Design, construction, deployment and testing of a full-scale Repoint Light track switch (I)

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ABSTRACT
A novel track switch actuation method, known as Repoint Light, is under full-scale prototype design phase at Loughborough University. The design concept uses parallel-channel actuation, locking and detection, allowing the switch to continue to function with no loss of performance in the event of a single channel fault. The prototype will be constructed, tested and deployed, including tests with the passage of traffic, upon a functional railway. This paper describes the design and performance challenges faced when introducing the concept into its real operating environment, as well as systems engineering processes followed in the design and considerations regarding reliability, maintainability and performance of the switch.

1 INTRODUCTION
'Repoint Light' is a novel concept for track switching under development at Loughborough University. Through a novel locking arrangement it allows parallel, multi-channel actuation and locking functions, providing a degree of fault tolerance (1-4). This concept is designed to meet the set of functional requirements for track switching solutions, in addition to offering several features that current designs are unable to achieve.

The objective of the Repoint (Phase 3) project is to advance the Repoint Light track switching system from its current status at 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 – albeit low-speed in the first instance.

The project is led by Loughborough University, working in conjunction with Ricardo Rail (engineering partners) and RSSB (project sponsor and funding body). The work is supported by the two major infrastructure custodians, Transport for London (TfL / LU) and Network Rail (NR).

This paper covers details of design and performance challenges faced when introducing the concept into its real operating environment. Section 2 presents track switching background. Section 3 describes current tasks developed for a full-scale track switch construction and future challenges. Section 4 introduces Repoint Light design in detail. Finally, Section 5 contains conclusions.
2 TRACK SWITCH SYSTEM

Railway track switching provides flexibility to a rail network, allowing vehicles to switch between many different routes. A general switch arrangement is shown in Figure 1. 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 blades to the correct position, before again locking them in place. The position of both blades and the integrity of the lock are detected and transmitted. This process normally takes up to 8 seconds. The position of the blades, 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.

Figure 1. Traditional switch layout (3)

Figure 1 shows a track switch layout with sleepers/bearers omitted for clarity. The different components of a track switch system are:

1. Lineside type electro-mechanical actuator featuring integral lock and detection (actuation/locking mechanism); (4-foot type also used);
2. Drive rod and drive stretcher (actuation mechanism);
3. Detection rods (detection mechanism);
4. Switch rail toes;
5. Stretcher bars (actuation mechanism);
6. Switch rails;
7. Stock rails;
8. Common crossing (of given angle);
9. Check rails.

Top-level functional requirements of a switch as defined in (5) are:

1. A track switch shall adequately support and guide all passing vehicles.
2. A track switch shall direct passing vehicles along the path specified by the interlocking.
3. A track switch shall confirm to the interlocking the route vehicles will be directed along, and that all active elements are safe for the vehicle to pass.

Existing track switch systems are the result of the evolution of a single design solution patented by Charles Fox in 1836. The requirements of railway systems have evolved in the intervening period. Track switches currently have a negative impact upon network performance with regards to maintainability, capacity, reliability, and cost.
3 REPOINT LIGHT (PHASE 3) PROJECT

The objective of the Repoint (Phase 3) project is to advance the Repoint Light track switching system from its current status at technology readiness level (TRL) 3-4 to TRL7. Current work can be divided into three main areas:

3.1 Requirements capture
An exhaustive document has been developed to capture applicable and relevant railway switching specifications and regulations from British and European standards, as well as input from relevant stakeholders regarding essential and desired requirements, in order to assure that the proposed novel system specifications are compliant, where possible, to all demands. Development of Repoint Light will be compliant with external interfaces such as signalling systems, permanent way, environmental regulations, among other requirements of relevance.

3.2 High-level and detailed design
Section 4 below summarizes different design tasks undertaken during the first months of the project. There are still some design challenges to be tackled before the full-scale prototype construction stage, but many track switching system desired requirements are already achieved with Repoint Light:

- System reliability and maintainability is improved over existing point systems.
- The switch can unambiguously move to a new route when commanded, due to the multiplicity of actuators.
- The concept can switch in a shorter time as the actuators do not have to be sized to overcome the variable friction on plates, and instead store energy in a spring (the rails) which can be used to assist in the motion for the second half of the throw.
- The locking elements of each bearer ensure the switch remains locked on a single route for traffic until commanded otherwise. The switch is even less likely to move under the mass of a train, as the mass acts downwards and thus further locks the switch.

3.3 Future work: Repoint Light full-scale track switch construction, deployment and testing
The project is currently moving towards the end of the design phase (early 2017). Design activities such as control algorithm improvement are still on-going work. A SIMPACK system model, with rail bending capabilities, has been developed to aid this task. Construction of the full-scale track switch will be started in May 2017, followed by several months of testing/validation/verification activities. By early 2018, the prototype will be deployed and tested, both the operation of the switch and passage of traffic, upon a functional railway.

4 REPOINT LIGHT DESIGN PHASE

In the Repoint approach, a bank of in-bearer type electro-mechanical actuators, featuring integral passive locking elements with detection system, allows multi-channel actuation to move the switch rails from one position to the desired switching position (Figure 2). For the Repoint Light design, the Repoint actuators covered in (1-4) have been adapted to function with an existing switch rail arrangement. These actuators can be isolated individually when faulty, and the switch operates using the remaining channels until repair is possible, without a reduction in system performance.
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 3).

4.1 Repoint Light actuator bearer

There are many ways to provide drive inside the actuator units. A simple method utilising a rack, two cams and followers has been demonstrated in the laboratory. The actuation elements are enclosed in sealed, line-replaceable units (LRU) (Figure 4). The Repoint Light actuator consists of: electric motor, gear-head, rack and pinion, cam, hopper and switch rails. A command signal is fed to the electric motor depending on the desired movement of the switch rails. The purpose of the motor, along with the gearhead connected to it, is to move the actuator rod, which is the rack in this mechanism, to the desired position.

