https://doi.org/10.26485/0459-6854/2018/68.1/1 PL ISSN 0459-6854

B U L L E T I N

DE LA SOCIÉTÉ DES SCIENCES ET DES LETTRES DE ŁÓDŹ

2018 Vol. LXVIII

Recherches sur les déformations no. 1

pp. 9–26

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TEST MODELS OF LINEAR ELECTRIC MOTORS

Summary

The article describes a structure and a principle of operation of several innovative models of linear electric motors. Energy of electricity is transformed into kinetic energy of forwards motions inside these engines, without mechanical intermediary components. A principle of operation is explained and discussed for each of the described models. Application of such motors is also briefly presented. Advantages of the describe motors include simple construction and reliability of operation.

Keywords and phrases: linear electric motor, electrodynamic force, neodymium magnet, pole, spiral, cart

1. Introduction

From the perspective of electrical and power engineering, electric motors are classified as electric machines. These machines transform the supplied electricity into kinetic energy, what allows setting in motion other machines and devices. Electric motors usually present circular motion. However, this kind of motion is not always the most useful one, e.g. in case of crane devices or means of transport, forward motion is more useful. A useful solution is application of linear electric motors. A characteristic feature of the mentioned engines is the fact that they transform the energy from electric current into the kinetic energy of forward motions, without intermediation of any mechanical components, such as gears, racks or cranks. Thanks to that, linear electric motors are characterized by a very simple structure and a high level of reliability. Thus, not a lot of materials and tools are needed to carry out the experiments described further. It is enough to employ several neodymium magnets, in a shape of a cylinder or a cuboid, a dozen or so meters of copper wire with or without sheathing, round alkaline or re-chargeable batteries, fragments of rod from insulating material and minor auxiliary items, such as pieces of strips and copper sheet. Neodymium magnets are manufactured from baked and compressed powders of lead, neodymium and boron, and coated with a protective layer of nickel. This layer protects the magnets from oxidation, and enables flow of electric current on their surface [1]. Small neodymium magnets can be purchased in shops with electronics. They cost a few zlotys per piece. These magnets are even cheaper in on-line stores. The neodymium magnets, which are very strong, must be handled with special care, because they can pinch the fingers skin painfully, or crack after hitting one another.

2. The simplest linear electric motor

In order to construct this motor on a round bar, with a diameter larger by 1–2 mm than the diameters of the neodymium magnets, there is a need to wind from several dozens to several hundreds of coils of copper wire, with diameter 0.5–1 mm, without sheathing. The coils must be winded equally, one next to the other, and they cannot cross. The easiest solution is to apply wire covered with a thin layer of silver, utilized for connections in electronic circuits, called silver wire. If such wire is not available, there is a need to remove the sheathing from enameled wire (so-called winding wire) with abrasive paper. In order to facilitate the procedure, the wire can be heated until it becomes red, in a flame of a burner or a gas stove. The winded wire needs to be slided off from the bar. Therefore, a spiral is obtained, with slightly shifted coils, which cannot touch each other, Fig. 1. The spiral can be attached to a ruler or a stripe with bands prepared from pieces of adhesive tape. Each neodymium cylinder-shape magnet needs to be applied to the ends of the round battery. The magnets diameter must be greater than the battery diameter by 1–2 mm. The magnets must be directed towards the battery unipolarly, as otherwise the motor will not operate.

A ready motor is presented in Photo 1. In order to start the engine up, there is a need to slide the battery completely into the spiral. (The magnets and batteries will be hereinafter referred to as a cart, for the sake of simplicity). It turns out that the cart will be either pushed out of the spiral, or pushed into it, and pushed out on the other side. If the cart is pushed out, it must be turned and pushed into the spiral through the second end.

3. Principle of operation of the simplest linear motor

After pushing the cart into the spiral, electric current flows from the positive pole of the battery through the applied magnet, actually through the nickel coating, Fig. 2. Further, the current flows through the spiral coils, located between the magnets, to the other magnet, which is applied to the battery's negative pole. A fragment

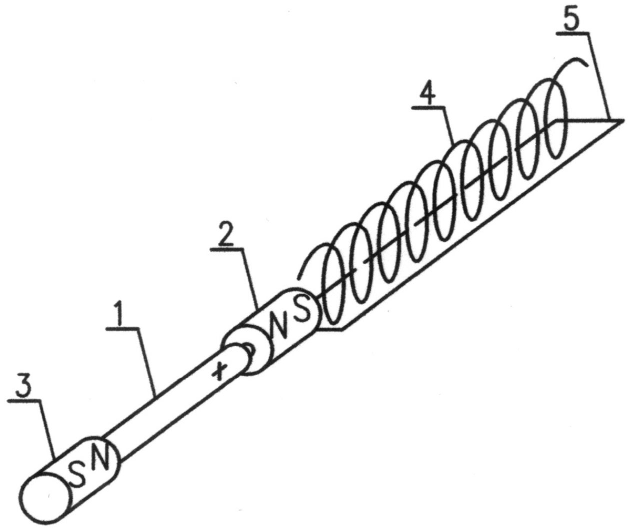

Fig. 1. Construction of the simples linear electric motor; 1 – a round alkaline battery, 2, 3 – cylindrical neodymium magnets, 4 – a spiral from copper wire without sheathing, 5 – a ruler or a strip, N, S – poles of neodymium magnets.

Photo 1. An example of the simplest, linear electric motor.

