INFORMATION REDACTED PURSUANT TOTHE FREEDOM OF INFORMATION ACT (FOIA), 5 U.S.C.552(B)(6)

OCT 2 - 2019
CL-11217635 - 3107

October 10, 2019
RE: Porsche Panamera Accident report #11217635:
Follow up information from engineering scientist [redacted]

INCIDENT SUMMARY: My wife and I were going to dinner. I was driving the car in a parking lot. As I was moving the car very slowly over the last foot before the curb of the designated parking space, the car accelerated at full speed and power on its own, without me causing it to do so. At that point I had NO control of the vehicle. It continued to go at full speed and acceleration for about 50 yards through rugged terrain - over an incline, large boulder, and plowed a path through brush, rocks and ruts. I was pushing the brake pedal down with full strength the entire scary ride. The car stopped just before we would have slammed into a large tree. We were lucky to walk away alive. The car was towed and proclaimed totaled by our insurance company.

POTENTIAL CAUSE: The key question is what caused the acceleration? I know it was NOT caused by any action taken by me. I was driving slowly through the parking lot, and was nearly at a total stop to avoid hitting the curb in front of the car when the vehicle accelerated on its own. To be clear: the event was not caused by me, and it did not result from high speed driving. Without much effort we found two very similar incidents on the internet that we forwarded in our original documentation to your office. In a third incident we have become aware of [redacted] and [redacted] didn't live to tell about their story. The incident killed them. I respectfully submit that all three incidents should be looked at by accident reconstruction experts, with an expertise in electromagnetism.

The car itself is the likely origin of these incidents related to a number of aspects. One very important potential cause of the acceleration is electrification. I believe that the root cause of my incident, and potentially of others, was electro-magnetic radiation, known as EMF. Further investigation may demonstrate that elector-magnetism produced from sources outside of the vehicle was not safely and properly isolated, and that the outside electro-magnetism acted with vehicle systems, to cause those systems to take unintended actions.

On September 18, 2019 a team of engineers from Porsche came to inspect the site of the accident and collect data from the car. I was in attendance, and able to measure the magnetic field generated by the vehicle. I found that magnetic field to be relatively high at idle - enough for me to be concerned that could be the reason for the incidents. There needs to be assurance that the controller has sufficient protection from EMF. The challenge is that EMF can come from different sources and is out of control.

POTENTIAL SOLUTIONS
With 200 patents, many relating to magnetics, I have significant expertise in this area. From my totality of patents, many of them deal with safety and digital engine controls. Attached above are several patents that relate to a path toward solutions for these issues The main problem is that although we cannot see magnetic lines, that doesn't mean they do not exist. The transfer of electricity causes magnetic fields. That's basic physics. The book 'Dirty Electricity' by Samuel Milham, MD< MPH.

NM
10/22/19
AS

should be studied. It's a short read with relevant information.

I invite you to visit me at my residence at the [redacted], Marana, Arizona where I can share additional aspects of the problem and solutions with you. Alternatively please feel free to call me at [redacted] to discuss further.

Regards,

[redacted]

[redacted]

[redacted] Marana, AZ [redacted]

(12) **United States Patent**
[redacted]

(10) **Patent No.:** [redacted]
(45) **Date of Patent:** **Nov. 10, 2015**

(54) **METHODS OF OPERATION OF FUEL INJECTORS WITH INTENSIFIED FUEL STORAGE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 264 days.

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F02M 47/02	(2006.01)
F02M 57/02	(2006.01)
F02M 51/06	(2006.01)

(52) **U.S. Cl.**

CPC ***F02D 41/20*** (2013.01); ***F02M 1/18*** (2013.01); ***F02M 47/02*** (2013.01); ***F02M 51/061*** (2013.01); ***F02M 57/02*** (2013.01); ***F02M 57/025*** (2013.01); *F02D 2200/0602* (2013.01); *F02M 2200/40* (2013.01)

(58) **Field of Classification Search**

CPC F02M 1/18; F02M 57/02; F02M 47/02; F02M 51/061

USPC 239/1, 5, 69, 88-90, 92, 96, 124, 127, 239/585.1; 123/294, 299, 300, 305, 467

See application file for complete search history.

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(57) **ABSTRACT**

Methods of operating fuel injectors with intensified fuel storage. At least one storage volume is provided in the intensifier type fuel injector, with a check valve between the intensifier and the needle chamber and storage volume preventing loss of injection pressure while the intensifier plunger cylinder is refilling with fuel. Using the check valve to isolate the storage volume from the intensifier to reduce and control pressure spikes that effect injector operation. This provides very efficient injector operation, particularly at low engine loads, by eliminating the wasted energy of compressing, venting and recompressing fuel for injection and reducing and controlling pressure spikes that effect injector operation.

15 Claims, 3 Drawing Sheets

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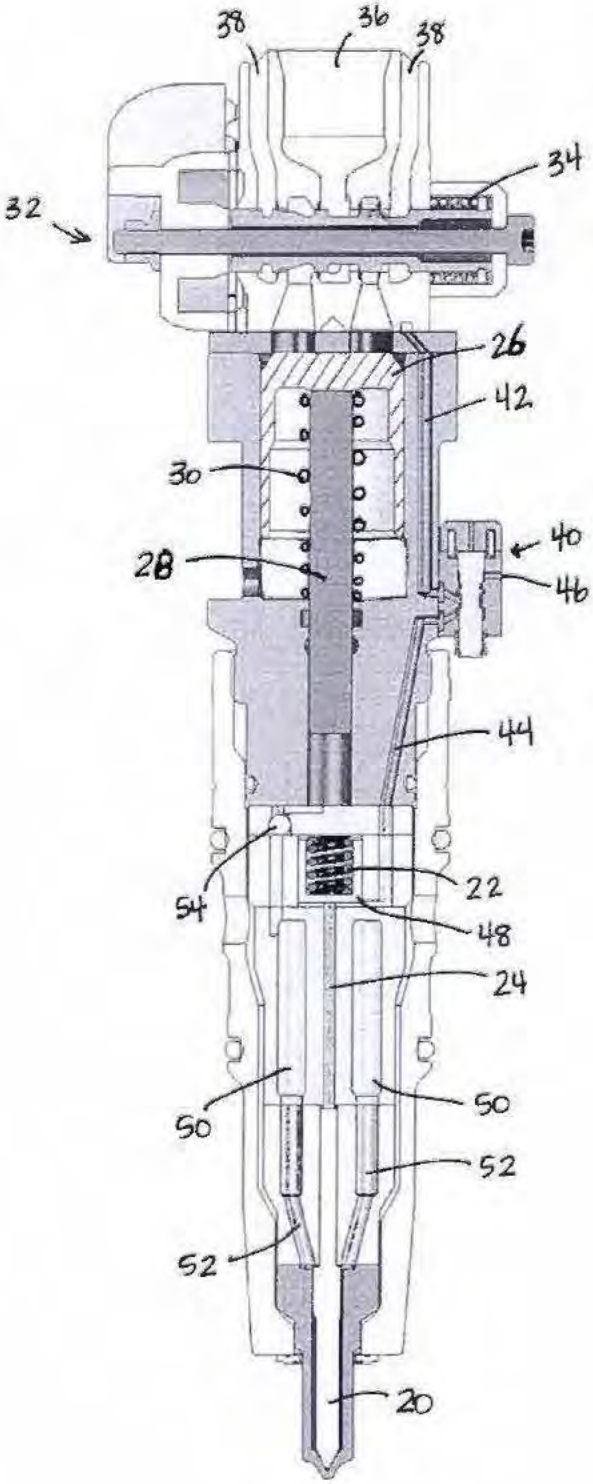

Fig. 1

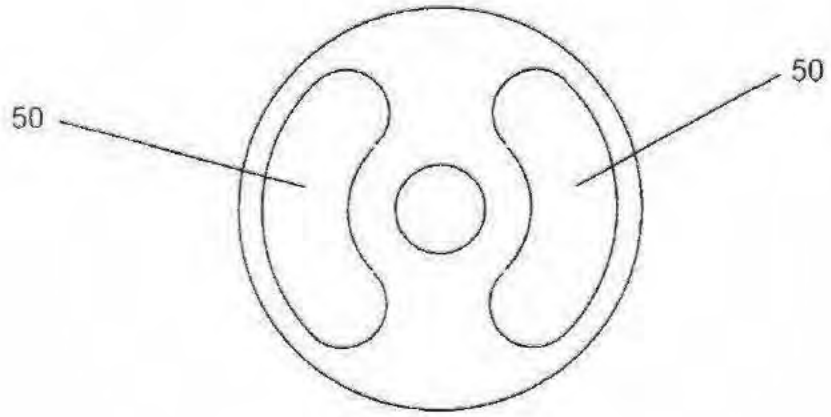

Fig. 2

METHODS OF OPERATION OF FUEL INJECTORS WITH INTENSIFIED FUEL STORAGE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of fuel injectors, fuel injection systems and methods of operation thereof.

2. Prior Art

Fuel injector performance, particularly in diesel engines, has a substantial influence in overall engine performance, especially with respect to emissions. Of particular importance is the speed at which fuel injection can be terminated. In particular, if fuel injection is terminated merely by the reduction in injection pressure it is difficult to rapidly terminate injection because of the compressibility of the fuel and actuation fluid in an intensifier type fuel injector, resulting in a trail off in atomization resulting in unacceptable levels of unburned fuel in the exhaust. Accordingly various types of direct needle control have been proposed to provide injection control other than by controlling injection pressure.

