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

Innovative Technologies for Railway Track Switches

Moussa Hamadache*, Ramakrishnan Ambur*, Osama Olaby*, Saikat Dutta*, Jou-Yi Shih*, Edward Stewart*, and Roger Dixon*

** School of Engineering, Birmingham Centre for Railway Research and Education (BCRRE), University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom. (Tel: +44 (0)121 414 7522; e-mail: m.hamadache@bham.ac.uk).*

Abstract: In this extended abstract paper, a few of the developed switches and crossings (S&C) mechatronic technologies within the Switch and Crossing Optimal Design Evaluation (S-CODE) project will be presented, where they were titled as demonstrators. Current conventional S&C are working for a long time with reasonable performances. They kept their mechanism with little changes. However, there are still many drawbacks that should be dealt with, especially its reliability and safety. Thus, the S-CODE project looked at developing radical future S&C technologies that can be integrated into existing rail network platforms, but also can achieve significant improved performances. These technologies will either accommodate potential faults in S&C through integrating condition monitoring (CM) and/or a fault tolerant control (FTC) strategies, in addition to define the optimal locations for sensors to be placed; or completely propose new actuating mechanisms (i.e., high redundancy actuator (HRA) and Maglev actuator); and/or consider a novel locking concept that base on the magneto-rheological fluid (MR) damper to improve railway track switching performances, especially with the strong tendency to introduce high-speed trains.

Keywords: Railways, switches and crossings (S&C), mechatronics, condition monitoring, reliability.

1. INTRODUCTION

The railway switches and crossings (S&C) system is a safety critical asset in the rail network that is required to be highly reliable (Hamadache et al. (2019)). Any failure in this system can cause delays in the rail network and/or even fatal accidents, such as the deadly train accident on February 4th, 2018 in Cayce, SC, United States that killed two people and injured 90 others (WIS News (2019)). Thus, within the Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation program, the Switch and Crossing Optimal Design Evaluation (S-CODE) project aims to achieve cost-effective infrastructures and improving capacity, reliability and safety, while reducing investment costs and life-cycle costs (University of Birmingham (2019)). It focuses on developing radical future S&C technologies that can be integrated to form innovative S&C with potential for significant improved performance (COMSA (2017)).

Conventional S&C are based on designs, which have been used for the last two centuries without major changes. They allow trains to change routes as shown in Fig. 1. This is accomplished by sliding the switch rails laterally over slide chairs that is nowadays achieved through electro-mechanical, hydraulic and/or pneumatic actuators. A comprehensive review of the existing CM techniques for railway S&C systems with the aim to overview the-state-of-the-art of the railway S&C technologies and its problems is detailed in (Hamadache et al. (2019)). Thus, to provide a platform for researchers, railway operators, and experts to research, develop and adopt the best methods for their applications. The sliding movement involves wear and friction. Thus, even though these current conventional S&C are working for a long time with acceptable performances, there are still many issues to be considered, especially its reliability and safety. Some of the developed technologies within the S-CODE project are introduced in this extended abstract paper, which focus on dealing with three requirements, including *monitoring and fault tolerant* that detect any abnormalities and accommodate potential faults in the railway S&C, in addition to define the optimal locations for sensors to be placed; *actuation* that proposes new actuating mechanisms by either proposing a high redundancy actuator (HRA) or exploiting the use of the Maglev technology, and *locking* that consider a novel locking concept that base on the magneto-rheological fluid (MR) damper.

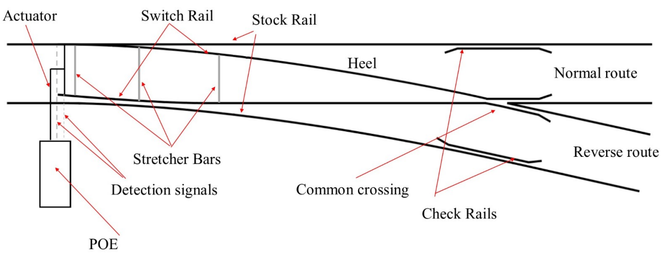

Fig. 1. Layout of the conventional S&C system.

This paper is organized as follows: Section 2 introduces in brief the sensor placement, the condition monitoring (CM), and the fault tolerant control (FTC) demonstrators. The novel actuation technologies including the HRA demonstrator and the Maglev-based one are given in Section 3. The novel locking concept that base on the MR damper is presented in Section 4. Finally, a conclusion is given in Section 5.

2. CONDITION MONITORING AND FAULT TOLERANCE

Diagnosing faults and incorporating this information within the analysis is also a part of the mechatronic system, which has been developed as a part of the S-CODE project. To detect and diagnose faults, sensors have to place at optimal locations. Condition monitoring on process faults and fault tolerant control on the sensor faults are developed as two independent methods to demonstrate the effectiveness of the technologies in the railway S&C domain. The following sub-sections explain these concepts.