The rack is then connected to pinions which are mounted on the cams. A cam-hopper mechanism moves it depending on the rotation of the pinion. A half rotation of the cam-pinion makes the hopper move from one position to the other position, i.e., switching the position of the rails, which are fixed on the hopper. Thus, the switch rails are moved to their desired position by the hopper movement.

The hopper is locked in the lowered position within grooves which prevent it from moving laterally. For this reason, during the switching operation, the hopper is first lifted from the grooves, i.e., unlocked from the locked position, then moved to the desired position and then placed on the grooves, i.e., locked again. As there are no significant uplift forces present compared to other axes, and indeed a significant net downward force from the spring stiffness and mass of the rails, they are unable to be unlocked without the action of one of the bearers, which is especially true when a train is present. This is referred to as 'passive locking'.
The movement of the hopper is a semi-circular path. The motor and gearbox arrangement is back-drivable, in order that, should a failure occur between positions, the mass and spring force of the lifted rail will cause the switch to drop back into one of the safe, lowered and passively locked positions.

The control schematic of the system is shown in Figure 5. The mathematical model of each part has been developed following first principles. A control algorithm has been then developed for the motion of the rack. In the present controller design, an outer loop position controller and an inner loop motor velocity controller were chosen. The controllers were selected as PI controllers, which perform the desired motion effectively. Improvement in the controller design using inner loop current control will be undertaken for better performance. The algorithm of the controller is shown in Figure 6.

The mechanism of the driveline from the electrical motor to the cam is adaptable and can be varied from the current design. The present mechanism consists of a rack and pinion arrangement. Possible alternatives such as a belt or shaft drive could increase the system efficiency and lower the overall mass. These do not alter the basic ‘lift and drop’ philosophy of moving the switch rails.

4.2 Actuator bearer positions
This analysis is based on the CVS switch layout described by corresponding Network Rail drawings (6), which is the candidate switch size for the trial. A representation of this drawing is shown in Figure 7. It has been assumed that the bearer spacing/centreline positions will not be changed. This allows maximum
commonality with existing switch assemblies and will allow tamping through the switch panel.

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.

![Figure 7. CVS switch simplified representation](image)

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, which will be described in detail as part of future publications.

4.2.1 Static cam torque
Cam torque has been calculated using static bending results from finite element analysis of the switch rails (Catia and ABAQUS FEA). Forces are resolved tangential to the cam rotation and converted to torque (Figure 8). This provides a first pass analysis of the static forces required to bend the switch rail toe to the desired location(s). The maximum force condition for each actuator-bearer occurs when that one bearer is operating the switch without assistance from the other two units. Models of the curved and straight switch rails were prepared in CAD based on Network Rail drawings (7) and (8). The switch rail neutral position in the transverse horizontal (y) direction was assumed to be in the centre of the switch rail travel. Switch toe opening was set to 115mm, and therefore the cam length is 57.5mm. Gravity acting on the mass of the switch rails is included. The mass of the hoppers and associated rail fastenings is not included at this stage. Forces in the vertical (z)
and transverse horizontal (y) directions were calculated using finite element analysis to bend the switch rail to positions on the 57.5mm radius semi-circular arc. The same radius was used at actuator bearers 1 and 5.

Figure 8. Definition of terms relating to force directions

Maximum forces were seen for bending the curved switch using only the actuator at position 5. The vertical bending force is approximately 3 times the horizontal bending force; however, the weight of the switch rails is the dominant factor and increases the total vertical force to 10 times the horizontal force. Vertical forces are greatest in the centre of the travel; horizontal forces are greatest at the ends of the travel. These horizontal and vertical forces were then resolved tangential to the arc of the cam travel and multiplied by cam length to give torque about the cam axis. The torques are calculated assuming a single equivalent cam. Due to the semi-circular motion of the cam, the tangential component of the force that the motor must overcome is significantly lower than the axial force on the cam. Figure 9 shows the torque curves using actuator bearers 1 and 5 acting singly to bend the switch rails. For this static case, peak torque occurs for the actuator bearer in position 5 around 20° actuator travel and is approximately 447Nm.

Figure 9. Cam torque profile for switch rail bending. 57.5mm arc at each actuator bearer location.

4.2.2 Dynamic cam torque

The static analysis above considers only the force required to hold the rails in a position on the cam travel arc. A dynamic analysis allows the addition of the forces required to accelerate and move the mass of the rails and hopper. A model of the cam and hopper arrangement was constructed in MATLAB/Simulink®. The results of the static analysis were used as a force input 'lookup table' to the dynamic model as the hopper traversed the arc. Switching time is 0.47 seconds, an extremely fast movement to generate a worst-case scenario.

Figure 10 shows the increase in torque from the baseline static case (this is the same curve as shown in black in Figure 9). Peak torque increases from 221Nm in the static case to 274Nm when including only the rail mass, and 286.9Nm when
including 25Kg for the mass of the hopper at position 1. The cam position at peak torque is shifted from approximately 20° to 30°.

Figure 10. Cam torque profile for switch rail bending (Bearer 1). Comparison of static and dynamic torque.

5 CONCLUSIONS

This paper introduced a novel track switching concept, Repoint Light, developed at Loughborough University, as well as different design stage tasks. Static and dynamic modelling of simultaneous operation of three actuators and control algorithm improvement are on-going design activities. Construction of the full-scale track switch will be started in May 2017, followed by several months of testing/validation/verification activities. A full-scale demonstrator operating in real rail environment will be delivered during 2018.

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