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LINEAR SOLENOID ELECTROMAGNETIC ACTUATOR WITH DIFFERENTIAL SERIES WINDINGS

Tatiana Kelemenová
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, Kosice, Slovak Republic, EU, tatiana.kelemenova@tuke.sk (corresponding author)
Ivana Koláriková
Technical University of Kosice, Faculty of Mechanical Engineering, Letna 9, Kosice, Slovak Republic, EU, ivana.kolarikova@tuke.sk
Ondrej Benedik
Kybernetes, s.r.o., Omská 14, Kosice, Slovak Republic, EU,
ondrej.benedik@kybernetes.sk

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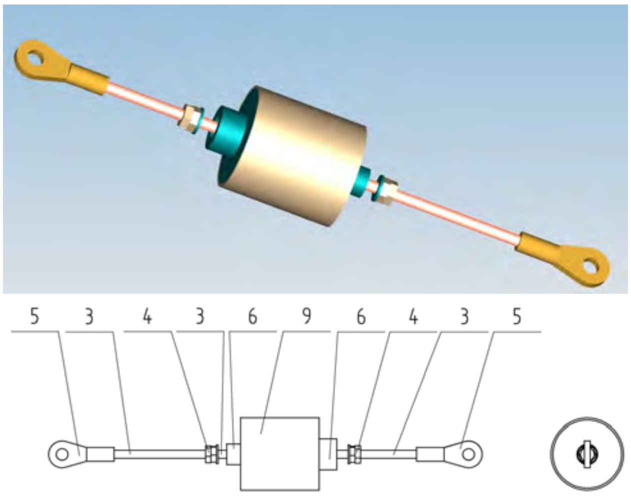
Abstract: A linear solenoid electromagnetic actuator is a device for creating a linear reciprocating motion with a force effect. It contains a moving part consisting of a permanent magnet in the housing, threaded spacers, threaded rods, nuts for adjusting the stroke of the actuator and the hanging eyes of the actuator. The device further comprises a non-moving part formed by the coil body, the left actuator coil winding, the right actuator coil winding and the actuator cover, the sense of winding the left actuator coil winding opposite.

1 Introduction

Solenoid linear electromagnetic actuators are often used in mechatronic systems, which are mostly formed by a single coil and a ferromagnetic core which is inserted into the coil by an electromagnetic field. The return movement is provided by a spring. The disadvantage of such solutions is that the resulting force is smaller by the value of the force required to compress the spring. At the same time, when moving backwards, the force is limited by the value of the stiffness of the spring and its deformation [1-6].

2 Principle of operation

The linear solenoid electromagnetic actuator with differential series-connected windings and a permanent magnet is intended for the transformation of electrical energy into mechanical work in the form of a linear displacement with a force effect (Figure 1). The fundamental of this actuator lies in the fact that the electric current passing through the actuator coils and the magnetic field of the coils interacts with the magnetic field of the permanent magnet, thus causing mutual movement between the actuator coils and the permanent magnet. The actuator has a coil body divided into two equal halves, with the left half of the coil containing a left-handed wound of enamelled copper conductor and the right half of the coil containing a clockwise-wound winding of the same enamelled copper conductor. Both coils are electrically connected in series, which creates a magnetic field with three poles when the same electric current passes through these coils, with two poles at each end of the coil and one in the middle of the coil between the windings. After inserting the core from the rod axially polarized permanent magnet into this coil, the magnetic field of the coil and the permanent magnet interact, and thus, its movement depends on the polarization of the coil and the permanent magnet. The length of the coil with both windings is twice the length of the permanent magnet, and so when moving, the magnet is moved between two extreme positions inside the device. Attached to the permanent magnet are threaded rods with suspension eyes, by means of which it is possible to transmit the movement of the permanent magnet to the device to be moved (Figure 1) [6].



1 - Permanent magnet in the housing; 2 - Threaded adapter; 3 - Threaded rod; 4 - Actuator stroke adjustment nut; 5 - Actuator hanging eye; 6 - Actuator coil body; 7 - Left winding of the actuator coil; 8 - Right winding of the actuator coil; 9 - Actuator cover

Figure 1 Linear electromagnetic solenoid actuator arrangement

The advantage of the solution is that, unlike conventional solenoid actuators, which consist of a ferromagnetic core with a single-coil, this actuator contains a rod axially polarized permanent magnet with two differential series-connected windings, which allows greater force effects while making better use of the permanent magnet magnetic field.

