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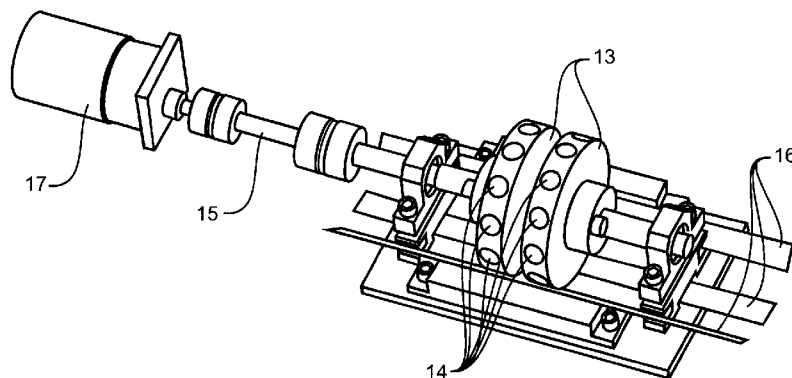


FIGURE 8

(57) Abstract: A flux pump is disclosed for inducing current and a magnetic field in a superconducting circuit device, which includes in the circuit a section of a type II high temperature superconductor, and the flux pump is arranged to cause a magnetic field to enter the superconducting circuit through the type II HTS section thus increasing current in the superconducting circuit, without creating a non-superconducting region (a normal spot) in the type II HTS section.

“SUPERCONDUCTING FLUX PUMP AND METHOD”

FIELD OF INVENTION

5 The invention relates to a flux pump and method or flux pumping.

BACKGROUND OF INVENTION

10 For example a flux pump may be used to energise a superconducting coil, or to top up any losses in a superconducting circuit resulting from current decay when the superconducting circuit is operated in persistent or near persistent modes.

A flux pump drags or moves magnetic flux, produced by one or more permanent magnets or electromagnets, into a superconductor. The change of trapped flux induces current in the
15 superconductor. Movement of the magnet(s) may be repeated in the same direction to further increase current.

SUMMARY OF INVENTION

20 In broad terms in one aspect the invention comprises a flux pump for inducing current and a magnetic field in a superconducting device, the superconducting device to be energised being in a superconducting circuit which also includes at least a section of a type II high temperature superconductor (HTS) , the flux pump being arranged to cause a magnetic field to enter the superconducting circuit through the type II HTS section thus energising or increasing current in
25 the superconducting device, without creating a non-superconducting region (herein: a normal spot) in the type II HTS section.

In broad terms in a further aspect the invention comprises a method of flux pumping to induce current and a magnetic field in a superconducting coil, which comprises causing a magnetic
30 field to move across a section of a type II HTS in a superconducting circuit and enter the superconducting circuit through the type II HTS section thus energising or increasing current in the superconducting circuit, without creating a non-superconducting region in the type II HTS section.

In the superconducting circuit there may be one or more non-superconducting or normal conducting sections such as one or more joints between sections of an HTS coil and/or to the type II HTS section for example.

- 5 The superconducting device may be a superconducting coil or other superconducting device.

Flux pumps are known at least for type I superconductor low temperature superconductors (LTS), which create a non-superconducting region or normal spot in the superconductor through which the pumping flux from a moving magnet or electromagnet is transferred into the superconducting
10 loop, by exceeding the critical field (B_c) of the superconductor locally to form this normal spot. For HTS the B_c is too high to create a normal spot in this way practically, but alternatively it would be possible to employ a heater to create a normal spot by exceeding the critical temperature (T_c) locally.

15 Flux pumps of the invention as above do not require a heater for creating a normal spot for introducing flux into the superconducting circuit by exceeding the critical temperature (T_c) of the superconductor locally, and do not require that the critical field (B_c) of the superconductor is exceeded locally where the pumping flux penetrates. In at least some embodiments of the flux pump and method of the invention a normal spot is not created. At least the part of the
20 superconducting circuit into which flux is pumped is a type II superconductor and remains superconducting while allowing the moving flux to penetrate into the superconducting material without changing the state of the superconductor i.e. a transition into the normal state does not occur.

25 In broad terms in another aspect the invention comprises a flux pump for inducing current and a magnetic field in a superconducting circuit, arranged so that the magnet which crosses the superconducting circuit is similar to or greater in dimension than the dimension of the part of the superconducting circuit in the direction in which the magnet crosses the superconducting circuit. In the direction in which the field crosses the superconducting circuit the field strength is sufficient
30 to maintain a type II condition across the whole dimension of the type II HTS in this direction.

In some embodiments the flux pump includes a rotating carrier carrying one or more permanent, electro or superconducting magnets and arranged to rotate to cause the magnetic field from the or each of the magnets to cross the type II HTS section and remove in a way that the flux is trapped
35 in the superconducting circuit thus energising or increasing current in the superconducting circuit.

In some embodiments the dimension of one or more individual permanent, electro or superconducting magnets in the direction in which the magnets crosses the superconducting circuit is similar to or greater in dimension than the dimension of the part of the superconducting which the magnet(s) cross.

5

In broad terms in a further aspect the invention comprises a method of flux pumping to induce current and a magnetic field in a superconducting circuit, which comprises moving across a part of the superconducting circuit a magnet having a dimension in the direction in which the magnet moves relative to the conducting circuit which is similar to or greater than the dimension of the conducting circuit in the direction in which the magnet crosses the superconducting circuit In the direction in which the field crosses the superconducting circuit the field strength is sufficient to maintain a type II condition across the whole dimension of the type II HTS in this direction.

10

The term “comprising” as used in this specification means “consisting at least in part of”. When interpreting each statement in this specification that includes the term “comprising”, features other than that or those prefaced by the term may also be present. Related terms such as “comprise” and “comprises” are to be interpreted in the same manner.

