# Magnetic Potential Well (MPW) Phenomenon Testing

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ABSTRACT: The Magnetic Potential Well (MPW) phenomenon as the ability of two spaced magnets, when at least one of them can be modeled as a closed loop of zero electrical resistance, to change attraction into repulsion by the decrease in spacing between them is demonstrated by means of tests. Proof of the MPW-existence taking into account the coil diamagnetism; MPW-manifestation when the superconductivity is destroyed by the critical field; MPW-levitation of two niobium rings in a rare-earth permanent magnet field; MPW-forces in a three-coil system of the superconducting bearing model, and tests with MPW-force levels of 700N and 7500 N are explained in greater detail.

## 1 INTRODUCTION

Among the fundamental interactions known in nature and recognized by physicists, only nuclear pairwise interaction has a local minimum of potential energy. Others are described by monotonically changing functions of distance. Some examples of this monotonicity are the inverse distance law of the potential energy of two gravitating masses or electric charges, and the inverse cubic law for the interaction of two magnetic dipoles.

The potential energy monotonicity of pairwise interaction is a keystone to the stability problem. Thereupon, Earnshaw’s theorem [4] using the inverse distance law proves the free equilibrium instability. This explains why attempts to suspend a permanent magnet in free equilibrium by other permanent magnets are always doomed to failure.

The fundamental facts regarding monotonicity and stability were being extended by exceptions to the rules. The first exception discovered by the German physicist Braunbeck [3] is diamagnetism of a substance. Superconducting repulsive levitation of a superconductor [7] in the form of a simple connected domain (spatially lengthy body “without a hole”), and electrodynamic levitation of a vehicle using diamagnetic properties of eddy currents are examples of Braunbeck’s permission to levitate.

The second exception is the Magnetic Potential Well (MPW) first discovered and proved in [5], a property of two spatially separated magnets to change attraction into repulsion by only decreasing the spacing between them. In other words, MPW means the magnetic pairwise interaction potential energy as a function of distance has a local minimum. Prima facie, MPW contradicts the classic monotonicity of magnetic interaction and Earnshaw’s theorem about instability of the free equilibrium in a passive (without automation) magnetic system without diamagnetic materials. Therefore testing the MPW can awaken some interest in Maglev devotees looking for possibilities to realize a resting or moving body freely suspended by magnetic forces without automation and electric losses.

## 2 THE MPW PHENOMENON

### *2.1 MPW-conditions*

The problem statement of the MPW-existence provides for such restrictions:

1. Two magnets separated by space
2. Only one linear changeable coordinate
3. Any artificial influence on either magnet is impossible
4. One (or two) magnet(s) is (are) zero resistance closed loop(s).

The last restriction means that MPW can be realized when one or two magnets are superconductive and operate in the persistent current mode.

The correct MPW-theory first derived in [5] gives such a condition of the MPW-existence for two zero resistance closed loops

$$\Psi_1 \Psi_2^{-1} = L_{12}(x_0)\, L_2^{-1} \quad . \tag{1}$$

The left part of (1) is the ratio of full magnetic fluxes (linkages) coupled with the loops. The right part of (1) is the ratio of the loops' mutual inductance $L_{12}(x_0)$ at the MPW-position $x_0$ and self-inductance $L_2$ of a loop whose frozen linkage is $\Psi_2$. Since the mutual inductance of two loops is always less than either individual inductance, both parts of (1) must be less than one. It means the magnetic linkages must be unequal in magnitude. On the other hand the case when one linkage equals zero is equivalent to MPW-existence at infinity – this is of no use. Therefore MPW occurs if the linkage ratio (a parameter the user can control) must satisfy the condition $0 < \Psi_1\Psi_2^{-1} < 1$.

### *2.2 MPW-condition test*

The MPW-existence condition (1) is tested by the installation sketched in Figure 1 [5]. Two identical super conductive coils 1 and 2 as representatives of zero resistance closed loops are placed inside a volume of liquid helium. Coil 2 is fixed while coil 1 is capable of occupying various positions coaxial to coil 2. The outer and inner coil diameters equal 44 mm and 34 mm respectively, thickness 5 mm. Coils are wound with 300 turns of a copper-clad niobium-titanium wire of 0.33 mm thickness. Non-magnetic rod 3 transmits magnetic force between coils to dynamometer 4 to measure this force at different separations h between the coils. Thermal switch 5 is used to destroy the superconductivity state of a small part of wire of coil 1.