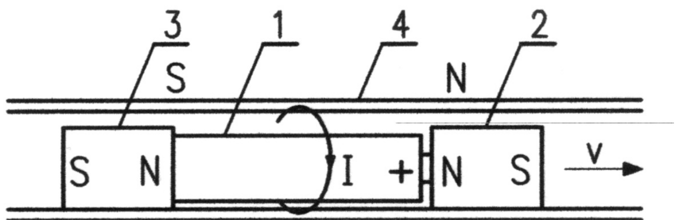

Fig. 2. Generation of magnetic field by a spiral fragment in the simplest linear electric motor; 1 – a round alkaline battery, 2, 3 – cylindrical neodymium magnets, 4 – a spiral from copper wire, without sheathing, 5 – a ruler or a stripe, N, S – poles of neodymium magnets, I – current, v – speed.

of a spiral included between the magnets becomes a solenoid, which the current flows through. This solenoid has two magnetic poles, affecting poles of neodymium magnets [2]. Here, a quite complex system emerges, composed from six poles in total, among which both attraction and repulsion phenomena take place. Although, crucial importance is borne by the action of the closest poles of the solenoid and magnets, for which the forces have the greatest value, Fig. 3. As a result, the cart is influence by a resultant force, which causes its motion.

It must be added that neodymium magnets also present mutual impact, and they should repulse, as they are turned to each other unipolarly. However, the impact forces exerted by the magnets are internal forces of the cart, and they are incapable of setting it in motion. These forces only cause that the batteries are squeezed. Furthermore, magnets' poles induce opposite poles in a steel cover of a battery (these are S poles in Fig. 2), and it can be stated that thanks to that, the S-N pairs of poles, located close to each other, become neutral. If the battery was too short, or if it did not have the steel cover, then the cart could not be created because of mutual repulsion of magnets. As the internal forces cannot set the cart in motion, they are omitted in Fig. 3 to preserve clarity.

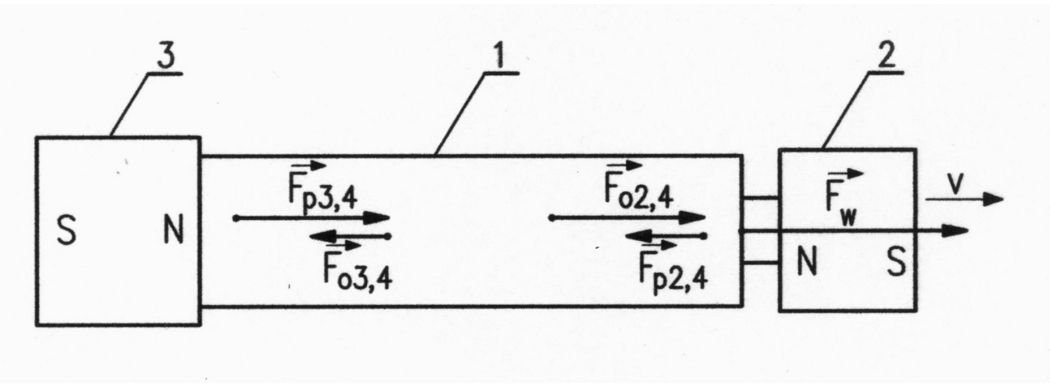

Fig. 3. Distribution of forces influencing the cart of the linear electric motor; 1 – a round alkaline battery, 2, 3 – cylindrical neodymium magnets, N, S – poles of neodymium magnets, v – speed, $F_{p3,4}$, $F_{p2,4}$ – attraction forces, respectively: of magnets 2 and 3 and the spiral fragment 4, $F_{o3,4}$, $F_{o2,4}$ – repulsion forces, respectively: of magnets 2 and 3 and the spiral fragment 4, F_w– resulting force influencing the cart.

Operation of the motor can be also explained in another manner, assuming that the lines of the magnetic field are curved around the magnets. As a result of this, there is a components of the vector of the magnetic field induction, perpendicular to the spiral coils, which electric current flows through (Fig. 4). According to well-known principles, e.g. to the principle of three fingers of the left hand, the coils are exposed to electrodynamic force, directed along the spiral axis. This force strives to shift the spiral, but it is impossible, as the spiral leans against a table. In such a situation, according to the third principle of dynamics, the spiral impacts the cart with a reactions force, turned in the opposite direction, causing it to shift. When the cart is shifted, the magnets activate other coils of the spiral. These coils become another solenoid, for which the described situation is repeated. It is repeated until the cart shifts to the end of the spiral, and one magnet slides out of it. Eventually, the electric current flow through the spiral is broken, and the magnetic field – necessary for the cart motion a – disappears.

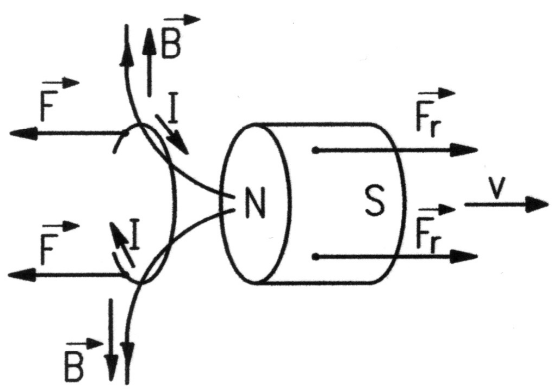

Fig. 4. An alternative explanation manner of the linear electric motor operation principle; N, S – magnets poles, B – induction of magnetic field, I – current, F – electrodynamic force influencing the spiral, F_r – reaction force influencing the cart, v – speed.

