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Development and Testing of a Full-Scale Repoint Track Switch System

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Abstract

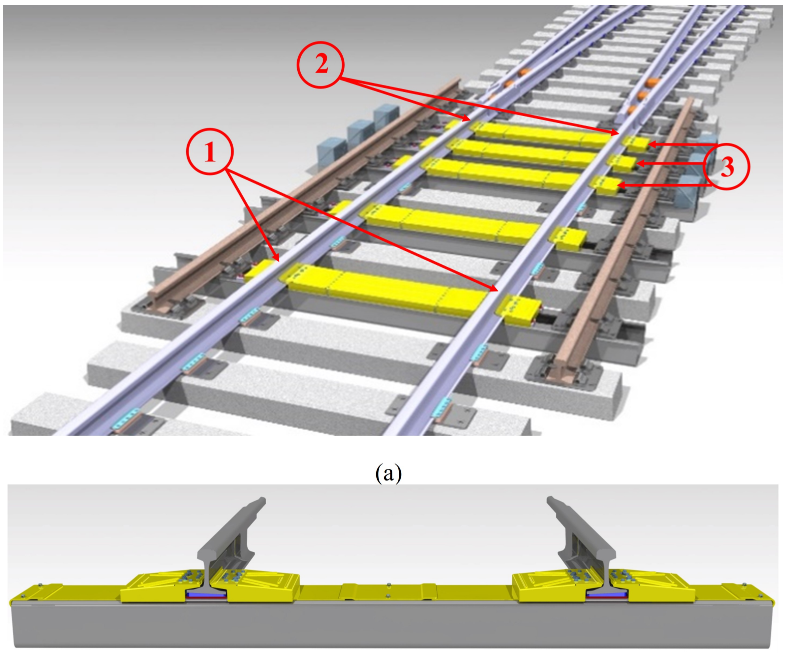
REPOINT is an innovative track switch system with a semicircular path motion mechanism, which allows passive locking and redundancy of actuation. Central to this study is the development and testing of a prototype system, which utilizes a single active bearer configuration tested at a 1:1 scale in the laboratory. The prototype embodies an enclosed active bearer equipped with dual servo motors, custom gearboxes and cams, sensors, and a passive locking mechanism, as well as a cascaded closed-loop control system, ensuring robust performance and high adaptability to various track and switch types. Testing results confirm the REPOINT system's operational efficacy, demonstrating rapid switching times and precise control within stringent railway standards. Future work will focus on scaling the system by adding two more active bearers to improve redundancy, test fault tolerance and integrate fault detection and condition monitoring strategies to bolster robustness. Through ongoing research and development, the REPOINT system aims to provide a scalable, reliable solution to modern rail network challenges.

Keywords: REPOINT switch, railway, track switch, prototype, control design, cascaded closed loop.

1 Introduction

In modern railway systems, track switch systems play a crucial role by not only providing flexible routes for trains but also by directly affecting the operational efficiency and reliability of the entire railway network. Conventional track switch systems are vital; however, their limitations are becoming increasingly apparent due to growing transport demands and complex operating environments. To address these challenges, REPOINT, an innovative track switch system, has been developed [1,2]. The overall project is part of the In2Track3 programme, which aimed to increase the reliability and fault tolerance of the system through the introduction of Redundant Engineering Points. The project was overseen by Network Rail and was a collaborative effort with the University of Birmingham and the Rail Safety and Standards Board. The new system incorporates an innovative track switch layout, actuation, and passive locking mechanisms, providing multi-channel actuation capability and a high degree of fault tolerance [3].

Related research and completed work on REPOINT includes 1) verification of the stub switch mechanical structure [4,5]; 2) REPOINT modelling and developing laboratory demonstrator [6,7,8]; 3) REPOINT Light field testing [9,10]. The REPOINT design concept has been applied to a conventional CVS switch panel (Figure 1).



