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(54) **Wireless energy transfer**

(57) A system and method are provided for induction mediated energy transfer through a metal wall. A first metal plate shape (22) is arranged in a manner that a secondary coil (12) is located between the first metal plate shape (22) and the metal wall (13), wherein the first metal plate shape (22) follows the coil windings in tangential direction and comprises an isolation barrier (50) arranged between lateral sides of the first metal shape thereby preventing electric conduction across the barrier

in a tangential direction. In an embodiment, a secondary magnetic field generator (23, 24) is positioned on the metal wall and adjacent opposite lateral sides of the first metal plate shape (22) thereby generating a secondary magnetic field (B2) extending into the wall along a contour between opposite lateral sides and directed between said lateral sides of the first metal plate shape so as to displace at least part of the primary magnetic field (B1) from the wall (13) and through the secondary coil (12).

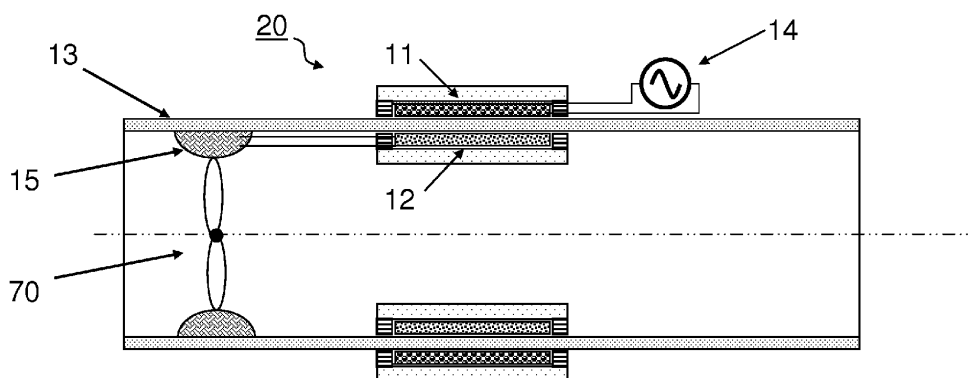


FIG 7

Description**FIELD AND BACKGROUND OF THE INVENTION**

[0001] The present invention relates to the field of energy transfer, in particular to a method for wireless energy transfer through metal walls.

[0002] An important aspect in the oil and gas industry is the measurement and control of fluid and gas streams in metal compartments such as pipes and other closed installations, e.g. using valves, pumps, sensors, etcetera. Oftentimes these actuators and sensors are located inside the compartment holding the fluid or gas streams, while the corresponding power source or control unit is situated outside the compartment. For their proper application and functioning it may thus be necessary to provide these devices with energy and/or communication means through the metal wall of the compartment, e.g. for steering or data readout. For this purpose typically electric cables or mechanical driving rods are fed through holes in the compartment wall. These holes form potential weaknesses in the wall and may be a source of problems such as leakage or rupture. Especially in situations wherein the compartment is used to house high pressure, toxic, and/or explosive materials a dangerous situation may occur.

[0003] A potential remedy for this problem may be found in the use of wireless energy and data transfer from a power source outside the compartment to a receiver inside the compartment. Typical forms of wireless energy and data transfer involve the use of electric and/or magnetic fields. The source and receiver in this case may be e.g. a pair of antennas or induction loops. For example, electromagnetic induction finds application in wireless transfer of energy, e.g. in the use of wireless charging of batteries or powering of RFID chips. However, a problem with induction arises when trying to wirelessly transfer energy through objects such as metal walls that conduct electric and/or magnetic fields. In particular the conducting object may shield the electric and/or magnetic fields from the receiver.

[0004] WO2009/143541 discloses a method and an apparatus for the transmission of energy using electromagnetic fields and information using load modulation in the presence of conductive objects, wherein an alternating electromagnetic field is produced, a transponder for the supply thereof procures energy from said field, for the purpose of data transmission the transponder carries out a load modulation using an effective frequency that exceeds the frequency of the alternating electromagnetic field, and said load-modulated signal is received by way of an antenna and is demodulated by a receiver in a read device. Because the high frequency modulation is not needed for energy supply, but for data transfer, a higher dampening of the modulation signal is deemed acceptable.

[0005] There is a need for a system and method providing enhanced efficiency for inductive energy and/or information transfer through a conductive wall.

SUMMARY OF THE INVENTION

[0006] In a first aspect there is provided a system for induction mediated energy transfer through a metal wall. The system comprises a power source, primary and secondary coils and a receiver. The power source is arranged for generating an alternating primary current. The primary coil is situated at one side of the wall while the secondary coil is situated at the other side of the wall. The primary coil comprises conductive windings electrically connected to the power source. The primary coil is arranged for conducting the alternating primary current and generating an alternating primary magnetic field. The secondary coil also comprises conductive windings and is arranged with respect to the primary coil such that the alternating primary magnetic field traverses the secondary coil so as to generate an alternating secondary current in the secondary coil. The receiver is electrically connected to the secondary coil and arranged for receiving the secondary current.

[0007] The system further comprises a first metal plate shape. The first metal plate shape is arranged for guiding the primary magnetic field through the secondary coil. The secondary coil is arranged substantially between the first metal plate shape and the wall. The first metal plate shape follows the coil windings in tangential direction and comprises an isolation barrier arranged between lateral sides of the first metal shape thereby preventing electric conduction across the barrier in a tangential direction.

[0008] It is to be appreciated that the first metal plate shape may act as a flux guide for guiding flux lines emanating from the primary coil through the secondary coil. The flux guide may improve transfer efficiency by guiding more flux lines through the secondary coil. To provide beneficial flux guiding effect over the entire coil, the flux guide is preferably arranged as a loop following the windings of the coils. However, the inventors surprisingly discovered that such a flux guiding loop may itself be a source of energy loss. This was attributed to the fact that the flux guide may act as a short circuited coil. By providing an electric isolation barrier in the flux guide, it is prevented that a current can run through a loop of the flux guide, which may otherwise lead to efficiency loss of the transfer.

[0009] In an advantageous embodiment, the system further comprises a secondary magnetic field generator. The secondary magnetic field generator is arranged for generating a secondary magnetic field through the wall substantially at positions where the primary magnetic field permeates the wall in absence of the secondary magnetic field generator.

for decreasing a magnetic permeability of the wall at said positions and displacing at least part of the primary magnetic field from the wall and through the secondary coil.

[0010] By providing a constant secondary magnetic field through the wall, a magnetic permeability of the wall is lowered which causes magnetic field lines of the primary magnetic field to traverse the wall. These emanating magnetic field lines on the other side of the wall may be guided by the first metal plate shape through the secondary coil thus generating a secondary current.

[0011] In a second aspect there is provided a method for induction mediated energy transfer through a metal wall.

[0012] Further advantages and areas of applicability of the present systems and methods will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the method and system for automatic posture evaluation, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] These and other features, aspects, and advantages of the apparatus, systems and methods of the present invention will become better understood from the following description, appended claims, and accompanying drawing wherein:

FIG 1 shows a conventional system for transferring energy through a metal wall using induction loops.

