IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X
PP 55-59
www.iosrjournals.org

Magnetic Wall Climbing Devices - A Review

N.R. Khirade [1], R.K. Sanghi [2], D.J. Tidke [3]

[1]*M.Tech. Student, Department of Mechanical Engg., G.H.Raisoni College of Engineering, Nagpur-440016,India*
[2]*Head, Department of Mechanical Engg., S.L.M. Polytechnic, Amgaon-441902, India*
[3]*Professor, Department of Mechanical Engg., G. H.Raisoni College of Engineering, Nagpur-440016, India*

Abstract: Wall climbing devices have been developed with the objective of replacing human operators in the accomplishment of essential safety in performing tasks in hazardous environments as with nuclear reactors, petrochemical plants, power stations etc. Electromagnetism based adhesion mechanisms have been widely used *to develop devices which stick to pipes, girders, wall of ferromagnetic material surfaces etc. These devices usually rely on uninterrupted supply of on board electrical power or power supply from base station. In the event of power failure the device falls off. This paper presents a survey of the design concepts and technologies based on magnetic adhesion principle. It also describes a new climbing device that makes use of permanent magnets instead of conventional electromagnets and uses compressed air supplied from base station. The pneumatically controlled device does not require electrical power supply for its operation.*

Keywords: *Adhesion principles, Electromagnetic gripping, Permanent magnet, Wall-climbing device*

I. INTRODUCTION

The interest in the development of climbing systems has grown rapidly in recent years. Robots with the ability to adhere to the surface of an iron structure could be useful in many types of facilities, such as oil reservoirs, spherical gas tanks and the steam drum of nuclear power plants for performing several tasks, e.g. inspections, short-blasting or painting. Protecting human health and safety is the top priority especially when the operating environment is hazardous and environmentally unfriendly. Many a times the operations are dangerous and a great amount of manpower and time is required for the non-productive work of erecting scaffolding. Automating such tasks with wall climbing robots could permit large monetary savings and human lives.

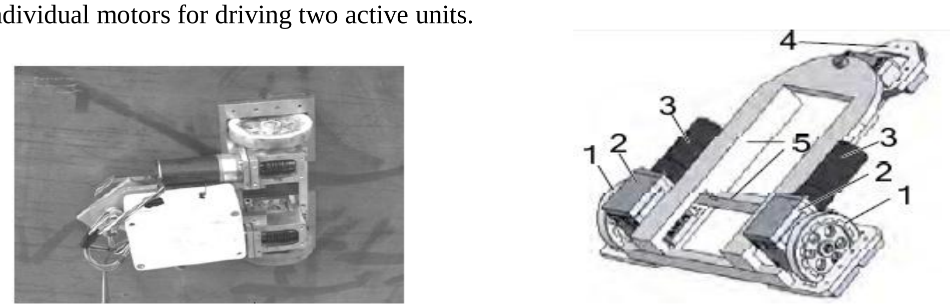
Various kinds of wall climbing robots and devices are being developed, and others are under development, for applications ranging from cleaning to inspection of difficult to reach constructions [1]. Different adhesion and locomotion principles, having specific merits and application potentials, have been used innovatively to build them. A wall-climbing device should not only be light, so that it may reduce excessive adhesion forces, but also have large payload carrying ability in order to hold instrumentations and ancillary equipment for the tasks it is designed, during navigation [2-3]. The wall climbing device should be as flexible as possible because it has to cover vertical distance with some complex shapes sometimes. Such a flexible robot can be quickly reconfigured for design and process modifications. Improved micro processing power and artificial intelligence techniques have also dramatically increased the value of those devices as flexible automation tools. This paper presents a survey of the design concepts and technologies based on magnetic adhesion principle.