4. A linear motor on two spirals

The simples linear motor with a cart moving inside the spiral is not always the most useful one. The cart can sometimes become locked in the spiral, especially, when the coils are not winded evenly, or the gaps between them are too big. Then, there is a need to push out the cart with a nonferromagnetic rod as quickly as possible, because the locking will discharge and heat up the battery. Nevertheless, some applications require carts moving outside the track, not inside a tunnel. In such situations a linear motor working on two spirals can be constructed, Fig. 5. For that purpose, spirals are winded on two rods or pipes from insulating material, e.g. plastic, with a diameter of about 15 mm, and length of several dozens cm, and the coils are located evenly one next to the other. This time, enameled wire with diameter of 0.5–1 mm must be applied. The wire must be secured against unwinding, e.g. through sticking its beginning and end to the bars with adhesive tape. After winding the spirals, the enamel is removed from their external surfaces, through rubbing with abrasive paper, Fig. 6. Both spirals should be placed in parallel, 1–2 mm from each other. It can be done with connectors screwed to the bars' ends. In the simplest case, it is enough to use insulation tape and wrap the bars' ends with it several times. At first, each bar is wrapped separately, and afterwards they are put together and wrapped in such a form.

When the cart is placed on the spiral in the same manner as before, its motion takes place, Photo 2. If the spirals are winded evenly, then it can be stated that the cart turns around the motion direct during the shift. It results from component contacting electrodynamic force acting on the magnets. This force is caused by the fact that the wire has certain thickness, and because of that the coils are not accurately perpendicular to the magnets' axis. By transforming Fig. 4 in such a manner that the coil, which the current I flows through, is positioned diagonally, and by applying the principle of left hand, it may be demonstrated that the contacting force that turns the cart emerges.

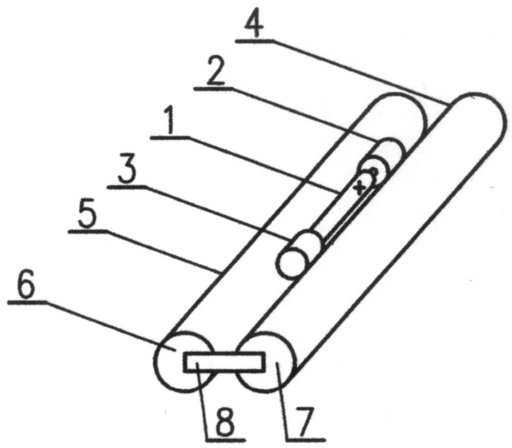

Fig. 5

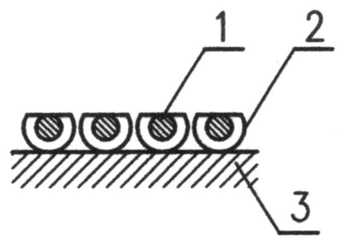

Fig. 6

Fig. 5. Structure of a linear electric motor with two spirals; 1 – a round alkaline battery, 2, 3 – cylindrical neodymium magnets, 4, 5 – spirals from copper wire in enamel, removed on the outside, 6, 7 – insulating rods, 8 – connector.

Fig. 6. The manner of removing enamel from the spiral, demonstrated in crosssection; 1 – copper wire, 2 – enamel, 3 – insulating rod.

Photo 2. An example of an electric motor with two spirals.

5. A motor with a concave guide

A fragment of a plastic stripe 30 cm, intended for cables, long was applied to construct this motor, Fig. 7. A single half – upper or bottom – of such a stripe will suffice. This stripe should be winded with copper wire, enameled, with diameter of about 1 mm. Particular coils of the wire must be placed evenly, one next to the other, and they cannot cross. The wire should not be stretched. Only one layer of coils is winded along the whole length of the stripe. The ends of the wire must be protected from unwinding, by pushing them through holes drilled in the stripe and bending them, or attaching with pieces of adhesive tape, wrapped around the stripe.

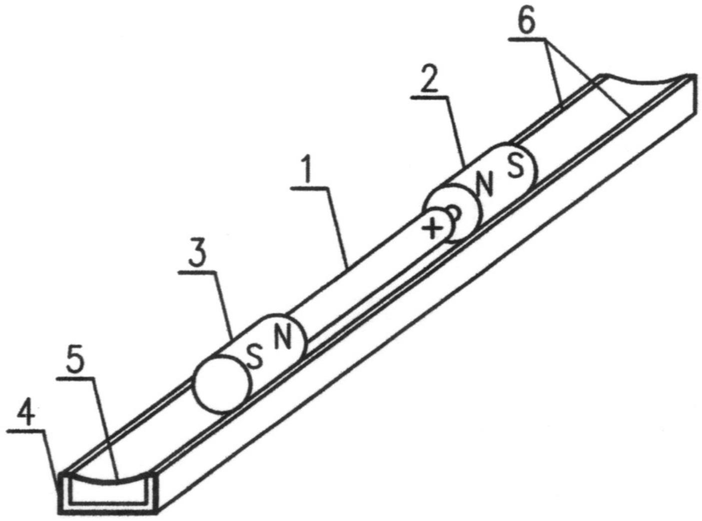

Fig. 7. Structure of a singleguide linear electric motor with a concave guide; 1 – round alkaline battery, 2, 3 – cylindrical neodymium magnets, 4 – a part of the stripe for cables, 5 – winding from enameled copper wire, 6 – wire surfaces without enamel.

