United States Patent

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[33] **France**
[31] **138895**

[54] **INDUCTOR DEVICE FOR LEVITATION PURPOSES**
5 Claims, 3 Drawing Figs.

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[51] **Int. Cl.** **H05p 5/00**, H05p 9/02
[50] **Field of Search** 219/7.5, 10.79; 308/10

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ABSTRACT: An inductor device for levitating a mass of approximately toroidal form comprising a conductor passing through the central space of the mass to be levitated and connected to a source of alternating current.

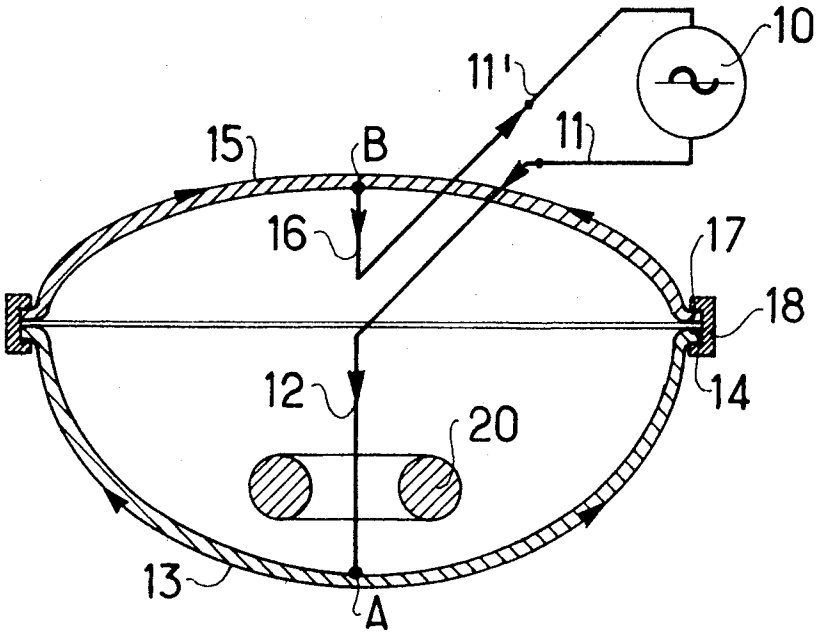


FIG. 1

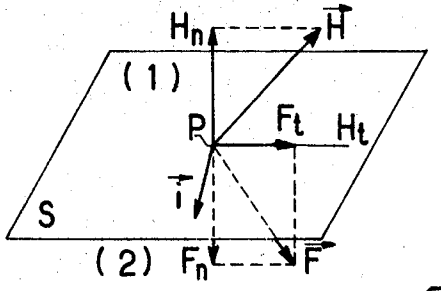


FIG. 2

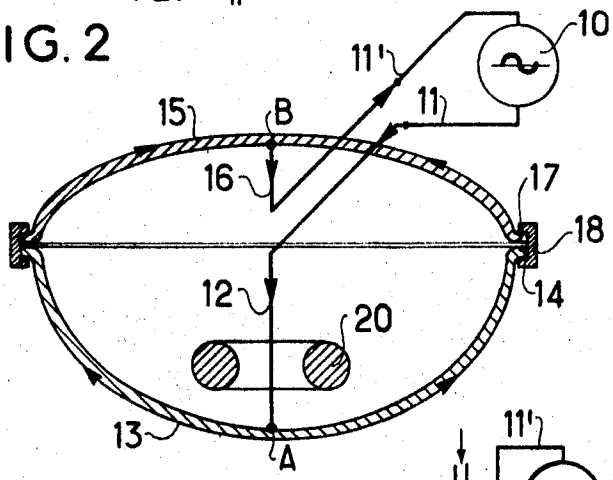
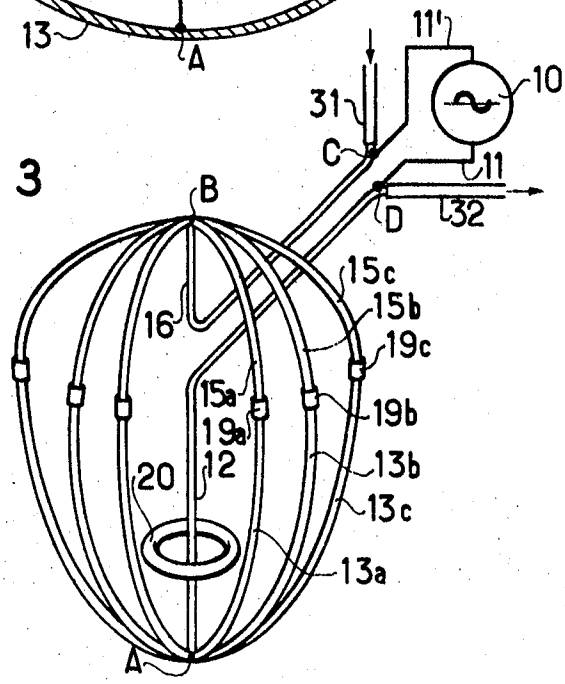


