INVESTIGATION OF POSSIBILITY OF CREATION OF LEVITATING QUADRUPOLE

A.M. Bishaev, A.A. Bush, I.V. Gladyshev, K.Y. Kamentsev, M.V. Kozintseva

Moscow Institute of Radio Engineering, Electronics and Automation (Technical University), Moscow, Russia

E-mail: kozintseva@mirea.ru

The configuration of the supporting magnetic field for the levitation of two superconducting rings is developed. It has been formed experimentally from four permanent coaxial magnets of N40 grade inserted one into another with alternate poles and having one common external surface. The ceramics rings form high-temperature superconductive (HTSC) phase Y-123 of proper sizes demonstrating superconducting properties with the critical current sufficient for their levitation have been manufactured. The existence of stable equilibrium positions for two superconducting rings with the current in the supporting magnetic field and in the field of the gravity force has been experimentally proved. Based on carried out experiments and calculations the configuration of the laboratory model of the levitating quadrupole has been proposed.

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1. INTRODUCTION

In the investigated up to now traps-Galateas [1-4], the plasma-embedded coils (so named “myxini”) are structurally fixed by holders. Myxini have to levitate in thermonuclear reactor. Proposed and realized now in USA [5] and Japan [6] levitating systems form the simplest magnetic field configuration: the dipole field. The quadrupole is the next one in complexity. The transfer from the levitating dipole to the levitating quadrupole bring along the main principal feature: it is necessary to obtain a levitation of two interacting coils with the current.

2. DEVELOPMENT OF SUPPORTING MAGNETIC FIELD CONFIGURATION

According to the generalization of Earnshow theorem [7], performed by Braunbek [8], the confinement of bodies with induced magnetic moments (diamagnetics, superconductors) is possible in the regions near the absolute minimum of $|H|^2$. Therefore in order to stabilize equilibrium states of superconducting rings in the magnetic field and in the field of the gravity force it has been necessary to find the configurations with minimums of the magnetic field. The development of the configuration of the supporting magnetic field for the levitation of superconducting rings has been carried out with the help of calculations by the program “FEMME”.

Due to the main coils in the selected by us variant of the magnetic quadrupole have the shape of rings, it is clear for reasons of symmetry the supporting them magnetic field must have the cylindrical symmetry too. The simplest system of this type, having the region of zero field, is the annular magnet with the axial magnetization. The real superconducting ring, placed into the zero field region, is also under the action of the gravity force which shifts the ring down, into the region of greater field values. The work performed by the gravity force is expended onto the increase of the ring energy in the magnetic field. As a result new equilibrium position corresponding to the energy minimum of the superconducting ring in the magnetic field and Earth gravity field appears.

The region of the most abrupt change of the magnitude of the magnetic field induction is located at the co-ordinate r, equal to the radius of the internal hole of the magnet. Therefore the stable levitating state for the superconducting ring with the radius of the order of the radius of the magnet internal hole is possible in the field of the given annular magnet.

As a result of carried out experiments the configuration with alternate poles, in which there is provided the existence of several minimums of the magnetic field, spaced in the altitude and surrounded by “magnetic walls” (i.e. regions with the sharply increasing field) of different radius, has been formed. In these regions one may expect the stable levitation of superconducting rings: rings of the different radius and at the different levitation altitudes.

The given configuration has been formed experimentally from four permanent coaxial magnets of N40 grade inserted one into another with alternate poles and having one common external surface. The corresponding calculated configuration of this system of magnets is presented in the Fig.1.