FIG 2 shows a system wherein flux guides are provided with an electric isolation barrier.

FIG 3 shows an advantageous embodiment of flux guides on a tube having an electric isolation barrier.

FIG 4 shows a system providing enhanced efficiency for inductive energy and/or information transfer through a conductive wall.

FIG 5 illustrates a difference between magnetic field lines for the configurations of FIG 1 and FIG 4.

FIG 6 shows embodiments of the system of FIG 4 applied to a straight wall and a tube.

FIG 7 shows an advantageous embodiment of a system for energy transfer for driving a rotor in a tube.

DETAILED DESCRIPTION

[0014] The following description of certain exemplary embodiments is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. In the following detailed description of embodiments of the present systems, devices and methods, reference is made to the accompanying drawings which form a part hereof, and in which are shown by way of illustration specific embodiments in which the described devices and methods may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the presently disclosed systems and methods, and it is to be understood that other embodiments may be utilized and that structural and logical changes may be made without departing from the spirit and scope of the present system. The following detailed description is therefore not to be taken in a limiting sense, and the scope of the present system is defined only by the appended claims. Moreover, for the purpose of clarity, detailed descriptions of well-known devices and methods are omitted so as not to obscure the description of the present system.

[0015] Induction refers to the production of voltage across a conductor exposed to a varying magnetic field. In a typical system involving magnetic induction, a varying current in a primary coil creates a varying magnetic field that traverses a second coil. This varying magnetic field induces an electromotive force (voltage) in the secondary coil.

[0016] Prior art methods for inductive energy transfer through a conductive wall have an important drawback that the efficiency of the energy transfer is limited. In practice only a reasonable amount of energy can be transferred in the case of a metal wall of a non-ferromagnetic metal as for example stainless steel. In case of a stainless steel pipe with a metal wall thickness of 1 cm and a frequency in the range of 50 Hz the efficiency of the power transfer is limited to a few percent. However in the case of a ferromagnetic metal wall in stead of a non-ferromagnetic metal wall, the efficiency for a metal wall thickness of 1 cm and a frequency in the range of 50 Hz, is rather in the order of parts per million than percent.

[0017] When the transferred energy is used to supply (low-power) sensors, a low efficiency of power transfer can be acceptable, as long as one is able to transfer sufficient energy to power the sensor and the sensor is able to transfer its data in the opposite direction with sufficient signal-to-noise ratio to make reliable detection of the data possible. In practice this will mean that if the power transfer efficiency decreases, the maximum data rate is accordingly lower. Or vice versa:

if one can improve the energy transfer efficiency, one needs less energy to put into the primary coil to power the sensor and the data rate for a given reliability of detection will increase. From this it will be clear that in case of ferromagnetic metals where the efficiency is much lower, the energy required to power a sensor will have to increase accordingly while the maximum data rate of the data sent in the opposite direction will be reduced accordingly.

[0018] If the transferred energy is used to power actuators (e.g. valves, motors) instead of sensors, the efficiency of the power transfer becomes even more important. Suppose one wants to power a valve or pump which requires a power of 100W. In case of a power efficiency of say 1 percent, the required input power will have to be 10kW. One should also consider that 99% of the total input power will show up as heat in the pipe wall and coil windings and will raise the temperature of the pipe wall accordingly.

[0019] FIGs 1A and 1B shows a conventional system 10 for induction mediated energy transfer through a metal wall 13 that is straight (FIG 1A) or comprised of by a tube (FIG 1B). In either case the primary induction coil is situated on one side of the wall while the secondary induction coil 12 is situated on the other side. In the case of the straight wall (FIG 1A), the conductive windings of the primary and secondary coils run substantially parallel along the wall in respective loops on opposite sides of the wall wherein the loops are arranged substantially along a common center line 17. In the case wherein the wall is comprised of by a tube (FIG 1B), the primary and secondary coils are arranged in a concentric manner substantially at a same position along a length of the tube. The conductive windings of in this case the primary coil 11 wraps around an outside of the tube while the conductive windings of the secondary coil 12 wraps along an inside of the wall 13 of the tube.

[0020] In both cases the system comprises a power source 14 arranged for generating an alternating primary current in the conductive windings of the primary coil 11. The conductive windings of the coil are typically arranged in a series of loops or windings. As a result of the primary current through the conductive windings, a primary magnetic field B1 is generated encircling the windings as shown in cross-section in the figures. Depending on the magnetic permeability of the wall 13, some of the magnetic field lines will travel through the wall between the two coils while other magnetic field lines may emerge on the other side of the wall and travel through the secondary coil 12. In particular the (alternating) magnetic field traversing the wall and crossing through the windings of the secondary coil 12 may contribute to the generation of a secondary voltage in the conducting windings of the secondary coil 12. The secondary coil 12 is electrically connected to a receiver 15 which is thus driven by the secondary voltage. In this way electric energy may be mediated from the power source 14 to the receiver 15 through the wall 13.

[0021] Unlike a typical transformer, wherein two coils may be magnetically connected by a common core, in the present case the two induction coils are situated on opposite sides of a conductive wall. This conductive wall acts as a third coil with one - electrically shorted - winding. So the magnetic field generated by the primary coil will also induce a voltage along the circumference of the metal wall. Due to the fact that the wall is electrically highly conductive, this voltage will lead to a large eddy current flowing along the circumference of the pipe wall, resulting in a significant energy absorption, and an accompanying decrease of the power transfer efficiency.

[0022] Furthermore if the wall thickness approaches or exceeds the so called skindepth, the magnetic field due to the primary coil is heavily suppressed in the direction of the secondary coil. This problem increases for ferro-magnetic metal walls with a magnetic permeability (much) higher than 1 leading to a wall which also forms a magnetically low conductive path. These both phenomena will make that the magnetic field lines of the varying magnetic field of the primary coil are conducted by the wall back to the primary coil without traversing the secondary coil. This effect is illustrated in FIGs 1A and 1B by the higher density of magnetic field lines in the wall compared to the field lines traveling through the secondary coil. In effect the conductive wall shields the secondary coil from the magnetic field of the primary coil.

[0023] FIG 2 shows an advantageous embodiment for a system 20 for wireless energy transfer through a metal wall, in this case of a tube. The overview 2A is further illustrated by two cross-sectional views 2B and 2C. In the system 20, the secondary coil 12 is arranged substantially between a first metal plate shape 22 and the wall 13. Furthermore the primary coil 11 is arranged substantially between a second metal plate shape 21 and the wall 13. In the current example both the coils and the flux guides are wrapped around a tube as shown in views 2A and 2B.

[0024] The inventors recognized that most of the energy loss for the wireless energy transfer through a metal wall 13 is due to eddy current loss in the (pipe) wall and loss in the primary winding. In fact the pipe wall can be seen as a third coil with a single turn winding, which is shorted. To improve the efficiency it is currently proposed to preferably add a ferromagnetic guide at the outside and inside of the pipe as shown in views 2A and 2B. A particularly preferred shape for the magnetic guides 21 and 22 is illustrated in view 2C where the magnetic guides are not only on top of the coils, but have also an extension at the sides of the coils for guiding the primary magnetic field B1 around the coils.

