Magnetic Levitation System for Take-off and Landing Airplane – Project GABRIEL

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Abstract: In the paper will be presented the construction of passive magnetic suspension with superconductors. The system of magnetic suspension was designed for GBRIEL project. There is presented numerical test bench of passive magnetic suspension with superconductor. This kind of suspension was selected for generation of magnetic levitation forces in a sledge of take-off and landing system of an airplane. This sledge will be used for verification and testing of GABRIEL system with small scale airplanes. The numerical test was made in the module AC/DC of Comsol Multiphysics with magnetic no current physics.

Keywords: magnetic suspension, magnets, superconductor, magnetic array.

1. Introduction

The safe, economic and ecology operation of airplanes conduct to search new construction. The modern airplane will has launcher for take-off and landing. It will replace chassis and it will assist or replace engines during take-off.

The launcher is built from magnetic linear suspension and linear electrical motor. The electrical drive is an ecological system. The jet engine works hard (full power) during take-off and introduces pollution to air around airport. The electrical motor provides the take-off speed and brake during landing and the jet engine is turn off or limited power.

The airplane is suspended under runway by the magnetic levitation system. The active and passive magnetic linear suspensions are used to generate magnetic forces. The magnetic levitation systems have got a lot of advantages. The elimination friction is principal advantage by magnetic suspensions. There aren't any additional installations as cooling and lubrication system.

Active magnetic suspension system uses the feedback control loop to change magnetic forces. The passive magnetic system haven't feedback loop. The magnetic forces are result of collaboration materials with different magnetic property. There are used permanent magnets, conductors and superconductors. The passive magnetic suspension can be divided in to: passive magnetic suspension with magnets, superconductors and electrodynamics [3]. There will be presented construction and numerical verification of the superconductor passive magnetic suspension.

2. Gabriel

GABRIEL concept is the future system take-off and landing for the communication airplanes. This system consists from the magnetic runway with a magnetic sledge and a cart. The cart is an element which merge an airplane with a sledge. The airplane hooks to the cart. The cart has control system of attachments. The linear electric motor drives the sledge with cart and airplane. When the speed of sledge is equal the take-off speed, the airplane unhooks and take-off. Take-off system assumes speed about 110 m/s and acceleration from 4 to 7 m/s^2.

The speed of sledge synchronies with airplane when the airplane lands. The airplane touchdowns when the relative speed between airplane and sledge equals zero. Next, the system of attachment hooks airplane with cart. The electrical motor passes to brake and the sledge stops.

The system take-off and landing designates for airplane class Airbus A320 (mass about 80 tons). Now the demonstrator of technology is designed. There will be used the magnetic suspension system with superconductor. The sledge will have four suspensions with four cylindrical shaped superconductors each. The sledge will be driven by a slotless electrical linear motor.

3. Model of passive magnetic suspension with superconductor

The model of magnetic suspension system with superconductor consists from magnetically rails and box with superconductors. The superconductors submerge in nitrogen. Nitrogen and superconductors are located in the box. The construction of system is presented in the figure 1. The cover of box has got two holes. It is used to pour down the nitrogen.

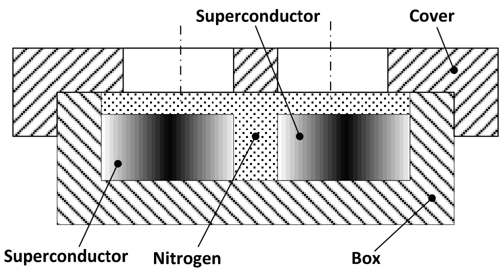
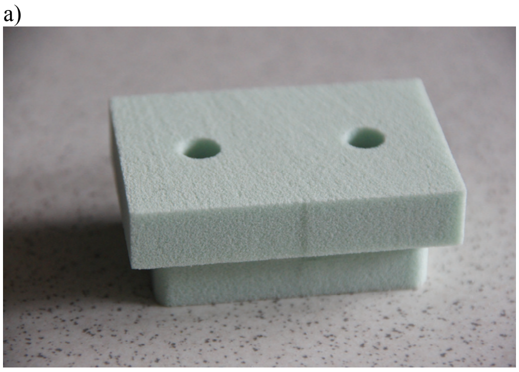