Also fuel injectors, particularly diesel fuel injectors, are using ever increasing injection pressures, now going as high as 3000 bar (45,000 psi). Diesel fuel has a compressibility of approximately 1% per 67 bar (1000 psi), so that at the injection pressure, the fuel has been substantially compressed. In intensifier type fuel injectors, injection occurs directly as a result of intensification, so that injection begins on intensification and terminates on termination of intensification. Consequently the volume of fuel intensified is set equal to the maximum injection volume needed, plus of course some overhead volume for the needle chamber, passageways to the needle chamber, etc. At a partial power setting for the engine, much less than the maximum injection volume is needed, yet the full amount is compressed and then depressurized, losing the energy required for the compression of the fuel not injected, which at low power settings and at idle, can be most of the substantial amount of energy used for intensification. In fuel injectors having direct needle control, the operation is a bit different, in that intensification occurs, then injection by the direct needle control, then termination of injection, again by direct needle control, and then depressurization to refill the intensification chamber for the next cycle. While this cycle is a bit different, the losses of intensification energy are not different.

Injectors using direct needle control to control injection of fuel supplied to the injector at injection pressure from an external source are also known. These injection systems are more efficient because fuel, once compressed, is sooner or later all injected regardless of the engine power setting. They also have the advantage of not cycling the fuel pressure in the needle chamber on each injection event, helping reduce, but not eliminate, the possibility of eventual injector tip breakage. However such systems have serious drawbacks. Aside from the safety issues of having a rail at injection pressures and the associated plumbing problems, there is a serious risk to the engine, in that if an injection tip breaks off, a direct and continuous flow path from the high pressure rail to the combustion chamber is provided, which could result in a hydraulic lock of the engine with catastrophic results.

Also known are methods of operation of intensifier type fuel injectors whereby a quantity of fuel is intensified by an intensifier and injection is controlled by direct needle control with the intensifier still being active until the remaining intensified fuel is less than needed for the next injection event or a portion of an injection event, at which time the intensifier is deactivated to refill the intensifier with fuel. Then the intensifier is activated again for subsequent injection events under control of the direct needle control. In U.S. Patent Application Publication No. 2010/0012745, a substantial storage volume for intensifier fuel is also provided in the injector. See also U.S. Patent Application Publication No. 2008/0277504. These methods of operation of fuel injectors are highly efficient, but it has been discovered, can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross section of a fuel injector that may be operated by a method accordance with the present invention.

FIG. **2** is an illustration of the high pressure fuel storage in the lower section of the fuel injector.

FIG. **3** is a cross section of an alternate fuel injector that may be operated by a method accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In accordance with the present invention, the prior art method of intensifying a quantity of fuel and controlling the injection by direct needle control while the intensifier remains activated is modified to intensifying a quantity of fuel, then isolating the intensified fuel from the intensifier and keeping it isolated during subsequent injection events or injection sub-events. Such operation has been found to have a number of advantages over the prior art. Specifically, such operation has been found to control and greatly reduce pressure spikes in the intensified fuel which can cause mechanical deterioration of the injector. Also an injector operating in the prior art manner exhibits an undesired lack of repeatability, perhaps not detectable to one not looking closely, but which is in fact present, limiting the extent to which the performance of each cylinder of a multi-cylinder engine can be equalized. These effects may arise in part from the presence of a valve (preferably a check valve) between the intensifier and the bulk of intensified fuel, which when the intensifier is maintained active during injection, will partially or fully open during injection because of intensified fuel flow from the intensifier, with the check valve slamming shut after an injection event or injection sub-event because of the pressure spikes arising from the compressibility of the fuel, the pressures involved and speed of operation of the needle. Whatever the cause, it has been found that simply assuring that the check valve (or other valve) between the intensifier output and the bulk of the intensified fuel is closed during each injection event or injection sub-event controls and limits the pressure spike, which makes the injector operation very repeatable. This in turn allows the adjustment of the injection, cycle to cycle, so that the pressure profiles in the cylinders of a multi-cylinder engine can be made to be substantially equal to each other in amplitude, shape and timing with respect to crank angle.

Thus the present invention is a new method of operating an intensifier type injector, such as a prior art intensifier type injector, to obtain substantially enhanced useful life and operating characteristics. Accordingly a prior art intensifier type injector that may be used with the present invention will be first described, and then more details of the invention will be described.

In the description to follow, the phrase "injection event" refers to a complete injection event, which may comprise injection sub-events, such as, by way of one example, a pre-injection that will be followed by a main injection, either as a single main injection, or a series of smaller injections. An

injection event may begin at any time after the end of a combustion cycle (power stroke) and will end before the end of the next combustion cycle (power stroke). Thus successive injection events in an engine operating in a two stroke or two cycle mode will occur on each engine crankshaft rotation (each 360 degrees of crankshaft rotation), while successive injection events in an engine operating in a four stroke or four cycle mode will occur on each pair of engine crankshaft rotations (each 720 degrees of crankshaft rotation).

First referring to FIG. **1**, a cross section of one embodiment of an injector that may be used with the present invention may be seen. The injector includes a needle **20**, normally held in the closed position by a spring **22** acting on an actuator pin **24** pushing against the top of the needle **20**. The injector is an intensifier type injector with intensifier piston **26** actuated by lower pressure actuation fluid acting against the top of plunger **28**, with coil spring **30** and fuel inlet pressure through a check valve (not shown) returning the intensifier piston **26** and plunger **28** to their unactuated position between injections. At the top of the injector is a single solenoid actuated three-way spool valve, generally indicated by the numeral **32**, with spring return **34**, which valve when in a first position will couple actuation fluid through port **36** to the region above the intensifier piston **26** or, alternatively, when in the second position, will couple the region above intensifier piston **26** to vents **38**.

A second smaller spool valve generally indicated by the numeral **40** is coupled to the side of the injector for direct needle control. In a preferred embodiment, spool valve **40** is a three-way magnetically latching spool valve, magnetically latching on actuation, and releasing for spring return on receipt of a small reverse current, though other types of valves, including other spool valves may be used if desired. In the embodiment disclosed, the valve either couples actuation fluid pressure in line **42** to line **44** when actuated, or alternatively, blocks the flow of actuation fluid in line **42** and couples line **44** to a low pressure vent **46** when the spool is released. The area above piston **48** is permanently coupled to the source of actuation fluid under pressure, and accordingly is always pressurized when the engine is running. Through the three-way valve **40**, pressure in line **44** controllably pressurizes the region under piston **48**, which in turn controls actuator pin **24**. For piston **48** and the intensifier, the actuation fluid is preferably engine oil, though some other actuation fluid may be used, such as fuel.

In the prior art, in operation, with the area under piston **48** vented, spring **22** and actuation fluid pressure above piston **48** will hold the needle closed, even against intensified fuel pressure in the needle chamber. When injection is to occur, needle control valve **40** is actuated to couple actuation fluid pressure to the region below piston **48**, which pressure balances the piston **48**, allowing intensified fuel pressure in the needle chamber to force the needle open against spring **22**. Of course at the end of injection, the needle control valve **40** is released to again vent the area under piston **48** to allow actuation fluid pressure over piston **48** to force the needle closed. Of course the needle control valve **40** may be operated more than once, first to provide a pre-injection, followed by a second injection, or even to provide pulsed injections.

Of particular importance to the present invention are the large storage volumes **50**, also shown in the cross section of FIG. **2**, the generous porting **52** and particularly the (ball) check valve **54**. In the present invention, the storage of fuel at the intensified pressure is facilitated by check valve **54**, which prevents depressurization of the intensified fuel pressure when the intensifier is deactivated (actuation pressure vented to a low pressure or a vent) so that, before the next injection

event (or injection sub-event), spring **30** and fuel supply pressure can raise the intensifier piston **26** and intensifier plunger **28** to refill the volume under the intensifier plunger. Thus injection is controlled by the needle control valve **40** when the intensifier actuation fluid over the intensifier piston **26** is not pressurized, and therefore the check (or other) valve is closed, isolating the pressurized fuel in the storage volume used for injection from the intensifier, and particularly from the flow to and from the storage volume, in part due to the fuel compressibility, that causes or can cause the check valve to slam shut. This allows the direct needle control to control injection using the isolated and intensified fuel in the storage volume, with the compressibility of the intensified fuel maintaining the required injection pressure with relatively minimum pressure drop. In addition, if the intensifier is carefully proportioned relative to the amount of intensified fuel that may be injected before the pressure of the intensified fuel in the storage volume decreases more than desired (preferably but not necessarily amounting to a plurality of injection events, even at maximum power), and if the check valve is close to the outlet from the cylinder within which the intensifier plunger operates, then each intensifier stroke for fuel intensification may be a single complete (maximum or near maximum) stroke so that the amount of intensified fuel that is returned to a non-intensified pressure (on recycling of the intensifier) without injection will be a minimum, maximizing the efficiency of the intensification operation. Alternatively, multiple strokes of the intensifier piston and plunger may be used, in which case the last stroke preferably is a maximum or near maximum stroke.

