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MODEL OF MAGLEV LOCOMOTIVE FOR EDUCATIONAL PURPOSES

Mariusz Stepien, Blazej Ploskonka, Boguslaw Grzesik
Silesian University of Technology, Faculty of Electrical Engineering, Gliwice, Poland

Abstract: *A model of MAGLEV train and its propulsion, and control is described in the paper. The MAGLEV suspention is based on YBCO bulk HTS material where train track is made of neodymuium magnets. A multisectional coil actuators forms propulsion system that is controlled by microcontroller (AtMega32-PI). basing on detection of the locomotive position in respect of each actuator. The start-up, braking and the speed are controlled. The MAGLEV suspension and propulsion is analysed using FEM modeling.*

Key Words: ***MAGLEV train, coil actuator, speed control, FEM modelling***

1. INTRODUCTION

The development of industrial applications of superconducting devices is very intensive in couple of recent years. The most popular are HTS coils, bearings, fault current limiters and superconducting shields [1], [2]. Also deep research on superconducting trains is carried out [3]. At the same time one can observe development of superconducting devices for educational purposes. They aid engineering education as well as build interdisciplinary interests. It is so since superconductivity embraces solid state physics, chemistry, mechanical and electrical engineering, power electronics and microprocesor technique. Understanding of two main phenomena: zero-resistance of superconductors and Meissner effect is very important in superconductivity area. The described MAGLEV train designed for educational purposes. The train is driven by inductor actuators and controled by microprocessor unit. The MAGLEV propulsion system has been analysed using ANSYS software (Finite Element Method (FEM)).

2. THE MAGLEV LOCOMOTIV

It is depicted in Fig. 1. The train model is made of two YBCO-123 bulk superconducting cylinders put in the vessel that are immersed in liquid nitrogen (LN2). It is suspended over permanent magnet rail track that is made of neodymium permanent magnets. Propulsion is realized by means of excitation coils of pantograph type. They are arranged as is shown in Fig. 1. Arrangement of the excitation coils along the track is shown in Fig. 2 and photograph Fig. 11.

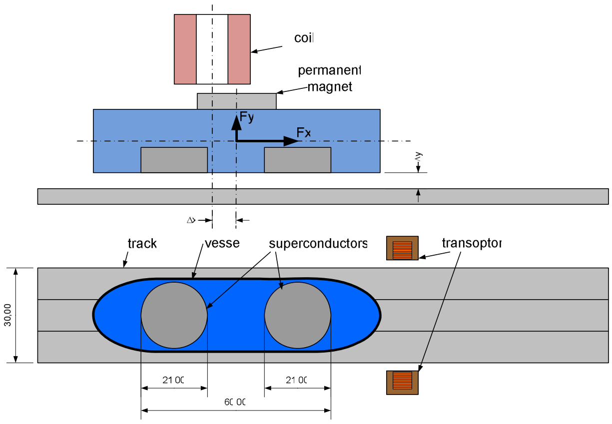

Fig. 1. *Idea of the train design*

In order to calculate forces that cause MAGLEV to be suspended and be driven the position of the locomotive is described in x, y coordinate system. Displacements x, y give the locomotive position in relation to the coordinate origin. Except the locomotive propulsion coil is given in this picture having coordinates of (0, h). The locomotive and the coil are parallel to x axis. The force exerted on the locomotive has three components, both are functions of its position. The first component, F_x, being a result of FEM analysis is depicted in Fig. 3.

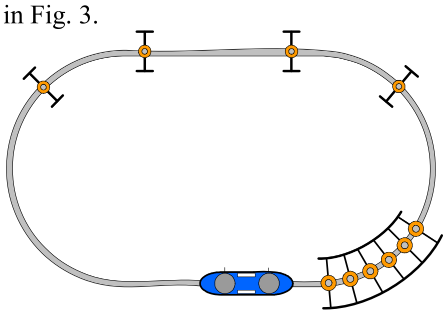

Fig. 2. *Arrangement of excitation coils*

The second component of force F_y is given by (2.1).

$$F_y = m \cdot g + F_{coil,y} + F_{SC,y} \quad (2.1)$$

$$F_{coil,y} = -(k_1 + k_2 \cos(\pi \frac{\Delta y}{w}) \quad (2.2)$$

$$F_{SC,y} = k_3 \Delta y \tag{2.3}$$

where m is a mass of locomotive together with superconductors and LN2. The above coefficients have the values: $k_1 = 0.2$, $k_2 = 1$, $k_3 = 7.5$, $w = 10$ mm. Therefore the locomotive is kept at the level $y = -0.17$ mm. The third component is assumed to be $F_z = 0$. Remark: the bottom of the locomotive is above the rail track of the distance 2 mm. The sample result of Ansys analysis is given in Fig. 4.