[0025] It is noted that in particular the first metal plate shape 22 guiding the magnetic field B1 around the secondary coil provides advantages. This first flux guide 22 competes with the metal wall for conduction of the magnetic field lines B1. The more flux lines are guided through the secondary coil, the more efficient the energy transfer between the coils will be. The second metal plate shape 21 guides the flux lines around the primary coil 11, which lowers the total magnetic impedance for the flux lines, which leads to a higher inductance for the primary windings and therefore a lower current in the primary winding for the same amount of magnetic flux generated by the primary winding. The lower current in the

primary windings decreases the power loss in the primary windings and therefore contributes to a higher efficiency. At the same time it may serve to generally enhance and/or focus the magnetic field at the desired position, i.e. preferably opposite the first flux guide 22.

[0026] Magnetic guides are preferably made of a material with a high magnetic permeability μ_r and a low electrical conductivity σ . Such a material is ferrite. Ferrite however, is a sintered product which has to be machined carefully due to its brittle nature and is therefore not only fragile but also expensive. A cheap alternative would be a ferromagnetic metal, with a high magnetic permeability but unfortunately also a high electrical conductivity. This means that both magnetic guides would not only act as a magnetic guide, but also as a short circuit winding that increases the losses.

[0027] The inventors recognized that a cheaper ferromagnetic metal such as iron or nickel may be used as long as the losses due to electrical conduction are prevented or at least limited. In particular the short circuit of a current through the metal plate shapes can be prevented by inserting an electric isolation barrier 50 somewhere in the circumference of the magnetic guides. As shown in view 2B the metal plate shapes 21 and 22 form flux guiding loops comprising an electric isolation barrier 50 in a tangential direction of the flux guiding loops. The electric isolation barrier in this case is in the form of a small air gap. Alternatively a slit in the circumference of the flux guide may be filled with an electrically insulating material, or an electrically isolating spacer. A small electric isolation barrier may have negligible effect on the flux guiding function of the metal plate shapes.

[0028] A further efficiency enhancement may be achieved if the induction coils 21 and/or 22 are themselves made superconducting. Such a system may be viable e.g. for tubes transporting liquid nitrogen, wherein the temperature of the nitrogen makes some particular materials superconducting, at least for the coil inside the tube.

[0029] FIG 3 shows an advantageous embodiment of flux guides 21 and 22 on a tube having an electric isolation barrier 50. 3A shows the pipe, 3B shows a cross-section perpendicular to the pipe axis and through the magnetic guides, 3C shows a way to prevent the bolt from short circuiting the magnetic guide; 3D shows a cross-section of the pipe in a plane containing the pipe axis.

[0030] It may be difficult to produce three co-axial pipes as shown in view 2B of FIG 2. A more practical construction is found in FIG 3 where each magnetic guide has been split into parts which are provided with flanges to make assembling more easy. One should take care that along the circumference for at least one of the interconnects, the gap between the adjacent flanges is locally electrically insulated by means of an electrically insulating spacer 50. One should also take care that the bolts 61, 62 which connect two adjacent flanges of the waveguide 21 or 22 will not electrically short the flanges. A possible solution is shown in 3C.

[0031] In an advantageous embodiment (not shown), at least part of the flux guide may be provided of the same material and/or as part of the wall of the tube, e.g. extending from the inside and outside of the wall enclosing the windings of the induction coils. This extension preferably comprises an electric isolation barrier in a tangential direction for preventing an electric current in a circumferential direction along the flux guiding parts.

[0032] In a case where the pipe is made of a ferromagnetic metal, the energy transfer efficiency is not only limited by the eddy current losses in the pipe wall but also by the decreasing magnetic field inside the pipe due to a high value of the magnetic permeability μ_r . A parameter describing the decrease of magnetic flux into the direction of the secondary winding due to the presence of the pipe, is the so called skin depth. Starting at the outside of the pipe wall, the decrease of the magnetic field $B(x)$ can be described as:

$$(E1) \quad B(x) = B_0 \exp(-x/\text{skindepth}),$$

wherein B_0 is the magnetic flux near the outside surface of the pipe, x is the distance starting at the outside surface of the pipe and going to the inside, and *skindepth* is the distance inside the pipe relative to the pipe wall, where the magnetic field has decreased to a factor $1/e$.

[0033] The *skindepth* for a given material can be written as

$$(E2) \quad \text{skindepth} = 1/\sqrt{\pi f \mu_0 \mu_r \sigma},$$

wherein $\sqrt{\dots}$ is the square root function, π is the ratio between the circumference and diameter of a circle, f is the frequency of the magnetic field, μ_0 is the magnetic permeability of vacuum, μ_r is the magnetic permeability of the material used, and σ is the electrical conductivity of the material used.

[0034] In a first example, a pipe of stainless steel (grade 316) has electrical conductivity $\sigma \sim 1.35$ MS/m and magnetic permeability $\mu_r \sim 1$. A pair of coils wrapped about the outside and inside of the pipe is operated at a frequency of 50 Hz. For this pipe the skindepth will be $s = 61$ mm. This means that for such a pipe with a metal wall thickness of e.g. 10 mm,

the magnetic flux density B reaching the inside of the pipe is still

$$(E3) \quad B/B_0 = \exp(-10/61) = 0.85.$$

[0035] This means that a significant part of the magnetic field is still apparent at the inside of the pipe and the main 'disturbing' effect of the pipe on the transformer is the energy loss in the 'one turn shorted winding' of the pipe circumference.

[0036] In a second example a pipe of ferro steel, e.g. grade st37 has electrical conductivity $\sigma \sim 6$ MS/m and a magnetic permeability $\mu_r \sim 500 \dots 1000$. The coil frequency is 50 Hz. The skindepth s for this pipe will be $s = 0.92$ mm. This means that for such a pipe with a metal wall thickness of e.g. 10 mm, the magnetic flux density B reaching the inside of the pipe will be

$$(E4) \quad B/B_0 = \exp(-10/0.92) = 1.9 \cdot 10^{-6}.$$

[0037] So the ferro-steel pipe will not only act as a shorted 'third' coil but also damp the magnetic field to such an extent that practically no magnetic energy will reach the inside of the tube at all. A lower magnetic damping with this type of pipe material is only possible by either decreasing the wall thickness, or increasing the skindepth. Increasing the skindepth means decreasing the frequency or choosing a pipe material with lower magnetic permeability or electrical conductivity.

[0038] In a third example, if the same ferro-steel (st37) has a metal wall thickness of 1 mm instead of 10 mm, the flux density will decrease to

$$(E5) \quad B/B_0 = \exp(-1/0.92) = 0.34.$$

[0039] Or alternatively, if the frequency is decreased from 50 Hz to 1 Hz, the flux density will decrease to

$$(E6) \quad B/B_0 = \exp(-10/6.5) = 0.21$$

[0040] Although the magnetic field is still significantly damped, sufficient energy can be transferred to power for example sensors. However thin walls are not always possible and the use of extremely low frequencies in the order of 1 Hz to transfer the energy is very impractical.