The electronic control system that controls injection may also keep track of the amount of fuel injected on each injection event, and recycle the intensifier when required. Correction of the electronic control system for its errors in the amount of fuel injected on each injection event, if desired, may be made for each intensification cycle by obtaining some measure of the intensification pressure itself, such as by providing a measure of the intensifier actuation fluid pressure on the intensifier piston during intensification, and by limiting the stroke of the intensifier piston and plunger to slightly less than the maximum allowable, and sensing the intensifier piston and plunger position at the end of the intensifier intensification stroke. This may be done, by way of example, by using a hall-effect sensor or an electromagnetic sensor, and using the actuation fluid pressure times the intensification ratio as a measure of the intensified fuel pressure. Now a longer than expected stroke in comparison to the stroke expected for the amount of intensified fuel that was estimated to be needed to replenish the amount of fuel that was injected since the last intensification cycle is somewhat greater than estimated by the controller, so that appropriate corrections may be made in keeping track of the fuel injected after the last intensification cycle.

At idle and during low power settings, the intensifier need only be recycled after numerous injection events. Even at a maximum power setting, preferably (but not necessarily) the storage provided is adequate for multiple injection events. Depending on the relative volumes, initially the intensifier will likely need to be cycled more than once to adequately pressurize the fuel in the storage volume **50**.

The present invention provides all the advantages and eliminates the disadvantages of a fuel rail at high injection pressures, and also substantially eliminates the high pressure spikes and improves the repeatability of the injector over that of injectors operated in accordance with U.S. Patent Application Publication No. 2010/0012745. In that regard, preferably the fuel in the total storage volume **50**, after decompress-

ing, is less than that that would cause a hydraulic lock in the engine cylinder if dumped into the cylinder on breakage of the injector tip. Also, the storage volume should not be so large as to jeopardize the structural integrity of the injector. Of course, while one exemplary form of direct needle control has been disclosed for purposes of setting the environment for the present invention, substantially any form of direct needle control may be used. Also while the check valve **54** is shown as a ball valve, other forms of check valves may also be used.

The exemplary embodiment of the injector disclosed herein also uses intensifier actuation fluid for direct needle control. Alternatively, intensified fuel pressure may be used for direct needle control. This is not preferred however, because of the valving difficulties at the intensified pressure. Of course, substantially any method of direct needle control may be used with the present invention, as it is the combination of direct needle control, however done, together with the ability to store fuel at the intensified pressure in isolation from the intensifier during injection, that provides the repeatability, efficiency and durability characteristics of the present invention.

Now referring to FIG. **3**, and alternate embodiment of injector that may be used with the present invention may be seen. This embodiment is functionally the same as the previously described embodiment, though has a more convenient mechanical arrangement. The embodiment of FIG. **3** includes a needle **20** with large storage regions **50** and generous porting **52** between the needle **20** and the storage regions **50**. The major difference between the embodiment of FIG. **3** and FIG. **1**, however, is the general arrangement of the intensifier and direct needle control. In particular, needle control pins **56** and **58** extend upward along the axis of the injector to a direct needle control piston **62** adjacent the top of the injector.

In the embodiment of FIG. **3**, the intensifier piston **26'** is concentric with the needle control pin **58** and operates against multiple plunger pins **60**. In one embodiment, this comprises three plunger pins, plumbed together and ported to storage regions **50** through porting not shown in the Figure. Between the plunger pins **60** are additional storage volumes **64**, which are also plumbed to the storage volumes **50**. The upper needle control pin **58** in this embodiment is encouraged to its downward most position by a relatively light spring **66**, with an additional return spring **68** for the intensifier piston **26**. The return of the plunger pins **60** is by way of fuel pressure provided underneath the plunger pins **60** from a relatively low pressurized fuel source through a ball valve which subsequently seals against intensified fuel pressures, as is well known in the art.

The operation of the embodiment of FIG. **3** is as follows. Engine oil under pressure is provided through port **70** to a small spool valve **72**, shown schematically, and a larger spool valve **74**, also shown schematically. The two spool valves **72** and **74** are preferably three-way valves. The spool valve **72** provides direct needle control, and when porting the engine oil through port **70** to the top of piston **62**, holds the needle **20** down against the needle seat to seal the same against fuel at intensified pressure. Thus as before, spool valve **74** may be used to port engine oil through port **70** to the top of intensifier piston **26'** to intensify the fuel pressure, with the intensification remaining typically through a plurality of injections as controlled by the needle control spool valve **72**. When the intensifier piston **26'** approaches the bottom of its range of travel, spool valve **74** is actuated to cut off engine oil communication between port **70** and the top of the intensifier piston **26'**, and instead will couple the region above intensifier **26'** to a vent or low pressure oil sump, typically directly or indirectly back to the engine crankcase. During this time a ball valve similar to ball valve **54** of FIG. **1** is used to retain the intensification pressure on the remaining intensified fuel while the intensifier is cycled to intensify another charge, preferably between injection events.

Again, the method of operating an injector with intensified fuel storage in accordance with the present invention is to operate the intensifier between injection events, or even injection sub-events if time allows, to provide intensified fuel to the intensified fuel storage volume, and then to isolate that stored intensified fuel from the intensifier before or as the intensifier is returned to its un-actuated position in readiness for its next intensification stroke. If a simple check valve such as a ball check valve is used for that isolation, the check valve will close as the intensifier is returned to its un-actuated position in readiness for its next intensification stroke.

Thus, like the method disclosed in U.S. Patent Application Publication No. 2010/0012745, the present invention method can very substantially reduce the energy loss of other types of prior art intensifier type fuel injectors and methods of operation by minimizing the fraction of the fuel that is raised to the intensified pressure but not injected, yet greatly reduces the pressure spikes and increases the repeatability of an injector with intensified fuel storage in comparison to the method of U.S. Patent Application Publication No. 2010/0012745, all with an increase in durability of the injectors used because of the limiting of the pressure spikes. In that regard, the pressure spikes put unnecessary forces on the injector tip, which can lead to a premature failure of the tip.

While certain preferred embodiments of the present invention have been disclosed and described herein for purposes of illustration and not for purposes of limitation, it will be understood by those skilled in the art that various changes in form and detail may be made in the method and in the injector used to practice the method without departing from the spirit and scope of the invention.

What is claimed is:

1. In an engine, a method of operating an intensifier type fuel injector having an intensifier piston responsive to actuation fluid pressure and at least one intensifier plunger in a plunger cylinder having a movement in a first direction to intensify the pressure of the fuel, and in a second direction when actuating fluid pressure is removed from the intensifier piston for refilling the plunger cylinder with fuel for intensification while the plunger moves in a second direction, the intensifier plunger having a limited stroke, comprising:

a) closing a needle of the fuel injector

b) intensifying fuel in a needle chamber surrounding the needle and in at least one intensified fuel storage volume within the injector to a desired pressure using the intensifier;

c) isolating the intensified fuel in the needle chamber surrounding the needle and in the at least one intensified fuel storage volume from the intensifier plunger by removing the actuating fluid pressure from the intensifier piston before d); and,

d) controllably opening and closing the needle for successive multiple fuel injection events while the intensified fuel is isolated from the intensifier plunger

e) then repeating b) through d).

2. The method of claim **1** wherein the intensifier type fuel injector further comprises a check valve a) between the plunger cylinder, and b) the needle chamber surrounding the needle and the at least one intensified fuel storage volume, and wherein isolating the intensified fuel in the needle chamber surrounding the needle and in the at least one intensified fuel storage volume from the intensifier plunger comprises

removing the actuating fluid pressure from the intensifier piston to close the check valve by movement of the plunger toward the second direction.

3. The method of claim 1 wherein in b), substantially all fuel in the plunger cylinder is expelled from the plunger cylinder.

4. The method of claim 3 wherein a controller for the injector also estimates the amount of intensified fuel the intensifier needs to replenish the needle chamber surrounding the needle and the at least one intensified fuel storage volume with intensifier fuel with the desired pressure, and initiates b) when fuel pressure in the needle chamber surrounding the needle and the at least one intensified fuel storage volume can be replenished by a single intensification of fuel then in the plunger cylinder.

5. The method of claim 4 wherein a measure of intensified fuel pressure is used for correction of the control system based on errors in the estimation by the control system.

6. The method of claim 5 wherein the intensifier actuation fluid pressure is used as a measure of intensified fuel pressure.

7. The method of claim 6 further comprising sensing the error in the amount of intensified fuel the intensifier needs to replenish the needle chamber surrounding the needle and the at least one intensified fuel storage volume with intensified fuel to the desired pressure.

8. The method of claim 7 wherein sensing the error in the amount of intensified fuel the intensifier needs to replenish the needle chamber surrounding the needle and the at least one intensified fuel storage volume with intensified fuel to the desired pressure comprises sensing a final position of the intensifier piston and plunger when in b), the motion in the first direction ends, and adjusting the amount of fuel being intensified in b) in a subsequent intensification to then obtain a final position approaching a limit in motion in the first direction.

9. In an engine, a method of operating an intensifier type fuel injector having an intensifier piston responsive to actuation fluid pressure and at least one intensifier plunger in a plunger cylinder having a movement in a first direction to intensify the pressure of the fuel, and in a second direction when actuating fluid pressure is removed from the intensifier piston for refilling the plunger cylinder with fuel for intensification while the plunger moves in a second direction, the intensifier plunger having a limited stroke, comprising:

a) closing a needle of the fuel injector;

b) intensifying fuel in a needle chamber surrounding the needle and in at least one intensified fuel storage volume within the injector to a desired pressure using the intensifier wherein substantially all fuel in the plunger cylinder is expelled from the plunger cylinder;

c) isolating the intensified fuel in the needle chamber surrounding the needle and in the at least one intensified fuel storage volume from the intensifier plunger by a check valve 1) between the plunger cylinder, and 2) the needle chamber surrounding the needle and the at least one intensified fuel storage volume, and wherein isolating the intensified fuel in the needle chamber surrounding the needle and in the at least one intensified fuel storage volume from the intensifier plunger comprises removing the actuating fluid pressure from the intensifier piston to close the check valve by movement of the plunger in the second direction prior to d);

d) controllably opening and closing the needle for multiple successive fuel injection events while the intensified fuel is isolated from the plunger cylinder; and

e) then repeating b) through d).

