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(54) Benævnelse: **PIEZOHYDRAULISK AKTUATOR**

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Description

The invention relates to a piezo-hydraulic actuator as well as a method for operating it.

In the case of actuators in particular four properties play a role, namely force, deflection, speed, and constructed space. In the case of many actuator applications there exist different working points, in which either a high force or a high speed is required. In the case of an actuator for the ejection of tools in the case of a machine tool the requirement is that the actuator travels the deflection at great speed until contact is made with the tool, wherein no particularly large forces are required. As soon as the actuator is in contact with the tool, the requirement is exactly reversed. Great forces are required to be able to eject the tool. However, no great speed is required, since the actuator deflection necessary for this purpose is very small. Thus, two required modes result for the actuator. A speed mode and a force mode. Such concept with these two modes is increasingly employed equally in robotics. An example of this is for instance known from patent application JP2000314402.

Commonly, a two-step gear drive is used, which offers the possibility of shifting between the two modes, namely the speed and the force mode. Disadvantageous in this connection are the torque/force jumps during shifting, in particular under load. [1] discloses a linear actuator, which counteracts the problem with the aid of a gear drive and an additional motor. ([1] A. Girard and H. Asada – A Two-Speed Actuator for Robotics with Fast Seamless Gear Shifting, 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)). Disadvantageously the complexity and the power density of such system still require major optimization.

Alternatively, commonly different actuator principles, such as for instance wire drives are offered, which are employable for the realization of two different modes. For instance twisted wires amongst other features have a non-linear transmission ratio so that twisted wires may equally be employed by an additional twisting for higher forces from the same motor unit. The advantage of such solution are smaller losses. However, the two modes are coupled to one another via a hysteresis-afflicted.

relaxation process. To counteract this effect researchers have developed a clutch mechanism with an additional motor unit. (see [2]: Y.J. Shin, H.J. Lee, K.-S. Kim, S. Kim, - "Dual-Mode Twisting Actuation Mechanism with an Active Clutch for Active Mode-Change and Simple Relaxation Process", 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)). Such system equally increases the complexity of the overall system. Control of twisted wires and the involved non-linearities continue to be a research subject.

It is the object of the invention to provide a piezo-hydraulic actuator in such a way that same in a first mode is optimized with regard to the force and in a second mode with regard to the speed of the deflection of the actuator, wherein in the first mode the force is to be as large as possible and in the second mode the speed is to be as large as possible. Moreover, an uninterrupted shifting between the two modes should be performable. Besides, an automatic shifting should be performable. The actuator should be employable in harsh or strenuous environments.

The object is achieved by a piezo-hydraulic actuator according to the main claim and by a method for operating a piezo-hydraulic actuator according to the further independent claim.

According to a first aspect a piezo-hydraulic actuator is proposed, which is configured as a system comprising four chambers, wherein a first chamber is a drive bellow filled with a hydraulic fluid and movable by a piezo actuator, the drive bellow being hydraulically connected via a first back pressure valve with a second chamber configured as a hydraulic cylinder filled with the hydraulic fluid as first output, the housing of which and the hydraulic piston of which are mechanically coupled in parallel to an output bellow filled with the hydraulic fluid and forming a third chamber as second output, wherein the output bellow is hydraulically connected via a second back pressure valve with a fourth chamber filled with the hydraulic fluid as reservoir, wherein same is hydraulically connected via a third back pressure valve with the output bellow and the hydraulic cylinder via a fourth back pressure valve with the output bellow.

Drive bellow is here in particular a reservoir, which is elastic, in particular in the direction of movement, containing a fluid and configured in such a way that force can be applied upon it.

Output bellow is herein particular a reservoir, which is elastic, in particular in the direction of movement, containing a fluid and configured in such a way that force can be output from it.