Afterwards, there is a need to bend all coils into the stripe's cavity. For this purpose, the stripe is located on a tough surface, e.g. on a floor, turning them with the internal part upwards, and a steel bar is located along the stripe. This bar must be struck with a hammer on its whole length. Therefore, the coils become bent towards the internal part of the stripe, and a concave surface of the guide emerges. The next actions is to remove the enamel insulation layer from the wire, from its concave part. Fine abrasive paper is applied for that purpose. The enamel must be removed from the top part of the coils, so the neighboring coils remain separated from each other.

After preparing the guide, two cylindrical neodymium magnets, covered with a protective nickel coating, must be applied to the round battery. The best solution is to use a new alkaline battery. Instead of a battery, a lithium-ion rechargeable battery in a cylindrical shape can be applied. The magnets must be turned towards the battery unipolarly, and their diameter must be greater by 1–2 mm from the battery diameter. The set, which is composed of batteries and magnets, i.e. a cart, is placed on the concave part of the guide, at half of its length, Photo 3. Then, it can be observed that the cart shifts towards a direction that depends on mutual orientation of poles of magnets, batteries and the direction, which the spiral is winded in. A reason for such motion is the action between the magnets' poles with the solenoid's poles, which is created by a fragment of spiral located between the magnets. A specific explanation of such a motor operation is the same as in case of the motor with a spiral, which was provided in the previous part of this article.

Photo 3. An example of an electric motor with a concave guide.

6. Motors with a cylindrical guide

The guide of that motor is prepared similarly to that described previously, with such a difference that the wire should be winded evenly on a round bar made from electro-insulating material, or on a pipe with diameter of 15 mm and length of 30–40 cm, Fig. 8. Using fine abrasive paper, insulation must be removed from the top part of the external surface of the wire. The cart is composed of two ring magnets, turned towards each other unipolarly, and applied to the poles of the round battery. Diameter of holes in the magnets should be greater than the guide diameter by 2–3 mm. The guide should be located vertically, leaning its ends on support, or it should be mounted on one side on a tripod. A support or a tripod should be prepared from nonferromagnetic material. If a cart with a battery directed downwards is slided on the guide, it will move on it. In order to obtain a greater speed, two batteries can be located between the magnets, turned with the same poles in a single direction. The batteries located in the carts bottom part, lower its center of gravity and ensure stability.

A motor with a cylindrical guide can be also constructed with cylindrical magnets, Fig. 9. Their diameter should be lower the the battery diameter by 3–4 mm. In this model, the battery and magnets will be located over the guide, which is why in order for the cart to remain its balance, there is a need to lower the center of gravity of the cart, through ballasting it from the bottom. It is done by a ballast with a properly

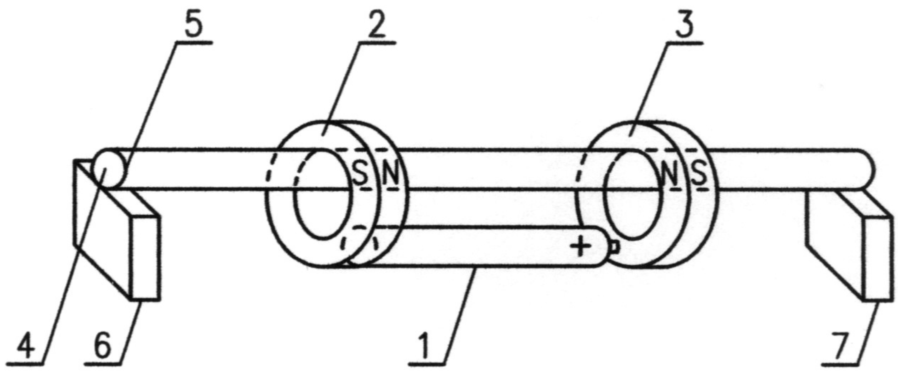

Fig. 8. Construction of a singleguide electric motor with a cart, a battery under the cylindrical guide; 1 – a round alkaline battery, 2, 3 – ring neodymium magnets, 4 – a round bar from electro-insulating material, 5 – winding from copper wire with enamel, removed on the outside, 6, 7 – supports, N, S – magnet poles.

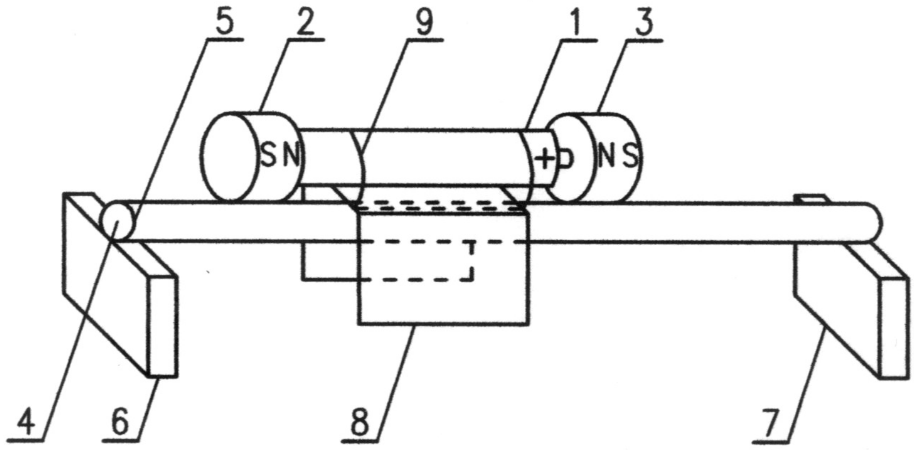

Fig. 9. Construction of a single-guide electric motor with a cart, a battery over the cylindrical guide; 1 – a round alkaline battery, 2, 3 – cylindrical neodymium magnets, 4 – a round bar from insulating material, 5 – winding from copper wire with enamel, removed on the outside, 6, 7 – supports, 8 – a ballast, 9 – a rubber band, N, S – magnet poles.