2.1 Sensor placements demonstrator

Data profiles for detecting common S&C faults have been investigated based on both Finite Element (FE) and Multi-body system (MBS) simulation and two measurements trial were carried out within the S-CODE project to justify the proposed sensor location and data acquisitions. The results have shown high potential for condition monitoring S&C degradation. Furthermore, faulty train can be identify, which is important for data selection for diagnose algorithm. In the end, a holistic condition monitoring system with multiple sensors at the optimal locations and data acquisitions were developed.

2.2 Condition monitoring (CM) demonstrator

The switch performance can be changed over a long period of time due to many reasons. The model-based CM approach is developed in this work to detect any change in performance of the switch actuation. An actuator of a working switch system, high-performance switch system (HPSS) is considered in this research and a validated multibody simulation model developed using Simpack (Dutta et al (2019)) is used to show the functionality of the CM approach. In this switch system, the system performances are monitored using data from the two sensors motor current and the displacement of the switch toe. The continuous time parameter estimation process is shown to predict the changes in the system parameters, such as motor torque, stiffness, friction in the system and overall inertia of the system.

2.3 Fault tolerant control (FTC) demonstrator

Within the actuation concept of switch by a track switch actuator, an open loop control is followed conventionally. It is necessary to feedback the displacement of switch for safety reasons. With this aim a closed feedback control loop is developed incorporating fault tolerance. This method is applied to all sensor faults through detection and accommodation. Apart from the position sensor, velocity and current sensors are also analysed as they are conventionally part of a general electric motor control loop similar to (Dixon, R. (2004)). Figure 2 shows the schematic of the method, where the three blocks in the bottom are part of fault tolerant control.

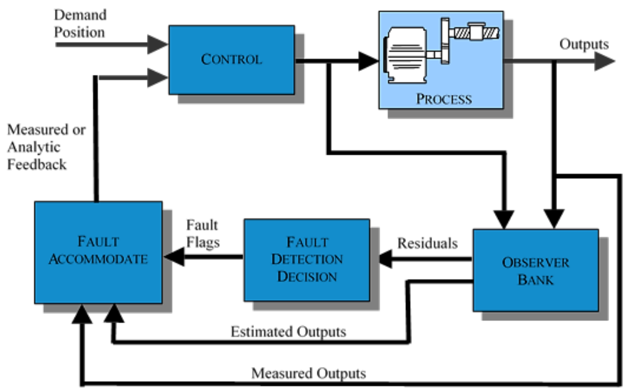

Fig. 2. Scheme of fault tolerant control applied to actuator of railway S&C.

3. NOVEL ACTUATION TECHNOLOGIES

3.1 High-redundancy actuator (HRA) demonstrator

A high-redundancy actuator (HRA) is designed and built to demonstrate the provision of fault tolerance using several (small) actuators, which are assembled in parallel and series configuration to form a single (big) actuator as shown in Fig. 3. Thus, if one of these several actuators fails, the remaining actuators can take over and ensure the functionality of the total system (i.e., the S&C system). Further, it was shown in (Antong, et al., (2016a); Antong, et al., (2016b); Steffen, et al., (2009); Du, et al., (2010)) that the parallel configuration not only increases the force generated, but also improves the loose fault tolerance, and the series configuration increases the travel as well as improving the Look-Up fault tolerance. This demonstrator comprises a HRA driving against a varying load as shown below.

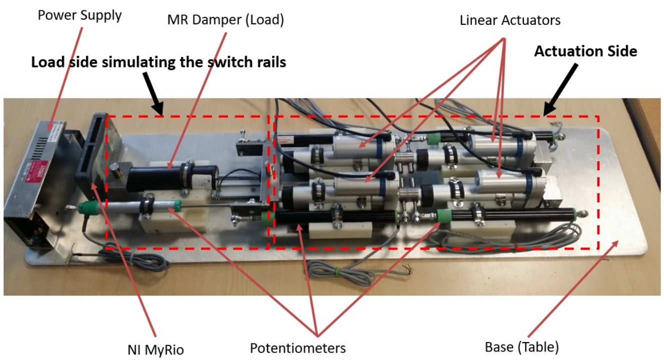

Fig. 3. Overview of the HRA demonstrator.

3.2 Maglev actuator demonstrator

A small scale demonstrator for a Maglev technology actuation has been developed in the S-CODE project. A remarkable feature of this technology is that the switch track levitates without any mechanical contact between the electromagnet actuators and the movable track rail. Figure 4 shows the rail switching concept based on Maglev actuator. Four electromagnetic actuators are used in this contactless track switch actuator. Open-loop control algorithm of four electromagnets actuators is developed to obtain the necessary trajectory of the proposed switch rail system. The proof of a novel concept of railway track switching has been achieved by controlling the Maglev actuators in open loop control mode using LabVIEW software and NI myRIO 1900 hardware.

