Preprints of the 21st IFAC World Congress (Virtual)
Berlin, Germany, July 12-17, 2020

Novel Actuation Mechanism for Railway Track Switch System based on Maglev Technology

Osama Olaby, Moussa Hamadache, Ramakrishnan Ambur, Saikat Dutta, Edward Stewart and Roger Dixon

Birmingham Centre for Railway Research and Education (BCRRE), School of Engineering,
University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK
(e-mail: o.olaby@bham.ac.uk)

Abstract: This extended abstract presents a concept of a novel mechanism for railway track switching based on Maglev technology. The main advantage of using this technology is the lack of contact between the actuator and the movable parts of the physical system and thus no wear and friction. This increases efficiency, reduces maintenance costs, and increases the useful life of the track switch system. The proposed new idea is based on using several Maglev actuators to switch the track that makes the new concept more reliable than the conventional switch form the point of view lacking the mechanical link between the actuator and the switch rail. The rail could be switched simply by magnetic principles by attracting the switch rail towards its appropriate location. A control algorithm is developed to achieve the rail track switching mechanism and validated to demonstrate the proof of the novel proposed technology of railway track switching.

Keywords: Railway Track Switches, Maglev Technology, Electromagnetic Devices, Prototyping, Control Algorithms.

1. INTRODUCTION

The railway switching mechanism is a safety-critical asset in the rail network that is required to be highly reliable since its failure or downtime can cause system delay or even fatal accidents [Hamadache et al. (2019)]. Despite the fact that the existing conventional switching mechanisms have been used a number of years, there are still many drawbacks that should be dealt with, especially its reliability, availability, maintainability and safety. Reliability of conventional switches in the UK network, causes significant delay to trains and high cost due to infrastructure maintenance. [Bemment et al., 2017] has analysed failure data from the UK mainline infrastructure custodian, covering more than 74,000 km of operation, in order to establish failure distribution parameters and reliability figures for different types of existing track switches. Thus, the Switch and Crossing Optimal Design Evaluation (S-CODE) project looked at developing new ways of switching railway tracks by coming up with radically different and novel technologies that are suitable for the future track switch and crossing (S&C) [COMSA (2017)]. This paper introduces one of these completely new switching mechanisms based on Maglev technology.

The Maglev technology itself is not a new one, in 1726 Jonathan Swift described the Maglev island of Laputa [Yaghoubi (2013)]. In the railway industry, this technology was introduced in the 1960s by James Powell and Gordon Danby that was further developed by the Japan National Railway [Powell et al. (1971)]. They developed and adopted the magnetically levitated trains (i.e., Maglev trains) that are certainly the most advanced vehicles currently available to railway industries, which improve and surpass high-speed railways (HSRs) in almost most fields [Yaghoubi et al. (2013)]. In the UK, many scientific works had started for developing a magnetically levitated train since the 1940s [Goodall (1976)]. It was at the Birmingham airport where the world's first commercial Maglev shuttle was operated in 1984 [Taylor et al. (1984)].

However, in this study, the proposed new mechanism for the railway track switch system based on Maglev technology is developed and tested using the REPOINT layout switching concept, where the switch layout is different from the traditional switch system as shown in Fig. 1. This stub switch uses a full-section rail throughout. The route is selected by bending or hinging the approach rails to position [Bemment et al. (2016)].

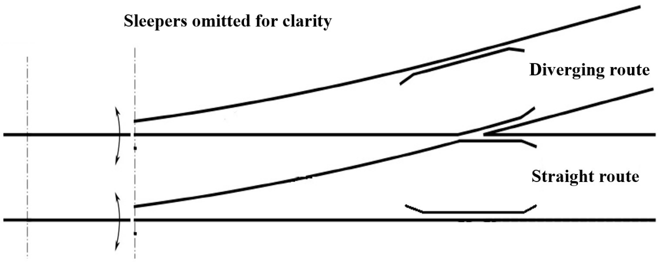

Fig. 1. Stub switch layout.

2. DESIGN AND BUILD A RAILWAY TRACK SWITCH USING MAGLEV TECHNOLOGY

The proposed switching technology using the Maglev actuator consists of a static rail and a movable rail as shown in Fig. 2. We propose using four electromagnet actuators (EMs) that have been installed vertically and horizontally. The vertically placed EMs are responsible for levitating the track, whereas the horizontally placed EMs are responsible for attracting or repelling the track to or away from them. Figure 2 shows a passive locking of railway track, similar to concepts in [Bemment et al. (2016)], that will be developed in the future stage of this research work.