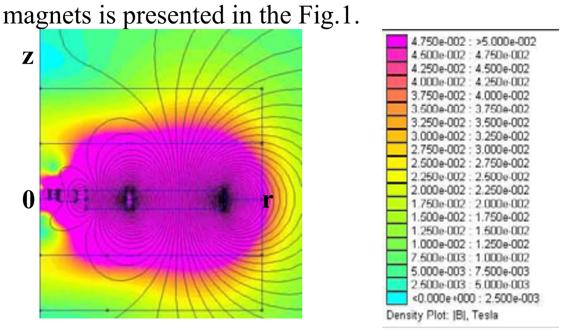

Fig. 1. Configuration of supporting magnetic field

The external magnet has the diameter $D_{ext.}$= 100 mm, the height h = 5 mm and the internal hole of the diameter $d_{int.}$ = 50 mm. The first intermediate magnet has $D_{ext.}$=47 mm, h=5 mm, $d_{int.}$=25 mm; the second intermediate magnet has $D_{ext.}$= 20 mm, h = 3 mm, $d_{int.}$ = 10 mm; the internal magnet has $D_{ext.}$= 10 mm, h = 2 mm, $d_{int.}$= 5 mm. Some asymmetry of the configuration is caused by the second intermediate magnet (of diameter 20 mm) and the internal magnet (of diameter 10 mm) are shifted in the height about the symmetry plane of the external and the first intermediate magnets. The experimental values of the magnetic field induction of the system from four magnets, measured at the different distances from the system external surface, agree within the limit of error (equal to about 5 %) with the calculated ones obtained by the program "FEMME".

In the field of this configuration three superconducting rings of diameter ~10 mm, ~25 mm, ~50 mm are able to levitate stably and they are able to levitate both each taken separately and all three (or any two of them) simultaneously.

3. EQUILIBRIUM POSITION OF SUPERCONDUCTING RINGS

In the program "FEMME" an ideal superconductor as a first approximation has been simulated by the definition on its boundary of zero value vector potential. Therefore all following discussions and calculations carried out by the program "FEMME" are concerned to the case when one may consider the magnetic field expulsion from the superconductor takes place (i.e. Meissner effect takes place). Preliminary calculations carried out in this approximation have shown under such simulation of a superconductor in the program "FEMME" one succeeded in correct physical presenting of its behavior without magnetic flux trapping. In other words, the ring is transferring to superconducting state at "infinity" and is bringing in the external magnetic field. The magnetic field flux through the superconducting ring remains equal zero in any position.

For the proposed configuration of the supporting magnetic field, the positions of several superconducting rings of specified sizes have been found by calculations, in which the force acting onto the ring from the magnetic field is equal to the gravity force acting on it (i.e. there are calculated their equilibrium positions in the magnetic field and in the field of the gravity force).

In accordance with the carried out above estimations the external diameters of the superconducting rings for the calculations have been taken equal to 20 and 50 mm. The cross-section of the rings has been specified in the shape of a (5×5) mm square according to the cross-section dimension of the press molds used under the superconducting manufacturing. The superconducting substance density under the calculation of the gravity force has been taken equal to $5 \cdot 10^3$ kg/m^3.

The equilibrium position of the "ideal" superconducting ring with the external diameter 20 mm in the supporting field of four magnets with alternate poles corresponds to the distance h = 5,7 mm between the lower surface of the superconducting ring and magnets common surface.

Under the equilibrium position of two "ideal" superconducting rings with the external diameters 20 and 50 mm, accordingly, in the supporting field of four magnets with alternate poles the distance between the lower surface of the lower superconducting ring (of diameter 20 mm) and magnets common surface is equal to 6 mm, and the distance between the lower surface of the upper superconducting ring (of diameter 50 mm) and magnets common surface is equal to 20 mm.

In accordance with the forecast the calculated equilibrium positions of two "ideal" superconducting rings of the different radius (and of the same cross-section and density) in the supporting field of four magnets with alternate poles correspond to the different altitudes above the magnets common surface: the equilibrium position of the ring with the greater radius is higher than the position of the ring with the smaller radius.

It is necessary to note, that the calculated altitudes of levitating equilibrium states have been obtained for "ideal" superconductors, therefore for the manufactured in MIREA superconducting rings experimentally observed altitudes, at which rings have been in the equilibrium state, were smaller than calculated values.

The obtained results and calculations are able only to forecast the behavior of real superconductors in real fields. Therefore only the carrying out of experiments with superconducting rings of different sizes, manufactured from the superconducting materials of the different type, can give the final answer onto the question about the stability of the levitating state of one or another system.

