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(54) **FORCE LIMITING DEVICE AND METHOD FOR CONTROLLING A FORCE LIMITING DEVICE**

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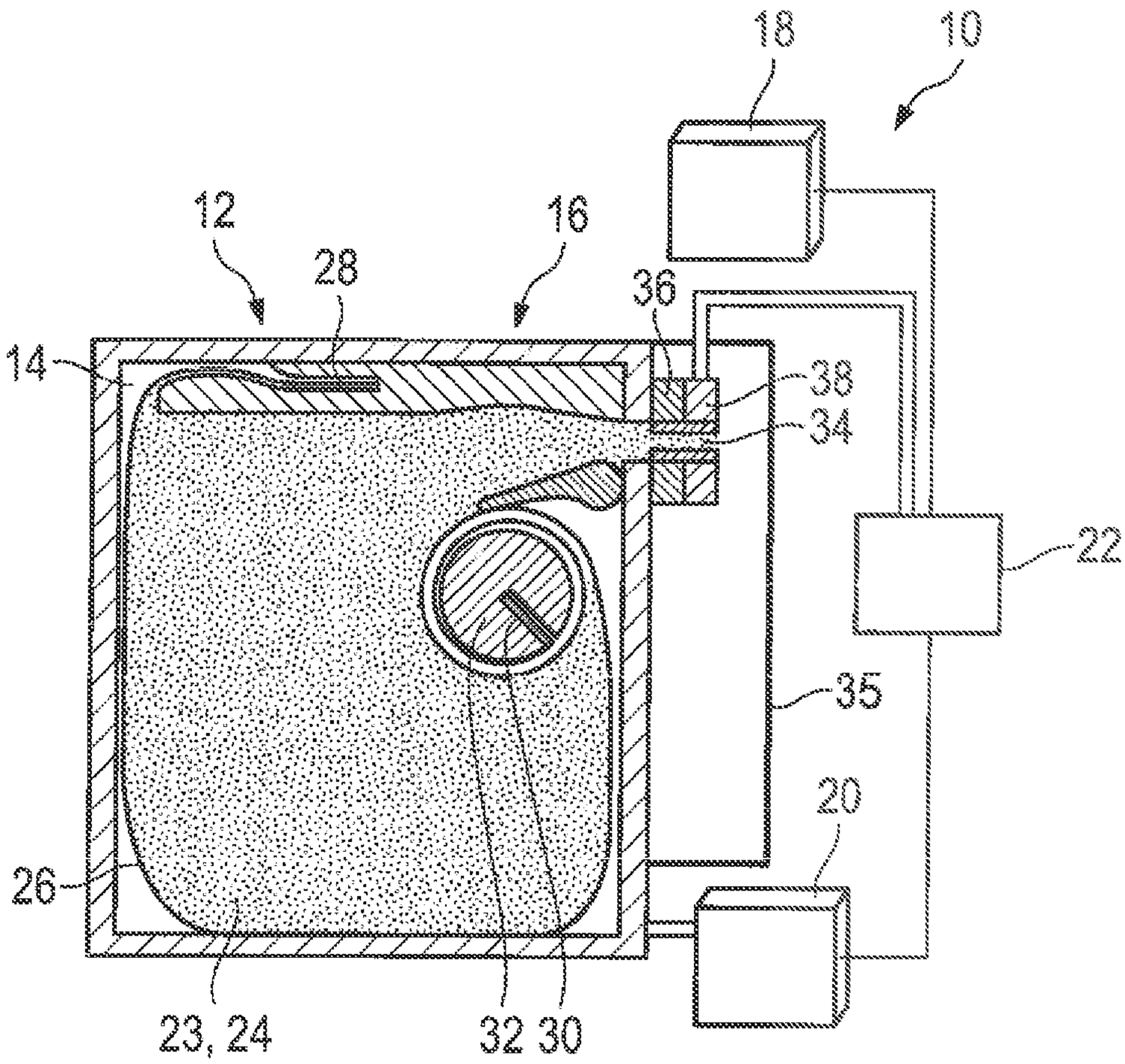
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(57) **ABSTRACT**

In a load limiting device (**10**), especially for a seat belt in a vehicle, comprising a controllable braking device (**18**) which has a fluid-filled compartment (**24**) including a conduit (**34**) through which the fluid (**23**) can flow, an element to be decelerated (**32**) which is coupled to the seat belt, at least one sensor (**18**) for detecting vehicle operating data, especially an acceleration sensor, a sensor (**20**) for detecting the webbing extension, and a controller (**22**) for controlling the braking power of the braking device (**16**) as a function of the vehicle operating data measured and the webbing extension measured, the fluid (**23**) is a magnetorheological fluid and a control magnet is provided which is adapted to generate a variable magnetic field inside the conduit (**34**) and to vary the viscosity of the magnetorheological fluid inside the conduit (**34**).



