



(11)

EP 3 503 131 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
26.06.2019 Bulletin 2019/26

(51) Int Cl.:
H01F 21/06 (2006.01) **H01F 27/40** (2006.01)
H01F 29/10 (2006.01) **H02H 9/02** (2006.01)

(21) Application number: **17208444.4**

(22) Date of filing: **19.12.2017**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD TN

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(54) **INDUCTOR AND METHOD FOR VARYING THE MAGNETIC PERMEABILITY OF AN INDUCTOR**

(57) There is provided an inductor (5) having a coil (10) enclosing at least a part of a core (15, 20, 70, 90). A sensor (40) senses a current when flowing in the coil (10). The core comprises a first part (15), and a second part (20, 70, 90) comprising a movable metal part mounted relative to the first part (15) of the core such that the second movable metal part (20, 70, 90) is separated from the first part (15) of the core by an air gap (25, 30). A least a portion of the second part (20, 70, 90) is arranged

to move relative to the first part (15), thereby to vary the magnetic permeability of the core (15, 20, 70, 90), according to an output of the sensor (40). In this way, if the output of the sensor (40) indicates an onset of saturation of the core (15, 20, 70, 90), the magnetic permeability of the core (15, 20, 70, 90) may be reduced by such movement. A method for varying the magnetic permeability of an inductor core (15, 20, 70, 90) is also provided.

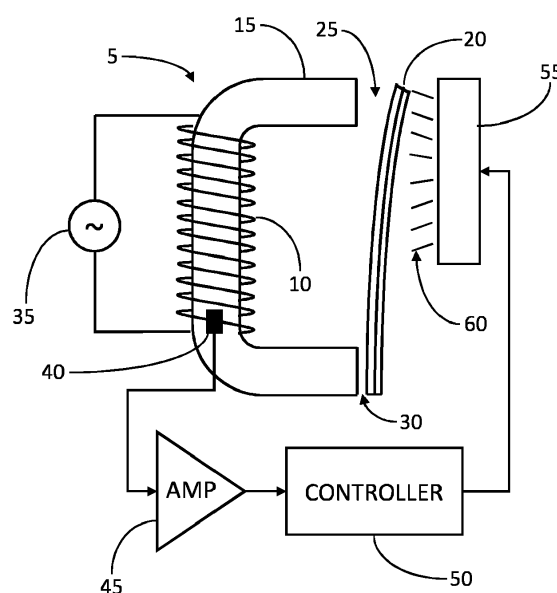


Figure 1b

Description

Technical Field

[0001] The present disclosure relates to an inductor and to a method for varying the magnetic permeability of an inductor.

Background

[0002] It is known to introduce gaps and to apply supplementary magnetic materials to inductor cores to achieve required inductor characteristics, including a required saturation profile. This technique enables an inductor to be designed for use in a particular application.

Summary

[0003] According to a first aspect disclosed herein, there is provided an inductor, comprising a coil enclosing at least a part of a core, and a sensor for sensing a current when flowing in the coil, wherein the core comprises a first part, and a second part comprising a movable metal part mounted relative to the first part of the core such that the second, movable metal part is separated from the first part of the core by an air gap, and wherein at least a portion of the second part is arranged to move relative to the first part, thereby to vary the magnetic permeability of the core, according to an output of the sensor.

[0004] Movement of at least a portion of the second part may be achieved in this way based upon a continuous control loop in which the sensed current determines the extent of movement of the at least a portion of the second part and hence the magnetic permeability of the inductor core.

[0005] In an example, at least a portion of the second part is arranged to move relative to the first part to vary the air gap according to the output of the sensor.

[0006] In an example, at least a portion of the second part is arranged to move relative to the first part to increase the air gap if the output of the sensor indicates an onset of saturation of the core. Increasing the air gap decreases the magnetic permeability of the core and so causes the current required to achieve saturation of the core to be greater than that flowing in the coil, so avoiding saturation of the coil.

[0007] In an example, at least a portion of the second part is arranged to move relative to the first part to vary the alignment of the second part with the first part of the core according to the output of the sensor.