15

BRIEF DESCRIPTION OF THE FIGURES

20

The invention is further described with reference to the accompanying figures by way of example and without intending to be limiting, in which:

Figure 1 is a schematic view of a flux pump of a first embodiment of the invention,

25

Figure 2 is another schematic view of the flux pump of Figure 1,

Figure 3 is a schematic view of a flux pump of another embodiment of the invention,

Figure 4 is a schematic view of a flux pump of a further embodiment of the invention,

30

Figure 5 is a schematic view of a flux pump of another embodiment of the invention,

Figure 6 is another schematic view of the flux pump of Figure 5,

35

Figure 7 is a schematic view of a flux pump of another embodiment of the invention,

Figure 8 shows a flux pump of the invention referred to in the subsequent description of experimental work, and

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Figure 9 is a plot of current in the coil versus time for various rotation frequencies in the experimental setup described subsequently.

10 DETAILED DESCRIPTION OF EMBODIMENTS

In the figures reference numeral 1 indicates a superconducting coil to be energised that is either persistent, or has a low series resistance (e.g. 20-1000 nanohms) such that superconducting current in it has a long decay time. The superconducting coil or device may be an HTS or LTS coil or device. In either case the superconducting circuit also includes at least a section 2 of type II HTS conductor in circuit with but physically separate from/spaced from the coil or device to be energised, as shown. The spacing may be small compared to the dimension of the coil and the type II HTS section may be mounted on the side of the coil for example. The whole circuit including also the coil 1 may comprise a type II HTS. In certain embodiments where the coil 1 is an HTS coil or device, the coil is wound with conductor, and the conductor section 2 is of the type comprising a layer or film of an HTS material, such as an REBaCuO superconductor for example, on a substrate (a 2G HTS conductor). In other embodiments the coil or device 1 is wound with conductor, and the conductor section 2 is, of the type comprising a superconducting material such as an BiSrCaCuO superconductor for example, in a silver tube or tubes (a 1G HTS conductor).

25

A flux pump includes a rotating carrier 3 comprising around its periphery a series of magnets 4, which may be permanent magnets, such as NdFeB magnets, or electromagnets. The magnets optionally may also each comprise an attached pole of iron or other ferromagnetic material machined to a desired size and shape to focus the flux from the magnets 4. Optionally the magnets 4 may each comprise a superconducting magnet such as a piece of magnetized ReBCO bulk material (the advantage being that the magnetic field produced by superconducting magnet is significantly higher than permanent magnet or electromagnet of the same dimension, thus the efficiency of flux pumping can be improved). The flux pump also comprises a motor (not shown) to rotate the carrier 3 and typically also a control system including a speed controller for the motor

30

driving the rotating carrier, and may also comprise a sensor such as a Hall sensor for detecting the strength of flux in the coil 1 with a feedback loop to the control system.

5 The superconducting circuit is cooled to a temperature at or below T_c of the lowest T_c part of the superconducting circuit, by a cryo-cooler or liquid nitrogen or helium, or other cryogen, as known in the art. The flux pump can be operated at a different temperature to that of the superconducting coil or device being energised. For example in a flux pump of the invention for energising an LTS coil or device the LTS coil will be cooled to a lower temperature while the flux pump may be operated at a higher temperature for example 77K with the HTS wires between the
10 flux pump and LTS coil or device comprising a temperature gradient along their length. For example the flux pump may be mounted on the first stage of a two stage cryo-cooler system for the HTS circuit or device for example.

In use the carrier 3 is driven to rotate, as indicated by arrow A, causing the magnetic field from
15 each of the magnets 4 to move across the conductor 2 in turn, from the outside to the inside of the superconducting loop, and then be removed in a way that the flux is trapped in the superconducting circuit thus increasing current in the superconducting circuit. In at least some embodiments the dimension of the magnets 4 and/or of the pumping field in the direction in which the magnets move across the conductor 2 is similar to or greater than the dimension of the
20 conducting circuit in this direction in which the pumping flux crosses the superconducting circuit.

The travelling magnetic field(s) increases the total flux within the superconducting circuit by dragging flux from outside the loop across the conductor 2 into the loop. The magnets 4 pass over the conductor 2 and are then lifted away after crossing the conductor 2, to avoid reversal of the
25 pumping effect. Alternatively if the magnets 4 are electromagnets (see below) the controller may be arranged to simply turn off current to each electromagnet once the magnetic wave has entered the superconducting circuit.

When the travelling magnetic field from each magnet 4 crosses the conductor 2 it induces current
30 in the conductor and as the direction of motion of the magnetic field is constant the current induced will be in the same sense and successive waves will induce more and more current. When the field crosses the conductor 2 flux lines penetrate the conductor and follow the motion of the magnet due to non-zero mobility of the flux in the material. Flux enters the superconducting circuit and the total flux in the circuit increases. When the magnet is removed the superconducting
35 circuit acts to keep the now increased trapped flux constant and therefore induces a voltage. A net

voltage will be achieved when the voltage in this step is larger than other parasitic voltages, due to eddy current losses or AC losses in the HTS section for example.

The superconducting circuit component 2 if not also the whole superconducting circuit is a type II superconductor, which allows the pumping flux to move through it without a transition into the normal state occurring, such as an REBaCuO or BiSrCaCuO superconductor, so that it remains superconducting at all times (with the magnetic field applied from the magnets 4 being below the critical magnetic field B_c). By a type II superconductor is meant a superconductor which exhibits a mixed state. The type II superconductor may have an N value of about less than about 50, preferably less than about 30 or 20 or less. The voltage drop along a superconductor follows a power law or in other words the voltage is proportional to the current to the power of N. This N-value can be considered a measure of how much flux motion is possible without a transition into the normal state. High N-values lead to extremely fast transition if flux lines start to move.

The control system may be arranged to cease flux pumping when a predetermined field strength from the coil 1 is achieved and/or activate the flux pump if the field strength decays below a threshold to maintain a predetermined level or a flux level within a predetermined range.