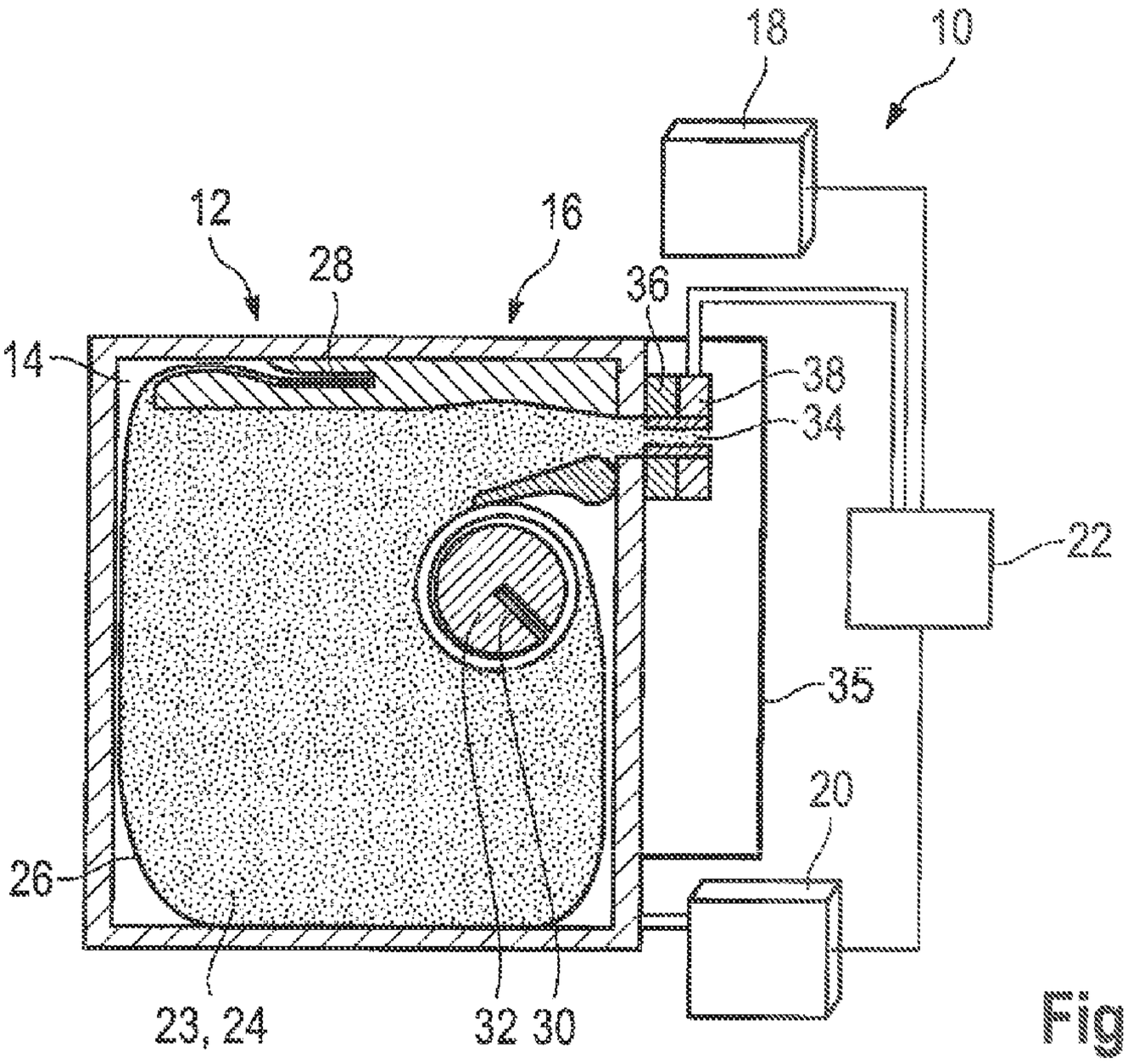

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Fig. 1

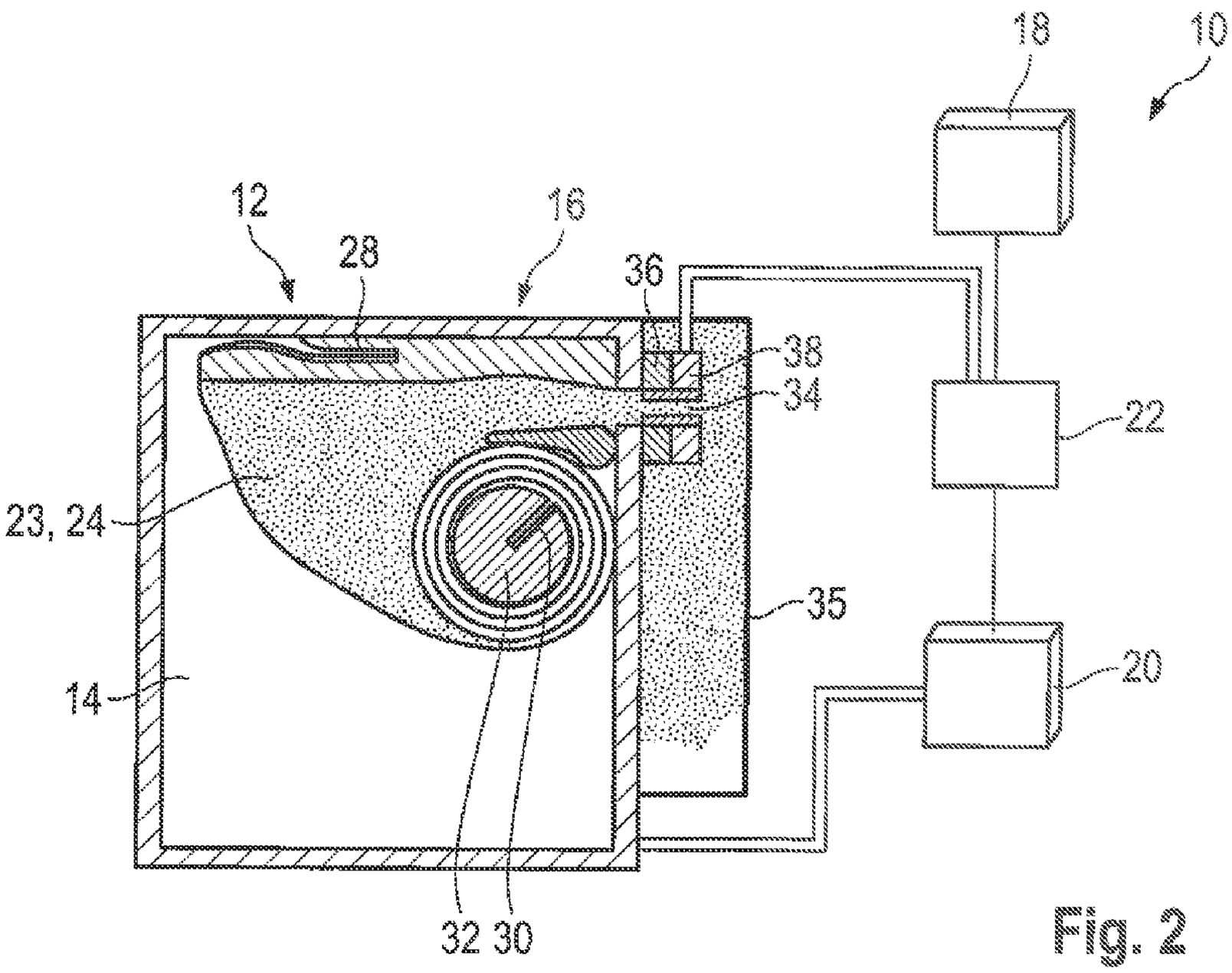

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Fig. 2

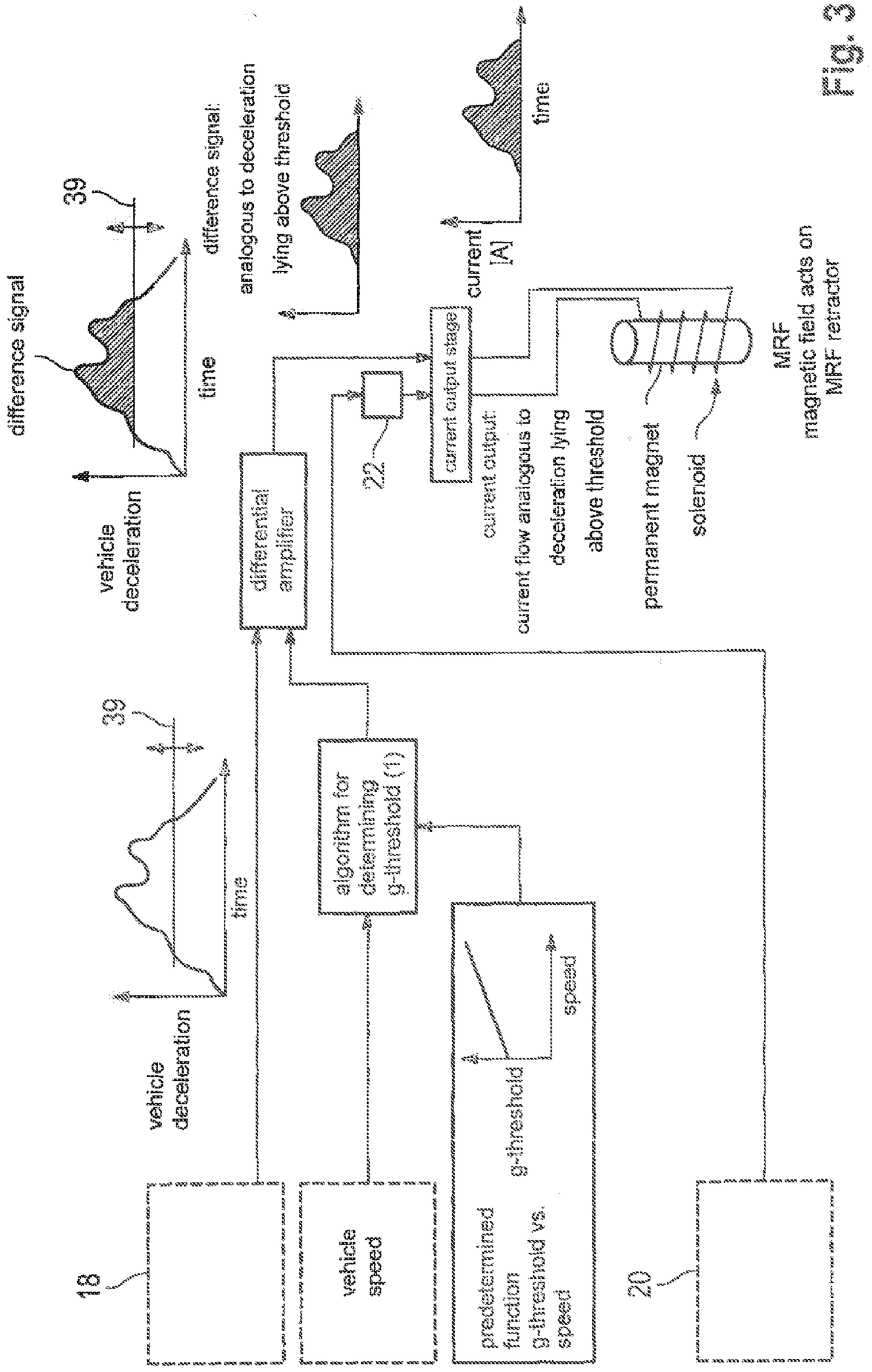

18
vehicle deceleration
vehicle speed
predetermined function g-threshold vs. speed
20
algorithm for determining g-threshold (1)
differential amplifier
current output stage
22
39
difference signal
time
vehicle deceleration
current output: current flow analogous to deceleration lying above threshold
permanent magnet
solenoid
MRF
magnetic field acts on MRF retractor

