On the development of a full-scale Repoint Light track switch

M L Sarmiento-Carnevali, T J Harrison*, S Dutta*, S D Bemment*, O Olaby*, C P Ward*, R Dixon**

**Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, United Kingdom
m.l.sarmiento-carnevali@lboro.ac.uk*

Keywords: railway track switching, fault-tolerant track switch system, triplex redundancy, railway infrastructure

Abstract

Repoint Light is a novel concept for track switching under development at Loughborough University. This engineering solution is designed to meet the set of functional requirements for track switching panels, in addition to offering several features that traditional designs are unable to achieve. The objective of the current phase of the Repoint project is to advance the Repoint Light concept from Technology Readiness Level (TRL) 3-4 to TRL7. TRL7 is defined by RSSB, the funding organisation as a 'prototype technology system in an operational railway environment'; i.e. a functioning Repoint Light switch deployed in a suitable test environment, integrated with signalling/power and able to accept train movements. This work focuses on the description of engineering challenges faced when introducing the concept into its real operating environment.

1 Introduction

Railway track switching provides flexibility to a rail network, allowing vehicles to switch between many different routes. The switch remains in position and locked until commanded to move via the signalling system. Upon command from the interlocking, the actuator in the switch panel unlocks and then moves the rails to the correct position, before again locking them in place. The position of both rails and the integrity of the lock are detected and transmitted. This process normally takes up to 8 seconds. The position of the rails and the integrity of the position lock is continually fed back to the interlocking via the subsystem known as detection. The crossing panel guarantees support and guidance of the passing wheelset, as the two running rails cross [1]. Existing track switch systems are the result of the evolution of a single design solution patented by Charles Fox in 1836 [2]. The requirements of railway systems have evolved in the intervening period. Therefore, track switches currently have a negative impact upon network performance with regards to maintainability, capacity, reliability and cost.

In the novel Repoint approach, a bank of in-bearer type electro-mechanical actuators, featuring integral passive locking elements with detection system, allows multi-channel actuation providing a high degree of fault tolerance [3,4]. The concept, based around a stub switch panel, offers several features improving current designs. The key aspect of this

approach is that individual actuators can fail but the overall system will still set routes. In the Repoint Light version, this concept is applied to a traditional CVS switch panel (Figure 1a). The main design change from a conventional switch actuation mechanism is that the Repoint Light actuators operate the switch rails through a two-dimensional arc, lifting them out of register before traversing them and then lowering them in the opposite register (Figure 1b). Currently, a full-scale prototype is being developed to evolve the concept from TRL 3-4 to TRL 7. Throughout this article, project engineering decisions and challenges are presented and discussed.

Figure 1: (a) Repoint Light switch layout: in-bearer actuators in grey [4]. (b) Rails movement by one of the actuator bearers.

The paper is organised as follows: Section 2 introduces the set of project tasks organised in a V-cycle diagram. This section later presents different activities and challenges for various sub-system level components. Section 3 describes test and validation activities, as well as decisions made regarding the appropriate test site to guarantee all prototype requirements at

this stage of technology readiness are satisfied. Finally, Section 4 presents conclusions and future work.

2 Repoint Light project

The prototype system under development specifically considers a bank of three in-bearer type electro-mechanical actuators, applied to a CVS switch panel using CEN 56 stock rail [5,6]. Initially, a document was developed to capture applicable and relevant railway switching specifications and regulations from British and European standards, as well as input from relevant stakeholders (RSSB, Network Rail and TfL) regarding essential and desired requirements. System-level architecture and single bearer mechanical design have evolved through different technology readiness levels [3]. Design improvements in comparison to previous versions are described later in this section. Currently, the team is actively working on sub-system level and component level tasks, including the specification and selection of adequate motors and sensors, definition of the logic to detect position of switch rails, electrical layout, control logic design and necessary hardware/software for the control sub-system. In addition, component manufacturing tasks, system assembly process, laboratory testing and field testing activities are being planned. Figure 2 summarises all project tasks.