Figure 1. The cross section by box.

a)



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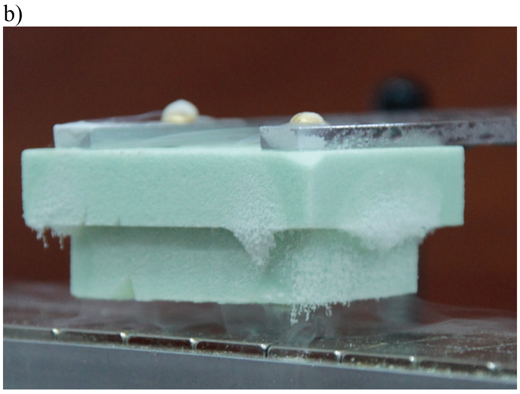


Figure 2. The box with superconductors(a) the box under levitation(b).

The box with superconductors and nitrogen is located under magnetic rails. The rail is presented in the figures 2 and 3. It is built from magnets which are mounted in the magnetic array. The array has three rows of magnets. The number of column depends from the length of rail. The designed and tested system is built from two rails and two boxes (fig. 3).

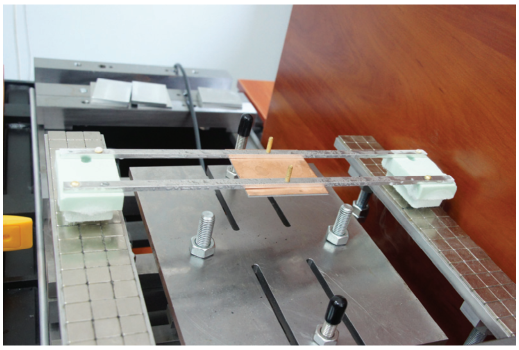


Figure 3. The laboratory test stand.

There were tested two configurations of magnetic arrays. Magnets outer rows have got the same orientation of magnetization. The central row of array has got opposite orientation of vector of magnetization. Configuration of magnetic array is presented in the figure 4.

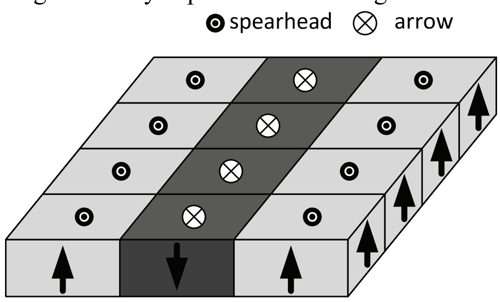


Figure 4. Configuration magnetic array – variant A.

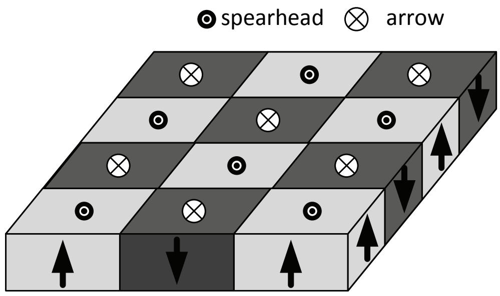


Figure 5. Configuration magnetic array - variant B.

