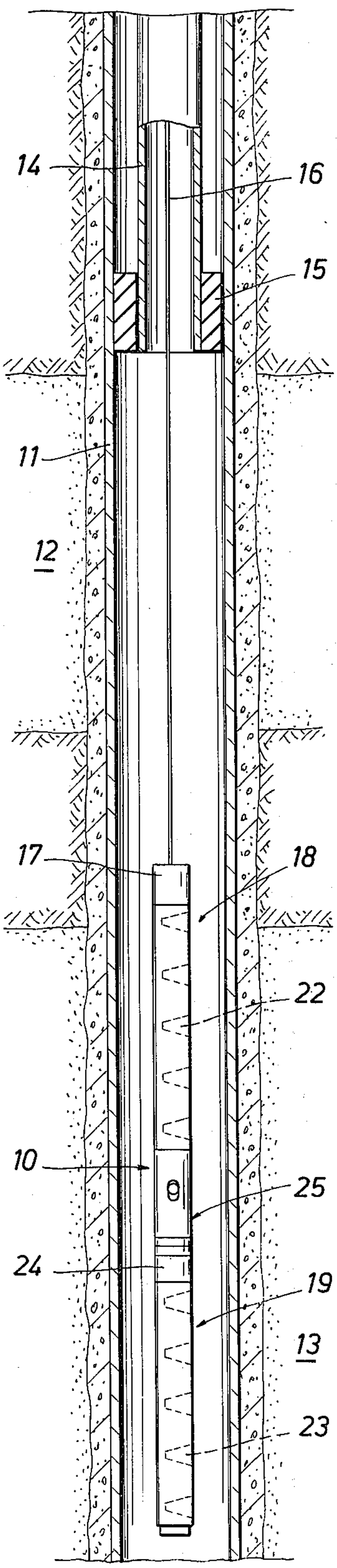


FIG. 2

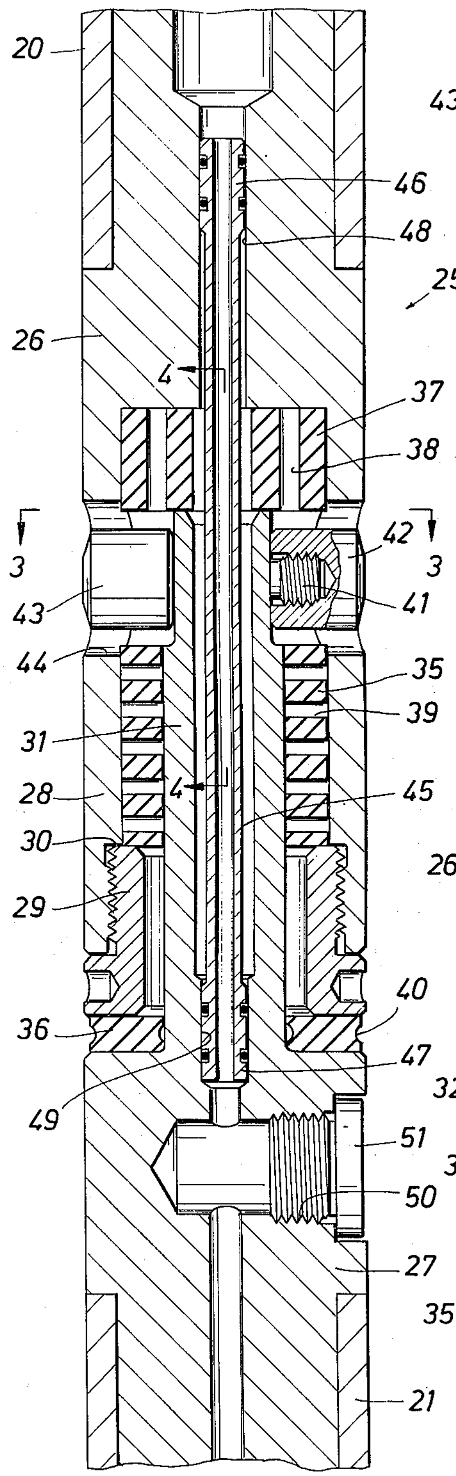
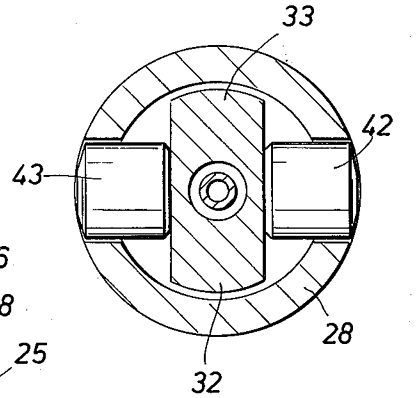