Figure 2: Repoint Light project systems engineering V-diagram.

The Repoint Light system is currently divided into 5 sub-systems:

1. Actuator bearers – Tasks involve the mechanical design of the bearers, including the operating mechanism and locking provisions within.
2. Lineside cabinet, signalling interface and power supplies - Tasks involve integration of control system and lock/detection system with the signalling system, power supply to the control system and lock/detection system.
3. Control system – Tasks include motor control at bearer level and the higher-level logic concerning normal operation, maintenance mode and provision for hand winding.
4. Lock/detection system independent of the control system – Tasks include taking outputs from sensors in the bearers and providing the system level normal/reverse position output.

5. Switch panel – Tasks involve the rails, (non-actuating) bearers and associated components.

Figure 3 indicates the location of the different sub-systems and components. The lineside control cabinet houses the logic for both the control system and the lock/detection system. Some of the electronic elements will be in the cabinet and some of the lock/detection elements will be within the actuator bearers. The following sections describe several engineering decisions considered in the development of the Repoint Light prototype.

Figure 3: Repoint Light switch layout including components.

2.1 Actuator bearers

As previously stated, there are three active bearers in the actuator bank for the Repoint Light demonstrator under development. The actuators will be located at bearer positions 1, 3 and 5. The three actuator bearers are to be identical, with the exception of alternative assembly of the drive mechanism to account for the differing lateral motion. Figure 4 shows that the entire operating mechanism is housed within the hollow bearer. There is no equipment beyond the ends of the bearer, nor any equipment above the bearer top between the rails. The depth of the bearers will match that of the standard concrete bearers. Discussion with project suppliers is ongoing regarding the use of half baseplates to secure the stock rails.

Figure 4: Repoint Light actuator bearer.

The switch rail mounting is a cradle design, positively holding the rail in the lateral sense. The cradle design allows for the changing radius and position of the switch rail in all

axes through the motion of the switch. The rail is clamped down into the cradle with allowance made for thermal expansion. The switch rail cradles are an integral part of the “hopper”. This component executes the function provided by the stretcher bar in conventional designs [6], maintaining the open switch rail position. The hopper also transfers the train loads through the locking blocks to the bearer base when the switch is in either the normal or reverse positions. Figure 5a shows the hopper, cams and locking blocks.

Inside each actuator, a cam-hopper mechanism moves the hopper depending on the rotation of two cams. The switch rails are mounted on the hopper, thus are moved to their desired position with the hopper movement, which is governed by the rotation of the cams. It is then the hopper that is lifted and translated by the cams to provide the switching motion. Each cam is operated by a separate motor (two motors per actuator bearer). This feature in the design responds to system requirements, such as maximum weight allowed per railway component, as well as mechanical simplicity. A modular actuator bearer design is desirable for operation and maintenance purposes.

(a)

(b)

Figure 5. (a) Repoint Light hopper, cams and locking blocks. (b) Switch rail and corresponding stock rail on top of one of the actuator bearers.

The motor and cam drive mechanism has evolved from a rack and pinion version [4], through a belt driven example, to the current concept. Switching time is to be approximately two seconds. Cam position sensors are to be fitted to each cam, both to ensure synchronous movement, and to allow recalibration and self-checking following power outage.

A static and dynamic modelling exercise, including the switch rails and bearers, has provided forces and torques at the cams, which in turn is input data for the motor and gear-train selection decisions. In this prototype, off-the-shelf components, sealed gearboxes and bearings will be used. Figure 5b shows one of the switch rails and corresponding stock rail in position on top of one actuator bearer.

2.2 Electrical design within the lineside cabinet

An experienced railway signalling consulting company has been chosen for the design and supply of the lineside cabinet, including signalling interface and power supply. Interfaces have been defined between the supplied cabinet and Loughborough designed equipment to be housed within. The top-level control and the lock/detection sub-system are described in the following sections. Figure 6 gives a rough idea on the complexity of the electrical layout and interfaces.