The configuration of second array is shown in the figure 5. There magnets mounted alternately. If the first column has configuration of vector of magnetization M [↑,↓,↑] (figure 5) the next column has magnetization M [↓,↑,↓]. This scheme of configuration of magnetization repeats in the next columns of array. Configuration of magnets from figure 5 has got important advantage, is very easy to make. The magnets mounted in the array generated strong attractive forces and the array is easy to assemble. The array from figures 4 and 6 is very difficult to assemble. The strong repulsive forces are generated between magnets from different columns. The process of realization of array is hard case and requires special equipment. The next advantage of configuration array from picture 5 is stronger magnetic field generate for array. The molecular current in the active walls of magnet added and generated strong magnetic field. The effect sum molecular current is weaker for configuration array in picture 4 (this rule is result from loop with molecular current as a model of magnet [4]). Distribution of molecular current in the rail is presented in the figure 6 and 7. The variant B of array has got only zone with sum of molecular current. The sum of current generates strong magnetic field in the all wall of magnets (this rule applies only active wall, which is definite in [4]). The magnetic flux can be obtained from the Biota-Savart law [1].

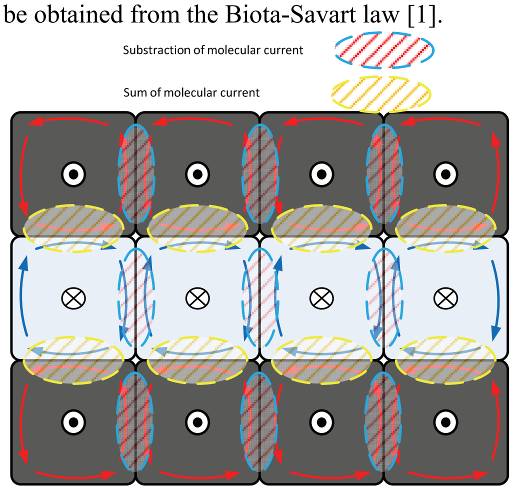


Figure 6. Sum and subtraction of molecular current – variant A.

The variant A has got zones where the molecular currents sums and subtract. The result of sum is the same as in variant B but the result of subtract is reduced the molecular current and reduced the magnetic field. The configuration A is similar to rails (two magnetic rails) which takes the superconductors between the rails.

The magnetic levitation of superconductors is a result of Meissner's effect. The phenomenon of superconductor is presented in a lot of publication [2], [3], [5] and the problem egress outside this paper.

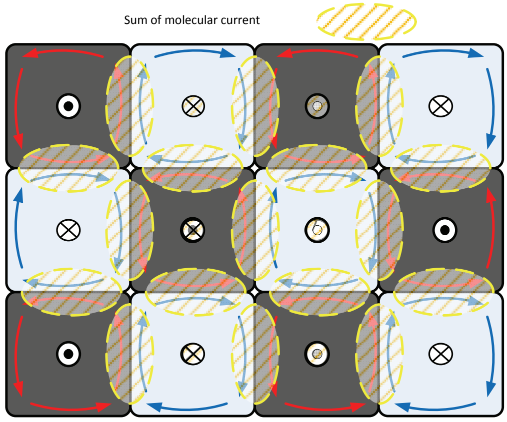


Figure 7. Sum of molecular current –variant B.

4. Model of magnetic suspension

The model of magnetic suspension was made in the Comsol Multiphysics. The Comsol was used to:

- analysis distribution of magnetic field and optimization it,
- optimization geometry of rail and magnets (influence dimension for optimal distribution magnetic field),
- optimization dimension of superconductors for generation magnetic forces and air gap.

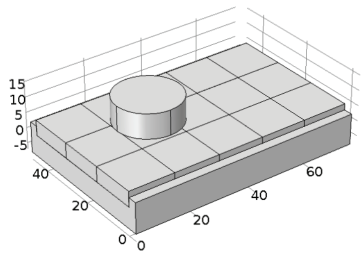


Figure 8. The geometry of magnetic suspension.

