A Novel Concept for Adjustable Internal Stroke Dependent Damping in Shock Absorbers

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ABSTRACT

Hydraulic dampers found in e.g., shock absorbers for off-road vehicles rely on the viscous forces that act against a piston that forces a fluid through small orifices as it is displaced along a cylinder. The many characteristics that dictate how a shock absorber responds to impacts include the amount of damping during compression and rebound and their adjustability is rather often crucial for high performance. There are numerous technologies that serve the purpose of regulating the damping forces, depending on speed or position of the piston relative to the cylinder that result from different types of impacts. The presented paper explains a concept that focuses on, but is not limited to the rebound; it should allow shock absorbers to respond quickly (less damping) against impacts that induce small strokes yet sufficiently slowly (more damping) with larger impacts. It allows for several *ride zones*, each corresponding to a range of stroke lengths. Furthermore, the invention solves the challenge of adjusting the magnitude of this property without disassembly while keeping the components internal.

With the proper implementation of the proposed mechanism it should be possible to have a shock absorber whose damping forces gradually decrease as the piston returns to its extended position and might increase -depending on the hydraulic circuitry- as it slides into the cylinder to its compressed position. The novelty of this concept lies in that the amount of damping that is dependent on the position of the piston can be adjusted with a single external dial, and the components with which the stroke dependent damping is achieved can remain fully internal.

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Definitions

Stroke can be referred to as the amount of compression, in length, the shock absorber experiences.

Ride Zone is the term used to describe a stroke range in which the damping force doesn't vary significantly.

Damping Curve is, within the present scope, the relationship between the stroke of the piston and damping force generated at that position given a linear spring driving the reboud. It is assumed that damping forces are ultimately dictated by restrictive orifice areas. While other literature might have described damping characteristics as linear, progressive and digressive, the terms *concavity* and *convexity* are used in this document.

Top / Above the piston refers to the side of the damper that is above the piston head according to the orientation of the figures in this document.

Bottom / Below the piston refers to the side of the damper that is below the piston head according to the orientation of the figures in this document.

Sub-circuit implies that there is a main circuit. The concept presented here comprises a hydraulic circuit for the damper with a bypass sub-circuit.

INTRODUCTION

There are two main components of a shock absorber for vehicles with wheels: a spring and a damper. Springs are what keeps the vehicle up and pushes it back up after an impact, they usually comprise coils or air chambers that resist compression. Both types have advantages and different properties that can be tuned. Engineers have found ways to add or modify properties of springs so that they respond in a more desirable way during a ride that encounters different types of impacts. Dampers, on the other hand, tend to be hydraulic. I.e., they rely on an incompressible fluid that is forced through orifices as impacts compress the shock absorber and through the same or different orifices as the spring extends it back. Most modern shock absorbers are designed around a main piston that travels through a cylinder, shortening the whole assembly during compression, and extending it back during rebound: these systems are able to passively decrease unwanted forces that riders/drivers would otherwise experience.

The purpose of shock absorbers should be to decrease compression forces and control the rebound forces, thereby substantially contributing to more comfortable, controllable, safer and faster rides.

The motivation to develop the presented system comes from the seemingly inherent need of having a shock absorber that extends quickly enough during smaller impacts -allowing for more responsiveness- and that is also capable of delaying the rate of such extension when it encounters a larger impact, preventing bouncing. Previous methods to achieve these results exist, but they might have disadvantages that prevent them from being used in a broad spectrum of applications. This concept aims to remove all possible disadvantages by keeping the system solely hydraulic/mechanical, by allowing the new components to remain internal (e.g., inside a cylinder), and by allowing adjustability of the amount of stroke dependent damping without disassembly.

THEORY AND ASSUMPTIONS

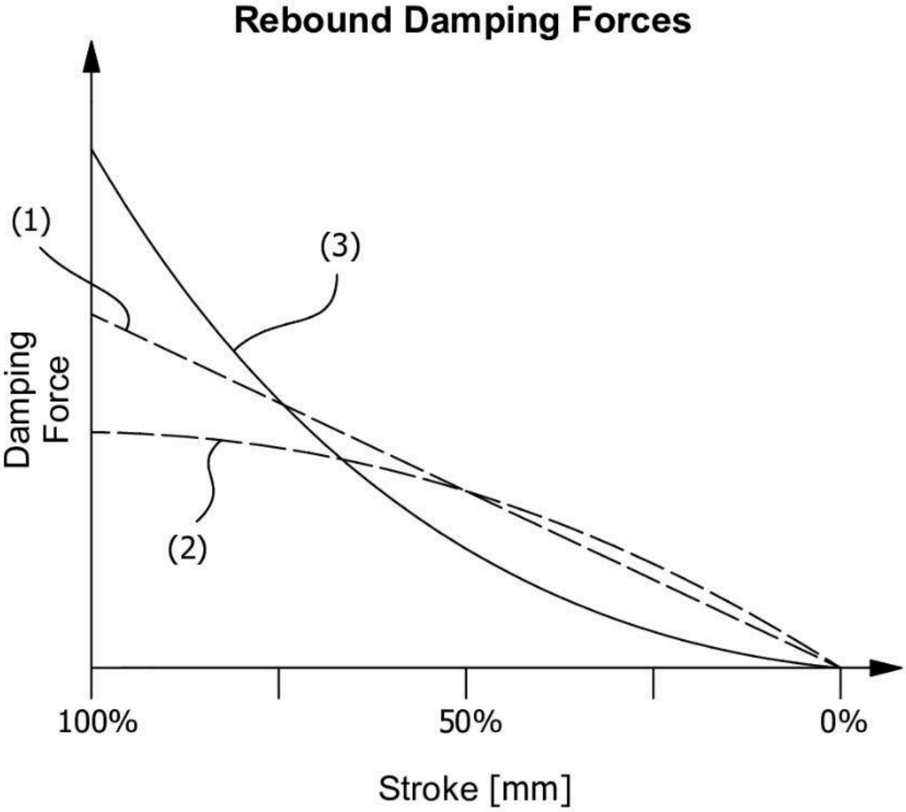

Figure 1: *Basic shapes of damping curves curves for an unweighted, non-preloaded shock absorber: Linear (1), Concave (2), and Convex (3).*

Figure 1 shows different examples of how damping forces caused by restrictive orifice areas may vary as the piston travels from fully compressed to fully extended. A linear rebound damping curve (1), a concave rebound damping curve (2), and a convex rebound damping curve (3). Linearity, as a base case, can be achieved by having a constant restrictive orifice area throughout the stroke; commonly, the use of an adjustable needle allows increasing or decreasing the area.

