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Rail Switching Device for Turnout using Electrohydraulic Actuator and its Performance Tests

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Abstract

This study aims to develop a prototype of a new switching device of switch rails with a focus on labor-saving for the maintenance of turnouts. Initially, the authors designed and produced the switching device using the electrohydraulic actuator installed in bearer, which can control and monitor the displacements and switching forces of switch rails. Subsequently, a series of performance validation tests were conducted. As a result, we confirmed that the device satisfies the concepts and can operate the switch rails stably monitoring the switching forces and displacements of rails.

Keywords: rail switching device, turnout, electrohydraulic actuator, switch rails, bearer performance test, water resistance, stability under running vehicle

1 Introduction

The purpose of this study is to develop a prototype of a new switching device for switch rails, designed to save the turnout maintenance labor. Turnouts are the track structures that divide railway tracks into two or more directions and switches the train's direction by moving the switch rails. In Japan, the Electric point machines, as shown in Figure1, are commonly used to move switch rails of turnouts. These machines can switch the rails using electricity as a power source, mechanically lock the rails, and verify the locking conditions or opening directions of turnouts. The NS type and TS type electric point machines widely used in Japan have demonstrated reliability due to their long history of achievements. However, these machines have a disadvantage in that filling and tamping of ballast are insufficient due to a switch rod or stretcher bars. Additionally, a significant amount of human labor is consumed for routine inspections and repair works of the turnouts. Therefore, further reduction in maintenance labor is necessary. Recently, related to the reduction in maintenance work, there are developments of switching devices of a different form than conventional mechanisms [1], [2], [3].

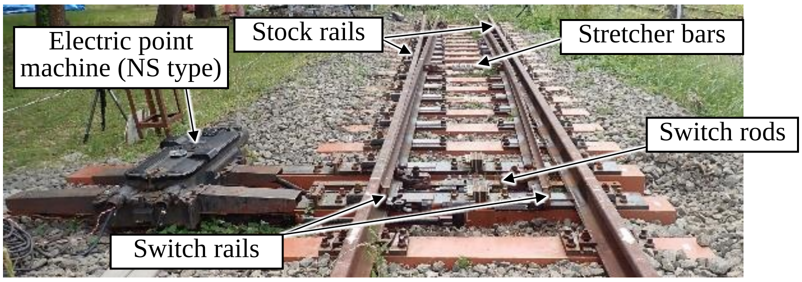


Figure 1: Components of switch panel and a conventional electric point machine.

This study aims to develop a new switching device for switch rails with a focus on labor-saving for turnout maintenance. Initially, we designed and produced the switching device using an electrohydraulic actuator installed in bearer, which can control and monitor the displacements and switching forces of switch rails. Subsequently, a series of performance validation tests were conducted.

2 Prototype of switching device installed in bearer

The author designed and manufactured a prototype of a switching device installed in a bearer which can control and monitor the displacements and switching forces of switch rails using an electrohydraulic actuator.

2.1 Concepts and designs of switching device

The switching device is designed based on the following concepts:

(a) The device can be installed in a bearer.

(b) The device can control and monitor the displacements and switching forces of switch rails.

(c) The device can be removed without dismantling.

(d) The device is compatible with existing electric point machines.

(e) The device has performance equal to or greater than existing electric point machines.

Concept (a) aims to enable the filling and tamping of ballast, eliminating the switch rod and stretcher bars used in existing electric point machines by installing the switching device inside a bearer. Concept (b) aims to save labor in the inspection of the gaps between switch rails and stock rails and to detect and prevent accidents caused by unswitchable conditions. Concept (c) is designed to facilitate easy replacement, anticipating the device's overhaul every few years. Concept (d) allows for application to existing turnouts, aiming for widespread adoption. Concept (e) aims to ensure performance and safety equal to or greater than existing electric point machines in terms of rail switching force, locking force, durability, insulation, water resistance.

Based on the concepts outlined above, we designed the switching device installed in the bearer. Figure 2 illustrates the composition of the switching device and bearer. The device is improved based on the devices previously designed by the authors [4] and is composed of an electrohydraulic cylinder, a servo motor, a servo amplifier, a hydraulic pump, sub lock device, programmable logic controller (PLC), an oil tank, pressure gauges and displacement meters.