According to a second aspect a method for operating a piezo-hydraulic actuator is suggested, which is configured as a system comprising four chambers, wherein a first chamber is a drive bellow movable by a piezo actuator and filled with a hydraulic fluid, the drive bellow being hydraulically connected via a first back pressure valve with a second chamber configured as a hydraulic cylinder filled with the hydraulic fluid as first output, the housing of which and the hydraulic piston of which are mechanically coupled in parallel to an output bellow filled with the hydraulic fluid and forming a third chamber as second output, wherein the drive bellow is hydraulically connected via a second back pressure valve with a fourth chamber filled with the hydraulic fluid as reservoir, wherein same is hydraulically connected via a third back pressure valve with the output bellow and same via a fourth back pressure valve with the hydraulic cylinder, wherein a compressing and pressing of the hydraulic fluid, performed by the expanding of the piezo actuator, against the first back pressure valve, which at a set pressure opens and the hydraulic fluid flows into the hydraulic cylinder and a transmission ratio or reduction ratio of the piezo stroke is performed, wherein by a retracting of the piezo actuator a negative pressure in the drive bellow is produced in such a way that the second back pressure valve opens and hydraulic fluid flows from the reservoir into the drive bellow and thus a repeatable cycle of a pumping is completed.

A piezo-hydraulic actuator according to the invention has the advantage that by same it can be deflected both in a force-optimized and in a speed-optimized way. The advantage over comparable conventional solutions working with gear speeds is that the described system can automatically change between speed mode and force mode. In particular it is possible to shift between the two modes without interruption. Moreover, in the case of using metallic encapsulations this drive due to metal

bellows is suitable for a harsh environment for instance in the case of strong vibrations or heavy contaminations.

Further advantageous embodiments are claimed in connection with the subclaims.

According to an advantageous embodiment the hydraulic cross-section of the hydraulic piston may be smaller than the hydraulic cross-section of the third chamber configured as output bellow and smaller than the hydraulic cross-section of the first chamber configured as drive bellow.

The hydraulic cross-section of a component is here in particular the surface provided by the component, upon which a force necessary for building up a pressure acts perpendicularly and which is oriented perpendicular to a direction of movement.

According to a further advantageous embodiment the fourth back pressure valve may be configured in such a way that it opens upon an increase of pressure in the first output as a consequence of an outer counterforce in such a way that hydraulic fluid is pumped additionally to the second output.

According to a further advantageous embodiment the third back pressure valve may have a leakage for the drifting back of hydraulic fluid from the output bellow to the reservoir.

According to a further advantageous embodiment in parallel to the third back pressure valve a throttle for the drifting back of hydraulic fluid from the output bellow to the reservoir may be hydraulically connected.

According to a further advantageous embodiment the mechanical output may be provided by a surface of the hydraulic piston.

According to a further advantageous embodiment the mechanical output may be provided by a surface of the third chamber configured as output bellow, wherein the hydraulic piston may be connected with the surface of the output bellow, in particular in a form-fitted or force-fitted way.

According to a further advantageous embodiment the hydraulic cylinder and at least partly the hydraulic piston may be positioned within the third chamber configured as output bellow.

According to a further advantageous embodiment the piezo actuator may be electrically controlled by pulse width modulation of a control voltage.

According to a further advantageous embodiment the third back pressure valve may open, if as a consequence of the pumping of the hydraulic fluid into the hydraulic cylinder a negative pressure in the output bellow is produced, and hydraulic fluid flows from the reservoir into the output bellow.

According to a further advantageous embodiment in case the first output drives against an adjustable counterforce, in particular an obstacle, and the pressure in the hydraulic cylinder increases, the fourth back pressure valve may open and hydraulic fluid may flow from the drive bellow additionally into the output bellow.

According to a further advantageous embodiment upon a retracting of the first output and the second output by the third back pressure valve hydraulic fluid may flow back into the reservoir bellow.

The invention is described in more detail based on embodiments in connection with the figures. These show in:

Fig. 1 a first embodiment of a piezo-hydraulic actuator according to the invention;

Fig. 2 a second embodiment of a piezo-hydraulic actuator according to the invention;

Fig. 3 a third embodiment of a piezo-hydraulic actuator according to the invention;

Fig. 4 an embodiment of a method according to the invention.