Most hydraulic suspension dampers have pressure relief valves that allow additional fluid through by adding to the restrictive area when the pressure in the fluid is high enough. Commonly, different pressure relief valves are assembled for compression and for rebound, being independently tunable in some cases. For the rebound, that would make a damping curve such as (2) in Figure 1; a concave damping curve. The main disadvantages of a concave or linear rebound damping curve typically manifest as one of the following:

- The rebound damping is set low (fast rebound) so that the suspension extends quickly, contributing to its responsiveness to highly-frequent, small impacts. Because of this, the suspension extends too quickly after a large impact.

- The rebound damping is set high (slow rebound) so that the suspension extends slowly, avoiding too much rebound after a large impact. Because of this, the suspension lacks responsiveness to highly-frequent, smaller impacts.

Thus even when riders/drivers find their preferred rebound damping setting, the suspension can never respond optimally to a broad variety of types of impacts during a single ride. That is not to say that pressure relief valves don't have benefits, but such benefits could be covered by a circuitry that makes a convex damping curve while eliminating the problem explained above.

Figure 2 shows the property that the invention presented in this document is intended to provide: a convex damping curve whose convexity can be modified (mainly for rebound but not limited to it) achieved by a mechanism that allows more fluid through as the piston extends.[1] This mainly makes different ride zones for different types of impacts in one setting, responding adequately to high-frequency small impacts as well as low-frequency large impacts.

[1] Both the constant orifice area (restricted by a needle) and the stroke dependent orifice area should be adjusted at least according to vehicle/rider weight.

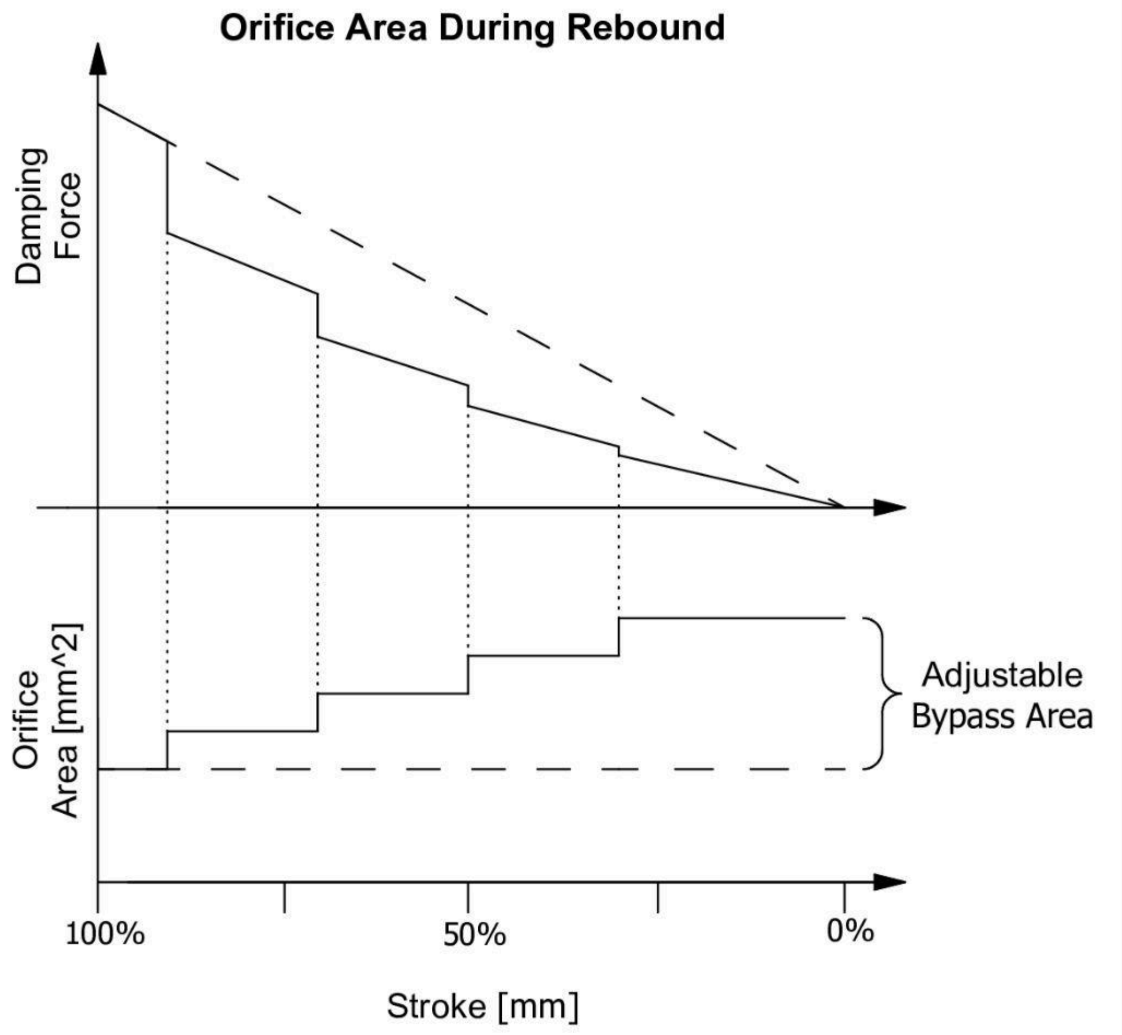

Figure 2: *Multiple independent bypass ports allow for multiple ride zones corresponding to the stroke length that each impact induces; each ride zone having an amount of damping that is dependent on the position of the piston.*

The figure assumes inverse linear proportionality between orifice area and damping forces, as well as a non-preloaded spring. It is considered fit for explanation purposes since the weight of the vehicle and rider/driver should offset the preload force. For an unweighted system there would be damping forces even as the piston reaches full extension.

