CUSTOMIZABLE STRUT ASSEMBLIES HAVING VARIABLE STROKE LENGTHS AND ARTICLES EMPLOYING THE SAME

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Disclosure: 10 comprising a housing 2; a piston 3 in slideable communication with the housing 2; an actuator 16 in operative communication with the piston 3 and/or the housing 2; wherein the actuator 16 is adapted to change the location of the housing 2 from a first position to a second position and/or change in a stroke length of the piston 3. Disclosed herein too is a method for changing the strut length of a strut assembly 10 comprising activating an actuator 16 that is in operative communication with a housing 2 or a piston of the strut assembly 10; and changing in the location of the housing 2 from a first position to a second position and/or changing a stroke length of the piston 3.
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CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Ser. No. 60/552,791 filed Mar. 12, 2004, the entire contents of which are hereby incorporated by reference.

BACKGROUND

[0002] This disclosure relates to strut assemblies whose stroke lengths can be customized depending upon external conditions and upon user preferences.

[0003] Strut assemblies are often used in automobiles to facilitate the opening, locking and positioning of doors, trunks, hoods, tail-gates, or the like. These assemblies have stroke lengths that are fixed during the design, manufacturing or assembly process. This can pose a problem for users of articles to which the strut assembly is attached. For example, a tailgate lift having a large stroke length can rise beyond the reach of smaller vehicle users.

[0004] It is therefore desirable to use strut assemblies that offer opportunities for customizing stroke length after the strut assembly has been assembled or after the strut assembly has been installed into an article such as a vehicle.

SUMMARY

[0005] Disclosed herein is a strut assembly comprising a housing; a piston in slideable communication with the housing; an actuator in operative communication with the piston and/or the housing; wherein the actuator is adapted to change the location of the housing from a first position to a second position and/or change in a stroke length of the piston.

[0006] Disclosed herein too is a method for changing the strut length of a strut assembly comprising activating an actuator that is in operative communication with a housing or a piston of the strut assembly; and changing in the location of the housing from a first position to a second position and/or changing a stroke length of the piston.

DETAILED DESCRIPTION

[0007] FIG. 1 is a schematic depiction of a strut assembly 10 comprising a housing 2 that is in slideable communication with a piston head 14 and a piston rod 12.

[0008] FIG. 2 is a schematic representation of an exemplary embodiment of the improved customizable strut assembly 10 of this disclosure wherein the assembly 10 comprises an actuator 16 disposed outside the housing 2.

[0009] FIG. 3 is a schematic representation of an exemplary embodiment of the improved customizable strut assembly 10 wherein the assembly 10 comprises an actuator 16 disposed inside the housing 2.

[0010] FIG. 4 is a schematic representation of another exemplary embodiment of the improved customizable strut assembly 10 wherein the actuator 16 comprises an active element 20 manufactured from a magnetorheological elastomer disposed inside the housing 2; and

[0011] FIG. 5 is a depiction of a schematic representation of strut assembly 10 that comprises a sleeve 30 that is disposed upon the outer surface of the housing 2. The sleeve 30 can be positioned along the housing to adjust the effective stroke length. A mechanical stop 34 can also be used to adjust the effective stroke length.

DETAILED DESCRIPTION

[0012] Disclosed herein are strut assemblies whose stroke lengths can be customized to provide the user with effective reach and control over articles that are in operative communication with the struts. The article may be any device that utilizes spatial positioning such as a door in an automobile or a residential building; the hood, trunk or tailgate of an automobile; the jaws of a vice or a press; the platens on machine tools such as injection molding machines, compression molding machines; arbors and chucks on lathes and drilling machines, or the like.

[0013] The customizable strut assemblies disclosed herein differ from those that are currently commercially available in that they comprise active materials that permit some functional attributes of the assemblies to be adjusted after manufacture. In one example, a car owner can adjust the stroke length of the customizable strut assembly to suit his or her anthropometrics. In another example, a dealer can advantageously adjust the stroke length of the strut assembly at the point of sale to customize certain characteristics of an otherwise mass produced vehicle to suit the desires of a specific buyer. In another embodiment, an owner can adjust the swing of an automobile door to prevent damage to the exterior of surrounding vehicles when the owner has to park repeatedly in tight parking spaces. In an exemplary embodiment, the stroke length can be adjusted either via hardware tuning or via software changes.

[0014] With reference to the FIG. 1, which represents the prior art, a strut assembly 10 comprises a housing 2 that is in slideable communication with a piston 3. The piston 3 comprises a piston head 14 and a piston rod 12. The piston head 14 is fixedly attached to the piston rod 12. The housing 2 contains a fluid 4. The piston head 14 has disposed in it channels 8 that permit the passage of fluid through the piston head 14 as it moves forward and backward in the housing 2. Seals 6 are circumferentially disposed upon the piston head 14 and seal the space between the piston head 14 and the cylinder 2. Seals 6 can also be optionally disposed between the piston rod 12 and the housing 2. The strut assembly 10 is in operative communication with a supporting body 50 (e.g., the body of the vehicle) and is also in operative communication with a suspended body 60 (e.g., a panel that swings back and forth such as a door). The supporting body 50 and the suspended body 60 are disposed at opposing ends of the strut assembly 10.