[0008] In an example, at least a portion of the second part is arranged to move relative to the first part to decrease the alignment of the second part with the first part of the core if the output of the sensor indicates an onset of saturation of the core. Decreasing the alignment of the first part 15 and the second part 20 reduces the magnetic coupling of the two parts 15, 20 of the core and so reduces the magnetic permeability of the core.

[0009] In an example, at least a portion of the second part is arranged to pivot about an axis. Such a movement may achieve one or both of varying the air gap and changing the alignment between the first and second parts of the core.

[0010] In an example, at least a portion of the second part is hinged at one end.

[0011] In an example, at least a portion of the second part is movable by a controllable actuator. The movement applied by the actuator may be controlled according to the output of the sensor.

[0012] In an example, at least a portion of the second part is a controllably deformable metal part. Deformation of at least a portion of the second part may achieve one or both of varying the air gap and changing the alignment between the first and second parts of the core.

[0013] In an example, the controllably deformable metal part comprises a bi-metal strip deformable by heating of the bi-metal strip.

[0014] In an example, a controllable source of heat is provided for heating the bi-metal strip, wherein the controllable source of heat is arranged to heat the bi-metal strip according to an output from the sensor and comprises at least one of: a heater arranged to radiate heat; a heater embedded within the bi-metal strip; a heater enclosing or surrounding at least a part of the bi-metal strip; and passing a variable electric current through the bi-metal strip thereby to heat the bi-metal strip according to the electrical resistance of the bi-metal strip.

[0015] In an example, the sensor comprises at least one of: a current sensing resistor; a current sensing coil; and a Hall Effect sensor for sensing a magnetic field due to a current when flowing in the coil.

[0016] According to a second aspect disclosed herein, there is provided a method for controlling the magnetic permeability of a core of an inductor having a coil enclosing at least a part of the core, wherein the core comprises a first part, and a second part comprising a movable metal part mounted relative to the first part of the core such that the second, movable metal part is separated from the first part of the core by an air gap, the method comprising:

sensing a current flowing through the coil; and moving at least a portion of the second part relative to the first part, thereby to vary the magnetic permeability of the core, according to the sensed current.

[0017] In an example of the method, moving at least a portion of the second part relative to the first part is arranged to reduce the magnetic permeability of the core if the sensed current indicates an onset of saturation of the core.

[0018] In an example of the method, moving at least a portion of the second part relative to the first part comprises at least one of: deforming the at least a portion of the second part; and moving the at least a portion of the second part by tilting or rotating the at least a portion of the second part about a pivot axis.

Brief Description of the Drawings

[0019] To assist understanding of the present disclosure and to show how embodiments may be put into effect, reference is made by way of example to the accompanying drawings in which:

Figure 1 shows schematically an example of an inductor arrangement in one state of operation, as described herein;

Figure 2 shows schematically the example inductor arrangement of Figure 1 in a further state of operation, as described herein; and

Figure 3 shows schematically a further example of an inductor arrangement, as described herein.

Detailed Description

[0020] There are various applications of inductors in which it is desirable to avoid the onset of inductor core saturation. For example, in some applications, saturation of the inductor core may lead to rapid increase in a current flowing through the inductor and consequent overheating of the inductor. This may be the case in particular in high-power applications. Example devices will now be described with reference to Figures 1 to 3 embodying a method for preventing the onset of inductor core saturation by varying the magnetic permeability of the core.

[0021] Referring initially to Figure 1, two schematic representations are provided in Figure 1a and Figure 1b of an example inductor 5 comprising a core and coiled windings 10. The core comprises a first C-shaped part 15 made from a ferro-magnetic such as iron, nickel or cobalt or ferri-magnetic material such as ferrite. The core also comprises a second part comprising a bi-metal strip 20 that is separated from the ends of the first C-shaped part 15, when in a normal configuration as shown in Figure 1a, by small air gaps 25, 30. The bi-metal strip 20 may be anchored at one end such that the air gap 30 at that end remains fixed. A deformation of the bi-metal strip 20, as shown in Figure 1b, causes the un-anchored end of the strip 20 to move away from the first part 15, so increasing the air gap 25. Alternatively, the bi-metal strip 20 may be anchored at another point along its length so that one or both of the air gaps 25, 30 may vary by a deformation of the strip 20.