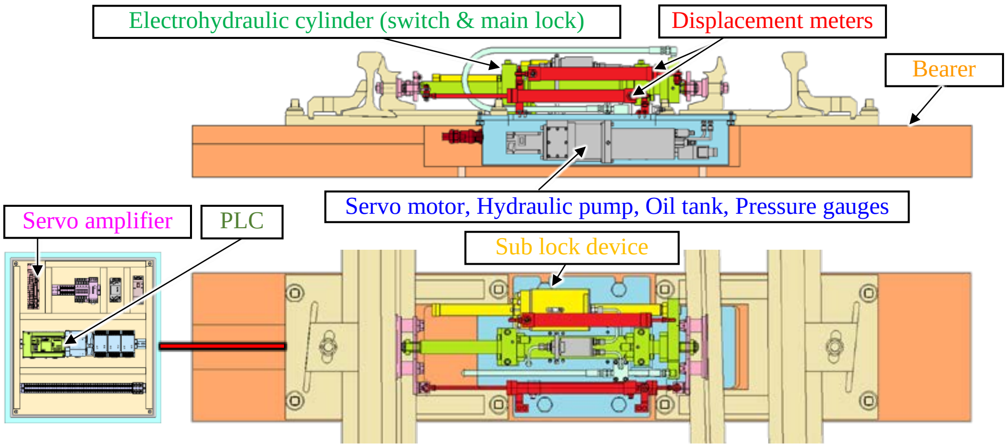


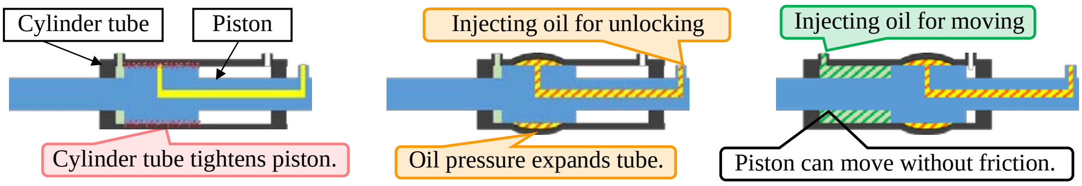
Figure 2: Composition of the switching device and bearer.

The cylinder of the device is selected to meet the specifications shown in Table 1. The switching force and time are determined based on the performance of the existing electric point machines. The locking force is determined based on the design value of lateral loads from outside the gauge, as specified in the Japanese standard for railway structures [5]. Additionally, the cylinder stroke length is determined for use in standard turnouts with a track gauge of 1067mm.

Specifications	Values
Switching force	$\geq$ 5kN
Locking force	$\geq$ 15kN
Cylinder stroke length	$\geq$ 165mm
Switching time	$\leq$ 7 seconds

Table 1: Specifications of cylinder.

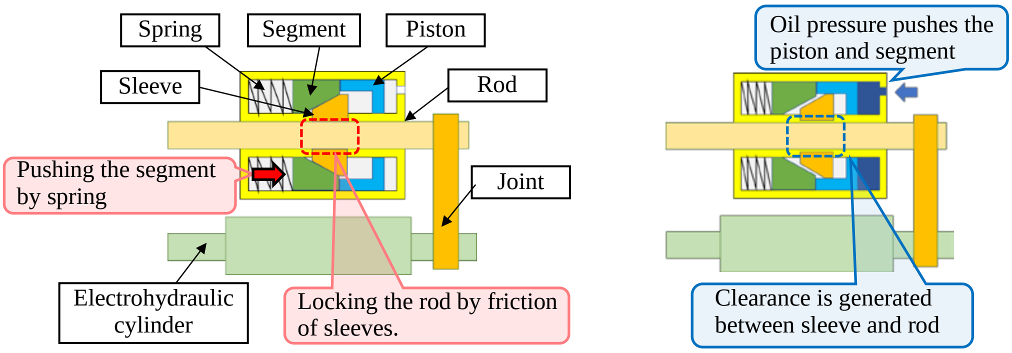
The switching mechanism utilizes an electrohydraulic actuator operated by a servo motor, which drives the pump and operates the cylinder. Figure 3 illustrates the operational mechanism of the cylinder. When the switch rails are stationary, the cylinder tube tightens the piston, locking the position through friction. During the movement of the switch rails, the piston is unlocked by expanding the cylinder tube through hydraulic pressure from the inside the piston. The absence of hydraulic pressure in the hydraulic oil results in a locked state. Therefore, in abnormal situations such as power outages, the locking of this actuator will act on the side of safety.