Fig. 1 shows a first embodiment of a piezo-hydraulic actuator 1 according to the invention. Figure 1 shows the concept according to the invention. As drive element a piezo actuator 5 is used, which is coupled with a hydraulic system. The hydraulic system comprises four chambers, namely a drive 3, a reservoir 15, an output 1 (A1), and an output 2 (A2). Output 1 (A1) in this case is configured as hydraulic cylinder 9 and both at its housing as well as at a hydraulic piston 11 mechanically firmly connected to the output 2 (A2), which is connected in parallel. Output 1 (A1) has a smaller hydraulic cross-sectional area than output 2 (A2) and, if applicable, than drive 3. For controlling the actuator 1 a voltage in the form of pulse width modulation (PWM) is applied. Due to the increase in voltage of the PWM signal the piezo actuator 5 expands, whereby the fluid 7 in the drive 3 is compressed and the pressure due to the quasi incompressibility increases. Thereby the back pressure valve RV1 opens so that oil as embodiment of the hydraulic fluid 7 flows from the drive 3 into the output A1, this means into the hydraulic cylinder 9. With smaller cross-section of output A1 in comparison with drive 3 a transmission of the piezo stroke is performed. Next, the PWM voltage at piezo actuator 5 is set to zero again, whereby the pressure in the drive 3 decreases and due to the reduction of the volume of the fluid 7 a negative pressure results (therein previously a part of the fluid 7 present in the drive 3 has been pumped into the output A1). As a consequence of the negative pressure the back pressure valve RV2 opens and fluid 7 is sucked from the reservoir 15 into the drive 3. Thereafter the PWM voltage may be increased again and the previously described cycle may be repeated. By the repetition oil as embodiment of the hydraulic fluid 7 is pumped step by step from the reservoir 15 via the drive 3 into the output A1. As a consequence of the deflection of the hydraulic piston 11, i.e. the output A1, equally the output A2 is deflected, since the two are mechanically coupled to one another. Reference sign 12 refers to an attachment point, at which an output bellow 13 is mechanically connected with the hydraulic piston 11. Since in the output A2 no hydraulic fluid 7 is actively pumped, negative pressure would develop, since the amount of fluid despite increasing volume of the second output A2 remains constant. Thereby a counterforce would develop at the output A1, whereby the deflection of the output A1 would be blocked. For this reason a hydraulic connection between output A2 and reservoir 15 is provided, which

comprises the back pressure valve RV3. This back pressure valve RV3 opens if as a consequence of the pumping of the hydraulic fluid 7 into the output A1 a negative pressure in the second output A2 is produced. Thereby in a passive way it is ensured that the second output A2 merely has a minor influence on the expansion of the first output A1.

As soon as the first output A1 is moved or drives against a counterforce, for instance due to an obstacle, for the actuator 1 for operation it is required that a lot of force is built up. However, with the first output A1 this is possible only to a limited extent, since the hydraulic cross-sectional area has been selected too small to provide a large speed transmission ratio. The smaller the hydraulic surface area of the first output A1, the smaller is the output force at a maximum pressure in the first output A1. For this reason between the first output A1 and the second output A2 a back pressure valve RV4 is installed. If the pressure in the first output A1 increases due to a counterforce, the back pressure valve RV4 opens, whereby the hydraulic fluid 7 in addition to the first output A1 is equally pumped into the second output A2. Since in the case of the second output A2 the hydraulic cross section is clearly larger, in comparison to the first output A1 at the same pressure the output force provided by the second output A2 increases.

The retracting of the first and the second output A1 and A2 according to this concept is effected by an inbuilt leakage. According to Figure 1 the third back pressure valve RV3 may be provided with a simple leakage in such a way that the hydraulic fluid 7 slowly drifts back from the second output A2 to the reservoir 15.

Figure 2 shows a second embodiment of a piezo-hydraulic actuator 1 according to the invention. Therein this second embodiment comprises largely the same elements as the first embodiment according to Figure 1. Alternatively, according to Figure 2 in parallel to the back pressure valve RV3 additionally a throttle 17 is installed. The throttle 17 may alternatively or cumulatively provide a slow drifting back of the hydraulic fluid 7 from the second output A2 to the reservoir 15. Figure 2 shows a surface 19 of the hydraulic piston 11 of the hydraulic cylinder 9, wherein by means of this surface 19 a force transmission of the actuator 1 according to the invention is performed.

