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DAMPER ASSEMBLY WITH FREQUENCY ADAPTIVE ORIFICE

Abstract

A damper assembly includes a housing having a tubular shape defining a main chamber extending along a center axis. A piston is movable along the center axis and divides the main chamber into a compression chamber and a rebound chamber. The piston includes a piston body defining a frequency-adaptive orifice (FAO) passage providing fluid communication between the compression chamber and the rebound chamber. The piston includes an FAO valve assembly having an FAO cover member configured to block fluid flow therethrough in response to application of a low-frequency excitation, and allowing fluid flow through the FAO passage in response to application of a high-frequency excitation. The FAO valve assembly also includes a tappet configured to translate relative to the piston body to bias the FAO cover member to selectively cover the FAO passage in response to the application of the low-frequency excitation.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This continuation-in-part application claims priority to U.S. patent application Ser. No. 17/723,421, filed Apr. 18, 2022, which claims priority to Chinese Patent Application No. 202210267856.X filed on Mar. 18, 2022. The contents of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION
1. Field of the Invention
[0002] The present invention generally relates to a damper assembly for a vehicle.
2. Description of the Prior Art
[0003] Damper assemblies are well known in the art for use in a vehicle. One such a damper assembly is disclosed in Patent publication U.S. Pat. No. 5,706,920A which discloses a monotube damper assembly including a main tube disposed on a center axis and extending between a first end and a second end. The damper defines a fluid compartment between the first end and the second end for containing a working fluid. A main piston is slidably disposed in the fluid compartment dividing the fluid compartment into a rebound chamber and a compression chamber. A piston rod is disposed on the center axis extending along the center axis to a distal end and attached to the main piston for moving the main piston between a compression stroke and a rebound stroke.
[0004] Conventional, passive shock absorber valves offer a poor compromise between performance, safety and driving comfort. To improve this situation, active and semi-active suspensions are often proposed. They, however, require the use of additional sensors, ECUs and control algorithms, what makes them complicated and extremely expensive. For this reason, adaptive passive valves are becoming more and more popular and are desired by car manufacturers.
[0005] Various adaptive valve technologies provide damping characteristics that depend not only on damper velocity but also on excitation frequency. Such solutions allow to achieve high damping forces for low frequencies, related to body motions and low damping forces for high frequencies, related to vibrations of the wheels.
[0006] It is known in the art for damper assemblies to include a frequency-dependent valve assembly to provide the damper assembly with the ability to reduce the level of damping force for high frequency events to provide better comfort and road holding for occupants. However, known valve assemblies are generally expensive, complex and have limited capabilities for tuning. Furthermore, most existing frequency-dependent valves are configured as add-ons that are attached to an existing damper design. These add-on valves may significantly increase dead-length of a damper. Moreover, they often require drilling of additional, intersecting bypass holes, which is an

expensive process that generates contaminants and can weakens portions of the damper, such as a valve tenon. Accordingly, an improved damper assembly is desired.

SUMMARY OF THE INVENTION

[0007] The present invention provides a damper assembly. The damper assembly includes a housing having a tubular shape extending along a center axis, and a piston movable through the housing along the center axis. The damper assembly also includes a body defining a frequency-adaptive orifice (FAO) passage providing fluid communication between a first chamber and a second chamber. The damper assembly also includes an FAO valve assembly having an FAO cover member configured to selectively cover the FAO passage to block fluid flow therethrough in response to application of a low-frequency excitation below a predetermined frequency, the FAO valve assembly further configured to allow fluid flow through the FAO passage in response to application of a high-frequency excitation above the predetermined frequency. The FAO valve assembly further includes a tappet configured to translate relative to the body to bias the FAO cover member to selectively cover the FAO passage in response to the application of the low-frequency excitation in an at least one of a compression direction or a rebound direction opposite the compression direction.

[0008] The present invention also provides a piston for a damper assembly. The piston includes a piston body defining a frequency-adaptive orifice (FAO) passage for providing fluid communication between a compression chamber and a rebound chamber. The piston also includes an FAO valve assembly having an FAO cover member configured to selectively cover the FAO passage to block fluid flow therethrough in response to application of a low-frequency excitation below a predetermined frequency. The FAO valve assembly is further configured to allow fluid flow through the FAO passage in response to application of a high-frequency excitation above the predetermined frequency. The FAO valve assembly further includes a tappet configured to translate relative to the piston body to bias the FAO cover member to selectively cover the FAO passage in response to the application of the low-frequency excitation in an at least one of a compression direction or a rebound direction opposite the compression direction.

[0009] In a further embodiment, the damper assembly includes a housing having a tubular shape extending along a center axis and a piston movable through the housing along the center axis. The piston is mounted on a rod within the housing. There is a body defining a frequency-adaptive orifice (FAO) passage providing fluid communication between a first chamber and a second chamber. An FAO valve assembly having an FAO cover member is configured to selectively cover the FAO passage to block fluid flow through in response to the application of a low-frequency excitation below a predetermined frequency. The FAO valve assembly is further configured to allow fluid flow through the FAO passage in response to the application of a high-frequency excitation above the predetermined frequency.

[0010] The FAO valve assembly has a tappet configured to translate relative to the body to bias the FAO cover member to selectively cover the FAO passage in response to the application of the low-frequency excitation in at least one of a compression direction or a rebound direction opposite the compression direction. A tappet spring disc configured to bias the tappet.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Other advantages of the present invention will be readily appreciated, as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

[0012] FIG. **1** shows a cross-sectional perspective view of a damper assembly;