[0015] While the FIG. 1 depicts the suspended body 60 as being contacted by the housing 2 and the supporting body 50 as being contacted by the piston rod 12, it is envisioned that the suspended body 60 can be contacted by the piston rod 12 while the supporting body can be contacted by the housing 2.

[0016] As the piston rod 12 slides back and forth in the housing 2 during the expansion or contraction of the strut assembly, the fluid 4 is forced to flow through the channels 8 in the piston head 14. This flow is restricted by the
channels 8 and the restricted flow gives rise to two forces that resist relative motion between the piston and the cylinder, an elastic force arising out of the compression of the fluid column that the piston head is pushing against, and a hydrodynamic force arising from the resistance to fluid flow through the channels 8 in the piston head 14. Friction brought on by the presence of the seal 6 between the piston head 14 and the inner wall of the housing 2, or between the piston rod 12 and the housing 2, also resists relative motion between the piston head and the cylinder.

[0017] As the geometries of the different elements of the strut assembly displayed in FIG. 1 are fixed at the time of design and manufacture of the strut assembly 10, there is no opportunity to vary the strut stroke-length to suit varying anthropometrics of the consumer. For example, the swing of a car door that employs the strut assembly of FIG. 1 cannot be increased to accommodate a very large person entering or exiting the car. Similarly, the swing of the door cannot be decreased to prevent the door from opening beyond the reach of a small person.

[0018] By being able to vary the stroke length of the strut assembly 10, the distance between the suspended body 60 and the supporting body 50 can be adjusted accordingly as desired. The stroke length is generally varied by the inclusion of an actuator in the strut assembly. The actuator may be disposed within the housing or external to the housing. The actuator generally comprises an active element that comprises a shape memory material (active material). The actuator can comprise one or more active elements that can be arranged in series or in parallel inside or outside the housing.

[0019] The actuator can be in operative communication with either the housing and/or the piston. In one embodiment, the actuator can cause a change in the stroke length of the strut assembly by changing the distance between the supporting body and the suspended body. This is accomplished by changing the location of the housing with respect to the supporting body and/or the suspended body. By changing the location of the housing from a first position to a second position, the supporting body is correspondingly moved from its first position to a second position. This change in the strut length brought on by changing the location of the housing can be manually controlled and effected or it can be computer controlled.

[0020] In another embodiment, the actuator can cause a change in the strut length of the strut assembly by changing the effective stroke length of the piston. Activating the actuator changes the length of travel of the piston in the housing. In one embodiment, upon changing the length of travel of the piston in the housing, the mean position of travel of the piston is changed. The mean position of travel of the piston is the location of mid-point of travel of the piston in the housing. For example, if the piston travels back and forth between points A and B in the housing (i.e., A and B represents the extremities of travel of the piston) then the mean position of travel will be the sum of A and B divided by 2. Thus in one embodiment, upon actuating the actuator, the length of travel can be changed, while the mean position of travel remains the same. In another embodiment, the length of travel of the piston is changed while the mean position of travel is also changed. This change in the strut length brought on by changing the effective length of travel of the piston, which can be manually controlled and effected or it can be computer controlled.

[0021] With reference now to the FIG. 2, which represents an embodiment of the improved customizable strut assembly 10 of this disclosure, the assembly 10 comprises an actuator 16 interposed between the suspended body 60 and the housing 2. The actuator 16 is in operative communication with the housing 2 and the suspended body 60. The actuator 16 comprises one or more active elements 20 that can be adjusted to effectively increase the stroke length in a direction parallel to the direction of travel of the piston rod 12. The actuator 16 may be used to assist the displacement of the suspended body 60 away from and/or towards the supporting body 50 depending upon the desires of the user. As noted above, the actuator 16 can be in operative communication with the housing 2 or the piston rod 12.

[0022] In one embodiment, a suitable example of actuators 16 that employ active elements 20 that comprise active materials are electric stepper motors, inchworms, piezoelectric inchworms, ultrasonic motors, electrohydrostatic actuators, nanomotion piezoelectric motors, compact hybrid actuator devices (CHAD), that may be employed in the actuator 16. These motors can be used in the customizable strut assemblies 10 external to the housing 2 as depicted in the FIG. 2 and can facilitate a change in distance between the suspended body 60 and the supporting body 50. In another embodiment, the active element 20 can involve a coil spring, memory or other geometrical shape manufactured from an active material that can facilitate a change in distance between the suspended body 60 and the supporting body 50.

[0023] Shape memory materials generally refer to materials or compositions that have the ability to revert to a specified configuration (e.g. crystal structure, shape, or the like) in response to suitable external stimuli, e.g., an activation signal. Exemplary shape memory materials suitable for use in the present disclosure include shape memory alloys, ferromagnetic shape memory alloys, shape memory polymers and composites of the foregoing shape memory materials with non-shape memory materials, and combinations comprising at least one of the foregoing shape memory materials. In another embodiment, the class of active materials used in the customizable strut assembly 10 are those that change their shape in proportion to the strength of the applied field but then return to their original shape upon the discontinuation of the field. Exemplary active materials in this category are electroactive polymers (dielectric polymers), piezoelectrics, and piezoceramics. Activation signals can employ an electrical stimulus, a magnetic stimulus, a chemical stimulus, a mechanical stimulus, a thermal stimulus, or a combination comprising at least one of the foregoing stimuli. In one embodiment, the return to the original shape is accomplished by the use of a restoring force such as, for example, a biasing spring. Exemplary materials that can employ a restoring force are shape memory alloys.