(a) Locking (b) Unlocking (c) Moving

Figure 3: Operational mechanism of electrohydraulic cylinder (switch and main lock).

The switching device is equipped with a secondary locking mechanism provided by the sub lock device, in case of a failure in the main locking by the previously mentioned electrohydraulic cylinder. Figure 4 illustrates the locking mechanism of the sub lock device. The sub lock device is composed of a spring, segment, sleeve, piston and is connected to the electrohydraulic cylinder by the joint part. The sub lock device operates using hydraulic pressure, similar to the electrohydraulic cylinder. During locking, the internal spring pushes the segment against sleeve, creating friction between the sleeve and piston. On the other hand, during unlocking, oil pressure pushes the piston, generating clearance between the sleeve and rod. The locking force specification of the sub lock device is 15kN, identical to that of the electrohydraulic cylinder.



(a) Looking (b) Unlocking

Figure 4: Locking mechanism of sub lock device.

Displacement meters and pressure gauges are installed to monitor the position and pressure of the cylinder, enabling control based on the output values of the displacement meters and pressure gauges. Displacement meters can measure the positions of the left and right switch rails with a fixed body on the bearer as the reference point. Pressure gauges can measure the hydraulic pressure when each switch rail is switched to the right and the left.

Figure 5 illustrates the structure of the joints between the cylinder and switch rails. The cylinder is connected to the switch rails through joint components, bolts and insulators. This structure is designed to follow the arcuate motion when the rails switch. Additionally, it is designed to transfer lateral train loads from the inner to the outer side of the gauges without resistance, directing them to the stock rails and rail braces.

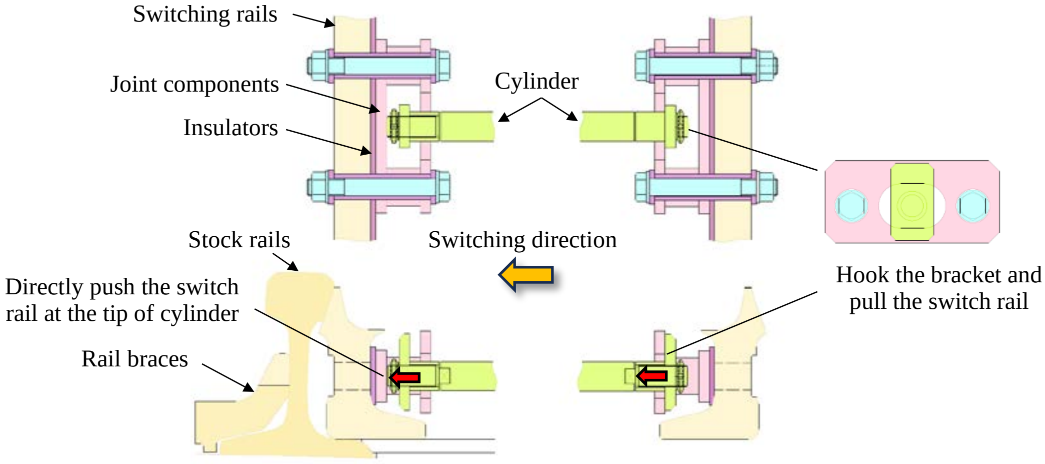


Figure 5: Structure of the joints between cylinder and switch rails.

The bearer is formed using fiber-reinforced urethane that satisfies the performance specified in the Japanese Industrial Standards JIS E1203 [6] and has a concave shape to enclose the switching device, as shown in Figure 6. The length and thickness of the bearer are the same as those specified for conventional sleeper in JIS E1203. The bearer's width is set at 400mm, considering the insertion length into the tool under the bearer for ballast tamping.