[0013] FIG. **2** shows an enlarged cross-sectional perspective view of a piston of the damper

assembly, including a frequency-adaptive orifice valve;
[0014] FIG. **3** shows an exploded view of the piston of the damper assembly including the frequency-adaptive orifice valve;
[0015] FIG. **4** shows a perspective view of a guiding sleeve for the frequency-adaptive orifice valve of the present disclosure;
[0016] FIG. **5**A shows an enlarged cross-sectional fragmentary view of the piston, showing fluid flow therethrough during application of a low-frequency excitation;
[0017] FIG. **5**B shows an enlarged cross-sectional fragmentary view of the piston, showing fluid flow therethrough during application of a high-frequency excitation;
[0018] FIG. **6**A shows an enlarged cross-sectional fragmentary view of the piston during a rebound stroke, in a low-frequency state, and showing fluid flow therethrough;
[0019] FIG. **6**B shows an enlarged cross-sectional fragmentary view of the piston during a rebound stroke, in a high-frequency state, and showing fluid flow therethrough;
[0020] FIG. **7**A shows an enlarged cross-sectional fragmentary view of the piston during a compression stroke, in a low-frequency state, and showing fluid flow therethrough;
[0021] FIG. **7**B shows an enlarged cross-sectional fragmentary view of the piston during a compression stroke, in a high-frequency state, and showing fluid flow therethrough;
[0022] FIG. **8** shows a graph illustrating rebound force vs. velocity characteristics of a damper with the frequency-adaptive orifice valve of the present disclosure under standard and high-frequency conditions; and
[0023] FIG. **9** shows a graph illustrating rebound force vs. stroking frequency of a damper with the frequency-adaptive orifice valve of the present disclosure and at constant velocity of 0.131 meters/second.
[0024] FIG. **10** shows an enlarged cross-sectional perspective view of a second embodiment of the piston of the damper assembly, including a frequency-adaptive orifice valve;
[0025] FIG. **11** shows an exploded view of the piston of the second embodiment of the damper assembly including the frequency-adaptive orifice valve;
[0026] FIG. **12** shows a partial cross sectional view of the piston of the second embodiment of the damper assembly including the frequency-adaptive orifice valve;
[0027] FIG. **13** shows a perspective view of the inlet disc;
[0028] FIG. **14** shows a perspective view of the outlet disc;
[0029] FIG. **15**A shows a face view of the damper rod;
[0030] FIG. **15**B shows a side view of the damper rod;
[0031] FIG. **16** shows a first graph illustrating rebound force vs. velocity characteristics of a damper with the frequency-adaptive orifice valve of the second embodiment; and
[0032] FIG. **17** shows a second graph of rebound force vs. stroking frequency of a damper with the frequency-adaptive orifice valve of the second embodiment.

DESCRIPTION OF THE ENABLING EMBODIMENT

[0033] Referring to the Figures, wherein like numerals indicate corresponding parts throughout the several views, it is one aspect of the present invention to provide a damper assembly **20**, which may be used as a part of a suspension in a vehicle, such as a passenger car or truck. The damper assembly **20** of the present disclosure is shown as a monotube damper. However, the principles of the present disclosure may be used with other types of dampers, such as in a twin-tube damper.
[0034] The damper assembly **20** of the present disclosure provides a unique solution for the implementation of a Frequency Adaptive Orifice (FAO) within a piston valve assembly.
[0035] As generally shown in FIG. **1**, the damper assembly **20** includes a housing **22** having a tubular shape extending along a center axis A between a first end **24** and a second end **26** and defining a main compartment **30**, **32**, **34** therein. The damper assembly **20** also includes a gas cup **28** disposed in the main compartment **30**, **32**, **34** in sealing engagement with the housing **22** and slidable along the center axis A to divide the main compartment **30**, **32**, **34** into a gas compartment

30 for containing a gas and a fluid compartment **32**, **34**. The gas compartment **30** extends between the first end **24** and the gas cup **28**, and the fluid compartment **32**, **34** extends between the gas cup **28** and the second end **26**.

[0036] The damper assembly **20** also includes a damper rod **36** that extends along the center axis A. The damper rod **36** includes a rod end **38** located inside of the fluid compartment **32**, **34**. A piston **40** is attached to the damper rod **36** adjacent to the rod end **38**, and configured to move with the damper rod **36** along the center axis A through the housing **22**. The piston **40** divides the fluid compartment **32**, **34** into a compression chamber **32** and a rebound chamber **34**. The compression chamber **32** extends between the piston **40** and the gas cup **28**, and the rebound chamber **34** extends between the second end **26** and the piston **40**.

[0037] A first closure **42** seals the gas compartment **30** at the first end **24** of the housing **22**. A damper mount **44** is attached to the first closure **42** and configured to attach the damper assembly **20** to a body of a vehicle (not shown). The damper assembly **20** of the present disclosure may be used in other configurations and/or orientations. For example, the damper mount **44** may connect the housing **22** of the damper assembly **20** to a chassis component of the vehicle **10**.

[0038] The damper assembly **20** also includes a second closure **46** disposed adjacent to the second end **26** of the housing **22** to enclose the rebound chamber **34**. The second closure **46** defines a bore **48** for the damper rod **36** to pass through. The second closure **46** may provide a fluid-tight seal with the damper rod **36** to prevent fluid from leaking out of the rebound chamber **34**.

[0039] FIG. **2** shows an enlarged cross-sectional perspective view of the piston **40** of the present disclosure. As shown in FIG. **2**, the damper rod **36** includes a rod body **50** having a cylindrical shape with a first diameter d**1**, a rod shoulder **52** spaced apart from and facing toward the rod end **38**. The damper rod **36** also includes a rod extension **54** extending from the rod shoulder **52** to the rod end **38** and having a generally cylindrical shape with a second diameter d**2** smaller than the first diameter d**1**.

[0040] As also shown in FIG. **2**, the piston **40** includes a piston body **60** disposed around the rod extension **54**. The piston body **60** includes an annular seal **62** of resilient material configured to seal against an inner surface of the housing **22** (not shown in FIG. **2**). The piston body **60** defines a rebound passage **64** in fluid communication with the rebound chamber **34** and providing a path for fluid flow to the compression chamber **32**. The piston body **60** also defines a compression passage **66** in fluid communication with the compression chamber **32** and providing a path for fluid flow to the rebound chamber **34**.