[0022] In an alternative arrangement of the bi-metal strip 20, not shown in Figure 1, the bi-metal strip 20 may be anchored such that the alignment of the first part 15 and the second bi-metal strip part 20 may be varied by a deformation of the strip 20. The variation of alignment may occur with or without a variation in one or both of the air gaps 25, 30.

[0023] A power source or signal source 35 may be connected to the coiled windings 10 according to the particular application of the inductor 5.

[0024] A sensor 40 is provided to sense a current flowing through the coil 10 or to sense the effect of a flowing current. Such a sensor 40 is thereby able to sense characteristics indicative of an onset of saturation of at least the first part of the core 15. The sensor 40 may comprise, for example, one or more current sensing resistors or a current sensing transformer. Alternatively, the sensor 40 may comprise a Hall Effect sensor provided to sense a changing magnetic field due to a current flowing in the inductor coil 10.

[0025] The sensor 40 is connected to an amplifier 45 of a type appropriate to the type of sensor 40 being used. The output of the amplifier 45 is input to a controller 50, comprising a micro-controller or other type of processor, or comprising an analogue circuit. The controller 50 is configured to interpret the amplified output of the sensor 40 with reference to preconfigured characteristics of sensed current flow or sensed magnetic field strength expected when at least the first part of the core 15 is close to saturation.

[0026] The controller 50 is linked to a controllable heat source 55 associated with the bi-metal strip 20. The controller 50 is configured to adjust the heat output 60 of the heat source 55 according to the output of the sensor 40 to vary the amount and the rate of bending of the strip 20. When the bi-metal strip 20 bends, as shown in the example in Figure 1b, one end of the strip 20 remains fixed in relation to the first part 15 of the core while the other end of the strip 20 bends away from the first part of the core 15, so increasing the air gap 25. Alternatively, as mentioned above, the bending of the bi-metal strip 20 may instead vary the alignment of the bi-metal strip 20 with the first part 15. An increase in the air gap 25 between the first part of the core 15 and the bi-metal strip 20 causes the magnetic permeability of the core 15, 20 to decrease. Similarly, a decrease in the alignment of the first part of the core 15 and the bi-metal strip 20 causes the magnetic coupling of the two parts 15, 20 and hence the magnetic permeability of the core 15, 20 to decrease. With a decreased magnetic permeability of the core 15, 20, a higher current would therefore be required to cause saturation of the core 15, 20 which, if higher than the current being supplied by the power or signal source 35, thereby avoids the onset of saturation of the core 15, 20.

[0027] The controller 50 may be configured to determine a rate of change in the current flowing through the coil 10 and adjust the rate of heating of the bi-metal strip 20 according to the sensed rate of change of current. That is, if the sensed rate of change in the current is high, then the controller 50 triggers a higher heat output by the heat source 55 thereby causing a higher rate of bending of the bi-metal strip 20. For a lower sensed rate of change in the current, the controller 50 causes a lower rate of heating by the heat source 55 and therefore a slower rate of bending of the bi-metal strip 20.

[0028] The heat source 55 may be mounted separately from the bi-metal strip 20 and arranged to heat the bi-metal strip 20 by radiated heat 60, as shown in Figure 1.

Alternatively the heat source 55 may partially enclose the bi-metal strip 20, for example in the form of a heating element formed around a part of the bi-metal strip 20. As a further alternative, the heat source 55 may be embedded or integrated within the bi-metal strip 20 to provide heating of the strip 20 by conducted heat. As a further alternative, a variable heating current may be passed through the bi-metal strip 20 by the controller 50 such that the strip 20 is heated according to the electrical resistance of the metals used in the strip 20.

[0029] The controller 50 is configured to operate a closed feedback loop whereby the extent of the air gap 25 is adjusted by varying the heating of the bi-metal strip 20 according to the current flowing in the coil 10 or the resultant magnetic field or the rate of change in the current or magnetic field, as sensed by the sensor 40. If the controller 50 determines that the sensed current flow in the coil 10 is no longer increasing or is reducing, the controller 50 correspondingly reduces or ceases heating of the bi-metal strip 20 by the heat source 55. The bi-metal strip 20 then gradually returns to the normal configuration shown in Figure 1a and the gap 25 decreases.