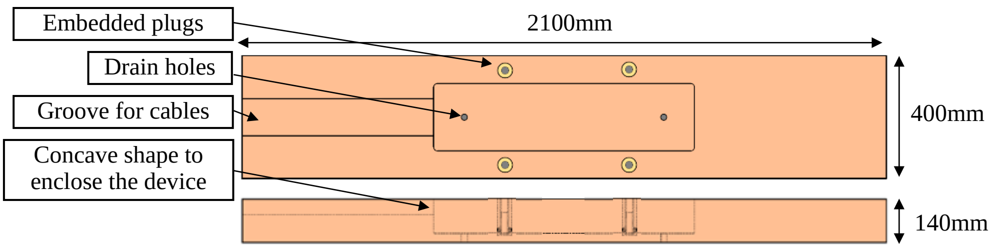


Figure 6: Bearer for installing the switching device.

2.2 Manufacture of switching device and bearer

As shown in Figure 7 and Figure 8, we manufactured the switching device and bearer based on the design mentioned above. Table 2 shows the specifications of the device.

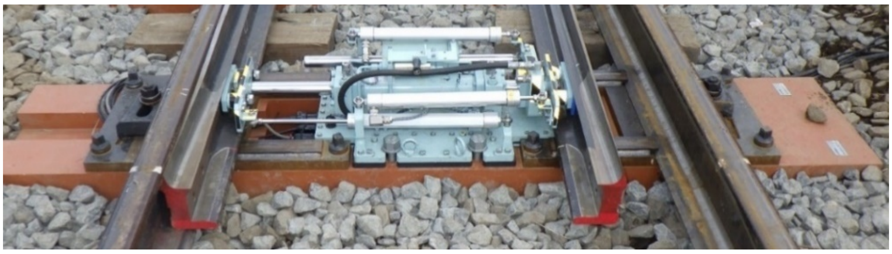


Figure 7: Manufactured rail switching device installed in bearer.

(a) Main body (b) Control box (c) Bearer

Figure 8: The main body, control box and bearer.

Specifications	Values
Power supply	AC 105V
Size of main body (length, side, height)	800mm, 320mm, 380mm
Weight of main body	110kg
Size of control box (height, width, depth)	1000mm, 700mm, 300mm
Weight of control box	60kg

Table 2: Specifications of device.

3 Performance test

We performed a series of tests to verify the performance of the device. Table 3 shows the performance items, test methods and their respective target values. The tests indicated in the table conform to the testing methods specified in the Japanese Industrial Standards [7], [8], [9] for existing electric point machines. Target value of the cycles of continuous switching test is determined with reference to JIS E3010 [10]. Additionally, the bending strength of the bearer is verified through the bending test [11], which is not further discussed in this paper.

Performance items	Tests	Target values
Switching force	Measurements of switching force	≥ 5kN
Locking force	Measurements of locking force	≥ 15kN
Water resistance	Water spray test JIS E3017 [7]	No abnormality in movement
	Water immersion test JIS E3017 [7]	No flooding into device
Workable limit temperature	Low temperature test JIS E3019 [8]	-20°C to 60°C
	High temperature test JIS E3019 [8]	
	Temperature cycle test JIS E3020 [9]	
Durability against continuous motion	Continuous switching test	≥ 200,000 cycles
Stability under vehicle running	Vehicle running test	No abnormality in movement

Table 3: Performance tests of switching device.

3.1 Measurements of switching force and locking force

The measurements of switching force were conducted as shown in Figure 9. Switching force was applied to the stock rail through the switching device installed in bearer, and it was measured using a load cell installed between the cylinder's tip and the stock rail. As a result, the maximum value of the measurement was 8.9kN, confirming that it exceeds the target value of 5kN for the switching force.