II. DEVICES DEVELOPED USING MAGNETIC ADHESION FORCE

Magnetic attachment is useful only where the surface is ferromagnetic. Where surface property allows it, the magnetic adhesion is by far the strongest and the most reliable form of adhesion. The most widely used approach is to use electromagnets. The adoption of permanent magnets, in place of electromagnets, makes the robot more reliable and safer as they are not dependent on external source of power. Permanent magnets are particularly suitable for applications in environment containing hazardous gases where a spark due to an electricity disorder can lead to an explosion. Permanent magnets also have the advantage that there is no need to spend energy for the adhesion process. Further, there is no loss of adhesion in the event of a power failure.

Tache et. al [4] have used magnetic wheels that allow implementing locomotion and adhesion at the same time. With respect to the locomotion type, the simpler alternatives usually make use of sliding segments with magnets that attach to surfaces in order to move [5-8]. Legged climbing robot have the advantages of allowing the creation of a strong and stable adhesion force to the surface and easily coping with obstacles or cracks found in the environment where they are moving with the disadvantages of achieving a low speed while requiring a complex control. Novel magnetic-wheel units permit achieving high velocities. These units consist of wheel, permanent-magnet blocks and connecting parts. Its characteristic is that the permanent-magnet block is set symmetrically around the wheel and there is some gap between the block and surface. Stable adsorption force between the unit and the surface is provided whatever be the surface curvature [9].The permanent magnet is mounted on the bottom of the robot, with the adsorption force up to 2,000N.

Kang Liu et. al [9] have designed a wall climbing robot composed of two active magnetic-wheel units and a drive-all-round magnetic-wheel unit. The disadvantage is that they need continuous electric power supply to run the two individual motors for driving two active units.



1-active magnetic wheel unit; 2-reducer; 3-motor; 4-paissive magnetic-wheel unit; 5-body

Fig. 1- The wall-climbing robot [9]

A magnetic wheeled climbing robot for thin and fragile surfaces has been proposed by W. Fischer et al [4]. The system uses two robots in a 'mother-child' structure. The novel system consists of a huge wall-climbing robot with high mobility (mother) for climbing and passing ridges and other obstacles. The mother robot uses an optimized version of the locomotion system described in [10] and a second, small and simple one (child) that is carrying the detector. This second robot is only able to drive horizontally along the welds on the thin metal sheets and is carried from weld to weld by the big mother robot. The mother robot consisting of 4 motorized wheel units and 2 linear actuators. Such a structure is able to pass ridge-type obstacles by consecutively lifting its wheels. Slight steering corrections are done by driving with different motor speeds on each side. All wheel rims are shaped conically to save mass without decreasing the magnetic force. They are covered with a thin tyre (rubber, 0.6mm), which increases the friction coefficient to the surface from μ = 0.2 - 0.3 to μ = 0.5 - 0.8 and thus significantly decreases the risk of slipping. The child robot has a very simple design, consists of one single motor and a pure mechanical guidance along the ridges. The system uses 4 motorized wheel units so it is fully dependent on externally supplied electric power for gripping mechanism.

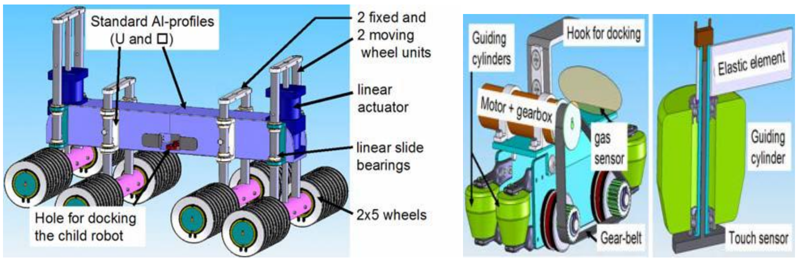


Fig. 2- Structure of the mother and child robot with mechanical guidance [4]

Climbing device working on friction wheel with sliding frame concept was developed by Kalra et. al [1]. The tracked wheel consists of a drive sprocket, a driven sprocket, rubber belt and steel magnet cups fastened with bolts on the belt. Each track has 26 magnets ensuring 10 magnets to be always in contact with the wall surface to keep the robot firmly adhered to the wall. The tracked wheel drives the train mechanism. It allows placing permanent magnets near the contact surface to create enough attraction force to keep the robot on the wall and enough flexibility to cross over small obstacles like welding seams.

