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SURGICAL ELECTROMAGNET

Filed Aug. 21, 1956

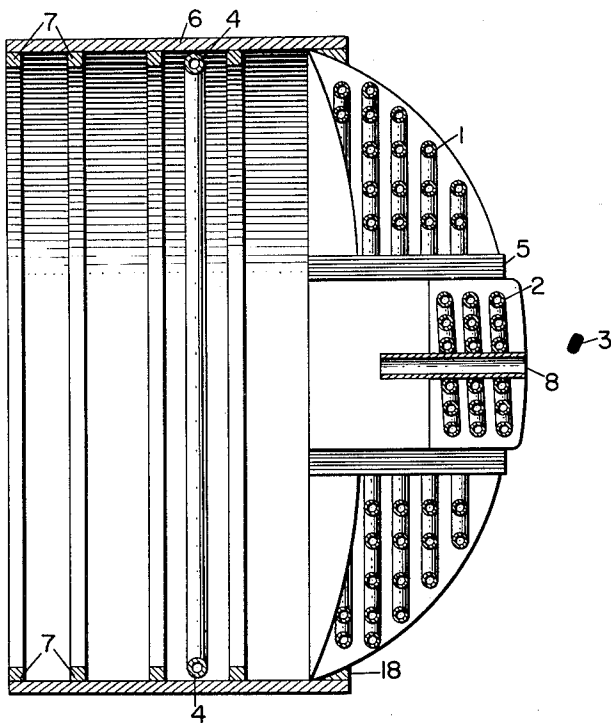


FIG. 1

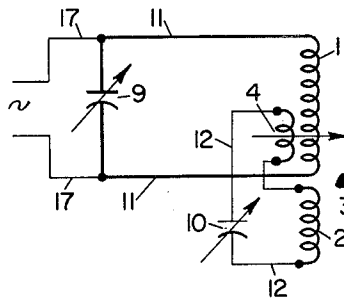


FIG. 2a

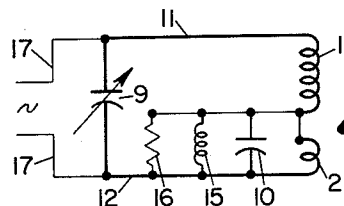


FIG. 2b

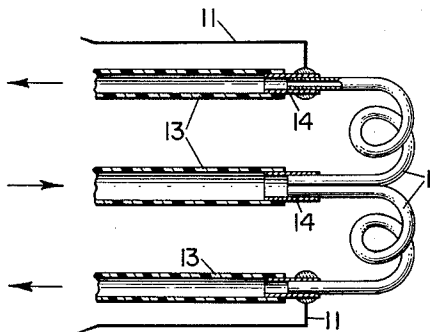


FIG. 3a

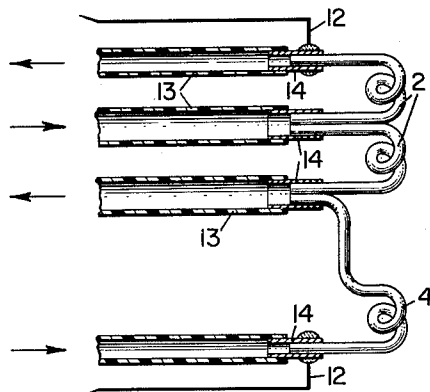


FIG. 3b

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SURGICAL ELECTROMAGNET
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This invention relates to an electromagnet for nonmagnetic metals and is concerned more particularly with novel control methods and means for producing the optimum adjustments of both phase and magnitude of current flowing in the element called the attractor. My Patent 2,400,869 issued May 28, 1946, discloses principles and construction features of an alternating current electromagnet which attracts and holds objects of nonmagnetic metals.

The invention functions by virtue of producing currents of substantially like phase in an attractor element and a nearby conducting object. The attractor may be of solid metal in various shapes and arrangements or it may comprise a winding. In this latter case the phase angle of the current in the attractor may be adjusted by introducing resistance, inductance, or capacitance in the attractor circuit, and also the winding can be of tubing to allow forced cooling which permits high current density.

It is desired to apply this electromagnet to surgery, particularly in eye surgery where there is great need because of the circumstance that most eyes, the vitreous of which is penetrated by fragments of nonmagnetic metal, are lost. The vitreous of the eye being a resisting medium considerable power is required to move particles of copper or brass through it and hence it becomes important to utilize expedients to enhance the efficiency and pull of the magnet.