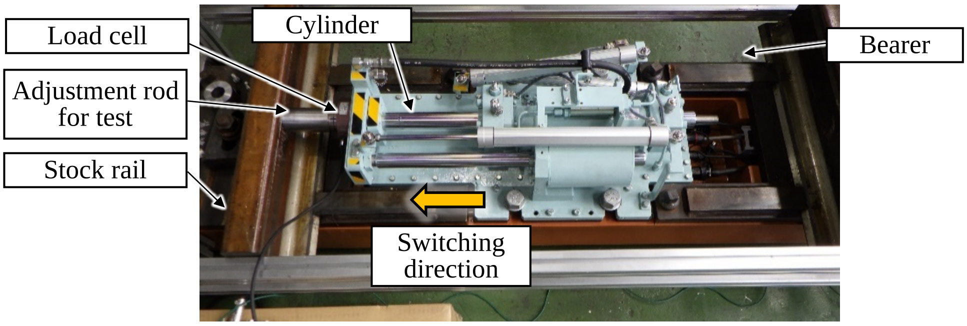


Figure 9: Measurements of switching force.

The measurements of locking force were carried out. As shown in Figure 10, a hydraulic jack installed between the stock rail and the cylinder was utilized to apply a load up to the target value of 15kN, and the displacement of the cylinder was measured using a dial gauge. As a result, the displacement of the cylinder was not observed, and the device confirmed the locking force exceeding the targeted 15kN.

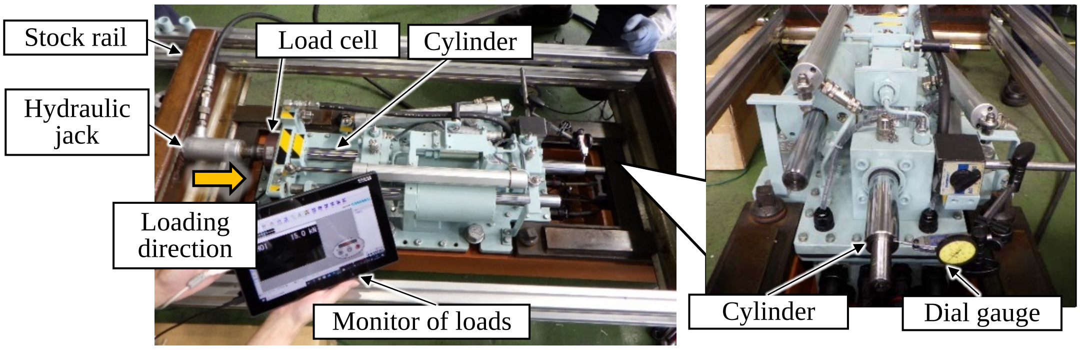


Figure 10: Measurements of locking force.

3.2 Water spray test and water immersion test

In order to confirm the water resistance, water spray test and water immersion test was carried out based on JIS E 3017, which details the waterproof test methods for railway signalling systems. Figure 11 shows the situation of the water spray test. In this test, water was sprayed onto the switching device installed in bearer from a sprinkler nozzle located 1300mm away from the device, at a 60 degrees angle and at a rate of 10mm/min. Spraying was conducted from each of the four directions for 10 minutes. After the spraying, the switching device was activated, and its normal operation was confirmed.

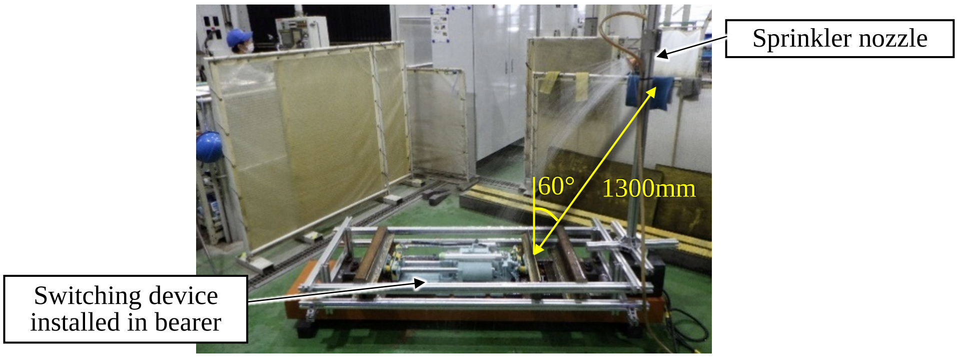
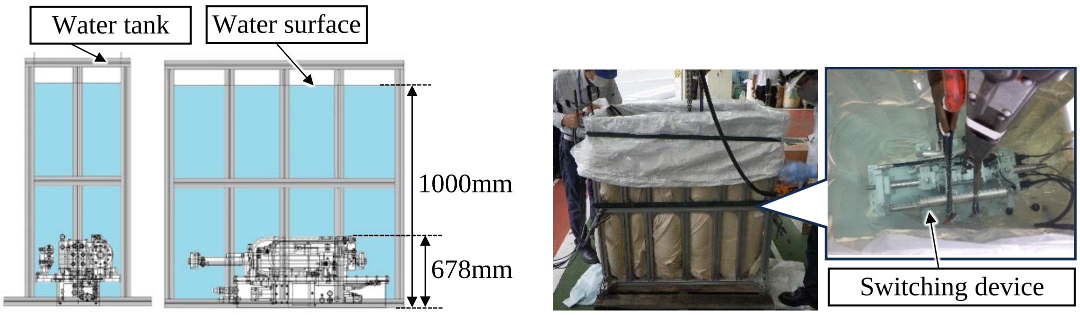