selected weight. The ballast is prepared from a fragment of sheet, bend in a "C" shape, turned with its shoulders downwards. The sheet must be nonferromagnetic. The best solution is to employ copper or brass sheet. The ballast is attached from the bottom, to the battery, so it does not touch the magnets. Side surface of the magnets should protrude outside the central part of the ballast, adjacent to the battery, Fig. 10. The ballast, after placing the cart on the guide, cannot touch the wire coils. In the simplest solution, the ballast can be attached with a rubber band, in such a way it grasps the support from the bottom and the battery from the top. If there is such a need, the cart can be ballasted with several pieces of plasticine, attached to the bottom parts of the ballast. The principle of operation of the motors described above, with the cylindrical guide, is the same as the principle of operation of the motor presented in the previous part of this article.

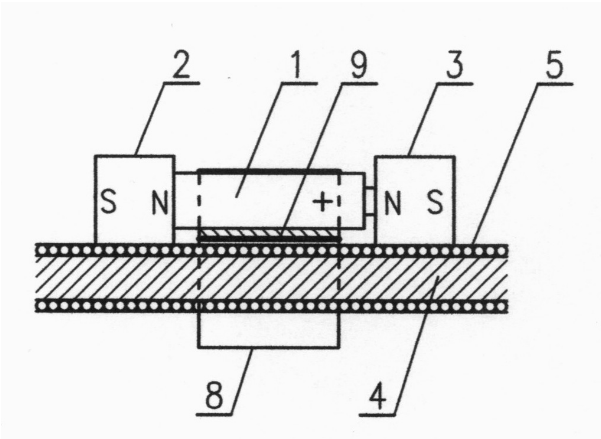

Fig. 10. Constructional details of a motor's cart from Fig. 9, demonstrated in the longitudinal crosssection; 1 – a round alkaline battery, 2, 3 – cylindrical neodymium magnets, 4 – a round bar from insulating material, 5 – winding from copper wire with enamel, removed on the outside, 6 – a ballast from nonferromagnetic material, 7 – a rubber band, N, S – magnet poles.

7. Motors with flat guides

In order to construct those motors, a guide is prepared through winding the enameled copper wire on a wooden stripe with square or rectangular cross-section, Fig. 11. Indicative thickness of such a stripe is 15–20 mm, and its length is 30–40 cm. The wire diameter and the remaining parameters are the same as previously. When the wire is winded, there is a need to remove the sheathing from one flat surface of the winding with fine abrasive paper. This is the surface, which the carts will be moving through. However, their structure is different from the previous one. Magnets in a cubical or cuboidal shape, turned unipolarly in the same direction, are applied to the round battery. Their magentisation direction, which is posed by a line connecting the poles, must be perpendicular to the longitudinal axis of the battery. Afterwards, contact plates cut out of copper sheet that is 1–2 mm thick, are applied to the end surfaces of the magnets. These plates should protrude a little from the bottom, below the magnets surface. In the simplest solution, in order to attach the plates to the magnets, a rubber band can be applied, grasping the cart horizontally. When the cart

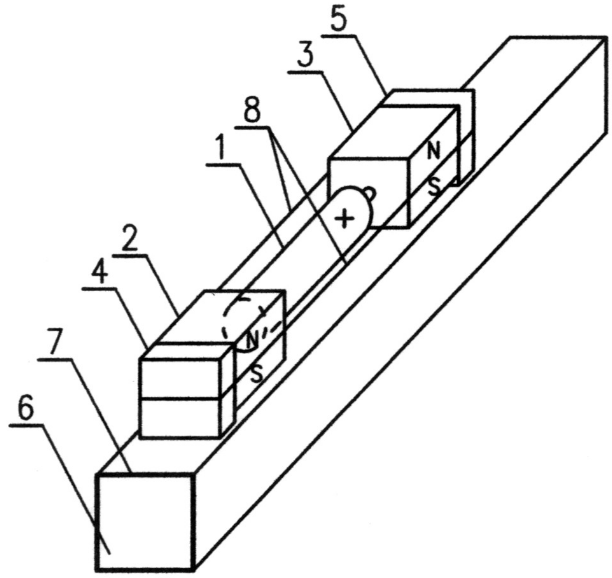

Fig. 11. Construction of a singleguide electric motor with a cart, moving above the flat guide; 1 – a round alkaline battery, 2, 3 – cuboidal neodymium magnets, 4, 5 – copper contact plates, 6 – a stripe, 7 – winding from copper wire with enamel, removed on the outside, 8 – a rubber band N, S – magnet poles.

is placed on the guide, it moves on it. If the cart underwent significant side shifts or kept falling of the guide, it can be prevented. For that purpose, rulers or stripes protruding above the upper winding surface by several mm should be attached to the side surfaces of winding.

The principle of operation of this motor is explained in detail in Fig. 12. Electric current flows from the positive pole of the battery, through the attached magnet and contact plate. This current reaches the second contact plate and the magnet applied to the negative pole of the battery. The current must also flow through the guide coils, located between the contact plates. These coils are situated in a magnetic field, generated by magnets applied to the battery ends. Winds that are under the magnets remain in the strongest magnetic field, with induction directed perpendicularly to them, and they are of crucial importance for the direction of the cart movement. These coils are influenced by electro-dynamic force, directed along the guide axis. In turn, the magnets are influenced by a reaction force, turned into the opposite direction, which causes the cart to move. Value of the force that sets the cart in motion can be increased by positioning a whole guide fragment, where the electric current flows – located between the contact plates – in a magnetic field. Structure of a motor that fulfills this requirement is presented in Fig. 13 and 14. It employs a magnet in a form of a bar, applied along the battery. This magnet cannot touch the contact plates, and it must be magnetized in a vertical direction.