[0024] For convenience and by way of example, reference herein will be made to shape memory alloys. Shape memory alloys (SMA's) generally refer to a group of metallic materials that demonstrate the ability to return to some previously defined shape or size when subjected to an appropriate thermal stimulus. Shape memory alloys are capable of undergoing phase transitions in which their elastic modulus,
yield strength, and shape orientation are altered as a function of temperature. Generally, in the low temperature, or martensite phase, shape memory alloys can be plastically deformed and upon exposure to a specified higher temperature will transform to an austenite phase, or parent phase, attempting to return to their shape prior to the deformation. Materials that exhibit this shape memory effect only upon heating are referred to as having one-way shape memory. Those materials that also exhibit shape memory upon recoiling are referred to as having two-way shape memory behavior.

**[0025]** Shape memory alloys can exhibit a one-way shape memory effect, an intrinsic two-way effect, or an extrinsic two-way shape memory. Annealed shape memory alloys generally exhibit the one-way shape memory effect. Sufficient heating subsequent to low-temperature deformation of the shape memory material will induce the martensite to austenite type transition, and the material will recover the original, annealed shape. Hence, one-way shape memory effects are only observed upon heating.

**[0026]** Intrinsic two-way shape memory alloys are characterized by a shape transition both upon heating from the martensite phase to the austenite phase, as well as an additional shape transition upon cooling from the austenite phase back to the martensite phase. In contrast, active connector elements that exhibit the extrinsic two-way shape memory effects are composite or multi-component materials that combine a shape memory alloy composition that exhibits a one-way effect with another element that provides a restoring force to return the first plate another position or to its original position. Active elements that exhibit an intrinsic one-way shape memory effect are fabricated from a shape memory alloy composition that will cause the active elements to automatically reform themselves as a result of the above noted phase transformations. Intrinsic two-way shape memory behavior must be induced in the shape memory material through thermo-mechanical processing. Such procedures include extreme deformation of the material while in the martensite phase, heating-cooling under constraint or load, or surface modification such as laser annealing, polishing, or shot-peening. Once the material has been trained to exhibit the two-way shape memory effect, the shape change between the low and high temperature states is generally reversible and persists through a high number of thermal cycles.

**[0027]** The temperature at which the shape memory alloy remembers its high temperature form when heated can be adjusted by slight changes in the composition of the alloy and through heat treatment. In nickel-titanium shape memory alloys, for instance, it can be changed from above about 100°C to below about −100°C. The shape recovery process occurs over a range of just a few degrees and the start or finish of the transformation can be controlled to within a few degrees depending on the alloy composition.

**[0028]** Suitable shape memory alloy materials for fabricating the active elements include nickel-titanium based alloys, indium-titanium based alloys, nickel-aluminum based alloys, nickel-gallium based alloys, copper based alloys (e.g., copper-zinc alloys, copper-aluminum alloys, copper-gold, and copper-tin alloys), gold-cadmium based alloys, silver-cadmium based alloys, indium-cadmium based alloys, manganese-copper based alloys, iron-platinum based alloys, iron-palladium based alloys, or the like, or a combination comprising at least one of the foregoing shape memory alloys. The alloys can be binary, ternary, or any higher order so long as the alloy composition exhibits a shape memory effect, e.g., change in shape orientation, changes in yield strength, and/or flexural modulus properties, damping capacity, and the like.

**[0029]** The thermal activation signal may be applied to the shape memory alloy in various ways. It is generally desirable for the thermal activation signal to promote a change in the temperature of the shape memory alloy to a temperature greater than or equal to its austenitic transition temperature. Suitable examples of such thermal activation signals that can promote a change in temperature are the use of steam, hot oil, resistive electrical heating, or the like, or a combination comprising at least one of the foregoing signals. A preferred thermal activation signal is one derived from resistive electrical heating.

**[0030]** The active element 20 may also be an electrically active polymer. Electrically active polymers are also commonly known as electroactive polymers (EAP's). The key design feature of devices based on these materials is the use of compliant electrodes that enable polymer films to expand or contract in the in-plane directions in response to applied electric fields or mechanical stresses. When electroactive polymers are used as the active element 20, strains of greater than or equal to about 100%, pressures greater than or equal to about 400 kPa (square centimeter (kg/cm²) can be developed in response to an applied voltage. The good electromechanical response of these materials, as well as other characteristics such as good environmental tolerance and long-term durability, make them suitable for use in active elements under a variety of manufacturing conditions. Electroactive polymers are suitable for use as an active element in many customizable strut assembly 10 configurations.

