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Magnetic levitation in industrial transport systems

***Abstract**. The paper presents a well known idea of using permanent magnets as a source of energy in an industrial transport system (for instance maglev). The idea of this paper is to present computation and simulation for a transport system in 2D space using the Ansys environment. An idea for a system which starts to operate only at the very moment when a worker needs help and is moving a heavy object, and is using it with a minimum amount of energy has become an idea about saving energy. When gravity is eliminated by magnetic fields forces, for moving heavy object, we only need to overcome the moment of inertia. All resistance practically disappears, because there is almost no friction in this system. In the paper the use of magnetic field concentration in Halbach array system for eliminating gravitational forces during a load movement has been presented.*

***Streszczenie.** W pracy przedstawiono dobrze znaną ideę wykorzystania magnesów trwałych, jako źródła energii w przemysłowym systemie transportu (na przykład maglev). Ideą tego artykułu jest prezentacja obliczeń i symulacji transportu systemu w przestrzeni 2D za pomocą środowiska Ansys. Pomysł na system, który działa tylko w momencie, gdy pracownik potrzebuje pomocy i porusza ciężkim przedmiotem i używa go przy minimalnej ilości energii, staje się pomysłem oszczędzania energii. Kiedy grawitacja jest eliminowana przez siły pola magnetycznego, do przemieszczania ciężkich obiektów wystarczy jedynie pokonać moment bezwładności. Cały opór praktycznie znika, ponieważ w tym układzie prawie nie ma tarcia. W artykule przedstawiono zastosowanie koncentracji pola magnetycznego w układzie macierzy Halbacha do eliminacji sił grawitacyjnych podczas ruchu ładunku. (**Lewitacja magnetyczna w systemach transportu przemysłowego**)*

Keywords: levitation, force, gravity, transport.
Słowa kluczowe: lewitacja, siła, grawitacja, transport

Introduction:

Industrial conditions, particularly those using production lines used to manufacture significantly heavy components or mass materials [4,5] whose weight exceeds the carrying capacity of a single worker, and require the use of auxiliary equipment for handling parts and components which are being assembled. The systems supporting this process are designed based on mechanical ideas (moving roller tables, ball tables, forklifts, production lines). In stationary conditions, all kinds of hoists, girders, cranes [6] are also used. The authors' idea is to search for a method of moving heavy elements using the phenomenon of levitation with the use of magnetic field from permanent magnets and the "Eddy current" effect which can be helpful in this field. Such devices are already in use in the drives in railway transport with linear motors. Suspending a vehicle by way of using the levitation principle gives great benefits by eliminating friction. Saving this part of energy reduces the costs of moving and handling, and eliminates the wear and tear on the track on which the load is moving.

Forming the field of permanent magnets (Halbach array):

The project considers many magnets arranged in close proximity to each other with polarisation as in Halbach array (This arrangement together with the position and polarisation of the magnets is shown in Fig. 1).

It is easy to see that such arrangements of magnets and orientations of the fields causes the transfer of a significant amount of energy of permanent magnets to one side of the combined magnets (top or bottom),(6).

If it is considered that the track is usually on one side of such a group of magnets, the energy thus concentrated can be used more intensively to produce the phenomenon of levitation.

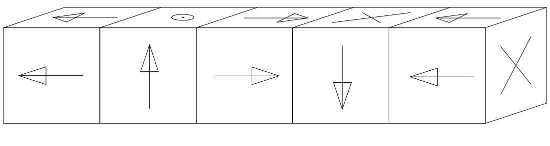

Fig. 1 Diagram of the arrangement and polarization of permanent magnets in Halbach array

Such arrangement of the magnetic fields will allow for augmentation of their interaction between the magnets and the track.

Project assumptions:

The main aim of this work is to create a mathematical model of an object in an electromagnetic space in order to determine how powerful levitation forces can be obtained using widely available permanent magnets. The computer simulation of an operation of this type of the system is an introduction to the further part of the research, to the construction of a platform allowing to transfer loads on the platform having eliminated the influence of gravity. The computer simulation will allow to calculate the size of loads to be carried by means of the platform created in this way, taking into account the number of magnets used to generate a permanent magnetic field. With such initial assumptions, the diagram of the structure under consideration in the paper is shown in Fig. 2.

The set of permanent magnets is at the same time the load-bearing platform of the system. With the polarization shown in Fig. 2, the field generated in this arrangement mainly acts in the direction of the track. In order to facilitate the flow of currents in the track, it is necessary to use a material with high conductivity, e.g. copper sheet.

The simulation does not take into account the weight of permanent magnets. The possibility of levitation can be confirmed by the force repelling from the track which was calculated during the simulation of the operation of the device..