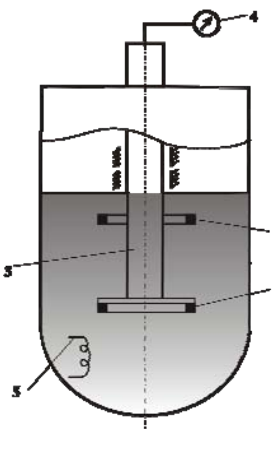

Figure 1. Installation for magnetic forces measurements between two coaxial super conducrive coils.

Experiments are conducted in two stages. At the first stage after cooling coils 1 and 2 below the superconductivity transition temperature, coil 1 is positioned below coil 2 so that the spacing between them is $h = h_0$. Then a part of coil 1 is transferred from the zero resistance state into the state of normal electrical conductivity by switch 5. After that, coil 2 is charged by a persistent current $I_0$. Subsequently switch 5 is shut off and zero resistance state of said part of coil 1 is restored. And finally, the magnetic force P between coils 1 and 2 is measured by dynamometer 4 at different separations h. The second stage of experiments is conducted in a similar way except that switch 5 is always turned on and the normal electrical conductivity state for the coil 1 is kept during measurements of the magnetic force $P_1$.

Plots of measured magnetic forces between coils are shown in Figure 2 by three pairs of curves 1, 2, and 3. Each pair consists of one broken curve corresponding to results of the first stage and one block line corresponding to the difference between measurements of the first and second test stages.

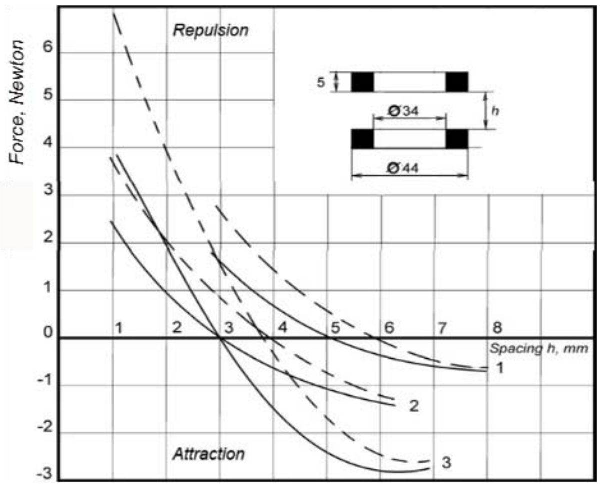

Figure 2. Magnetic forces P, $P_2$ between tow coaxial super conductive coils versus spacing h between them.

The pair of curves denoted by 1 in Figure 2 corresponds to initial experimental conditions $h_0$ = 5 mm and $I_0$ = 10 Amp, curves denoted by 2 to initial values $h_0$ = 3 mm and $I_0$ = 10 Amp, and the curves pair 3 to $h_0$ = 3 mm and $I_0$ = 15 Amp.

The magnetic force P consists of two parts, one is due to magnetic interaction between electric currents flowing in short-circuited super conductive coils, and the second part $P_1$ stands for diamagnetism of these coils. The solid curves in Figure 3, which depict the "pure" MPW-force $P_2$ = P

- $P_1$, are obtained after excluding the “diamagnetic” part $P_1$ from P.

Tested results verify condition (1). Clearly, as is visible from Figure 2, the zero of “pure” MPW-forces are at spacing $h_0$ = 3 mm and $h_0$ = 5 mm as they must be in accordance with (1). Moreover, a spacing $h > h_0$ corresponds to increasing magnetic attractive forces up to the maximal value with the increase of h. In this range h the magnetic force is similar to an expanded mechanical spring force. At separations less than $h_0$ the MPW-force is repulsive in nature and acts like compressed spring.

### *2.3 MPW under condition of superconductivity destruction*

A non-typical MPW-force in the form of "saw teeth" is shown in Figure 3. It is obtained for the samarium-cobalt disc magnet of 40mm diameter and 8mm thickness and coaxial to the magnet thin niobium ring of 40 mm diameter. After positioning the ring on the magnetic pole at room temperature, the magnet-ring pair is cooled in a liquid helium cryostat and then the magnetic force as a function of separation between coaxial magnet and ring is measured.