Figure 11: Water spray test.

Figure 12 shows the situation of the water immersion test. In this test, the switching device was submerged underwater, with the device positioned at least 150mm below the water surface at its top and at least 1000mm below at its bottom, and kept in this state for 30 minutes. After 30 minutes, the switching device was lifted from underwater, and the internal components were disassembled as shown in Figure 13. As a result, the invasion of water into the device was not observed and the waterproof performance rated at IPX7 was confirmed.



(a) Arrangement of device (b) Situation of test

Figure 12: Water immersion test.

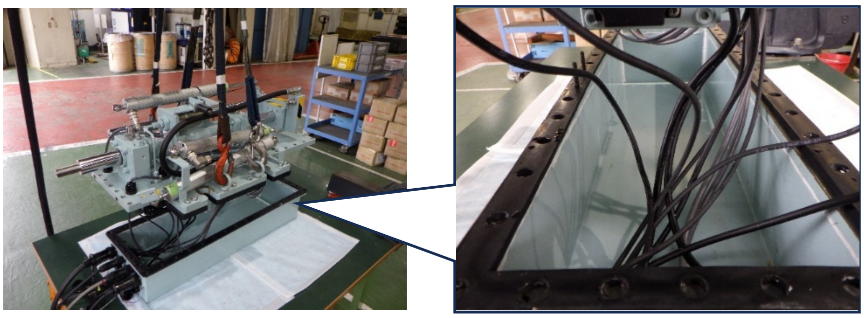


Figure 13: Disassembled device after being submerged under water for 30 minutes.

3.3 Temperature cycle test and low & high Temperature test

To verify the suitability under conditions of repeated rapid temperature changes, the temperature cycle test was conducted based on JIS E3020 which details the temperature test methods for railway signalling systems. Note that the target minimum temperature for the device is -20°C. However, since there are no test conditions corresponding to -20°C in this JIS, the test was conducted at a minimum temperature of -30°C. Figure 14 shows the situation of temperature cycle test. The test was conducted following the procedures. Firstly, the device was placed in a low-temperature chamber and left at -30°C for over 3 hours. Then, the device was transferred to a high-temperature chamber and left at 60°C for over 3 hours. This cycle was repeated five times. Finally, after leaving the device at normal temperature for 1-hour, operational verification and observation were performed. As a result, no abnormalities were observed in the device.

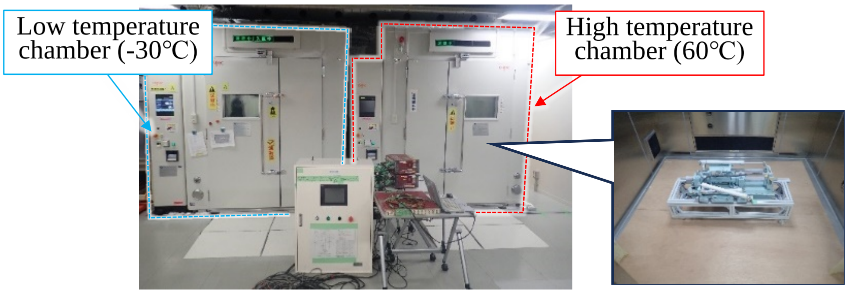


Figure 14: temperature cycle test.