Figure 3 shows a third embodiment of a piezo-hydraulic actuator 1 according to the invention. Therein the third embodiment comprises largely the same system elements as the first embodiment according to Figure 1. Accordingly, Figure 3, as well as Figure 2, is equipped with the same reference signs as compared to Figure 1. According to the embodiment according to Figure 3 the mechanical output in contrast to Figure 2 is not effected via the surface 19, but rather via the surface 21, which is configured via the output bellow 13 of the second output A2. Therein the hydraulic piston 11 in the second output A2 may be mechanically connected at the attachment point of the output bellow 13 with the hollow cylinder piston 11, either in a form-fitted or in a force-fitted way.

Figure 4 shows an embodiment of a method according to the invention. The method relates to the operation of the piezo-hydraulic actuator 1 for instance according to the embodiments described in the above. By a first step S1 an expanding of the piezo actuator and a compressing and pressing of the hydraulic fluid against the first back pressure valve is performed, which opens at a set pressure and allows the hydraulic fluid to flow into the hydraulic cylinder and therein a transmission ratio or reduction ratio of the piezo stroke is performed. By a second step S2 a contracting of the piezo actuator is performed, wherein a negative pressure in the drive bellow is produced in such a way that the second back pressure valve opens and hydraulic fluid flows from the reservoir into the drive bellow and in this way a cycle of a pumping is completed. Steps S1 and S2 may be cyclically repeatedly performed.

Patentkrav

1. Piezohydraulisk aktuator (1), der er udformet som et system med fire kamre, hvor et første kammer er en drivbælg (3), der kan bevæges af en piezoaktuator (5) og er fyldt med en hydraulikvæske (7), og som via en første kontraventil (RV1) er hydraulisk forbundet med et andet kammer, der er udformet som en hydraulikcylinder (9), der er fyldt med hydraulikvæsken (7), som første udgang (A1), hvis hus og hydraulikstempel (11) mekanisk er parallelkoblet til en udgangsbælg (13), der er fyldt med hydraulikvæsken (7) og udgør et tredje kammer, som anden udgang (A2), hvor drivbælgen via en anden kontraventil (RV2) er hydraulisk forbundet med et fjerde kammer, der er fyldt med hydraulikvæsken (7), som reservoir (15), hvor dette via en tredje kontraventil (RV3) er hydraulisk forbundet med udgangsbælgen (13), og hydraulikcylinderen (9) via en fjerde kontraventil (RV4) er hydraulisk forbundet med udgangsbælgen (13).

2. Piezohydraulisk aktuator (1) ifølge krav 1,
kendetegnet ved, at
hydraulikstemplets (11) hydrauliske tværsnit er mindre end det hydrauliske tværsnit af det tredje kammer, der er tilvejebragt som udgangsbælg (13), og især mindre end det hydrauliske tværsnit af det første kammer, der er tilvejebragt som drivbælg (3).

3. Piezohydraulisk aktuator ifølge krav 1 eller 2,
kendetegnet ved, at
den fjerde kontraventil (RV4) er indrettet på en sådan måde, at den ved en trykstigning i den første udgang (A1) som følge af en ydre modkraft åbner på en sådan måde, at hydraulikvæske (7) pumpes foruden den anden udgang (A2).

4. Piezohydraulisk aktuator ifølge krav 1, 2 eller 3,
kendetegnet ved, at

den tredje kontraventil (RV3) har en lækage til tilbagestrømning af hydraulikvæske (7) fra udgangsbælgen (13) til reservoiret (15).

5. Piezohydraulisk aktuator ifølge et af de foregående krav,
kendetegnet ved, at
der parallelt med den tredje kontraventil (RV3) hydraulisk er tilsluttet en drossel (17) til tilbagestrømning af hydraulikvæske (7) fra udgangsbælgen (13) til reservoiret (15).

