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(54) **COMPACT LINEAR SOLENOID WITH IMPROVED GEOMETRY OF MAGNETICALLY ACTIVE SURFACES**

(57) The object of the invention is a compact linear solenoid with the improved geometry of magnetically active surfaces. The geometry of the magnetically active surfaces is improved with the innovative shape of the plunger and/or base. Compared to a conventional solenoid of a conical type, the improved geometry of the invention provides for an increase in the performance of the solenoid in terms of higher actuating force, higher holding force, constancy or linearity of the course of the

force or adjustment of the course of the force to a specific application at a limited consumption of electric power and limited dimensions of the solenoid. Furthermore, the geometry enables a stop of the movable assembly in the end position without a risk of latching. The solution further represents improvement in terms of resistance to vibrations, simplicity of production, robustness and deterministic operation, life span and possibility of series production.

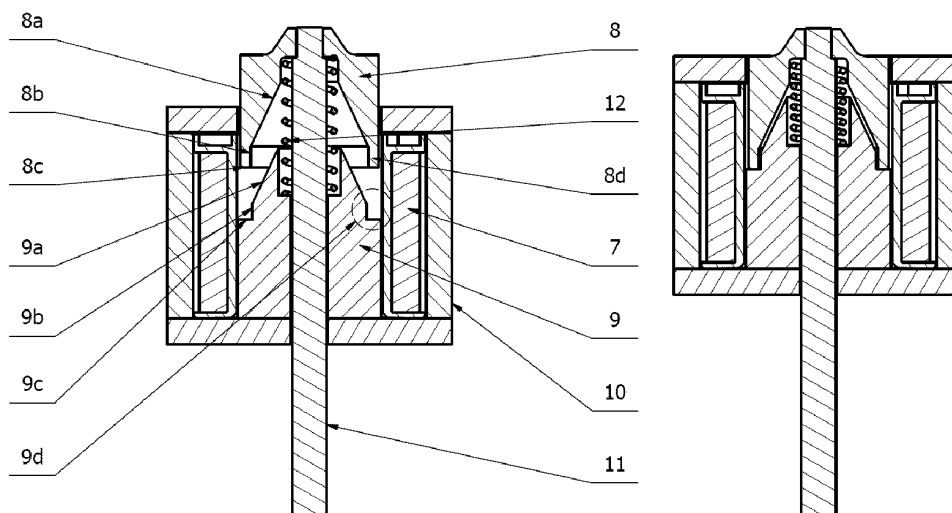


Figure 2

Description

FIELD OF INVENTION

[0001] The object of the invention is a compact push/pull linear solenoid with the improved geometry of magnetically active surfaces. The object of the invention belongs to the field of constructional and electromagnetic solutions to electromagnets, class H01F7/16 of the International Patent Classification.

[0002] The notion magnetically active surface represents any surface of a ferromagnetic element of a solenoid, via which magnetic field lines run during operation and on which magnetic force is exerted. The notion geometry of magnetically active surfaces represents a conical shape of a movable assembly - a plunger and the corresponding conical immovable base - which additionally serves as a stop of a plunger stroke. Said conical shapes allow for two modes of operation: an actuating and a holding mode. The actuating mode starts with switching on the electric current in a coil that creates a magnetic field in the axial direction of the solenoid and consequently creates a magnetic force to the plunger. The created magnetic force moves the movable plunger from the initial position to the end position defined by the immovable base. In other words, the magnetic force acts on the plunger in axial direction, such that the plunger and the base create a mutual contact on their conical surfaces, thus closing the magnetic circle. The second mode is a holding mode, in which the magnetic force holds the plunger in the end position of its linear stroke. When the power supply is interrupted, regardless of the operation mode of the solenoid, an integrated spring returns the plunger back to its initial position. By selecting the geometry of the plunger and of the immovable base, the actuating force (beginning of a stroke), the holding force (end of a stroke) and the entire course of the magnetic force along the plunger stroke can be influenced. This means that the entire functional characteristic of the solenoid is adjustable and can be carried out to reach as high actuating force as possible, as high holding force as possible, constancy or linearity of the course of the force or adjustment of the course of the force to a specific application at a limited consumption of electric power and limited dimensions of the solenoid. An important aspect of the solenoid is also a low mass of the plunger with respect to the created magnetic force. The lower the ratio between them, the better resistance to vibrations a solenoid can reach. A low plunger mass at a selected pretension of the spring allows for an undisturbed operation under the influence of vibrations from the environment. For the reasons indicated above, the solenoids of this type having adjustable characteristics are suitable for applications in automotive and other industries where higher forces at smaller dimensions are required. An example of use is a switch-like shift of mechanical levers in an automatic gearbox. Concepts of computer-aided design in combination with advanced methods of numerical

analysis are used, such as electromagnetic and mechanical simulations by using the finite element method.