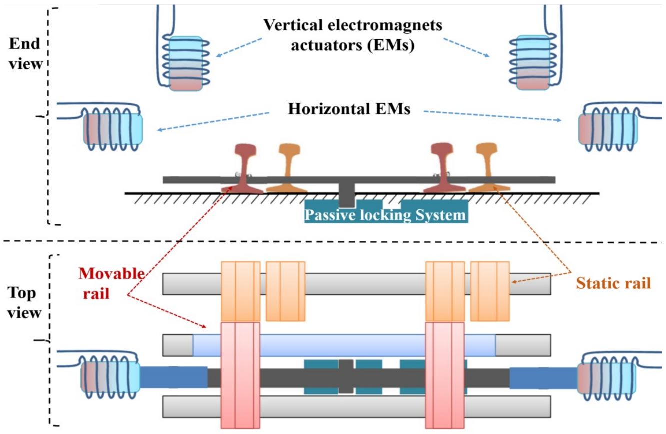

Fig. 2. Concept of the railway track switch system using electromagnets.

Figure 3 shows a physical model of a railway track switch using Maglev actuators. We proposed to install four permanents magnets (PMs) that are placed on the movable rail facing the EMs. Using permanent magnets in this movement has obvious benefits, such as increasing the magnetic attractive force, and as a passive movement without the requirement of high energy consumption, thereby making the system efficient [Poletkin et al. (2018)]. The rails used in this model are made of stainless steel at 1:22 scale with plastic bearers. One of the bearers has been replaced by a longer one, which supports the four PMs, and is part of the actuation mechanism.

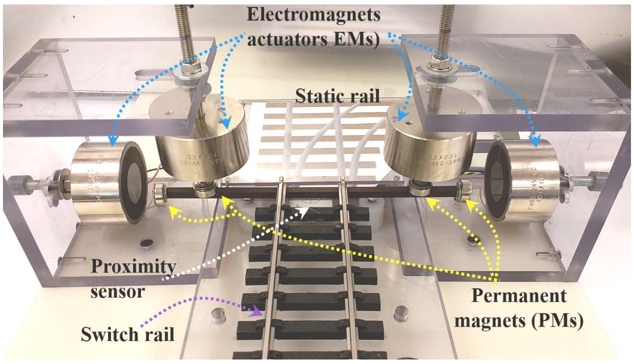

Fig. 3. Physical lab scale demonstrator of the proposed railway track switch system using Maglev actuators (front view).

Each PM has a pull force of 80 N and a flux density of 4400 gauss. However, each electromagnet actuator (diameter 65mm, length 111mm, depth 35mm) has a maximum holding force of 1.67 kN when a 340mA DC current is applied. Since the magnetic force is proportional to 1/(air gap)^2, the holding force can be reduced by changing the air gap. For a gap of 2mm between the EM and steel armature surfaces, the EM pull force will fall to 1.4% of the maximal force value. The challenge was to increase the air gap between the effective electromagnet surface and the switch rail. This is an essential point that will allow levitating of the attracted rail by the vertical EM actuators without touching the actuator. Also, for this reason, we installed four PMs on one of the bearers. Thus, the nominal air gap between the vertical EM and PM is 23.5mm, whereas it is 17mm between each horizontal EM and PM. To define practically the nominal air gap needed between the EMs and PMs, the vertical and horizontal positions for each EM have been initially made adjustable during the configuration demo setup. In the practical switch applications, EMs position adjustment not needed for every track switching movement. For this stage of development, physical constraints have been installed on the platform, this is to provide mechanical guidance of the switch rail's movement. The lifted switch rail should then be ready to slide right or left by careful control of the current of the four EMs actuators. The track switch movement (up/down) can be detected using a proximity sensor placed underneath the actuated bearer of the track switch as shown in Fig. 3.