6. Piezohydraulisk aktuator ifølge et af de foregående krav,
kendetegnet ved, at
den mekaniske udgang tilvejebringes ved hjælp af en flade (19) af hydraulikstemplet (11).

7. Piezohydraulisk aktuator ifølge et af de foregående krav,
kendetegnet ved, at
den mekaniske udgang tilvejebringes ved hjælp af en flade (21) af det tredje kammer, der er tilvejebragt som udgangsbælg, hvor hydraulikstemplet er forbundet, især form- eller kraftsluttende, med udgangsbælgens flade.

8. Piezohydraulisk aktuator ifølge et af de foregående krav,
kendetegnet ved, at
hydraulikcylinderen og i det mindste delvist hydraulikstemplet er positioneret i det tredje kammer, der er tilvejebragt som udgangsbælg.

9. Piezohydraulisk aktuator ifølge et af de foregående krav,
kendetegnet ved, at
piezoaktuatoren styres elektrisk ved hjælp af pulsbreddemodulation af en styrespænding.

10. Fremgangsmåde til drift af en piezohydraulisk aktuator, der er udformet som et system med fire kamre, hvor et første kammer er en drivbælg, der kan bevæges af en piezoaktuator og er fyldt med en hydraulikvæske, og som via en første kontraventil (RV1) er hydraulisk forbundet med et andet kammer, der

er udformet som en hydraulikcylinder, der er fyldt med hydraulikvæsken, som første udgang (A1), hvis hus og hydraulikstempel mekanisk er parallelkoblet til en udgangsbælg, der er fyldt med hydraulikvæsken og udgør et tredje kammer, som anden udgang (A2), hvor drivbælgen via en anden kontraventil (RV2) er hydraulisk forbundet med et fjerde kammer, der er fyldt med hydraulikvæsken, som reservoirbælg, hvor denne via en tredje kontraventil (RV3) er hydraulisk forbundet med udgangsbælgen, og denne via en fjerde kontraventil (RV4) er hydraulisk forbundet med hydraulikcylinderen, hvor

komprimering og presning af hydraulikvæsken, der udføres ved hjælp af udvidelse (S1) af piezoaktuatoren, mod den første kontraventil (RV1), der åbner ved et indstillet tryk, og hydraulikvæsken strømmer ind i hydraulikcylinderen, og der udføres en transmission eller reduktion af piezoslaget, hvor der ved hjælp af en sammentrækning (S2) af piezoaktuatoren genereres et undertryk i drivbælgen på en sådan måde, at den anden kontraventil (RV2) åbner og hydraulikvæske strømmer fra reservoiret til drivbælgen, og en gentagelig pumpningscyklus dermed er afsluttet.

11. Fremgangsmåde ifølge krav 10,
kendetegnet ved, at
den tredje kontraventil (RV3) åbner, når der genereres et undertryk i udgangsbælgen som følge af pumpning af hydraulikvæsken til hydraulikcylinderen, og hydraulikvæsken strømmer fra reservoirbælgen til udgangsbælgen.

12. Fremgangsmåde ifølge krav 10 eller 11,
kendetegnet ved, at
hvis den første udgang (A1) kører mod en indstillelig modkraft, især en forhindring, og trykket stiger i hydraulikcylinderen, så åbner den fjerde kontraventil (RV4) sig, og hydraulikvæsken strømmer yderligere fra drivbælgen til udgangsbælgen.

13. Fremgangsmåde ifølge krav 10, 11 eller 12,
kendetegnet ved, at
hydraulikvæske ved tilbagetrækning af den første udgang (A1) og den anden

udgang (A2) ved hjælp af den tredje kontraventil (RV3) strømmer ind i reservoirbælgen.

