U.P.B. Sci. Bull., Series D, Vol. 73, Iss. 2, 2011 ISSN 1454-2358

DESIGN AND EXPERIMENTAL RESEARCH ON THE DISPLACEMENT STRUCTURE OF AN ORIGINAL CONSTRUCTION OF ROLLING ROBOT

Viorel GHEORGHE[1], Nicolae ALEXANDRESCU[2], Despina DUMINICĂ[3]

Lucrarea prezintă unele din cele mai relevante rezultate ale cercetării experimentale efectuate asupra unei structuri originale de robot mobil ce se deplasează prin rostogolire. Sunt prezentate componentele robotului precum şi modul său de funcţionare.

The paper presents several important results of the experimental research performed in order to test the viability and the behavior of a novel construction of rolling robot developed by the authors. The innovative design of the robot and its operation mode are also presented.

Key words: Mobile robots, Magnetic couplings, Rolling, Dodecahedron

1. Introduction

There are many ways to instill mobility to a robot. Robots can have wheels, legs, others can jump, crawl or roll. The rolling ones and especially those with a spherical structure have several advantages: can recover easily after an obstacle encounter, they cannot be overturned and can move in any direction without having to steer from a stop position.

The sphere-shaped robots are built based on several principles: a system of weights, that are moved radially along spokes fixed inside the sphere in order to change the center of gravity of the robot and thus the roll is obtained [1]; a normal wheeled robot that moves inside a sphere shell [2]; deformable sphere created from shape memory alloy materials [3]; pendulum-type ball robot that moves the ballast mass generating the changing of the center mass [4].

This paper presents a novel approach of a rolling robot developed by the authors and focuses more on the experiments done on some of the mechanisms that composed the robot.

[1]Eng. PhD student, University "Politehnica" of Bucharest, Romania, email: viorel.gheorghe@upb.ro
[2] Prof., Faculty of Mechanical and Mechatronics Engineering, University "Politehnica" of Bucharest, Romania, email: nicolasalexandrescu@yahoo.fr
[3] Assist. prof., Faculty of Mechanical and Mechatronics Engineering, University "Politehnica" of Bucharest, Romania, email: despina_duminica@yahoo.com

The chosen solution was of a robotic structure with extendable legs that propels the robot and also ensures greater outer rolling surface, useful for moving over small obstacles without problems.

The CAD representation of the regular dodecahedron shaped robot can be seen in figure 1. Twelve extending legs are disposed in a radial manner in the centers of the dodecahedron faces [5]. Each leg is endowed with a helical compression spring that is used to store the energy needed for the locomotion of the robot. Basically the robot displaces itself by changing its mass centre position due to an impulse given by one or more legs. The movement phases can be observed in figure 2. In its stable position (phase I), the robot is standing on three legs, all of them extended. In order to get the impulse needed to roll the robot, a leg must be retracted, situation in which the helical spring is compressed. The other two legs will remain extended and will provide the support for the rolling process.

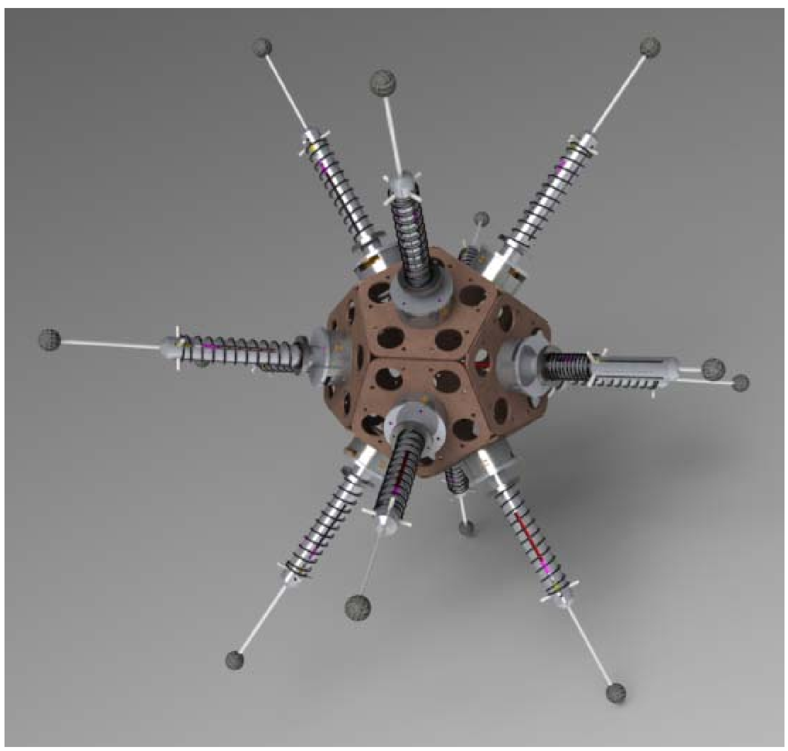

Fig. 1. CAD representation of the robot.