Fig. 3

Fig. 4

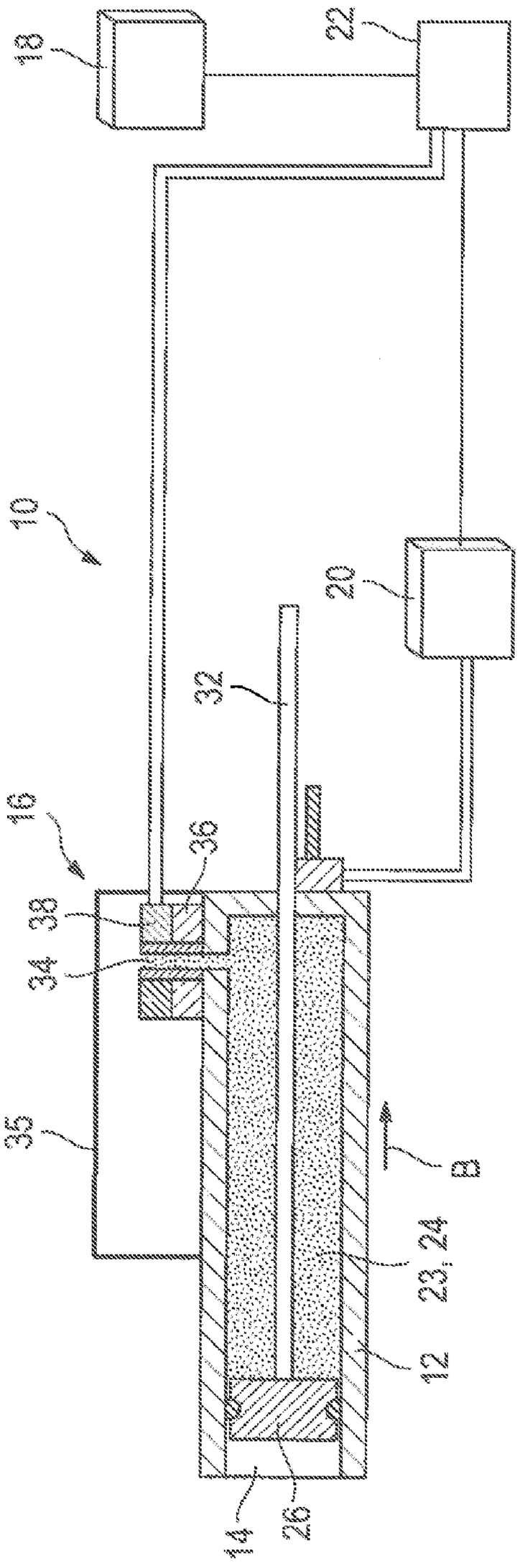
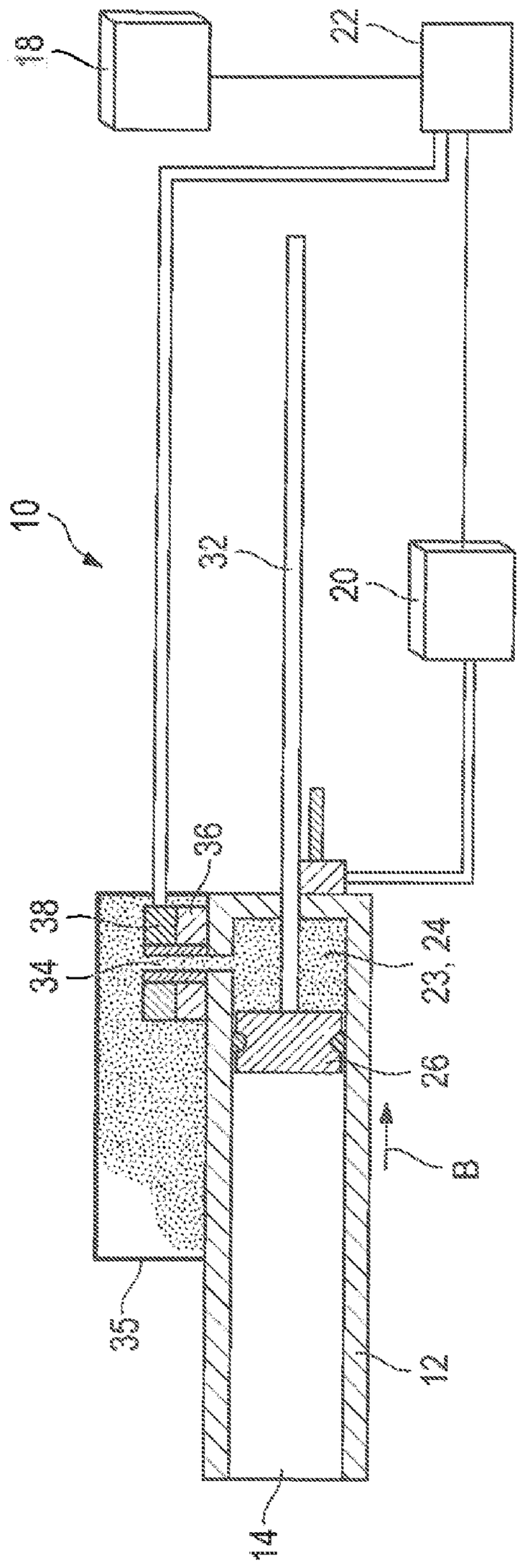

18
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23, 24
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Fig. 5


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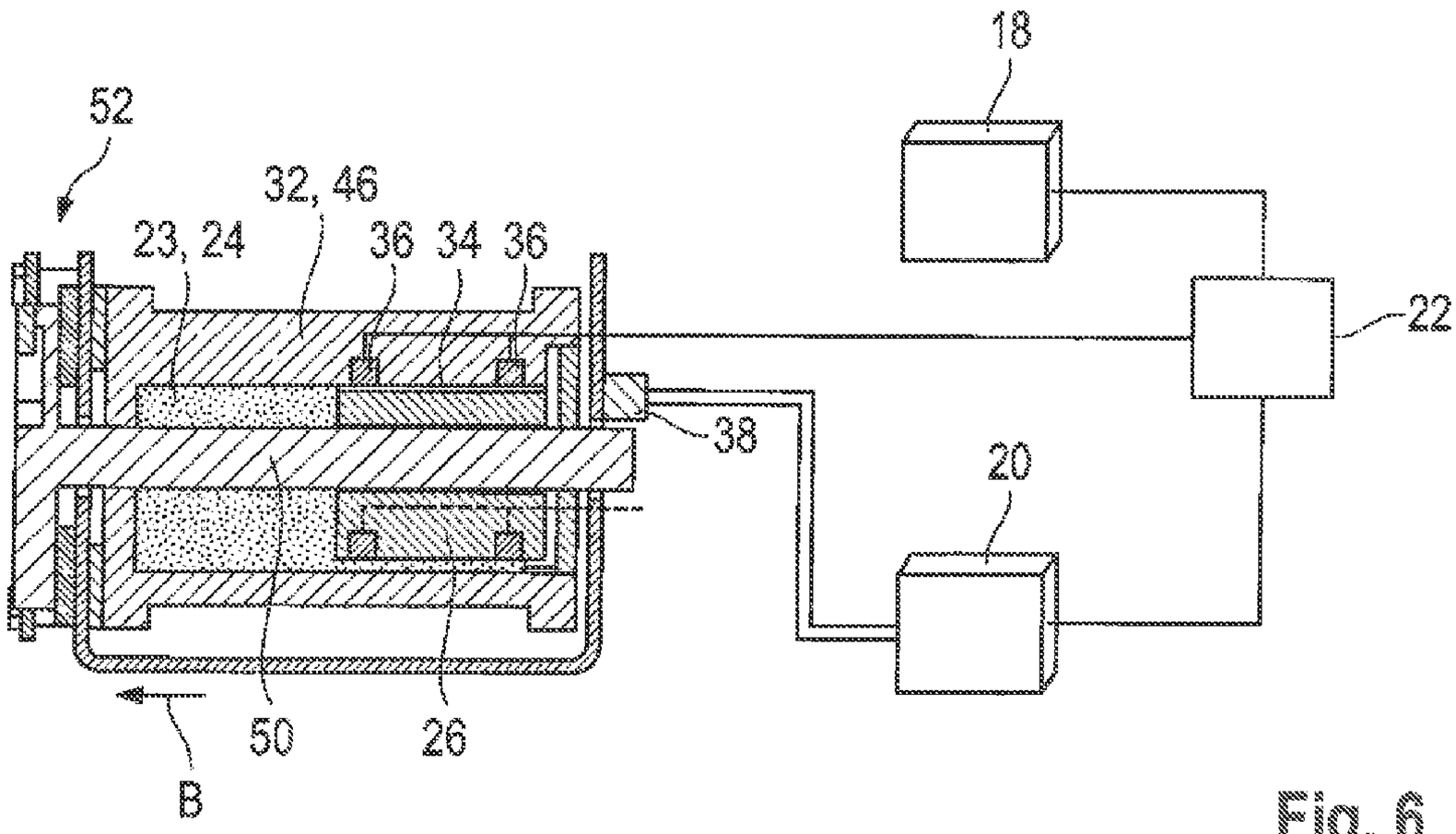