(b)

Figure 1: (a) Full REPOINT switch layout with two-route stub switch, 1. Stock rails, 2. Movable stub rail (at switch joint), 3. Three active bearers with actuators, passive locking and detection system. (b) Front view of one active bearer with mounted stub rail-joint.

This paper is organized as follows: Section 2 describes the working principles and key technologies of the REPOINT system. Section 3 builds a prototype and presents the test results. Each section highlights the innovation and practical value of the REPOINT technology. The final section summarizes the results of this study and discusses possible directions for future work.

2 REPOINT Development

The REPOINT system development focuses on three key subsystems: 1) Active bearer and passive locking system; 2) Electrical system; 3) Control and detection system. This prototype is built based on a CEN60 track and a C-Switch geometry switch panel. The design is based on relevant railway track switch specifications and regulations, including standards from the UK and Europe, and the expectations and needs of stakeholders.

2.1 Active bearer and locking system

Since the inception of the REPOINT concept, the core of the design has been a purely rotary drive, due to the ability to adapt well to the arced motion profile of the rail. The designed switch system contains three active bearers, as shown in Figure 1(a). Each active bearer, located at different positions, drives a pair of stub switch rails using dual actuators, including motors and the corresponding mechanical transmissions, all operating on the same basic principle of motion.

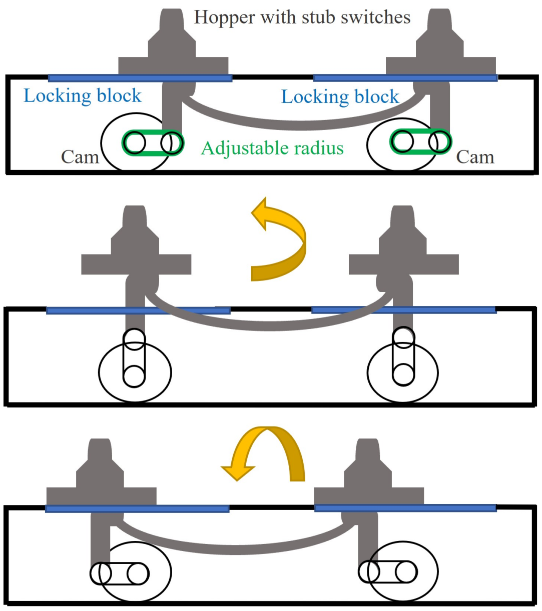


Figure 2: REPOINT stub switch movement principle.

The basic principle, shown in Figure 2 (motion top to bottom), involves an electric servomotor transmitting rotational power to the hopper through the rotation of the cam. The stub switch is mounted on the hopper, and the hoppers on both sides are connected by the central regulator and floating mechanism. All actuation parts and connecting mechanisms are covered and fully enclosed in the active bearer. Driven by the electric motor, the hoppers (with stub switches) can rotate from 0° to 180° (from right to left), thus completing the actuation operation. The prototype uses a Schneider electric motor with a customized reduction gearbox, providing an overall maximum output of 184Nm, demonstrating triple redundancy and track bending force considerations.

The active bearer uses a hollow metal bearer to minimize external environmental impacts and carry the load of trains. The system specifically accounts for the autonomous adjustment of the radius of the cam (or hopper or stub switch) via a drive stepper motor and a rolling plate adjuster, using worm gearing for maximum leverage. This adjustability (from 50 mm to 66 mm) accommodates the different needs of the active bearers arranged in parallel.