[0041] FIG 4, shows a cross-sectional view 4A of a system providing enhanced efficiency for inductive energy and/or information transfer through a conductive wall. 4B shows a typical magnetization curve of a ferromagnetic material such as ferro steel. The effective value for μ_r is the derivative dB/dH of this curve. Around $H=0$ the effective value of μ_r is in the order of 500...1000. But in the saturation region ($H \gg 0$ or $H \ll 0$) the ferro-steel is fully magnetized and μ_r drops down close to a value of 1. In the currently proposed method the skin depth is increased by changing the effective μ_r of the ferro-steel by applying a DC (constant) magnetic field.

[0042] A method to bring the ferro-steel into saturation would be applying a strong DC-current or adding a permanent magnetic field from a strong permanent magnet. A strong DC-current introduces additional loss, so the preferred method is to add a magnetic field from one or more permanent magnets. 4A shows how permanent magnets 23, 24 are applied from both sides of the wall. The magnets 23a and 24a both face with their south poles S to the wall 13. On the other side of the coils 11 and 12, the magnets 23b and 24b both face the wall with their north poles N. This particular configuration causes the magnetic field lines that travel from north to south and vice versa, to travel along the wall 13 in an area between the coils 11 and 12. As may be noted from 4B this permanent magnetic field in the wall 13 between the coils 11 and 12 may saturate the wall locally leading to a significantly reduced magnetic permeability μ_r and consequently a higher skin depth.

[0043] Thus in an advantageous embodiment the system 20 comprises a secondary magnetic field generator 23, 24 arranged for generating a constant secondary magnetic field B2 through the wall 13 substantially at positions where the primary magnetic field B1 permeates the wall in absence of the secondary magnetic field generator 23, 24 for decreasing a magnetic permeability of the wall 13 at said positions and displacing at least part of the primary magnetic field B1 from

the wall and through the secondary coil 12. It is noted that whereas the figure shows how two secondary magnetic field generator 23 and 24 are used on both sides of the wall 13 for decreasing a magnetic permeability of the wall 13, a similar though perhaps lesser effect may also be achieved by either one of the secondary magnetic field generators 23 or 24 separately, e.g. situated only on the in or outside of the wall.

[0044] In a further advantageous embodiment, the system 20 also comprises flux guides 21 and 22 for guiding the flux of both the primary magnetic field (B1, shown in FIG 5) and the secondary magnetic field B2 around the respective coils. It is noted that the secondary magnetic field generators may form part of the respective flux guides.

[0045] In an advantageous embodiment the secondary magnetic field B2 in the pipe wall is at least 1.5 T (Tesla), preferably higher than 2 T, more preferably higher than 3 T. In a further advantageous embodiment, the primary magnetic field B1 varies with an amplitude of preferably not more than 50% of B2.

[0046] The flux guides should preferably have a thickness such that in combination with the sum of the applied magnetic fields B1 and B2, the flux guides themselves will not saturate.

[0047] It is noted that in the field of defect detection there is an improved MFL (Magnetic Flux Leakage) detection technique called SLOFEC (Saturation LOW Frequency Eddy Current). Though this technique is deemed not directly relevant for the present invention it is perhaps illustrative for some of its embodiments.

[0048] MFL is used in the non-destructive testing of metal objects e.g. pipes or plates for local erosion. In MFL measurements, a magnet within a yoke construction is used to establish a uniform magnetic flux in the material to be inspected. The magnetization should be up to a high level close to magnetic saturation. In a defect free plate the magnetic flux is uniform. In contrast a metal loss type defect, such as local corrosion or erosion, not only distorts the uniformity of the flux but a small portion of the magnetic flux is forced to leak out of the plate. Sensors placed between the poles of the magnet or yoke construction can detect this small local leakage.

[0049] In an improved MFL technique called SLOFEC the original sensors that measure this leakage field are replaced by so called eddy current sensors which superimpose a local HF (high-frequency) magnetic field on top of the permanent magnetic field. This HF field induces eddy-currents in the metal object, and these eddy currents cause an additional HF magnetic field which is superimposed on the original HF magnetic field. The resulting HF magnetic field is detected by the eddy-current sensors. Compared with the original MFL method, smaller and different type of anomalies in the metal object can be detected because anomalies as cracks and pits can have a significant influence on the path of the locally induced eddy currents and therefore also the shape of the local HF magnetic field.

[0050] Eddy currents in steel have a small penetration depth due to the high relative magnetic permeability, say 500 or more. This limits penetration of the eddy currents to the outer surface. However, in the SLOFEC technique, this so called skin effect is reduced by magnetic saturation of the wall, causing a low relative permeability, say close to 1.

[0051] FIGs 5A and 5B illustrate a difference between magnetic field lines for the configurations of FIG 1 and FIG 4, respectively.

[0052] In FIG 5A, no particular efficiency enhancing structure is present. Due to the distance between the primary and secondary coil, the skindepth of the metal wall and the high magnetic permeability of the wall 13, most of the magnetic field B1 generated by the primary coil 11 is guided back through the wall and not around the secondary coil 12, where a flux change would lead to the generation of a voltage in the secondary coil 12. As a result, the system 10 of FIG 5A has a low efficiency for energy transfer between the coils 11 and 12.

[0053] In FIG 5B on the other hand, a secondary magnetic field generator is provided in the form of permanent magnets, similar as in FIG 4. The secondary magnetic field generator generates a DC field in the wall leading to an area of relatively low magnetic permeability in the wall and therefore an increased skin depth. This causes that an increasing number of magnetic field lines of the primary (alternating) magnetic field B1 will pass the wall to the other side. By providing a first flux guide 22, this leaking magnetic field may be guided preferably around the windings of the secondary coil 12.

[0054] Another way to look at this is that the magnetic field B1 lines will seek a path of least resistance, wherein a higher magnetic permeability means a lower resistance. By simultaneously decreasing the magnetic permeability in the wall 13 and increasing the magnetic permeability through the second coil by use of the metal plate shape 22, the balance of where the magnetic field lines will go shifts in favor of a path through the secondary coil 12 leading to an enhancement of the energy transfer efficiency. It is noted that in order to prevent further energy losses in the flux guides, due to a current that may arise in the flux guides as a result of the oscillating magnetic field, an electric isolation barrier or conductance gap may be provided in a tangential direction along a circumference of a loop formed by the flux guide as was shown in FIGs 2 and 3.

[0055] FIGs 6A and 6B show two embodiments of the enhanced efficiency wireless energy system 20 of FIG 4 applied to a straight wall and a tube, respectively.

[0056] In FIG 6A the system 20 is applied to a straight wall similar to FIG 1A, wherein the coils are arranged to form parallel loops on either sides of the wall 13. The coils are shown to have a substantially common center line 17 around which the coils may be arranged in a circle symmetric manner, except for an electric isolation barrier along a loop of the flux guides.

[0057] In FIG 6B the system 20 is applied to a tube similar to FIG 1B, wherein the coils are arranged to wrap on the

inside and outside of the tube in a circle symmetric and concentric manner around a central axis 17. Again the flux guides may be provided with an electric isolation barrier in a tangential direction along a circumference of the loop formed by the flux guide around the tube.