KEY CONCEPTS AND FEATURES

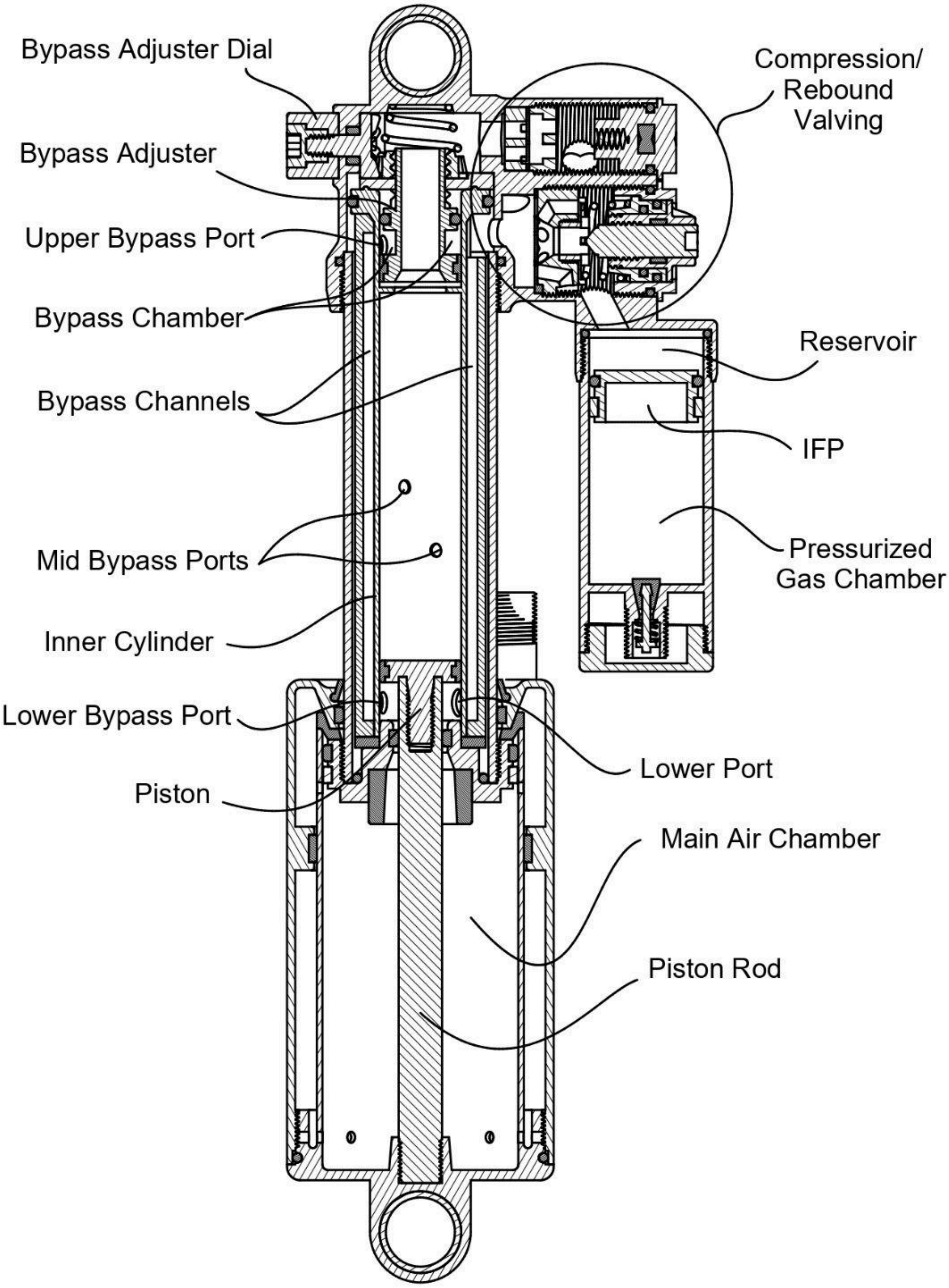

Figure 3: *Longitudinal section view of a shock absorber showing some of the bypass ports and channels along and around the piston cylinder, the adjuster that controls their influence, and bypass ports that allow this sub-circuit.*

The figures in this document show an example of implementation of the concept in a rear shock for a mountain bike. One of the main aims of this proof of concept is to show that the components can be arranged even under the dimensional constraints of the conventional industry standards. For this example, the length from eyelet to eyelet is 215.9 mm (8.5 in), the outer diameter of the air can is 49 mm, and the stroke length is 63.5 mm (2.5 in). The overlap rigidity might be a challenge due to the longitudinal constraint.

In essence, the principles that this damper is based on are the same as for most modern hydraulic dampers, and the air spring is no different. This shock is similar to some others in that the piston pushes the full column of oil above it when under compression, that oil passes through the compression/rebound valving where flow is adjustably restricted depending on the direction (compression or rebound), and some of it enters the reservoir while the rest is displaced below the piston. The opposite direction of the circuit applies for the rebound stroke, but the new implementation may allow additional oil from below to above the piston through bypass channels. The air spring works simply by compressing the air within the air can. There is some complexity in the specifics of modern air chambers, but an explanation is beyond the scope of this paper and the compression/rebound valving designed for this example is explained in general terms in the appendix.