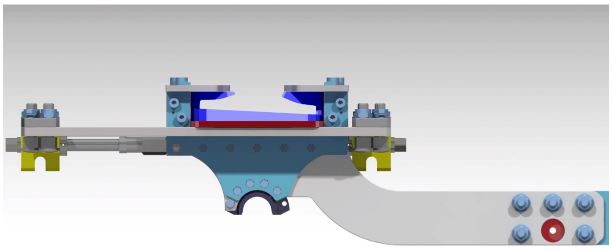
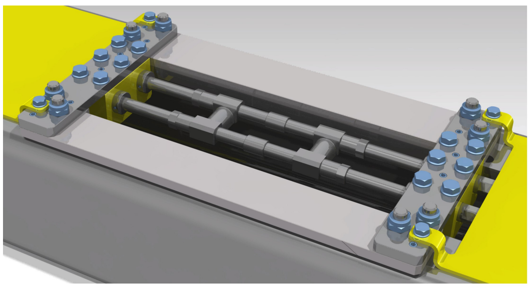
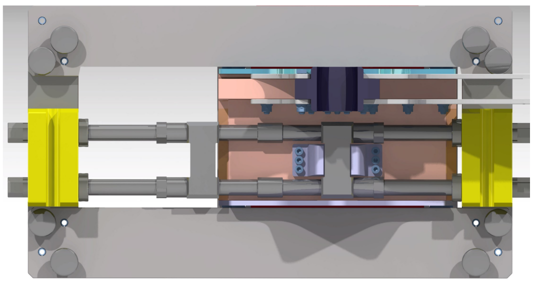


Figure 3: Left hopper main plates and rail bracket.



(a)



(b)

Figure 4: (a) Lower locking blocks (above view), (b) Locking interface (below).

The key components of the hopper system are manufactured from sheet steel attached directly to the rail bracket (Figure 3) and pass through the bearer well. The connection structure consists of a buffer system, which maintains a high degree of track bending stability while allowing for a certain range of track gauge fluctuations when the hopper plate moves down from the rail bracket. An important feature is the passive locking system, which prevents accidental rail movement by relying on gravity and the mass of the train. Passive locking components (Figure 4) include an upper locking block on the hopper and lower locking blocks on threaded rods, which are fixed to the bearer. The locking tube nut secures these elements and can be adjusted to accommodate different actuator radii.

2.2 Electrical systems

The electrical cabinet design accommodates power, signalling, and control systems, ensuring stable operation under various railway conditions to ensure that all components can work stably in different environments. To comply with Network Rail's specification requirements, all circuits are designed according to the typical circuits of the wayside and track equipment. Figure 5 shows the internal configuration of the electrical cabinet, as well as the front panel and block diagram windows of the controller code developed using NI-LabVIEW software. Each active bearer contains two drivers for driving two servomotors, which are adapted to the selected Schneider motors. The NI central processor (Compact RIO-9056) is selected for its adaptability to high shock and vibration environments configured with necessary analogue and digital modules.

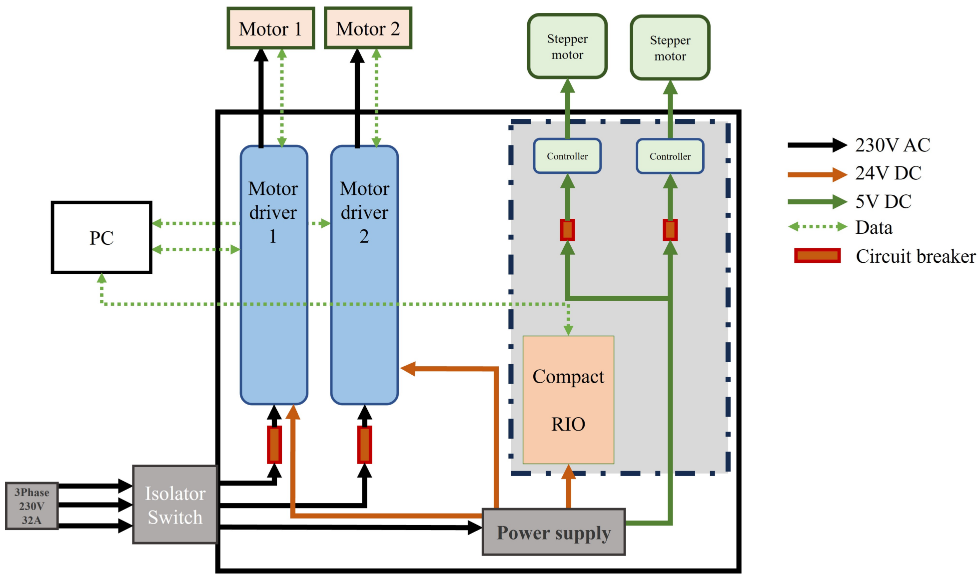


Figure 5: REPOINT electrical system layout.