One aim is to provide a construction giving good cooling characteristics requisite for handling high power. Another object of the present disclosure is to provide for greater effectiveness on particles. A still further aim is to disclose features which make the apparatus useful in attracting particles of either magnetic or nonmagnetic material to the same designated spot. Another object is to control heating of the object.

It has been found that in order to produce the greatest possible attractive force on a particular object with a given power input at a specific alternating current supply frequency means should be provided whereby both the phase and magnitude of the current flowing in the attractor can be adjusted so as to bring about a reasonably good coincidence of phase between the current in the attractor and that in the object to be attracted, and at the same time have as large a current flowing in the attractor as may be effective.

In the previous disclosure the current is usually induced in the attractor without specific control as to magnitude, and while this works well the current so induced is often below the value that gives the maximum response in the way of attractive force. Alternative means were shown for connecting the attractor coil either in series or parallel opposition to or with the main coil but without provision for bringing about the desired optimum coordination.

The present invention provides an additional element (called the feeder) which cooperates with the original elements without noticeably disturbing the impedance or other operating characteristics of the device and yet provide the desired high degree of flexibility and adjusting of attractor current with consequent improved performance.

FIG. 1 is a sectional view of an improved electromagnet. FIGS. 2a and 2b are diagrammatic of electrical connections and FIGS. 3a and 3b are diagrammatic also, showing water connections.

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As a specific embodiment the following data apply. A field coil 1, FIG. 1, is wound preferably in three pie-sections, to an interior diameter of $1\frac{1}{8}$ inches and outside diameter of $3\frac{3}{8}$ inches, with 23 turns in the forward section, 17 turns in the mid-section and 22 turns in the back section. The conductor is .062" O.D. x .04" I.D. copper tubing wrapped with varnished cambric insulation .005" thick. At approximately .4 of the length of each section (this is not critical) leads are brought out as cooling taps. The completed coil is shaped by pressure to have a desired curvature and clamped in this shape, insulating varnish applied and the coil baked at about 250 degrees F. for five hours. A suggested curvature of this coil is to a radius of $1\frac{1}{2}$ " as referred to a point $1\frac{1}{2}$ inches from front or face of the coil and $\frac{1}{4}$ inch radially outward from the axis. In some models the coil is tapered more in the region intended to be near the nose than on the side away from the nose. The axial length of the 3-section coil at the core is $\frac{3}{4}$ inch.

The attractor, 2, consists of 16 turns, 4 layers of 4 turns of the same tubing size as used in the outer coil and similarly insulated. It is wound on a $\frac{1}{8}$ inch form to an outside diameter of $1\frac{3}{16}$ " with cooling taps brought out at the ends of the 2nd and 3rd layer. The 16 turns are in series. An intermediate core of high silicon steel fills the space between the attractor and the field coil with a layer of .01" fish paper between core and field coil. The core consists of 1200 pieces of grain oriented steel .002" thick, $\frac{1}{8}$ " wide, $1\frac{1}{4}$ " long, formed into an annulus. Varnish is used to make a firm structure and in some models epoxy casting resin is used. The attractor and core assembly may protrude $\frac{1}{8}$ " through the opening in the field coil.

The additional winding called the feeder which is adjustable in position and length is provided connected in series with the attractor usually, but not always, connected so that voltage induced in it adds to the voltage induced in the attractor by the field coil. In FIG. 1 the main field coil is 1 and the attractor 2, the feeder is 4, magnetic core 5. A housing, 6, of a phenolic condensation product or the like $2\frac{1}{2}$ " long with $\frac{1}{16}$ " wall is fitted over the coil and cemented into place with, for example, epoxy resin, 18. Small bosses, 7, of the same composition as the housing are cemented to the inside wall of the housing diametrically opposite each other to receive the feeder loop, hold it firmly and yet allow adjustment. The feeder loop, 4, consists of two or more paralleled conductors of the insulated copper tubing mentioned and is made long enough (about 2 feet long) to form 2 turns around the periphery of the field at the back just inside the housing. It is preferably water cooled.