Below is an description of the key components of the invention:

Inner/Piston Cylinder: This could be similar to a conventional cylinder but with some bypass ports at specific locations. The presented design does show a few minor modifications to fit it into the whole arrangement.

Bypass Sleeve: A tube or section of a tube with ribs inside it that when pressed or attached over the inner tube makes a series of longitudinal channels (bypass channels) along and around the outside of the piston cylinder. An alternative could be to fabricate the cylinder so that it includes the bypass channels (e.g., by welding them longitudinally.

Bypass Adjuster: A part that lies inside the inner tube and creates a chamber between two seals through which the oil that is bypassed can flow, with a geometry so that the area of the upper bypass ports can be altered by sliding it vertically.

Bypass Adjuster Dial and its interface with the Bypass Adjuster: The mechanism with which the bypass adjuster can be externally adjusted, making it slide vertically inside the inner tube (see *Figure A2* in the appendix for an example of implementation).

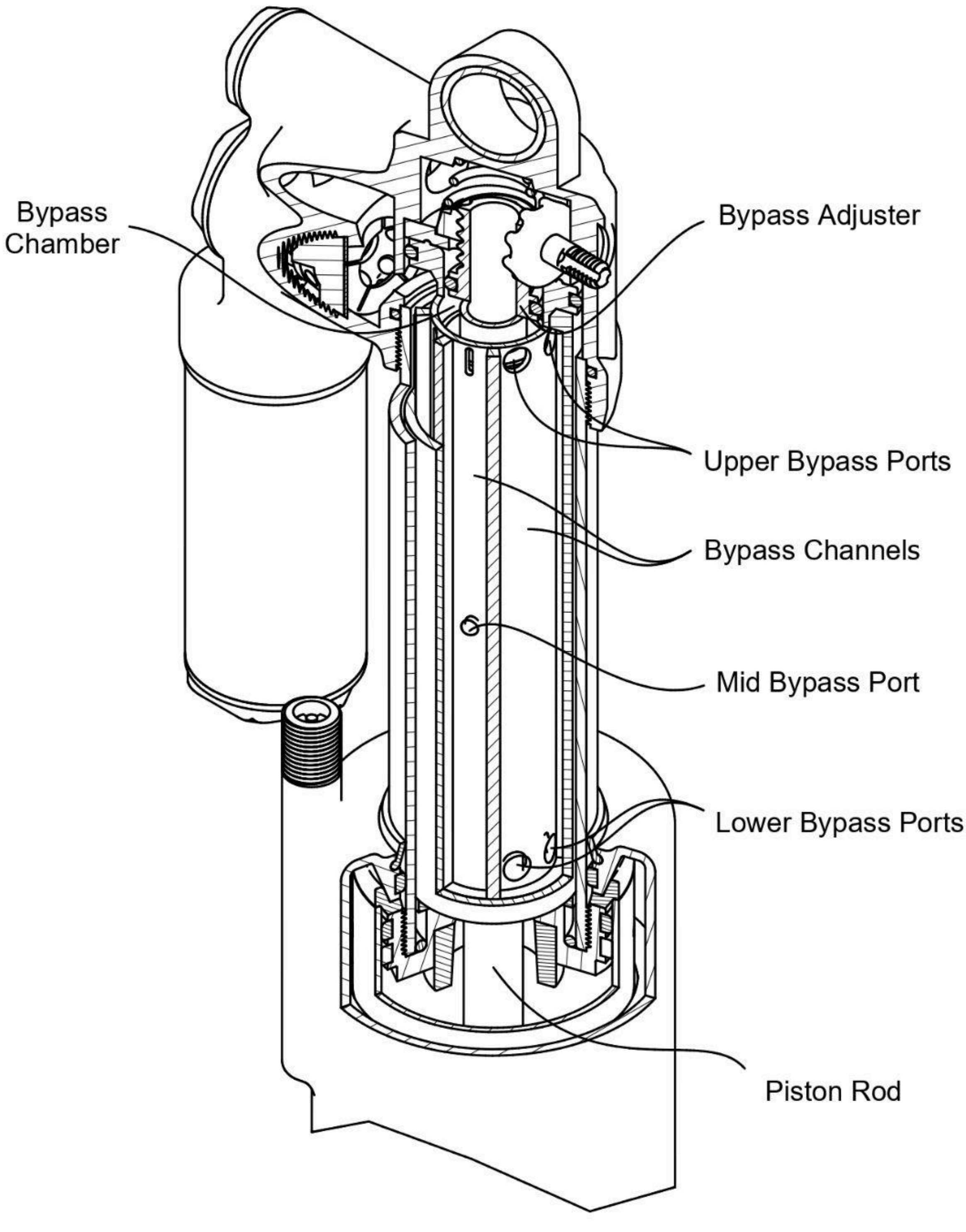

Figure 4: *Cut-away view of the model exposing the bypass ports in the inner cylinder and how a sleeve creates the channels.*