Fig. 6

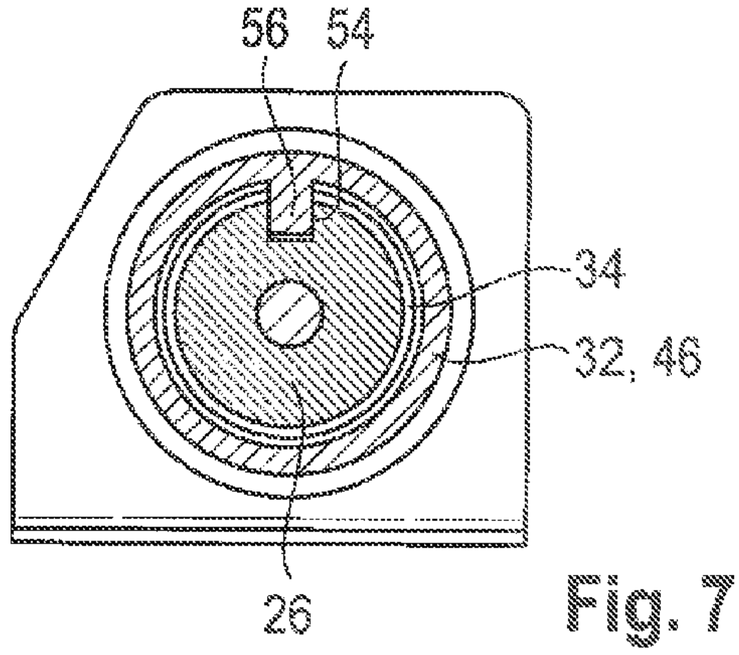


Fig. 7

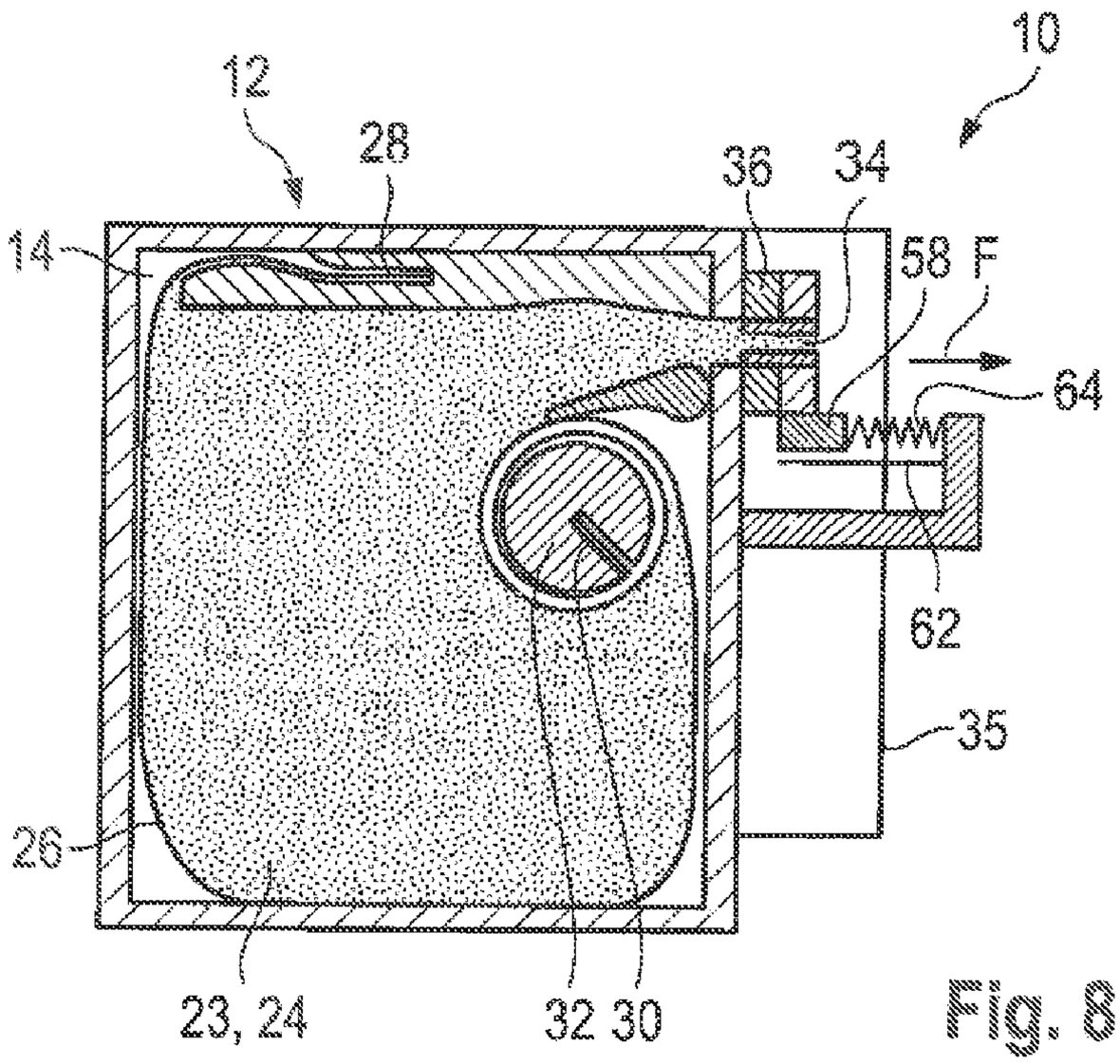

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Fig. 8

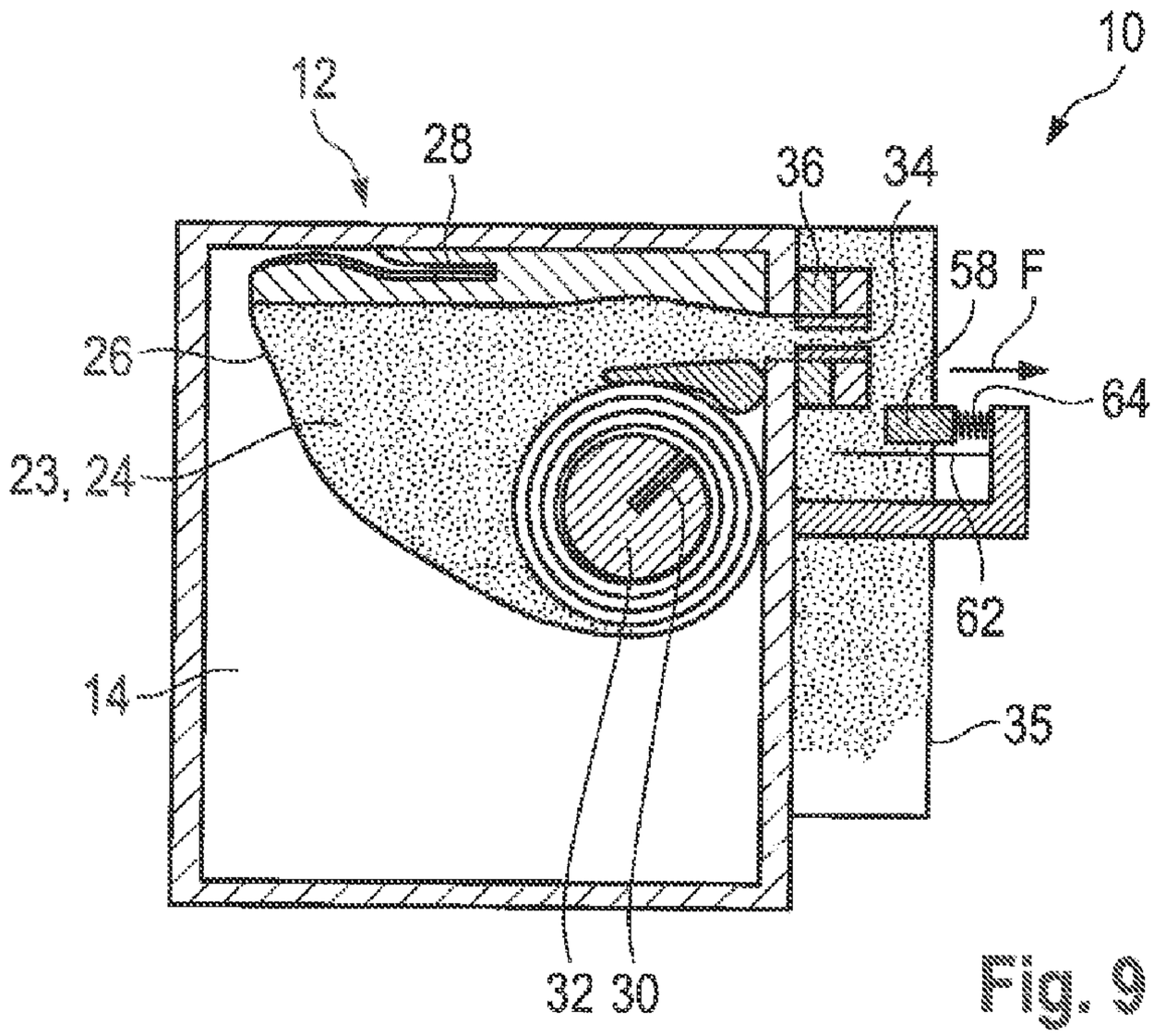

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Fig. 9

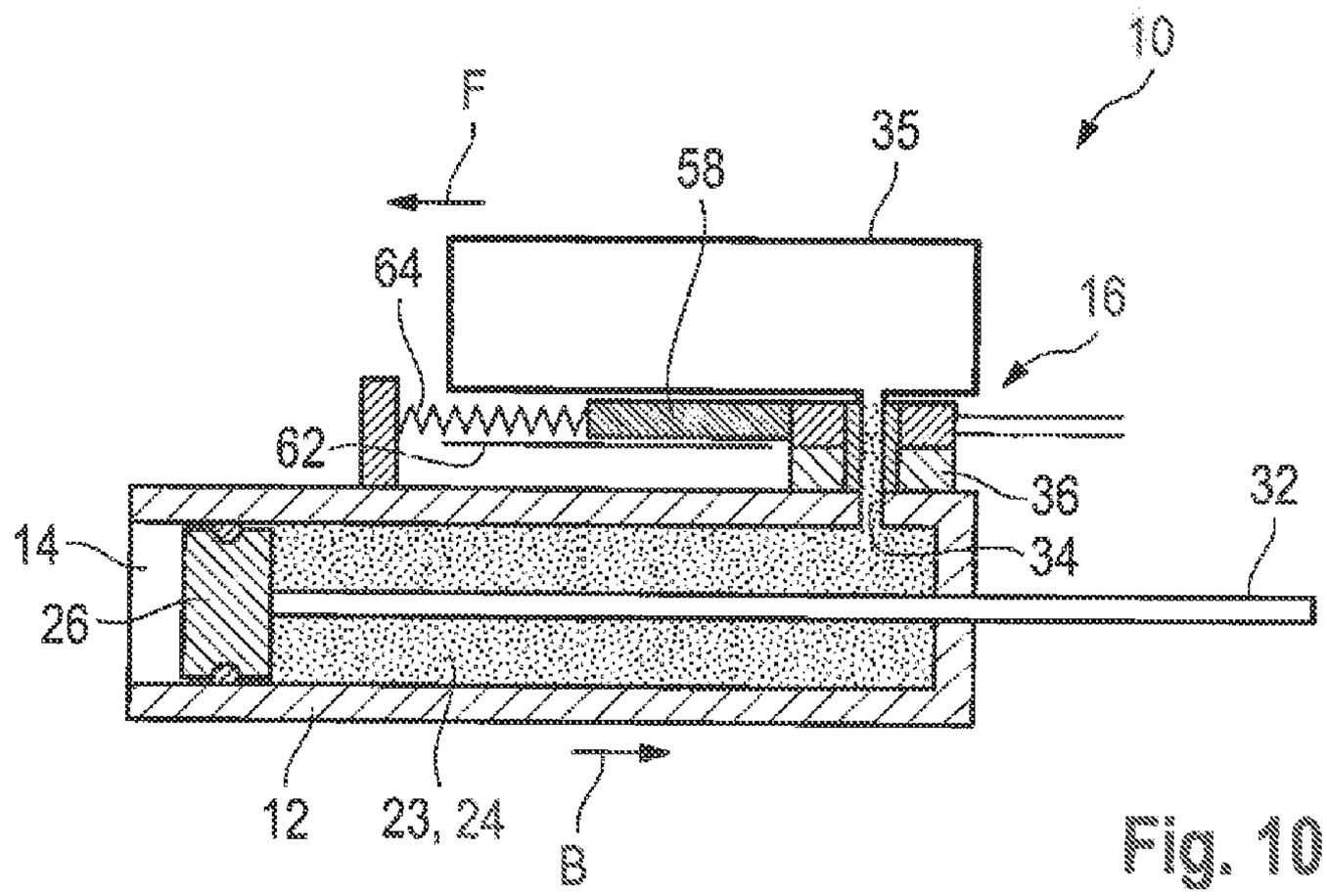

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Fig. 10

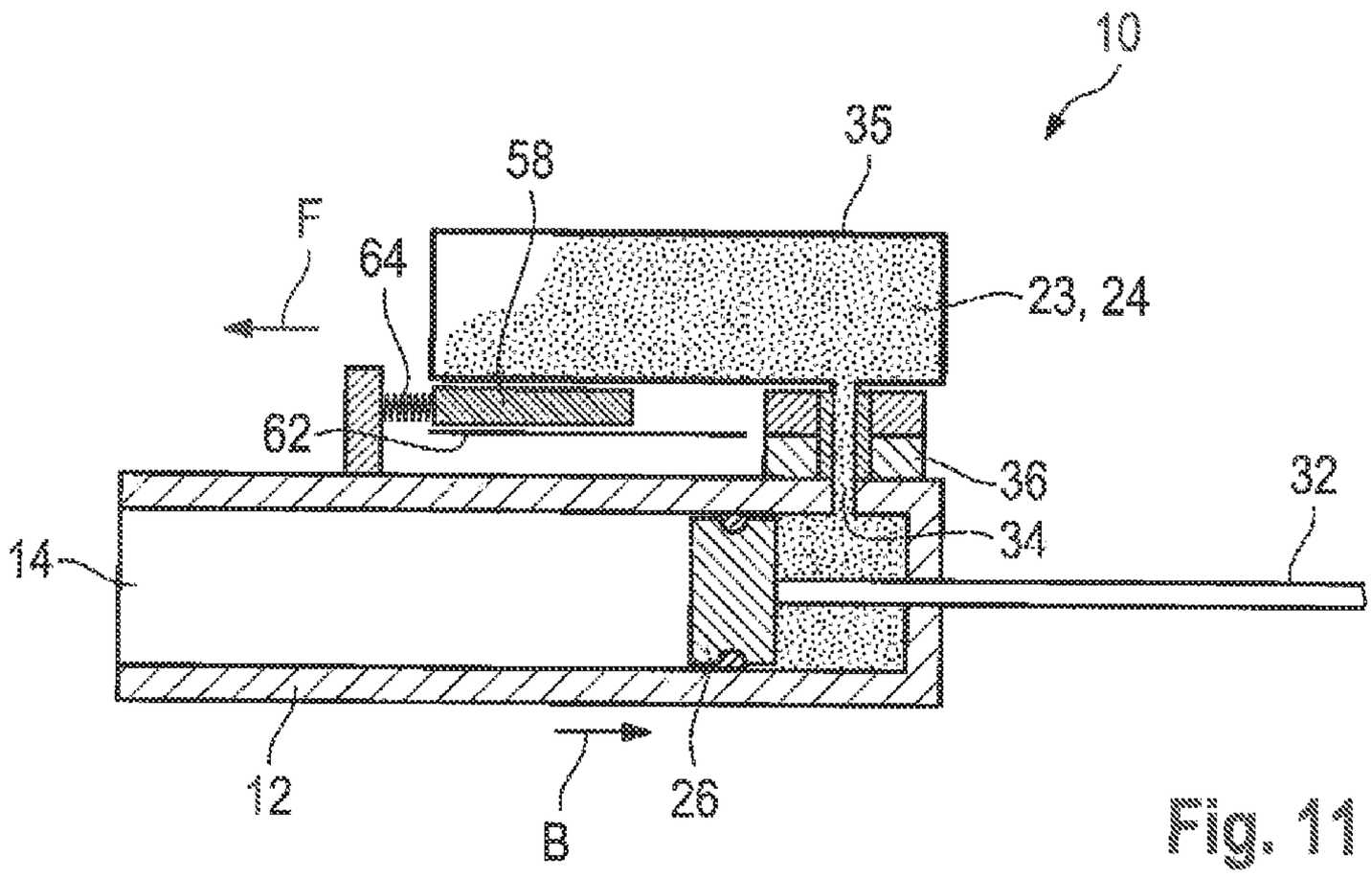

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Fig. 11

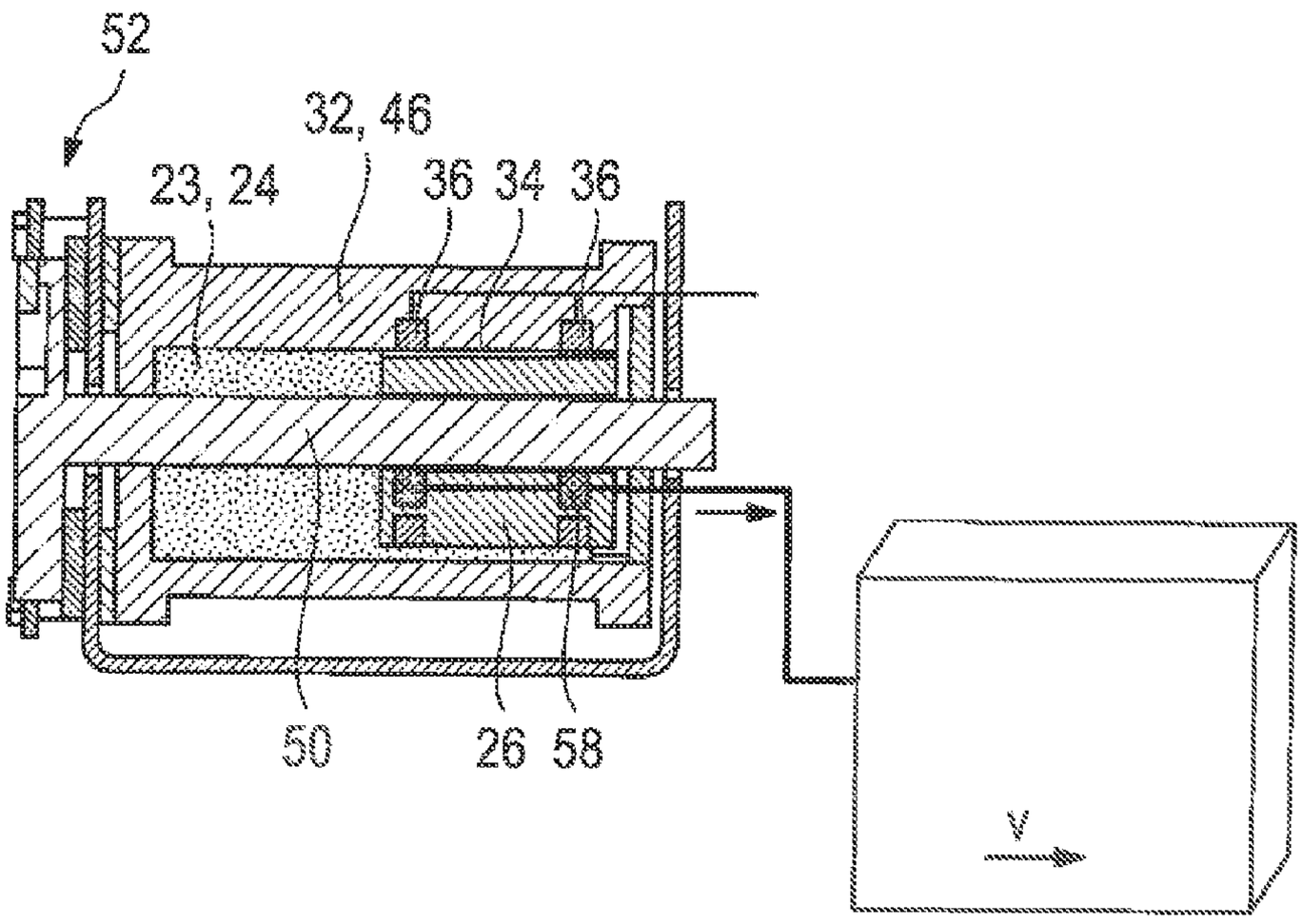


Fig. 12

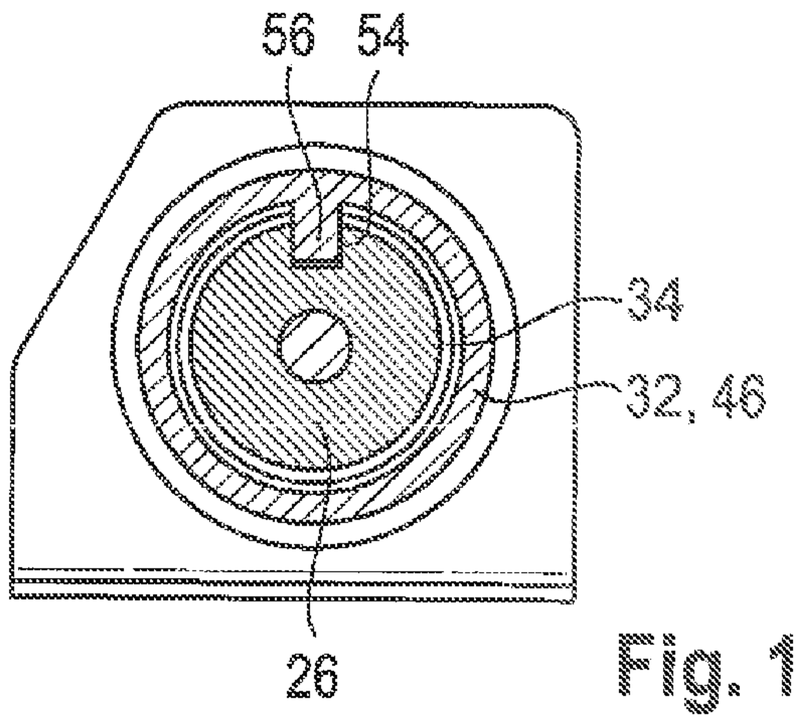


Fig. 13

FORCE LIMITING DEVICE AND METHOD FOR CONTROLLING A FORCE LIMITING DEVICE

RELATED APPLICATIONS

[0001] This application corresponds to PCT/EP2013/003741, filed Dec. 11, 2013, which claims the benefit of German Application Mo. 10 2012 024 270.0, filed Dec. 12, 2012, the subject matter, of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] The invention relates to a load limiting device, especially for a seat belt in a vehicle. The invention moreover relates to a method of controlling such load limiting device.

[0003] Load limiting devices permit limited extension of the belt webbing when the seat belt blocks so as to reduce the load on the vehicle occupant. Such load limiting device includes braking means which regulates the webbing extension via the element to be decelerated. From the state of the art braking means are known comprising a fluid-filled compartment including a conduit through which the fluid is allowed to flow. In or at the fluid-filled compartment a displacing element is arranged which is coupled to the seat belt via an element to be decelerated and upon blocking of the seat belt or release of the load limiting device is moved inside the fluid-filled compartment so that the fluid flows through the conduit.