There was used module ACDC with magnetic field no currents. This physic is very handy for test magnetic phenomena where magnets are source of magnetic field. There wasn't tested influence of speed of superconductor in the no-uniform magnetic field for magnetic force. The geometry is presented in the figure 8. There are magnets (dimension 15x15x5), rail and cylindrical superconductor (ϕ21 and height 8). The magnets was made from neodymium N38 (B_r=1.24 [T] and H_c=955[kA/m]). Configuration of magnet is shown in the figure 9. The magnetic permeability of magnet was obtained as relationship between B_r and H_c.

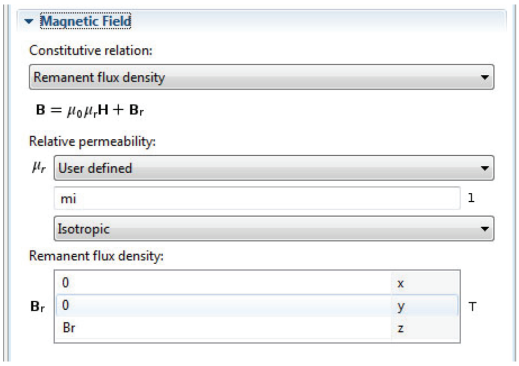


Figure 9. Model of magnet.

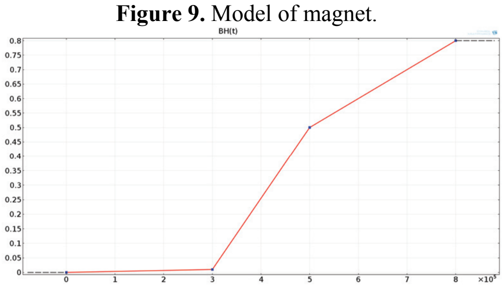


Figure 10. Magnetization curve of YBCO [5].

The superconductor was modeled as magnetic material. There was used superconductor type II. This superconductor has got three regions. The first region refers to ideal diamagnetic. The second region refers to mixed property (this is transitional property between superconductor and normal conductor). The last region is related to conductor's property. There was modeled material YBCO which worked as superconductor for temperature 93°K. The magnetization curve of YBCO is shown in the figure 10. The magnetization curve of YBCO was assigned from [3] and [5].

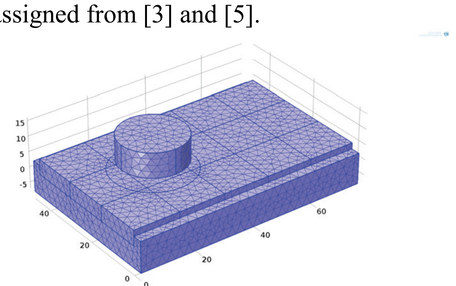


Figure 11. Mesh.

The model includes region which make from alumina and air. The material library of Comsol was used to describe property of alumina and air.

The mesh was generated for five regions: rail, magnets, superconductor and two regions of air. The air around superconductor was selected as independent region for this region was generated concentrated mesh. The mesh of superconductor, magnets and rail was shown in the figure 11.

5. Magnetic field of array

The test of array started from analysis of magnetic field. The first question is determined the desirability of magnetic arrays in the construction. Does the magnetic array effective then single magnet?

In the figure 12.a is presented magnetic flux density under magnet N38 15x15x5 and in the figure 12.b is shown magnetic flux density above array mounted from three magnets (the magnet from figure 12.a was used to build a layer of magnetic array). The magnetic flux density was measured 5 mm above magnet and array. The length x equal 22.5 mm in the figure 13 correspondent to central location of magnet and array.

a)

b)