[0041] The piston **40** also includes a rebound valve assembly **68** configured to regulate fluid flow from the rebound chamber **34** to the compression chamber **32** during a rebound stroke, with the damper rod **36** pulling the piston **40** toward the second end **26**. The rebound valve assembly **68** includes a rebound disc stack **70** including a plurality of discs covering an end of the rebound passage **64** opposite from the rebound chamber **34** and configured to deflect away from the rebound passage **64** in response to a pressure differential thereacross, and to thereby regulate fluid flow through the rebound passage **64** and into the compression chamber **32**.

[0042] The rebound valve assembly **68** also includes a shoulder nut **72** and a spring seat **74**, with a spring **76** extending therebetween to bias the rebound disc stack **70** to cover the rebound passage **64**. A rebound spacer disc **77** having a disc shape is disposed around the rod extension **54** between the rebound disc stack **70** and the shoulder nut **72**. The rebound spacer disc **77** has a smaller diameter than the rebound disc stack **70** for supporting an inner region of the rebound disc stack **70** while allowing a radially outer portion of the rebound disc stack **70** to deflect axially away from the piston body **60** for regulating the fluid flow through the rebound passage **64**.

[0043] The piston **40** also includes a compression valve assembly **80** configured to regulate fluid flow from the compression chamber **32** to the rebound chamber **34** during a compression stroke, with the damper rod **36** pushing the piston **40** toward the first end **24** of the housing **22**. The compression valve assembly **80** includes a compression disc stack **82** having a plurality of discs covering an end of the compression passage **66** opposite from the compression chamber **32**. The compression disc stack **82** is configured to deflect away from the compression passage **66** in response to a pressure differential thereacross, and to thereby regulate fluid flow through the compression passage **66** and into the rebound chamber **34**.

[0044] As can be seen in FIG. **2**, the compression valve assembly **80** includes a compression disc retainer **84** having a ring shape disposed about the rod extension **54** between the rod shoulder **52** and the compression disc stack **82**. The compression valve assembly **80** also includes a first spacer disc **86** disposed around the rod extension **54** adjacent to the compression disc stack **82** and between the compression disc retainer **84** and the compression disc stack **82**. The first spacer disc **86** has a smaller diameter than the compression disc stack **82** for supporting an inner region of the compression disc stack **82** while allowing a radially outer portion of the compression disc stack **82** to deflect axially away from the piston body **60** for regulating the fluid flow through the compression passage **66**. The compression valve assembly **80** also includes a second spacer disc **88** having a disc shape disposed around the rod extension **54** adjacent to the compression disc stack **82** and opposite from the first spacer disc **86**. The thickness of the second spacer disc **88** may define a preload of the compression disc stack **82**. The compression disc retainer **84** and the rod extension **54** together define a lower chamber **85** adjacent to the rod shoulder **52**.

[0045] The piston **40** also includes a frequency-adaptive orifice (FAO) valve assembly **90** that includes a guiding sleeve **92** disposed around the rod extension **54**. The guiding sleeve **92** includes a proximal tubular portion **94** having a tubular shape disposed around and coaxial with the rod extension **54** and adjacent to the rod shoulder **52**. The proximal tubular portion **94** has a first inner surface **96** that is spaced apart from the rod extension **54** to define a first balance passage **98** therebetween. The guiding sleeve **92** also includes a disc-shaped portion **100** extending radially outwardly from an end of the proximal tubular portion **94** spaced apart from the rod shoulder **52**. The disc-shaped portion **100** is disposed annularly about the proximal tubular portion **94** of the guiding sleeve **92**. The guiding sleeve **92** also includes a distal tubular portion **102** having a tubular shape and extending axially from the disc-shaped portion **100** away from the rod shoulder **52**. The distal tubular portion **102** is disposed coaxially with and tightly against the rod extension **54**, with little to no space therebetween. The guiding sleeve **92** further defines a second balance passage **104** extending radially outwardly from the first balance passage **98** and axially through the disc-shaped portion **100**. The compression valve assembly **80** is disposed around the proximal tubular portion **94** of the guiding sleeve **92**, with the second spacer disc **88** separating the compression disc stack **82** from the disc-shaped portion **100**. The distal tubular portion **102** of the guiding sleeve **92** further defines a plurality of indentations **106** in an outer surface thereof.

[0046] The FAO valve assembly **90** also includes a tappet **110** having a ring shape disposed around and engaging the guiding sleeve **92** and configured to translate relative to the piston body **60** in an axial direction. The tappet **110** includes an inner tubular portion **112** disposed around the distal tubular portion **102** of the guiding sleeve **92** and configured to slide therealong. The tappet **110** further includes a flange portion **114** having an annular shape extending radially outwardly from the inner tubular portion **112**. The tappet **110** also includes an outer tubular portion **116** extending annularly around the flange portion **114** and axially toward the rod shoulder **52**. The outer tubular portion **116** of the tappet **110** is disposed annularly around the disc-shaped portion **100** of the guiding sleeve **92** and is configured to slide therealong. The tappet **110** defines a tappet chamber **118** surrounded by the outer tubular portion **116** and extending between the flange portion **114** and the disc-shaped portion **100** of the guiding sleeve **92**.

[0047] The piston body **60** defines an FAO chamber **120** having a generally cylindrical shape coaxially surrounding the rod extension **54**, with a lower wall **122** facing toward the rod shoulder **52**. The guiding sleeve **92** and the tappet **110** are disposed within the FAO chamber **120**. The piston body **60** also defines an inner bore **124** having a cylindrical shape coaxially surrounding the rod extension **54** extending in an axial direction from the lower wall **122** away from the rod shoulder

52. The inner bore **124** is configured to receive an end of the distal tubular portion **102** of the guiding sleeve **92** for locating the guiding sleeve **92** with the piston body **60**.

[0048] The piston body **60** also defines a first FAO passage **126** providing fluid communication between the compression passage **66** and the FAO chamber **120**. The piston body **60** further defines a second FAO passage **128** providing fluid communication between the rebound passage **64** and the FAO chamber **120**. The piston body **60** also includes an annular protrusion **130** extending in an axial direction from the lower wall **122** and into the FAO chamber **120** adjacent to and radially outwardly from the second FAO passage **128**.