Magnetic wheel-type [4] and track-type mechanisms [1] are used in many steel environments. The wheel-type mechanism can move and turn flexibly but the contact surface between the wheels and the wall is small and so the energy-use ratio is low. As a result, this approach is mainly used for designing small detection robots. The track-type mechanism has a large contact area and so the adsorptive force is great and it can move flexibly. However, it is hard to change directions. To overcome these disadvantages, a novel non-contact adjustably permanent magnetic adhesion mechanism for the wall-climbing welding robots (WCWR) has been proposed by Wu et.al [11]. Here, magnets are installed under a chassis and there is gap between the magnet and the wall surface so as to adsorb in a non-contact manner. The adsorptive area is big enough to generate great force so that the robot can carry a heavy load and gives a good performance in passing obstacles. The mobile platform is the core of the WCWR and is directly bound up with the robot's performance. Six wheels and three groups of magnet suckers are mounted under a mobile platform and can be lifted up to pass obstacles. The disadvantage, however, is that the mobile platform has 9 DC servomotors, six for the driving wheels and three for the lifting mechanisms which are required to be driven independently using a power source.

In [12], Shen et. al have presented a wall climbing robot with non-destructive testing tools mounted on the frame of the body, the servo motors and transmission system. Each track comprises a roller chain, two sprockets, and evenly arranged permanent magnetic units. When the robot is moving, there are always a certain number of units in good contact with the surface which enables the robot to stay reliably attached to it. The device needs servo motors and the transmission system to provide drive for the roller chain. The tracked locomotion mechanism, the permanent magnetic adhesion mechanism, and the anti-toppling system for inspecting the oil tanks without the aid of scaffolds enables the system to possess high reliability, simple control and ability to run at a high speed.

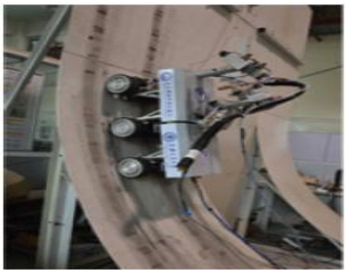


Fig. 3- Prototype of the WCWR [11]

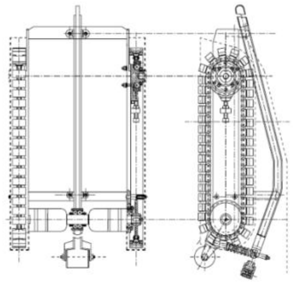


Fig. 4- Mechanical architecture of the wall climbing robot [12]

Wall climbing robot using permanent magnet disks for wheels has been proposed by Hirose et al [13]. This wall-climbing robot named ‘Disk Rover’ is capable of steady and smooth omni-directional locomotion on the surface of a curved iron wall. It uses disk-shaped permanent magnets as wheels. This configuration permits most of the body of the magnet to be in the immediate vicinity of the wall surface, enabling it to produce a higher net adhesive force, in other words, a higher ratio of adhesive force to mass than the magnetic roller. A wheel-shaped permanent magnet effectively fulfils both the functions of adhesion and translation. The device incorporates two magnetic disks and two swivel casters to maintain the orientation of the disks. The chassis of the body is composed of recently developed light-weight carbon fibre reinforced plastic (CFRP) sandwiched Aluminium honeycomb. All necessary control devices and the battery are mounted on device so it can be tele-operated by wireless controller. Proximity sensors have also been installed around the body to halt it automatically when it contacts obstacles.