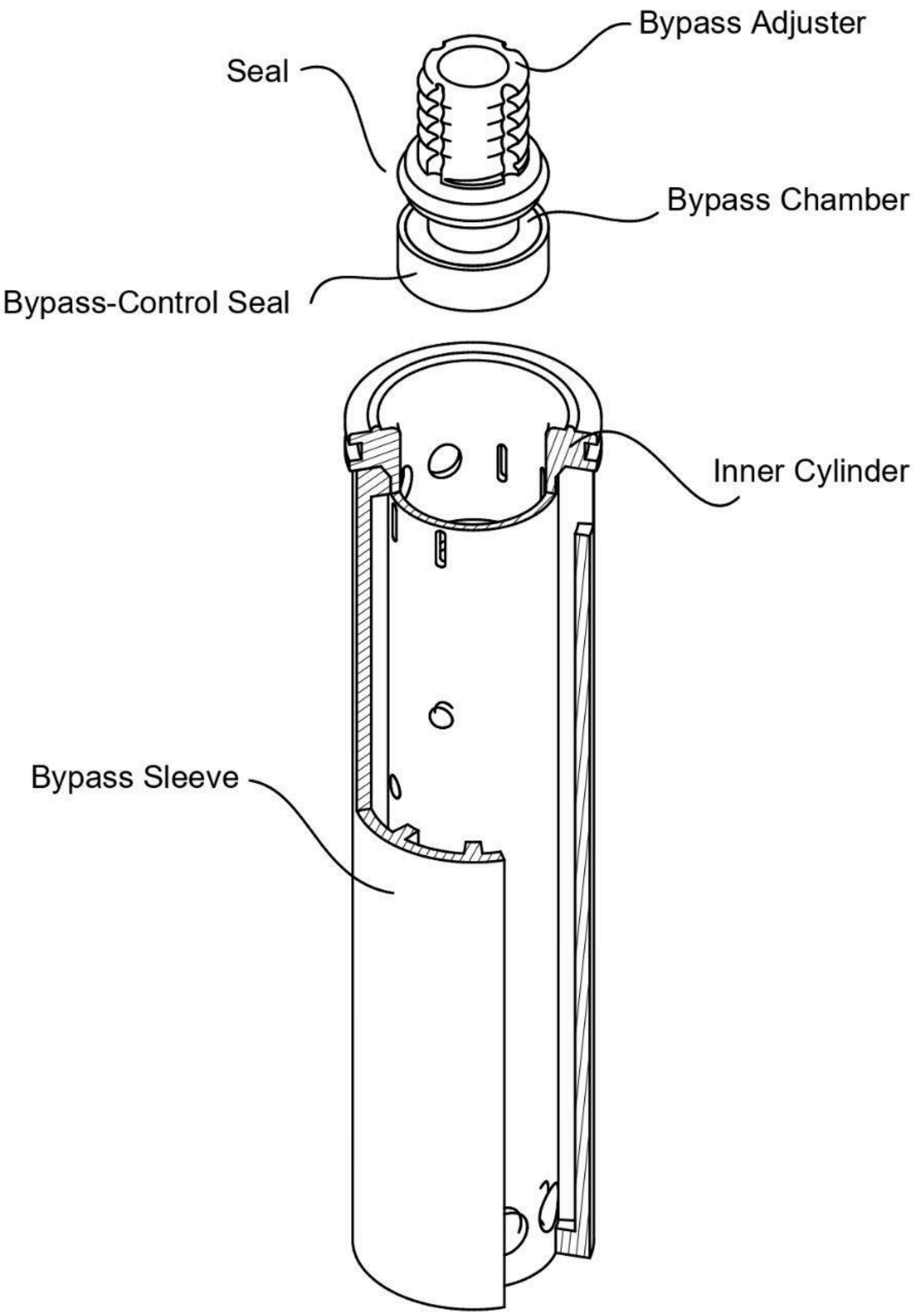

Figure 5: *Exploded cut-away view of the piston cylinder and sleeve and the bypass adjuster with the seals that create the bypass chamber.*

MECHANISM

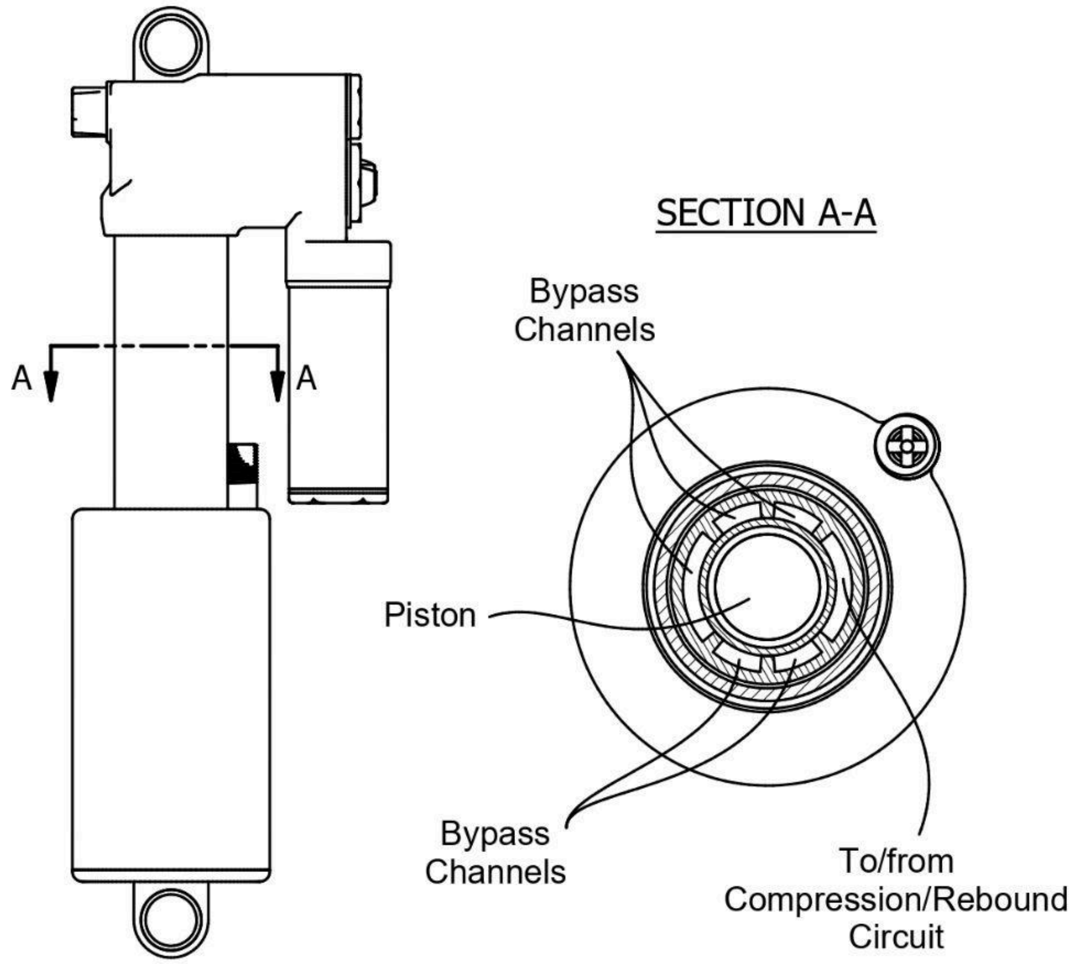

Figure 6: *Cross-sectional view of the inner and outer cylinder, exposing the independent bypass channels.*