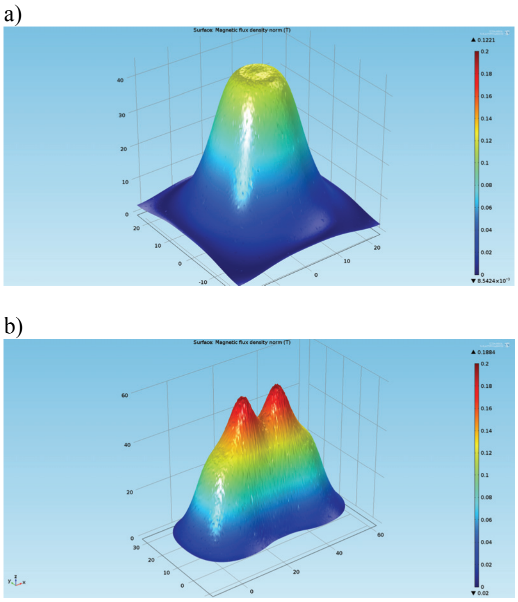


Figure 12. Distribution of magnetic flux density 5 mm under magnet (a) and magnetic array (b).

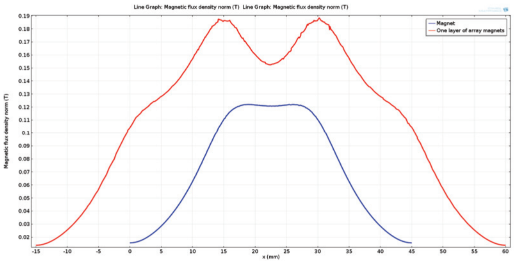


Figure 13. Module of magnetic flux density above magnets (up 5 mm).

The module of magnetic flux density is bigger for magnets array then single magnet. The connected magnets with different orientation of magnetization (figure 13) generate strong magnetic field around walls. The effect is presented in the figure 12.b. There is characteristic ramp and the module of magnetic flux density is larger then single magnet (figure 13).

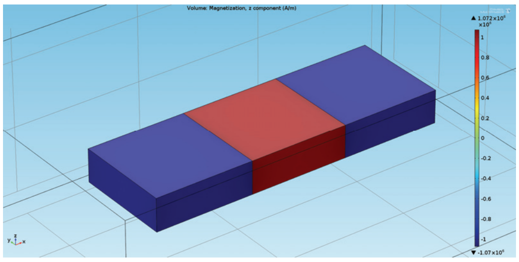


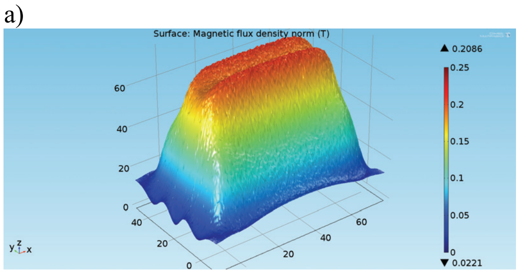
Figure 14. The magnetization of magnetic array.

This phenomena is an effect of connection active wall of magnets [4] with different orientation magnetization. The magnetization of one layer of array is shown in the figure 14.

6. Magnetic field of rail

The magnetic array from figure 14 is used to make a rail. Those arrays are connected for two variants presented on figures 4 and 5. The result of connection magnets for array variant A and B is shown on the figure 15. The array for variant A has got characteristic gutter. The gutter is an effect of merge ramps from different layers. This phenomenon is presented on the figure 15.a.

a)



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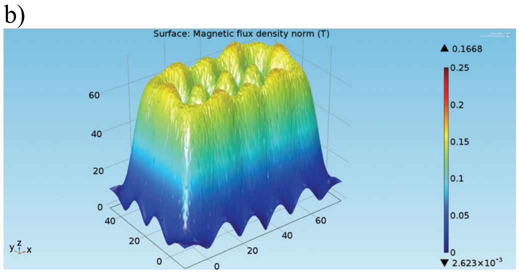

Figure 15. Module of magnetic flux density under array of magnets (up 5 mm) variant A (a) and variant B (b).

The variant B has got distribution as unregularly impulses. The impulses are a result of influence of strong corners in cubical magnet. The direction of molecular current is changed in the corner and the resultant current is reduced in the corner. The maximal value of magnetic flux density in the variant B is lesser then variant A. The maximum module of magnetic flux density is equal for variant B 0.167 T and for variant A 0.2 T. The maximal value of module magnetic flux density was obtained from tool "Max/Min Surface" (figure 16).