Preferably the section of a type II HTS comprises minimal or no normal conducting metal, to reduce any eddy current losses, such as no metal having resistivity equivalent to Cu (at 295K, $r=1.7 \mu \text{ Ohm cm}$) or Ag (at 295K, $r=1.6 \mu \text{ Ohm cm}$) or lower. In one form the section of a type II HTS comprises a high resistivity substrate, a buffer layer, a layer of the HTS material on the buffer layer, and a high resistance layer over the HTS layer. In one form, the substrate is made of stainless steel (at 295K, $r=75 \mu \text{ Ohm cm}$) and Ni-W alloys which both exhibit higher resistance than Cu and Ag. Alternatively, single crystals for example Sapphire, MgO, YSZ, LaAlO₃, SrTiO₃ may also be used as the substrate. The buffer layer serves as a diffusion barrier between the substrate and HTS layer to prevent corruption of the two layers. Metal oxides for example CeO₂, Y₂O₃, MgO, YSZ may be used in buffer layer. A layer or cap over the HTS layer having low resistance to reduce eddy current losses but good thermal conductance may protect the HTS layer, such as a very thin metallic layer such as of Ag or Cu of thickness less than 10 microns or 5 microns, or alternatively or in addition a layer of a non-electrically conductive material such as Sapphire, MgO, YSZ, LaAlO₃, SrTiO₃, or AlN for example.

In Figures 1 and 2 a single rotating carrier 3 for magnets 4 is shown but other embodiments may comprise multiple such moving carriers 3 with magnets 4 arranged in parallel i.e. to rotate or move

about the same axis, or in any other configuration, and also multiple rotating carriers 3 – magnets 4 may contra-rotate relative to one another, all to increase the current induced in the HTS section (or sections) 2 and thus superconducting circuit on each pass of a magnet 4. Instead of permanent magnets or electromagnets the magnets 4 may comprise superconducting coils (having high flux density) to further increase the current induced in the superconducting circuit. One or more magnetic tapes or magnetic elements may be positioned between rotating carrier 3 and a ferromagnetic plate (not shown), or between two rotating carriers to increase the magnetic flux and thereby increase the current induced in the superconducting circuit. One or more moving magnet carriers may be arranged to move such that their magnets cross the HTS 2 at the same time as the magnets of one or more other moving magnet carriers (in phase), or at different times (out of phase). In one embodiment where magnetic tape(s) and multiple rotating carriers 3 are used, the rotating carriers preferably rotate at the same speed and so that the poles are facing and when magnets cross the magnetic tape, a north pole faces a south pole. Preferably the orientation of the magnetic tape(s) is substantially perpendicular to HTS 2 when magnetic flux penetrates in the HTS section of a superconductor circuit, and is rotated by approximately 90 degrees when magnets leave the HTS section. More preferably, a shield for example a diamagnetic shield may be positioned in the exit path of magnets over the HTS section to replace the magnetic tape or further enhance the effect of the magnetic strip.

The control system may be arranged to vary the speed at which the carriers-magnets move, to maintain a constant current in the superconducting circuit e.g. to increase the rotational speed of carrier 3 to increase the current or, decrease the speed or reverse the rotation of one or more carriers-magnets to reduce the induced current or to control the induced current to a desired level. The control system may also be arranged to induce a steady field at a chosen ramp rate (rate of field increase).

The moving magnet carrier(s) may be driven by a metal wire wound motor or motors operating at room temperature. The motor may comprise a rotor shaft which extends through a thermally isolating vacuum chamber and into a cryogenic chamber where the superconducting circuit and flux pump are housed and cooled to at or below T_c . Alternatively magnetic coupling between the motor and rotating carrier(s) may be used to eliminate a motor drive shaft extending into the cryogenic chamber. In another alternative embodiment, the motor may be a superconducting motor itself positioned in the same cryogenic chamber as the superconducting circuit and flux pump.

In an alternative embodiment the rotating carrier(s) 3 with physically moving magnets or electromagnets or superconducting magnets 4 about its periphery may be replaced with a linear array across the conductor 2 of two or more electromagnets. In use a first (outermost) electromagnet is energised followed by one or more electromagnets one after the other each closer in turn to the inside than the outside of the superconducting loop, to thereby create a magnetic field which moves across the conductor 2. This may be repeated by reenergising each electromagnet in turn multiple times to induce further current in the superconducting circuit.

Conventional flux pumps create a non-superconducting region, or normal spot, in the superconducting circuit, through which the pumping flux from a moving magnet or electromagnet is transferred into the superconducting loop. In the flux pump and flux pumping method of the invention a normal spot is not required. Thus for flux pumping HTS the flux pump need not comprise a heater for thermally creating and moving a normal spot in the superconducting circuit. The flux pump can therefore be simpler. The conductor 2 must be at T_c or below but beyond that thermal control is not required. However, it is not intended to preclude heating the HTS section 2 where the magnets cross, to a temperature at which flux pumping into the HTS conductor may be most efficient, but still below the critical temperature T_c above which a normal spot will occur through thermal heating. Also if performance of the flux pump varies with variation in temperature (below T_c) then a heater a heater may be provided to stabilise the temperature of the flux pump at an optimum temperature. The flux pump temperature may also be varied to vary and in particular fine tune the amount of flux pumped into the device or circuit.