10. The method of claim 9 wherein in b), substantially all fuel in the plunger cylinder is expelled from the plunger cylinder.

11. The method of claim 10 wherein a controller for the injector also estimates the amount of intensified fuel the intensifier needs to replenish the needle chamber surrounding the needle and the at least one intensified fuel storage volume with intensifier fuel with the desired pressure, and initiates b) when fuel pressure in the needle chamber surrounding the needle and the at least one intensified fuel storage volume can be replenished by a single intensification of fuel then in the plunger cylinder.

12. The method of claim 11 wherein a measure of intensified fuel pressure is used for correction of the control system based on errors in the estimation by the control system.

13. The method of claim 12 wherein the intensifier actuation fluid pressure is used as a measure of intensified fuel pressure.

14. The method of claim 13 further comprising sensing the error in the amount of intensified fuel the intensifier needs to replenish the needle chamber surrounding the needle and the at least one intensified fuel storage volume with intensified fuel to the desired pressure.

15. The method of claim 14 wherein sensing the error in the amount of intensified fuel the intensifier needs to replenish the needle chamber surrounding the needle and the at least one intensified fuel storage volume with intensified fuel to the desired pressure comprises sensing a final position of the intensifier piston and plunger when in b), the motion in the first direction ends, and adjusting the amount of fuel being intensified in b) in a subsequent intensification to then obtain a final position approaching a limit in motion in the first direction.

* * * * *

United States Patent [19]

[redacted]

[11] 3,743,266

[45] July 3, 1973

[54] **ENERGY ABSORBING ISOLATION SYSTEM**

[75] Inventors: [redacted] Northridge; [redacted] Venice, both of Calif.

[73] Assignee: **Inca Manufacturing Corporation,** Inglewood, Calif.

[22] Filed: **Aug. 26, 1971**

[21] Appl. No.: **175,186**

[52] **U.S. Cl.** **267/31**, 267/162

[51] **Int. Cl.** **B60g 11/34**

[58] **Field of Search** 267/31, 36, 162, 267/3; 293/86, 89; 188/196

[56] **References Cited**

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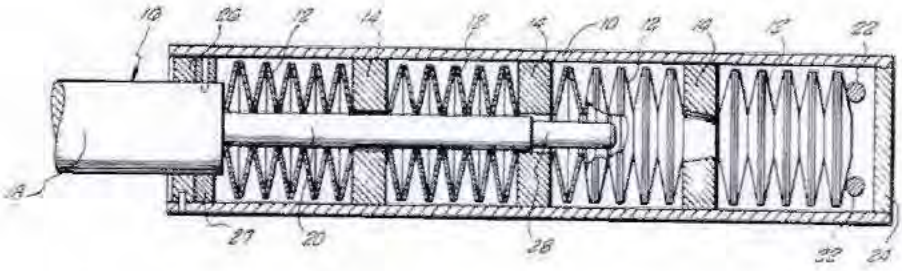
Primary Examiner—James B. Marbert

Attorney—Leonard Golove, Marvin H. Kleinberg et al.

[57] **ABSTRACT**

This invention relates to a novel energy absorbing isolation device which will absorb and dissipate a major portion of the energy associated with vehicle collisions. The present invention comprises a cylindrical tube, housing a plurality of Belleville spring washers which are compressed on impact by the wide portion of a movable shaft having a relatively wide portion and a relatively narrow portion. The relatively narrow portion of the shaft advances axially into the cylindrical tube as the Belleville washers are compressed. The energy of impact is absorbed and dissipated by compression of the Belleville washers and by interactions between the washers, the inside surface of the cylindrical tube, and the narrow portion of the shaft.

27 Claims, 3 Drawing Figures



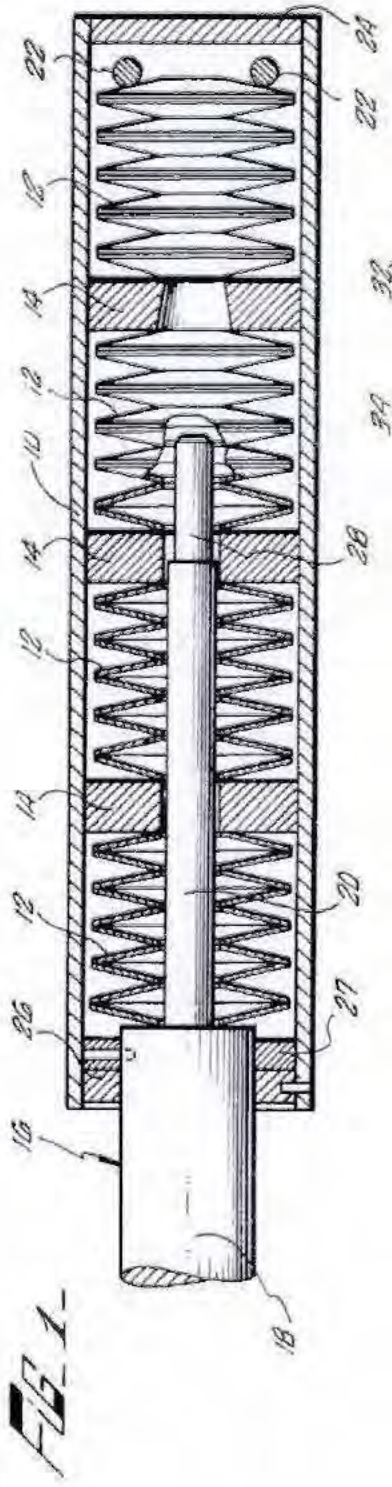


FIG. 1

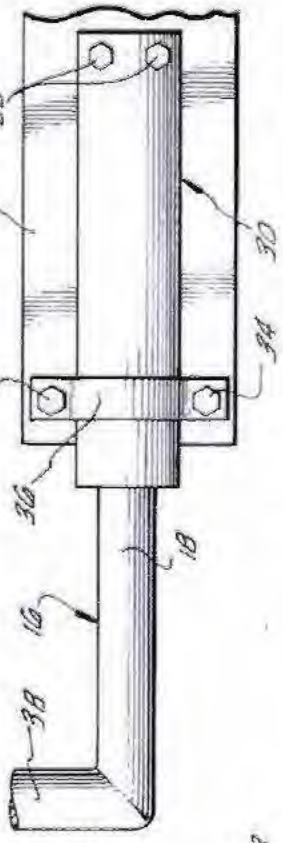


FIG. 2

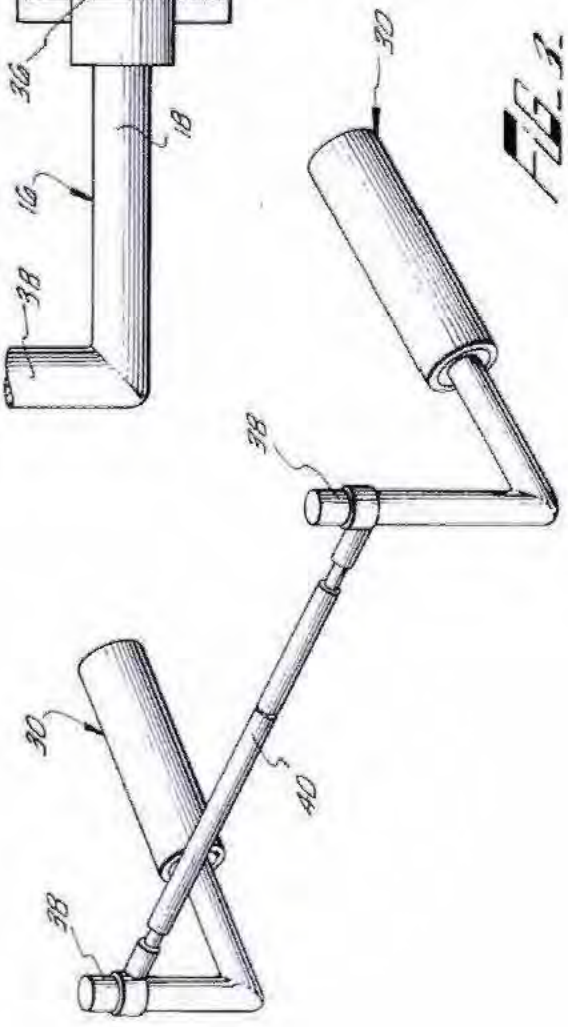


FIG. 3

ENERGY ABSORBING ISOLATION SYSTEM

This invention relates to an energy absorbing isolation device for use with a moving vehicle and more particularly to a shock absorbing system which will absorb and dissipate a major portion of the energy associated with vehicle collisions.

Referring to U.S. Pat. No. 3,313,567, for a "Belleville Spring Biased Bumper," issued to O. E. Sturman, the co-inventor of the present improvement, it is pointed out therein that moving vehicles in a situation of high impact, that is a collision or other accident, suffer relatively large damage and that serious injury to passengers frequently result therefrom. In the prior Sturman patent, the use of a plurality of Belleville washers to absorb some of the energy necessarily created by the collision is discussed.