**[0031]** Electroactive polymer actuator elements used in customizable strut assembly 10 may be selected based on one or more material properties such as a high electrical breakdown strength, a low modulus of elasticity (for small deformations), a high dielectric constant, and the like. In one embodiment, a polymer is selected such that it has an elastic modulus at most about 100 MPa. In another embodiment, the polymer is selected such that it has a maximum actuation pressure between about 0.05 MPa and about 10 MPa, and preferably between about 0.3 MPa and about 3 MPa. In another embodiment, the polymer is selected such that it has a dielectric constant between about 2 and about 20, and preferably between about 2.5 and about 12. The present disclosure is not intended to be limited to these ranges. Ideally, materials with a higher dielectric constant than the ranges given above would be desirable if the materials had both a high dielectric constant and a high dielectric strength. In many cases, electroactive polymers may be fabricated and implemented as thin films. Thicknesses suitable for these thin films may be below 50 micrometers.

**[0032]** As electroactive polymers may deflect at high strains, electrodes attached to the polymers should also deflect without compromising mechanical or electrical performance. Generally, electrodes suitable for use may be of any shape and material provided that they are able to supply a suitable voltage to, or receive a suitable voltage from, an
Electroactive polymer. The voltage may be either constant or varying over time. In one embodiment, the electrodes adhere to a surface of the polymer. Electrodes adhering to the polymer are preferably compliant and conform to the changing shape of the polymer. Correspondingly, the present disclosure may include compliant electrodes that conform to the shape of an electroactive polymer to which they are attached. The electrodes may be only applied to a portion of an electroactive polymer and define an active area according to their geometry. Various types of electrodes suitable for use with the present disclosure include structured electrodes comprising metal traces and charge distribution layers, textured electrodes comprising varying out of plane dimensions, conductive greases such as carbon greases or silver greases, colloidal suspensions, high aspect ratio conductive materials such as carbon fibrils and carbon nanotubes, and mixtures of ionically conductive materials.

Materials used for electrodes may vary. Suitable materials used in an electrode may include graphite, carbon black, colloidal suspensions, thin metals including silver and gold, silver filled and carbon filled gels and polymers, and ionically or electronically conductive polymers. It is understood that certain electrode materials may work well with particular polymers and may not work as well for others. By way of example, carbon fibrils work well with acrylic elastomer polymers while not as well with silicone polymers.

The electroactive polymers used herein are generally conjugated polymers. Suitable examples of electroactive polymers are poly(aniline), substituted poly(aniline), polycarbazoles, substituted polycarbazoles, polynolides, polypyrrols, substituted polypyrrols, polyanilines, substituted polyanilines, poly(thiophenes), substituted poly(thiophenes), poly(acetylenes), poly(ethylenedioxythiophenes), poly(ethylene dioxythiophenes), poly(ethyleneoxythiophenes), poly(phenylene vinylenes), or the like, or combinations comprising at least one of the foregoing electroactive polymers. Blends or copolymers or composites of the foregoing electroactive polymers may also be used. Similarly blends or copolymers or composites of an electroactive polymers with an electroactive polymers precursor may also be used.

The actuator element 20 used in the customizable strut assembly 10 may also comprise a piezoelectric material. Also, in certain embodiments, the piezoelectric material may be configured for providing rapid deployment. As used herein, the term "piezoelectric" is used to describe a material that mechanically deforms (changes shape and/or size) when a voltage potential is applied, or conversely, generates an electrical charge when mechanically deformed. As piezoelectric actuators have a small output stroke, they are usually coupled with a transmission (e.g. a compliant mechanism) that serves to amplify the output stroke at the expense of a reduction in the output force. As an example, a piezoelectric material is disposed on strips of a flexible metal sheet. The piezo actuators are coupled to the sheet in a manner that causes bending or unbending of the sheet when the actuators are activated. The ability of the bending mode of deformation in a flexible sheet to amplify small axial strains into larger rotary displacements is used to advantage. The strips can be unimorphic or bimorph. Preferably, the strips are bimorphic, because bimorphs generally exhibit more displacement than unimorphs.

In contrast to the unimorph piezoelectric device, a bimorph device includes an intermediate flexible metal foil sandwiched between two piezoelectric elements. Bimorphs exhibit more displacement than unimorphs because under the applied voltage one ceramic element will contract while the other expands. Bimorphs can exhibit strains up to about 20%, but similar to unimorphs, generally cannot sustain high loads relative to the overall dimensions of the unimorph structure.

Suitable piezoelectric materials include inorganic compounds, organic compounds, and metals. With regard to organic materials, all of the polymeric materials with non-centrosymmetric structure and large dipole moment group(s) on the main chain or on the side-chain, or on both chains within the molecules, can be used as candidates for the piezoelectric film. Examples of suitable polymers include, for example, but not limited to, poly(sodium 4-styrenesulfonate) ("PSS"), poly S-119 (polyvinylpyridine backbone azo chromophore), and their derivatives; polyfluorocarbons, including polyvinyliden fluoride ("PVDF"), its co-polymer vinylidene fluoride ("VDF"), triluroethylene ("TFe"), and their derivatives; polyvinylcarbazoles, including poly(vinyl chloride) ("PVC"), polyvinylidenedichloride ("PVC2"), and their derivatives; polyacrylonitriles ("PAN"), and their derivatives; polycarboxyl acids, including poly(methacrylic acid ("PMA"), and their derivatives; polyureas, and their derivatives; polyurethanes ("PUE"), and their derivatives; bio-polymer molecules such as poly-L-lactic acids and their derivatives, and membrane proteins, as well as phosphotau bio-molecules; polyanilines and their derivatives, and all of the derivatives of tetramines; polyimides, polyetherimides ("PEI"), and their derivatives; all of the membrane polymers; poly(N-vinyl pyrrolidone) ("PVP") homopolymer, and its derivatives, and random PVP-co-vinyl acetate ("PVAc") copolymers; and all of the aromatic polymers with dipole moment groups in the main-chain or side-chains, or in both the main-chain and the side-chains, and mixtures thereof.