DESCRIPTION OF THE TECHNICAL PROBLEM

[0003] The technical problem solved by the invention consists of several segments. The improved geometry of conical components allows for improvements in the field of linear solenoids, particularly from the aspect of performance at a prescribed size, vibrational resistance and simplicity of production. It further has impact on other properties of solenoids, such as robust and deterministic operation, long lifetime, fitness for series production, material adaptability, a smaller quantity of a wire in a coil, smaller dimensions of the solenoid, high speed of actuation, high integrability, adjustability of a functional characteristic and application in a variety of conditions, such as: environment with high and low temperatures (-40 °C to +125 °C), corrosive environment, environment with oil mist for automatic gear boxes, etc.

PRIOR ART

[0004] There are many available solutions in the field of linear solenoids that use conical surfaces to reach desired characteristics, which are similar to the present invention in terms of the basic principle of operation. The most basic variant of a solenoid with conical surfaces is disclosed in patent US3735302, where a plunger is formed of an inner tapered cone and its base is formed of a compatible outer tapered cone. A drawback of such a variant is particularly a relatively low actuating force, an extremely low holding force and incapability of mechanical contact of magnetically active surfaces (risk of latching), this is why an element for a mechanical limitation of the stroke is needed. In patent US3505628, an increase in the holding force and a possibility of mechanical contact of magnetically active surfaces are carried out by an application of an additional circular or annular surface. On the other hand, such a variant has a rather negative impact on the actuating force. The improvement in the actuating force and in the constancy of the force line along the stroke is possible by using the solution from patent US3381250, where the plunger and the base use a combination of a conical and a cylindrical shape. Unfortunately, such a solution does not contribute to the increase in the holding force. A solenoid from patent US6076550 can be indicated as a derivate of the presented solutions. Here, the magnetically active surfaces of the plunger and the base do not fit along all faces. The conical surfaces of the plunger and the base are not limited to the same conical angle; moreover, the plunger uses two annular faces and a cylindrical surface, while the base uses additional two annular faces. This solution is an improvement of a simple solenoid with conical faces particularly due to the fact that it allows a mechanical contact of the magnetically active surfaces, an increase in the holding force and linearity of the course of the force

along the stroke, while an increase in the actuating force is not worth mentioning. In fact, a use of annular faces reduces the actuating force, while an additional cylindrical surface improves the created situation by 8% at the most, according to the author. The improvement in the actuating force of a solenoid with one conical surface on a plunger and a base, respectively, is possible with an introduction of an additional conical face of a reversed orientation - patent US3805204, yet the improvement value does not exceed 8%. This type of the geometry of the magnetically active surfaces is very demanding for manufacturing. An additional problem shared by all presented solutions is a low ratio between the created actuating force and the mass of the plunger, which results in sensitivity to the vibrations from the environment. The solution disclosed in patent US20090128271A1 uses two, three or more conical magnetically active surfaces for the plunger and the base, and an additional cylindrical plate on the plunger (similar to the low-profile solenoids). The presented concept allows the mechanical contact of the magnetically active surfaces and is universal to such an extent to allow adjustments in order to reach high actuating force, high holding force, and adjustment of the course of the force along the stroke. A limitation of this solution lies in a combination of inner and outer conical faces that are very demanding for production and a low ratio between the actuating force and the plunger mass. The additional cylindrical plate on the plunger considerably contributes to the mass of the plunger, while it does not contribute to the actuating force of the solenoid. Solutions are also known in the field of proportional solenoids. They enable an optional adjustment of the course of magnetic force along the stroke (example in EP1887677A1); however, such variants do not allow reaching high holding forces because of the radial orientation of the magnetic flux through an air gap.