Figures 3 to 6 show flux pumps of further embodiments of the invention. In Figures 3 to 6 the same reference numerals indicate the same elements as in Figures 1 and 2 unless indicated otherwise. The embodiment of Figure 3 is similar to that of Figures 1 and 2 except that in this embodiment the rotating carrier 3 carrying around its periphery magnets 4 rotates over two or more parallel arms 2a and 2b of type II HTS conductor 2, which doubles (or more) the amount of flux trapped in the superconducting circuit with each rotation of the carrier 3 and magnets 4, or each pass of a single magnet 4, thus increasing current in the superconducting circuit at a higher rate. The HTS arms 2 are connected to a superconducting coil or other device to be energised as before. In this embodiment and the earlier described embodiments each type II HTS length may be a stack of multiple type II HTS sections or conductors to also increase current induced in the superconducting circuit on each magnet pass. In the embodiment of Figure 4 the HTS conductor 2 (or multiple parallel sections of HTS conductor as in the embodiment of Figure 3) pass axially around rotating carrier 3 so that the magnets 4 move around the HTS conductor 2, rather than rotating above the HTS conductor as in the embodiments of Figures 1 to 3.

In the embodiment of Figures 5 and 6 four sections 2c-2f of electrical contact pads on a type II HTS conductor of planar geometry 2, either all in a superconducting circuit with a single superconducting coil or device or each connected to a separate superconducting coil or device, are arranged in an annular form as shown. Each of the contact pads 2c-2f is connected in parallel to the coil(s) to be energised by an individual HTS lead 2g (one of four) on one side and by a common HTS lead 2g from the centre of the planar HTS element 2. Rotating carrier 3 mounting magnets 4 faces the planar HTS element 2 as shown and rotates in the direction of arrow A to pump flux into each of the electrical circuits 2c-2f.

Figure 7 is a schematic view of a flux pump of another embodiment of the invention. In this embodiment comprises multiple sections 2h of the type II HTS conductor in series, which is achieved in this embodiment by forming a coil of a length of type II HTS conductor, as a spiral around an annulus as shown, within which moves a rotating magnet carrier similar to that described previously in relation to Figures 1 and 2. The same reference numerals indicate the same elements.

Referring again to possible heating of the part of the HTS circuit component(s) 2 over which the flux passes, selective heating to optimise flux transport may be possible. For example a flux pump comprising two or more HTS conductors under two or more adjacent moving flux pump carriers/magnets may operate at too low a temperature for optimal pumping, and a heater or heaters may operate alternately or selectively to heat the HTS conductor over which a magnet is crossing at the moment of magnet crossing to achieve optimal pumping. The other HTS conductor(s) over which no magnet crossing is occurring at that moment may not be heated.

The superconducting coil to be energised by the flux pump may instead of being a coil wound with 1G or 2G HTS may be a Bitter-type electromagnet, of discs of substrate carrying an HTS film (2G discs) with insulating spacers but conductively linked, stacked in a helical configuration, and in this specification the term "coil" is to be understood as including such a Bitter-type coil.

Flux pumps of the invention may be useful in HTS magnet systems such as HTS magnet system used in NMR systems, in portable systems employing HTS magnets (e.g. minesweepers), in LTS-HTS hybrid systems where current leads dominate the heat losses, and DC generators (e.g. wind turbines), for example.

Example

The invention is further illustrated by the following description of experimental work: A flux pump of the invention as shown in Figure 8 was constructed, comprising permanent magnets 14 mounted on two discs 13 with a diameter of 70 mm, in turn mounted on a shaft 15 of 150 mm length. The discs were positioned above a length of one or more 2G conductor tapes 16 aligned side by side parallel with the shaft. On the circumference of each disc 13 12 NdFeB N38 magnets 14 were uniformly distributed. The magnet dimensions were $\varnothing 10$ mm x 10 mm and they were separated by 9 mm. The shaft was mounted on ball bearings and driven by a 4 W DC motor 17 with a motor-controller unit. The rotation speed of the motor was limited to 4 Hz.

The flux pump was connected to the leads of a superconducting coil by soldered joints. The circuit was not fully superconducting due to the solder joints - the resistance of such a joint is of the order 40-200 n Ω depending on the length of overlap. The superconducting coil comprised a double pancake coil constructed using 40 m of 2G wire from American Superconductor Corporation, Boston, MA, USA with $I_c(77\text{ K in self-field}) = 88\text{ A}$. It had an outer diameter of 94 mm, an inner diameter of 50 mm and a total of 163 turns. The inductance was $L=2.7\text{ mH}$ and the coil's critical current was determined to be $I_c = 55\text{ A}$.

A cryogenic hall sensor (AREPOC HHP-NA) was mounted centred with the coil-axis. The detected field was correlated to the current circulating through calibration using a power supply. The 2G conductor employed in the flux pump was supplied by Superpower Inc, NY, USA. The 12 mm wide tape was soldered to the coil leads using InBi solder.

The flux pump and superconducting circuit were immersed in liquid nitrogen in a styrofoam box.

The flux in the circuit was increased in steps as individual magnets crossed the tape in the flux pump unit. Figure 9 shows the current in the coil over time at several rotation frequencies.

CLAIMS:

1. A flux pump for inducing current and a magnetic field in a superconducting device, the superconducting device being in a superconducting circuit to be energised which also includes a
5 section of a type II high temperature superconductor (HTS), the flux pump being arranged to cause a magnetic field to enter the superconducting circuit through the type II HTS section thus increasing current in the superconducting circuit, without creating a non-superconducting region (herein: a normal spot) in the type II HTS section.
- 10 2. A flux pump for inducing current and a magnetic field in a superconducting circuit, arranged so that the magnet which crosses the superconducting circuit is similar to or greater in dimension than the dimension of the part of the superconducting circuit in the direction in which the magnet crosses the superconducting circuit.
- 15 3. A flux pump according to either claim 1 or claim 2 wherein the superconducting device is an HTS device.
4. A flux pump according to any one of claims 1 to 3 wherein the section of a type II HTS conductor is in circuit but physically separate from the superconducting device.
20
5. A flux pump according to any one of claims 1 to 4 wherein substantially all of the superconducting circuit is a type II HTS.
6. A flux pump according to either claim 4 or claim 5 wherein the device is a coil or magnet
25 wound with an HTS conductor.
7. A flux pump according to any one of claims 1 to 6 comprising a magnet carrier carrying one or more magnets and arranged to rotate to cause the magnetic field from the or each of the magnets to cross the type II HTS section and remove to trap flux in the superconducting circuit.
30
8. A flux pump according to claim 7 wherein the magnet carrier comprises a series of magnets around a periphery thereof.
9. A flux pump according to either claim 7 or claim 8 comprising multiple of said magnet
35 carriers.