FIG. 2a diagrams the preferred electrical connections. Here, 1, is the field coil, 2 the attractor, 3 the object to be attracted, 4 the feeder, 9 the field coil tuning capacitors, 10 the attractor capacitance, 11 the leads to 9 and 12 the leads to 10, 17 the leads to the supply circuit. FIG. 2b is an alternative arrangement in which the attractor is in series with the field coil but shunted by capacitors 10, inductance 15, or resistor 16, or any combination of these.

FIGS. 3a and 3b also show the arrangement of leads and water connections for the field coil and attractor respectively. The leads from coils are brought out 2 to 3 inches from the back of coils and junctions made by soldering into sleeves, 14, of larger copper tubing as adaptors. For example tubing $\frac{3}{16}$ " interior diameter is used for 2 or 3 of the .062" tubes. Water connections are made by flexible plastic tubing, 13, $\frac{3}{16}$ " interior diameter with $\frac{3}{32}$ " wall being a good size and vinyl chloride a satisfactory composition. Water pressures up to 100 p.s.i. are used.

The ends of the conductors of the three pie-sections of the field coil are joined (soldered) together so as to parallel the three sections. No electrical connection is made to the intermediate water cooling taps, but soldering these into copper sleeving for the plastic tubing also assures good electrical continuity for the winding. The plastic tubing is held firmly on the sleeve, 14, by bonding, by clamps or by twisting enameled wire around the plastic tubing. As shown in FIG. 3a by arrows the middle water tubing may be the water inlet and the other two the outlets. Electrical connections from coils to the capacitors are made by means of flexible stranded braid conductor equivalent to No. 2 B and S gage.

An insulating coating of an epoxy resin may be applied over the face of the electromagnet, or a thin layer of varnished cambric or silicone fabric baked on. The device may be sterilized at 105° C. dry heat for one hour before use.

In some models the aperture, 8, is left open to serve as a peep hole for observation of the incision and in others the space is filled with high silicon steel as used in the core 5. Quantitative data are given for the aperture open.

Electrical characteristics of the assembly are as follows: With 400 volts applied to the field coil tuned at 7.8 kilocycles with 24 microfarad capacitance in the field coil circuits, and 250 microfarad in the attractor circuit, one turn of feeder winding $\frac{1}{4}$ " back of field coil at periphery, the Q is 9.3, the resistive impedance of the electromagnet is 8.0 ohms, and the power consumed is 20 kilowatts. The attractor voltage is 17 volts and gives about twice the attractor current and twice the pull as measured without the feeder under similar conditions, showing a marked gain in results by the use of the feeder. With this setting there are 9700 ampere turns in the field coil and 4400 in the attractor coil. For this configuration this is about as high a ratio of field to attractor ampere turns as can be tolerated. It serves to give a combination which will be effective on both high resistance metals such as brass or lead and low resistance metals such as copper. If the material of the object to be attracted is known to be of high resistance such as brass, a better setting can be made by decreasing both the capacitance and the feeder coupling. For example the attractor capacitance may be decreased to 200 and the single turn feeder moved back an inch or reduced to $\frac{1}{2}$ or $\frac{3}{4}$ turns. Decreasing the attractor capacitance further brings about an approach to a resonance condition in the attractor circuit.

A further advantage of exercising control of the attractor current magnitude and phase is that when the setting most favorable to high resistance materials is employed, magnetic materials may also be attracted to the same spot, i.e., the aperture of the attractor as is the case for a material such as brass. If the feeder is left free to move somewhat and is observed, a condition of quadrature is found by varying the attractor capacitance so that the feeder shows no tendency to move. Now, if the capacitance is decreased slightly from this condition, say by 10%, a small piece of iron ($1\frac{1}{2} \times 1\frac{1}{2} \times 1\frac{1}{2}$ mm.) placed 5 to 10 mm. directly out on the axis of the attractor aperture will be drawn to the aperture, as will a similar particle of brass or copper. If the feeder is repelled from the field coil the lag is greater than 90°, if attraction is exhibited the lag is less than 90°. If the attractor capacitance is still further diminished from quadrature setting attraction on copper may be lost, but when the capacitance is diminished just enough to produce some attraction between feeder and field, copper, brass or iron are attracted to the aperture. It is sometimes in doubt as to whether a metal object in the eye is really magnetic or nonmagnetic and it is therefore advantageous to have an arrangement which can be used to draw either to the aperture. In the usual setting of the device a piece of iron in front

of the attractor aperture moves toward the annular pole structure, away from the attractor aperture.