Following the same example and based on the concepts of *Figure 3* and *Figure 4* in the previous section and *Figure 6* in this section, a description of how the mechanism works is given below. *Figure 7* and *Figure 8* further explain the hydraulic circuitry:

Upon a compressive force and as the piston moves upwards, all the fluid that is above it flows through the bypass adjuster, then through the compression/rebound valving and back into the lower chamber below the piston through a couple of lower ports. Since the piston rod is moved inside, its volume in fluid has to be displaced, thus the use of a reservoir. A pressurized gas chamber isolated by an Internal Floating Piston (IFP) always keeps the fluid under pressure.[2] The flow restriction during the compression stroke acts only against the fluid entering the reservoir through a series of valves in the compression valving assembly, so there can't be a bypass effect during compression, there isn't any significant flow restriction elsewhere.[3]

For the rebound stroke the fluid needs to get back to the upper chamber above the piston. If the upper bypass ports are fully shut by the bypass adjuster, the fluid simply follows the opposite direction to the compression stroke; it is partially restricted by a needle in the rebound circuit and the fluid in the reservoir is always free to exit it due to the arrangement of the valves. If the bypass isn't fully shut, then fluid under the piston has additional ways to travel from below to above the piston: From a fully compressed position the bypass ports and channels don't have an effect, but as the piston is displaced it passes the first of the mid bypass ports allowing fluid from under the piston through a bypass channel that goes from the lower bypass ports to the bypass chamber, and through the correspondent bypass channel that leads to said bypass port. As the piston keeps expanding, the same process is repeated for the second bypass port, and so on, reducing damping forces. The bypass adjuster can be slid vertically, changing the restrictive orifice area of all the bypass routes simultaneously (at the upper bypass ports). It controls the magnitude of the bypass effect. Were the bypass routes not individually channeled, the fluid could flow between them through some of the upper bypass ports, canceling out the adjustable flow restriction that the bypass adjuster controls at the upper bypass ports.

[2] Regions of high and low pressure form during every stroke of the cylinder and with a magnitude that varies with suspension design, settings, and impact size. For the instants with the greatest pressure differentials, the gas-chamber-driven IFP must be able to maintain a positive pressure within the whole system in order to avoid cavitation.

[3] Detailed drawings of the compression/rebound valving assembly are included in the appendix.

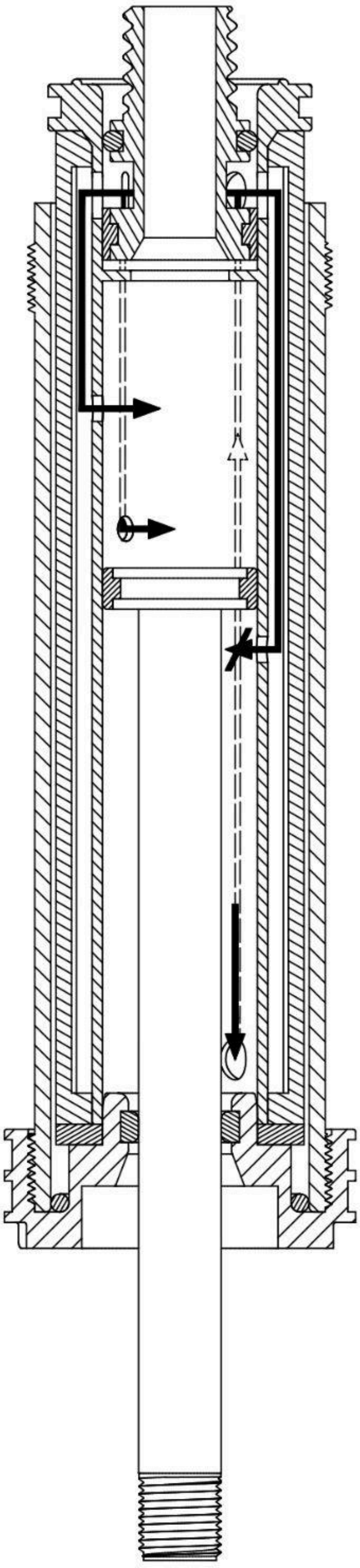

Figure 7: *Bypass circuit, a sub-circuit of the damper. As the piston travels downwards during the rebound stroke, the bypass channels that it passes become accessible to an extent that is controlled by the bypass adjuster.*