Unquestionably, magnetic adhesion devices are most promising for systems moving around on steel structures for assorted applications. Devices using permanent magnets or electromagnets can be found for climbing large steel structures for internal inspection of iron pipes and several such applications. However, the adhesion strength as well as number and nature of magnets pose limitations on these applications. It should be noted that the centre of gravity of the robot must be kept as close as possible to the vertical surface since this reduces the adhesion force required to hold the device against the wall surface. The overall weight of any wall climbing device must also be kept to the minimum.

Almost all existing designs described herein have been using electromagnets or motorized wheel units which are energized using on board power or power supplied through cables from base station. Their performance is not quite satisfactory when a large adhesion force is warranted. Further, they are unable to retain and provide firm grip when power fails and do not work satisfactorily when surfaces are rough [14].

III. PNUEMATICALLY OPERATED MAGNETIC DEVICE

A device that makes use of permanent magnets and a pneumatic control system has been proposed recently [15]. It is operated through pneumatic actuators which use compressed air available at the base station but does not require on board or external power supply. The device developed consists of four magnetic base units of the same specification for gripping the ferromagnetic wall surfaces. Two different types of cylinders have been used. The main cylinder is used for forward movement while two small cylinders actuate the magnets as required.

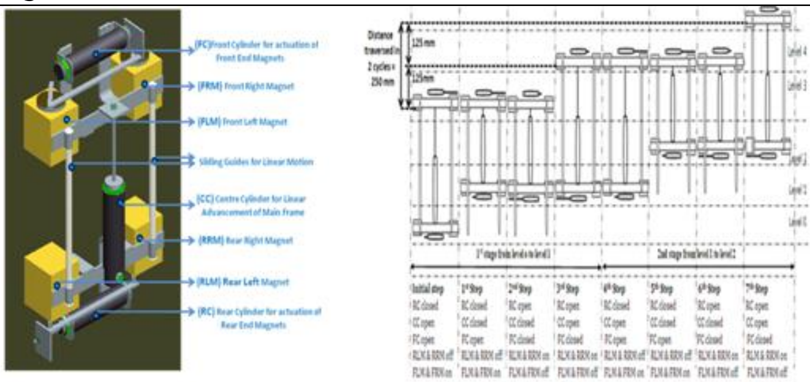


Fig. 5- View of wall climbing robot with permanent magnets and pneumatic cylinders showing stage wise actuation of cylinders and advancement of main frame [15].

The main cylinder placed at the centre of the frame is for exerting force to advance one end the device in forward direction while other end remains fixed and the second, two similar cylinders are placed at front and rear end of device which provides the actuation of the two set of magnets present at the front and the rear ends. Both the magnets connected to each end get switched on and off simultaneously due to the link connecting them to the actuating cylinder. While climbing, the pneumatically actuated permanent magnetic device undergoes stepwise linear advancement using magnetic adhesion principle. See Figure 5. The device applies a total of 38KN magnetic force. During testing on horizontal and vertical surfaces the performance of the permanent magnet bases was found satisfactory. The device has sufficient payload capacity to execute the job on ferromagnetic wall under hazardous environment, typically observed in maintenance and inspection of high pressure boilers in power plants.

IV. CONCLUSIONS

It is observed that magnetic adhesion based wall climbing devices systems are reliable and provide a strong adhesion so long as power supply is reliably available. The pneumatically controlled permanent magnet wall climbing device proposed [15] works even if the supply fails. However, the use of conventional magnetic base units in the system does not permit lifting these units clear off the traced surface and hence they continue to slide over and rub on during movement even after they are demagnetized. There is therefore a need to develop a mechanism to lift the each pair of magnetic bases clear off the wall surface to obtain friction free forward movement. It is also required to develop a mechanism that shall provide a controlled movement of the device along a predetermined path in place of the straight line path presently achieved. The addition of these features to the wall climbing device described above would improve its control and performance and enable having a much cheaper solution to several wall climbing related applications.

REFERENCES

[1] Love P. Kalra, Jason Gu, “A Wall Climbing Robot for Oil Tank Inspection.” in Proceedings of the 2006 IEEE International Conference on Robotics and Biomimetics, December 17 - 20, 2006, Kunming, China.