[0030] If necessary, the controller 50 may be configured to trigger further actions, for example to make adjustments to an underlying cause of saturation of the core 15, 20 so that a return to near-saturation of the core 15, 20 may be avoided. Alternatively, the controller 50 may simply continue to respond to the sensed onset of saturation and adjust the heating of the bi-metal strip 20, so far as it is possible to do, to prevent the onset of saturation of the core 15, 20.

[0031] An alternative example of an inductor will now be described with reference to Figure 2 in which the second part 20 of the core is movable by a rotation rather than by a deformation of the second part 20.

[0032] Referring to Figure 2, the same inductor coil 10 and first C-shaped part 15 of the core are shown as in Figure 1. However, in this example, a second part 70 of the core comprises a movable metal portion which may be made, for example, using a ferro-magnetic or ferri-magnetic material, optionally using the same material as the first part of the core 15. The second part 70 of the core is arranged to tilt about a pivot or hinge 75 so that the air gap 25 between the first and second parts 15, 20 may be varied according to the degree of tilt applied to the second part 70 relative to the first part 15. An actuator 80, linked to the second part 70, may be controlled by the controller 50 to vary the angle of tilt of the second part 70 and hence the size of the air gap 25.

[0033] The pivot or hinge 75 shown in Figure 2 may alternatively be positioned at a point other than at an end of the second part 70 so that when the second part 70 pivots or tilts, both of the air gaps 25, 30 may vary.

[0034] An alternative implementation of the inductor 5 will now be described with reference to Figure 3.

[0035] Referring to Figure 3, three schematic views are provided, in Figure 3a, 3b and 3c, showing a different arrangement for a second part 90 of the core. In Figure

3a, the same inductor coil 10 and first C-shaped part 15 of the core are shown as in Figure 1. However, in this example, a second part 90 of the core is mounted upon a spindle 95 that may be rotated by an actuator 100, under the control of the controller 50, to vary the alignment of the second part 90 with the first part 15 of the core. As the second part 90 rotates, the air gaps 25, 30 remain substantially constant. However, the alignment of the second part 90 of the core with the first part 15 of the core varies from a normally aligned configuration, as shown in a view of the second part 90 along the axis of the spindle 95 in Figure 3b, to a displaced configuration as shown in Figure 3c. An increased displacement of the second part 90 relative to the first part 15 of the core, reduces the magnetic coupling of the two parts 15, 90 of the core and so reduces the magnetic permeability of the core 15, 90, so avoiding the onset of saturation.

[0036] In another example of the inductor 5, the second part 20, 70, 90 may comprise a deformable metal part, such as a bi-metal strip, that may be moved as well as deformed by any one of the techniques described above. The amount and speed of variation in deformation and/or movement of the second part 20, 70, 90 is determined by the variation required in magnetic permeability of the core to avoid the onset of saturation of the core.

[0037] As mentioned above, the controller 50 may comprise an analogue circuit configured to adjust the heat output by the heat source 55, or to control the actuator 80, 100 according to an output of the sensor 40. In particular, the analogue circuit 50 may be configured to respond to predetermined characteristics of a current supplied to the inductor coil 10, or of a magnetic field due to the supplied current, to: adjust the rate of heat output by the heat source 55, and hence the rate and extent of deformation of the second part 2; or to adjust the rate and extent of movement of the second part 70, 90 of the core by the actuator 80, 100 respectively.

[0038] In principle, the inductor arrangement and control loop implemented by examples disclosed herein may be applied to many different types of inductor in various different applications. Some specific examples in which the inductor arrangement and control loop may be used with particular advantage include power supplies, transformers, actuators, transmitters, induction cookers etc.

[0039] It will be understood that when the controller 50 is implemented using a processor, the processor or processing system or circuitry may in practice be provided by a single chip or integrated circuit or plural chips or integrated circuits, optionally provided as a chipset, an application-specific integrated circuit (ASIC), field-programmable gate array (FPGA), digital signal processor (DSP), graphics processing units (GPUs), etc. The chip or chips may comprise circuitry (as well as possibly firmware) for embodying at least one or more of a data processor or processors, a digital signal processor or processors, baseband circuitry and radio frequency circuitry, which are configurable so as to operate in accordance with the exemplary embodiments. In this regard,

the exemplary embodiments may be implemented at least in part by computer software stored in (non-transitory) memory and executable by the processor, or by hardware, or by a combination of tangibly stored software and hardware (and tangibly stored firmware).