Figure 6: Repoint electrical systems layout diagram.

A full width location case to BRS-SM431 will be provided at lineside to house power supply, signalling and control systems. All circuitry will be designed to Network Rail codes of practice – Lineside & On Track Equipment Typical Circuits [7]. Local controls are to be placed in a lockable box that can be installed on the outside of the lineside cabinet. These will consist of: a normal/reverse selector switch and a mode change switch to change mode from normal operation to maintenance. Normal and Reverse indications will be fitted.

The following circuits are required for point operation:

- Normal and reverse point operation relays – to be double cut, fed by the normal/reverse rotary switch.
- Latch lock relays.

- A single contactor to isolate the motors.
- A time delay unit (as usually fitted to cut off motor power supply in-case of mechanical jam or limit switch failure) is not required.

The following circuit will be fitted for point detection:

- Detection is fed back to the signalling logic over a two-wire polar circuit from normal and reverse contacts in the lock/detection subsystem. Relays to be single cut. Normal contacts closed when detected in the normal position, Reverse contacts closed when detected in the reverse position.

Power supply to the lineside cabinet is to be 240V 50Hz single phase AC. Transformers and transformer/rectifiers within the lineside cabinet will provide the following:

- 240Vac to the motor controllers.
- 110Vac for lineside cabinet lamps and heating.
- 24Vdc for detection and signalling relay logic and indicator lamps.
- 24Vdc for control electronics power supply.

2.3 Control system

The main objective of the controller is to move the actuator bearers as specified by the signal from the signalling logic block. Figure 7 shows the Repoint Light control architecture.

Figure 7: Repoint light control system top level architecture.

After reading the signal, the Central Processor Unit (CPU) sends the desired position command to the six motor controller units which run the motors. The 'Lock/detection concentrator' block checks the position of the switch rails and locks when the actuation is completed and sends the detection signal to the central processor unit and to the signal logic block. Regarding the control algorithm for each actuator bearer, a command signal is fed to the electrical motors, which is connected to a gear head. The output of the gearhead is connected to the cam through a pinion. Detailed information of this algorithm was presented in [4].

The design of the controller has been carried out in Simulink and the switch panel is modelled in Simpack. The bending of the switch rails has been modelled using Finite Element (FE) analysis in Abaqus and imported into Simpack as flexible bodies. The final co-simulation between Simulink and

Simpack is performed using the SIMAT interface in Simulink environment. Figure 8 shows the co-simulation environment.

Figure 8: Co-simulation between Simpack and Simulink.

The four working modes of the Repoint Light switch are explained as:

- Normal: move the switch rails from reverse position to normal position with the working bearers.
- Reverse: move the switch rails from normal position to reverse position with the working bearers.
- Maintenance mode: in this mode, two tasks can be achieved: (1) Isolation of a faulty bearer and return to normal/reverse working mode and (2) replacement of a faulty bearer with a new one and return to normal/reverse mode.
- Hand wind: isolate the bearers from the power source and open the option for hand wind.

The control logic for each working mode has been developed.

2.4 Signalling consolidation logic

This section describes the Repoint light lock/detection concentration logic development. The fundamental difficulty is differentiating between a genuine mechanical blockage that prevents the switch from completing its motion, and a sensor or detection system fault that indicates a failure despite correct mechanical operation. In cases of mechanical failure, the system should not allow trains to approach. However, in cases of sensor failure, the system should be fault tolerant and allow trains to operate.

In each bearer, there will be two sensors for each of the two switch rails. One sensor detects the rail in its closed (against the stock rail) position, the second sensor detects the switch rail in its open position. Four sensors per bearer and 3 bearers gives a total of twelve sensors. Figure 9 shows an example of the sensor/system arrangement. The three bearers in the Repoint light demonstrator move the two switch rails between the open and closed positions. The lock/detection concentration logic takes inputs from the sensors in the three

bearers and consolidates those inputs to provide an output to the signalling system.