The cooling provided is adequate for pulses of 1 to $1\frac{1}{2}$ seconds in length spaced 5 to 10 seconds apart.

With the apparatus as described pieces of copper 2 x 2 x 2 mm. have been drawn through the vitreous of eyes of experimental animals from about 10 mm. to the incision, and pieces of copper 1 x 1 x 1 mm. and of brass 2 x 2 x 2 mm. have been drawn 6 mm. similarly. The surgeon can rotate the eye so it is unnecessary to work at greater distances than to about the center of the eye and a large proportion of the volume of the eye is within 6 mm. of the surface. The pull of the apparatus has been approximately doubled since these experiments were made. No adverse effects due to heating of the metallic object or because of exposure of the eye to the field have been noted.

In the condition described for the feeder being attracted toward the field coil the combined field out on the center line through the aperture is increased over the value it has for the repelled-feeder condition and heating of an object in the region in front of the attractor is increased. In some instances it is felt desirable to apply heat to the object in the eye in short pulses to assist in freeing the object from surrounding fibrinous material, so the ability to make adjustments influencing the heating of the object is advantageous. The heating of the object is of course influenced also by the choice of operating frequency. Frequencies of 4000 cycles to 10,000 cycles have been used.

It is remarked that for the embodiment given the ratio of ampere turns in field coil to those in attractor ranges from about two to one to four to one, and that the attractor current can be too large or too small if these ratios are greatly exceeded. However the embodiment is not to be taken as a limitation as many variations can be made in dimension. For example if the field coil is made larger in diameter in proportion to the attractor coil than is set forth here, the field set up by it near the attractor would be correspondingly weaker and in such event the number of ampere turns in the field coil should be increased commensurately to preserve ratios of field strengths.

Where comparisons are given for the specific embodiment such as adjustments said to increase or decrease attractor current it is understood that the frequency of the alternating supply current and the number of ampere turns in the primary or field coil are held constant.

Some of the experiments have been described in a paper by Lovell, Electronics, September 1955, page 164, in addition to a joint paper by King, Lovell, Den, Stow, and Owens presented at the International Congress of Ophthalmology September 1954 in New York city.

I claim as my invention:

1. An alternating current electromagnet comprising means for inducing current in adjacent windings and in a nearby object of nonmagnetic metal, means comprising attracting means fixed in position interiorly with respect to the first means and in which current is circulated by induction from the first means, the current being of such phase and magnitude as to attract the said nonmagnetic metal object, and means for independently adjusting the phase and magnitude of current in the attracting means to augment or diminish the field produced by the inducing means in the region of the nonmagnetic object according as more or less heating of the object is desired.

2. An alternating current electromagnet comprising inducing means for inducing current in adjacent windings and in nearby pieces of metal, a coil comprising attracting means fixed in position interiorly with respect to the first means and in which current is circulated by induction from the first means, and means for independently adjusting the phase and magnitude of the current in the attracting means so as to attract particles of both magnetic and nonmagnetic metal toward the same designated spot in the magnet structure from a location near the attracting means.

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3. Alternating current electromagnetic apparatus comprising a primary coil as means for inducing current in adjacent windings and in nearby objects of nonmagnetic metals whereby such objects are subjected to electro-mechanical force and electro-thermal heating, a secondary coil positioned interiorly with respect to the inducing means and in which current is circulated by induction from the first means, and means for independently adjusting the phase and magnitude of the current in the secondary coil so as to independently vary the heating in and force on the said nearby objects of metal.

4. An alternating current electromagnet comprising a coil connected to an alternating current source as means for inducing current in adjacent windings and in a nearby object of nonmagnetic metal, a coil comprising attracting means fixed in position interiorly with respect to the first means in which current is circulated by induction from the first means, the current being of such phase and mag-

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nitude as to attract the said nearby object, an adjustable extension of the coil comprising attracting means which is called the feeder and which is also subject to the field of the inducing coil whereby the magnitude of current in the attracting means may be varied, means in the circuit of the attracting means whereby the phase of the attractor current may be varied, the combination of the feeder and phase adjusting means comprising means whereby optimum force on and heating in the said metallic object is achieved.

References Cited in the file of this patent

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