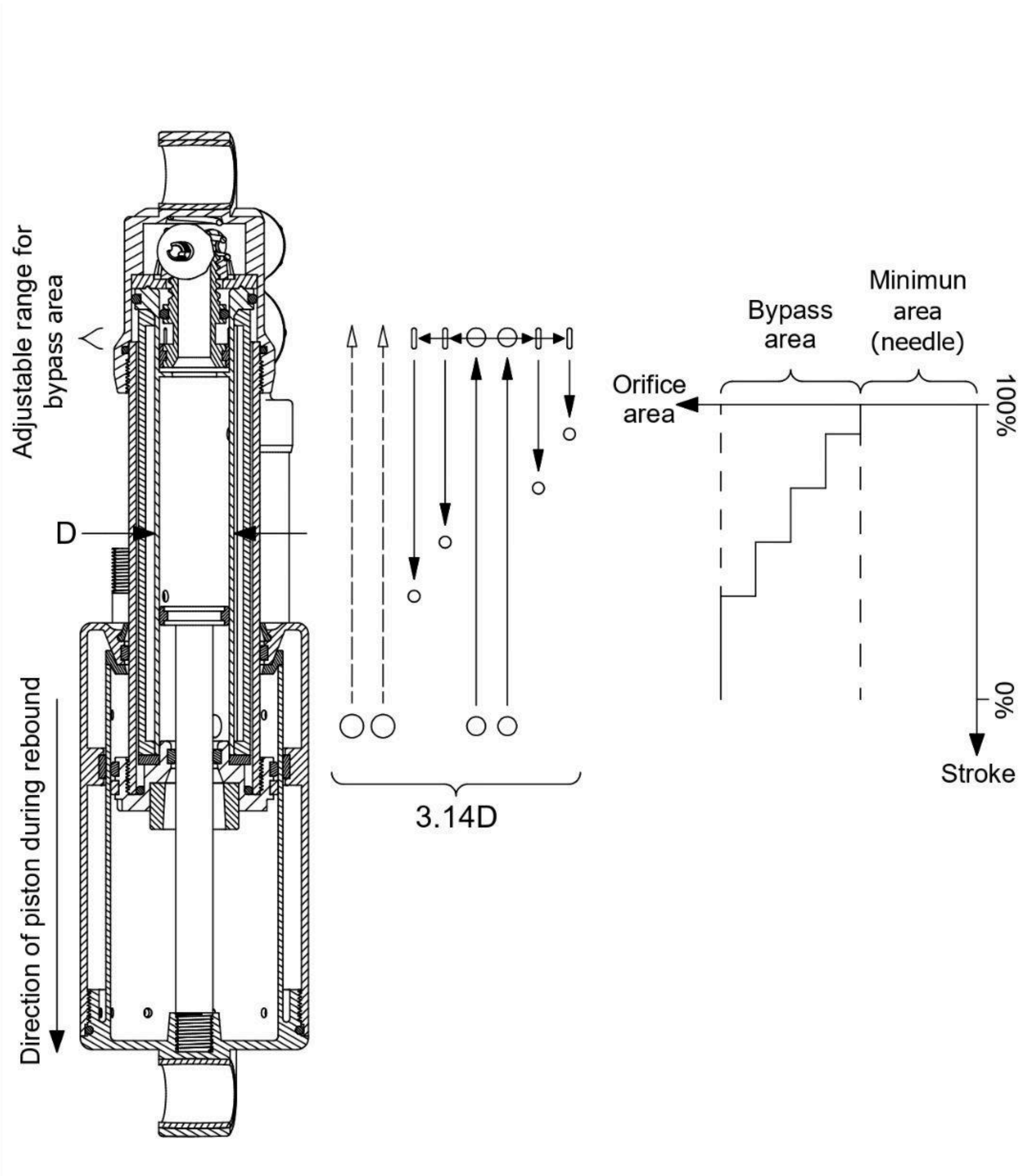

Figure 8: *A description of the bypass sub-circuit during a rebound stroke. The layout of the ports illustrates an extended view of how they are located around the cylinder, and the graph shows how the bypass area adds to the total orifice area as each port becomes available; the total bypass area being adjustable. A channel with two lower bypass ports routes the fluid to the mid bypass ports through the bypass chamber while a different set of lower ports routes it through the main circuit.*

CONCLUSION

It seems evident that a great amount of the innovations in the field of suspension technology come from off-road sports: such as Mountain Biking and Motocross. Suspension technology has delivered safe, reliable and varied products for this and other industries (e.g., automotive) for several decades, but beyond safety and reliability performance tends to come next when it comes to constant improvement. The outdoors industry pushes the boundaries and a reason is competition. In some disciplines, such as the formerly named, suspension plays a huge role in performance. Often, innovations in sports equipment find their way into other fields and thus it should not be intended to limit this invention to one specific area. This idea, however -as well as the examples in this document- was motivated by a rear shock for mountain bikes.

Challenges for this concept might include manufacturability, testing, and overlap rigidity. However, it should be noted that while it was attempted to make the concept clear with the use of an example of implementation, the mere mechanism does not need to be restricted to any specific method of implementation, such mechanism being the hydraulic circuit that comprises channeled ports (bypasses) through the outside of a piston cylinder along which they originate to a location (the bypass chamber) inside the same cylinder (above the piston) where the critical flow-restrictive areas of these bypass channels can be simultaneously altered by a slidable adjuster.