The saw-toothed character can be explained in the following way. The magnetic field generated by the magnet at the ring location measured before force testing is 0.1 Tesla – that is a little less than the critical magnetic field (approximately 0.14 Tesla) for niobium at temperature 4 K. After cooling below the ring superconductivity transition, some magnetic linkage is frozen in the ring. To satisfy the linkage invariability of closed zero electric resistance loops, in the process of increasing ring-magnet separations from zero an increasing electric current appears in the ring. As a result, the sum of "own" magnetic field generated by this current and the part of permanent magnet field exceeds the niobium critical field destroying the ring superconductivity (point 1 in Fig. 3). This provokes some transient processes (heating ring as resistor by ring’s diminishing current, cooling ring by helium etc.), so that at point 2 in Figure 3 the ring superconductivity state is restored before zero current in the ring. At this separation, a lesser part of the magnet’s flux proves to be coupled with the ring, and increasing separations result in the repeating picture and in the second destruction of the superconductivity state (point 3 in Fig. 3).

Points A, B, and C on the same force level in Figure 3 depict points of stable balancing with the saw-toothed magnetic attractive force as a function of spacing. This means that only discrete levitation positions are possible with MPW-interaction and destruction of the superconductivity caused only by changes in separations between levitating body and magnetic field source.

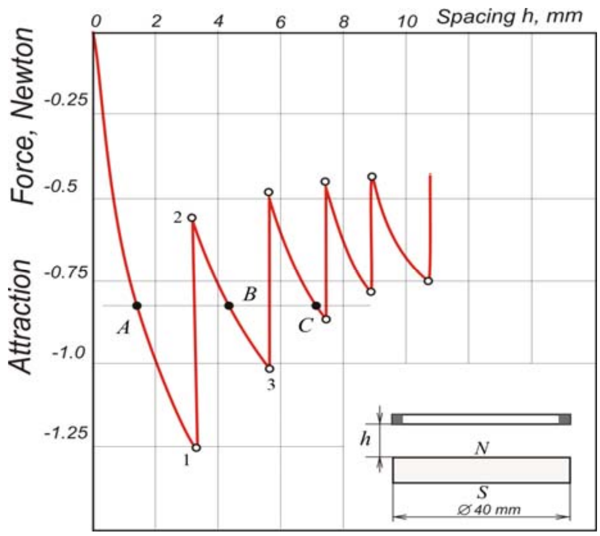


Figure 3. Permanent magnet-niobium ring magnetic force.

This result can be used to explain some properties of high temperature superconductor levitation such as “sticking in an invisible heap of sand” [1]. If such a specimen can be represented as a plurality of loops different in size and orientation, floating like “sticking” can be explained as a consequence of the saw-shape MPW-force. According to this, the continuous range of stable positions ascribed to levitation of high temperature superconductors [2] is an approach from a set of discrete (quantized) equilibrium positions to the continuity of these positions. This is possible for a large number of zero resistance loops different in size and orientation, and operating near the critical magnetic field.

### *2.4 Two- body levitation*

The MPW-force contributes to the stability in the MPW-direction. This ability can be used to balance the weight and suspend bodies in the free equilibrium when the MPW-direction is vertical [5, 6]. First permanent magnet 1, two niobium rings 2, 3 on non-magnetic support 4 were symmetrically placed below magnet 1 (Figure 4a). Thereupon the whole system was cooled in the glass Dewar’s vessel by liquid helium to achieve rings superconductivity state, and support 4 was slowly sunk with respect to magnet 1.

As a result, rings 2 and 3 occupied free positions shown in Figure 4b. This double free equilibrium was clearly observed through non-silver strip in the Dewar’s vessel. Vibrations and influences of extraneous magnet moving outside the Dewar’s vessel disturbed rings positions. In all cases of disturbances, changes of the ring positions were observed visually (complex oscillations). These changes were damped slowly after elimination of disturbances.

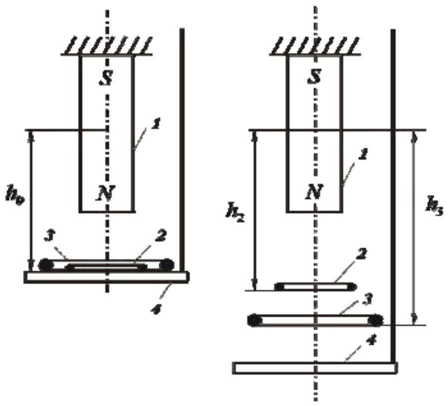


Figure 4. MPW- levitation of two niobium rings.

In our experiment the samarium-cobalt magnets were used in the form of a cylinder of 6mm diameter and 18 mm length. The mass of the smaller niobium ring was 0.19 g; its inside diameter 10 mm and thickness 0.5 mm. The mass of the larger ring was 0.35 g, inside diameter 15 mm, and thickness 0.5 mm. The dependences of levitation separations on initial separation $h_0$ are shown in Figure 5. At $h_0 \approx$ 17.5 mm rings free equilibrium proved to be impossible because the maximal MPW-force was less than the weights of the rings.