[0049] The FAO valve assembly **90** further includes an FAO cover member **132** configured to selectively cover the second FAO passage **128** to block fluid flow therethrough. The FAO cover member **132** may be formed as a disc that is disposed annularly around the distal tubular portion **102** of the guiding sleeve **92** abutting the annular protrusion **130**, as shown in FIG. **2**. However, the FAO cover member **132** could have a different shape or configuration. The FAO valve assembly **90** also includes an FAO spacer **134** having a ring shape disposed annularly around the distal tubular portion **102** of the guiding sleeve **92** and between the tappet **110** and the FAO cover member **132**.

[0050] The distal tubular portion **102** of the guiding sleeve **92** includes an outer surface defining a first seal slot **136** holding a first O-ring seal **138** that seals against an inner surface of the inner tubular portion **112** of the tappet **110**. The disc-shaped portion **100** of the guiding sleeve **92** includes an outer surface defining a second seal slot **140** holding a second O-ring seal **142** that seals against an inner surface of the outer tubular portion **116** of the tappet **110**.

[0051] The FAO valve assembly **90** also includes a valve control disc **144** having an annular shape and disposed adjacent to the rod shoulder **52** and between the rod shoulder **52** and the compression disc retainer **84**. As best shown on FIG. **3**, valve control disc **144** defines a control orifice **146** that extends at least partially through the valve control disc **144** in a radial direction from an outer edge thereof for providing fluid communication between the rebound chamber **34** and the lower chamber **85**.

[0052] Referring back to FIG. **2**, the first balance passage **98** and the second balance passage **104** together provide fluid communication between the lower chamber **85** and the tappet chamber **118** to pressurize the tappet chamber **118** during a rebound stroke. This pressurization of the tappet chamber **118** causes the tappet **110** to be biased away from the rod shoulder **52** and toward the FAO cover member **132**, thereby causing the FAO cover member **132** to cover the second FAO passage **128** and to prevent fluid flow therethrough.

[0053] The FAO cover member **132** is supported by the tappet **110** that preloads the FAO cover member **132** depending on a volume of fluid, such as oil, and pressure in the tappet chamber **118**. The tappet chamber **118** is supplied with oil from the rebound chamber **34** via the valve control disc **144**, which is located between the rod shoulder **52** and the compression disc retainer **84**. According to an aspect of the present disclosure, the FAO cover member **132** works in both directions, and thus provide extended functionality in both rebound and compression strokes.

[0054] FIG. **3** shows an exploded view of the piston **40** including the FAO valve assembly **90**. FIG. **4** shows a perspective view of the guiding sleeve **92**. FIG. **5**A shows an enlarged cross-sectional fragmentary view of the piston **40**, showing fluid flow therethrough during application of a low-frequency excitation, below a predetermined frequency. During low-frequency operation, shown in FIG. **5**A, the throttling effect of the control orifice **146** is low, so the tappet chamber **118** surrounded is effectively fed with fluid through the valve control disc **144** and the balance passages **98**, **104**. Pressure in the tappet chamber **118** is relatively high, and the tappet **110** is forced against the FAO cover member **132**, thus increasing its preload.

[0055] FIG. **5**B shows an enlarged cross-sectional fragmentary view of the piston **40**, showing fluid flow therethrough with the damper assembly **20** during application of a high-frequency excitation, above the predetermined frequency. During high-frequency operation, the FAO cover member **132** throttles the flow of fluid, and so there is high pressure drop between the rebound chamber **34** and the tappet chamber **118**. Pressure acting on the tappet **110**, and thereby preload of the FAO cover member **132** is relatively small, making the FAO valve assembly **90** less stiff.

[0056] FIG. **6**A shows an enlarged cross-sectional fragmentary view of the piston **40** during a rebound stroke, in a low-frequency state, and showing fluid flow therethrough. FIG. **6**A shows the FAO valve assembly **90** in an inactive state, with the FAO cover member **132** blocking fluid flow through the second FAO passage **128**. The FAO cover member **132** may be biased to block the second FAO passage **128** during the rebound stroke, preventing fluid flow therethrough. For example, the tappet **110** may press the FAO cover member **132** to block the second FAO passage **128** by fluid pressure in the tappet chamber **118** being greater than a fluid pressure in the FAO chamber **120**. FIG. **6**B shows an enlarged cross-sectional fragmentary view of the piston **40** during a rebound stroke, in a high-frequency state, and showing fluid flow therethrough. The FAO valve assembly **90** may allow fluid flow through one or more FAO passages **126**, **128** in response to application of a high-frequency excitation above a predetermined frequency. The predetermined frequency may also be called a cutoff frequency.

[0057] As shown in FIG. **6**B, the FAO valve assembly **90** provides a rebound bypass fluid path from the rebound chamber **34** to the compression chamber **32**, bypassing the rebound valve assembly **68**, in response to a high-frequency rebound excitation applied to the piston **40**. The FAO valve assembly thereby reduces the force generated by the damper assembly **20** in response to the high-frequency rebound excitation by allowing fluid flow through the rebound bypass fluid path. The FAO valve assembly **90** also blocks the rebound bypass fluid path in response to a low-frequency rebound excitation applied to the piston **40**, as shown in FIG. **6**A.

[0058] The rebound bypass fluid path through the FAO valve assembly **90** is illustrated in FIG. **6**B and includes the FAO passages **126**, **128**. More specifically, the rebound bypass fluid path includes fluid flow from the rebound chamber **34**, through the rebound passage **64** and the second FAO passage **128**, past the FAO cover member **132** and into the FAO chamber **120**. The rebound bypass fluid path then includes the fluid flowing from the FAO chamber **120** through the first FAO passage **126** and the compression passage **66** and then to the compression chamber **32**. In this case, rebound damping force is decreased.