FIG. 3



INDUCTOR DEVICE FOR LEVITATION PURPOSES

Background of the Invention

1. Field of the Invention

This invention relates to an inductor device for levitation purposes, more particularly for effecting levitation of a liquid mass, even if it has no surface tension.

2. Description of the Prior Art

It is possible, by the means of an inductor of appropriate form through which a sufficiently strong current is passed, to induce in a conductive body eddy currents on which the magnetic induction field acts so as to create a force which, for well-chosen values of the parameters, is capable of opposing gravity and maintaining the conductive body in suspension without a material support. This technique is known as "levitation." In association with heating by induction, it is very useful, for example, since it is thereby possible to melt two levitated metallic masses at the same time, and to then obtain by cooling, an alloy between the metals without contact with any crucible, the material of which might be corroded and entrained in solution as an impurity by a very reactive metal such as titanium, for example. Such inductors for levitation are already known.

Some advantages of the technique of levitation are therefore essentially related to the possibility of maintaining a liquid mass in levitation. Now, the levitation of a liquid mass presents more difficult problems than the levitation of a solid, because, owing to the cohesion which characterizes a solid, it is sufficient for a lifting force of sufficient strength to be applied to a small zone of the solid in order to maintain the whole solid in levitation. However, the problem is more complex in the case of a liquid mass. It is known that surface tension forces act on the surface of a liquid in the manner of a diaphragm having a certain resistance. The resistance of this "diaphragm" effectively acts to assist the cohesion of the liquid mass by the levitation effect.

In known levitation devices, the surface tension does not perform an essential function, but if the surface tension is low and does not contribute effectively to the cohesion of the liquid mass, the margin of safety becomes very small.

Summary of the Invention

The present invention provides a generally improved form of inductive device for levitation of a liquid mass, even if the latter has negligible surface tension. The action of the magnetic field on the liquid mass must be that of a diaphragm which entirely encloses the levitated liquid, exerting an inwardly directed normal force on the liquid particles.

According to the present invention, there is provided in combination with a conductive mass to be levitated, an inductor device for levitating the mass comprising a conductor extending through the central space of the mass which is at least approximately of toroidal form and means for connecting the conductor to a source of alternating current.

The toroidal form, or at least the form approximately comparable to a torus, which is adopted for the mass to be levitated arises from the fact that it is the simplest geometrical surface on which a current not having two zero points can be induced. This property may be connected with the fact that there may be imparted to the torus a displacement which does not affect its attitude (for example by turning it about its axis), without its having a single zero point (as hereinafter explained). This would not be the case with a spherical surface or a cylindrical surface, because under the same conditions these surfaces have two zero points. It is shown by the laws of electromagnetism, combined with topological considerations, that the currents induced in surfaces of the second type exhibit two zero points, while there is no zero current point on the toroidal surface. Now, it is clear that, if the current is cancelled out at one point, the force of cohesion generated by the magnetic field is cancelled out at this point. On the other hand, on a surface of toroidal form traversed in its central region by a conductor carrying an induction current, the induced current is not cancelled out at any point, and it is possible to generate, throughout the mass, forces which not only combat gravity, but also combat the absence of cohesion of the liquid mass.

Levitation operations are generally associated with heating and melting operations performed by the same inductor. There will therefore be taken as the starting point, a solid shaped in toroidal form which, in the state of levitation and fusion, will retain its cohesion in the form of a toroidal liquid mass having no material support. Brief Description of the Drawing

FIG. 1 is a graph illustrating the principles on which the invention is based.

FIG. 2 is a diagrammatic sectional view of a first form of inductor device of the invention.

FIG. 3 is a diagrammatic view, in perspective, of a second form of inductor device. Description of the Preferred Embodiments

Referring to Figure 1 there is illustrated therein, an element of a surface S separating an insulating medium(1), which is the seat of a magnetic induction field, and a conductive medium (2). The vector $\vec{H}$ represents the value of the magnetic field as it would exist at a point P of the surface S in the absence of the conductor (2).