[0004] By adjusting the fluid quantify flowing through the conduit and, resp., the flow rate in the conduit the resistance counteracting a movement of the displacing element and thus the level of load limitation and, resp., of webbing extension can be adjusted.

[0005] In order to achieve highly exact adaptation of the load limiting device e.g. to the weight of the vehicle occupant or the intensity of deceleration, such bad limiting devices include sensors for detecting vehicle operating data, for example of the acceleration of the vehicle, and for detecting the webbing extension as well as a controller. The controller allows controlling the extension of the webbing as a function of the measured data so that the range available for load limitation is perfectly exploited and the load on the vehicle occupant is minimized. In order to ensure most exact control of the braking device it is required to regulate the flow through the conduit as accurately as possible.

SUMMARY OF THE INVENTION

[0006] It is the object of the invention to provide a load limiting device of the afore-mentioned type including a reliable accurately controllable braking device. It is furthermore the object of the invention to provide a method of controlling such load limiting device.

[0007] In order to achieve the object it is provided in a load limiting device, especially for a seat belt in a vehicle, comprising a controllable braking device having a fluid-filled compartment including a conduit through which the fluid can flow, an element to be decelerated which is coupled to the seat belt, at least one sensor for detecting vehicle operating data, especially an acceleration sensor, a sensor for detecting the webbing extension and a controller for controlling the braking power of the braking device as a function of the vehicle operating data measured and the webbing extension measured that the fluid is a magnetorheological fluid and a control magnet is provided which is capable of generating a variable magnetic field in the conduit and of varying the viscosity of the magnetorheological fluid in the conduit. In the previously known load limiting devious the flow through the conduit is controlled by mechanical measures, for example a variable constriction of cross-section or by a mechanical valve in the conduit For this purpose, movable parts are required in the conduit, however. By using a magnet for varying the viscosity of the fluid in the conduit it is possible to control the flow without additional movable parts having to be arranged in the fluid and, resp., in the conduit. By continuous adaptation of the magnetic field further an exact regulation of the braking device and thus of the load limiting device is possible. Since no movable parts are provided in the conduit, a maintenance-free reliable possibility of controlling the bad limiting device is provided.

[0008] The variable magnetic field can be generated in the conduit in different ways. In a first embodiment, the control magnet is a solenoid adapted to be switched on or off by the controller and to generate a variable magnetic field in the conduit. In this embodiment, the control magnet is fixedly installed and the magnetic field is set by varying the current intensity applied to the solenoid, thus causing the intensity of the magnetic field to be adapted at will.