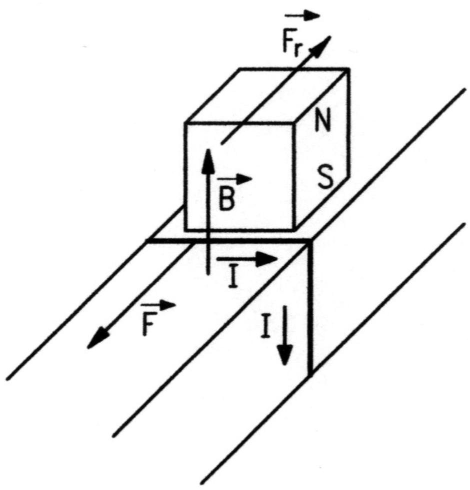

Fig. 12. Explanation of the operational principle of the linear electric motor with a cart over a flat guide; B – magnetic field induction, I – current, F – electrodynamics force acting the winding, F_r – reaction force powering the cart, N, S – magnet poles.

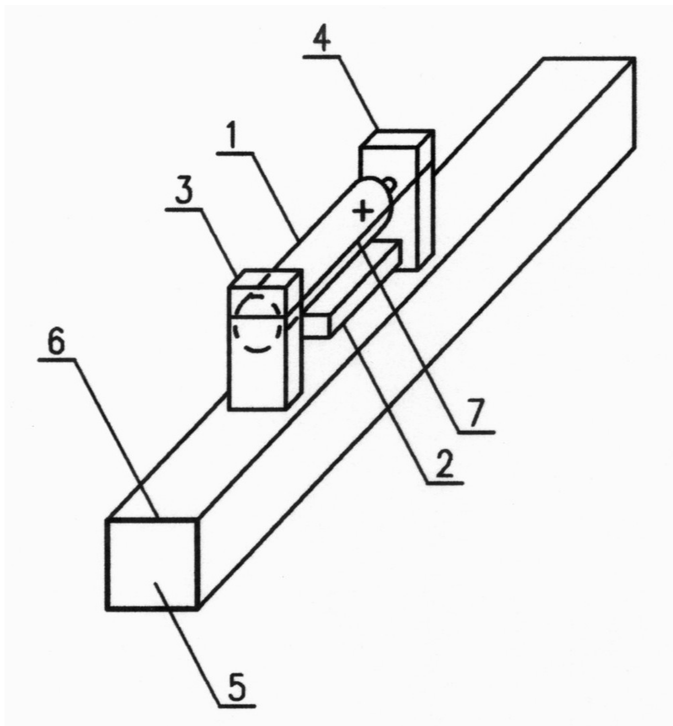

Fig. 13. Construction of a singleguide electric motor with increased speed, with a cart, moving above the flat guide; 1 – a round alkaline battery, 2 – plate neodymium magnet, 3, 4 – nonferromagnetic contact plates, 5 – a stripe, 6 – winding from copper wire with enamel, removed on the outside, 7 – a rubber band N, S – magnet poles.

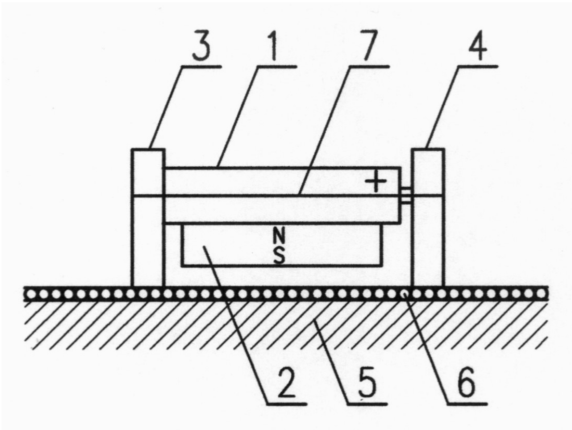

Fig. 14. Constructional details of a motors cart from Fig. 13, demonstrated in the side view; 1 – a round alkaline battery, 2, 3 – cylindrical neodymium magnets, 4 – a round bar from insulating material, 5 – winding from copper wire with enamel, removed on the outside, 6 – a ballast from nonferromagnetic material, 7 – a rubber band N, S – magnet poles.

8. Linear-rotational motor

A characteristic feature of this motor is realization of forwards motion thanks to a cart rolling. The following elements are necessary to construct an engine: a piece of aluminum foil, sized 10 × 20 cm or greater, a round alkaline battery (ideally if it is new), and two neodymium magnets in a shape of a cylinder, with a diameter slightly greater from the battery diameter, and length of 10–15 mm. In order to construct the motor, it is enough put the flat walls of the magnets to both ends of the battery, and to place it on a piece of foil, lying on a flat surface, Fig. 15, Photo 5. Two conditions must be met for proper operation of the engine: The magnets must be directed towards the battery unipolarly, and applied to it coaxially. In order to meet the first condition, before applying the magnets, they are approximated to each other with their flat sides, and it is checked whether they repulse. If not, one magnet must be turned around its transverse axis, and only after that it is applied to the battery. In order to meet the second condition, it is inspected visually whether the edge of each magnet protrudes from the battery edge in the same manner. Moreover, the aluminum foil should be smooth, and it should lay on an accurately flat surface, far away from any ferromagnetic items.