The present invention is basically an improved device using the Belleville springs discussed in the prior Sturman patent. The improvements over the prior Sturman patent lie in providing an energy dissipative device that allows energy to be dissipated in a more economical and practical manner.

The improvement maximizes the amount of energy dissipated between the Belleville springs and both the center shaft and the inside surface of the cylindrical tube. Hence, the total energy dissipating device can be made shorter in length, lighter in weight and less expensive to fabricate.

The second principal area of improvement over the prior Sturman device is that the present invention is adapted to protect the vehicle and its passengers from collisions occurring at an angle to the normal direction of movement of the vehicle. As was the case above in connection with the first area of improvement, the earlier device is capable of absorbing collision produced forces either in, or at a relatively small angle to, the normal direction of motion of the vehicle. The present improved device increases substantially the angle of collisions which can be accomodated and increases the efficiency of the device with respect to such angled collisions.

An additional improvement over the prior Sturman patent lies in the consistancy in performance and repeatibility. The device described herein, by design, can be made such that it can be cycled hundreds of times with no degradation in performance or energy dissipative ability.

A still further improvement provided by the present invention over the prior Sturman device is that the automatic holding device, which retained the Belleville springs in their compressed position to avoid rebound of the spring washers, has been eliminated since the increased energy absorbing capability of the present invention reduces the need for this protection to the point where this protective feature can be eliminated.

Briefly described, the present invention comprises a cylindrical tube which houses a plurality of Belleville springs mounted face to face and back to back. A movable shaft having a relatively wide portion of relatively large diameter, and a relatively narrow portion of relatively small diameter is introduced into the cylindrical tube such that the relatively wide portion contacts the plurality of Belleville washers at the end of the stack of washers such that force applied to the shaft will be transmitted to the washers. The stack of Belleville washers is divided into a plurality of segments by a plurality of sliding rings which are introduced into the cylindrical tube at intervals.

The relatively narrow portion of the shaft is adapted to fit into the sliding rings, which serve as a guide for the shaft as well as other functions which will be discussed below. The cylindrical tube may be either closed at the end opposite the shaft or the Belleville washers may be restrained from movement outside the cylindrical tube by relatively heavy bolts which can also be used to couple the energy absorbing structure to the vehicle frame.

Upon impact, the shaft exerts force on the Belleville washers which in turn compress, absorbing energy, and which deform such that the inner diameter of the washers decreases and the outer diameter of the washers increases. Frictional forces between the narrow portion of the shaft and the inner surface of the Belleville washers account for some energy dissipation. Frictional forces between the outer surface of the Belleville washers and the cylindrical tube account for still more energy dissipation. Frictional forces between adjacent Belleville washers account for still more energy dissipation and, depending upon the impact forces, movement of the narrow portion of the shaft against the compressed washers may cause the washers to shear off part of the metal composing the narrow portion of the shaft. Movement of the Belleville washers against the cylindrical tube also may cause removal of metal from the tube. In both of these cases, removal of metal, when it occurs, dissipates a very substantial portion of the energy applied to the device.

In addition to the energy absorbing means described above, it is believed that the narrow portion of the shaft exhibits flexibility under relatively heavy and angled loads, and that this flexibility results in still further frictional and shear forces which assist in dissipating additional energy.

The effective operation of the present device under relatively large side or angled loads is accomplished by a number of means.

The relatively wide portion of the shaft is held in place by a front ring which is fixed to the shaft. When the springs are compressed by movement of the shaft, the fixed ring also moves providing both support and positioning of the center shaft.

Additionally, the sliding guide rings maintain the position of the shaft relative to the cylindrical tube. Other structural elements also assist in side load accommodation as will be pointed out in detail hereafter. In operation, it has been found that the present invention tends to function more efficiently under side loads than under direct frontal impacts. It is believed that this advantage is due to the fact that frictional forces are increased by the increase in force normal to the direction of motion of the shaft.

It is therefore an object of the present invention to provide an improved energy absorbing device for moving vehicles.

Still another object of the invention is the provision of an improved energy dissipating and absorbing device which lessens the effect of impact on the vehicle and on the passengers therein.

Another significant advantage of the present invention is that it can be applied to motor vehicles having an already existing bumper system. A novel method of attachment of the shock absorbing system to existing vehicles, which minimizes the amount of additional

weight which must be added to the vehicle and which does not present an unpleasing appearance, has been developed.

To achieve this result, each of the novel shock absorbing units described above is attached directly to the frame (or equivalent) of the vehicle below the level of the existing bumper. The movable shaft, referred to above, is extended beneath the bumper to a point several inches in front of the furthest projection of the vehicle. The shaft itself is bent to form a right angle, and is mounted such that one of its sides serves as a vertical guard. One of the shock absorbing units is placed on each side of the vehicle and a cross bar is attached between the vertical guard members through swivel joints which are used so that each shock absorbing unit may operate independently. The cross bar itself is a telescoping member to prevent deformation under minor impacts. Since impact forces are applied directly to the shock absorbing units, no relatively heavy transmission members are required and the added weight to the vehicle is minimized.

Still another object of this invention is to provide an improved energy absorbing device in which a relatively large portion of the energy produced by an impact is dissipated rather than stored.

A further object of the invention is to provide an energy absorbing device which functions at a relatively large angle of impact.

A still further object of the present invention is to provide a vehicle bumper system which provides all of the advantages set forth above.

Another and still further object of the present invention is to provide a novel method of attachment of a vehicle bumper system to an existing motor vehicle which requires no alteration of the present structure of the vehicle, which adds minimum weight to the vehicle, and which does not substantially impair the appearance of the vehicle.

These and other advantages and further objects of the invention will be apparent to those skilled in the art from the following specification and the appended drawings in which:

FIG. 1 is a sectional view of the energy absorbing system of the present invention;

FIG. 2 is a plan view of the shock absorbing system showing the system mounted on the frame of the vehicle;

FIG. 3 is a perspective view of a pair of shock absorbing systems as used on a vehicle together with the cross member connecting the shock absorbing units.

Turning now to FIG. 1, the details of construction of a novel shock or energy absorbing system are shown. A cylindrical tube **10** houses a plurality of Belleville springs **12**, mounted face to face and back to back. The springs **12** are divided into segments by a plurality of sliding rings **14**. A movable shaft **16**, having a relatively wide portion of relatively large diameter **18** and a relatively narrow portion of relatively small diameter **20**, is introduced into the cylindrical tube **10**, such that the relatively wide portion **18** contacts the plurality of Belleville washers **12** at one end of the stack of washers **12**. Thus, force applied to the shaft **16** will be transmitted to the washers **12**.

The opposite end of the stack of Belleville washers **12** is restrained by a pair of bolts **22**, which may also be used to assist in mounting the energy absorbing system to a vehicle. In the embodiment shown, a relatively light end member **24** seals the opposite end of the cylindrical tube **10**, however the bolts **22** could be eliminated if the member **24** were used to restrain the washers **12**. In this case, the member **24** would have to be of very substantial strength. The relatively wide portion **18** of the shaft **16** is maintained in its position even under very severe angled impacts by a front ring **27**, which is pinned to the shaft **16**, together with the plurality of sliding rings **14**. The stationary ring **26** is pinned to the tube body **10**. This stationary ring **26** retains the Belleville springs and prevents the springs from exiting the tube after impact or cycling. In addition, the ring **26**, as a retainer, allows the plurality of springs **12** to be preloaded or compressed at assembly. Preload of springs **12** shapes the dissipative force curve. The sliding ring **27** is adapted to contact the wide portion of shaft **16** with the cylindrical tube **10**, whereas the plurality of sliding rings **14** is adapted to guide the relatively narrow portion **20** of the shaft **16**.

As shown, the end of the relatively narrow portion **20** of the shaft **16** is provided with a bevelled surface to allow easy entry into the sliding rings **14**. One or more of the sliding rings **14** is also biased to further assist in the introduction of the end of the narrow portion **20** into the sliding rings **14**.

A portion **28** of the narrow portion **20** is relieved as shown (exaggerated) for reasons which will be explained fully below.

Turning now to FIG. 2, the shock absorbing system is shown mounted to a portion of the frame of a vehicle. The shock absorbing unit **30** is fixed to a portion of the frame of the vehicle **32** by a pair of bolts **34** which retain the unit **30** by means of a strap **36**. The additional pair of bolts **22** further secures the unit **30** to the frame. As has been pointed out above, the bolts **22** are also used to retain the Belleville springs **12**. The shaft **16** is shown having one end bent at a right angle. In use, the right angled portion **38** serves as a vertical guard for the vehicle body and is placed such that impact is received on the vertical portion. Forces applied to the vertical portion of the shaft **38** are, of course, transmitted to the Belleville springs **12**, as has been described above.

FIG. 3 shows a pair of shock absorbing units **30** together with a cross member **40**. As shown, a shock absorbing unit **30** is placed on each side of the vehicle and the cross bar **40** is attached to the vertical portions **38** through a swivel joint. These swivel joints permit each shock absorbing unit **30** to operate independently. The cross bar **40** is in fact a telescoping structure as shown, which prevents bending of the cross bar **40** when side loads are applied. As can be seen from FIG. **3**, each end of the cross bar **40** is adapted to permit relative shortening or lengthening of the member **40** when forces require such contraction or elongation.