[0040] To the extent that at least some aspects of the embodiments described herein with reference to the drawings comprise computer processes performed in processing systems or processors, the invention also extends to computer programs, particularly computer programs on or in a carrier, adapted for putting the invention into practice. The program may be in the form of non-transitory source code, object code, a code intermediate source and object code such as in partially compiled form, or in any other non-transitory form suitable for use in the implementation of processes according to the invention. The carrier may be any entity or device capable of carrying the program. For example, the carrier may comprise a storage medium, such as a solid-state drive (SSD) or other semiconductor-based RAM; a ROM, for example a CD ROM or a semiconductor ROM; a magnetic recording medium, for example a floppy disk or hard disk; optical memory devices in general; etc.

[0041] The examples described herein are to be understood as illustrative examples of embodiments of the invention. Further embodiments and examples are envisaged. Any feature described in relation to any one example or embodiment may be used alone or in combination with other features. In addition, any feature described in relation to any one example or embodiment may also be used in combination with one or more features of any other of the examples or embodiments, or any combination of any other of the examples or embodiments. Furthermore, equivalents and modifications not described herein may also be employed within the scope of the invention, which is defined in the claims.

Claims

1. An inductor (5), comprising a coil (10) enclosing at least a part of a core (15, 20, 70, 90), and a sensor (40) for sensing a current when flowing in the coil (10), wherein the core comprises a first part (15), and a second part (20, 70, 90) comprising a movable metal part mounted relative to the first part (15) of the core such that the second, movable metal part (20, 70, 90) is separated from the first part (15) of the core by an air gap (25, 30), and wherein at least a portion of the second part (20, 70, 90) is arranged to move relative to the first part (15), thereby to vary the magnetic permeability of the core (15, 20, 70, 90), according to an output of the sensor (40).
2. The inductor (5) according to claim 1, wherein at least a portion of the second part (20, 70, 90) is arranged to move relative to the first part (15) to vary the air gap (25, 30) according to the output of the sensor

(40).

3. The inductor (5) according to claim 2, wherein at least a portion of the second part (20, 70, 90) is arranged to move relative to the first part (15) to increase the air gap (25, 30) if the output of the sensor (40) indicates an onset of saturation of the core (15, 20, 70, 90).
4. The inductor (5) according to any one of claims 1 to 3, wherein at least a portion of the second part (20, 70, 90) is arranged to move relative to the first part (15) to vary the alignment of the second part (20, 70, 90) with the first part (15) of the core according to the output of the sensor (40).
5. The inductor (5) according to claim 4, wherein at least a portion of the second part (20, 70, 90) is arranged to move relative to the first part (15) to decrease the alignment of the second part (20, 70, 90) with the first part (15) of the core if the output of the sensor (40) indicates an onset of saturation of the core (15, 20, 70, 90).
6. The inductor (5) according to any one of claims 1 to 5, wherein at least a portion of the second part (20, 70, 90) is arranged to pivot about an axis (75, 95).
7. The inductor (5) according to any one of claims 1 to 6, wherein at least a portion of the second part (20, 70, 90) is hinged (75) at one end.
8. The inductor (5) according to any one of claims 1 to 7, wherein at least a portion of the second part (20, 70, 90) is movable by a controllable actuator (80, 100).
9. The inductor (5) according to any one of claims 1 to 8, wherein at least a portion of the second part (20, 70, 90) is a controllably deformable metal part.
10. The inductor (5) according to claim 9, wherein the controllably deformable metal part (20, 70, 90) comprises a bi-metal strip (20) deformable by heating of the bi-metal strip (20).
11. The inductor (5) according to claim 10, comprising a controllable source of heat (55) for heating the bi-metal strip (20), wherein the controllable source of heat (55) is arranged to heat the bi-metal strip (20) according to an output from the sensor (40) and comprises at least one of: a heater arranged to radiate heat (60); a heater embedded within the bi-metal strip (20); a heater enclosing or surrounding at least a part of the bi-metal strip (20); and passing a variable electric current through the bi-metal strip (20) thereby to heat the bi-metal strip (20) according to the electrical resistance of the bi-metal strip (20).