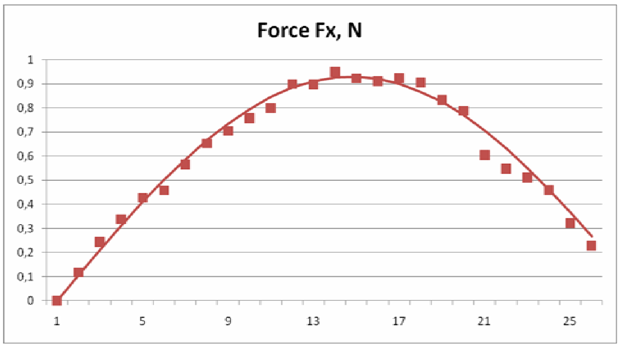

Fig. 3. *Force Fx vs distance (0 – symmetry)*

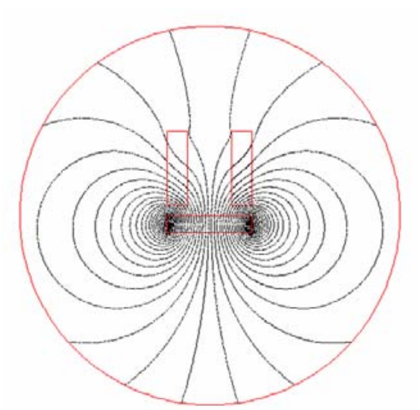

Fig. 4. *Magnetic flux density at 0 distance*

3. CONTROL UNIT

The control unit is basing on the microcontroller AtMega32-PI. The coils are supplied if the transoptor sensors detects locomotive in proper position. The block diagram of the control unit is shown in Fig. 5.

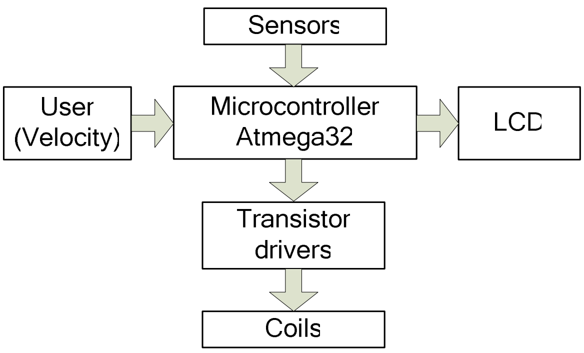

Fig. 5. *Block diagram of control unit*

The control system consists of four essential parts: sensors matrix, control unit, user interface (controller and LCD) and power elements (transistors and coils). The control unit is made using AtMega32 microcontroller. General structure of AtMega 32 is shown in Fig. 6. The sensors (transoptors with gap 15 mm) are arranged in matrix 4x8. This arrangement allows to control of 32 sensors by 12 channels of microcontroller. Additionally the common signal of interrupt is delivered from sensors to microcontroller by logic NAND 74HC30 circuit. It indicates sensor release and is used to calculate velocity of the locomotive.

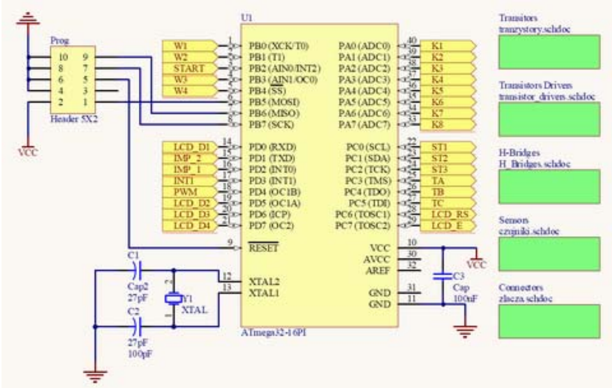

Fig. 6. *Microcontroller of the control system*

The control unit generates 16-bit PWM signal to control the velocity of the locomotive. The actuators are forced by current of the transistors. The PWM signal is proportional to the current of the actuator and influences on the velocity of the locomotive. The circuit of the power output (PWM input marked) is shown in Fig. 7. The velocity is set-up by incremental encoder and LCD display gives the information on the locomotive location and real velocity. The locomotive is propelled by one base section (with six actuator) and four single sections. Each single section contains two optic sensors and one actuator located in between the sensors.

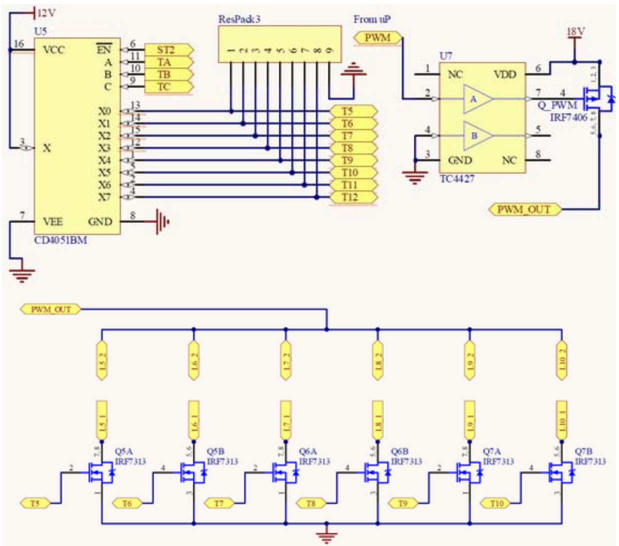

Fig. 7. *Power output of the control system*

4. CONTROL PROCEDURE

The control procedure contains three modes, start-up, hold-up and velocity control (acceleration or deceleration). Two first stages are possible only by base section. The single sections are dedicated only to velocity control.