[0005] As a reference in the presentation of the invention, a simple solenoid with conical surfaces - Figure 1 is used. It comprises a coil 1, a plunger 2, a base 3, a housing 4, a plunger rod 5 and a return spring 6. Magnetically active surfaces between the plunger and the base are an inner conical surface 2a of the plunger and an outer conical surface 3a of the base. A typical course of the magnetic force of such a solenoid as a function of the stroke is shown in Figure 6.

DESCRIPTION OF THE NEW SOLUTION

[0006] Hereinafter, a compact linear solenoid with the improved geometry of magnetically active surfaces is described as the object of the invention and shown in figures, in which:

Figure 1 shows a reference solenoid in the initial and end positions

Figure 2 shows an embodiment of the solenoid with a plunger sleeve in the initial and end positions

Figure 3 shows an embodiment of the solenoid with

a chamfer of the plunger in the initial and end positions

Figure 4 shows an embodiment of the solenoid with two cones of a base in the initial and end positions

Figure 5 shows a universal solenoid in the initial and end positions

Figure 6 shows magnetic force as a function of the stroke for the indicated embodiments of the solenoid

[0007] The first embodiment of the solenoid with the improved magnetically active surfaces is an upgrade of the solenoid presented in Figure 1. It is shown in Figure 2. It comprises a coil 7, a plunger 8, a base 9, a housing 10, optionally a plunger rod 11 and optionally a return spring 12. The plunger 8 is provided in its end part with an additional sleeve 8d of the plunger 8, such that additional magnetically active surfaces of the plunger 8 are formed, precisely an inner cylindrical surface 8b and a ring 8c. The height of the sleeve 8d of the plunger 8 represents 5% to 35% of the total height of the plunger 8; the height of the sleeve 8d of the plunger 8 preferably represents 15% to 25% of the total height of the plunger. In the embodiment, the height of the sleeve 8d of the plunger 8 represents 18% of the total height of the plunger. The base 9 is provided with an adequately adapted counter surface; the base 9 is provided in its end part with a cylindrical chamfer 9d, such that additional magnetically active surfaces of the base 9 are formed, precisely a cylindrical surface 9b and a ring 9c. The term "end part" refers to those parts of the plunger 8 or the base 9 which contact each other or come to direct vicinity in the linear movement of the solenoid. The cylindrical chamfer 9d of the base 9 fits in its form to the sleeve 8d of the plunger 8, the linear movement of the plunger 8 is thus enabled and the ring 8c sits on the ring 9c. In this case, the magnetically active surfaces of the plunger 8 are an inner conical surface 8a, the inner cylindrical surface 8b and the ring 8c, and the magnetically active surfaces of the base 9 are an outer conical surface 9a, the outer cylindrical surface 9b and the ring 9c. The angles of the conical surfaces of the plunger and of the base match up to a tolerance of 10°, the physical production of the magnetically active surfaces may include chamfering and rounding of edges in tolerances +0.5 mm and -0.5 mm, and a variety of production related simplifications of the geometries of the magnetically active surfaces, e. g. stepping, polynomial approximation, etc. The solenoid can be adapted to a push or pull function, the return stroke is provided by a return spring 12 or an external force.

Such an upgrade represents an improvement in the actuating force by at least 24% and an improvement in the holding force by 118% compared to the reference solenoid. The course of the magnetic force of the solenoid as a function of the stroke is shown in Figure 6. Additionally, an improvement from a mechanical point of view is present; the rings 8c and 9c, these are annular magnetically active surfaces, are oriented normally with respect

to the stroke of the plunger 8 and enable its mechanical contact in the end position without a risk of getting latched. Such an embodiment contributes to low wear, dimensional stability, and a long lifetime of the solenoid. Further, a low ratio between the plunger mass and the actuating force provides for high resistance of the solenoid against vibrations.

[0008] In a further embodiment of the solenoid shown in Figure 3, the plunger 8 and the base 9 are formed in their end part as a conventional solenoid with conical surfaces and the plunger 8 has additional chamfer of the outer edge 8e on the opposite side of the end part of the plunger 8. The chamfer is carried out at an angle between 5° and 35°, preferably an angle of 27° with respect to the straight line running through the centre of the axis. The magnetically active surfaces between the plunger 8 and the base 9 are the inner conical surface 8a of the plunger and the outer conical surface 9a of the base. The angles of the conical surfaces of the plunger 8a and of the base 9a match up to a tolerance of 10°, the physical production of the magnetically active surfaces may include chamfering and rounding of edges in tolerances +0.5 mm and -0.5 mm, and a variety of production related simplifications of geometries of the magnetically active surfaces, e. g. stepping, polynomial approximation, etc. The solenoid can be adapted to a push or pull function, the return stroke is provided by a return spring 12 or an external force.