Figure 9: Switch in the normal position, sensor states and bearer states shown for all bearers.

The output from the lock/detection concentration logic will be a set of contacts to confirm the switch is in the normal position and a set of contacts to confirm the switch is in the reverse position. The signalling logic reads these contacts as follows:

Switch condition	Contacts	
	Normal contacts	Reverse contacts
Switch not detected	Open	Open
Switch detected in Reverse position	Open	Closed
Switch in detected normal position	Closed	Open
Fault condition (Switch not detected)	Closed	Closed

Table 1: Signalling logic. Position of contacts.

The logic can be broken down into two steps. The bearer logic takes the signals from the four sensors within an individual bearer and outputs the bearer position. The second part consolidates the information from each bearer into a single output regarding the switch position. To allow a degree of fault tolerance, 2/3 voting will be used for the logic combining information from the 3 bearers, falling back to 2/2 when a fault has been identified in any given bearer. Figure 10 depicts this logic.

Figure 10: Lock/detection system overview.

The four sensors within each bearer can show a total of sixteen combinations. From these sixteen, the bearer will only output a switch “Normal” indication when the Normal (straight) switch rail is closed against the stock rail and the Reverse (curved) switch rail is open. Similarly, the bearer will

only output a switch “Reverse” indication when the Normal (straight) switch rail is open and the Reverse (curved) switch rail is closed against the stock rail. There are two other possible outcomes; the switch is moving between the Normal and Reverse positions, i.e. in Transit, and conditions that can only occur if a Fault occurs, for example, the switch rail is detected in two positions simultaneously, or both switch rails are detected closed simultaneously.

The consolidated output to the signalling must handle the various non-normal and fault conditions that can be identified in the information from the three bearers. When all three bearers do not detect a fault, but do not agree regarding switch position, then some combinations are considered acceptable to confirm Normal or Reverse to the interlocking, and some combinations are considered unsafe. Similarly, when one or even two of the bearers detect a fault condition, it is possible to use the remaining bearer(s) to detect the switch position.

2.5 Switch panel design

As indicated in previous sections, the switch panel is to be CVS using CEN 56 stock rail. This is the design REPW1602 [6] with some modifications. As the switch blade tip position, must be controlled, it has been assumed that the first actuator bearer should be at the bearer 1 position. Based on an even bearer spacing, possible locations for three actuator bearers are: 1-2-3, 1-3-5 and 1-4-7. The Repoint Light architecture does not include conventional stretcher bars. The hopper components take on the role of maintaining correct switch rail lateral position.

Using bearers at positions 1, 2 and 3 would not provide sufficient lateral support to maintain the minimum flangeway throughout the length of the switch panel. With actuator bearers in positions 1, 4 and 7, it would not be possible for the actuator bearer in position 7, acting alone, to lift the switch rail toes sufficiently to pass over the locking blocks at position 1, in case of failure of the other two actuators.

Hence, the remaining configuration, with actuator bearers at positions 1, 3 and 5 is the preferred solution for a switch of this length - a trade-off between having the third actuator bearer sufficiently close to the switch rail toe to lift the position 1 actuator bearer over its locking blocks, and sufficiently far from the toe to provide lateral restraint to the open switch rail. This is a pragmatic design decision, considering the limited number of possible locations for three actuator bearers in the length of a C switch. A rail bending analysis was performed in order to provide bearer position, cam torque and cam length as inputs to the Repoint Light actuator bearer design.

Distance blocks vs switch rail foot

Certain switch panel components require modification from standards such as distance blocks. The distance blocks are bolted through the web of the switch rail and make contact with the web of the closed switch rail to provide lateral

support to the switch rail in the closed position. Figure 11 highlights the distance blocks (in red) on an extract from Network Rail drawing RE/PW/1602 (CVS switch assembly).

Figure 11: Distance blocks (red).