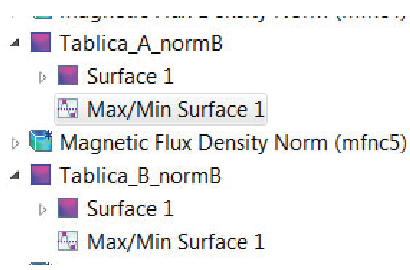

Figure 16. Obtain the maximal value of magnetic field 5 mm under surface of array.

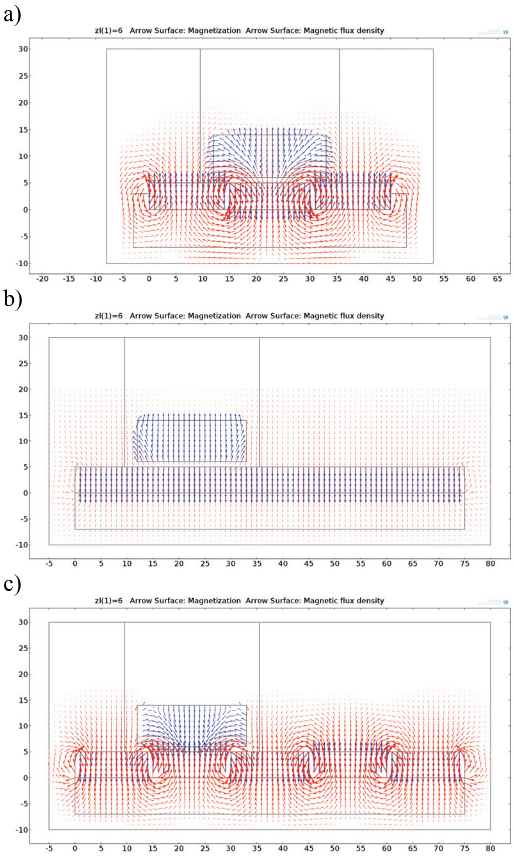

Figure 17. The Meissner's effect.

6. Magnetic force tested

Next research of passive magnetic suspension with superconductors included analysis distribution magnetization and magnetic flux density. There was tested model of superconductor. The main attribute of superconducting phenomena is a Meissner's effect. This effect is an expulsion of a magnetic field from a superconductor during its transition to the superconducting state.

There located the superconductor shaped as a cylinder under the array for variant A and B. Next was solved task where was changed the air gap between superconductor and magnetic array.

The result of research is presented in the figure 17. The fig. 17.a presents magnetization in the surface Oyz (fig. 15). This distribution is the same for variant A and B (for location superconductor as showed in the figure 8). In the figure is marked magnetization as blue arrows and magnetic flux density as red arrows. The directions of magnetization and magnetic flux density in magnets have the same direction. The magnetization doesn’t exist in an air. The magnetization in the superconductor has opposite direction to external magnetic flux density.

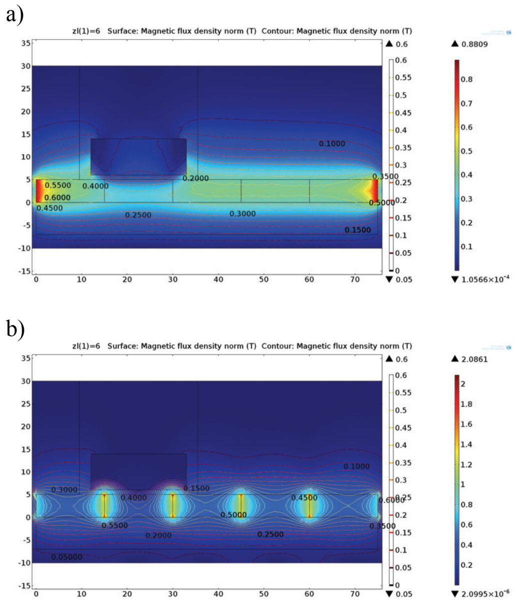

Figure 19. The distribution of magnetic flux density in the surface Oxz for variant A (a) and variant B (b).