Such an upgrade introduces an improvement in the functioning of the solenoid, particularly from the point of view of providing for a constant course of the magnetic force along the stroke without a reduction in the actuating force. In this embodiment, the increase in the magnetic force along the stroke amounts to 237% of the actuating force, while the increase amounts to 385% with the reference solenoid. The course of the magnetic force of the solenoid as a function of the stroke is shown in Figure 6. Such an embodiment of the solenoid provides for a low level of vibrations and noise during operation, while the actuating force remains unchanged.

[0009] In a further embodiment of the solenoid, which is here called a solenoid with two cones of the base, and which is shown in Figure 4, the plunger 8 is provided in its end part with an additional sleeve 8d of the plunger 8, while the base 9 is provided in the end part with an additional conical chamfer 9e instead of a cylindrical chamfer, such that additional magnetically active surfaces of the base 9 are formed, precisely an additional outer conical surface 9f and a ring 9c. The height of the additional conical chamfer 9e lies between 5% and 35% of the total height of the plunger 8. The base 9 is formed of two cones, wherein the angles of the outer conical surfaces 9a and 9f are different and the angle of the additional outer conical surface 9f is smaller than the angle of the existing outer conical surface 9a. The angle of the additional outer conical surface 9f lies between 2° and 25°, preferably 7° with respect to the straight line running through the centre of the axis.

The solenoid in the presented embodiment comprises a coil 7, a plunger 8, a base 9, a housing 10, optionally a plunger rod 11 and optionally a return spring 12. In this case, the magnetically active surfaces of the plunger 8 are the inner conical surface 8a, the inner cylindrical surface 8b and the ring 8c, and the magnetically active surfaces of the base 9 are the outer conical surface 9a, the outer conical surface 9f and the ring 9c. The angles of the conical surfaces 8a and 9a match up to a tolerance value of 10°, the angle of the additional outer conical surface 9f does not depend on them and is different, namely smaller than the angle of the existing outer conical surface 9a.

Such an upgrade preserves the performance of a solenoid with a plunger sleeve (Figure 2) in terms of actuating and holding forces, while it eliminates inflexion points in the course of the magnetic force along the stroke, thus allowing for a wider range of use and better compatibility with linear mechanical springs. The course of the magnetic force of the solenoid as a function of the stroke is shown in Figure 6. Both the solenoid with the plunger sleeve (Figure 2) and the solenoid with two cones of the base (Figure 4) provide for a stop of the plunger in the end position without a risk of latching, which results in lower wear, dimensional stability and a long lifetime of the solenoid. Further, a low ratio between the plunger mass and the actuating force provides for high resistance of the solenoid against vibrations.

[0010] In a still further embodiment of the solenoid, which is here called the universal solenoid and is shown in Figure 5, the plunger 8 has additional chamfer of the outer edge 8e on the opposite side of the end part of the plunger 8. The chamfer is carried out at an angle between 5° and 35°, preferably an angle of 27° with respect to the straight line running through the centre of the axis. The solenoid in the presented embodiment comprises a coil 7, a plunger 8, a base 9, a housing 10, optionally a plunger rod 11 and optionally a return spring 12. In this case, the magnetically active surfaces of the plunger 8 are the inner conical surface 8a, the inner cylindrical surface 8b and the ring 8c, and the magnetically active surfaces of the base 9 are the outer conical surface 9a, the outer conical surface 9f and the ring 9c. Such an upgrade preserves the performance of the solenoid with two cones of the base (Figure 4) in terms of actuating force and linearity of the course of the magnetic force along the stroke (without inflexion points), while the magnetic force at the end of the stroke is reduced due to the chamfer of the plunger, and this has a positive effect on vibrations and noise of the solenoid. The course of the magnetic force of the solenoid as a function of the stroke is shown in Figure 6. The universal solenoid (Figure 5) provides for a stop of the plunger in the end position without a risk of latching, which results in lower wear, dimensional stability and a long lifetime of the solenoid. A low ratio between the plunger mass and the actuating force provides for high resistance of the solenoid against vibrations. When designing a solenoid, the presented set of the magnetically

active surfaces of the universal solenoid offers numerous possibilities for adaptation of the characteristic of the magnetic force to a given application.