Lifting the switch rail (more than a set distance) will bring the foot of the switch rail into contact with the distance block(s). Studying Network Rail drawings RE/PW/1602 (CVS switch assembly) and RE/PW/1612 (switch distance blocks) together with the rail geometry shows that the gap between the top of the switch rail foot and the bottom of the distance block(s) is 8.48mm.

Modelling of the switch rail bending suggests that contact between the switch rail foot and distance blocks will only occur at the first and second distance blocks. The proposed solution is to machine the underside of the distance blocks sufficiently to allow the switch rail enough space to pass. This will not alter the function of the blocks and is a current topic of discussion with project stakeholders.

3 Test and validation activities

At the end of this phase of the project, there will be a full-scale Repoint Light demonstrator which could be tested in a yard at Loughborough. While many of the engineering goals of the project could be achieved in a non-railway environment, the intention of the project has always been to achieve TRL7: prototype demonstration in an operational environment. However, this is not the end of the Repoint story. There is still a significant activity required to take the Repoint concept to a product; from TRL7 to TRL9. This will require support from collaborators and a significant investment to deliver commercial Repoint product(s). The demonstration of the Repoint track switch, in a railway environment, with a train passing over it, is viewed as essential to the next steps for Repoint.

3.1 Test site selection

The following sub-sections describe some aspects of testing activities, requirements and decisions made by the Loughborough Team.

3.2 Test requirement

To trial the Repoint Light switch on plain line to prove the design is appropriate for mainline use. This would include a minimum number of throws (number to be determined) and vehicle tests (to be determined) to prove the actuator in a

railway environment and that it can withstand traffic. At TRL 7, it will not require repeated cycles with tonnage.

3.3 Review of sites

The Repoint team undertook an exercise to review several possible sites and ranked them based on the following criteria, which were considered the key factors in test site choice: cost, testing ease, access ease, representative test (compared to TfL), impact of successful test outcome, relationship with test site, risk to other activities at test site, control we could exercise over testing, likely influence of test site on design, influence of site on delivery timescale and impact on TRL7 project deliverables. These factors were scored, weighted and ranked. The REPOINT team have reviewed the options and the recommendation is to undertake track testing for TRL 7 at Great Central Railway Loughborough. The benefits are location, ease of installation and costs.

4 Conclusions and future work

The project is part way through developing a full-scale demonstrator. The plan is to have a single actuator bearer under test at Loughborough in May 2018. This will be followed by the remaining 2 actuators bearers, the lineside cabinet and control system by Summer 2018. In Autumn 2018 the full system, including switch panel, will be tested. The final demonstration that will see the switch installed at Quorn on the Great Central Railway is scheduled for late 2018.

Acknowledgements

The Loughborough University Team would like to acknowledge the support of the funding body RSSB (Rail Safety and Standards Board), as well as project stakeholders Network Rail, TfL (Transport for London)/London Underground and companies involved in the development of the Repoint Light prototype.

References

- [1] J. C. Morgan. "British Railway Track", *The Permanent Way Institution*, (2001).
- [2] A. B. Dow. "The Railway: British Track since 1804", *Pen & Sword Transport – Books Ltd*, (2014).
- [3] S. D. Bemment, E. Ebinger, R. M. Goodall, C. P. Ward and R. Dixon. "Rethinking Rail Track Switches for Fault Tolerance and Enhanced Performance". *Journal of the Institution of Mechanical Engineers*, (2016).
- [4] M.L. Sarmiento-Carnevali, T.J. Harrison, S. Dutta, S.D. Bemment, C.P. Ward and R. Dixon. Design, construction, deployment and testing of a full-scale Repoint Light track switch. *Stephenson Conference 2017*, London, UK, (2017).
- [5] Track Design Handbook, NR/SP/TRK/0049 Issue 9, *Network Rail*, (2006).
- [6] Drawing RE/PW/1602, *Network Rail*, (2007).
- [7] Network Rail codes of practice – Lineside & On Track Equipment Typical Circuits.