12. The inductor (5) according to any one of claims 1 to 11, wherein the sensor (40) comprises at least one of: a current sensing resistor; a current sensing coil; and a Hall Effect sensor for sensing a magnetic field due to a current when flowing in the coil (10). 5
13. A method for controlling the magnetic permeability of a core (15, 20, 70, 90) of an inductor (5) having a coil (10) enclosing at least a part of the core (15, 20, 70, 90), wherein the core comprises a first part (15), 10 and a second part (20, 70, 90) comprising a movable metal part mounted relative to the first part (15) of the core such that the second, movable metal part (20, 70, 90) is separated from the first part (15) of the core by an air gap (25, 30), the method comprising: 15
- sensing (40) a current flowing through the coil (10); and
- moving at least a portion of the second part (20, 70, 90) relative to the first part (15), thereby to vary the magnetic permeability of the core (15, 20, 70, 90), according to the sensed current. 20
14. The method according to claim 13, wherein moving at least a portion of the second part (20, 70, 90) relative to the first part (15) is arranged to reduce the magnetic permeability of the core (15, 20, 70, 90) if the sensed current indicates an onset of saturation of the core (15, 20, 70, 90). 25 30
15. The method according to claim 13 or claim 14, wherein moving at least a portion of the second part (20, 70, 90) relative to the first part (15) comprises at least one of: deforming the at least a portion of the second part (20, 70, 90); and moving the at least a portion of the second part (20, 70, 90) by tilting or rotating the at least a portion of the second part (20, 70, 90) about a pivot axis (75, 95). 35 40

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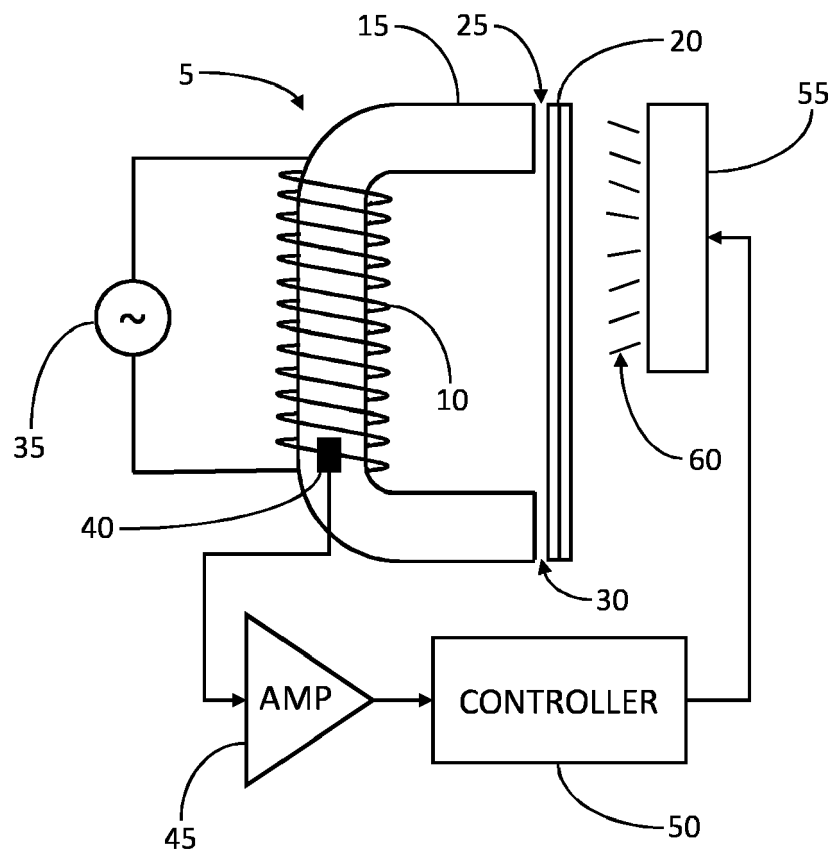