[0059] FIG. **7**A shows an enlarged cross-sectional fragmentary view of the piston **40** during a compression stroke, in a low-frequency state, and showing fluid flow therethrough. FIG. **7**A shows the FAO valve assembly **90** in an inactive state, with the FAO cover member **132** blocking fluid flow through the second FAO passage **128**. In this inactive state, the FAO cover member **132** may be biased to block the second FAO passage **128** during the compression stroke, preventing fluid flow therethrough. For example, the FAO cover member **132** may be deflected to block the second FAO passage **128** by fluid pressure in the FAO chamber **120** being greater than a fluid pressure in the second FAO passage **128**. FIG. **7**B shows an enlarged cross-sectional fragmentary view of the piston **40** during a compression stroke, in a high-frequency state, and showing fluid flow therethrough.

[0060] As shown in FIG. **7**B, the FAO valve assembly **90** provides compression bypass fluid path from the compression chamber **32** to the rebound chamber **34**, bypassing the compression valve assembly **80**, in response to a high-frequency compression excitation applied to the piston **40**. The FAO valve assembly thereby reduces the force generated by the damper assembly **20** in response to a high-frequency compression excitation by allowing fluid flow through the compression bypass fluid path. The FAO valve assembly **90** also blocks the compression bypass fluid path in response to a low-frequency compression excitation, as shown in FIG. **7**A.

[0061] The compression bypass fluid path through the FAO valve assembly **90** is illustrated in FIG. **7**B and includes the FAO passages **126**, **128**. More specifically, the compression bypass fluid path includes fluid flow from the compression chamber **32**, through the compression passage **66** and the first FAO passage **126**, and into the FAO chamber **120**. The compression bypass fluid path then includes the fluid flowing from the FAO chamber **120**, past the FAO cover member **132**, through the second FAO passage **128** and the rebound passage **64**, and then to the rebound chamber **34**. The indentations **106** in the distal tubular portion **102** of the guiding sleeve **92** (shown in FIG. **4**) may provide a path for fluid flow from the FAO chamber **120** and to the second FAO passage **128** when the FAO cover member **132** is deflected toward the piston body **60**, as shown in FIG. **7**B.

[0062] The operating characteristics of the FAO valve assembly **90** can be adjusted by one or more of: oil flow area of the control orifice **146** (e.g. number and width of slots), a number and thickness of working discs comprising the FAO cover member **132**, a number and/or cross-sectional area of the first FAO passages **126** and/or second FAO passages **128** in the piston body **60**, and/or a thickness of the FAO spacer **134** that defines a nominal working disc preload of the FAO cover member **132**.

[0063] FIG. **8** shows a first graph **200** illustrating rebound force vs. velocity characteristics of a damper with the frequency-adaptive orifice valve of the present disclosure under standard and high-frequency conditions. The first graph **200** includes a first plot **202** showing force vs. velocity for the damper under low-frequency excitation conditions. The first graph **200** also includes a second plot **204** showing force vs. velocity for the damper under high-frequency excitation conditions. FIG. **9** shows a second graph **250** with a plot **252** showing rebound force vs. stroking frequency of a damper with the frequency-adaptive orifice valve of the present disclosure and at constant velocity. The FAO valve assembly **90** may be adjusted or tuned to provide any predetermined cutoff frequency ranging from about 2.0 Hz to about 12 Hz.

[0064] The FAO valve assembly **90** of the present disclosure is shown and described as located within a compression side of the piston **40**. However, other configurations are possible. For example, the FAO valve assembly **90** may be located on the rebound side of the piston **40** or on both sides of the piston **40**, simultaneously. Alternatively or additionally, an FAO valve may be disposed within a compression valve assembly (i.e. a base valve assembly) of a twin-tube damper assembly. Such a twin-tube damper may include an inner tube disposed within the housing **22** and defining a main chamber within the inner tube and an exterior chamber between the inner tube and the housing **22**, wherein the piston divides the main chamber into a compression chamber and a rebound chamber. A twin-tube damper may also include a base assembly including a base valve configured to regulate fluid flow between the main chamber and the exterior chamber. The base assembly may include the body that defines the FAO passage.

[0065] With reference to FIGS. **10** through **17**, a second embodiment of the present invention is illustrated. In this embodiment, greater space or volume is created in the piston shown generally at **240**. The piston **240** includes a first piston **260** and a second piston **289** to create this volume, and a sleeve **221**, which in the disclosed embodiment is made of metal. This creates more volume than the original piston **40**. The FAO **290** is mounted between these two pistons, **260** and **289**. The two pistons **260** and **289** are operatively connected by the sleeve **221**. This creates technological space for building a more complex FAO system than the original invention.

[0066] The rebound valve assembly **68** is the same as previously described as rebound valve assembly **68**, and the numbering is the same as previously numbered. This is the main rebound valve, and part of the oil stream can flow through bypass disc stack **222**. The disc stack **222** can deflect and let oil flow through, as seen in FIG. **12**.

[0067] The piston **240** also includes a frequency-adaptive orifice (FAO) valve assembly **290** that is configured to work in parallel with the rebound valve assembly **68** and may include a dynamic pressure feedback circuit configured to provide (e.g., during a rebound stroke) relatively high damping forces for relatively low-frequency excitations and relatively low damping forces for relatively high-frequency excitations. The low-frequency and high-frequency thresholds and the associated damping forces may be altered (e.g., increased or reduced) and the slope of the drop characteristic may be adjusted by changing the valve settings.

[0068] The FAO valve assembly **290** is disposed between a second piston **289** and first piston **260** that may be interconnected by a connecting sleeve **221**, and the rebound valve assembly **68** and the compression valve assembly **280** are disposed on either side of the FAO valve assembly **290**. The FAO valve assembly **290** includes a tappet spring disc stack **292**, a tappet spring spacer **294**, a retainer **296**, and a second spacer **298**. The tappet spring disc stack **292** is positioned adjacent to the piston **289** and the tappet spring spacer **294** is disposed between the tappet spring disc stack **292** and the retainer **296**. The second spacer **298** is disposed between the retainer **296** and an accumulator disc stack **200**. The piston **260** defines one or more apertures or passages **264** that may be configured to receive and direct the working fluid to and from the piston **289** and the piston **260**.