3. IMPLEMENTATION AND EXPERIMENTAL RESULTS

Two different positions of the switch rail are achieved by controlling the Maglev actuators in open-loop control mode (see Fig 4) using LabVIEW software and NI myRIO 1900 hardware. This was to demonstrate the concept of the proposed novel technology of railway track switching and so to achieve the rail track switching mechanism using Maglev technology. Figure 5 shows the human-machine interface that has been developed to permit the interfacing between the hardware components used in building the novel switch system and the operator who is responsible to switch the railway track to either the straight or divergent route position (see Fig. 1). Figure 6 shows the flowchart of a logic control algorithm developed to drive the switching mechanism between the two different positions. This illustrates how the algorithm operates and what instructions will appear on the user manual interface shown in Fig. 5. For example, if the operator needs to change to the diverging route, the Right button should be clicked and so the two verticals EMs will be ON. Thus, the switch rail will go up. Then, the right horizontal EM will be ON, which will attract the movable rail to the Right. Then, reversing the polarity for both vertical EMs will make the switch rail going down in a new position. Upon completion of this sequence, a dialogue box on the LabVIEW front panel appears which depicts the user that the right switching operation is completed. As soon as the user presses OK, all the EMs are automatically turned OFF and so waiting for the next switching operation.

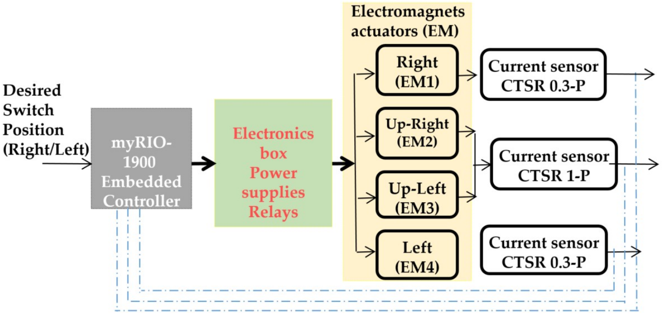

Fig 4. Designed control system for the track switch system

Fig.5. Developed human-machine interface using NI-LabVIEW software.

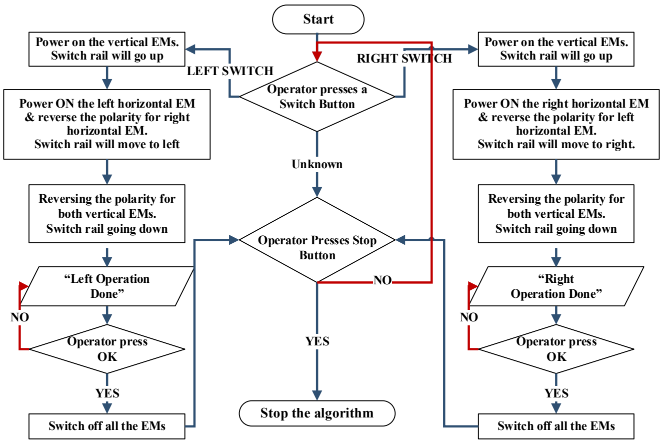

Fig. 6. Flowchart of the developed control algorithm for the new proposed railway track switch.

Three current sensors, as it is shown in Fig. 4, have been calibrated and then used in the switch rail model to provide the needed data about the behaviour of the system. The first current sensor (model CTSR 1-P) was used for measuring the current flowing through the pair of vertically placed EMs and the two others (model CTSR 0.3-P) were used for the right and left EMs. Figure 7 shows the current signals from all EMs. The triangular-shape current ramp is only due to a low sampling rate of 10Hz. The positive current represents the attracting operating condition of the Right/Left EM i.e. when the force attracts the PM. Whereas the negative current represents the polarity reverse condition in which the Right/Left EM repels the track away from it. During any switching operation irrespective of the switch chosen, the vertically placed EMs are always involved in levitating the rail track as it is shown in Fig. 7. In this scenario, the switch rail is lifted, at the time of 52 seconds, and moved from left to right to be dropped off at 57 seconds. This switching time (5s) meets the settling time of control requirements which is set to be less than 7s as per the UK railway standards. The rail switching action is repeated in the opposite direction at 98 seconds. Each current curve shows a peak value equal to 0.35A. Since the EMs powered by 24V, the peak power for every switch rail movement will be 21.6W. This is a reasonable power consumption considering the lab-scale of this model. This could make the system efficient and economical.

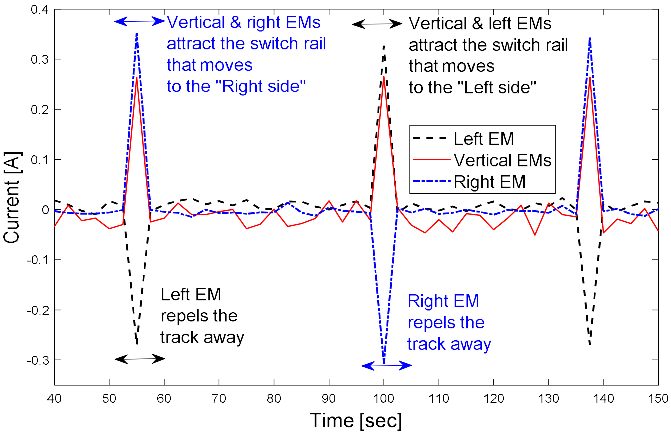

Fig. 7. The experimental results of the electromagnets actuators' DC current signals.