Figure 1a

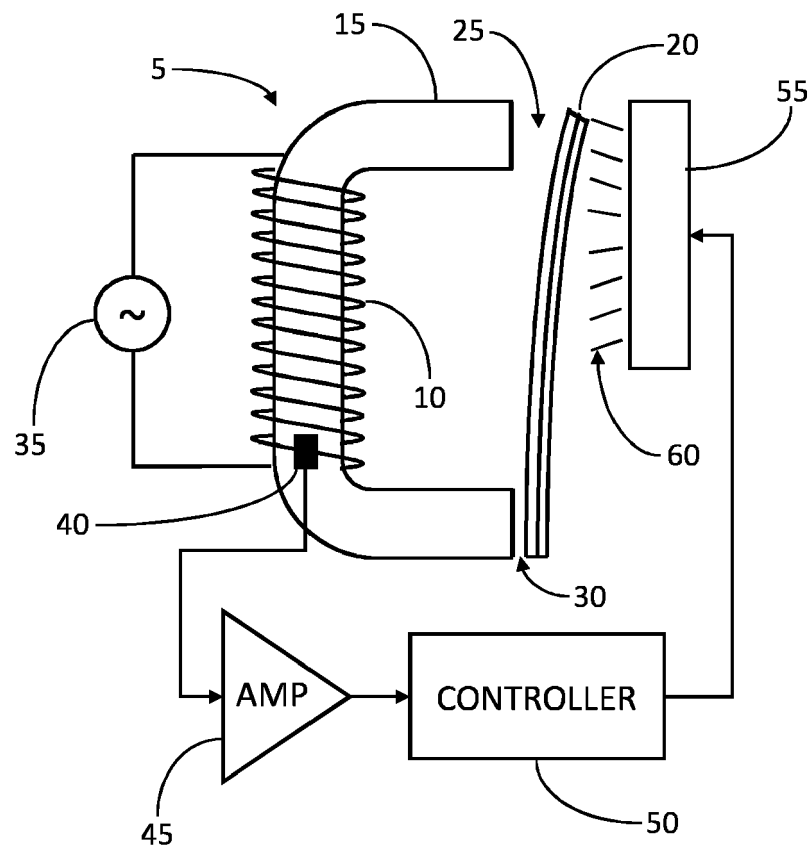


Figure 1b

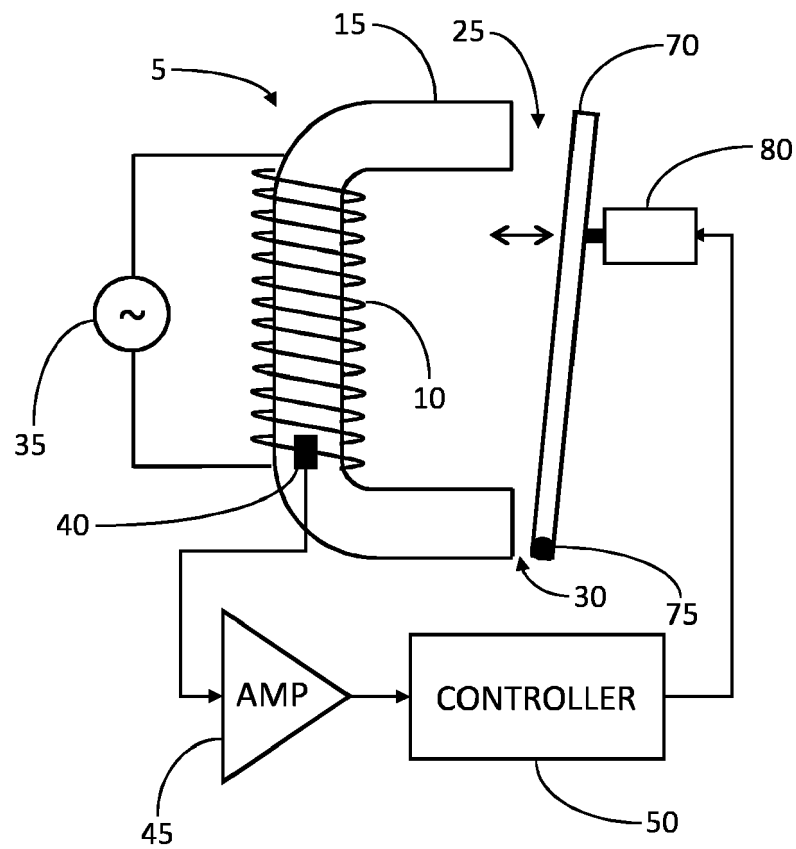


Figure 2

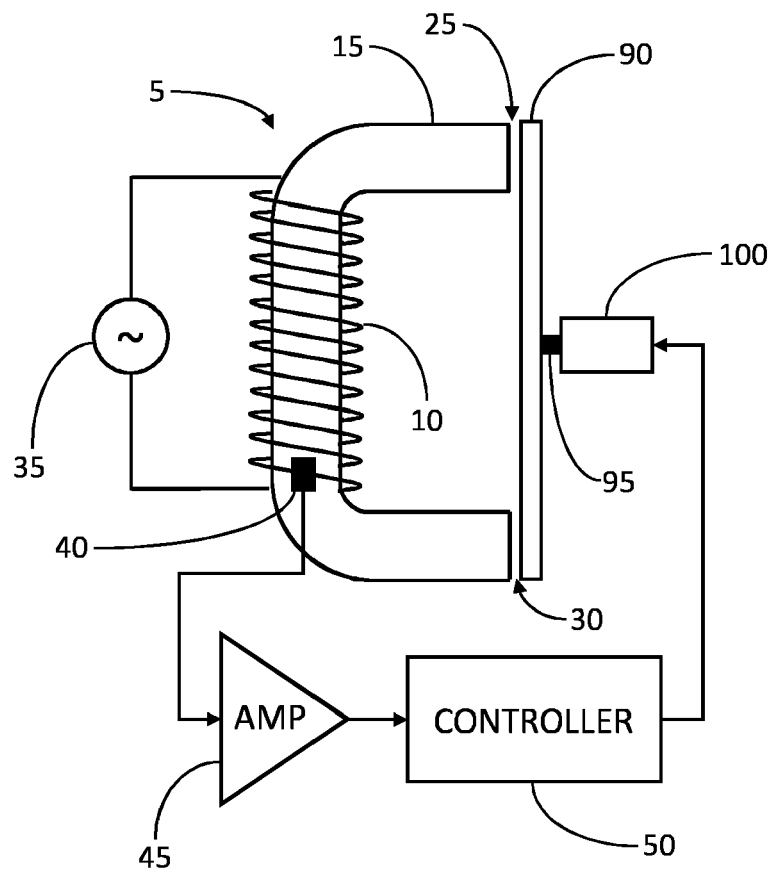


Figure 3a

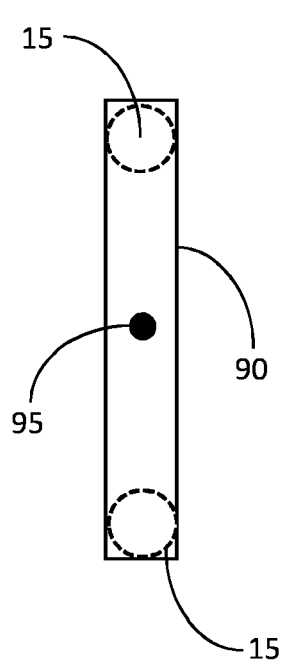


Figure 3b

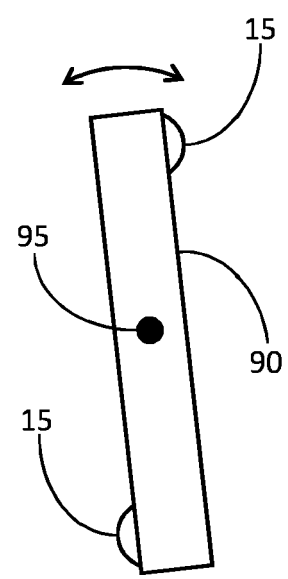


Figure 3c



EUROPEAN SEARCH REPORT

Application Number
EP 17 20 8444

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DOCUMENTS CONSIDERED TO BE RELEVANT			
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 11 June 2018	Examiner Tano, Valeria
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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