3 Actuator implementation

A prototype of a linear solenoid electromagnetic actuator with differential series-connected windings and a permanent magnet (figs. 2, 3) was created, which consists of a permanent magnet (1) in housing and which is connected on both sides by riveting to threaded spacers (2). A threaded rod (3) with the actuating eyes (5) of the actuator is attached to both threaded spacers (2). Nuts (4) for adjusting the actuator stroke are also located on the threaded rods (3). The assembly of the permanent magnet (1) in the housing, threaded spacers (2), threaded rod (3), nuts (4) for adjusting the actuator stroke and actuator eyelets (5) forms a moving part of the actuator and is inserted into the carcass hole (6) actuator coils. The actuator coil body (6) comprises a left actuator coil winding (7) and a right actuator coil winding (8), the sense of winding the left actuator coil winding (7) being opposite to the right actuator coil winding (8), thus achieving a specific magnetic arrangement coil field. The frame (6) of the actuator coil, the left winding (7) of the actuator coil and the right winding (8) of the actuator coil are covered by the actuator cover (9) (Figure 2).

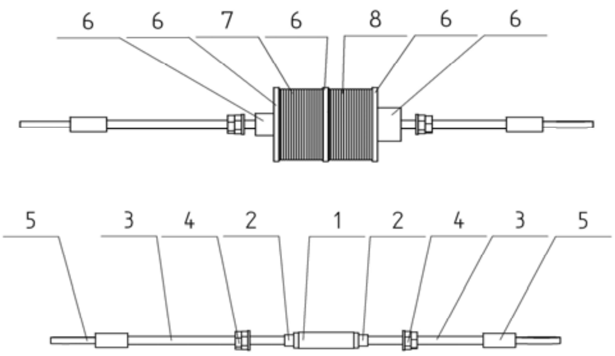


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Figure 2 Actuator winding and plunger with permanent magnet

After activating the actuator by the passing current, a magnetic field is created around the left winding (7) of the actuator coil, and the right winding (8) of the actuator coil and the interaction of the magnetic field of the permanent magnet (1) in the housing creates actuator stroke. The actuator stroke can be adjusted using the actuator stroke adjustment nuts (4) according to the needs and application of the device. The frame (6) of the actuator coil comprises on both sides a mounting shoulder for application. It is assumed that the frame (6) of the actuator coil is firmly held as a non-moving part. The moving part of the actuator consisting of a permanent magnet (1) in the housing, threaded spacers (2), threaded rod (3) and nuts (4) for adjusting the actuator stroke and actuator eyelets (5) is attached by means of actuator eyelets (5). to the moving part of the selected application (Figure 2, Figure 3).