[0058] It is to be appreciated that while the presently disclosed system 20 provides an advantageous energy transfer efficiency gain through ferromagnetic walls, e.g. iron tubes, a still further increase in efficiency may be achieved by arranging a non-ferromagnetic wall between the coils. On the other hand it may be that ferromagnetic materials such as iron are cheaper to obtain than non-ferromagnetic materials such as stainless steel. Accordingly, in an embodiment there is provided a metal wall having a ferromagnetic part and a non-ferromagnetic part, wherein the non-ferromagnetic part is arranged between the primary coil and secondary coil.

[0059] Advantageously, by applying this construction, only the part of the wall where energy is to be transferred through needs to comprise a non-ferromagnetic material while the rest may be of a cheaper ferromagnetic material. Such a construction could e.g. be easily applied in a tube wherein a single tube segment with the system 20 comprises stainless steel while the other segments comprise iron. This may provide an overall cheaper construction of the tube and since long tubes naturally comprise multiple segments no sacrifice is made to the structural integrity of the wall. Of course the usual precautions may need to be taken to prevent rust formation at the boundary surfaces between the segments of different materials.

[0060] FIG 7 shows an advantageous embodiment of a system for energy transfer for driving a rotor 70 in a tube. Energy supplied by energy source 14 in the form of an alternating current drives the primary coil 11 of the wireless energy transfer system 20. The system 20 transfers the energy through the wall 13 by induction to a secondary coil 12 on the other side of the wall 13. The secondary coil 12 is electrically connected to a receiver 15 in this case comprising a rotor 70, e.g. for propelling a fluid or gas through the tube. The tube may typically have a width e.g. of 10 - 100 cm or more. Typical powers that may be transferred by the energy source to the secondary coil and rotor may be e.g. in the range of 10 W - 1 kW. The currently proposed system 20 provides an advantage that the integrity of the tube wall 13 is not compromised by any electric windings through the wall. This makes the system 20 particularly suitable in case the tube is used to transport dangerous materials such as explosive or toxic compounds.

[0061] It is noted that throughout this text where there is a reference to an advantage for the wireless transfer of energy this same advantage also applies to the transfer of information or data e.g. by modulating a frequency and/or amplitude of the magnetic field. In particular it is noted that whereas the skin depth for increasing frequencies goes down, the currently proposed system may counteract this deficiency, e.g. by pre-saturating the wall with a constant magnetic field, thus allowing higher frequencies to penetrate the wall which may be equated to a higher data throughput. Thus it is argued that the currently proposed system not only provides advantages for energy transfer, e.g. for actuators, but also for information transfer, e.g. for sensors.

[0062] The various elements of the embodiments as discussed and shown offer certain advantages, such as a higher efficiency. Of course, it is to be appreciated that any one of the above embodiments or processes may be combined with one or more other embodiments or processes to provide even further improvements in finding and matching designs and advantages. It is appreciated that this invention offers particular advantages for transport of oil through metal tubes and in general can be applied for any system wherein energy and/or information needs to be transferred through a conductive wall without compromising the integrity of the wall. It is noted that also any kinematic inversions having similar functionality are considered as part of the disclosure, e.g. while it is shown in the figures that the primary coil is on the outside of the tube and the secondary coil on the inside, this may also be reversed, e.g. for a power source inside a tube that generates power, e.g. using a dynamo in a stream of water that flows through the tube, and sending this power to the outside of the tube. Such a system may find application e.g. in water power plants.

[0063] This description of the exemplary embodiments is thus intended to be read in connection with the accompanying drawings, which are to be considered part of the entire written description. In the description, relative terms as well as derivative thereof should be construed to refer to the orientation as then described or as shown in the drawing under discussion. These relative terms are for convenience of description and do not require that the apparatus be constructed or operated in a particular orientation unless expressly indicated. Terms concerning attachments, coupling and the like, such as "connected" and "interconnected," refer to a relationship wherein structures are secured or attached to one another either directly or indirectly through intervening structures, as well as both movable or rigid attachments or relationships, unless expressly described otherwise.

[0064] Finally, the above-discussion is intended to be merely illustrative of the present system and should not be construed as limiting the appended claims to any particular embodiment or group of embodiments. Thus, while the present system has been described in particular detail with reference to specific exemplary embodiments thereof, it should also be appreciated that numerous modifications and alternative embodiments may be devised by those having ordinary skill in the art without departing from the broader and intended spirit and scope of the present system as set forth in the claims that follow. The specification and drawings are accordingly to be regarded in an illustrative manner and are not intended to limit the scope of the appended claims.

[0065] In interpreting the appended claims, it should be understood that the word "comprising" does not exclude the

presence of other elements or acts than those listed in a given claim; the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements; any reference signs in the claims do not limit their scope; several "means" may be represented by the same or different item(s) or implemented structure or function; any of the disclosed devices or portions thereof may be combined together or separated into further portions unless specifically stated otherwise; no specific sequence of acts or steps is intended to be required unless specifically indicated; and no specific ordering of elements is intended to be required unless specifically indicated.

Claims

1. A system for induction mediated energy transfer through a metal wall, the system (20) comprising
 - a power source (14) arranged for generating an alternating primary current;
 - a primary coil (11) situated at one side of the wall (13), the primary coil (11) comprising conductive windings electrically connected to the power source (14) and arranged for conducting the alternating primary current so as to generate an alternating primary magnetic field (B1);
 - a secondary coil (12) situated at the other side of the wall (13), the secondary coil (12) comprising conductive windings and arranged with respect to the primary coil (11) such that the alternating primary magnetic field (B1) traverses the secondary coil (12) so as to generate an alternating voltage in the secondary coil (12); and
 - a receiver (15) electrically connected to the secondary coil (12) arranged for receiving power generated in the secondary coil; wherein
 - the system (20) further comprises a first metal plate shape (22) arranged in a manner that the secondary coil (12) is located between the first metal plate shape (22) and the metal wall (13), wherein the first metal plate shape (22) follows the coil windings in tangential direction and comprises an isolation barrier (50) arranged between lateral sides of the first metal shape thereby preventing electric conduction across the barrier in a tangential direction.
2. System according to claim 1, further comprising a secondary magnetic field generator (23) positioned on the metal wall and adjacent opposite lateral sides of the first metal plate shape (22) thereby generating a secondary magnetic field (B2) extending into the wall along a contour between opposite lateral sides and directed between said lateral sides of the first metal plate shape so as to displace at least part of the primary magnetic field (B1) from the wall (13) and through the secondary coil (12).
3. System according to any of the previous claims, further comprising a second metal plate shape (21) arranged in a manner that the primary coil (11) is located between the second metal plate shape (21) and the metal wall (13), wherein the second metal plate shape (21) follows the coil windings in tangential direction and comprises an isolation barrier (50) arranged between lateral sides of the second metal shape (21) thereby preventing electric conduction across the barrier in a tangential direction.
4. System according to any of the previous claims, wherein the secondary magnetic field generator (23, 24) comprises magnetic field generators at both sides of the wall.
5. System according to any of the previous claims, wherein the secondary magnetic field generator (23, 24) comprises permanent magnets.
6. System according to any of the previous claims, wherein the wall (13) is comprised of by a tube, the primary and secondary coils (11, 12) arranged in a concentric manner substantially at a same position along a length of the tube wherein the conductive windings of one of the primary or secondary coils wraps around an outside of the tube and the conductive windings of the other of the primary or secondary coil wraps on an inside of the tube.
7. System according to claim 6, wherein the first and/or second metal plate shapes (21,22) are each comprised of by separate pieces forming a loop on an inside of the tube, the pieces connected by an isolating element forming the electric isolation barrier (50).
8. System according to any of the claims 6-7, wherein the tube is arranged for transporting a hazardous material.
9. System according to any of the claims 1 — 5, wherein the wall (13) or part thereof is substantially planar, the conductive windings of the primary and secondary coils running substantially parallel to the wall (13) in respective

loops on opposite sides of the wall (13), the loops arranged substantially along a common center line (17).