In operation, when a substantial force is applied to the shaft **18**, the shaft **18** compresses the plurality of Belleville springs **12**. During the compressive process kinetic energy is dissipated by both frictional interaction between Belleville springs **12** themselves, and also by frictional interaction between the inner diameter of the springs **12** and the central cylindrical shaft **20**. Further, additional frictional interaction occurs between the outer diameter of the springs **12** and the cylindrical tube **10**, which dissipates energy in a like manner. The amount of energy dissipation is controlled by selecting tube **10** and shaft **20** diameters, as the Belleville springs **12** expand on their outer diameter and constrict on

their inner diameter when compressed. The amount of expansion is controllable by design of the spring, hence any degree of frictional interaction can be produced in the device, thus enabling the device to be fabricated to accommodate a wide range of energy dissipation requirements.

Frictional forces are further enhanced by the movement of the spring **12** with respect to both tube **10** and center cylindrical shaft **20.** As the device is actuated and the Belleville springs **12** compress, they slide toward the restraining bolts **22,** thereby affecting a sliding frictional interaction between tube **10,** springs **12** and shaft **20.**

The above description is applicable to the design of an energy dissipating device that can be cycled or actuated many times with no degradation in performance. Under certain conditions, it may be desirable to assemble a device that is extremely dissipative and which need not be cycled or actuated more than once, i.e. not resetting. This may be accomplished in this invention by designing the clearance between springs **12,** tube **10** and shaft **20** such that both the tube **10** and shaft **20** are physically deformed when the device is actuated. Substantial amounts of energy may be dissipated through tube and shaft deformation.

In order to control the dissipation of energy, the narrow portion **28** of shaft **20** was introduced. Relief of the shaft **28** allows an even distribution of frictional interaction over the surface of the shaft **20.** In addition, relief of the shaft **28** aids in locating the shaft **20** when it is undergoing movement through the springs **12,** which occurrs when external force is applied to shaft **18.**

In other embodiments, the shaft can be of lesser diameter so that all energy dissipation takes place between the Belleville springs and the outer cylindrical tube. Alternatively, the outer tube can completely clear the expanding Belleville springs, and energy can be dissipated solely in the interaction between the shaft and the springs.

Other embodiments of the present invention, and modifications of the embodiments presented herein, may be developed without departing from the essential characteristics thereof. For example, shapes other than circular could be used for the tube, the Belleville springs and the central shaft. Alternative designs might include polygons of various shapes such as triangles, squares, rectangles or other, more complex shapes. Similarly the aperture in the springs and the shaft which is insertable in the springs may have a similar or even a different polygonal cross section. Accordingly, the invention should be limited only by the scope of the claims appended below.

What is claimed as new is:

1. An energy absorbing isolation device for receiving and dissipating a major portion of the energy associated with relatively high energy impact loads, said device comprising:

a support member having a bore of cross sectional dimension d_1 extending therethrough;

a plurality of Belleville spring washers having a maximum dimension d_2, less than d_1, adapted to be compressed and thereupon to expand, stacked axially within said bore, said dimensions d_1 and d_2 having a ratio such that, upon compression of said Belleville spring washers, the dimension d_2 approaches and exceeds the dimension d_1;

a movable shaft axially positioned within said bore, adapted to receive high energy loads, and further adapted to advance within said bore in response to said loads;

said shaft having a first portion of relatively large diameter and a second portion of relatively small diameter, said first portion positioned at one end of said stack of Belleville washers for compressing said washers upon advance of said shaft, said second portion positioned axially within said stack of Belleville washers and advancing with said first portion;

whereby, upon compression of said washers, frictional contact is made between said outer periphery of said Belleville washers and the inner surface of said bore, and contact is made between said inner periphery of said Belleville washers and the surface of said second portion of said movable shaft.

2. Apparatus according to claim **1** in which said bore has a circular cross-section, said cross-sectional dimension is a diameter d_1, and in which said Belleville spring washers are circular and said maximum dimension is a diameter d_2.

3. Apparatus according to claim **1** in which said bore has a polygonal cross-section, said cross-sectional dimension is a length l_1 and in which said Belleville springs are correspondingly polygonal and said maximum dimension is length l_2, where l_1 corresponds to d_1 and l_2 corresponds to d_2.

4. Apparatus according to claim **1** further including a plurality of movable separation elements, said plurality dividing the plurality of Belleville spring washers into segments.

5. Apparatus according to claim **4** further including means coupled to said support member with said bore and to said movable shaft, together with said plurality of movable separation elements, for maintaining said movable shaft in a position substantially axial within said bore when said high energy loads are side loads.

6. Apparatus according to claim **5** in which the end of said second portion of said shaft is of smaller diameter than the remainder of said second portion of said shaft.

7. Apparatus according to claim **6** in which said end of said second portion of said shaft is bevelled and in which at least one of said separation elements is biased.

8. Apparatus according to claim **1** in which said Belleville washers have an inner opening with a minimum dimension of d_3 and said shaft has a maximum diameter of d_4, upon compression of said washers, the dimension d_3 approaches and can be less than d_4 for dissipating a substantial portion of the energy by frictional contact between the inner opening of said Belleville washers and said movable shaft.

9. Apparatus according to claim **1** wherein a substantial portion of energy dissipated is in frictional contact between the outer dimension of said Belleville washers and the inner dimension d_1 of said bore.

10. An automobile bumper utilizing the isolation device of claim **1** comprising:

a pair of energy absorbing isolation devices, according to claim **1,** mounted one on each side of the frame of the automobile;

a telescoping cross bar pivotably mounted at each end thereof, to one of said movable shafts of said energy absorbing isolation devices.

11. An energy absorbing isolation device for receiving and dissipating a major portion of the energy associated with relatively high energy impact loads, said device comprising:

a support member having a bore of circular cross-section extending therethrough;

a plurality of Belleville spring washers stacked axially within said bore;

said washers adapted, upon compression thereof to increase their outer diameter and decrease their inner diameter;

a movable shaft axially positioned within said bore, adapted to receive high energy loads, and further adapted to advance within said bore in response to said loads;

said shaft having a first portion of relatively large diameter and a second portion of relatively small diameter;

said first portion positioned at one end of said stack of Belleville washers for compressing said washers upon advance of said shaft;

said second portion positioned axially within said stack of Belleville washers and advancing with said first portion, whereby upon compression of said washers, frictional contact is made between said outer periphery of said Belleville washers and the inner surface of said bore and contact is made between said inner periphery of said Belleville washers and the surface of said second portion of said movable shaft.

12. An energy absorbing isolation device for receiving and dissipating a major portion of the energy associated with relatively high energy impact loads, said device comprising:

a plurality of Belleville spring washers each having a central opening;

a support means adapted to receive the axial stack of Belleville washers;

a movable shaft axially positioned within said support means adapted to receive high energy loads and further adapted to advance within said support member in response to said loads;

said shaft having a first portion of relatively large diameter and a second portion of relatively small diameter, said first portion positioned at one end of said stack of Belleville washers for compressing said washers upon advance of said shaft, said second portion positioned axially within said stack of Belleville washers and advancing with said first portion;

whereby, upon compression of said washers, frictional contact is made between said central opening of said Belleville washers and the surface of said second portion of said movable shaft.

13. Apparatus according to claim 12 in which said shaft second portion has a circular cross-section, said cross-sectional dimension is a diameter d_1 and in which said Belleville spring washers have a circular central opening, and the normal dimensions of said central opening is a diameter d_2 where d_2 is normally greater than d_1, but upon compression of said Belleville spring washers, d_2 diminishes and becomes less than d_1.

14. Apparatus according to claim 12 in which said shaft second portion has a polygonal cross-section, said cross-sectional dimension is a length l_1 and in which the central opening of said Belleville springs is correspondingly polygonal having a normal dimension of length l_2 where l_2 is normally greater than l_1, but upon compression of said Belleville spring washers, d_2 diminishes and becomes less than l_1.

15. Apparatus according to claim 12 further including a plurality of movable separation elements, said plurality dividing the plurality of Belleville spring washers into segments.

16. Apparatus according to claim 15 further including means coupled to said support means and to said movable shaft, together with said plurality of movable separation elements, for maintaining said movable shaft in a position substantially axial within said support means when said high energy loads are side loads.

17. Apparatus according to claim 16 in which the end of said second portion of said shaft is of smaller diameter than the remainder of said second portion of said shaft.

18. Apparatus according to claim 17 in which said end of said second portion of said shaft is bevelled and in which at least one of said separation elements is biased.

19. An automobile bumper utilizing the isolation device of claim 12 comprising:

a pair of energy absorbing isolation devices, according to claim 12, mounted one on each side of the frame of the automobile;

a telescoping cross bar pivotably mounted at each end thereof to one of said movable shafts of said energy absorbing isolation devices.

20. An energy absorbing isolation device for receiving and dissipating a major portion of the energy associated with relatively high energy impact loads, said device comprising:

a support member having a bore of cross-sectional dimension d_1 extending therethrough;

a plurality of Belleville spring washers having a maximum uncompressed dimension d_2, less than d_1, adapted to be compressed and thereupon to expand to a dimension greater than d_1, stacked axially within said bore; and

a movable shaft axially positioned within said bore adapted to receive high energy loads and further adapted to advance within said bore in response to said loads, for compressing said washers upon advance of said shaft,

whereby, upon compression of said washers, frictional contact is made between said outer periphery of said Belleville washers and the inner surface of said bore.