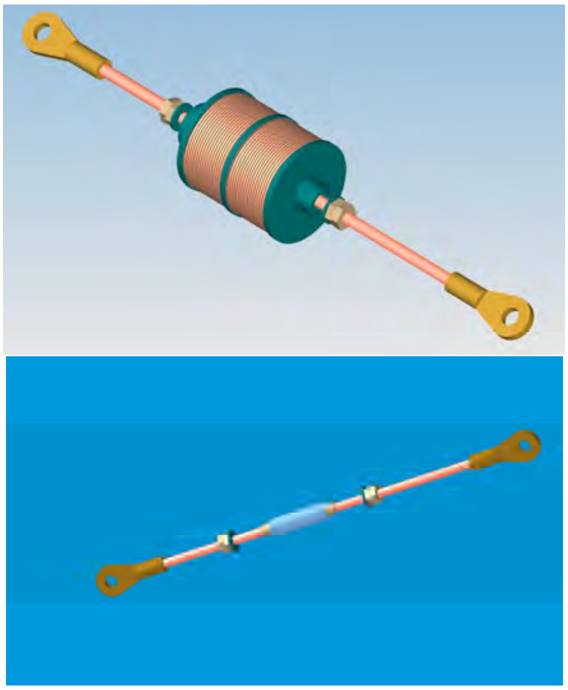

Figure 3 Virtual model of the actuator and permanent magnet

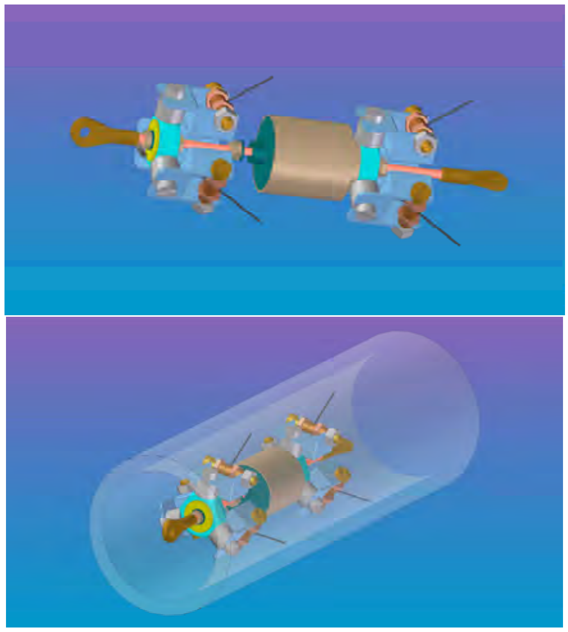

Figure 4 Implementation of an in-pipe robot for locomotion in the pipeline

The device, according to the proposed solution, can be used to create a linear reciprocating motion with a force effect in applications where it is necessary to move the masses between two defined end positions. An example of such an application is an in-pipe robot for moving in a pipeline, which uses this actuator to perform a movement in the pipeline in order to transport objects to the pipeline or inspect the pipeline (Figure 4).

4 Experimental examination

The aim was to experimentally investigate the traction force of such an actuator depending on the position of the magnet relative to the actuator coil. The design of the actuator (Figure 5) is designed for application in an in-pipe robot. The permanent magnet is axially polarized and is made of NdFeB material. During the measurement, the actuator was held in a holder, and the ends of the permanent magnet were attached to a bowl with weights using a system of cable and pulley. Using a suitable combination of weights, a loading force was created, and the actuator was tested in the experiment to see if it could exert a force to lift this weight (Figure 6).

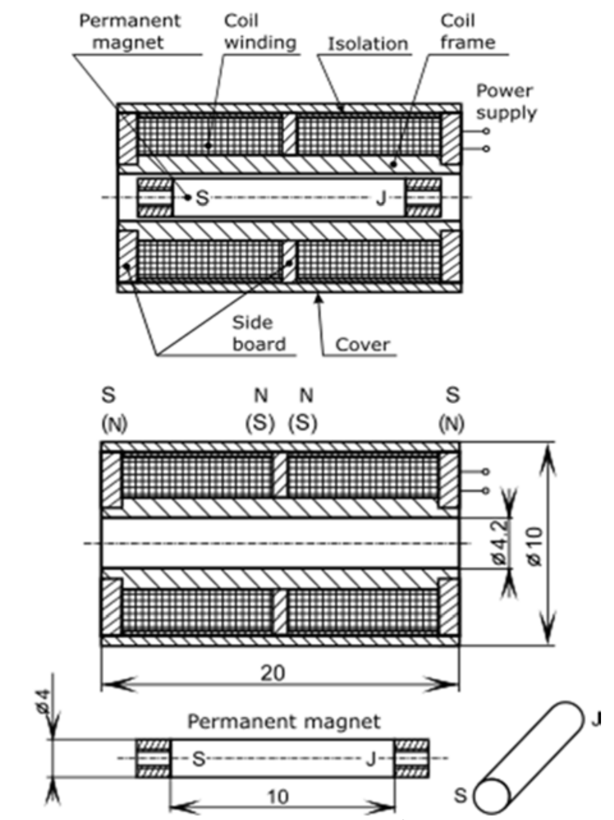

Figure 5 Arrangement and dimensions of the actuator coil and magnet

The actuator was excited by a constant electric current, which was shaped by the control unit in the form of switching pulses. Excitation by a constant electric current is very important because due to the flowing current, the coil of the actuator winding heats up and thus its electrical resistance changes, which would mean a decrease in the magnitude of the electric current when excited by a constant voltage source since it is known from electromagnetic field theory that the strength of the magnetic field depends on the electric current flowing through the coil of the actuator winding.