Actually, the rolling axis will be the virtual axis between the ends of the two support legs (phase II). After the leg that has been retracted, the release of the energy stored in the spring, provoke rolling with respect to the virtual axis mentioned before (phase III).

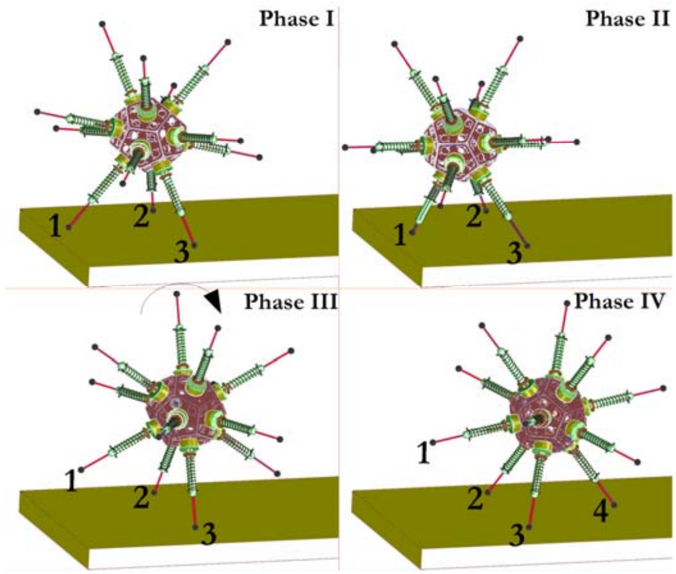

Fig. 2. The locomotion of the robot.

After this transitory stage the robot will reach another stable position, standing on three legs. Two of them are the same support legs previously used, the last one being the leg closest to them in the direction of movement (phase IV). Afterwards, the robot will activate another leg, based on the trajectory that needs to be followed. The path described by the robot will be a zigzag one.

2. The robot leg

The robot has twelve identical legs. The kinematic diagram of one the legs can be seen in figure 3. The figure 4 presents the prototype of the leg, along with the electronic modules used for controlling the linear stepper motor.

The base 1 (figure 3) holds the linear stepper motor enclosure 3, along with the leg sleeve 5, through holding screws 16. The motor is a special kind of stepper motor that generates linear motion directly with the help of an embedded screw/nut mechanism (the rotor 2 playing the role of the nut and threaded shaft 6 playing the role of the screw). The mechanism is actuated by the windings 4.

The initial load of the helical spring 7 can be adjusted by sliding the spacer 15 using the positioning screws 14. In order to obtain linear displacement from the stepper motor, the rotation of the shaft must be suppressed using the anti-rotation pin 8 that slides into a longitudinal cut along the leg sleeve. The permanent magnet 13, attached on the shaft 6, along with the mild steel part 12 that is fixed on the firing rod 10, form together an automatic magnetic coupling device. The other end of the helical spring rests on the retaining disk 11, disk that is joined with the firing rod by fixing bolts. In order to prevent the leg from slipping as much as possible, the firing rod ends with a rubber sphere 9.

In order to operate, the leg first needs to be completely extended. This is achieved by moving slowly the shaft of the linear motor in the direction of end of the leg. When the leg is extended completely the magnetic coupling is armed.

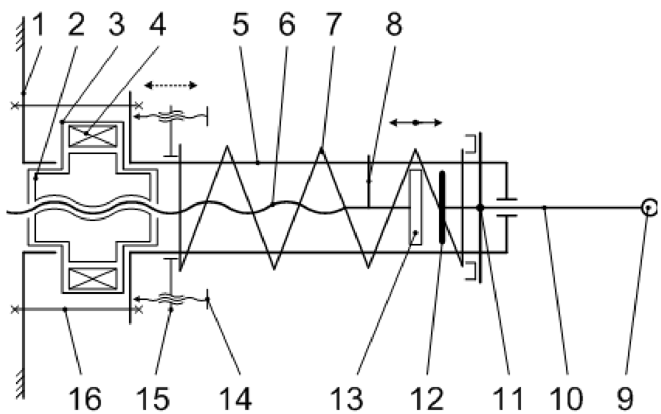

Fig. 3. The kinematic diagram of the leg. 1 – base; 2 – threaded rotor; 3 – motor housing; 4 – motor winding; 5 – leg sleeve; 6 – threaded shaft; 7 – helical spring; 8 – anti-rotation pin; 9 – rubber sphere; 10 – firing rod; 11 – retaining disk; 12 – mild steel part; 13 – magnet; 14 – positioning screws; 15 – spacer; 16 – holding screws.