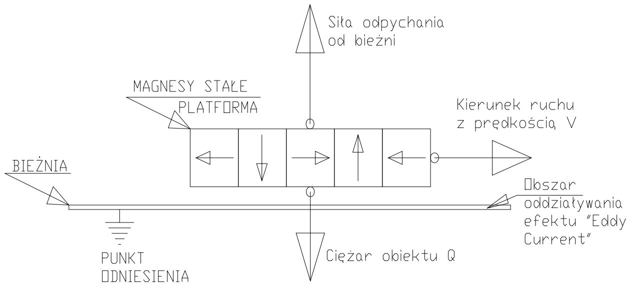

Fig. 2 Diagram of forces acting on a load-bearing platform made up of permanent magnets in Halbach array.

Calculation methodology

The computer simulation was conducted in the ANSYS environment, based on the Tenor Method for the Maxwell equation [1, 2, 3]. The velocity of the slide V=100mm/s was assumed. The magnetic material according to [6] is NdFe35 neodymium material. The track is copper with the parameters consistent with the data from the Ansys environmental library. In the area under consideration, 5 neodymium magnets have been arranged with a rigid connection, as one block acting as a load-bearing platform (Fig.3). In the drawing the block of magnets is visible in the starting position in the front part of the motion tunnel.

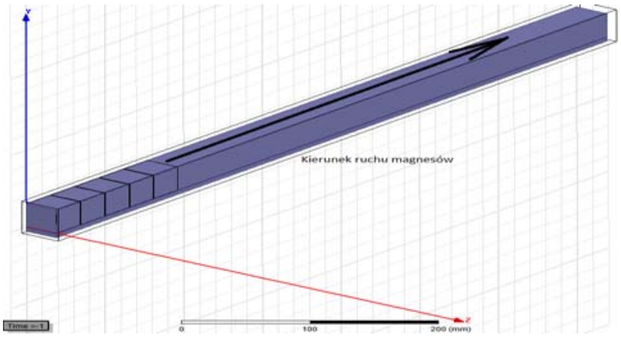

Fig. 3 Operating diagram of the levitation inductor as a load-bearing platform composed of permanent magnets in Halbach array (3D drawing from ANSYS environment)

The magnets, moving at the set speed, move in accordance with the arrow shown in Figure 3 and the X axis, on a 700 mm long track. The 30x30x30 mm permanent magnets are polarized according to the scheme shown in Figure 1. Under the magnets there is a 5 mm thick copper track. The magnet block moves in a corridor above the 700 mm long track. The air gap between the magnets and the copper track is 1 mm. The corridor of the block movement/motion together with the track is surrounded by a space meeting zero boundary conditions.

The "Transient" system allows to simulate the movement of the magnets in a specific area with a preset a priori speed. Levitation can only be triggered by setting the magnets in motion, the "Transient" system in the Ansys environment is the only way to induce/exert a force opposing gravity.

The mathematical assumptions of the method of analysis are presented in the description of the "Ansys" environment in the documentation [1]. The pull/push force F [N] resulting from the Maxwell equation in a vector form is described by relation (1). The forces may run/occur/flow in any direction in the X, Y planes (spaces X, Y, Z). Only the component of the force calculated along the Y axis, attached to the magnet block, is of interest to the authors of this paper. The source of the anti-gravitational force is the energy of the movement of the magnet block being affected/influenced by the "Eddy Current" effect. The excited currents generate a magnetic field acting in the opposite direction to that generated by the permanent magnets. Due to the fact that the levitation inductor is a rigid body, it is not important at which point of the block made of permanent magnets the calculated/measured force has been attached. The shape of the track and the motion tunnel described in the environment additionally prevents any rotation (torsion/turning/twisting) of the inductor and no additional force or torque on the inductor is calculated/measured/is taken into account. . The formula of the calculated the component of force $\vec{F_i}$ is described by formula (1).

(1) $$\vec{F_i} = \int_C \left[\frac{1}{\mu_0} B(B.\vec{n}) - \frac{1}{2\mu_0} B^2.\vec{n} \right] dC$$

The sum of the forces $\vec{F_i}$, as projections of the force calculated in the ANSYS program on the X axis of the X, Y, Z spatial coordinate system is the resultant force acting on the levitation inductor, shown in Fig. 3..

(2) $$F_x = \sum_i \vec{F_i} * \cos\alpha$$

where α is the angle between the vector of the component force $\vec{F_i}$, and axis X.

The values in formulas (1) and (2) stand for respectively:

B- momentary values of peripheral distribution of induction in the slot B [T],

n - unit vector of the component force parallel to the X axis of the coordinate system,

μ_0 – magnetic permeability of vacuum μ_0 = 4π x 10^7 [H/m].