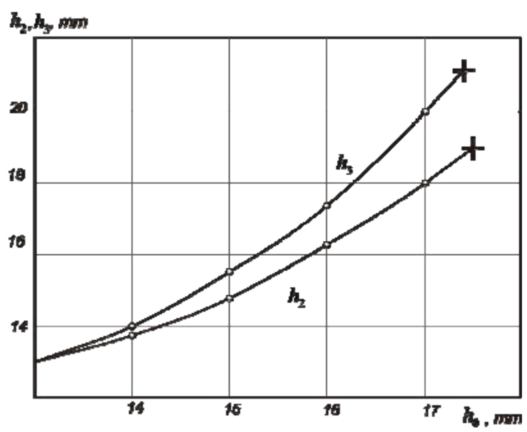


Figure 5. Levitation gaps $h_2$, $h_3$ versus spacing $h_0$.

## 3 BEARING FORCES MODELING

In the light of practical applications it is important to estimate the maximum MPW-force. This problem was dealt with by measuring the magnetic force between coaxial super conductive coils when two constraints were satisfied: one, existence of the MPW; and two, existence of current conditions approaching the critical mode of one of the coils [6]. Three coil windings were of niobium-titanium composition. Two smaller coils were movable and the third larger one was fixed. Before testing two smaller coils kept close face-to-face were placed symmetrically inside the larger coil (x = 0 in Figure 6) and transferred into non-zero electrical resistance state by thermal keys.

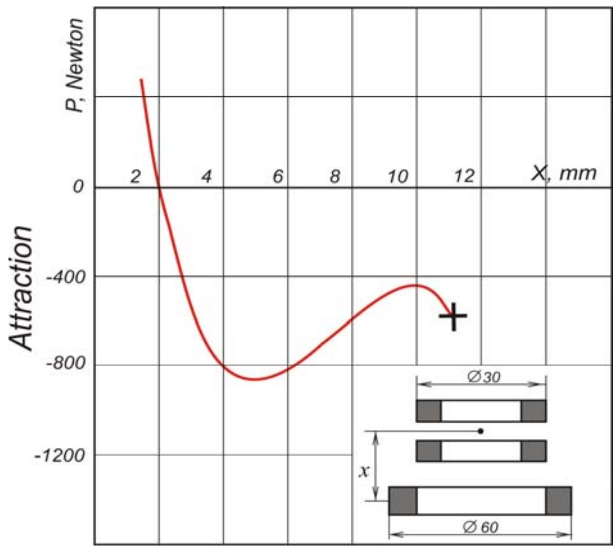


Figure 6. MPW- suspension nearby the critical current mode.

First the critical current $I_c$ destroying super conductive state of larger coil was measured. After that this coil was repeatedly energized by a current I, which was a little lesser than $I_c$, and first the larger coil and subsequently two smaller ones were transferred into zero resistance state. Thereupon, two smaller coils were moved apart symmetrically and owing to this they form a gap h. Subsequently the gap h was invariant. Finally, the pair of smaller coils was displaced and the magnetic force P was measured as a function of displacement x.

We found an unusual law of the force P in the form of a wave plot as shown in Figure 6. Furthermore, displacements of two smaller coils destroy the super conductive state, denoted by the + sign plotted at the end of the curve in Figure 6. It is significant that this destruction depends on x but does not necessarily correspond to the maximum force. The magnetic force P shown in Figure 6 increases from zero at x = 2 mm to a maximum of 900 N at x = 5 mm as an increasing modulo function of spacing *x* that guarantees the axial stability of levitation.

## 4 BIG MAGNETS

MPW-testing was conducted also in a side wall levitation configuration with three identical super conductive coils of 600mm inside diameter, 100mm height, and of small ratio between the coil thickness and diameter [6].

An individual metal cryostat was fabricated for each coil. They were of disk form with horizontal-working axis. The coil was located at the bottom of the helium volume while the nitrogen volume was at the top. Detachable cooled input terminals, the maximum current was 300 Amp, were incorporated in the design together with a special-purpose power unit. They ensured transfer of horizontal and vertical forces up to 10,000 N and 20,000 N respectively as well as reliable operation of the coils in the persistent current mode.

The distance separating ends of two outer super conductive magnets could vary so the axial “warm” spacing between ends of the moving and fixed super conductive magnets could also vary over a range of zero to 200 mm.

Some idea about the scales of this experimental installation in comparison with the tester stature can be obtained from Figure 7. Two super conductive magnets were mounted to the frame by screws. Such design allowed fixing the variable spacing between immobile magnets and the movable one. In Figure 8 the movable super conductive magnet on a special stand is shown.