[0069] The FAO valve assembly **290** may also include one or more (e.g., two) accumulator spacers **202**, a floating sleeve **206**, a tappet **212**, a guiding sleeve **216**, and a bypass disc stack **222**. The accumulator spacers **202** may have a smaller diameter than the discs of the accumulator disc stack **200** and an inner diameter of the floating sleeve **206**. An outer o-ring **204** is disposed about an outer periphery of the floating sleeve **206**, and a centering disc **208** and orifice disc **211** are disposed between the accumulator spacers **202** and a guiding sleeve **216**. The orifice disc **211** is generally the same as the outlet disc **210**, except that the slots are larger to allow oil flow into and out of a secondary chamber **219**. An inner o-ring **214** is disposed within an inner periphery of the tappet **212** and the guiding sleeve **216** is disposed within the tappet **212**. A bypass spacer **218** is disposed between the guiding sleeve **216** and the bypass disc stack **222**. In this embodiment, an inlet control orifice **224** is disposed between the bypass disc stack **222** and the upper piston **260**.

[0070] FIG. **11** shows an exploded view of the piston assembly **240** shown in FIG. **10**. FIG. **12** illustrates a partial-cross-sectional view of the piston assembly **240** shown in FIGS. **10** and **11**. During a rebound stroke, the working fluid may be routed from the rebound chamber **32** to the compression chamber **34** through the piston assembly **240**. As an example, the working fluid may be forced through the rebound passages **264** defined by the piston **260** towards the rebound disc stack **70**, and the working fluid may be split into one or more (e.g., two) paths disposed on each side of the piston **260**. One of the two paths **264** may route the working fluid to the compression chamber **34** by the rebound valve assembly **68**.

[0071] The frequency effect is obtained in part by means of the specific arrangement of inlet disc **224** and outlet disc **210**. With reference to FIGS. **13** and **14**, the inlet disc **224** has a central opening **304**, slots **300** and openings **302**, which in the disclosed embodiment are half-moon shaped. It will be understood by those of ordinary skill in the art, that the number, shape and size of the slots and openings may change depending upon the parameters desired. The outlet disc **210** has a central opening **308** and slots **306**. It will be understood by those of ordinary skill in the art, that the number, shape and size of the slots and openings may change depending upon the parameters desired. The damper rod **36** shown in FIGS. **15**A and **15**B has reliefs **310** formed on opposing sides of rod **36**. The openings **304** and **308** are received by the rod **36** and the slots **300** and **306** are in communication with reliefs **310** to allow oil to flow therebetween.

[0072] The rebound valve assembly **68** operates in the same manner as previously described. Rebound valve assembly **68** is the main rebound valve, and part of the oil stream path **400** can flow through inlet disc **224** and bypass disc stack **222**. The disc stack **222** can deflect and let oil flow through, as seen in FIG. **12**.

[0073] Tappet **212** preloads the disc stack **222**. Tappet **212** works in the same manner as previously described with respect to tappet **112**. Oil flows into the tappet chamber **219** to preload the disc stack **222**. The amount of oil entering chamber **219** is controlled by small orifice **300** on inlet disc **224**. As the pressure increases inside the tappet **212**, it moves to the right and acts upon disc stack **222** to control flow through the disc stack **222**. So the greater the pressure inside the tappet **212**, the greater the reaction force on discs **222**, resulting in less oil flow through disc stack **222**.

[0074] In this embodiment, more control of the pressure inside the tappet **212** is provided. Accumulator disc stack **200** is provided and is clamped between spacers **202**, **294**, **298**, and retainer **296** but the outer areas of accumulator disc stack **200** can deflect. As a result, when the pressure grows inside the tappet **212**, the tappet **212** moves to the right, but the floating sleeve **206** moves to the left, as illustrated, or away from the tappet **212** and deflects accumulator disc stack **200**. So now the volume of oil in chamber **219** increases as floating sleeve **206** moves to the left as shown in the drawings or as it moves away from tappet **212**. The volume in chamber **219** increases in both directions, as tappet **212** moves in one direction and floating sleeve **206** moves in the opposite direction. Retainer **296**, which in the disclosed embodiment is a solid disc, controls the amount of deflection of accumulator disc stack **200**.

[0075] The tappet spring disc stack **292** provides extra force on the tappet **212**. The tappet spring disc stack **292** forces the tappet **212** to the right even if there is no pressure inside chamber **219**. The result is that tappet **212** moves or floats between the disc stacks **222** and **292**. For example, in the steady state, when the damper is not moving, and there is no pressure in chamber **219**, discs **222** and **292** hold the tappet **212** in place. An important benefit is the ability to preload the tappet **212**. Spacer **294** can be sized to allow discs **292** to deflect in the initial stage to preload discs **292**. The spacer **294** can be sized such that the discs **292** are fixed at their central portion, but flex at the outer portion of the discs **292**. This results in the preloading of the disc's outer portion to the right, as illustrated.

[0076] The solid line **406** represents the cumulative oil flow through the FAO **290** flow path. With reference to FIGS. **12**, and **14** through **15**B, oil flows along the reliefs **310** on rod **36** and through the slots **300** in inlet control orifice **224**. The slots **300** are precisely tuned to control the amount of oil flowing into chamber **219**. The openings **302** allow the oil to flow between the rebound passage **64** in the piston **260** and disc stack **222**, as shown by fluid path **400**. Fluid path **400**, represents the bypass flow, and the solid line **402** is the control circuit. The oil flows through the inlet control orifice **224**, along the reliefs **310** with a small amount of oil entering chamber **219** and a small amount of oil flows along path **404** to move second piston **289** and flow along second piston **289** to the compression chamber **34**. The outlet control orifice **210** has slots **306** to permit the oil to flow along path **404**. The slots **306** are tuned or sized as needed. Therefore, by applying specific ratios of the slots **300** on the inlet control orifice **224**, and the slots **306** on the outlet control orifice, the pressure in accumulator **219** can be controlled.