10. System according to any of the previous claims wherein the electric isolation barrier (50) comprises one or more of an air slit, a slit filled with an electrically insulating material, or an electrically isolating spacer.

11. System according to any of the previous claims wherein one or more of the coils (11, 12) is superconducting.

12. System according to any of the claims 2 — 11 wherein the secondary magnetic field generator (23, 24) is positioned on both sides of the metal wall (13).

13. System according to any of the previous claims, comprising a metal wall having a ferromagnetic part and a non-ferromagnetic part, wherein the non-ferromagnetic part is arranged between the primary coil and secondary coil.

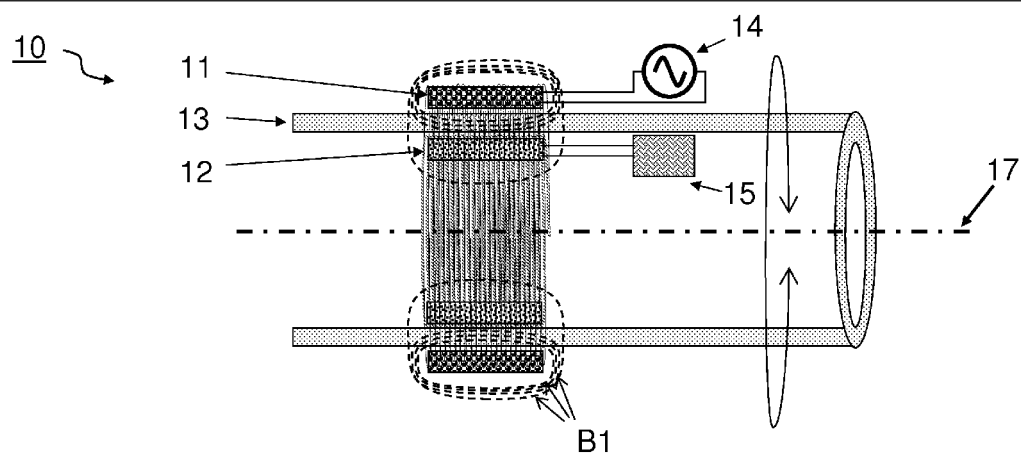
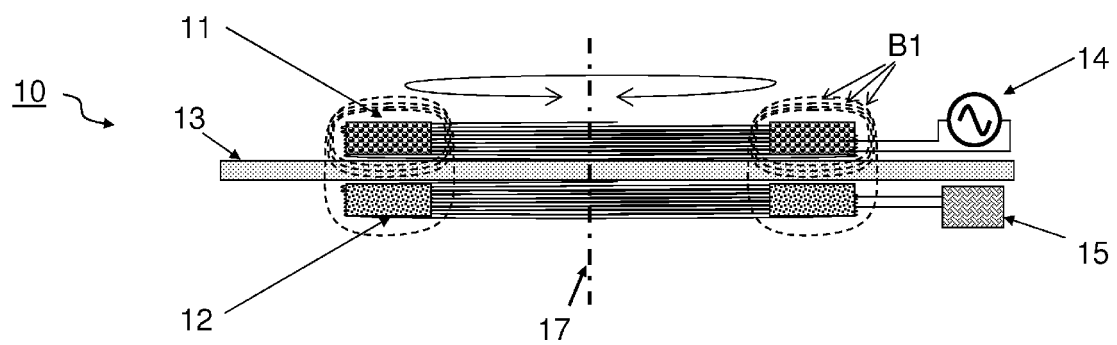
14. Method for induction mediated energy transfer through a metal wall (13), the method comprising the steps of:

- generating an alternating primary current in a primary coil (11) situated at one side of the wall (13), the primary coil (11) comprising conductive windings electrically connected to the power source (14) and arranged for conducting the alternating primary current so as to generate an alternating primary magnetic field (B1);
- providing a secondary coil (12) at the other side of the wall (13), the secondary coil (12) comprising conductive windings and arranged with respect to the primary coil (11) such that the alternating primary magnetic field (B1) traverses the secondary coil (12) so as to generate an alternating secondary current in the secondary coil (12); and
- receiving (15) electrical power from the secondary coil; wherein
- the method further comprises:

- o arranging a first metal plate shape (22) in a manner that the secondary coil (12) is located between the first metal plate shape (22) and the metal wall (13), wherein the first metal plate shape (22) follows the coil windings in tangential direction and comprises an isolation barrier (50) arranged between lateral sides of the first metal shape thereby preventing electric conduction across the barrier in a tangential direction.

15. Method according to claim 14, wherein the method further comprises:

- o generating a secondary magnetic field by a secondary magnetic field generator (23) positioned on the metal wall and adjacent opposite lateral sides of the first metal plate shape (22) thereby generating a secondary magnetic field (B2) extending into the wall along a contour between opposite lateral sides and directed between said lateral sides of the first metal plate shape so as to displace at least part of the primary magnetic field (B1) from the wall (13) and through the secondary coil (12).