Further, piezoelectric materials can include Pt, Pd, Ni, Ti, Cr, Fe, Ag, Au, Cu, and metal alloys and mixtures thereof. These piezoelectric materials can also include, for example, metal oxide such as SiO2, Al2O3, ZrO2, TiO2, SrTiO3, PbTiO3, BaTiO3, Fe2O3, Fe3O4, ZnO, and mixtures thereof; and Group VIA and IIB compounds, such as CdSe, CaS, GaAs, AgGaSe2, ZnSe, GaP, InP, ZnS, and mixtures thereof.

The active element 20 can also comprise magnetorheological (MRE) elastomers. Magnetorheological elastomers (MRE) are suspensions of micrometer-sized, magnetically polarizable particles in a polymeric elastomer. When a magnetorheological elastomer is exposed to a magnetic field, the normally randomly oriented particles form chains of particles in the direction of the magnetic field lines. The particle chains increase the effective stiffness of the elastomer. The change in the effective stiffness of the MRE is accomplished by changing the shear and compression/tension moduli of the magnetorheological elastomer by varying the strength of the applied magnetic field. The magnetorheological elastomers typically develop structure when exposed to a magnetic field in as little as a few milliseconds. Discontinuing the exposure of the magnetorheological elastomer to the magnetic field reverses the process and the elastomer returns to a lower viscosity state.

Suitable magnetorheological elastomer materials include an elastic polymer matrix comprising a suspension
of ferromagnetic or paramagnetic particles, wherein the particles are described above. Suitable polymer matrices include poly-alpha-olefins, copolymers of poly-alpha-olefins and natural rubber.

[0041] Suitable ferromagnetic or paramagnetic include iron; iron alloys, such as those including aluminum, silicon, cobalt, nickel, vanadium, molybdenum, chromium, tungsten, manganese and/or copper; iron oxides, including Fe₂O₃ and Fe₃O₄; iron nitride; iron carbide; carbonyl iron; nickel and alloys of nickel; cobalt and alloys of cobalt; chromium dioxide; stainless steel; silicon steel; or the like, or a combination comprising at least one of the foregoing particles. Examples of suitable iron particles include straight iron powders, reduced iron powders, iron oxide powder/straight iron powder mixtures and iron oxide powder/reduced iron powder mixtures. A preferred magnetic-responsive particulate is carbonyl iron, preferably, reduced carbonyl iron.

[0042] The particle size should be selected so that the particles exhibit multi-domain characteristics when subjected to a magnetic field. Diameter sizes for the particles can be less than or equal to about 1,000 micrometers, with less than or equal to about 500 micrometers preferred, and less than or equal to about 100 micrometers more preferred. Also preferred is a particle diameter of greater than or equal to about 0.1 micrometer, with greater than or equal to about 0.5 more preferred, and greater than or equal to about 10 micrometer especially preferred. The particles are preferably present in an amount between about 5.0 and about 50 percent by volume of the total composition.

[0043] With reference now again to the FIG. 2, in one embodiment, in one manner of operating the customizable strut assembly 10 in order to vary its stroke length, an external stimulus is applied to the active element 20. A preferred external stimulus is one derived from thermal activation preferably one that is derived from resistive electrical heating. As described earlier, the active element 20 can be a composite of SMP, an elastic material and one or more active material based actuators (e.g. SMA or EAP); or a composite of SMP and an elastic material; or a sub-assembly comprising one or more active material based actuators that are mechanically coupled to elastic restoring elements; etc. In each case, the overall axial dimension of the active element can be changed in response to the activation signal to achieve the desired strut stroke adjustment. This change in length facilitates the displacement of the suspended body 60 with respect to the supporting body 50, thereby changing the effective stroke length of the customizable strut assembly 10. The magnitude of the change in length can be proportioned to the magnitude of the activation signal.

[0044] FIGS. 3 and 4 depict exemplary embodiments of customizable strut assemblies that utilize active elements that are disposed inside the housing 2. With reference now to the FIG. 3, the customizable strut assembly 10 comprises plates 22 that are in operative communication with the active element 20. The plates are perforated to allow easy passage for the fluid. The plates 22 and the active element 20 are disposed within the housing 2. The active element 20 for purposes of this embodiment is a coil spring, though it can be varied in shape and size in other configurations. The plates 22 are disposed on opposing sides of the piston head 14 and are in operative communication with the piston head 14. The perforations in the plate 22 allow for a smooth displacement of the fluid 4 within the housing 2 as the piston 3 slides back and forth in the housing 2.