Claims

1. A compact linear solenoid with the improved geometry of magnetically active surfaces, which comprises a coil (7), a plunger (8), a base (9), a housing (10), optionally a plunger rod (11) and optionally a return spring (12), wherein the solenoid has a substantially conical shape of the movable assembly, **characterized in that** the plunger (8) is provided in its end part with an additional sleeve (8d) of the plunger (8) and the base (9) has a cylindrical chamfer (9d) in the end part, such that the magnetically active surfaces of the plunger (8) are the inner conical surface (8a), the inner cylindrical surface (8b) and the ring (8c), and the magnetically active surfaces of the base are the outer conical surface (9a), the outer cylindrical surface (9b) and the ring (9c).
 2. Solenoid according to claim 1, **characterized in that** the height of the sleeve (8d) of the plunger (8) represents between 5% and 35% of the total height of the plunger, preferably between 15% and 25%.
 3. Solenoid according to claims 1 and 2, **characterized in that** the cylindrical chamfer (9d) of the base (9) fits in its form to the sleeve (8d) of the plunger (8), such that the linear movement of the plunger (8) and the mechanical contact of the ring (8c) with the ring (9c) are enabled.
 4. Solenoid according to claims 1 and 2, **characterized in that** the base (9) has an additional conical chamfer (9e) in the end part instead of a cylindrical chamfer, such that the magnetically active surfaces of the plunger (8) are the inner conical surface (8a), the inner cylindrical surface (8b) and the ring (8c), and the magnetically active surfaces of the base (9) are the outer conical surface (9a), the additional outer conical surface (9f) and the ring (9c), wherein the linear movement of the plunger (8) and the mechanical contact of the ring (8c) with the ring (9c) are enabled.
 5. Solenoid according to claim 4, **characterized in that** the height of the additional conical chamfer (9e) lies between 5% and 35% of the total height of the plunger (8).
 6. Solenoid according to claims 4 and 5, **characterized in that** the angles of the outer conical surfaces (9a) and (9f) are different and the angle of the additional outer conical surface (9f) is smaller than the angle of the existing outer conical surface (9a), wherein
- the angle of the additional outer conical surface (9f) lies between 2° and 25°, preferably 7° with respect to the straight line running through the centre of the axis.
 7. Solenoid according to claims 1, 2, 4, 5 and 6, **characterized in that** the plunger (8) has additional chamfer of the outer edge (8e) on the opposite side of the end part of the plunger (8).
 8. A compact linear solenoid with the improved geometry of magnetically active surfaces, which comprises a coil (7), a plunger (8), a base (9), a housing (10), optionally a plunger rod (11) and optionally a return spring (12), wherein the solenoid has substantially a conical shape of the movable assembly, **characterized in that** the plunger (8) and the base (9) are formed in their end part as a conventional solenoid with conical surfaces and the plunger (8) has additional chamfer of the outer edge (8e) on the opposite side of the end part of the plunger (8).
 9. Solenoid according to claims 7 and 8, **characterized in that** the chamfer (8e) is carried out at an angle between 5° and 35°, preferably an angle of 27° with respect to the straight line running through the centre of the axis.
 10. Solenoid according to claims 1 to 9, **characterized in that** the angles of the conical surfaces (8a) and (9a) match up to a tolerance value of 10°.
 11. Use of the solenoid according to claims 1 to 10 for a push or pull function, wherein the return stroke is provided by an integrated spring (12) or an external force.