The following are the power and signal configurations of the electrical box: 1) 240V 32A three-phase AC power support for the cabinet, and as the power supply for the servomotors; 2) 24VDC and 5VDC power supply for the rest of the central controller, detection sensors, indicators and some other electronic equipment; 3) Necessary isolator switches, current breakers are also equipped to ensure safety.

2.3 Control and detection systems

When developing the REPOINT control and detection systems, an important requirement is the synchronous movement of actuator motors to ensure correct switch operation. The control system is designed for user needs and ease of maintenance, using uniform control algorithms and gain settings across all actuators for consistency and efficiency. Based on the NI cRIO hardware platform, the system manages automated conversion operations, monitors status, performs error detection, and communicates with subsystems, including detection systems. It also supports manual control, failure mode, and maintenance mode management. Key aspects of the control system design include:

1. Automated normal and reverse switch: The system automatically completes track switching from normal to reverse and vice versa.

2. Manual operation: Allows precise positioning and switching for special situations or maintenance.

3. Failure and emergency maintenance mode: Quickly switches to safety mode in case of failure to protect equipment and operators.

4. Safety limit system: Ensures the system does not exceed the operating range or cause danger.

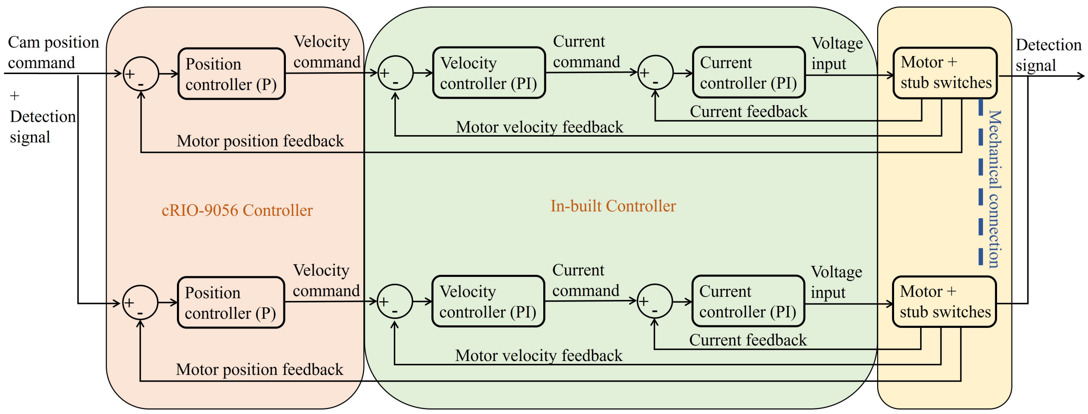


Figure 6: REPOINT control system structure for a single active bearer.

The control loop of each active bearer contains two motors managed through a triple-cascaded control loop: an inner-loop motor current controller, a middle-loop motor speed controller, and an outer-loop position controller. The structure is shown in Figure 6. The inner and middle loops use proportional-integral (PI) control, while the outer loop uses proportional (P) control, achieving zero steady-state error due to the inherent integral action. The control system limits the maximum current for safety and reliability. The switching time is required within 7 seconds to comply with

British track switch specifications, and the maximum permissible overshoot is set at 2° to prevent over-rotation of cams. For each active bearer, the control system uses the desired cam angle as the command position, converting motor encoder signals to cam angles (1 revolution of motor = 18 degrees of cam).