FIG. 3



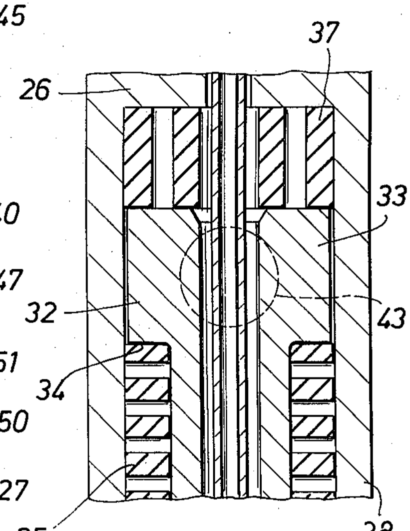


FIG. 4

WELL BORE PERFORATING APPARATUS

Present-day completion techniques often require the perforation of a well at two or more different depth intervals. Very often this must be carried out without removing the small-diameter production tubing from the well. To accomplish this, it is customary to tandemly arrange a corresponding number of small-diameter perforating guns into a selectively controlled unitary assembly and, by means of a typical electrical cable, lower the assembled tool through the production string to the depth interval where the first gun is to be operated. Thereafter, the perforator tool is repositioned and the second gun is operated for perforating the formations at the second depth interval. This procedure is repeated until all of the several guns in the perforator tool have been fired.

Those skilled in the art will, of course, appreciate that where each of these guns include a number of shaped explosive charges, the simultaneous detonation of these charges will impose severe shocks and sudden impacts on the entire perforator tool. This problem has been accentuated by the recent development of more-powerful charges. In particular, where the charges are carried in thin-wall tubular carriers such as those shown in U.S. Pat. No. **3,048,102** and U.S. Pat. No. **3,429,384,** these carriers are typically so light that the entire perforator tool will often be driven laterally with considerable force each time the charges in one of the carriers in the tool are detonated.

Accordingly, it has been not at all uncommon to find that the operation of the first set of charges in a tandem assembly of such light-weight carriers has damaged one or more of the unexpended shaped charges in the adjacent carriers in the perforator tool. For example, as shown in FIG. 2 of the aforementioned U.S. Pat. No. **3,429,384,** there is ordinarily a minimal clearance space between the internal carrier wall and the forward and rearward portions of the shaped charges. Thus, the sudden impact or shock developed upon firing of one set of charges will rapidly drive or shift an adjacent carrier of this type laterally in relation to the several shaped charges enclosed therein since the charges are typically supported by only a thin, generally flexible metal strip. Forceful inertial movements of this nature are known to be particularly responsible for damage to the exposed forward ends or skirt portions of the fragile liners typically used in such shaped charges. Similarly, it has been found that vertical movements or jumping of the perforator tool caused by detonation of one set of charges can also damage the metal strips carrying the unexpended shaped charges in adjacent carriers. In either case, it has been found that often one or more of the shaped charges in these adjacent carriers are sufficiently damaged that they will not operate properly when these charges are subsequently detonated.