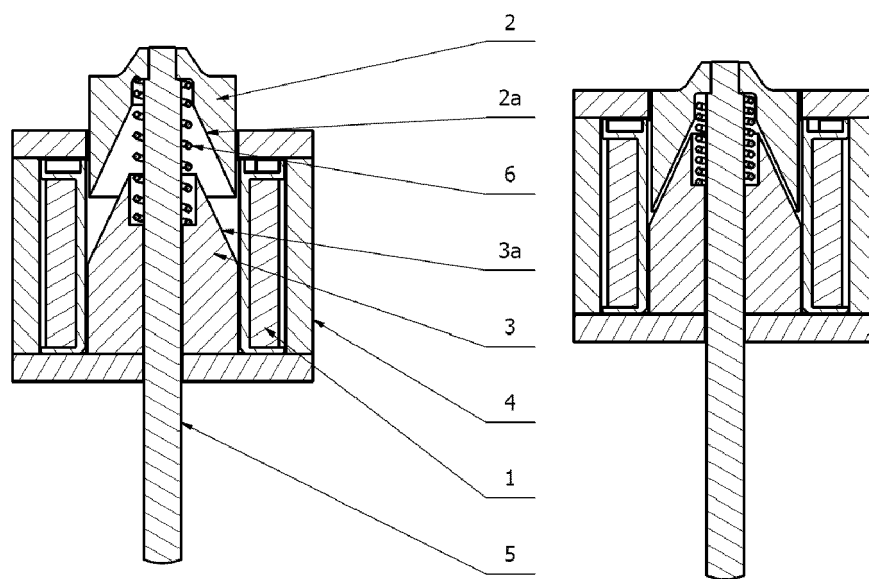


Figure 1

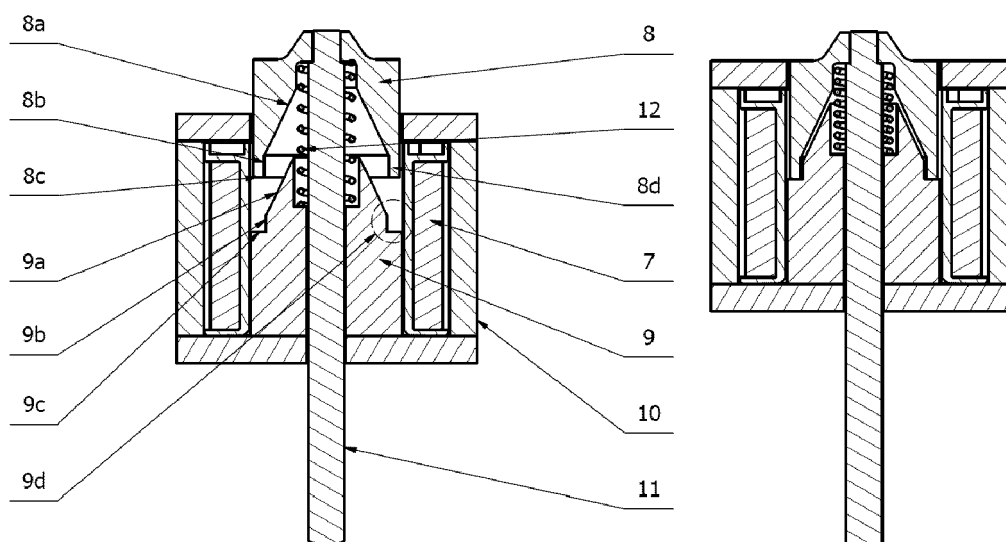


Figure 2

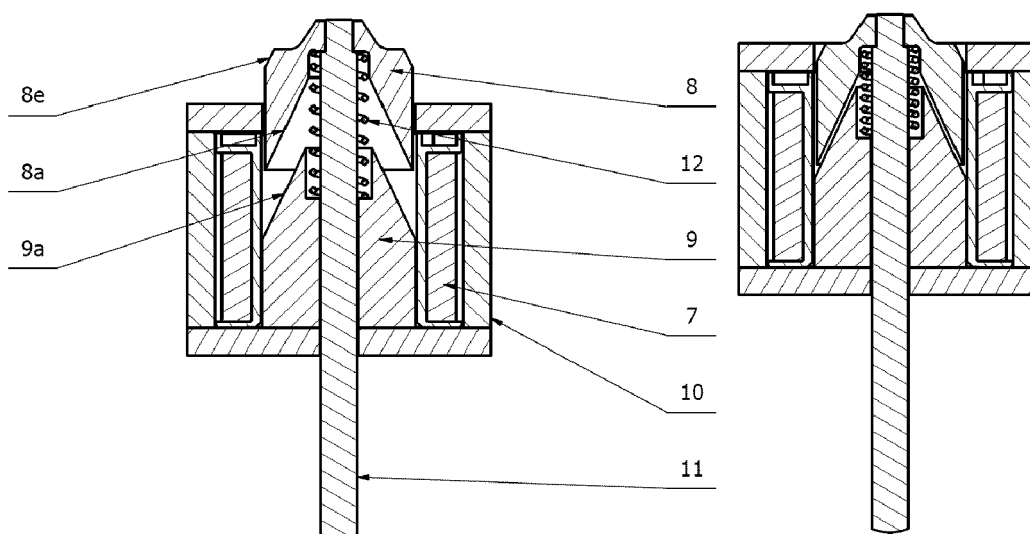


Figure 3

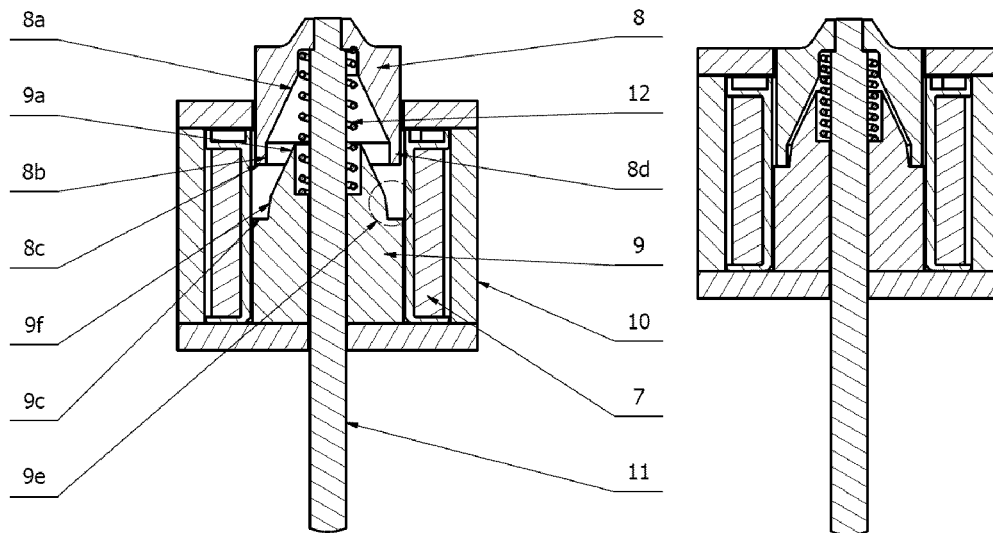


Figure 4

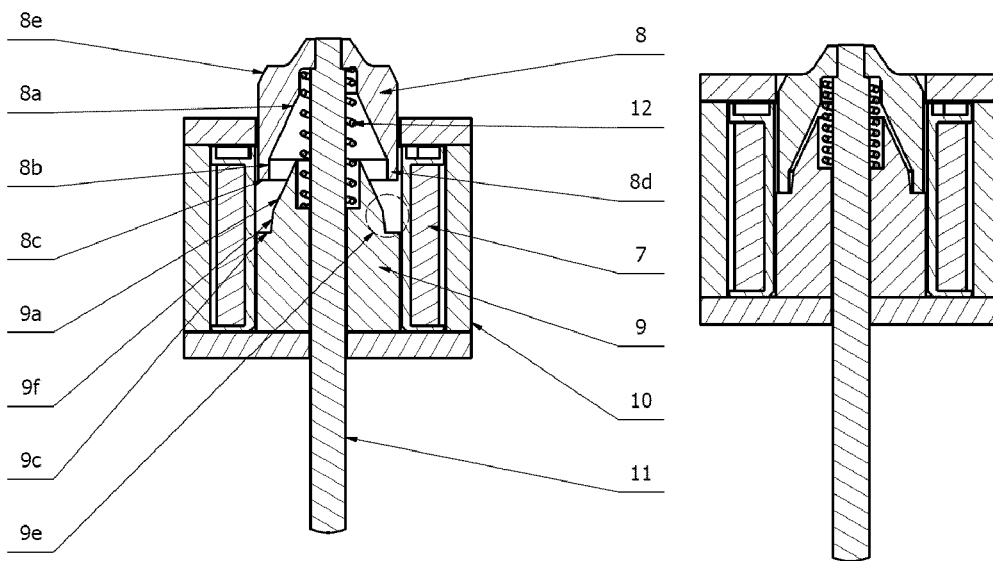