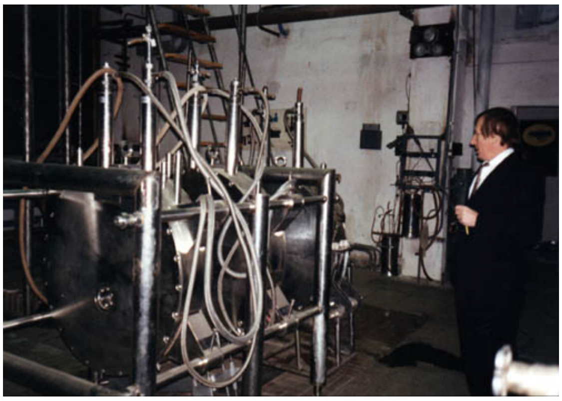

Figure 7. Three super conductive magnets of side wall configuration and frame before testing.

The frame, bodies and main details of super conductive magnets were manufactured from stainless steel. During testing the movable magnet was held, lifted, and lowered by an elevating crane. The platform for a load (lead ingots of known masses) measuring vertical magnetic forces between immobile and movable magnets at different vertical

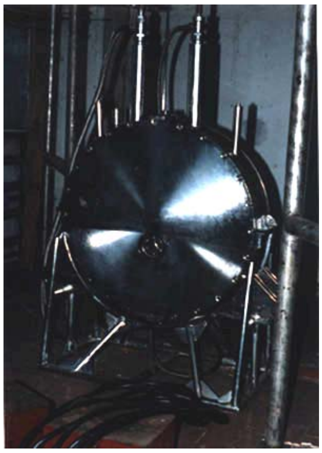

Figure 8. Movable super conductive magnet.

separations was attached to the movable magnet bottom. Upon cooling, super conductive magnets were energized by individual low voltage sources. During force measurements magnets operated in the persistent current mode.

The major result of these experiments is the corroboration of the MPW-force law in the vertical direction i.e. increasing magnetic force from zero at initial non-misalignments between two immobile super conductive coils and coil of the movable magnet to some maximal force at more lowered movable magnet together with said loaded platform, and measurements of this maximal magnetic force that proved to be 7500 N at “warm” vertical spacing no less than 120 mm.

## 5 TWO MAGNETS OF 700 NEWTON FORCE LEVEL

Increasing MPW-force from zero at some small spacing to approximately 500-700 Newton of the maximal attraction force at higher spacing is convenient method to demonstrate MPW in the simplest way, by hand. To this aim two super

Figure 9. Two magnetic “suitcases”.

conductive magnets in the parallelepiped form ("magnetic suitcases") were fabricated. One of them was fixed and the second flexible could be dangled thus changing the horizontal spacing between two pairs of coaxial super conductive coils any of which was mounted at the bottom of fixed and dangled magnets (on the right in Figure 9). Magnetic force was measured by a dynamometer at various spacing between two neighbouring vertical walls of fixed and dangled magnets (Figure 10).

Figure 10. MPW-force measurements by hand.

After cooling and attaining the super conductive state of all coils in both magnets, at some initial horizontal spacing that equalled 10 mm to 50 mm, the fixed magnet was energized by electric current of 80 to 100 Amp and subsequently it operated in the persistent current mode with the charging source cut off. During charging of the fixed magnet, a part of super conductive windings of the dangled magnet was transferred to resistive state. After charging of the fixed magnet the super conductive state of said part was restored and both magnets operated in the persistent current mode. Then separations between the magnets were changed from the initial value by hand, and the force was measured by the dynamometer.

Tests corroborated the increase up to 500-700 N of the maximal value of the magnetic attractive force with the increase in spacing to 60-70 mm between neighbouring walls of the fixed and dangled magnets, and the magnetic force decreased with subsequent increase in horizontal spacing.

## 6 CONCLUSIONS

Tests with magnets when one or two of them are superconductive and operate in the persistent current mode, and exactly determined condition connecting ratios of frozen magnetic linkages and mutual/own inductances are satisfied corroborating the Magnetic Potential Well (MPW) phenomenon manifestation, as the ability of two separated magnets to spontaneously change attraction into repulsion by only decreasing the spacing between them.

MPW assists the free body position stability i.e. levitation operating without automation, irrespective of speed and diamagnetism of any kind.

Tests corroborated MPW-levitation of two free bodies in the field of a permanent magnet.

Tests of MPW-manifestation discovered discrete permissible levitation positions that can be used to interpret some features in the behavior of levitated high temperature superconductors.

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