[2] W. Yan, L. Shuliang, X. Dianguo, Z. Yanzheng, S. Hao, and G. Xueshan, “Development & Application of Wall-Climbing Robots,” in Proceedings of the IEEE International Conference on Robotics and Automation (ICRA ’99), pp. 1207–1212, Detroit, USA, May 1999.

[3] Giuk Lee, “Compliant Track-Wheeled Climbing Robot with Transitioning Ability and High-Payload Capacity.” in Robotics and Biomimetics (ROBIO), 2011 IEEE International Conference on 7-11 Dec. 2011.

[4] W. Fischer, F. Tâche, and R. Siegwart, “Inspection System for Very Thin and Fragile Surfaces, Based on a Pair of Wall Climbing Robots with Magnetic Wheels.” in Proceedings of the 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems, San Diego, CA, USA, Oct 29 - Nov 2, 2007.

[5] P. G. Backes, Y. Bar-Cohen, and B. Joffe, “The Multifunctional Automated Crawling System (MACS).” in Proc. of the IEEE ICRA, Albuquerque, New Mexico, USA, April 1997, pp. 335.340.

[6] H. R. Choi, S. M. Ryew, T. H. Kang, J. H. Lee, and H. M. Kim, “A Wall Climbing Robot with Closed Link Mechanism.” in Proc. of the IEEE/RSJ IROS, 2000, pp. 2006 . 2011.

[7] N. Elkmann, T. Felsch, M. Sack, J. Saenz, and J. Hortig, “Innovative Service Robot Systems for Facade Cleaning of Difficult-To-Access Areas.” in Proc. of the IEEE/RSJ IROS, 2002, pp. 756 . 762.

[8] H. Zhang, J. Zhang, R. Liu, and G. Zong, “A Novel Approach to Pneumatic Position Servo Control of a Glass Wall Cleaning Robot.” In Proc. of the IEEE/RSJ IROS, Sendai, Japan, September 28.October 2 2004, pp. 467.472.

[9]Kang Liu, Wenzeng Zhang, Peng Zeng, “Symmetrically Centralized Magnetic-Wheel Unit for Wall-Climbing Robots.” in proceedings of the 13th IASTED International conference, ROBOTICS AND APPLICATIONS, August 29-31, 2007, Wiirzburg, Germany.

[10]W. Fischer, F. Tâche, and R. Siegwart, "Magnetic Wall Climbing Robot for Thin Surfaces with Specific Obstacles" published in 6th International Conference on Field and Service Robotics - FSR 2007, Chamonix : France, 2007.

[11]Minghui Wu, et.al, "Design and Optimal Research of a Non-Contact Adjustable Magnetic Adhesion Mechanism for a Wall-Climbing Welding Robot." International Journal of Advanced Robotic Systems, vol. 10, 2013.

[12]Weimin Shen and Jason Gu, Yanjun Shen, "Proposed Wall Climbing Robot with Permanent Magnetic Tracks for Inspecting Oil Tanks" in Proceedings of the IEEE, International Conference on Mechatronics & Automation, Niagara Falls, Canada, July 2005.

[13]Shigeo Hirose, Hiroshi Tsutsumitake, "Disk Rover: A Wall-Climbing Robot Using Permanent Magnet Disks" in Proceedings of the 1992 IEEE/RSJ International Conference on Intelligent Robots and Systems, Raleigh, NC July 7-10, 1992.

[14] R. K. Sanghi, "Magnetic Wall Climbing Devices - A Review" in Proceedings of the National Conference on Improving Productivity and Quality of Manufacturing Systems, (ISBN 978-93-5087-876-7) held at GHRCE, Nagpur during 28-29 November 2012.

[15]R.K.Sanghi, "Design and Development of Magnetic Wall Climbing Device in Power Station", M. Tech. Dissertation, RTM Nagpur University, June, 2013.