Figure 5

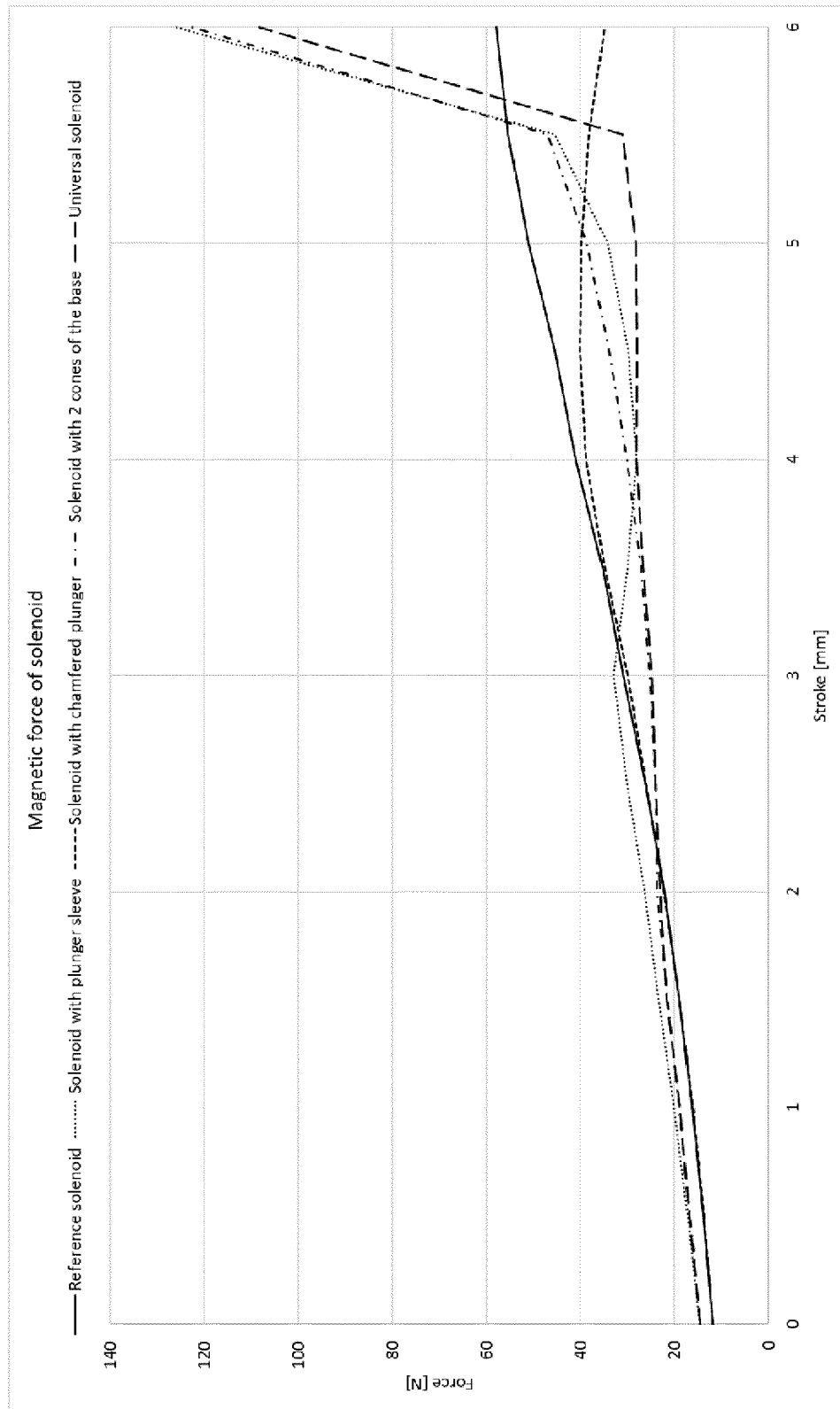


Figure 6



EUROPEAN SEARCH REPORT

Application Number
EP 18 00 0363

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			TECHNICAL FIELDS SEARCHED (IPC)
			H01F
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 16 November 2018	Examiner Tano, Valeria
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 18 00 0363

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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