Accordingly, it is an object of the present invention to provide new and improved repetitively operated shaped charge perforating apparatus which is cooperatively arranged for protecting unfired shaped charges in the apparatus from explosive impacts or violent shocks which might otherwise damage or disrupt these unexpended charges upon the detonation of other shaped charges in the apparatus.

This and other objects of the present invention are attained by tandemly intercoupling upper and lower perforating guns by means of a rigid inner member

which is cooperatively disposed within a rigid outer member and yieldably isolated therefrom by one or more yieldable members arranged between the rigid members; with one of the guns being secured or coupled to one of these rigid members and the other gun being secured or coupled to the other rigid member. In this manner, the yieldable members between the load-supporting members will effectively isolate the two guns from shocks developed upon actuation of the other gun. The assembly of coupler members is further arranged to define a protective wire passage for carrying interconnecting electrical wires between the two guns.

The novel features of the present invention are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may be best understood by way of the following description of exemplary apparatus employing the principles of the invention as illustrated in the accompanying drawings, in which:

FIG. **1** shows new and improved perforating apparatus arranged in accordance with the present invention as that apparatus is being positioned in a typical well bore;

FIG. **2** is an enlarged longitudinal cross-sectional view of a preferred embodiment of a new and improved shockresistant inter-carrier coupler incorporating the principles of the present invention; and

FIGS. **3** and **4** are cross-sectional views of the unique inter-carrier coupler respectively taken along the lines **3—3** and **4—4** in FIG. **2.**

Turning now to FIG. **1**, new and improved through-tubing perforating apparatus **10** is shown as it is being positioned in a typical cased well bore **11** adjacent to one of two producible earth formations **12** and **13.** As is customary, a string of small-diameter tubing **14** is suspended in the well bore **11** and extended through a typical packer **15** set therein above the earth formations **12** and **13** for isolating the two producing zones from that portion of the well bore above the packer. The perforating apparatus **10** is suspended in the usual manner from a suitable electrical cable **16** that is spooled from a winch (not shown) at the surface and connected to the upper end of the perforating apparatus. As is customary, a typical casing collar locator **17** is employed for providing indications at the surface representative of the depth of the perforating apparatus **10.**

Inasmuch as it is intended that the perforating apparatus **10** will be successively positioned opposite each of the formations **12** and **13,** the perforating apparatus includes separate upper and lower guns **18** and **19** which are cooperatively arranged to be individually operated upon command from the surface. In the preferred embodiment depicted in FIG. **1**, the two guns **18** and **19** are respectively arranged in accordance with the through-tubing perforators shown in either U.S. Pat. No. **3,048,102** or U.S. Pat. No. **3,429,384,** each of which is hereby incorporated by reference. Thus, as fully described in either of the aforementioned patents, each of the guns **18** and **19** respectively includes an enclosed carrier **20** and **21** formed of a suitable length of thin-walled steel tubing which has a number of typical shaped explosive charges, as at **22** and **23,** mounted at longitudinally spaced intervals along an elongated metal strip (not shown) arranged therein for positioning each of the charges for firing in a selected lateral direction. It will, of course, be appreciated that each of the guns **18** and **19** is respectively provided with an electrically-responsive detonator (not shown) which is coupled to a length of typical detonating cord (not shown) operatively disposed along the rear portion of each of the charges, as at **22** or **23**, for simultaneously detonating them when the detonator in that gun is energized.