The base sections contains six actuators and two sensors. The four inner actuators are supplied by four H-bridges. The H-bridge circuit is presented in Fig. 8. In the start-up mode the coils are polarized in the same direction as remained two coils. The start-up of the locomotive is realized by repulsive force in the same way as acceleration (details described below). In the hold-up mode four coils are polarized to generate attractive force. The locomotive is hold-up and suspended in between actuator and racetrack. The PWM control and the reverse of the locomotive are also possible in the base section.

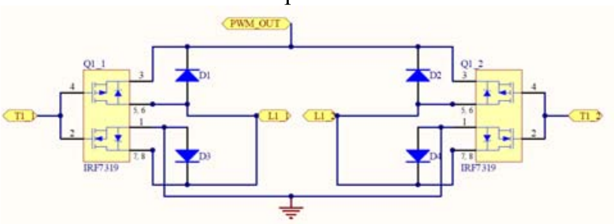

Fig. 8. *H-bridge circuit*

The velocity control mode contains two procedures, acceleration and deceleration. In both of them actuators are polarized to generate repulsive force (in the single sections this is the only possibility).

The idea of the acceleration is shown in Fig. 9. The actuator is forced by sensor following the coil when the locomotive is in positive Δx distance – c.f. Fig. 3. The reactive force F_R push the locomotive forward (in the same direction as inertial force F_0).

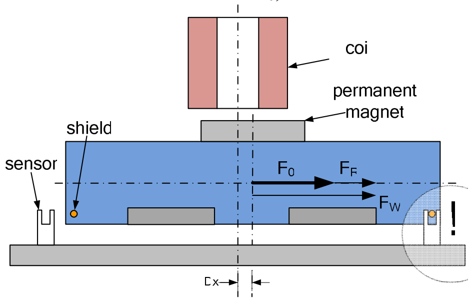

Fig. 9. *Acceleration of the locomotive*

During the deceleration the actuator is forced by sensor preceding the coil when it is at negative Δx location – Fig. 10. The reactive force F_R is in opposite direction to the inertial force F_0 and cause deceleration of the velocity.

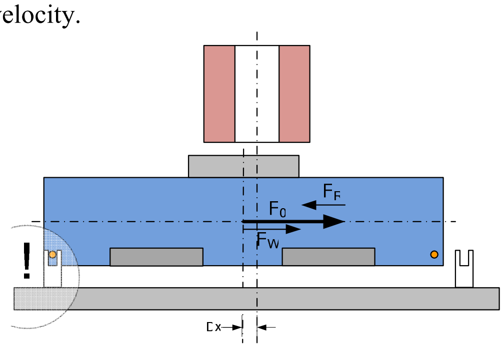

Fig. 10. *Deceleration of the locomotive*

5. LABORATORY TESTS

The laboratory prototype and set-up were constructed. The tests shows that proposed method of driving and control of train model is proper and sufficient. The photograph of locomotive model under laboratory tests is shown in Fig. 11.

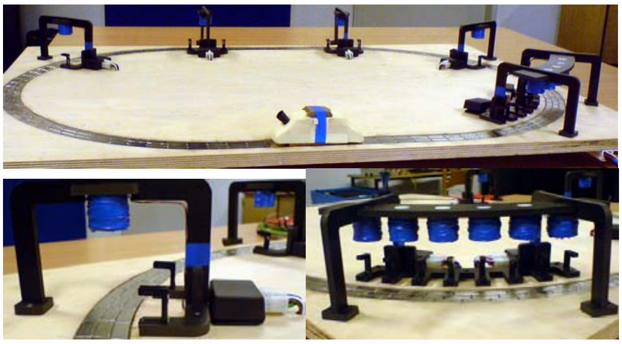

Fig. 11. *Prototype of superconducting train model (upper), single section (left) and base station (right)*

The maximum speed of the locomotive 1 m/s was measured. Above this speed the centrifugal force tilts the locomotive over the allowable limit.

5. EDUCATIONAL ASPECTS

The constructed levitation system with propulsion system has very important educational aspects. It is laboratory system of superconducting application. It has both cognitive and measuring objectives. The cognitive objective concerns to superconductivity field while measuring objectives are focused on drive dynamics. The system will be part of laboratory exercises.

6. CONCLUSIONS

The objective has been obtained - the system operates properly being suitable for educational purposes. It combines relatively broad range of problems to be solved during laboratory exercises starting of FEM analysis of electromagnetic field and calculation of the forces that are exerted on the locomotive through the control strategy realized by means of microcontroller to dynamic of the locomotives and measurements of the magnetic flux density and the above mentioned forces. The model of MAGLEV locomotive will give relative deep insight into superconductivity that could be an encourage for interdisciplinary education.

7. REFERENCES

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