The calculations were made under fixed air gap conditions, without any change in its thickness and a stable linear velocity along the X axis of the inductor. The air gap between the track and the inductor was set at the distance of 1 mm. The simulation allows us to change the material of the track and examine the effect of such a change on the action of the inductor and the relation to gravity and its counteracting forces. In the case of construction of the actual inductor system, the authors anticipate the analysis of the influence of the thickness? of the track, air gap and material on the forces counteracting gravity. The need to use a 3D space instead of a 2D one is explained in the next section.

A 2D or a 3D space (This is the question!)

The Ansys Maxwell environment was used to simulate the electromechanical system. It is an ideal environment for simulating all kinds of electromechanical converters and electromagnetic field distribution. The main parts of the simulated system are permanent magnets as the tested product. All these elements can be simulated in the Ansys environment using the FEM method and Maxwell Tensors Stress Tensors calculations. This procedure allows you to calculate the distribution of the magnetic field in the simulated system, and then calculate the forces and moments generated by the tested system.

These types of problems can be analyzed in 2D and 3D in the Ansys environment. The use of a 3D model allows the problem to be analyzed without limiting the current flow range. Figure 2 shows the basic differences between 2D and 3D models. In the left 2D model, the currents in question may flow perpendicular to the surface. By treating the computer screen as the surface to be analyzed, currents can flow in and out perpendicular to the screen. In the 3D model, we can analyze additional currents flowing parallel to the screen surface. It allows for the analysis of edge effects and their impact on the studied phenomena. In the case of searching for anti-gravity forces, it is not possible to calculate the forces in the X axis. The 3D modeling space of the problem in question requires enormous computing power and memory space as well as time-consuming calculations. Limiting the analytical space to a 2D model reduces the simulation perspective and limits the flow of currents only in the direction perpendicular to the plane of the analyzed space (Fig. 2), which prevents the analysis of the elements acting against the forces of gravity.

Reducing the analyzed space to a two-dimensional model allows for faster calculations and simplifies the analysis of the phenomena. However, it requires a precise planning of the experiment in order not to lose the possibility of drawing accurate conclusions by limiting the area of the analysis.

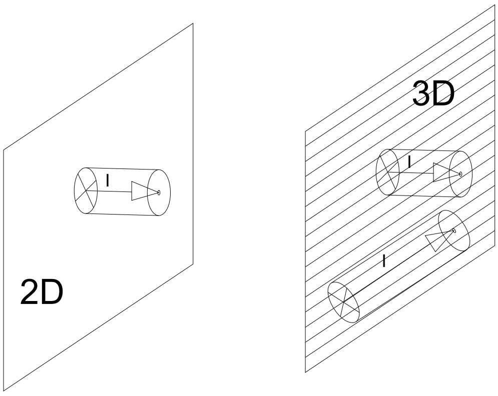

Fig . 4 Direction of the currents flow in 2D and 3D simulations.

The problem discussed in the article does not require modeling the influence of boundary phenomena on the system. Its aim is to present the idea of using the design of the inductor of the force counteracting gravity. The boundary phenomena occurring in the construction of the induction coil drive are not the subject of this article, and the anty gravitational forces require calculations of the forces counteracting gravity using the "EDDY Current" effect, the 3D space was used for simulation.

Analysis of calculations

The mathematical description in a 3D space was used for the calculations. This requires the use of computer hardware with high performance and significantly large RAM. With 150,000 finite elements, ca. 4 GB of RAM and ca. 70 GB of hard disk space had to be used. A temptation to carry out the analysis in a two-dimensional space is likely to have shortened the calculation time and reduced the memory used in the computer, but at the same time it may have reduced the area and possibilities of the analysis, and mainly it may have resulted in an inability to calculate the forces that were of most interest to the authors, i.e. those acting along the Y axis, against gravity. The simulation was carried out with the data presented in section 4. The plot of the force depending on the time and position of the magnets is shown in Fig.5. After a relatively short transient state, appeared a force directed according to the Y axis, located in the space X,Y,Z and vertically upwards against gravity. The force under these conditions was 615N. This value was achieved using five NdFe35 magnets with a total volume of 45 cm^3 and a speed of 100 mm/s.