Since the guns **18** and **19** are to be independently fired, suitable provisions must be made for their selective operation. Those skilled in the art will recognize, of course, that any one of several typical switching arrangements may be utilized for achieving such selective control. For example, selectively operated switching systems such as those shown in either U.S. Pat. No. **3,327,791** or U.S. Pat. No. **3,517,758** could be successfully employed with the new and improved perforating apparatus **10** of the present invention where the switching is to be directly controlled from the surface. Alternatively, if it is preferred that the switching be accomplished upon firing of the lower gun **19**, for example, a detonation-responsive control system, as at **24**, would be included with the new and improved perforating apparatus **10.** Typical detonation-responsive control systems, as at **24**, are fully described in U.S. Pat. No. **3,246,707** and U.S. Pat. No. **3,246,708**, each of which is incorporated herein by reference. It will, of course, be appreciated that since it is ordinarily preferred to shoot the lowermost gun first and then subsequently shoot the next-higher gun, the detonation-responsive control system **24** is operatively positioned adjacent to the upper end of the lower gun **19** so that successful detonation of the charges, as at **23**, will electrically connect the cable **16** to the detonator for the yet-unexpended charges, as at **22**, in the upper gun **18.** Since the two last-mentioned patents fully explain the operation of the detonation-responsive control system **24**, no further explanation is believed necessary. It should be realized, however, that regardless of the control system used, electrical wires must be connected between the upper and lower guns **18** and **19** and it is essential to their successful operation that these wires remain undamaged at least until the upper gun is fired.

The upper and lower guns **18** and **19** in the new and improved perforating apparatus **10** are tandemly intercoupled by means of a uniquely-arranged shock or impact-resistant inter-carrier coupler **25** which, as will be subsequently explained, is cooperatively arranged for substantially absorbing the severe impact or shock forces developed upon detonation of the shaped charges, as at **23**, in the lower gun **19** to thereby protect the yet-unfired charges, as at **22**, in the upper gun **18** from unwanted damage. Thus, as best seen in FIG. **2**, in its preferred embodiment the unique shock or impact-resistant inter-carrier **25** includes longitudinally-spaced cylindrical bodies or upper and lower heads **26** and **27** which are respectively adapted to be complementally fitted and secured in known angular positions within the adjacent ends of the upper and lower carriers **20** and **21.** The upper head **26** is further provided with a depending support or tubular extension **28** which is terminated by an inwardly-enlarged shoulder that, in the illustrated preferred embodiment, is provided by an externally threaded split-ring **29** sized for defining an upwardly facing surface as at **30.** The lower head **27** is, on the other hand, provided with an upstanding support or reduced-diameter extension **31** which is coaxially disposed in the depending extension **28** and, as best seen in FIGS. **3** and **4**, terminated at its upper end by an outwardly-enlarged shoulder that is preferably arranged as opposed lateral projections **32** and **33** that respectively define downwardly-facing surfaces, as at **34**, well above the upwardly facing surface **30.**

It will, of course, be appreciated that where the switching system **24** is arranged in accordance with the aforementioned U.S. Pat. No. **3,246,707** or U.S. Pat. No. **3,246,708**, for example, the lower head **27** can also be conveniently arranged as necessary for readily supporting the components of such a detonation-responsive system as well as for being complementally fitted and fluidly sealed within the upper end of the lower carrier **21.**

As depicted in FIG. **2**, the unique shock-resistant inter-carrier **25** is further provided with an elongated sleeve **35** of a yieldable or resilient shock-absorbing material such as a suitable elastomer, with this thick sleeve being cooperatively fitted within the annular space defined between the extensions **28** and **31** and engaged with the opposed shoulders **30** and **34** for yieldably supporting the lower head **27** on the upper head **26.** To further isolate the upper and lower heads **26** and **27** against the transmission of shock forces between the upper and lower perforating guns **18** and **19**, a second shock-absorbing member **36** is preferably arranged between the lower head **27** and the lower face of the split-nut **29** and a third shock-absorbing member **37** is disposed between the upper head **26** and the upper faces of the shoulders **32** and **33.** These additional shock-absorbing members **36** and **37** are preferably formed of a yieldable or resilient material similar or identical to that used for the major shock-absorbing member **35.** To assure that there is a reasonable degree of free movement between the upper and lower heads **26** and **27**, the several shock-absorbing members **35–37** are provided with one or more expansion spaces such as multiple openings or passages, as at **38** and **39**, in the upper and intermediate shock-absorbing members respectively and recesses, as at **40**, in the lower shock-absorbing member.