10. A flux pump according to claim 9 wherein at least two magnet carriers are arranged to contra-rotate relative to one another.

5 11. A flux pump according to any one of claims 7 to 10 comprising two or more parallel arms of type II HTS conductor.

12. A flux pump according to any one of claims 1 to 11 comprising multiple adjacent type II HTS sections.

10 13. A flux pump according to any one of claims 1 to 6 comprising multiple sections of type II HTS conductor, either all in a superconducting circuit with a single superconducting device or each connected to a separate superconducting device, arranged in an annular form, or of a disc form with multiple electrical contacts thereon, and each connected in parallel to the coil(s) to be
15 energised, and facing the annular or disc HTS section(s) a rotating carrier carrying one or more magnets and arranged to rotate to cause the magnetic field from the or each magnet to cross the type II HTS sections and remove to trap flux in the circuits.

20 14. A flux pump according to any one of claims 7 to 13 wherein the magnet or magnets is/are permanent magnets or electromagnets.

15. A flux pump according to claim 14 wherein the magnet(s) each comprise an attached pole of ferromagnetic material to focus flux from the magnets.

25 16. A flux pump according to any one of claims 7 to 13 wherein the magnet or magnets is/are a superconducting magnets.

30 17. A flux pump according to any one of claims 7 to 11 also comprising a motor to drive the magnet carrier and a control system including a speed controller for the motor, and a sensor for detecting the strength of flux in the circuit with a feedback loop to the control system.

18. A flux pump according to any one of claims 1 to 6 comprising a linear array across the type II HTS section of two or more electromagnets, and a control system arranged to energise a first (outermost) electromagnet followed by one or more other electromagnets one after the other

each closer in turn to the inside than the outside of the superconducting loop, to thereby create a magnetic field which moves across the type II HTS section.

19. A flux pump according to any one of claims 1 to 18 comprising a control system arranged
5 to cease flux pumping when a predetermined field strength in the device or circuit is achieved.
20. A flux pump according to any one of claims 1 to 19 comprising a control system arranged
to activate the flux pump if the field strength in the device or circuit decays below a threshold.
- 10 21. A flux pump according to any one of claims 7 to 17 comprising a control system arranged
to vary the speed at which the carriers-magnets move, to maintain a constant current in the
superconducting circuit or to induce a steady field at a chosen ramp rate (rate of field increase).
22. A flux pump according to any one of claims 1 to 21 wherein the type II superconductor
15 has an N value of about less than about 50.
23. A flux pump according to any one of claims 1 to 21 wherein the type II superconductor
has an N value of about less than about 30.
- 20 24. A flux pump according to any one of claims 1 to 21 wherein the type II superconductor
has an N value of about 20 or less.
25. A flux pump according to any one of claims 1 to 24 wherein the or each type II HTS
section comprises a stack of multiple type II HTS conductors.
25
26. A flux pump according to any one of claims 1 to 25 arranged to be cooled by the first
stage of a two stage cryo-cooler system for the HTS circuit or device.
27. An HTS magnet system comprising a flux pump according to any one of claims 1 to 25.
30
28. An NMR system comprising an HTS magnet system including a flux pump according to
any one of claims 1 to 25.
29. A DC generator comprising an HTS magnet system including a flux pump according to
35 any one of claims 1 to 25.

30. An LTS-HTS hybrid magnet system comprising an LTS magnet system including a flux pump according to any one of claims 1 to 25.

5 31. A system according to any one of claims 29 to 30 wherein the flux pump is arranged to be cooled by the first stage of an associated two stage cryo-cooler system.

32. A method of flux pumping to induce current and a magnetic field in a superconducting coil or magnet, which comprises causing a magnetic field to move across a section of a type II HTS
10 in a superconducting circuit with the coil or magnet and enter the superconducting circuit through the type II HTS section thus increasing current in the superconducting circuit, without creating a non-superconducting region in the type II HTS section.

33. A method of flux pumping to induce current and a magnetic field in a superconducting
15 circuit, which comprises moving across a part of the superconducting circuit a magnet having a dimension in the direction in which the magnet moves relative to the conducting circuit which is similar to or greater than the dimension of the conducting circuit in the direction in which the magnet crosses the superconducting circuit.

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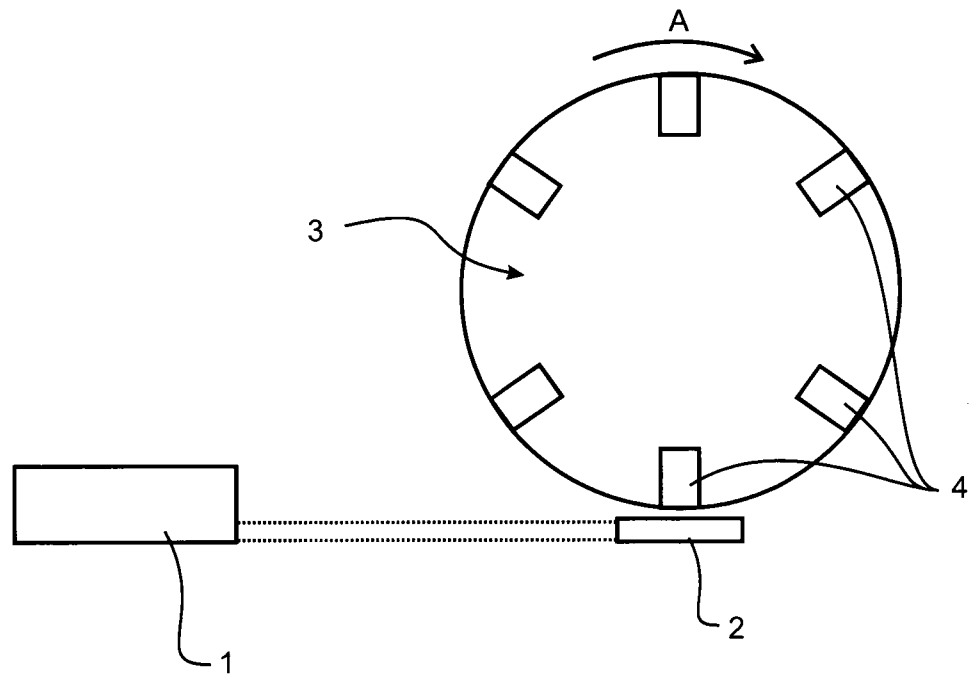