The distribution magnetization in the surface Oxz depends from configuration of array. The superconductor has uniform distribution of magnetization in the variant A (fig. 17.b). In the variant B the distribution of magnetization is similar to distribution in the surface Oyz and depends from position superconductor under magnet.

The distribution of magnetic flux density for the variant of array A is presented in the figure 18.a and for variant of array B is presented in the figure 18.b. The magnetic field from superconductor is an expulsion (fig. 18). This test confirms model of superconductor suspension.

The magnetic forces can be obtained after positive verification model of superconductor (the Meissner’s effect). The position of superconductor above runway is described by the Cartesian coordinates. The orientation of coordinates is presented in the figure 15. The forces were obtained for move the superconductor in the Oz direction (vertical move) and in the Ox direction (horizontal move).

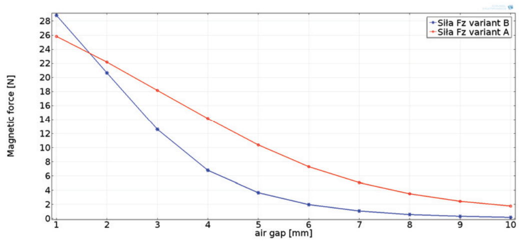

Figure 20. Magnetic force for vertical move of superconductor

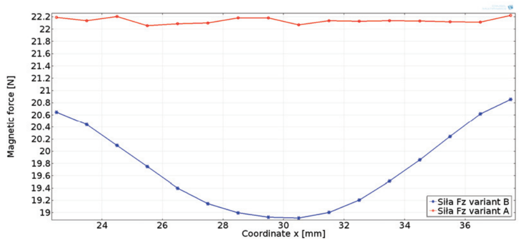

Figure 21. Magnetic force for horizontal move of superconductor.

The magnetic forces for vertical move are presented in the figure 20. The runway for variant A generated greater magnetic force then variant B. The magnetic force was estimated in relation to air gap. The air gap is a distance between magnets of rail and superconductor.

The next figure presents magnetic variation of forces in function of coordinate x (fig. 21). There is modeled horizontal move of superconductor. The vertical magnetic force in the variant A has constant value during move superconductor above rail (red line). The vertical magnetic force in the variant B changes during the move. The value of magnetic force changes sinusoidal wave (blue line) with the length of wave equal dimension of magnet (15 mm). The superconductor was moving above connected active wall of magnets during the horizontal move. This effect is presented in the figure 19. The active wall works as steps when superconductor horizontally moves. There generates vibration and the box with superconductors works unstably. The frequency of vibration depends from dimension of magnet and speed of box above magnetic rail. This effect is only in the variant B.

7. Conclusions

The Comsol Multiphysics was used to analysis and design magnetic suspension with superconductor. The main task was obtained magnetic forces and verification construction of magnetic suspension. There were used commercial superconductors and magnets to design the suspension. Therefore magnets and superconductors must be tested by numerical verification. There was performed verification numerical model by analysis Meissner's effect.

The variant A of magnetic rail was selected to implement launcher. This variant of suspension generated stable magnetic force during horizontal move of superconductor. The box has got 3 mm underside. The admissible air gap is equal 4 mm. The suspension system generated 14 N for air gap 4 mm per one bulk of superconductor.

The variant B of magnetic rail wasn't select to implement. This variant generated smaller forces and generated vibration during horizontal move of superconductor. This variant of rail was suggested as a brake for the end of runway. The magnetic steps can be worked as a protection of end of runway, which was protected sledge before slip down from runway.

8. References

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9. Acknowledgements

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