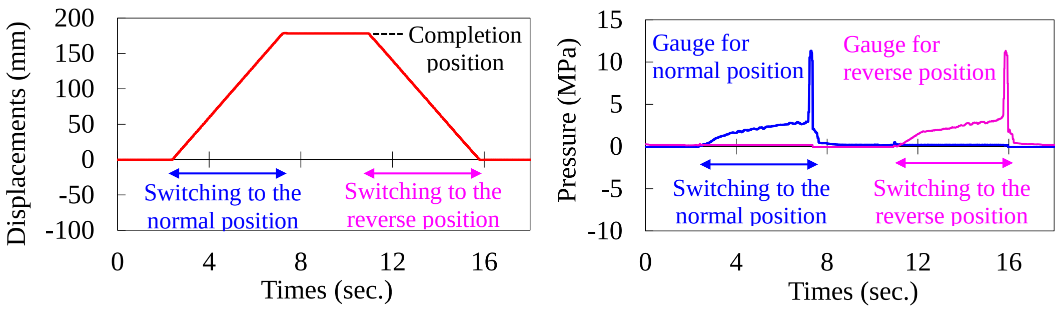
After the temperature cycle test, low temperature test and high temperature test was conducted based on JIS E3019. Each test was performed following the procedures outlined below. Firstly, the device was placed inside a constant temperature chamber as well as the temperature cycle test and subjected to a temperature change to the set temperature. The set temperature is -20°C for the low temperature test and 60°C for the high temperature test. Next, the device was left at the set temperature for 2hours. After 2 hours, with the temperature maintained, the device was operated inside the chamber. As a result of low temperature test, no abnormalities were observed. On the other hand, in case of high temperature test, the sub lock device could not be unlocked, resulting in an error. This is caused by the integration of the hydraulic circuits of the hydraulic cylinder and the sub lock device into the same system, aiming to simplify the circuit. Therefore, it is anticipated that this issue can be resolved by completely segregating both systems into independent circuits.

3.4 Continuous switching test and vehicle running test

To verify the durability under continuous operation, the switching device was installed at a test switch panel as shown in Figure 15 and a continuous switching test was conducted. At first, the switching device was operated and the output values of pressure gauges and displacement meters during the switching were verified. Figure 16 shows examples of output values. As a result, it was confirmed that the device can move the switch rails stably and appropriate outputs from the gauges were confirmed.

(a) Overview of a test swich panel (b) Swich motion

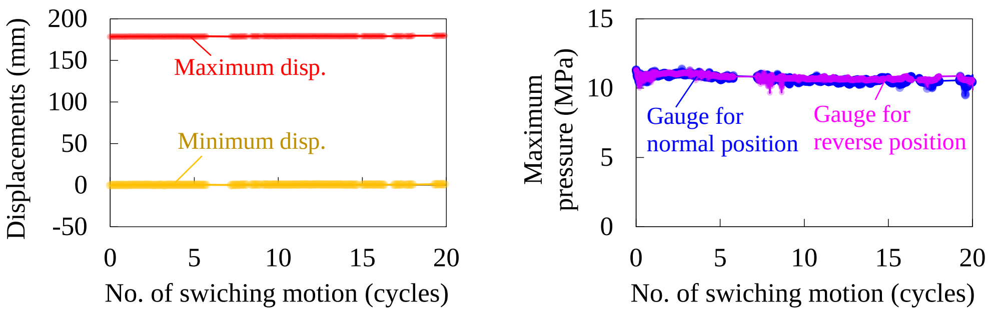
Figure 15: Switching device and bearer installed at a test switch panel.



(a) Displacement meter (b) Pressure gauges

Figure 16: Examples of output values under the switch motion.

Figure 17 shows the relationship between the number of switching cycles and output values. In the continuous switching test, the output values have consistently shown stable trends, with no significant increases or decreases observed. As a test result, we achieved 210,000 cycles, exceeding the targeted values of 200,000 cycles.



(a) Displacement meter (b) Pressure gauges

Figure 17: Relationship between the number of switching cycles and output values.