If a battery with magnets prepared in such a way is placed on the foil, it can be observed that is starts to roll. The principle of operation of this motor is explained in detail in Fig. 16. Neodymium magnets are covered with a protective layer of nickel, which is a good conductor of electricity. Aluminum foil, although covered with a thin layer of oxide when contacted with air, also makes a good electricity conductor. The neodymium magnets are attracted to a steel cover of the battery, and contact with its poles. When a battery with magnets lays on foil, it then closes the electric circuit and

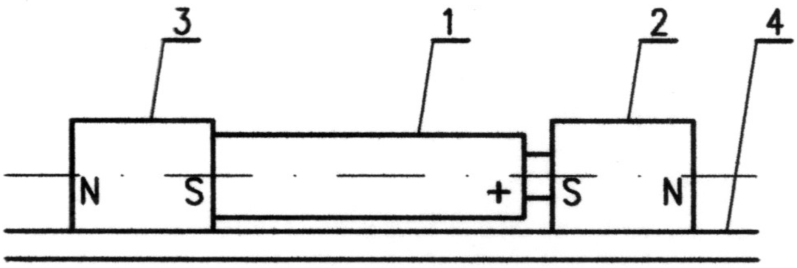

Fig. 15. The presentation manner of components of a linearrotational motor; 1 – round alkaline battery, 2, 3 – cylindrical neodymium magnets, 4 – aluminum foil, N, S – magnet poles.

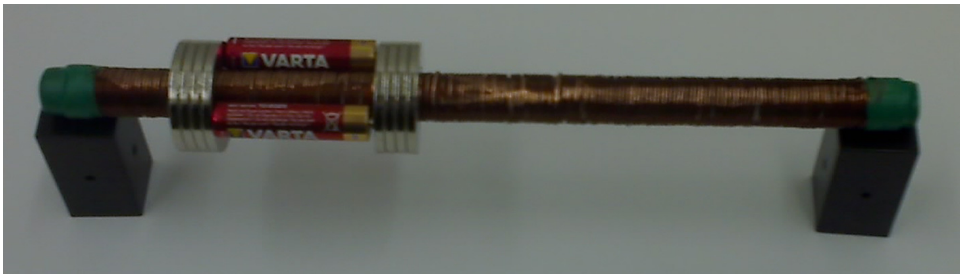

Photo 4. External appearance of one of the two linear electric motors with a cylindrical guide.

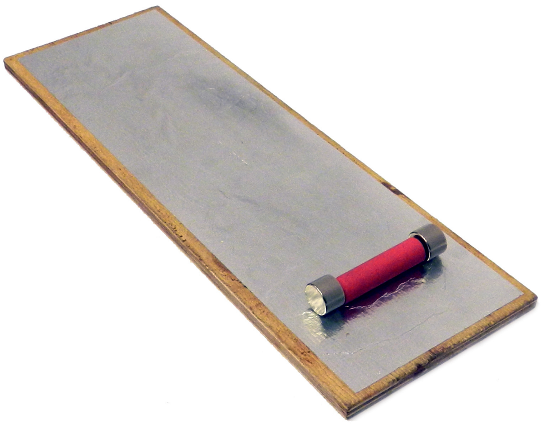

Photo 5. External appearance of the constructed linear-rotational motor.

the electric current flows from the positive pole of the battery, through the magnet that contacts it. Further, the electric current flows through the foil located under the battery, and reaches the magnet that contacts the negative pole of the battery.

This current present the so-called distribution on the surface of magnets and foil. However, its thickness is the greatest along the lone with the lowest electric resistance. Therefore, it can be approximately assumed that the current flow is realized radially, through the magnets, to their contact spots with foil. As the magnetization direction of the magnets is axial, the electric current flowing radially is perpendicular towards the direction of their vector of magnetic induction **B**. In such a situation, the magnets are influenced by electrodynamic forces **F**, directed tangentially to the magnets. These forces provide torques towards the contact spots between the magnets and the foil. Under influence of those torques the magnets turn together with the batteries, and roll through the surface. The batteries motion direction depends on the mutual spatial orientation of the poles of magnets and batteries. While adopting the principle of the left hand, and changing Fig. 16, it can be demonstrated clearly, which direction the battery will roll into, when N north poles of the magnets are applied, or if its positive pole is situated on the left side of this figure.

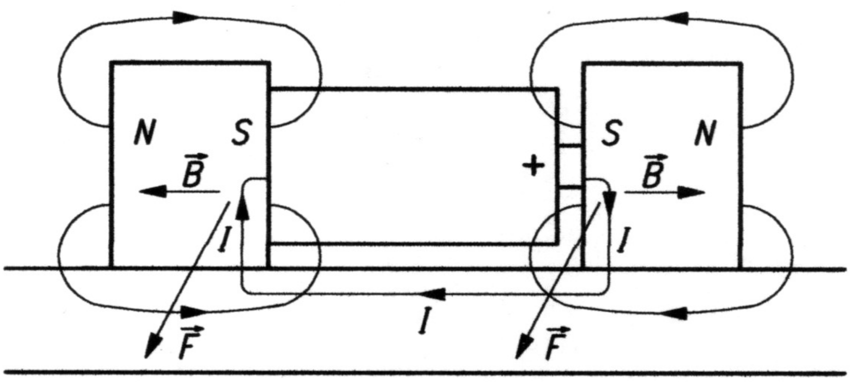

Fig. 16. Explanation of the operational principle of the linearrotational motor; B – magnetic field induction, I – current, F – electrodynamics force, N, S – magnet poles.