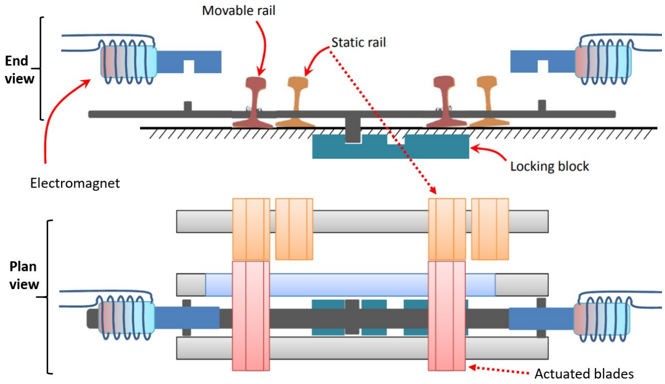

Fig. 4. Concept of the railway track switch system using Maglev actuators.

4. NOVEL LOCKING CONCEPT

A major challenge for a new locking mechanism is to provide secure lock at locked position and allow self-adjustment of the system if needed. Different locking technologies have been evaluated in the early part of this project and a lock using Magneto-rheological (MR) devices is developed to demonstrator stage, which has shown to provide the required locking while allowing self-adjusting behaviour. The new concept has the potential to ease the scheduled maintenance procedure. MR fluid is one of the controllable fluids which has the ability to change its viscosity when the applied magnetic field changes.

A new MR damper is designed to achieve the required force of 30kN when activated. The lock is achieved when two MR dampers are connected with the switch rails and their adjacent stock rails at the toe position. During the actuator movement, no current is fed to the dampers and they work as passive viscous dampers. After the switching movement, the voltage is applied to the MR damper to generate the magnetic field, and the MR dampers provide a high locking force, which prevents movement of the switch rails.

5. CONCLUSION

Six technologies developed within the S-CODE project for improving the railway S&C reliability and safety have been summarized in this extended abstract paper. Some of which did accommodate current problems in the conventional S&C by either integrating CM and/or FTC strategies, in addition to define the optimal locations for sensors to be placed (i.e., sensor placement technique). The others focused on proposing radical new future S&C technologies that can be integrated into existing rail network platforms such the HRA and the Maglev-based actuators. In addition to a novel locking concept that base on the MR damper. All these new technologies were fulfilled and built as demonstrators to prove their feasibility. The presentation will cover these areas in more details, including video clips and photos of the proposed new concepts.

REFERENCES

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. In the *19th International Conference on Control, Automation and Systems (ICCAS 2019)*, ICC Jeju, Jeju, Korea, 6 pages.

WIS News, (2019). NTSB releases final report on deadly 2018-train accident in Cayce, available online at https://www.wistv.com/2019/09/30/ntsb-releases-final-report-deadly-train-accident-cayce/ (accessed on 04 Nov. 2019).

University of Birmingham. (2019). S-CODE Objectives, available at http://www.s-code.info/objectives/, School of Engineering, University of Birmingham (accessed on 05 Nov. 2019).

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).

Hamadache, M., Dutta, S., Olaby, O., Ambur, R., Stewart, E., and Dixon, R. (2019) On the fault detection and diagnosis of railway switch and crossing systems: An overview" *Applied Sciences*, 9(23), 32 pages. https://doi.org/10.3390/app9235129

Dutta, S., Harrison, T., Ward, C.P., Dixon, R. and Scott, T., (2019). A new approach to railway track switch actuation: Dynamic simulation and control of a self-adjusting switch. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, p.0954409719868129.

Dixon, R. (2004). Observer-based FDIA: application to an electromechanical positioning system. Control Engineering Practice, 12(9), pp. 1113-1125.

Antong, H., Dixon R., and Ward, C. P. (2016a). High redundancy actuator with 12 elements: Open- and closed-loop model validation. *IFAC-PapersOnLine*, 49(21), pp. 254–259.

Antong, H., Dixon R., and Ward, C. P. (2016b). Least squares estimation and fuzzy logic based condition monitoring for high redundancy actuator. *IFAC-PapersOnLine*, 50(1), pp. 3189–3194.

Steffen, T., Michail, K., Dixon, R., Zolotas, A. and Goodall, R. (2009). Optimal passive fault tolerant control of a high redundancy actuator. *IFAC Proceedings,* 42(8), pp. 1234–1239.

Du, X., Dixon, R., Goodall R., and Zolotas, A. (2010). Modelling and control of a high redundancy actuator. *Mechatronics*, 20(1), pp. 102–112.