[0045] In the prior art strut assembly (e.g., as shown in FIG. 1), the ends of the strut stroke are marked by (near) contact between the flat ends of the piston head and the respective cylinder ends. In the adjustable strut assembly shown in the FIGS. 3 and 4, the end of stroke is marked by contact between the elements 22 and the respective ends of the cylinder. Therefore, it is clear that by changing the axial length and/or the stiffness of the active elements 20, the effective stroke of the strut can be adjusted.

[0046] In one embodiment, the active element 20 can be a composite of a shape memory polymer, an elastic material and one or more active material based actuators (e.g., a shape memory alloy or an electroactive polymer); or a composite of shape memory polymer and an elastic material; or a sub-assembly comprising one or more active material based actuators that are mechanically coupled to elastic restoring elements; or the like. In each case, the overall axial dimension of the actuator can be changed in response to the activation signal to achieve the desired strut stroke adjustment. Depending on the active materials and the configuration in which they are used, the change in the stroke may stay in effect until it is changed again, or the change may be made just-in-time for an operation and will remain in effect only for that operation. In another embodiment, the active element 20 comprises a spring made of a shape memory alloy in its martensitic-phase over the operating temperature range for the strut.

[0047] As noted above, the actuator 16 generally comprises an active element 20 that comprises an active material. An active material generally refers to a group of materials that demonstrate an ability to return to some previously defined shape or size when subjected to an appropriate external stimulus. The active material, upon activation facilitates the displacement of the suspended body 60 towards and/or away from the supporting body 50 and also permits control over the magnitude of the displacement.

[0048] In another embodiment, the actuator 16 can also comprise a composite of an active material. In one embodiment, the composite can comprise a shape memory alloy and a shape memory polymer. In another embodiment, the composite can comprise a shape memory alloy and a material that is not an active material, i.e., a material that does not return to some previously defined shape or size when subjected to an appropriate external stimulus. In yet another embodiment, the composite can comprise two or more active materials such as for example a shape memory alloy and a shape memory polymer or in addition to and a material that is not an active material.

[0049] For example, an actuator can comprise a composite that comprises one or more elastic elements made from spring steel distributed within a shape memory polymer matrix together with one or more shape memory alloy elements. The shape memory polymer has a characteristic temperature known as its glass transition temperature (Tg), such that the elastic modulus of the material drops significantly e.g., a factor of about 30 to about 150 when it is heated above its Tg. The shape memory polymer is a soft and easily pliable polymer above the Tg, and it can be
deformed significantly (up to 200% recoverable strain) by a relatively low force. On cooling the deformed shape memory polymer below its Tg, the material reverts back to its stiffer form, while retaining the deformed shape in a stress-free condition. If a specified limiting temperature is not exceeded during the heating process, the aforementioned procedure comprising heating, deforming and cooling can be repeated multiple times.

[0050] The elastic elements in the above embodiment are mechanically coupled to the shape memory polymer matrix and, they determine the overall configuration (i.e. geometry, dimensions, etc) of the active element. The relative stiffnesses of the elastic elements and the shape memory polymer matrix are chosen such that, when the shape memory polymer is below the lower Tg, it is the dominant contributor to the overall stiffness of the actuator; whereas when the shape memory polymer is above the Tg, the elastic elements are the dominant contributors to the overall active element stiffness. Depending on the manner in which the shape memory elements are activated, they can either compress or elongate the elastic elements and thereby, control the overall configuration of the active element when the shape memory polymer is above the Tg.

[0051] The use of the actuator can be illustrated by describing the process in which the actuator is reconfigured to tailor the strut-stroke. The shape memory polymer is softened by heating it to a temperature above its Tg. The shape memory alloy elements are then activated to change the overall configuration of the actuator while the shape memory polymer is soft. Once the actuator achieves the desired configuration (e.g. axial dimension), the shape memory polymer is allowed to cool down to a temperature below its Tg, whereupon it regains its stiff form. The shape memory alloy elements are then powered off. As described earlier, the stiffness of the shape memory polymer matrix dominates that of the elastic elements, and hence the active element will retain the above configuration until it is heated above its Tg. The above reconfiguration process can then be repeated.

[0052] As the piston 3 slides within the housing 2, the active elements 20 are compressed at one or both ends of the strut’s stroke. If the stiffness of these active elements 20 is small, e.g., when the shape memory alloy is in its martensitic phase, they can be easily compressed between the piston 3 and the housing 2. Hence, they will not affect the length of the stroke. However, if the stiffness of the active elements is high, e.g., when the shape memory alloy is in its austenitic phase, they resist relative motion between the piston 2 and the housing 2 with considerable force at the extremities of the strut’s stroke. The amount of change in the stroke length is directly proportional to the length of the active element 20 and its stiffness. Thus a stiffening of the active element 20 upon activation will result in a reduction of the effective stroke length for the customizable strut assembly 10.