FIG 1

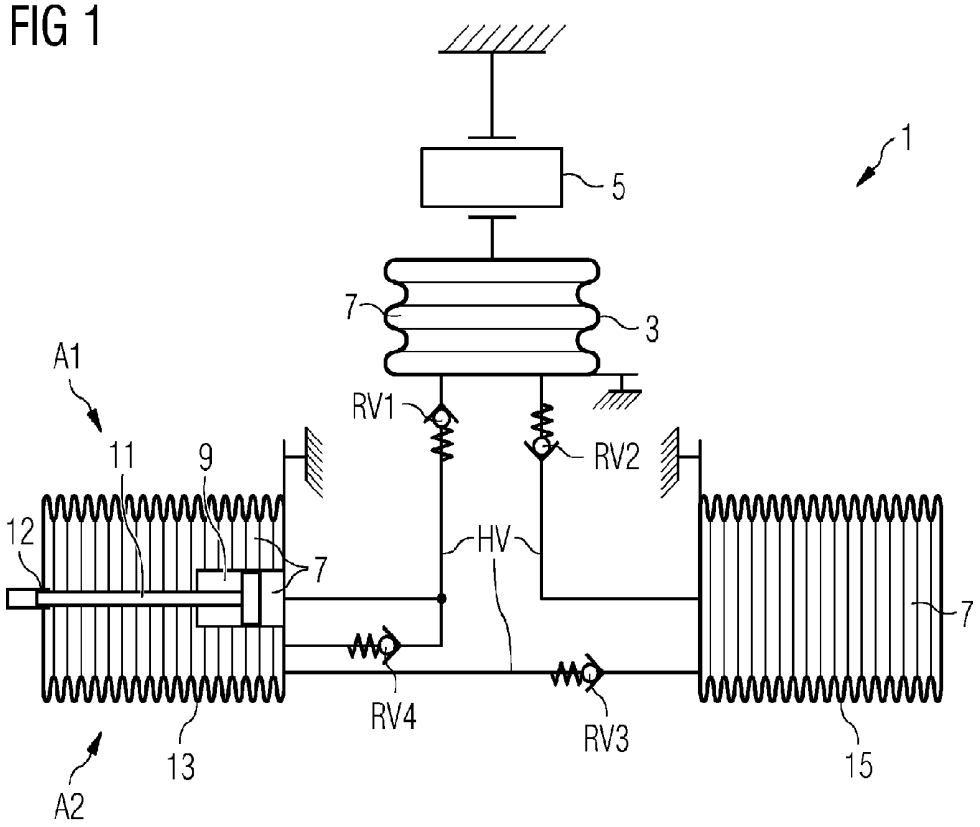
1
5
7
3
A1
RV1
RV2
11
9
12
7
HV
7
RV4
RV3
13
15
A2

FIG 2

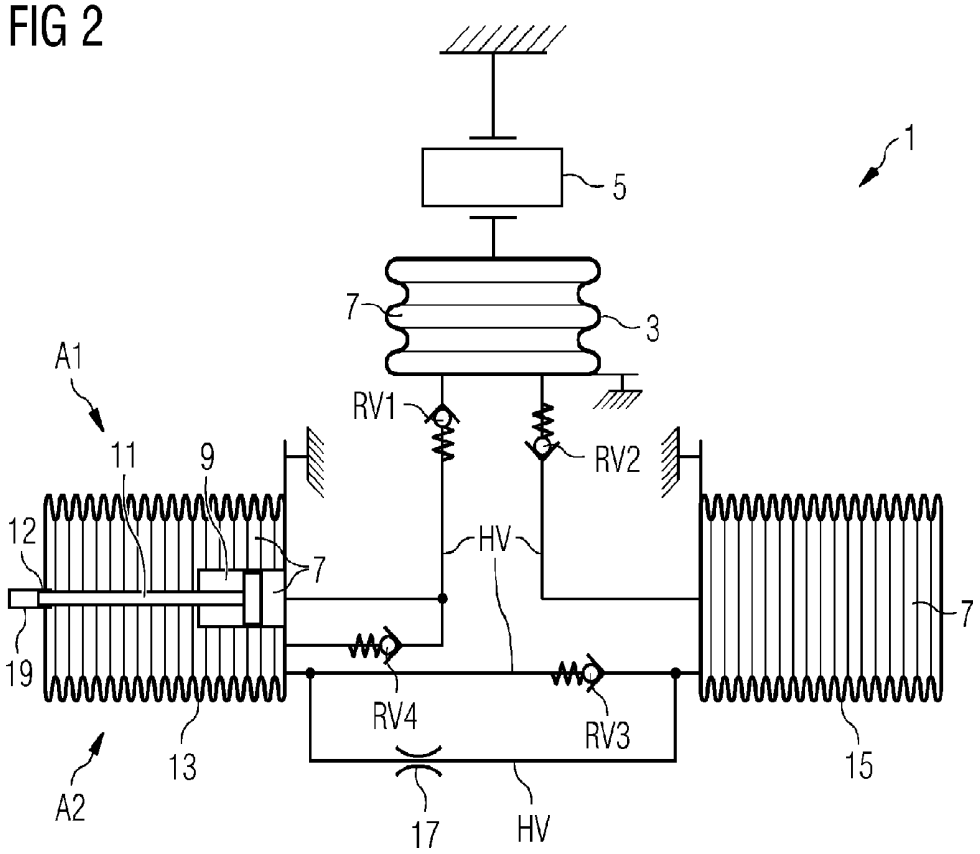
1
5
7
3
A1
RV1
RV2
11
9
12
7
HV
7
19
RV4
RV3
13
15
A2
17
HV