Each active bearer has two detection sensors for the stub switch: one for the closed position and one for the open position. The output of the centralized detection logic confirms the switch position using a 2/3 voting mechanism, reverting to 2/2 when a fault is detected, enhancing system reliability. Dual control logic and fault detection strategies ensure safe and reliable long-term operation, with the NI system interfacing with detection sensors and the user interface to monitor power and communication, triggering alarms and operations as needed.

3 Experimental Setup and Results

In this preliminary test, we construct a prototype REPOINT with one single active bearer. The main components include a fully enclosed active bearer, stub switches, fixed stub switches, a standard bearer, movable hoppers and an active bearer cover as shown and labelled in Figure 7. The system workflow begins when detection sensors record the switch positions. Two cams, driven by motors within the active bearer, move the hoppers along a semicircular path. The hoppers lift from the locking blocks and rotate 180°, then fall onto the opposite locking blocks, achieving passive locking and preventing horizontal movement. The detection sensors then indicate the switch condition, thus completing the switching operation.

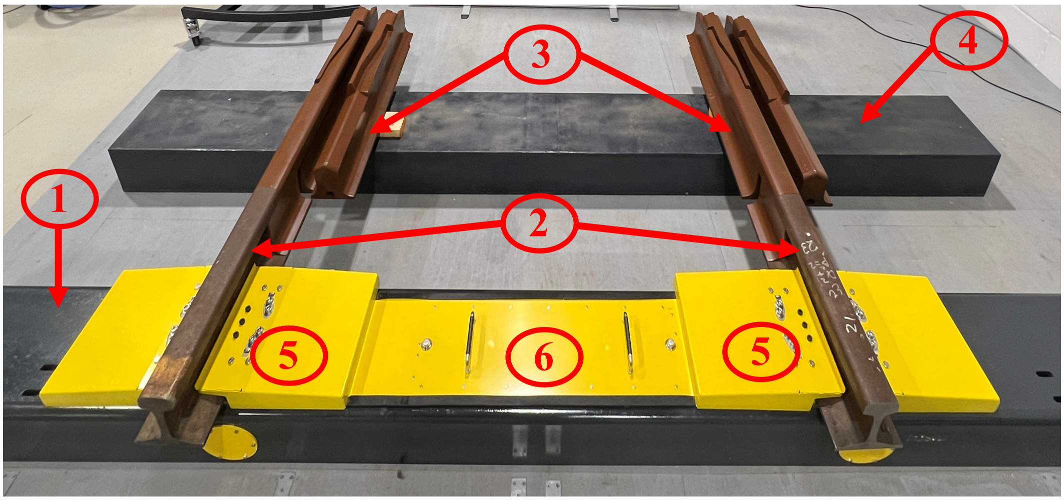


Figure 7: Diagram of the prototype switch: 1. fully enclosed active bearer, 2. stub switches, 3. fixed stub switches, 4. standard bearer, 5. movable hoppers, 6. active bearer cover.