FIGURE 1

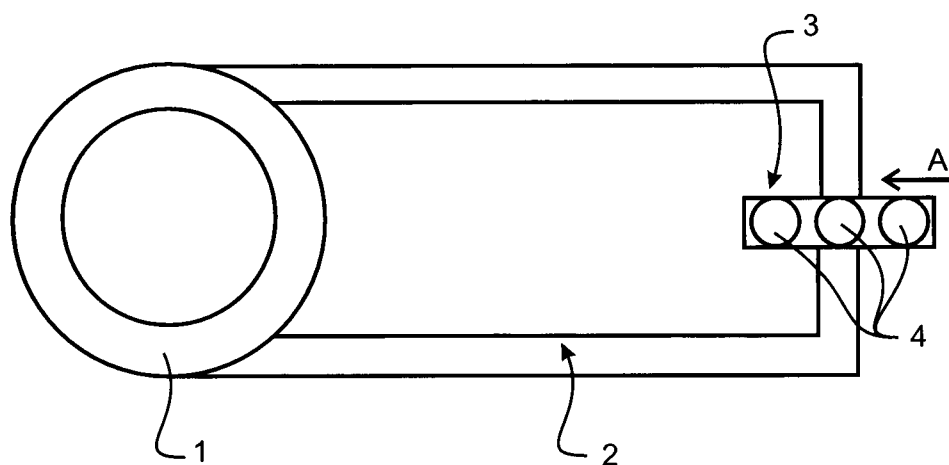
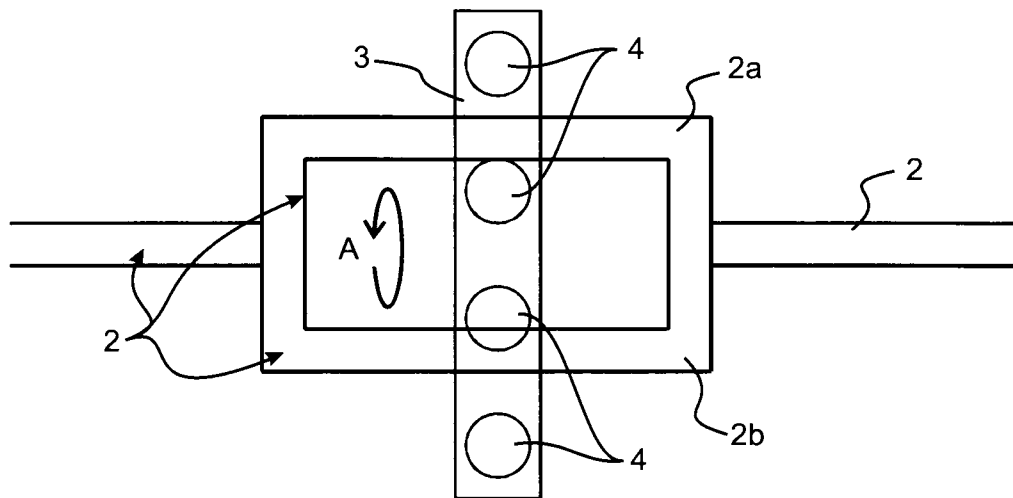
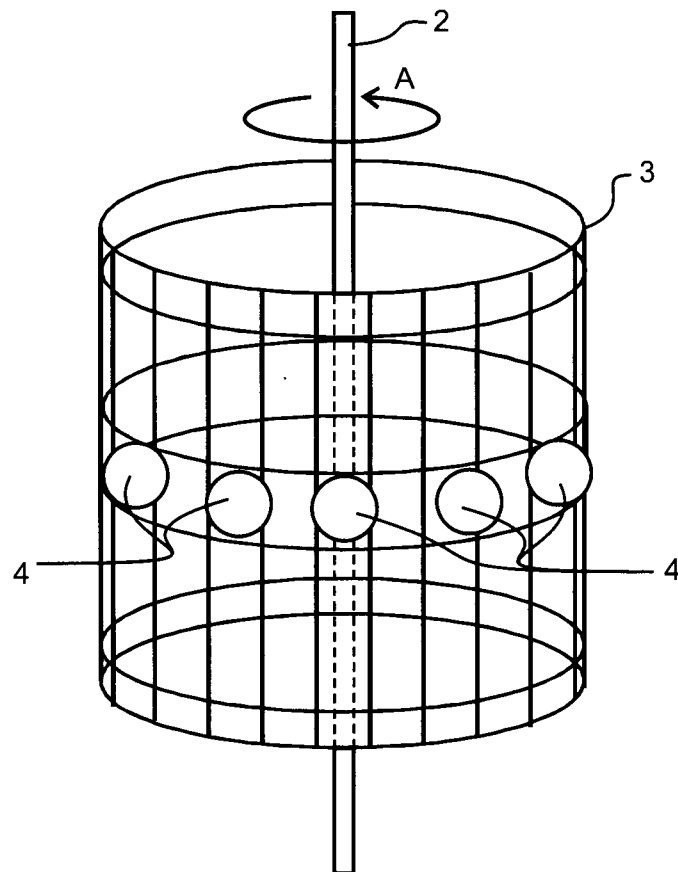
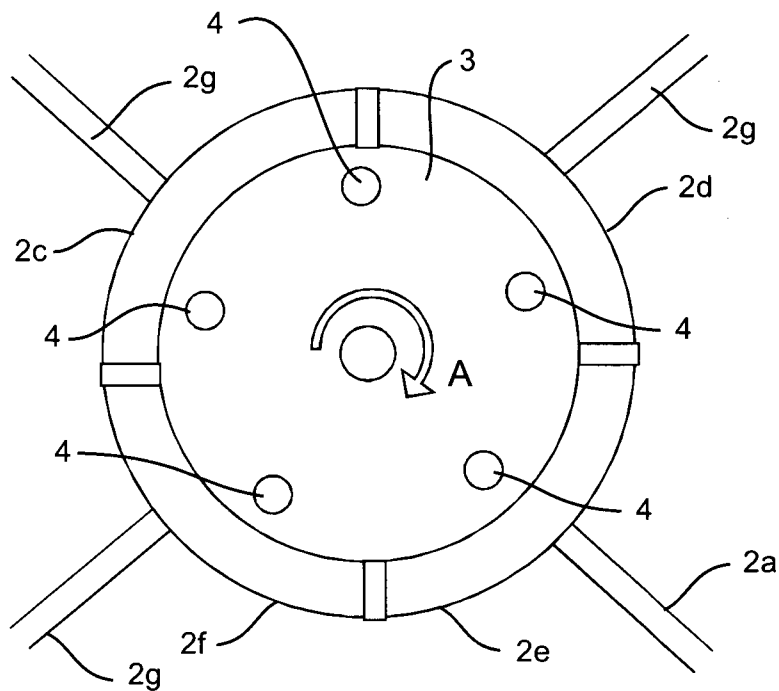
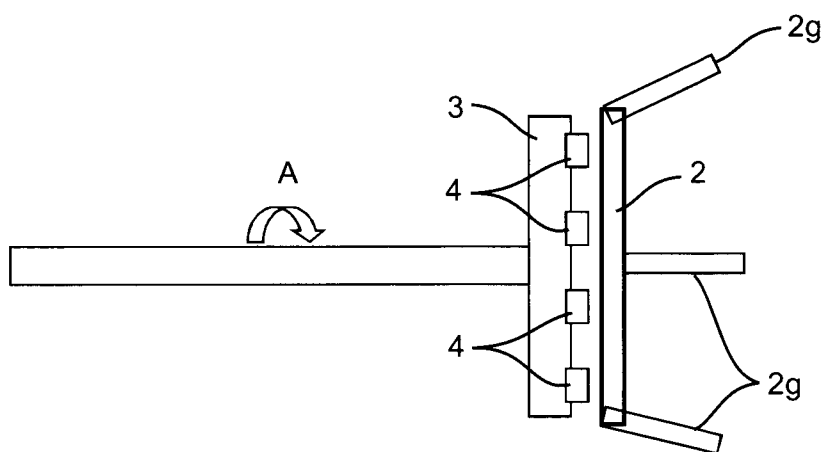