[0077] This system provides high damping forces when the suspension operates with low frequency and low damping forces when the suspension works with high frequency. This result is obtained mainly through the flow characteristics through the inlet control orifice **224**. When there is a higher pressure on the inlet control orifice **224** side facing piston **260**, the oil will flow through, path **404**. But because slots **300** are relatively narrow, the pressure on the opposite side of inlet control orifice **224**, the side facing the second piston **289**, raises at a lower rate than the pressure on the side facing the first piston **260** at high frequencies. The new embodiment as describes provides more time for the pressures to rise.

[0078] The invention distinguishes and controls ride characteristics between, for example normal conventional asphalt roads and brick or gravel roads. If the road is smooth, maybe wavy, but the surface is not rough, the FAO valve **290** should be closed. The pressure inside the tappet **212** should rise and the bypass valve **222** should be closed. But when you enter, let's say gravel, when the wheel is shaking with high frequency, the bypass valve **222** should stay opened and then the damper should provide low damping to isolate the vehicle body from this surface roughness.

[0079] FIG. **16** shows a first graph **500** illustrating rebound force vs. velocity characteristics of a damper with the frequency-adaptive orifice valve of the present disclosure under standard and high-frequency conditions. The first graph **500** includes a first plot **502** showing force vs. velocity for the damper under low-frequency excitation conditions. The first graph **500** also includes a second plot **504** showing force vs. velocity for the damper under high-frequency excitation conditions. FIG. **17** shows a second graph **550** with a plot **552** showing rebound force vs. stroking frequency of a damper with the frequency-adaptive orifice valve of the present disclosure and at constant velocity.

[0080] Obviously, many modifications and variations of the present invention are possible in light of the above teachings and may be practiced otherwise than as specifically described while within the scope of the appended claims. These antecedent recitations should be interpreted to cover any combination in which the inventive novelty exercises its utility.

[0081] According to an aspect of the present disclosure, a damper assembly is provided. The damper assembly includes a housing having a tubular shape extending along a center axis; a piston movable through the housing along the center axis; a body defining a frequency-adaptive orifice (FAO) passage providing fluid communication between a first chamber and a second chamber; and an FAO valve assembly having an FAO cover member configured to selectively cover the FAO passage to block fluid flow therethrough in response to application of a low-frequency excitation below a predetermined frequency, the FAO valve assembly further configured to allow fluid flow through the FAO passage in response to application of a high-frequency excitation above the predetermined frequency. The FAO valve assembly further comprises a tappet configured to translate relative to the body to bias the FAO cover member to selectively cover the FAO passage in response to the application of the low-frequency excitation in an at least one of a compression direction or a rebound direction opposite the compression direction.

[0082] In some embodiments, the housing defines a main chamber, the piston divides the main chamber into a compression chamber and a rebound chamber, the first chamber includes the compression chamber, and the second chamber includes the rebound chamber. In some embodiments, the piston includes a piston body and the piston body is the body defining the FAO passage.

[0083] In some embodiments, the tappet is configured to bias the FAO cover member to selectively cover the FAO passage in response to the application of the low-frequency excitation in the rebound direction.

[0084] In some embodiments, the piston body defines an FAO chamber with the tappet disposed therein; and the FAO chamber is in fluid communication with the compression chamber.

[0085] In some embodiments, the piston body defines a rebound passage in fluid communication with the rebound chamber; the piston further comprises a rebound valve assembly including a rebound disc stack covering an end of the rebound passage to regulate fluid flow from the rebound chamber to the compression chamber during a rebound stroke; and the FAO passage extends between the rebound passage and the FAO chamber to provide fluid communication therebetween.

[0086] In some embodiments, the damper assembly further includes a damper rod extending along the center axis and including a rod end located within the main chamber; the piston is attached to the damper rod adjacent to the rod end; the piston further comprises a guiding sleeve disposed about the damper rod; and the tappet has ring shape disposed around and engaging the guiding sleeve.

[0087] In some embodiments, the piston further comprises a compression valve assembly configured to regulate fluid flow from the compression chamber to the rebound chamber during a compression stroke, the compression valve assembly including a compression disc stack disposed annularly around the guiding sleeve.

[0088] In some embodiments, the guiding sleeve includes a distal tubular portion disposed coaxially with and tightly against the damper rod; and the tappet is disposed around the distal tubular portion and is configured to slide therealong.

[0089] In some embodiments, the distal tubular portion of the guiding sleeve includes an outer surface defining a first seal slot receiving a first O-ring seal for sealing against an inner surface of the tappet.

[0090] In some embodiments, the guiding sleeve further includes a disc-shaped portion that extends annularly around the damper rod and radially outwardly from the distal tubular portion; the tappet includes an inner tubular portion disposed around the distal tubular portion of the guiding sleeve and configured to slide therealong; the tappet further includes a flange portion and an outer tubular portion, the flange portion having an annular shape extending radially outwardly from the inner tubular portion, the outer tubular portion extending annularly around the flange portion; and the outer tubular portion of the tappet is disposed annularly around the disc-shaped portion of the guiding sleeve and configured to slide therealong.

[0091] In some embodiments, the tappet and the guiding sleeve together define a tappet chamber extending between the flange portion of the tappet and the disc-shaped portion of the guiding sleeve; and the tappet chamber is in fluid communication with the rebound chamber via a balance passage.

[0092] In some embodiments, the disc-shaped portion of the guiding sleeve includes an outer surface defining a second seal slot with a second O-ring seal disposed therein and sealing against an inner surface of the outer tubular portion of the tappet.

[0093] In some embodiments, the tappet defines, at least in part, a tappet chamber; wherein the tappet chamber is in fluid communication with the rebound chamber via a balance passage; and the guiding sleeve defines, at least in part, the balance passage.

[0094] In some embodiments, the guiding sleeve includes a proximal tubular portion having a tubular shape disposed around the damper rod and spaced apart therefrom to define, at least in part, the balance passage therebetween.

[0095] In some embodiments, the tappet defines, at least in part, a tappet chamber; the tappet chamber is in fluid communication with the rebound chamber via a balance passage; and the FAO valve assembly further comprises a control orifice configured to restrict fluid flow between the rebound chamber and the tappet chamber.