[0009] The control magnet may also be a movable permanent magnet, however, which can be displaced relative to the conduit. The magnetic field is varied inside the conduit by the distance of the control magnet from the conduit. In this embodiment, the permanent magnet can especially be moved as a function of acceleration, for example by strong deceleration.

[0010] In all embodiments a further permanent magnet can be provided at or in the conduit, the magnetic field thereof extending in the opposite or the same direction relative to the magnetic field of the control magnet. That is to say, the control magnet attenuates the magnetic field generated by the permanent magnet in the conduit or else intensifies the same. For example, in the conduit such strong magnetic field can be generated by the permanent magnet that the viscosity of the magnetorheological fluid in the conduit is so high that it cannot flow or can only flow through the conduit at a high resistance. The resulting magnetic field is attenuated by the opposed control magnet so that the viscosity of the magnetorheological fluid is reduced to such extent that it can flow in the conduit. In the case of power failure, the load limiting device is thus blocked or set to a very high level so that excessive webbing extension is safely prevented in the case of power failure or failure of the control magnet.

[0011] The braking device can include a displacing element, for example, which is coupled to the element to be decelerated and forces the fluid through the conduit in the case of movement of the element to be decelerated.

[0012] This displacing element can be a metal sheet tor example, and the element to be decelerated can be a shaft onto which the metal sheet can be wound. The shaft may be coupled to a belt retractor or a belt reel, for instance. Preferably the metal sheet is arranged so that it reduces the volume in the fluid-filled compartment upon winding onto the shaft so that the fluid is forced through the conduit out of the fluid-filled compartment. Such embodiment is preferably suited for a belt retractor in which the shaft is adapted to be coupled to the belt reel or any other rotating component of the belt retractor.

[0013] In another embodiment the displacing element is a piston and the element to be decelerated is a plunger on which the piston is retained. The displacing element is linearly moved in this embodiment.

[0014] The displacing element can also be moved by the fluid, with the conduit being formed between an inner wall of the fluid-filled compartment and the displacing element, i.e. provided in the fluid-filled compartment.

[0015] Preferably additional sensors for detecting vehicle-specific data are provided so that the control of the braking device can be based on various factors.

[0016] In addition, for achieving the object a method of controlling a load limiting device, especially for a seat belt in a vehicle, is provided comprising a controllable braking device, an element to be decelerated which is coupled to the seat belt, at least one sensor for detecting vehicle operating data, especially an acceleration sensor, and comprising a sensor for detecting the webbing extension. In accordance with the invention, the braking power is set as a function of the vehicle operating data and the webbing extension so that the maximum webbing extension and/or the webbing extension rate is dependent exclusively on the vehicle operating data. That is to say that the braking device is adjusted independently of weight. It is adjusted so that for all vehicle occupants the maximum available range for load limitation can be exploited so that the load on the vehicle occupant can be largely reduced.

[0017] The vehicle operating data are acceleration data, for example. The maximum webbing extension and/or the webbing extension rate are determined as a function of the acceleration data so that they can be adjusted to the respective deceleration of the vehicle.

[0018] Preferably the acceleration must exceed a defined limit for the vehicle acceleration which is especially dependent on the vehicle speed or other vehicle operating data so that in the case of low decelerations the load limiting device is not triggered.

[0019] Further advantages and features are resulting from the following description in combination with the enclosed drawings, in which:

[0020] FIG. **1** shows a first embodiment of a load limiting device according to the invention in the non-activated state,

[0021] FIG. **2** shows the load limiting device from FIG. **1** in the activated state,

[0022] FIG. **3** shows a schematic of the control of the load limiting device according to the invention,

[0023] FIG. **4** shows a second embodiment of a load limiting device according to the invention in the non-activated state,

[0024] FIG. **5** shows the load limiting device from FIG. **4** in the activated state,

[0025] FIG. **6** shows a third embodiment of a load limiting device according to the invention in the non-activated state,

[0026] FIG. **7** shows a sectional view across the load limiting device from FIG. **6**,

[0027] FIG. **8** shows a fourth embodiment of a load limiting device according to the invention in the non-activated state,

[0028] FIG. **9** shows the load limiting device from FIG. **8** in the activated state,

[0029] FIG. **10** shows a fifth embodiment of a load limiting device according to the invention in the non-activated state,

[0030] FIG. **11** shows the load limiting device from FIG. **10** in the activated state,

[0031] FIG. **12** shows a sixth embodiment of a load limiting device according to the invention, and

[0032] FIG. **13** shows a sectional view across the load limiting device fern FIG. **12**.

[0033] In FIGS. **1** and **2** a first embodiment of a load limiting device **10** for a seat belt in a vehicle is illustrated. The load limiting device **10** comprises a casing **12** including a compartment **14** in which a braking device **16** is arranged as well as a first sensor **18** for detecting vehicle operating data, for example the acceleration of the vehicle, and a second sensor **20** adapted to detect a webbing extension. Both sensors are connected to a controller **22**.

[0034] The braking device **16** comprises a compartment **24** filled with a magnetorheological fluid **23** and confined by a displacing element **26** in the form of a metal sheet which is fastened by one retaining end **28** to the casing **12** and by a second end **30** to an element to be decelerated **32** being configured as a shaft in this embodiment. The shaft is coupled to the belt reel or any other component of the seat belt so that regarding FIG. **1** the shaft is rotated anti-clockwise during webbing extension.

[0035] The braking device **16** further includes a conduit **34** provided at the casing **12** and being fluid-communicated with the fluid-filled compartment **24** as well as a collecting vessel **35** which is fluid-communicated with the conduit **34**,

[0036] When the shaft is rotated anti-clockwise during webbing extension, the metal sheet is wound onto the shaft so that the volume of the fluid-filled compartment **24** is reduced. The fluid **23** is forced cut of the compartment **24** through the conduit **34** into the collecting vessel **35** by the reduction of volume. When the flow rate of the fluid **23** through the conduit **34** is reduced so that the fluid **23** cannot flow out of the compartment **24** at the required velocity, tensile stress is exerted on the metal sheet by the pressure increasing in the fluid-filled compartment **24**, This tensile stress counteracts the rotation of the shaft anti-clockwise, causing the webbing extension to be decelerated and, resp., stopped.

[0037] For controlling the flow rate through the conduit a permanent magnet **38** as well as a solenoid **33** being coupled to the controller **22** and constituting a control magnet are provided at the conduit **34**. The permanent magnet **36** permanently generates in the conduit **34** a magnetic field by which the viscosity of the magneto-rheological fluid **23** is increased so that the fluid **23** cannot flow or can flow through the conduit **34** only while overcoming high resistance. Since the magnetorheological fluid **23** cannot flow out of the fluid-filled compartment **24**, the shaft cannot be rotated or can only be rotated against high resistance. Hence the load limiting device **10** is adjusted to a high load limiting level at which only minimum webbing extension is possible.

[0038] The solenoid **38** is arranged in this embodiment so that the magnetic field of the switched-on solenoid **38** is aligned opposed to the magnetic field of the permanent magnet **36**. When the solenoid **38** is switched on, the resulting magnetic field in the conduit **34** acting on the magnetorheological fluid **23** is reduced so that the viscosity of the magnetorheological fluid **23** is reduced and the latter can flow through the conduit **34** at a tower resistance into the collecting vessel **35** (FIG. **2**).

[0039] As a function of the current intensity applied to the solenoid **38** and the magnetic field of the solenoid **38** generated in this way, the resulting magnetic field in the conduit and

thus the viscosity of the fluid **23** in the conduit **34** can be set at will, thus allowing the braking power of the braking device **16** to be freely adjusted.

[0040] A method of controlling said load limiting device **10** is schematically illustrated in FIG. **3**.

[0041] The measured values of the sensor **18** for detecting vehicle operating data, in this case the deceleration values of the vehicle, are transmitted to the controller **22**. Depending on the vehicle speed, a threshold **39** is fixed below which the deceleration values of the vehicle are not taken into account, hence the load limiting device **10** is not adjusted, as in the case of said acceleration values no response of the load limiting device **10** is required. Based on the values of the acceleration above said threshold **39** a difference signal is formed which is transmitted via a differential amplifier to the current output stage driving the solenoid **38** analogously to the deceleration being above the threshold **39** so that the braking device **16** can be set corresponding to the vehicle deceleration.

[0042] The braking device **16** is set in this case only dependent on the vehicle deceleration and not dependent on the weight of the vehicle occupant so that the deceleration values and, resp., the load limiting values are equal for all vehicle occupants. Independently of the vehicle occupant, this permits ideal exploitation of the webbing extension available for load limitation.

[0043] In addition, the webbing extension can be measured by the sensor **20** so that exceeding of the maximum webbing extension ands resp., exceeding of the maximum webbing extension rate can be prevented.