To assure that the upper and lower heads will not become accidentally uncoupled while the new and improved perforating apparatus **10** is being operated, abutments such as one or more oppositely directed threaded projections, as at **41**, are provided on the upper end of the upright inner extension **31** and enlarged caps **42** and **43** which are coupled thereto are loosely disposed in slots, as at **44**, formed in the adjacent side walls of the outer extension **28.** In this manner, the lower surfaces of the opposed slots, as at **44**, will define shoulders for holding the outwardly projecting abutment caps **42** and **43** should the shock-absorbing member **35** fail or be disintegrated while the perforating apparatus **10** is in the well bore **13.** It will also be recognized that the abutment caps **42** and **43** and their respectively associated slots, as at **44**, will further serve to maintain the upper and lower heads **26** and **27** in a given angular orientation relative to one another. This angular orientation can, of course, be readily reversed should it be desired to face the shaped charges **22** in the opposite direction from the shaped charges **23.**

To facilitate the necessary electrical interconnection between the guns **18** and **19**, a wire passage is provided through the inter-carrier coupler 25 by way of an elongated and somewhat-flexible tubular conduit 45 which is coaxially disposed within the inner extension 31 and has its enlarged upper and lower ends 46 and 47 fluidly sealed within complementally formed longitudinal passages 48 and 49 respectively arranged through the upper and lower coupling heads 26 and 27. It will be noted from FIG. 2 that the passages 48 and 49 are arranged and are of sufficient length to accommodate the longitudinal movements of the conduit 45 during the use of the new and improved inter-carrier coupler 25. As a matter of operating convenience, a lateral port 50 with a threaded plug 51 are provided in the lower head 27 to facilitate the splicing of the interconnecting detonator wires (not shown) running between the two guns 18 and 19.

It will be recognized, therefore, that with the upper and lower guns 18 and 19 being intercoupled to one another solely by the unique coupler 25, the lower gun is directly connected to the upper gun only by way of the resilient members 35–37. Thus, an upwardly directed shock on the upper gun 18 as will be occasioned by the detonation of the charges, as at 23, in the lower gun 19 will be substantially cushioned by the respective expansion and compression of the resilient coupler members 35–37. Similarly, since the resilient members are sufficiently yieldable under impact for allowing the rigid coupler members 28 and 31 to tilt in relation to one another, the resilience of the several resilient coupler members 35–37 will effectively absorb or dampen a considerable amount of the laterally directed shocks or impacts which would otherwise be transmitted to the upper gun 18 when the lower gun 19 is fired. It should be noted at this point that although firing of the lower gun 19 will impart a substantial accelerational force to the lower gun, the operation of the inter-carrier coupler 25 will be effective for at least minimizing or reducing the acceleration of the upper gun 18.

Accordingly, it will be appreciated that the new and improved repetitively operated perforating apparatus of the present invention is well suited for guarding yet-unfired shaped charges from damage as other shaped charges on the apparatus are fired. By intercoupling two or more typical shaped charge guns with the new and improved inter-carrier coupler disclosed herein, the severe explosive shocks and excessive accelerational forces developed upon actuation of one of the guns in the assembled tool will be sufficiently dampened or absorbed that there will be little or no risk of damage to the shaped charges in the other guns.

While only a particular embodiment of the present invention has been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. Perforating apparatus comprising:

first and second perforating guns cooperatively arranged to be sequentially actuated for successively perforating spaced intervals of a well bore wall; and

shock-isolating means tandemly intercoupling said perforating guns cooperatively arranged for attenuating shocks transmitted to one of said perforating guns upon actuation of the other of said guns and including inner and outer rigid coupler members telescoped together and respectively coupled to said first and second perforating guns, and yieldable means cooperatively arranged between said rigid coupler members for shock isolating said rigid coupler members from one another and yieldably supporting said inner member within said outer member to accommodate relative longitudinal and bending movements therebetween.