4. EXPERIMENTS ON LEVITATION OF SUPERCONDUCTING RINGS IN SUPPORTING MAGNETIC FIELD

In order to carry out experiments ceramics rings (with the external diameter from 8 up to 46 mm) demonstrating superconducting properties with the critical current sufficient for their levitation have been manufactured from HTSC phase Y-123 on the base of the available in MIREA equipment and technique.

The two rings stable levitating states have been experimentally observed in the four magnets supporting field for rings diameters: 8 and 16, 12 and 46 mm, 16 and 46 mm, 19 and 46 mm, 8 and 46 mm. The photo of one of the superconducting levitating rings configuration which is stable both to horizontal and to vertical shifts is presented in Fig. 2.

Fig. 2. Stable configuration of two levitating superconducting rings. Diameter of external ring is equal to 46 mm, diameter of internal ring - 19 mm

It is important to note that the levitation altitudes of external and internal rings are different for all investigated configurations, that corresponds to the forecast, carried out on the base of calculations.

Thus carried out on the given step experiments in the levitation of two superconducting rings in the supporting magnetic field of four permanent magnets with alternative poles have proved the existence of stable equilibrium in such system.

5. CONCLUSIONS

The analysis carried out on the basis of carried out experiments and calculations shows that the model of levitating quadrupole must be consist of: two levitating coils ("myxini"); unlevitating coils which compensate myxini magnetic attraction ("repulsers") and unlevitating coils which compensate myxini gravity ("antigravity" coils). Currents in repulsers may be comparable with the currents in myxini by the order of magnitude, and one chooses such location of repulsers under which the trap barrier field becomes higher. Currents in antigravity coils are by the order of magnitude smaller than in myxini. It means the fields produced by antigravity coils will not practically disturb the main magnetic configuration. In order to ensure stable equilibrium position it is necessary to use superconducting materials under manufacturing of myxini, repulsers and antigravity coils.

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ИССЛЕДОВАНИЕ ВОЗМОЖНОСТИ СОЗДАНИЯ ЛЕВИТИРУЮЩЕГО КВАДРУПОЛЯ

А.М. Бишаев, А.А. Буш, И.В. Гладышев, К.Е. Каменцев, М.В. Козинцева

Разработана конфигурация поддерживающего магнитного поля для левитации двух сверхпроводящих колец. Экспериментально она сформирована из четырех соосных магнитов марки N40, вложенных друг в друга с чередованием полюсов и имеющих одну общую внешнюю поверхность. Изготовлены керамические кольца из высокотемпературной сверхпроводящей (ВТСП) фазы Y-123 соответствующих размеров, проявляющие сверхпроводящие свойства с критическим током, достаточным для их левитации. Экспериментально доказано существование устойчивых равновесных состояний для двух сверхпроводящих колец с током в поддерживающем магнитном поле и в поле силы тяжести. На основании проведенных экспериментов и расчетов предложена конфигурация лабораторной модели левитирующего квадруполя.

ДОСЛІДЖЕННЯ МОЖЛИВОСТІ СТВОРЕННЯ ЛЕВІТУЮЧОГО КВАДРУПОЛЯ

А.М. Бішаєв, А.А. Буш, І.В. Гладишев, К.Е. Камєнцев, М.В. Козінцева

Розроблена конфігурація підтримувального магнітного поля для левітації двох надпровідних кілець. Експериментально вона сформована з чотирьох співвісних магнітів марки N40, вкладених один в одного з чергуванням полюсів і що мають одну загальну зовнішню поверхню. Виготовлені керамічні кільця з високотемпературної надпровідної (ВТНП) фази Y-123 відповідних розмірів, що проявляють надпровідні властивості з критичним струмом, достатнім для їх левітації. Експериментально доведено існування стійких рівноважних станів для двох надпровідної кілець із струмом в підтримувальному магнітному полі і в полі сили тяжіння. На підставі проведених експериментів і розрахунків запропоновано конфігурацію лабораторної моделі левітуючого квадруполя.