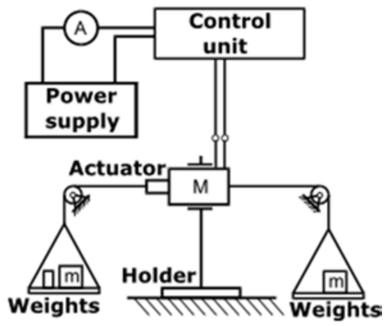

Figure 6 Measuring chain arrangement

The actuator loading was performed first from the left side and then from the right side (Figure 6). The load was increased by adding weight until the maximum weight that the actuator was able to lift at the set position of the permanent magnet relative to the actuator coil was determined. The maximum developed force of the actuator was 0.85 N when excited by a constant electric current of 1A and corresponded to the central position of the permanent magnet with respect to the centre of the actuator coil. The measured values were approximated only by the spline curve, as it is quite complicated to describe this course by one regression function (Figure 7).

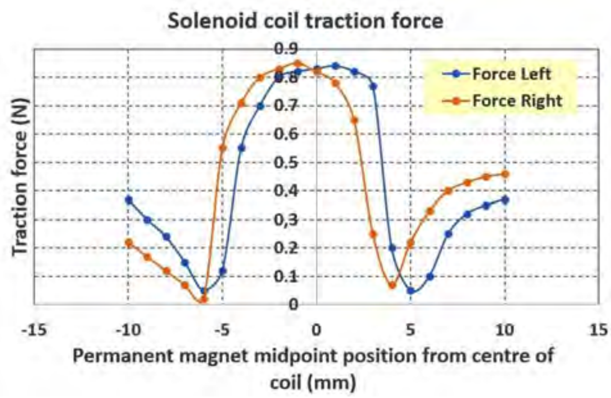

Figure 8 Dependence of the traction force of the actuator on the position of the centre of the permanent magnet relative to the centre of the coil

From previous measurements (Figure 8), it is clear that the optimal position for the use of the actuator in terms of achieving the maximum value of traction force is when the centre of the permanent magnet is in the centre of the actuator coil.

When applying this actuator, it will perform a certain stroke around this optimal position. This mechanical work will therefore be used for a specific application. From the point of view of the application, it is important to know the dependence of the magnitude of the traction force on this stroke. It is assumed that the achievable force will decrease with larger strokes.

This experiment was carried out in such a way that the stroke limit was set with the adjusting screws, and the actuator was tested for the maximum load that the actuator was still able to develop.

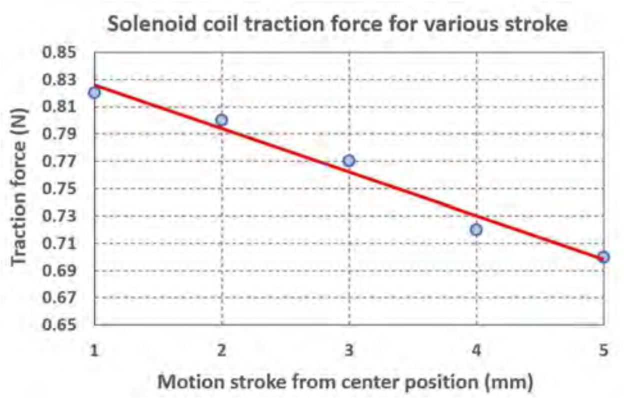

Figure 9 Dependence of the traction force of the actuator at the stroke height around the centre position of the coil

The experiments (Figure 9) confirmed that the traction force decreases with increasing stroke as the permanent magnet moves further away from the centre of the coil. This dependence therefore makes it possible to assess the suitability of this actuator for a particular application. If the required stroke is known, then it is possible to determine the traction force that can be developed by this actuator.

5 Conclusion

The obtained experimental dependence shows:

1. The functional dependence acquires in the middle position (the radial axis of the magnetic core is identical with the radial axis of the coil). This is shown as a significant extreme, i. weight of weight resp. the equivalent force with which the actuator can still move.

2. The whole magnetic core is inserted into the coil in the working position, which makes much more use of the magnetic properties of the permanent magnet.

The designed arrangement of the solenoid actuator thus provides energetically better use of the magnetic field of the permanent magnet coil. This fact can be an advantage, especially with miniaturized sizes of this type of actuator [7-24].

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