[0096] In some embodiments, the damper assembly further comprises a damper rod extending along the center axis and including a rod end located within the main chamber; the piston is attached to the damper rod adjacent to the rod end; the damper rod includes a rod body having a first diameter, a rod shoulder spaced apart from and facing toward the rod end, and a rod extension extending from the rod shoulder to the rod end and having a second diameter smaller than the first diameter; and the FAO valve assembly further comprises a valve control disc disposed around the rod extension and defining, at least in part, the control orifice.

[0097] According to an aspect of the present disclosure, a piston for a damper assembly is provided. The piston includes: a piston body defining a frequency-adaptive orifice (FAO) passage for providing fluid communication between a compression chamber and a rebound chamber; an FAO valve assembly having an FAO cover member configured to selectively cover the FAO passage to block fluid flow therethrough in response to application of a low-frequency excitation below a predetermined frequency, the FAO valve assembly further configured to allow fluid flow through the FAO passage in response to application of a high-frequency excitation above the predetermined frequency; and the FAO valve assembly further includes a tappet configured to translate relative to the piston body to bias the FAO cover member to selectively cover the FAO passage in response to the application of the low-frequency excitation in an at least one of a compression direction or a rebound direction opposite the compression direction.

[0098] In some embodiments, the piston further includes a guiding sleeve; and the tappet has ring shape disposed around and engaging the guiding sleeve.

[0099] In some embodiments, the guiding sleeve includes a distal tubular portion having a tubular shape; and the tappet is disposed around the distal tubular portion and is configured to slide therealong.

[0100] In some embodiments, the guiding sleeve further includes a disc-shaped portion that extends radially outwardly from the distal tubular portion; the tappet includes an inner tubular portion disposed around the distal tubular portion of the guiding sleeve and configured to slide therealong; the tappet further includes a flange portion and an outer tubular portion, the flange portion having an annular shape extending radially outwardly from the inner tubular portion, the outer tubular portion extending annularly around the flange portion; and the outer tubular portion of the tappet is disposed annularly around the disc-shaped portion of the guiding sleeve and configured to slide therealong.

[0101] Obviously, many modifications and variations of the present invention are possible in light of the above teachings and may be practiced otherwise than as specifically described while within the scope of the appended claims. These antecedent recitations should be interpreted to cover any combination in which the inventive novelty exercises its utility.

Claims

1. A damper assembly comprising: a housing having a tubular shape extending along a center axis; a piston movable through the housing along the center axis; a rod upon which said piston is mounted; a body defining a frequency-adaptive orifice (FAO) passage providing fluid communication between a first chamber and a second chamber; an FAO valve assembly having an FAO cover member configured to selectively cover the FAO passage to block fluid flow therethrough in response to application of a low-frequency excitation below a predetermined frequency, the FAO valve assembly further configured to allow fluid flow through the FAO passage in response to application of a high-frequency excitation above the predetermined frequency; and the FAO valve assembly having a tappet configured to translate relative to the body to bias the FAO cover member to selectively cover the FAO passage in response to the application of the low-frequency excitation in an at least one of a compression direction or a rebound direction opposite the compression direction; a tappet spring disc configured to bias said tappet.
2. The damper assembly of claim 1, wherein said tappet floats between said tappet spring disc and said FAO cover member, whereby in a steady state, when the damper is not moving, said tappet spring discs and said FAO cover member hold said tappet in place.
3. The damper assembly of claim 2, wherein said tappet spring discs preload said tappet.
4. The damper assembly of claim 1, wherein said tappet spring discs are mounted between tappet spring spacers, said spacers have a diameter less than the diameter of said tappet spring discs whereby said spacers engage said tappet spring discs a spaced distance from the periphery of said tappet spring discs allowing the outer periphery to flex.
5. The damper assembly of claim 1, wherein the housing defines a main chamber, the piston divides the main chamber into a compression chamber and a rebound chamber, the first chamber includes the compression chamber, and the second chamber includes the rebound chamber; and wherein the piston includes a piston body and the piston body is the body defining the FAO passage.
6. The damper assembly of claim 1, further including an inlet control orifice operatively controlling fluid flow into out of said FAO chamber.
7. The damper assembly of claim 6, wherein said inlet control orifice includes at least one inlet slot for the passage of fluid out of said FAO chamber.
8. The damper assembly of claim 7, wherein said rod includes a recess, said recess and said inlet slot cooperate to allow fluid to pass.
9. The damper assembly of claim 6, wherein said inlet control orifice includes at least one slot for the passage of fluid out of said FAO chamber and into said secondary chamber.
10. The damper assembly of claim 6, wherein said inlet control orifice includes at least one additional opening, allowing fluid to simultaneously flow into said secondary chamber and bypass said secondary chamber.
11. The damper assembly of claim 1, further including a floating sleeve mounted adjacent said tappet, said floating sleeve and said tappet defining a secondary chamber, said secondary chamber volume changes as said floating sleeve and said tappet move with respect to one another, said volume increases as said floating sleeve and said tappet move away from one another.
12. The damper assembly of claim 9, further including accumulator discs biasing said floating sleeve.

13. The damper assembly of claim 1, further including a second piston.
14. The damper assembly of claim 12, further including a first outlet control orifice adjacent said second piston.
15. The damper assembly of claim 13, wherein said first outlet control orifice includes at least one outlet slot for the passage of fluid around said piston.
16. The damper assembly of claim 15, wherein said rod includes a recess, said recess and said outlet slot cooperate to allow fluid to pass.
17. The damper assembly of claim 13 including a second outlet control orifice adjacent said secondary chamber, allowing fluid flow into said secondary chamber.
18. The damper assembly of claim 17, wherein said second outlet control orifice includes at least one outlet slot for the passage of fluid around said piston.
19. The damper assembly of claim 18, wherein said rod includes a recess, said recess and said outlet slot cooperate to allow fluid to pass.
20. The damper assembly of claim 2, wherein the piston body defines said FAO chamber with said tappet disposed therein; and wherein said FAO chamber is in fluid communication with the compression chamber.