[0044] In this first embodiment, the element to be decelerated **32** is a shaft which may be coupled to a rotating component of the seat belts for example the belt reel. FIGS. **4** and **5** illustrate a second embodiment in which the displacing element **26** is a piston which can be linearly displaced in an elongate fluid-filled compartment **24** and which closes and, resp., seals the fluid-filled compartment **24**. A plunger which constitutes the element to be decelerated **32** and may be coupled to a belt fitting of the seat belt, for example, is mounted on the piston. The other components correspond to the embodiment illustrated in FIGS. **1** and **2**.

[0045] For load limitation the plunger and, resp., the piston is moved in an operating direction B in the fluid-filled compartment **24**. The fluid is forced through the conduit **34** out of the compartment **24**, the viscosity of the magnetorheological fluid **23** being adjusted by the permanent magnet **38** and the solenoid **38** in this embodiment, too.

[0046] In both embodiments the magnetic field of the permanent magnet **38** is attenuated by the control magnet in the form of solenoid **38** so that the magnetorheological fluid **23** has a lower viscosity and can flow through the conduit **34** with lower resistance. This offers the advantage that in the case of power failure or failure of the controller **22** a magnetic field generating high viscosity of the magnetorheological fluid **23** is provided by the permanent magnet **36** so that a high load limiting level is given.

[0047] However, also embodiments exhibiting no permanent magnet are imaginable in which a control magnet generates a permanent magnetic field that is reduced as a function of speed or deceleration. The magnetic field of the control magnet can also be aligned in the same direction as the magnetic field of the permanent magnet **36**.

[0048] A third embodiment of a load limiter **10** according to the invention is illustrated in FIGS. **6** and **7**. In this embodiment the fluid-filled compartment **24** is provided inside a belt reel **44**. The element to be decelerated **32** is constituted by the base member **46** of the belt reel **44** in this case. The displacing element **28** is coupled to a shaft **50** which can be held in a rotationally fixed manner by a blocking means **52**, wherein when the displacing element **26** is rotated relative to the shaft **50** the displacing element **26** is moved in an actuating direction B.

[0049] The displacing element **26** is coupled to the base member **46** of the belt reel **44** via a guide **54**, **56** in a rotationally fixed manner. The diameter of the displacing element **26** is slightly smaller than the diameter of the fluid-filled compartment **24** so that a conduit **34** is formed between the displacing element **26** and the inner wall **60** of the fluid-filled compartment **24**. However, recesses forming conduits **34** may also be formed at the displacing member **26** or at the base member **46**.

[0050] When the belt reel **44** is rotated with a high pull-off force, the displacing element **26** is moved in the actuating direction B through the fluid-filled compartment **24**, wherein the fluid **23** flows through the conduits **34** passing by the displacing element **32**. The solenoid **38** is arranged at the base member **46** of the belt reel **44** in this case so that it generates a magnetic field in the conduits **34** by which the viscosity in the conduits **34** is increased.

[0051] In all three embodiments the viscosity of the magnetorheological fluid **23** is controlled in the conduits via a control magnet in the form of solenoid **38** which is switched on and/or off by a controller **22**, the magnetic field of the solenoid **38** being adapted to be continuously adjusted.

[0052] The viscosity is adjusted exclusively as a function of the vehicle operating data measured so that in defined operating states, for example deceleration of the vehicle, load limitation and thus limited webbing extension takes place, but in the case of specific different operating states, for example in the case of vehicle rollover, no webbing extension takes place, thus allowing the load limitation and the webbing extension to be perfectly adapted to the particular state of the vehicle.

[0053] Deviating from the previously illustrated embodiments, it is also imaginable, however, that the magnetic field is controlled exclusively mechanically, wherein no moving parts are arranged in the conduit **34**,

[0054] Such load limiting device **10** is shown in FIGS. **8** and **9**, for example. The load limiting device **10** substantially corresponds to the load limiting device **10** illustrated in FIGS. **1** and **2**. Deviating herefrom, in this embodiment the control magnet is not a solenoid but a second permanent magnet **58** which is movably supported in a support **82** in the driving direction F. A spring **64** which loads the permanent magnet **58** against the driving direction F is provided at the support **62**. In this position the permanent magnet **58** is adjacent to the conduit **34** so that a strong magnetic field is generated in the conduit and the viscosity of the fluid **23** in the conduit **34** is increased, i.e. a high load limiting level is given.

[0055] If the vehicle experiences strong deceleration, the permanent magnet **58** is moved in the driving direction F, wherein the spring **64** is upset (FIG. **9**). In this way the permanent magnet **58** is moved away from the conduit **34** so that the magnetic field in the conduit **34** is attenuated and the viscosity of the fluid **23** in the conduit **34** is reduced and the fluid **23** can flow out of the compartment **24** with lower resistance, i.e. a lower load limiting level is provided. The

control magnet is supported in said embodiment such that it is only displaced in the case of deceleration in the longitudinal vehicle direction.

[0056] A second embodiment of such mechanical control is illustrated in FIGS. **10** and **11**. The load limiting device **10** substantially corresponds to the load limiting device shown in FIGS. **4** and **5**. Instead of a solenoid **38**, also in this case a permanent magnet **58** movably supported in the driving direction F is provided which is moved away from the conduit **34** in the case of deceleration in the driving direction F.

[0057] In the embodiment illustrated in FIG. **12**, too, the solenoid is replaced with a permanent magnet **58** adapted to be moved away from the conduit **34**.

[0058] However, in these embodiments the permanent magnet **58** may also be supported so that in the case of deceleration it is moved toward the conduit **34**.

1-12. (canceled)

13. A load limiting device (**10**) for a seat belt to protect an occupant in a vehicle, comprising a controllable braking device (**16**) which includes a fluid-filled compartment (**24**) having a conduit (**34**) through which the fluid (**23**) can flow, an element to be decelerated (**32**) which is coupled to the seat belt, at least one sensor (**18**) for detecting vehicle operating data, especially an acceleration sensor, a sensor (**20**) for detecting the webbing extension, and a controller (**22**) for controlling the braking power of the braking device (**16**) as a function of the vehicle operating data measured and the webbing extension measured, wherein the fluid (**23**) is a magnetorheological fluid and a control magnet is provided which is adapted to generate a variable magnetic field inside the conduit (**34**) and to vary the viscosity of the magnetorheological fluid inside the conduit (**34**), and wherein the controller (**22**) adjusts the braking power independently of the weight of the occupant.

14. The load limiting device according to claim **13**, wherein the control magnet is a solenoid (**38**) adapted to be switched on or off by the controller (**22**) and adapted to generate a variable magnetic field inside the conduit (**34**).

15. The load limiting device according to claim **13**, wherein the control magnet is a movable permanent magnet (**58**) which can be displaced, especially as a function of acceleration, relative to the conduit (**34**).

16. The load limiting device according to claim **13**, wherein at or in the conduit (**34**) a permanent magnet (**58**) is provided the magnetic field of which extends in the opposite direction or in the same direction relative to the magnetic field of the control magnet.

17. The load limiting device according to claim **13**, wherein the braking device (**16**) includes a displacing element (**26**) coupled to the element to be decelerated (**32**) and forcing the fluid (**23**) out of the fluid-filled compartment (**24**) during movement of the element to be decelerated (**32**).

18. The load limiting device according to claim **17**, wherein the displacing element (**26**) is a metal sheet and the element to be decelerated is a shaft onto which the metal sheet can be wound.

19. The load limiting device according to claim **17**, wherein the displacing element (**28**) is a piston and the element to be decelerated is a plunger at which the piston is retained.

20. The load limiting device according to claim **13**, wherein a displacing element (**26**) is provided which is moved by the fluid (**23**), the conduit (**34**) being formed between an inner wall (**60**) of the fluid-filled compartment (**24**) and the displacing element (**28**).

21. The load limiting device according to claim **13**, wherein additional sensors for detecting vehicle-specific data are provided.

22. A method of controlling a load limiting device (**10**) for a seat belt to protect an occupant in a vehicle, comprising a controllable braking device (**16**), an element to be decelerated which is coupled to the seat belt, at least one sensor (**18**) for detecting vehicle operating data, especially an acceleration sensor, and comprising a sensor (**20**) for detecting the webbing extension, wherein the braking power is set as a function of the vehicle operating data and the webbing extension so that the maximum webbing extension and/or the webbing extension rate is/are dependent exclusively on the vehicle operating data and independently of the weight of the occupant.

23. The method according to claim **22**, wherein the vehicle operating data are acceleration data and the maximum webbing extension and/or the webbing extension rate are determined as a function of the acceleration data.

24. The method according to claim **23**, wherein the acceleration has to exceed a defined limit for the vehicle acceleration which is especially dependent on the vehicle speed or any other vehicle operating data.

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