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APPENDIX

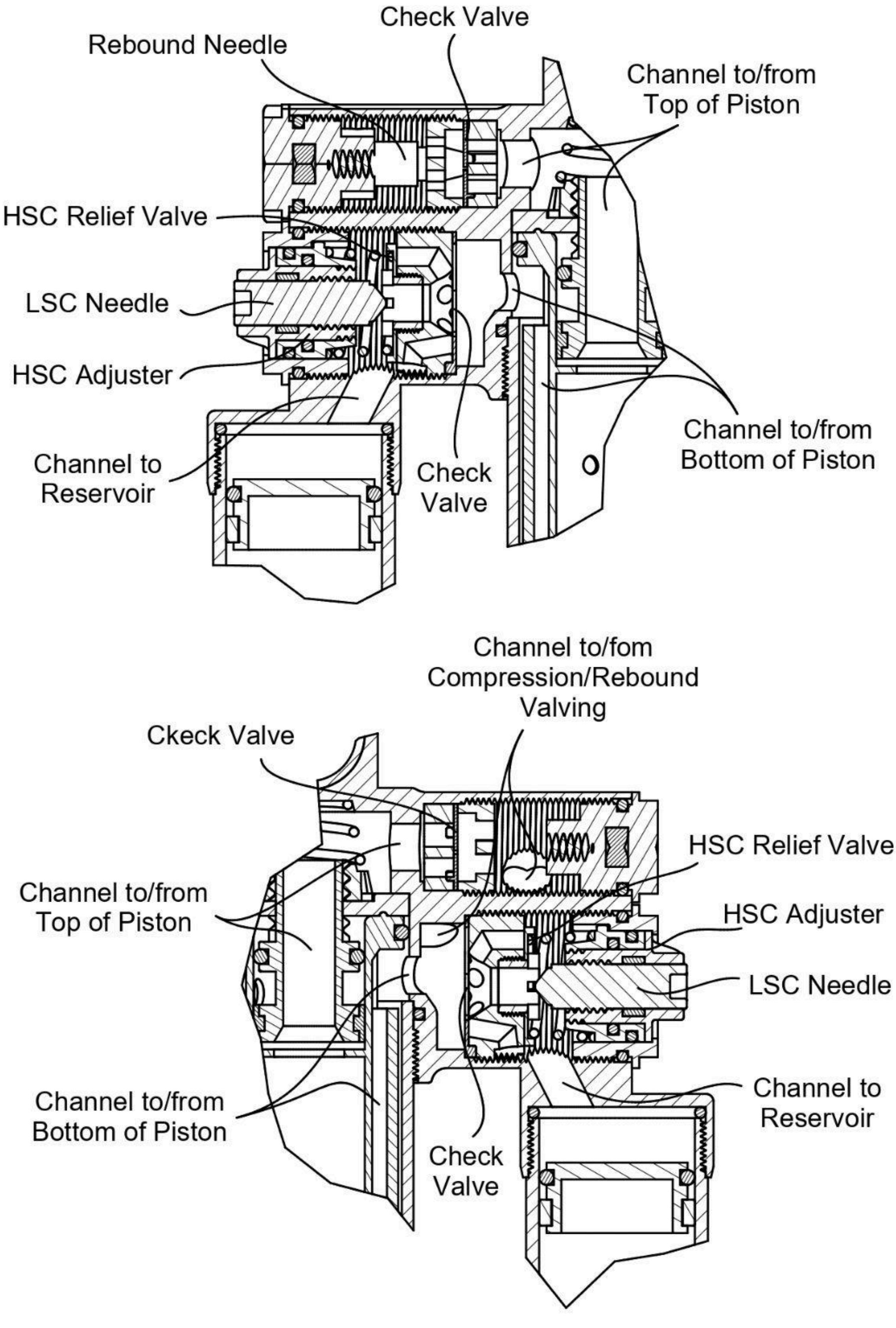

Figure A1*: Details of the compression/rebound assembly*

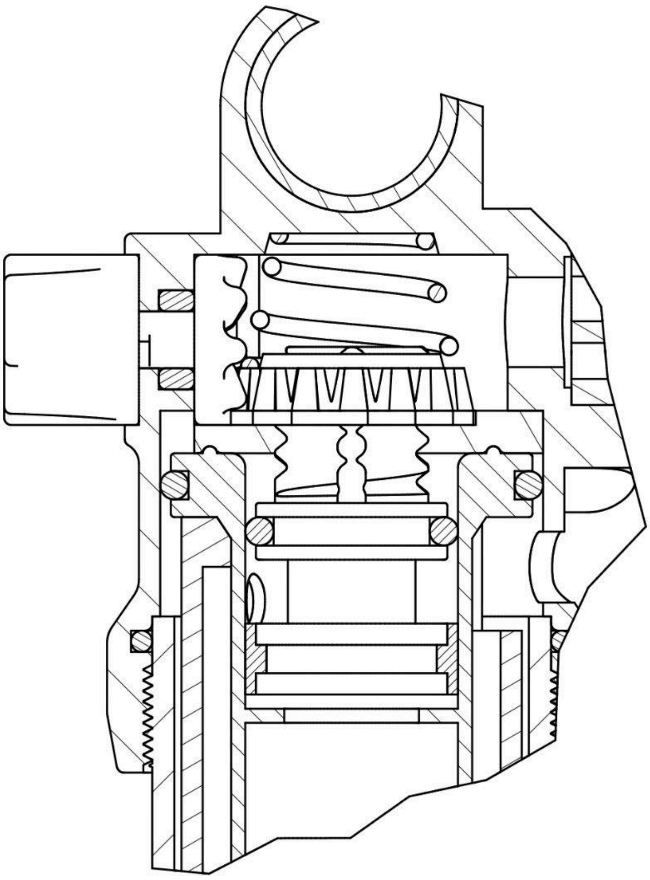

***Figure A2**: A proposed mechanism to fix the position of the bypass adjuster*

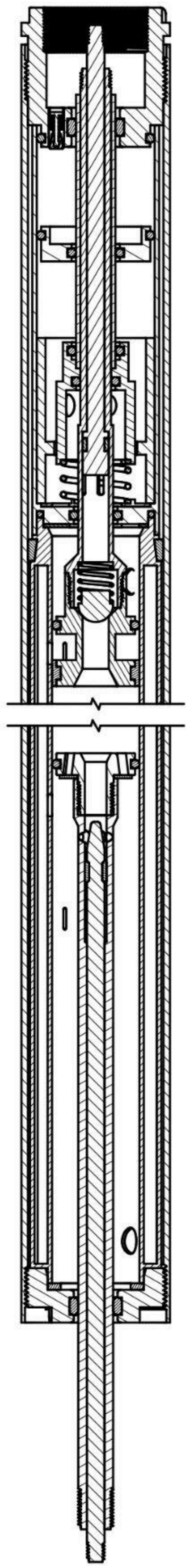

***Figure A3**: The principle can be expanded to the damper leg of a suspension fork*