4. CONCLUSION AND FUTURE WORK

This paper has presented a novel technology concept that integrates Maglev principles in a railway track switch as a means of actuation. It presents the conception, development, operation, and lab-scaled demonstration of track-switching technology. The main advantage of this concept is that the track switch can move without any mechanical contact between the electromagnet actuators and the track rail, which eliminates the source of the main failure of the existing railway switches, the wear, and friction. Another important feature of the proposed mechanism is the ability for developing a redundancy system and a passive locking of the railway track. A physical model has been designed and several tests have been carried out to check the proper functioning of this novel switching movement. Four PMs and four EMs actuators are used in this contactless track switch model. The four EMs were controlled based on an open-loop control algorithm to obtain the necessary trajectory of the proposed switch rail system. The experimental results show a low power consumption to complete the rail switching mechanism.

For future work, first, a mathematic model of the switching system will be developed for simulation purposes and calculating the system response for ensuring a smooth motion of the track switch. Second, two-feedback control loop algorithms will be further considered. The first one is for controlling the air gap between each EM and its opposite PM installed on the active bearer. The second feedback control loop is for controlling the current of the Maglev actuators, which will enable a smooth attraction of the movable rail upward, then to slide, and drop off it in the new switch position. The two controllers are under development to improve self-adjusting behaviour in the Maglev actuators.

ACKNOWLEDGMENT

The work described has been supported by the S-CODE project. This project has received funding from the Shift2Rail Joint Undertaking under the European Unions Horizon 2020 research and innovation programme under grant agreement No 730849. This publication reflects only the author's view and the Shift2Rail Joint Undertaking is not responsible for any use that may be made of the information it contains.

REFERENCES

Bemment, S. D., Ebinger, E., Goodall, R. M., Ward, C. P., and Dixon, R. (2016). Rethinking rail track switches for fault tolerance and enhanced performance. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit.*

Bemment, S. D., Goodall, R. M., Dixon, R and Ward, C. P., (2017), Improving the reliability and availability of railway track switching by analysing historical failure data and introducing functionally redundant subsystems, *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit.*

COMSA Corporation, S-CODE Project Deliverables, D1.1 (2017). Review of definition, standard operating parameters, best practice and requirements, including future technologies and horizon scanning, Available online at http://www.s-code.info/results-and-publications/, (accessed on 05 Nov. 2019).

Goodall, R. M. (1976). Suspension and guidance control system for a dc attraction Maglev vehicle. *Institution of Electrical Engineers Conference Publication. 2nd Conference on Adv. in Magn. Mater. and their Application*, London, England. p. 100-103.

Hamadache, M., Dutta, S., Ambur, R., Olaby, O., Stewart, E. and Dixon, R. (2019). Residual-based fault detection method: application to railway switch & crossing (S&C) system. *19th International Conference on Control, Automation and Systems (ICCAS 2019)*, Jeju, Korea, 6 pages.

Taylor, D. R. D., Goodall, R. M., & Oates, C. D. M. (1984). Theoretical and practical considerations in the design of the suspension system for Birmingham MAGLEV. In *Maglev Transport: Now and for the Future : IMechE conference publications,* (pp. 185-192). Inst. of Mechanical Engineers, London by Mechanical Engineering Pub Ltd.

Powell, J.-R. and Danby, G.-T. (1971). Magnetic suspension for levitated tracked vehicles. *Cryogenics*, Volume 11, Issue 3, 192-204.

Poletkin, K.-V., Asadollahbaik, A., Kampmann, R. and Korvink, J.-G. (2018). Levitating Micro-Actuators: A Review. *Actuators*, volume *7*(2), 17; Multidisciplinary Digital Publishing Institute, https://doi.org/10.3390/act7020017

Yaghoubi, H. (2013). The Most Important Maglev Applications. *Journal of Engineering*, Hindawi Publishing Corporation, Article ID 537986, 19 pages, http://dx.doi.org/10.1155/2013/537986.