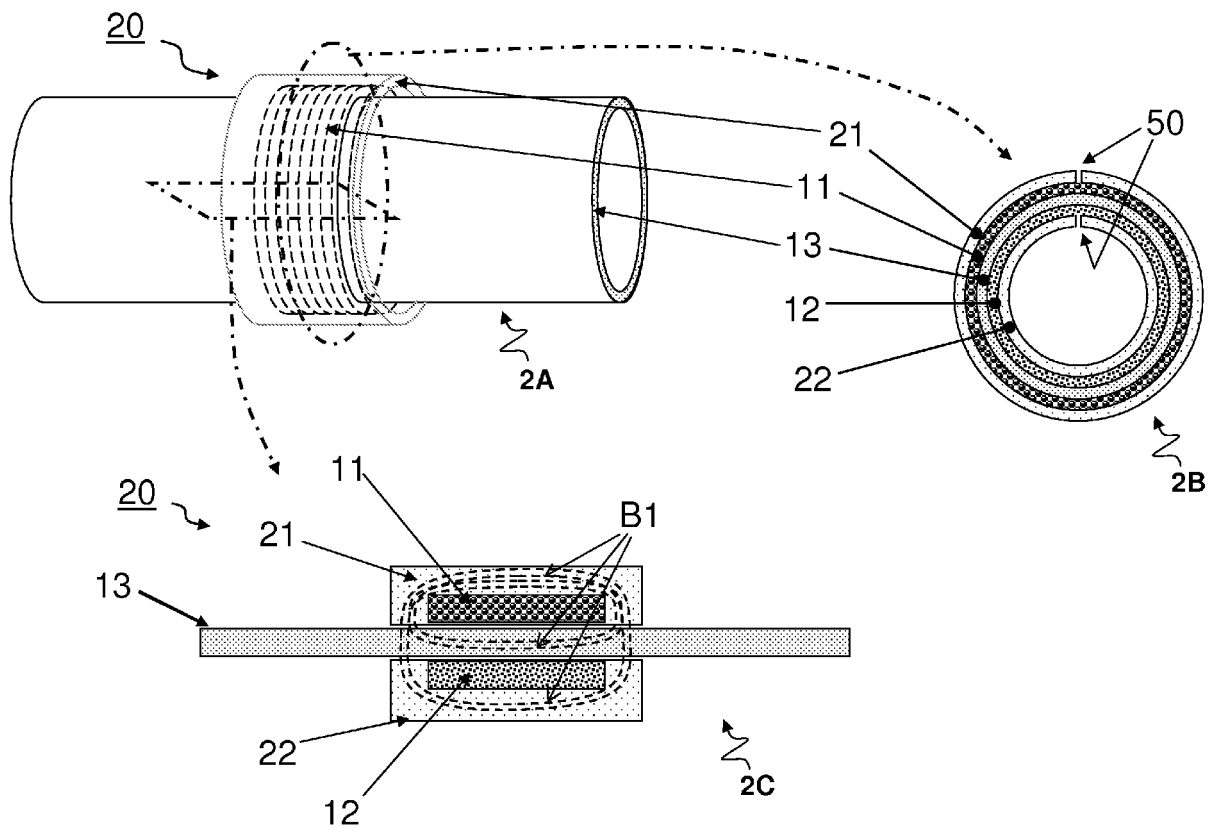


FIG 2

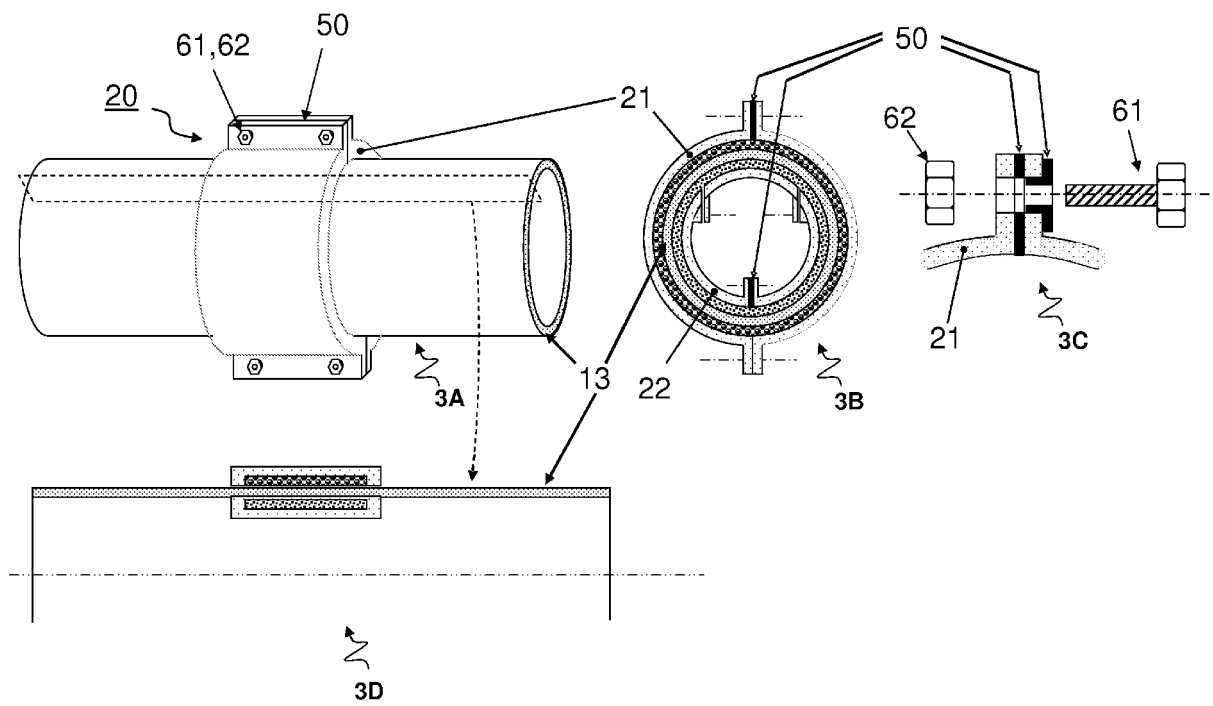


FIG 3

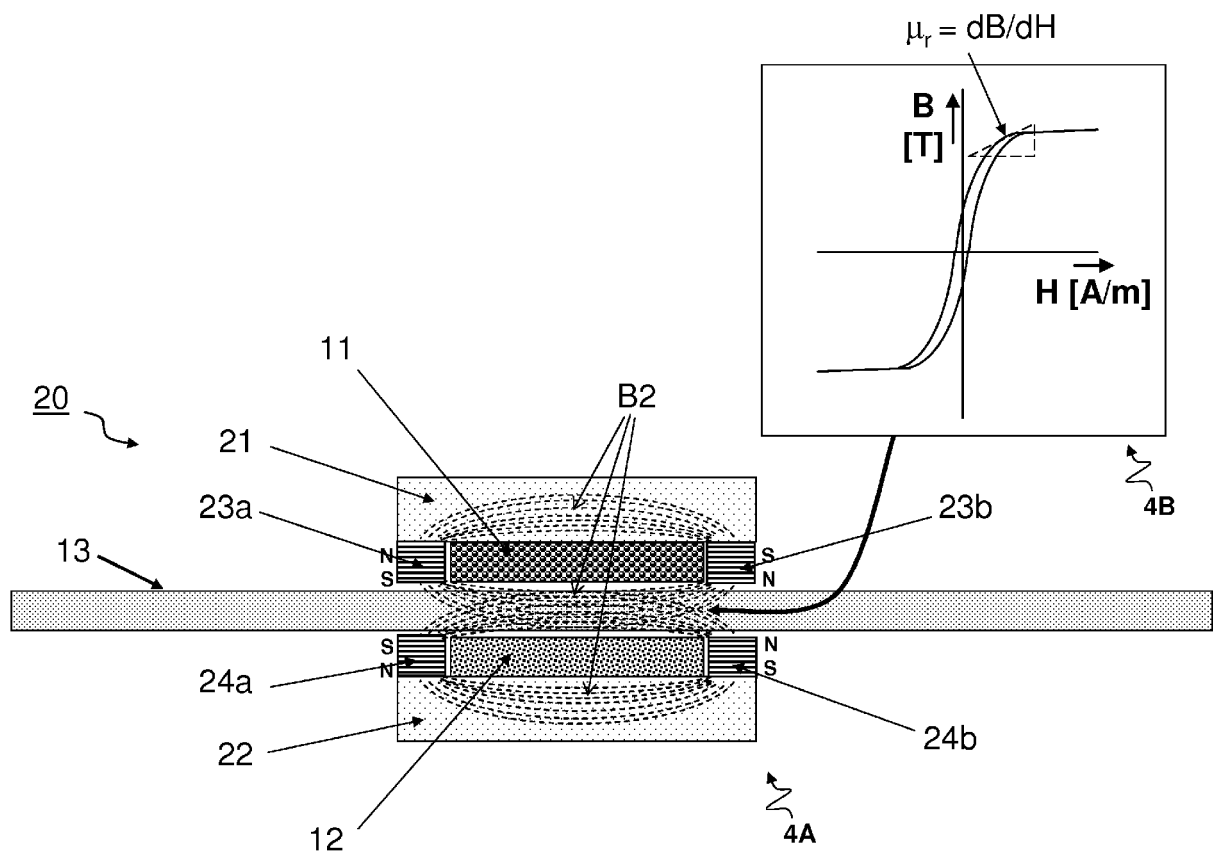
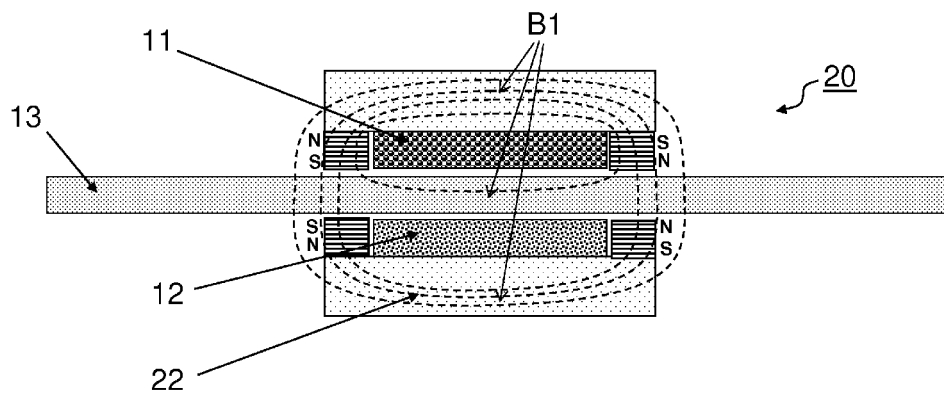
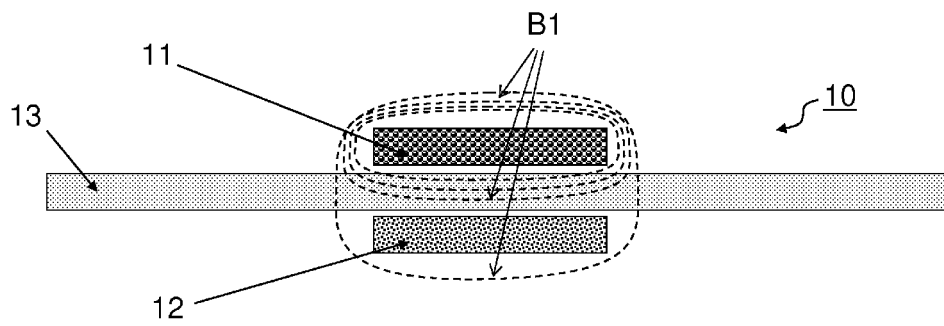


FIG 4



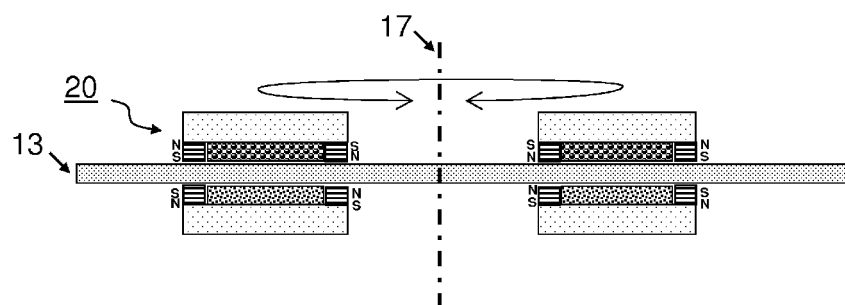


FIG 6A

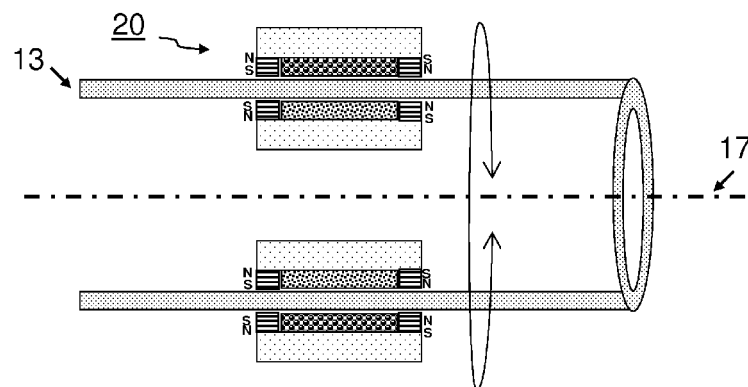