21. An energy absorbing isolation device for receiving and dissipating a major portion of the energy associated with relatively high energy impact loads, said device comprising:

a support member having a bore of circular cross-section extending therethrough;

a plurality of Belleville spring washers having central openings stacked axially within said bore;

said washers adapted, upon compression thereof, to increase their outer diameter and decrease their inner diameter;

a shaft having a diameter less than the uncompressed inner diameter and greater than the compressed inner diameter of said washers axially positioned within said central openings adapted for movement relative to said support member in response to said loads; and

means for compressing said washers in response to relative motion between said support member and said shaft resulting from applied high energy input loads,

whereby upon compression of said washers, frictional contact is made between said central openings of said Belleville washers and the outer surface of said shaft.

22. An energy absorbing isolation device for receiving and dissipating a major portion of the energy associated with relatively high-energy impact loads, said device comprising:

a support member having a bore of circular cross-section extending therethrough;

a plurality of Belleville spring washers stacked axially within said bore;

said washers adapted, upon compression thereof to increase their outer diameter and decrease their inner diameter;

a shaft axially positioned within said bore adapted to advance within said bore in response to applied high energy loads;

said shaft having a first portion of relatively large diameter and a second portion of relatively small diameter;

said first portion positioned at one end of said stack of Belleville washers for compressing said washers upon motion of said shaft relative to said support member in an advancing direction;

said second portion positioned axially within said stack of Belleville washers and advancing with said first portion,

whereby upon compression of said washers, frictional contact is made between said outer periphery of said Belleville washers and the inner surface of said bore.

23. An energy absorbing isolation device comprising:

a support member having a bore extending therein,

a plurality of Belleville spring washers having central openings stacked axially within said bore,

a shaft axially positioned to extend through said central openings and movable relative to said support member in response to relatively high-impact axial loading,

means for compressing said washers in response to relative motion between said support member and said shaft resulting from axial loading, and

guide means acting cooperatively with said shaft and said support member to maintain the axial position of and support said shaft when it is subjected to angled impacts.

24. Apparatus according to claim **23** wherein said guide means comprises at least a pair of spaced rings axially positioned to surround said shaft within said support member and adapted to interact with said shaft and said support member to position and support said shaft under angled impacts.

25. Apparatus according to claim **24** wherein one said ring is fixed to said shaft adjacent the foremost of said Belleville spring washers.

26. Apparatus according to claim **25** wherein each remaining said ring is unattached to either said shaft or said support member and is held in position by said Belleville spring washers.

27. An energy absorbing device comprising a stack of Belleville spring washers, a space of annular section for the stack of washers defined between inner and outer members which can move relatively to each other to compress the washers, the washers being capable when compressed of interfering with the opposing surface of at least one of the members.

* * * * *

United States Patent [19]

[redacted]

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[54] **SHOCK ABSORBING SEATBELT ACTUATOR**

[76] Inventor: [redacted] Northridge, Calif.

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[51] **Int. Cl.** **B60r 21/10**
[58] **Field of Search** ..... 280/150 SB, 150 B; 188/1 C; 296/65 A

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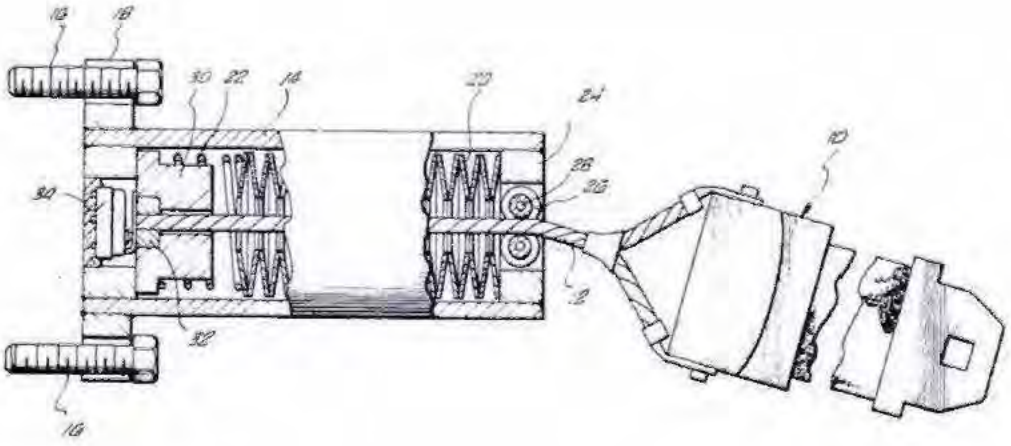
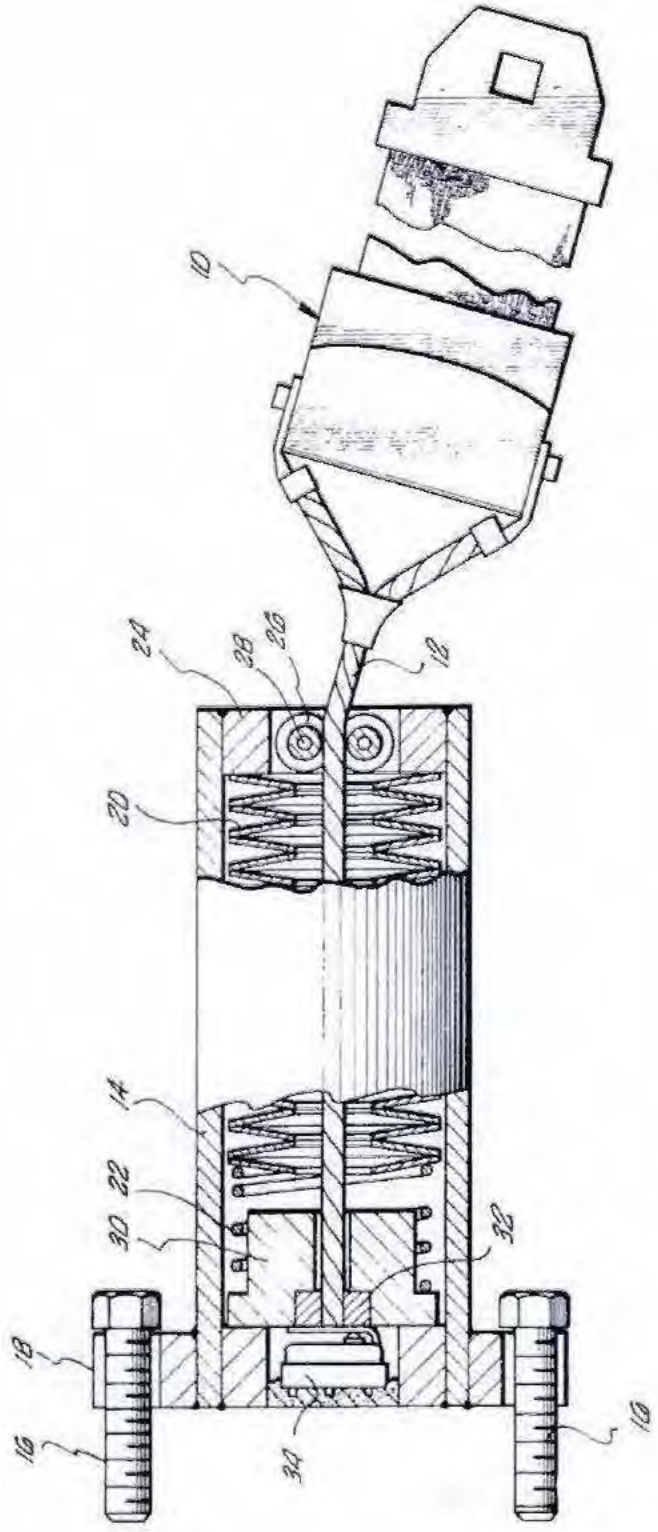
[57] **ABSTRACT**

The invention relates to a shock absorbing device for use in a safety belt system which substantially decreases the forces applied to a human body restrained by the safety belt in high impact situations. The invention comprises a plurality of Belleville springs which are used to absorb and dissipate the energy produced by a vehicle collision. The novel configuration disclosed increases the comfort of the confined individual and protects him from those injuries which have been encountered with the use of conventional safety belts.

4 Claims, 1 Drawing Figure

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SHOCK ABSORBING SEATBELT ACTUATOR

This invention relates to a safety belt having provisions for shock absorbing and more particularly to a shock absorbing device used in connection with a safety belt adapted to be used in an automobile or other moving vehicles.

It is well known and acknowledged that the use of a safety belt to restrain movement of a human body during a collision or other automobile accident substantially reduces the number of injuries suffered by occupants in the vehicle involved in an accident and minimizes the severity of the injuries suffered. In spite of this, many members of the public have been reluctant to have seatbelts installed in their automobiles or to use seatbelts when they are provided. In some of these instances, the public's reluctance can be explained by the fact that the tight fitting seatbelt is restraining and uncomfortable, combined with the fact that there are some situations in which the seatbelt itself causes injury. There have been many instances where a powerful impact will result in an extremely forceful contact between the individual and the seatbelt, resulting in external and internal injury to the wearer of the seatbelt.

The present invention provides apparatus which would tend to minimize or limit such injuries, which apparatus is relatively simple, inexpensive, reusable and effective.

In general, the shock absorber functions as an energy dissipating device for harmlessly absorbing the energy imparted to a human body when that body is subjected to rapid deceleration or high gravity load due to vehicle collisions or other incidents. Existing seatbelt systems are firm restraints which do not permit the restrained body to move in a controlled manner under extraordinary stress and which therefore subject the restrained individual to extremely large forces which can and do result in severe external and internal injury.