Fig. 4. The leg prototype.

Now, the motor shaft and the firing rod are connected through the magnetic coupling. Afterwards the motor retracts its shaft, compressing the helical spring.

The automatic magnetic coupling will keep the shaft and the firing rod joined until the spring has stored enough energy to break their union based on the attraction force between the magnet and the mild steel plate.

When the magnetic coupling is broken, the energy stored into the spring is released and the leg is extended rapidly, creating the needed impact to roll the robot.

3. Experimental research

Due to the simplicity and reliability of the magnetic coupling devices, such mechanism has been preferred to assure a trouble free coupling/decoupling of the firing rod.

The designed coupling mechanism ensures that the connection between the motor shaft and the firing rod is firm and the possible misalignments between the axes of the linear stepper motor and the firing rod are corrected.

To ensure the proper operation of the leg was of utmost importance to know the amount of holding force that the magnetic coupling can sustain at different air gap values.

A simplified estimation of the magnetic force (F) that holds a steel part tied to the magnet can be computed using (1). The formula can be used in cases when the volume of the magnet is far greater than the volume of the air gap.

$$F \approx \frac{B^2 A}{2\mu_0} \quad (1)$$

where B - magnetic flux density, A - area of the magnet contacting the mild steel part, μ_0 - permeability of the free space ($4\pi \times 10^{-7}$ T•m/A).

The most important factor that affects the magnetic holding force is the value of the magnetic flux density. But also must be taken in consideration the remanence variation due to the inherent properties of the permanent magnet itself, the environmental temperature, the composition and condition of the attracted material. For cylindrical magnets, the parallelism between their faces and the attracted steel plate must be assured and since the automated magnetic coupling is guided inside the leg sleeve, this problem is unlikely to appear.

The leg design was restrictive and a small factor mechanism had to be used. And since the neodymium magnets have the highest remanence, coercivity and maximum energy product of all commercially available magnets, such a magnet has been preferred.

For the automated magnetic coupling a N48 grade neodymium magnet was preferred, after it has been encapsulated into a small mild steel shell.

The magnetic coupling had to be lightweight, thus the volume of attracted mild steel had to be small as well. The volume could not be very small, because exists the risk of magnetic saturation occurrence. A mild steel part has been designed taking in account the above restrictions. For comparison, a large part of mild steel has also been used for experiments.

In figure 4 can be observed the experimental test bed used for verifying the holding force that the magnetic coupling can offer. Using a mechanical force gauge, the magnetic holding force has been measured, while the air gap has been increased from zero to 0.5mm in steps of 0.01mm.

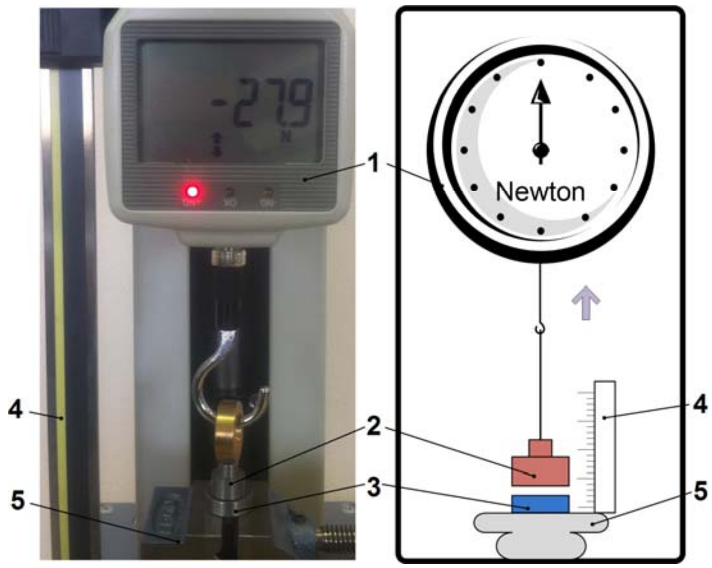

Fig. 4. Experimental test bed for testing the automated magnetic coupling. 1 - mechanical force gauge; 2 – magnet; 3 – mild steel part; 4 – incremental ruler; 5 – stand.