FIG 6B

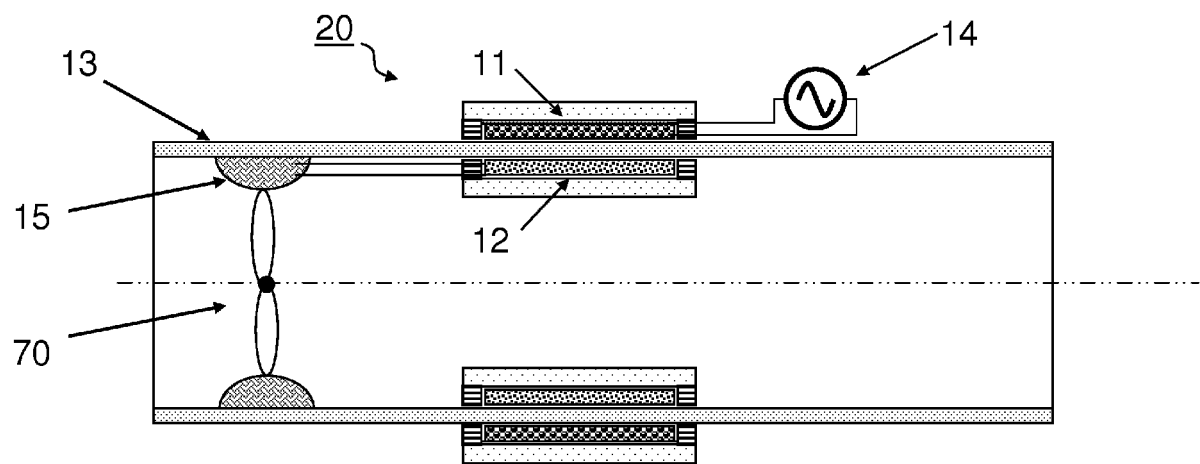


FIG 7



EUROPEAN SEARCH REPORT

Application Number
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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 21 December 2011	Examiner Gols, Jan
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