The energy absorber which is the subject of the present invention allows a body confined by a seatbelt or other safety appliance to move in a controlled manner over a measured distance, thereby increasing the deceleration time of the body and limiting the maximum "g" forces which would normally be applied to the confined body in a vehicle collision. The limitation of the "g" forces in this manner greatly reduces or eliminates the likelihood of severe injuries which can and do occur when safety systems are used which are rigidly anchored to the structure of an automobile or other vehicle.

The underlying reason for the advantage provided by the present invention can be understood from the following.

The force applied to a body is measured by the mass of the body times its acceleration ($F=Ma$, the well known Newtonian law). The acceleration of a body can be expressed as

$$a = \Delta v / \Delta t$$

Thus increasing the deceleration time reduces the acceleration of the body proportionately, this, in turn, proportionately reduces the force on the body. Since the deceleration time for a rigidly confined body is extremely small (theoretically zero), relatively small increase in the deceleration time produce extremely large reductions in the force applied to the restrained body. For the reasons given above, the device which is the subject of the present invention is extremely effective in reducing or eliminating injuries.

Briefly described, the present invention is an assembly which is mechanically connected to the body of a vehicle. The assembly comprises a cylindrical tube which houses a plurality of substantially identical Belleville springs mounted face to face and back to back. A connecting wire cable or equivalent flexible load transmitting member is connected to a compression block assembly, adapted to compress the Belleville springs, which is connected to the seatbelt web. When subjected to the large forces encountered in a collision or the like, a sudden heavy load is applied to the seatbelt which transfers the applied force through the flexible cable to the compression block assembly, causing compression of the Belleville springs and growth in the outer diameter of the springs. When sufficient load is applied to the springs, continued growth in their diameter occurs until such time as the outer surface of the springs interferes with the inside surface of the cylindrical housing. The housing itself then tends to absorb energy until the forces applied to the spring slide along the surface against the relatively large frictional and other forces resisting this motion. All of these energies are thus dissipated in a harmless manner. It has been found that the system described above may be cycled any desired number of times with no degradation in performance. The system which will be described in detail below also contains a relatively low tension spring which permits some degree of movement by the confined individual before the relatively high resistance of the Belleville springs is encountered. The limited freedom thus afforded the individual tends to minimize the "confined feeling" which is annoying to many people.

An object of the present invention is to provide a novel energy absorbing device for use with a safety belt system which tends to reduce the force applied by the safety belt system to the individual by a collision or the like.

Another object of the present invention is to provide a novel energy absorbing device for use with a safety belt system, providing a limited degree of freedom to the confined individual, while controlling the movement of the individual under the forces generated by high impact.

Still another object of the present invention is to provide a novel energy absorbing system, for use in a safety belt system, which permits controlled movement of the confined body.

A further object of the present invention is to provide a novel energy absorbing system, for use in a safety belt system, which is relatively inexpensive to manufacture and which has extremely high reliability.

The novel features which are believed to be characteristic of the invention, both as to organization and method of operation, together with further objects and advantages thereof will be better understood from the following description considered in connection with the accompanying drawings in which several preferred embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the invention.

FIG. 1 is a partially cut-away plan view of the energy absorbing system of the present invention, together with a portion of the safety belt system.

Turning now to FIG. 1, there is shown the energy absorbing system which is the subject of the present invention, together with a portion of a safety belt system. One side of the safety belt web **10** is shown including a strap and a clasp member which are attached to a flexible steel cable **12** which provides coupling to the frame of the vehicle into which the system has been installed. A cylindrical housing **14** is mounted in the vehicle body, probably fastened to the floor of the vehicle to the cylindrical housing **14** through a cylindrical member **18** which is rigidly coupled to the cylindrical housing **14**.

The cylindrical housing **14** houses a plurality of Belleville springs **20**, mounted face to face and back to back, as shown in FIG. **1**. Immediately adjacent the Belleville springs **20** is a helical spring **22**. The steel cable **12** is introduced into the cylindrical housing **14** through a fixed ring **24** into which is mounted a pair of guide rollers **26** which are pinned to the ring **24** by pins **28**, such that the guide rollers **26** are free to rotate. The steel cable **12** is held at the axis of the cylindrical housing **14** by the guide rollers **26** and is threaded through the Belleville springs **20** and the helical spring **22**, to a compression block **30**. The steel cable **12** is attached to the compression block **30** by a jam nut **32**. The compression block **30** is positioned so that it can make contact with the helical spring **22** and the Belleville springs **20**, such that force on the steel cable **12** will tend to compress the helical spring **22** and the Belleville springs **20**.

As has been stated, compression of the helical spring **22**, which is a relatively low tension spring, permits the body confined by the safety belt system a degree of freedom for those body movements which are normal to an individual. However, when the compression block assembly **30** contacts the Belleville springs **20**, substantial resistance to movement is encountered. In the case of an impact forcing the confined body into the safety belt assembly with a high degree of force, the Belleville washers **20** will first tend to compress, absorbing some of the energy of impact, and will at the same time expand, making contact with the cylindrical housing **14**. Still more energy is dissipated by frictional forces between the Belleville springs themselves, between the expanded edges of the Belleville springs **20** and the surface of the cylindrical housing **14**, and by other frictional, compressional and rotational forces and torques. Ultimately, if enough force is applied, the edges of the Belleville springs **20** will remove a thin layer of metal from the cylindrical housing **14**. The removal of metal, however, absorbs a great deal of energy; often more than is encountered in a collision. The dissipation of energy can be controlled by an appropriate choice of dimension factors such as the dimensions of the Belleville springs and the dimensions of the cylindrical housing **14**.

The energy absorbing unit which is the subject of the present invention may be provided with a safety switch in electrical series connection with the starter mechanism of the vehicle, so that the vehicle can not be started unless the safety belt system is fastened in position. The switch **34** would be placed within the cylindrical member **18** such that pressure applied on the switch **34** by the compression block **30** would prevent operation of the vehicle. When the safety belt is fastened, however, a relatively small amount of tension on the cable **12** against the resistance of the low tension spring **22** would allow operation of the switch **34** and permit the vehicle to start. Since the switch would not affect normal operation of the vehicle, movement of the occupant after the vehicle engine has started would not affect the operation of vehicle.

There has thus been described an embodiment of the present invention. Other embodiments of the present invention, and modifications of the embodiments presented herein, may be developed without departing from the essential characteristics of the present invention. Accordingly, the invention should be limited only by the scope of the claims appended below.

What is claimed as new is:

1. In combination with a safety belt adapted to be used in a moving vehicle to restrain the movement of a body under the relatively high energy impact loads associated with vehicle collisions, the device comprising:

a support member adapted to be mounted on the vehicle having a bore of cross-sectional dimension d_1 extending therethrough;

a plurality of Belleville spring washers having a maximum uncompressed dimension d_2, less than d_1, adapted to be compressed and thereupon to expand, stacked axially within said bore, said dimensions d_1 and d_2 being such that, upon compression of said Belleville spring washers, the dimension d_2 expands, approaching and exceeding dimension d_1;

a compression element positioned axially within said bore, for compressing and expanding said washers; and

a flexible connecting member connected to the safety belt and to said compression element for transmitting loads applied to the safety belt to compress and expand said washers.

2. Apparatus according to claim **1** in which said bore has a circular cross-section, said cross-sectional dimension is a diameter d_1 and in which said Belleville spring washers are circular, and said maximum dimension is a diameter d_2.

3. In combination with a safety belt adapted to be used in a moving vehicle to restrain the movement of a body under the relatively high energy impact loads associated with vehicle collisions, the device comprising:

a support member adapted to be mounted on the vehicle having a bore extending therethrough;

energy absorbing means positioned axially with said bore including a plurality of Belleville spring washers for frictional interference with said bore;

a relatively low tension spring positioned axially within said bore adjacent said energy absorbing means;

a compression element, positioned axially within said bore, for compressing said energy absorbing means and said low tension spring; and

a flexible connecting member connected to the safety belt and to said compression element for transmitting loads applied to the safety belt to said low tension spring and to said energy absorbing means;

whereby relatively small loads compress said low tension spring and relatively large loads compress both said low tension spring and said energy absorbing means.

4. In combination with a safety belt adapted to be used in a moving vehicle to restrain the movement of a body under the relatively high energy impact loads

associated with vehicle collisions, the device comprising:

a support member adapted to be mounted on the vehicle having a bore extending therethrough;

said bore having a circular cross-section of diameter d_1;

relatively high tension spring means comprising a plurality of Belleville spring washers positioned axially with said bore;

said Belleville spring washers being circular having an uncompressed diameter d_2 less than diameter d_1, said diameters d_1 and d_2 being such that, upon compression of said Belleville spring washers, the diameter d_2 expands, approaching and exceeding the diameter d_1;

a relatively low tension spring positioned axially within said bore adjacent said high tension spring means;

a compression element, positioned axially within said bore, for compressing said Belleville spring washers and said low tension spring; and

a flexible connecting member connected to the safety belt and to said compression element for transmitting loads applied to the safety belt to said low tension spring and to said high tension spring means;

whereby relatively small impact loads compress said low tension spring and relatively large loads compress both said low tension spring and said high tension spring means, expanding said Belleville spring washers to a diameter greater than that of said bore.

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