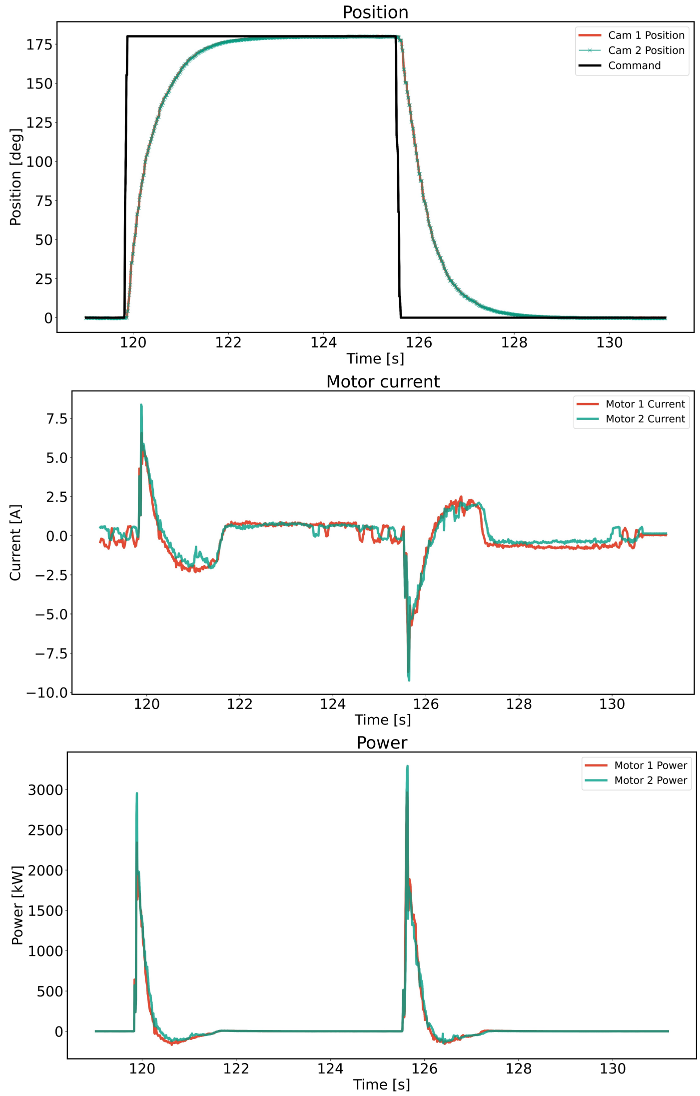


Figure 8: Experimental results for cam position, current and mechanical power curves.

The angle control strategy and motor speed adjustments are managed by the motor drives, with PI gains downloaded to the motor drive hardware. The outer loop position control is programmed in NI-LabVIEW and deployed on the cRIO-9056 embedded controller.

Figure 8 illustrates the system's transient performance, showing the cam angle, current output and mechanical power curves. The cam angle graph demonstrates synchronized cam rotation with a smooth transition from 0° to 180°. The closed-loop system's response time is about 2 seconds, highly below the 7-second requirement, with no overshoot or steady-state error. Each motor's maximum input current is under 8A, meeting the rated requirements. Notably, motor current changes direction during the transient response until reaching a steady state due to the PI control method. Minor discrepancies in motor performance may be due to mechanical alignment and manufacturing tolerances. The mechanical power curves are generated by using the torque constant of the servo motor (BMH1002T02A1A from Schneider Electric) is 0.72 Nm/A, which indicates that there is no significant difference in the total mechanical power between the two motors, suggesting that both motors are subjected to almost identical loads.

4 Conclusions and Contributions

This paper has summarised the development of the new track switch system demonstrator from three major aspects, focusing on the prototype's design, construction, and performance testing in a lab environment. The system uses three electromechanical actuator bearers and innovative movement methods to achieve fault tolerance in railroad switches, significantly enhancing reliability and usability, and being adaptable to various types of switches and tracks.

This is the first complete 1:1 scale test of the REPOINT system prototype, although it only includes one active bearer. However, this not only verifies its feasibility for practical applications but also symbolizes a critical transition from theoretical research and small-scale laboratory testing to full-scale application, elevating the Technology Readiness Level (TRL) from 3-4 to 5-6. The experiment demonstrated the system's operational efficiency, rapid response time, and high precision control capabilities, all conforming to strict railway industry standards.

Future research will focus on expanding the system configuration by increasing the number of active bearers to enhance redundancy and reliability. Additionally, advanced fault detection and condition monitoring strategies will be explored to improve adaptability and stability in complex environments. Through continuous technological innovation and research, the aim is to provide long-term, sustainable support for global railway switching reliability and efficiency.

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