[0053] In one embodiment, by activating the active element 20, the length of the active element 20 can be varied, thereby varying the length of travel of the piston 3 in the housing 2. This will alter the stroke length of the strut assembly 10. The activation signal can be a thermal signal brought on by resistive heating of the spring. Depending on the range of stroke variation required, similar plates can also be connected to one or both ends of the housing 2 through active elements 20, whose lengths and/or stiffnesses can be varied upon activation.

[0054] In addition to changing the stroke of the strut assembly 10, varying the stiffness of the various active elements in the strut assembly can enable control over which part of the stroke is curtailed (e.g., the tailgate lift needs to be reduced for shorter owners; the tailgate may need to be held partially open when transporting over size cargo that extends partially out of the vehicle, in which case the tailgate closure needs to be restricted), and afford smoother operation of the customizable strut assembly 10.

[0055] When the active element 20 in the FIG. 3 is a coil spring made from a shape memory alloy material, the customizable strut assembly can be modified to function in various modes. In one mode, when the spring is in its martensitic phase over the temperature range of operation of the customizable strut assembly 10, it has a low stiffness and hence a low spring constant than when it is in the austenitic form. Passage of an electric current through the spring can induce a martensitic to austenitic transition in the spring material, thereby increasing its stiffness e.g. three-fold. The dual-stiffness nature of the SMA spring can be used to vary the stroke of the strut as described above. Depending on the composition of the shape memory alloy material, the transition from soft to stiff can be sharp or gradual, thereby yielding greater control over the behavior of the strut at the extremities of its stroke.

[0056] In yet another embodiment, depicted in the FIG. 4, magnetorheological elastomers can be employed as the active element 20. In this embodiment, the piston 3 comprises an electromagnet 26 that is in mechanical and electrical communication with the magnetorheological elastomer of the active element 20. The magnetorheological elastomer is in the form of a block that is disposed on opposing surfaces of the piston head 14. The active element 20 has a size effective to vary the length of the stroke as its stiffness is increased. When an electrical current is passed through the electromagnet 26, a magnetic field is set up inside the magnetorheological elastomer. Since the stiffness of the magnetorheological elastomer can be varied by varying the strength of the magnetic field, the change in stiffness can be controlled by varying the electrical current passing through the electromagnet. By changing the stiffness of the magnetorheological elastomer, the length of the stroke can be varied in a manner that is conceptually similar to that described above in the context of SMA springs. As the elastomer becomes less stiff, it can be easily compressed between the piston 3 and the inner surface of the housing 2, thereby permitting a longer stroke length. As the electrical current is varied to increase the stiffness of the elastomer, it cannot be easily deformed between the piston 3 and the inner surface of the housing 2. Thus by varying the magnitude of the activation signal to the active element 20, the length of travel of the customizable strut assembly 10 can be adjusted. The use of a biasing permanent magnet, whose influence on the MRE can be counteracted by an electromagnet allows this concept to be extended to both: increase and decrease the effective strut stroke.

[0057] In yet another exemplary embodiment, depicted in the FIG. 5, the strut assembly 10 comprises a sleeve 30 that is disposed upon the outer surface of the housing 2. The
sleeve 30 is hollow and comprises a braking mechanism 32 that fixedly attaches it to the housing 2 depending upon the user’s preference. The sleeve 30 can have any suitable cross-sectional geometry that permits sliding motion with the housing 2, when the braking mechanism 32 is released. The braking mechanism is generally released when it is desirable to change the effective length of the strut assembly 10 after which it is reengaged to fixedly attach the sleeve 32 to the housing 2. The braking mechanism 32 can be engaged or disengaged by a suitable stimulus to change the effective length of the strut assembly. Adjusting the position of the sleeve 32 controls the distance labeled DS2.

[0058] A mechanical stop 34 is fixedly attached to the piston rod 12 at the user’s discretion and can be used to adjust the effective stroke length by displacing the mechanical stop when desired. The location of the mechanical stop 34 determines the distance DS1 as shown in the FIG. 5. The mechanical stop 34 can be adjusted upon temporary removal of the sleeve 30. When the braking mechanism 32 is disengaged, the sleeve 30 can be freely positioned at any desirable point over the length of the housing 2 subject to mechanical interference constraints imposed by the cylinder dimensions. When the braking mechanism 32 is engaged and the sleeve 30 is mechanically coupled to the housing 2, the effective length of the strut assembly is controlled by the larger of the two distances, DS1 and DS2.

[0059] Once the position of the mechanical stop 34 is fixed relative to the piston rod 12, the motion of the suspended body 60 is governed by the smaller of the two distances DO1 and DO2 as shown in the FIG. 5. These correspond to mechanical interference between the piston 3 and the end of the cylinder proximate to the supporting body 50, and between the end of the cylinder proximate to the supporting body 50 and the mechanical stop 34. Changing the position of the mechanical stop 34 allows the length DO2 to be adjusted. This affords control over the motion of the suspended body 60 when it is to be opened completely.