2. The perforating apparatus of claim 1 wherein said rigid coupler members are tubular for defining a longitudinal passage through each of said rigid coupler members and further including:

an elongated conduit slidably mounted within said longitudinal passages and adapted for carrying interconnecting electrical conductor means between said perforating guns.

3. The perforating apparatus of claim 1 further including:

longitudinally-spaced opposed abutments cooperatively arranged on said rigid coupler members for preventing separation of said rigid coupler members.

4. Perforating apparatus comprising:

first and second perforating guns cooperatively arranged for selectively perforating spaced intervals of a well bore wall;

shock-isolating means intercoupling said perforating guns and including an inner member having one portion coupled to said first perforating gun and another portion thereof providing at least one outwardly projecting shoulder, an outer member having one portion coupled to said second perforating gun and another portion thereof coaxially disposed around said other portion of said inner member and having upper and lower inwardly-projecting shoulders provided thereon which are spatially disposed respectively above and below said outwardly-projecting shoulder on said inner member, yieldable shock-attenuating means cooperatively arranged between said outwardly-projecting shoulder and at least one of said inwardly-projecting shoulders for yieldably supporting said inner member within said outer member and attenuating shocks transmitted between said perforating guns, and conduit means cooperatively arranged through said inner and outer members for carrying interconnecting electrical conductor means between said perforating guns; and

control means cooperatively arranged for sequentially actuating said perforating guns in succession.

5. The perforating apparatus of claim 4 wherein said yieldable shock-attenuating means include a member formed of a resilient material engaged between said outwardly-projecting shoulder and said upper inwardly-projecting shoulder.

6. The perforating apparatus of claim 4 wherein said yieldable shock-attenuating means include a member formed of a resilient material engaged between said outwardly-projecting shoulder and said lower inwardly-projecting shoulder.

7. The perforating apparatus of claim 4 wherein said yieldable shock-attenuating means include a first member formed of a resilient material engaged between said outwardly projecting shoulder and said upper inwardly projecting shoulder and a second member formed of a resilient material engaged between said outwardly pro-

jecting shoulder and said lower inwardly projecting shoulder.

8. The perforating apparatus of claim **7** further including:

means defining first and second normally spaced opposed abutments on said other portions of said inner and outer members respectively and cooperatively arranged for preventing separation of said inner member from said outer member.

9. The perforating apparatus of claim **7** further including:

means cooperatively arranged between said inner and outer members for retaining said inner and outer members in a fixed angular relationship with one another without preventing relative longitudinal movement therebetween.

10. Well bore apparatus comprising:

a first body adapted for coupling to a first perforating gun and including an enlarged axially-aligned opening having upper and lower inwardly directed shoulders arranged on the walls thereof;

a second body adapted for coupling to a second perforating gun and including a reduced axially aligned portion coaxially disposed within said opening in said first body and having at least one outwardly directed shoulder cooperatively arranged thereon and positioned between said inwardly directed shoulders;

first shock-attenuating means including a first resilient member coaxially mounted around said reduced body portion between said outwardly directed shoulder and one of said inwardly directed shoulders for resiliently supporting one of said bodies on the other of said bodies as well as dampening movements of said one body in one axial direction;

a second shock-attenuating means including a second resilient member cooperatively mounted between said outwardly directed shoulder and the other of said inwardly directed shoulders for resiliently dampening movements of said one body in the opposite axial direction;

wire-passage means extending through said first and second bodies; and

means co-rotatively coupling said first and second bodies together for slidably retaining them in a selected angular relationship without preventing axial movements therebetween.

11. The well bore apparatus of claim **10** wherein said wire-passage means include:

first and second longitudinal passages respectively formed through said first and second bodies, and an elongated tubular conduit slidably disposed in said longitudinal passages and respectively extending between said first and second bodies.

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