9. Linear-rotational motor efficiency

Now, estimation of the electrodynamic forces torque, influencing the battery, as well as the power and efficiency of such a motor will be provided. The electrodynamic force F is expressed with a well-known equation

$$F = BIl \tag{1}$$

where B means induction of the magnetic field, I – the current, and l – length of the conductor. For the applied neodymium magnets, the value B was measured with the Hall effect measuring device, and the value of 0.22 T was obtained. Regarding very low resistance of the nickel layer on magnets and foil, the battery works practically in a short circuit state. In this situation, the current I can be measured with a directly connected ammeter, the resistance of which also can be skipped. The measurement resulted in 4.6 A. As l, the r radius of the magnet was assumed, amounting to 5 mm, i.e. 0.005 m. Thus the calculation $F = 5.1 \cdot 10^{-3}$ N. It is a very small value. For comparison, weight of one kg of salt is 9.81 N. Therefore, motion of the motor is stopped by slight inclination of the surface, where the foil lays, or its minor irregularities. The total torque of the electrodynamic forces M driving the motor, is calculated with the following equation

$$M = 2\int_0^r r dF = 2\int_0^r rBIdr = BIr^2. \tag{2}$$

Having substituted the previously assumed values from the equation (2), $M = 2.5 \cdot 10^{-5}$ Nm was obtained.

As the battery with magnets rolls, what means that it performs the rotational and forward motion at the same time, while calculating the motor power P_u, there is a need to consider those both types of motion. Deriving from this and from well-known basics of the mechanics of formulas, the following equation should be compiled [3]

$$P_u = Fv + M\omega \tag{3}$$

symbol ω in the formula (3) means the angular speed of the battery, which is related to the linear speed with the equation $\omega = v/r$. Assuming that the battery motion becomes uniform quickly, the linear speed v was calculated from the formula $v = s/t$. Deriving from this, after previous measurement of the time of it motion t on the path s, $v = 0.04$ m/s was obtained. After substitution of this value and the values calculated previously to the formula (3), $P_u = 3 \cdot 10^{-4}$ W was obtained. The power delivered to P_d, is the power of electric current flowing from the battery. This power is calculated from the formula $P_d = U \cdot I$, where U – voltage measured on the battery poles and approximately equal to its electromotive force. For the applied battery $U = 1.54$ V. Considering this result, and the previously measured value I, $P_d = 7.1$ W was obtained. At the end, motor efficiency $\eta = P_u/P_d$ can be calculated. After substituting the previous results $\eta = 4.2 \cdot 10^{-5} = 0.0042\,\%$ is obtained. Thus, efficiency of this motor is very low. Majority of electric energy is transformed into heat. It may be easily checked with touch, because temperature of battery increases significantly after several hours of the engine operation. Low efficiency of this motor may cause difficulties in its broad application. A very simple structure and an intriguing principle of operation cause that these engines are perfect for educational purposes. The same comment applies to the remaining models of electric linear motors, described in this article.

10. Applications of linear electric motors

As it was already mentioned at the beginning, the linear electric motors are broadly applied in numerous devices. They are applied in those areas, where the forward motion is needed. Examples of technique sector, where linear electric motors are applied are as follows: transport, machine tool industry or mechatronics, integrating mechanical, electric and electronic, sometimes even optical components in a single device. Such an integration takes place e.g. in scanners or photocopiers. A significant advantage of such motors is the fact that they do not include any additional elements, e.g. gears, guides, racks or crank mechanisms, which serve for transformation of rotational movement into forward motion, which wear off quickly. It causes simplification of structure of those engines, and improvement of their reliability. An important advantage of the described engines is supply of electricity, which can be fed more easily with cables than oil under high pressure, which serves for starting up the hydraulic engines. These servo-motors also play a role of linear motors, e.g. in machinery for ground works. High-pressure hoses, feeding the oil, should be sealed and highly durable. Fulfillment of those technical requirements is often hard. High-speed trains are a promising and intensively developed sector for applications of linear electric motors. They hover over tracks thanks to magnetic levitation, what reduces their motion resistance significantly [4, 5]. Experimental structures of those vehicles, known as MAGLEV (an abbreviation from magnetic levitation), constructed in Japan and China, reach speed of about 600 km/h. Therefore, construction and inspection of linear electric motors, described in this articles, and development of their new structural versions, is a good theme for a creative educational project.

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Presented by Leszek Wojtczak at the Session of the Mathematical-Physical Commission of the Łódź Society of Sciences and Arts on July 8, 2016.

TESTOWE MODELE LINIOWYCH SILNIKÓW ELEKTRYCZNYCH

S t r e s z c z e n i e

W artykule opisano budowę i zasadę działania kilku innowacyjnych modeli liniowych silników elektrycznych. W tych silnikach zachodzi zamiana energii prądu elektrycznego na energię kinetyczną ruchu postępowego bez mechanicznych elementów pośredniczących. Dla każdego z opisanych modeli wyjaśniono i przedyskutowano zasadę jego działania. Przedstawiono również krótko zastosowania tych silników. Zaletami opisanych silników są bardzo prosta konstrukcja i niezawodność działania.

Słowa kluczowe: liniowy silnik elektryczny, siła elektrodynamiczna, magnes neodymowy, biegun, spirala, wózek