In one experiment, the attracted part was the designed mild steel part and in another one the large part of mild steel. The results obtained from the performed experiments have been plotted and can be noticed in figure 5. On the same figure a FEM simulation of the magnetic coupling have been computed and plotted also.

The FEM simulation (dotted line) and the results of the performed experiments are roughly the same. There is an important difference between simulation and measurements when the air gap among the magnet and the steel parts nears zero. The situation can be explained easily, knowing the fact that zero air gap can be obtained only in ideal situations.

In real conditions must be taken in consideration the dimension of the protective layer that covers the magnet, the roughness of the steel plate and the influence of the mechanical force gauge.

The discrepancies between the graphs of the test mild steel part (dashed line) and the final mild steel part (solid line) are quite small and has shown that there is no risk of magnetic saturation.

The automated magnetic coupling must be broken when it is pulled by a force of approximately 30N. To achieve this, a 0.1 thickness plastic foil has been glued to the magnet.

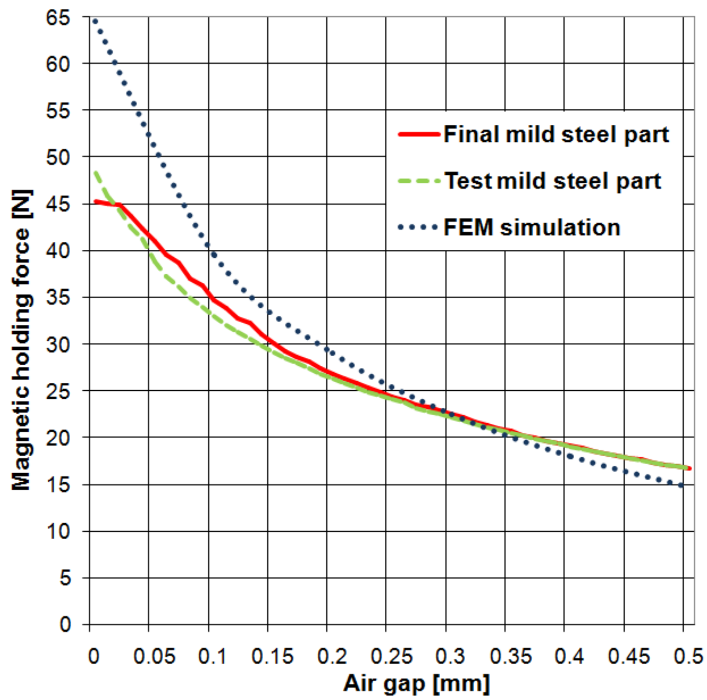

Fig. 5. The variation of the magnetic holding force.

Beside the force alteration purpose the foil also minimizes the coupling shock, given the high attraction force of the magnet.

As presented previously the robot moves by rolling when a leg is extended rapidly, therefore is important to know the amount of force the leg can develop along its extension in real conditions and in what amount differs from the values targeted in the design stage.

During its displacement, the robot uses the energy stored in a spring mounted on the leg, as mentioned before. When the leg is compressed completely the firing rod is retracted into the leg sleeve. This limit is considered to be the start point of the extension. The leg will extend 50mm. In this position the leg is completely extended.

To verify the variation of the force that the leg might generate along of its extension an experimental test bed (figure 6) was built. The force generated by the leg was measured using a mechanical force gauge. The leg was completely retracted and than was extended from zero to 50mm in steps of 0.01mm.