[0060] In an alternative embodiment, the position of the mechanical stop 34 can be adjusted using an optional biasing spring 36 as depicted in the FIG. 5. The bias spring can be of a length effective to keep the mechanical stop in communication with the end of the sleeve 30 proximate to the supporting body 50. The spring force (i.e., the spring constant) is negligible compared to the braking resistance produced when the mechanical stop 32 is engaged. Therefore, the spring 36 does not affect the position of the mechanical stop 32, when the brake is engaged. In one embodiment, in one method of determining the fully open position of the suspended body 60, the mechanical stop 34 is disengaged and the braking mechanism 32 is engaged thereby permitting the swing panel to be displaced into the desired fully-open position. At this point the mechanical stop 34 is engaged locking in the range of desired motion for the strut assembly 10. The sleeve 30 moves with the suspended body 60 during its motion and the mechanical stop 34 moves with the spring 36 to its new location.

[0061] The desired fully-shut position can be set in a similar way. Here the braking mechanism 32 is disengaged and the suspended body 60 is moved to the desired fully-shut position before the braking mechanism 32 is engaged again. The piston rod 3 can be used to displace the sleeve 30 to the desired position. Again, a soft bias spring (not shown) can be used to keep the sleeve 30 flush against the end of the piston rod that is proximate to the supporting body 50.

[0062] The ability to customize the length of travel of a customizable strut assembly 10 can be advantageously used in automobiles, aircraft, ships, in machine tools, or the like, to improve usability. The length of travel can be adjusted at any time during the life cycle of an article that employs the customizable strut assembly. The length of travel can also be adjusted to accommodate ambient weather conditions, consumer anthropometrics or to offset the deleterious effects of component wear. The length of travel can be adjusted manually or by computer as desired.

[0063] While the disclosure has been described with reference to an exemplary embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure without departing from the essential scope thereof. Therefore, it is intended that the disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this disclosure, but that the disclosure will include all embodiments falling within the scope of the appended claims.

1. A strut assembly comprising:
   - a housing;
   - a piston in slideable communication with the housing;
   - an actuator in operative communication with the piston and/or the housing;
   - wherein the actuator is adapted to change the location of the housing from a first position to a second position and/or change in a stroke length of the piston.

2. The strut assembly of claim 1, wherein the customizable strut assembly is disposed between and in operative communication with a suspended body and a supporting body, and wherein the actuator upon actuation facilitates a change in the location of the suspended body from a first position to a second position.

3. The strut assembly of claim 1, wherein the actuator comprises one or more active elements 20 that comprise a shape memory material, a passive material that does not have shape memory properties, or a combination of the shape memory material and the passive material.

4. The strut assembly of claim 1, wherein the actuator comprises more than one active elements, and wherein the active elements are disposed in series or parallel.

5. The strut assembly of claim 1, wherein the actuator is disposed inside or outside the housing.

6. The strut assembly of claim 3, wherein the shape memory materials comprise compositions that have the ability to remember their original shape, and wherein the original shape can be recalled by applying an external stimulus, and wherein the shape memory materials are shape memory alloys, piezoelectrics, electroactive polymers and/or piezoceramics.

7. The strut assembly of claim 1, wherein the actuator is an electric stepper motor, an inchworm, a piezoelectric inchworm, an ultrasonic motor, an electrohydrostatic actuator, a nanomotion piezoelectric motor, a compact hybrid actuator device or combinations thereof.
8. The strut assembly of claim 1, wherein the actuator is adapted to change the stroke length of the piston or adapted to change in the mean position of travel of the piston.

9. The strut assembly of claim 1, wherein the actuator is adapted to change the stroke length of the piston while retaining the mean position of travel of the piston.

10. The strut assembly of claim 1, wherein the actuator is located outside the housing and is disposed between a supporting body and the housing or between a suspended body and the piston.

11. The strut assembly of claim 1, wherein the actuator is located inside the housing and is in operative communication with the piston and/or within the housing.

12. The strut assembly of claim 11, wherein the actuator comprises a coil spring manufactured from a shape memory alloy or wherein the actuator comprises a block of a magnetorheological elastomer.

13. An article that employs the strut assembly of claim 1.

14. The article of claim 13, wherein the article comprises a door on an automobile, aircraft, water craft or a residential building; a hood or trunk of the automobile; a jaw of a vice or a press; platens on machine tools; or arbors and chucks on machine tools.

15. A method for changing the strut length of a strut assembly comprising:

activating an actuator that is in operative communication with a housing or a piston of the strut assembly; and changing in the location of the housing from a first position to a second position and/or changing a stroke length of the piston.

16. The method of claim 15, wherein the activating of the actuator occurs by the application of an external stimulus to a shape memory material employed in the actuator, and wherein the external stimulus can be an electrical stimulus, a magnetic stimulus, a thermal stimulus, a chemical stimulus, a mechanical stimulus, an ultrasonic stimulus or a combination comprising at least one of the foregoing external stimuli.

17. The method of claim 15, wherein actuating the actuator facilitates a change in the stroke length of the piston and a change in the mean position of travel of the piston.

18. The method of claim 15, wherein actuating the actuator facilitates a change in the stroke length of the piston while retaining the mean position of travel of the piston.

19. The method of claim 15, wherein the actuator is located outside the housing and wherein the actuator upon actuation displaces the housing either towards the supporting body or away from the supporting body.

20. An article employing the method of claim 15.