FIG 3

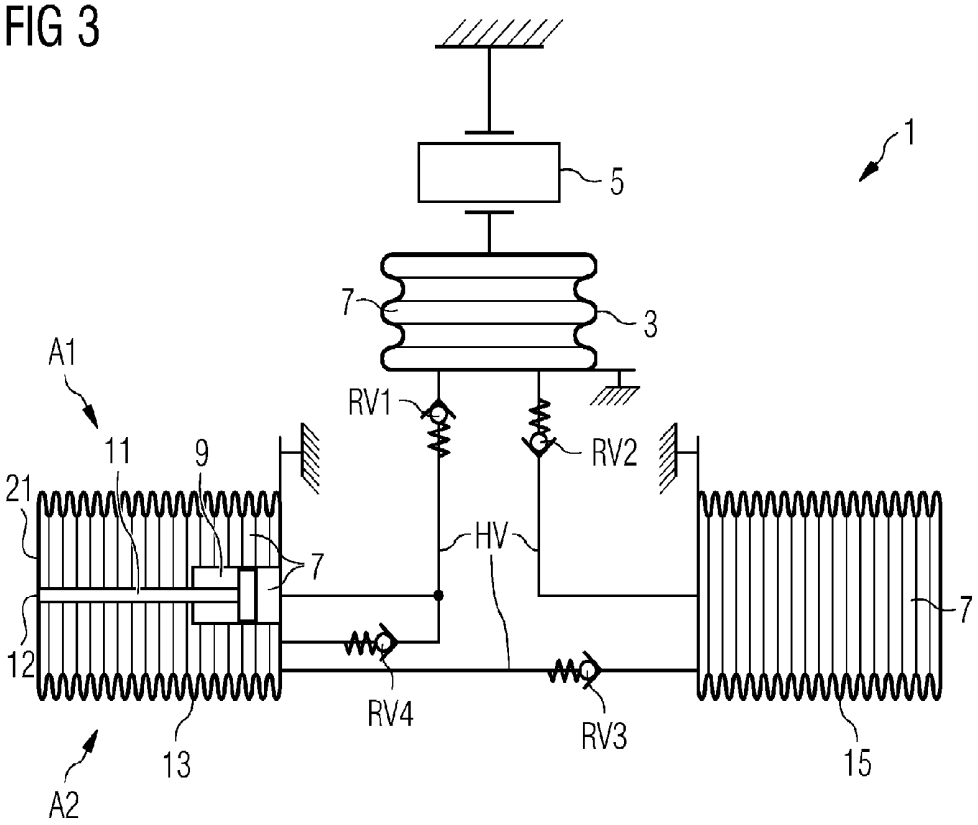

FIG 4