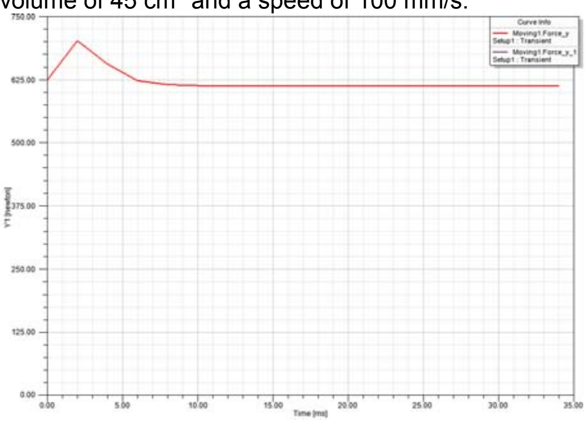

Fig 5 Diagram of the generated Fy force counteracting gravity.

Considering the specific weight of a neodymium magnet as about 7.5 g/cm^3, the weight of 45 cm^3 magnets is about 30 dkg. With the force generated by the magnets, this generates a significant surplus of forces related to the force counteracting gravity over the weight of the magnets. With identical parameters, the next simulation was carried out when the track thickness was changed, i.e. reduced to 3 mm. This experience was expected to direct the authors in the directions of changes that take place when experimenting with the design of the device.

That influence on the generated forces is shown in Fig. 6. Decreasing the levitating force to 592 N while reducing the volume of copper in the track does not surprise and it naturally results from decreasing energy density in the system under consideration..

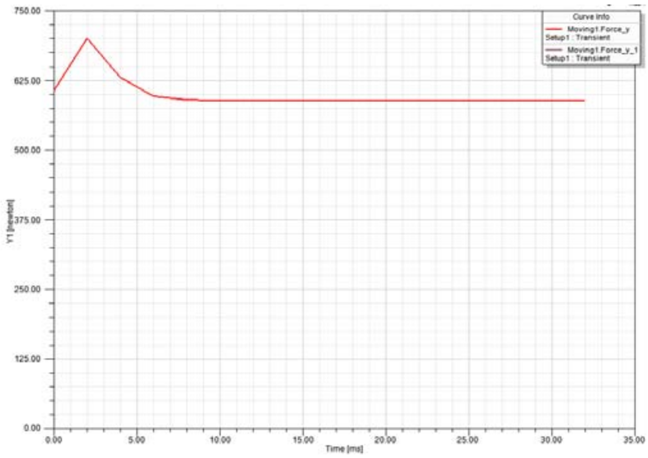

Fig 6 Diagram of generated force Fy counteracting gravity at the track thickness reduced to 3 mm.

The results of the simulation are shown in Table 1. The diagram of the generated force indicates its stable course while maintaining a constant speed of the movement of the magnet block. The results of other simulation variants are presented in a tabular form/in the form of a table. The presentation of their course in the form of dependence of these forces on time does not affect how to interpret them.

Table 1. Simulation results

1 mm air gap				
Track thickness [mm]	3	3	5	5
Linear velocity of the moving magnets [mm/s]	50	100	50	100
Force generated by the magnets counteracting gravity [N]	602	590	540	615

This data allows conclusions to be drawn as to further decisions on the design of the device

Conclusions

The design has met the authors' expectations. The forces generated in the system of the permanent magnets set in Halbach Array are large enough to be used to carry/move loads in the gravitational field. This allows us to hope that they can be used to move loads/weights. However, the following problems must be taken into account:

The forces generated by the permanent magnets appear only during the movement of the magnets (the platform). In order to obtain/generate the lifting force of the system, a man needs to make the platform with the magnets move. If the platform with the magnets does not move in relation to the track, it will not generate forces enabling the lifting of the load. Static friction will make it impossible to move both the platform and the load. [8].

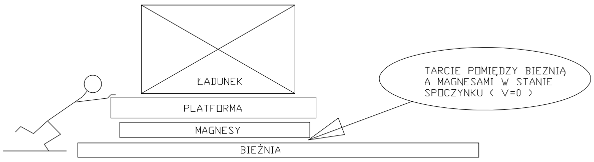

Fig 7. Depicted attempts at shifting the load without the initial speed of the platform. (Vo=0)

The method proposed by the authors works on the load only in dynamic conditions. The load needs to have an initial speed (Fig. 7).

This conclusion leads to another one that arises in this situation. There is a possibility of full levitation of the designed construction if another movement vector is used. A stable suspension of the load within the gravitational field requires an additional source of energy of the rotating system of magnets set in Halbach Array. The rotation of the magnets will cause the effect of "Eddy current". The forces generated in this way can hold still the load-bearing platform in one place. After stopping the rotating movement of the magnets, the "Eddy current" effect will disappear, the platform will descend, and friction forces will hold it on its supporting structure. The switching on and off of such a system will only involve switching on and off the motor system driving the permanent magnet rings. Arranging them in the Halbach array will result in strengthening the influence of permanent magnets on the transport track. The authors plan to consider this idea further.

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The calculations for this paper have been made by accessing the structure discussed herein.

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