FIGURE 2

2/5**FIGURE 3****FIGURE 4**

3/5**FIGURE 5****FIGURE 6**

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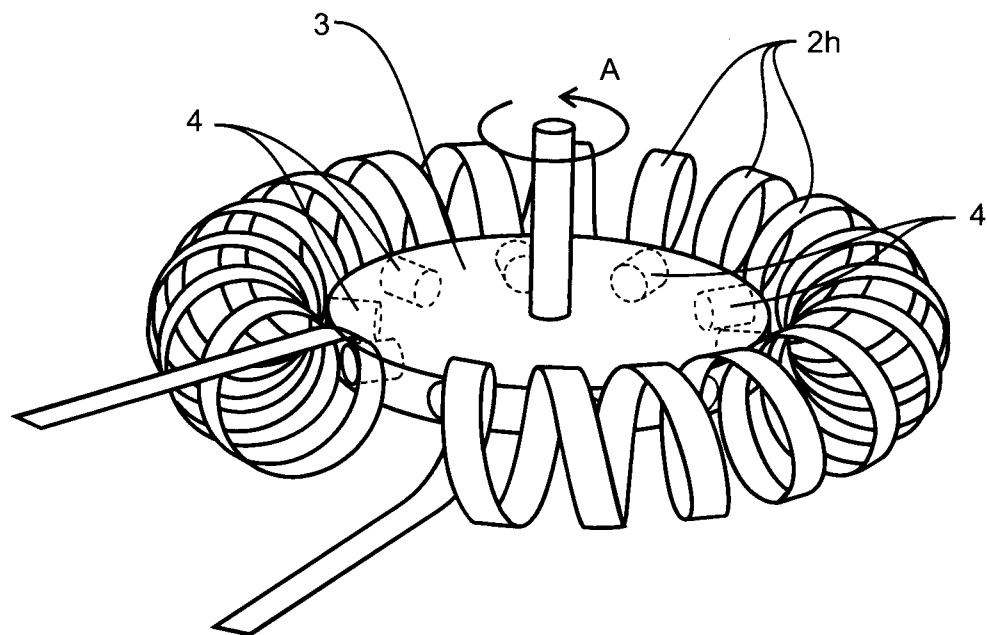