H_n and H_t are the components of the vector $\vec{H}$ along the normal and in the plane tangent to the surface S at the point P, respectively.

Assuming that the medium (2) and the frequency of the magnetic induction field $\vec{H}$ are such that the depth of penetration of the currents to a surface current density $\vec{i}$ which is perpendicular to $\vec{H}$ in the plane tangent to S, and the value of which is proportional to H_t, the electromagnetic force $\vec{F}$ which is produced by the action of the induction field $\vec{H}$ on the induced current $\vec{i}$ is perpendicular to $\vec{H}$ and $\vec{i}$. Therefore, it has a tangential component F_t proportional to $H_n \cdot H_t$ and a normal component F_n proportional to H_t^2.

If a liquid mass is to be maintained in the state of levitation by the electromagnetic force $\vec{F}$ which is exerted on each element of its external surface, the said force $\vec{F}$ must be normal at all points to the external surface of the mass, because the existence of a tangential force would produce a displacement of material resulting in a modification in the shape of a liquid body appropriate to satisfy this condition, or again a separation of the mass into a number of fragments. Consequently, a liquid mass can be maintained in levitation, in the absence of an appreciable surface tension, only if its external surface is tangent throughout to the magnetic induction field.

More particularly, it is impossible to maintain in electromagnetic levitation a closed liquid volume which does not surround any electric current and which does not contain any source in its interior. On the other hand, it is possible to obtain the levitation of a liquid mass without appreciable surface tension which has a toroidal or similar form to permit the induction current to pass in the space defined by the liquid mass.

Referring to FIGURE 2 an alternating-current generator **10** is connected by leads **11**, **11'** to an inductor comprising a first rectilinear conductor **12**, and a second conductor **13** in the form of a concave surface of revolution around the axis of the conductor **12** to which it is connected at the point A. The conductor **13** terminates in a circular flange **14**. The inductor further comprises a further conductor **15** which also forms a surface of revolution and acts as a return conductor extending towards the lead **11'** through a rectilinear element **16** connected at the point B. The conductor **15** terminates in a circular flange **17**. The electrical continuity between the two conductors **13** and **15** is achieved by a collar **18** which grips the two flanges **14** and **17** in abutment. When assembled, the whole has the appearance of a pan.

The conductor **12** extends through the central space of the mass **20** which is of toroidal form and is to be levitated along its axis. The direction of the current along the various conductors is indicated by arrows.

Referring to FIG. 3, in which like parts are indicated by the same reference numerals as in FIGURE 2, there is illustrated a

construction in which the continuous surface **13** of FIGURE **2** is replaced by a group of curvilinear conductors **13***a*, **13***b*, etc. lying in a surface of revolution about the conductor **12** and connected to the conductor **12** at the point A, and the continuous surface **15** is replaced by a second group of curvilinear conductors **15***a*, **15***b*, etc. also lying in a surface of revolution and connected to the conductor **16** at the point B. The conductors in the respective groups are of the same number and each conductor **13** (*a*, *b*, etc.) is connected to a conductor **15** of like order, by a sleeve **19** (*a*, *b*, etc.) The whole has the form of a double umbrella. As is known in the techniques of levitation and in heating by induction, the conductors are hollow and means are provided for passing a current of cooling water therethrough. For example, water circulatory supply **31**, **32** may be connected to the points C, D.

Other forms of inductor are possible within the scope of the invention, the preceding forms having been given only by way of example.

What I claim is:

1. In combination with a conductive mass to be levitated, an inductor device for levitating the mass comprising a conductor extending through the central space of the mass which is approximately of toroidal form, means for connecting the conductor to a source of alternating current and a curved conductive surface connected to the conductor and having a shape of a surface of revolution about said conductor to form a dish around the mass.

2. The inductor device as set forth in claim **1**, further comprising a return conductor partially formed of a conductive surface which is connected to the edge of the aforesaid surface of revolution.

3. The inductor device as set forth in claim **2**, wherein the said two surfaces are respectively provided with abutting flanges and the device further comprises a collar gripping the two flanges together.

4. The inductor device as set forth in claim **1**, wherein said curved conductive surface connected to the conductor and having a shape of a surface of revolution about said conductor comprises a first group of curvilinear conductors connected to the aforesaid conductor and lying in a surface of revolution about said conductor, a second group of curvilinear conductors of the same number as those of the first group and also lying in a surface of revolution about the aforesaid conductor and sleeves connecting the free ends of the conductors of the respective groups.

5. The inductor device as set forth in claim **4**, wherein the conductors of the two groups are hollow and said device further comprises means for passing a cooling fluid therethrough.