After that, a comparison was conducted between the switching force and locking force before and after the continuous switching test. Table 4 shows the comparison of these forces. The switching force after the test was 8.6kN and exceeded the target value of 5kN. On the other hands, it was confirmed that the locking forces after the test, both for the hydraulic cylinder and sub lock device, significantly decreased compared to their values before the test. Therefore, we found that problem remain in the decreases in the locking forces caused by continuous motion over 200,000 cycles.

Before and after the motion over 200,000 cycles	Switching force	Locking force	
		Hydraulic cylinder (Main lock)	Sub lock device (Sub lock)
Target values	≥ 5kN	≥ 15kN	≥ 15kN
Before the test	8.9kN	≥ 15kN	≥ 15kN
After the test	8.6kN	9.6kN	4.1kN

Table 4: Switching force and locking force after the continuous switching test.

As the final phase of the performance test, the switching device was installed on the test track, and a vehicle running test was conducted. Figure 18 shows the situation of a vehicle running test. In the test, video was recorded to capture the condition of switching device and swich rails when the vehicle passed through the turnout. The vehicle operated at a low speed of 36km/h, running along the straight line of the turnout. Additionally, the output values of the device were verified. The results confirmed that there were no issues in the behaviour of the switching device and switch rails during the passage of the vehicle.

The performance test results are summarized in Table 5. As results, it was confirmed that the switching device generally exhibits the specified performance, despite issues observed in its behaviour during high-temperature conditions and locking forces after continuous switching motion.

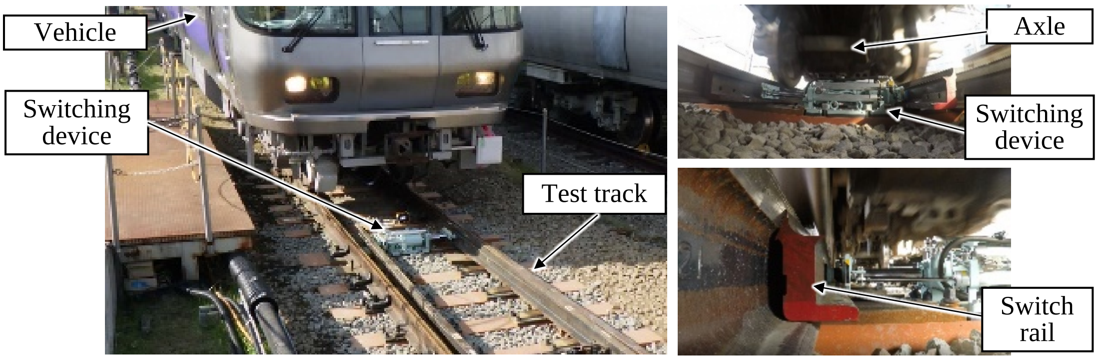


Figure 18: Situation of vehicle running test.

Performance items	Target values	Test results
Switching force	≥ 5kN	Achieved the target
Locking force	≥ 15kN	Achieved the target
Water resistance	No abnormality in movement No flooding into device	Achieved the target
Workable limit temperature	-20℃ to 60℃	There were no issues at -20℃. However, unlocking does not work at 60℃
Durability against continuous motion	≥ 200,000 cycles	After the over 200,000 cycles, locking force was decreased.
Stability under vehicle running	No abnormality in movement	Achieved the target

Table 5: Performance test results.

4 Conclusions

The authors produced the prototype of a new switching device of switch rails and conducted performance tests. The switching device using electrohydraulic actuator was designed based on the concepts of labor-saving for turnout maintenance. The device was manufactured according to the design, and various performance items such as the switching force, locking force, water resistance, workable temperature, durability against continuous motion and stability under vehicle running were evaluated during the tests. The results confirmed that the switching device generally exhibits the specified performance, although several issues were observed in its behaviour during a high temperature condition and locking forces after continuous switching motion.

This study is a step toward achieving the goal of developing a switching device for labor-saving of the maintenance work of turnouts. Several challenges still need to be addressed to reach the goal. Continuous improvements to the device are necessary based on the results obtained from this work.

Acknowledgements

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