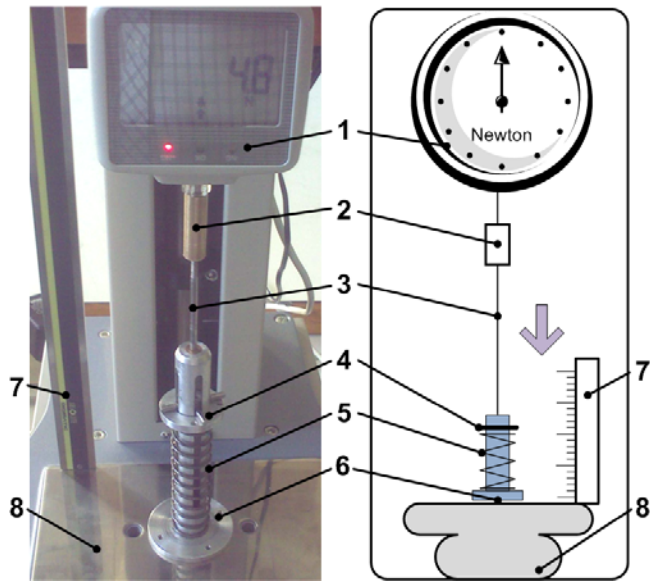

Fig. 6. Experimental test bed for the measurement of the generated leg force. 1 - mechanical force gauge; 2 – connector; 3 – firing rod; 4 – retaining disk; 5 – helical spring; 6 – leg sleeve; 7 – incremental ruler; 8 – stand.

As expected, the variation of the force generated by the leg is closer to a linear one; the helical spring is losing insignificant energy due to the friction among the leg elements involved in motion (figure 7).

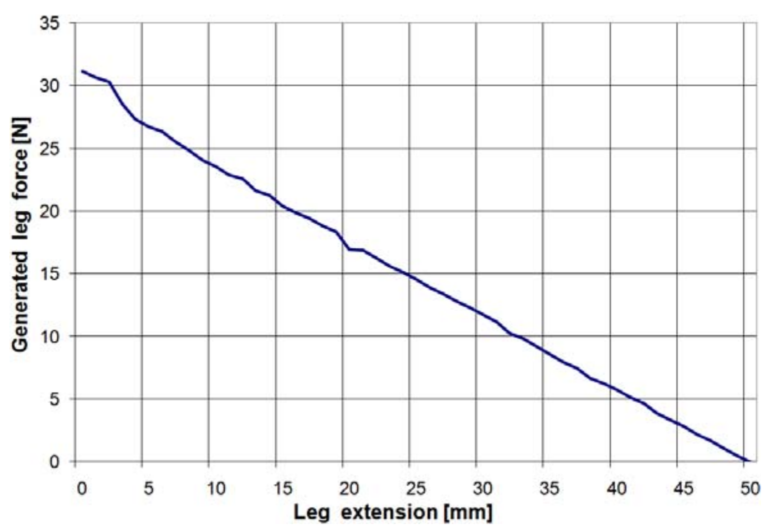

Fig. 7. The generated leg force versus its extension.

4. Conclusions

The experimental research on the automated magnetic coupling proved its capabilities and the need of correcting its behavior in order to comply with the proposed design.

The leg was also tested in order to verify its ability to provide the output force needed in order to perform a step. The tests confirmed that the energy losses due to friction were minimal and the solution proposed for the leg was able to cope with all the requirements imposed in the design stage.

The obtained results allow going ahead with the integration of the leg in a dodecahedron structure similar to the final one, as presented in figure 8. The purpose of the research will be to test if the leg is able to produce the rolling of the robot body.

In this stage, dummy legs will be used for the remaining eleven legs. If the experimental results will match the results obtained by numeric simulation, the final robotic structure will be built.

Fig. 8. The prototype leg integrated in the dodecahedron structure used for testing.

REFERENCES

[1] *R. Mukherjee, M. A. Minor and J. T. Pukrushpan*, "Simple motion planning strategies for spherobot: A spherical mobile robot" Proceedings of the 38th Conference on Decision and Control, Phoenix, USA, 1999, 3, pp. 2132-2137

[2] *A. Bicchi, A. Balluchi, D. Prattichizzo and A. Gorelli*, "Introducing the Sphericle: An experimental testbed for research and teaching in non-holonomy" Proceedings IEEE International Conference on Robotics and Automation. Albuquerque, NM, USA, 1997, 3, 2620-2615

[3] *Y. Sugiyama and S. Hirai*, "Crawling and jumping by a deformable robot" IEEE/RSJ International Conference on Intelligent Robots and Systems, Sendal, Japan, 2004, 4, pp. 3276-3281

[4] *Michaud E. Laplante, J-E H. Larouche, A. Duqiiette, Caron S. Letourneau and D. P. Masao*, "Autonomous spherical mobile robot to child development studies" IEEE Transactions on Systems, Man and Cybernetics, 2005, 35, pp. 471-480

[5] *V. Gheorghe, N. Alexandrescu, D. Duminica and L. A. Cartal* "Rolling Robot with Radial Extending Legs" International Symposium on Resilient Control Systems, Idaho, USA, 2010.