FIGURE 7

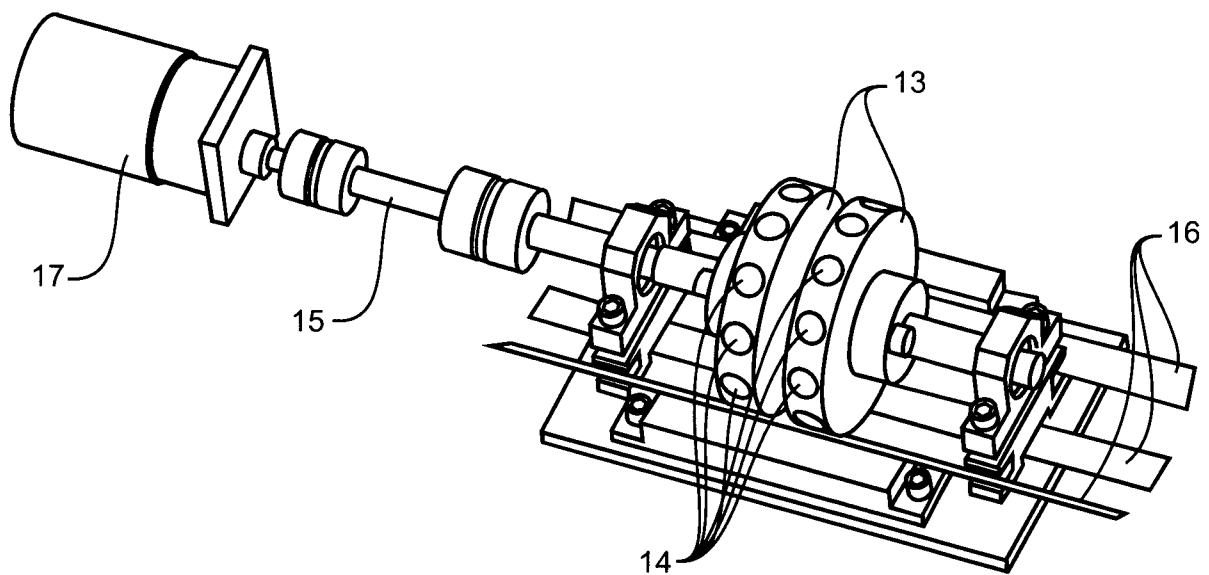
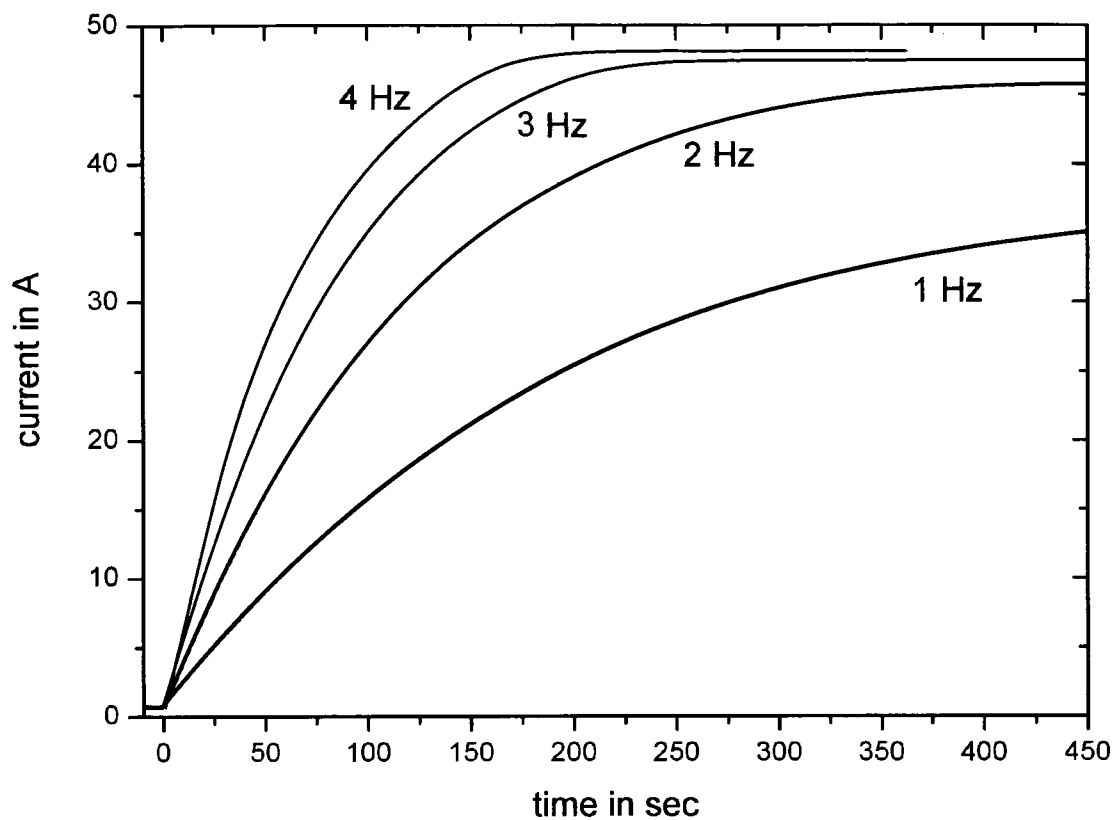


FIGURE 8

5/5**FIGURE 9**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NZ2011/000150

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

H01F 13/00 (2006.01)

H01F 6/00 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, INSPEC, TXTE, Google Patents: flux pump, superconductor, high temperature, HTS, magnets and similar key words.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/070319 A1 (MAGNIFYE LIMITED) 24 JUNE 2010 Fig.5-7, 14; first paragraph on page 1, last paragraph on page 4, first two lines on page 5, third paragraphs on page 7 and page 25, fifth paragraph on page 9, last two paragraphs on 16 and last three paragraphs on page 17	1-12, 14-33



Further documents are listed in the continuation of Box C



See patent family annex

* Special categories of cited documents:

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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"&" document member of the same patent family

"P" document published prior to the international filing date but later than the priority date claimed

Date of the actual completion of the international search

09 November 2011

Date of mailing of the international search report

24/11/2011

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/NZ2011/000150

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member	
WO	2010070319	EP	2359375	US	2011227677
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.					
END OF ANNEX					