Study of Anomalous Characteristics Exhibiting Between Fixing Force of Switch and Tongue Rail Opening Force

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The tongue rail opening force of a turnout is measured to indirectly estimate the fixing force of a turnout. Although tongue rail opening force is known to be proportional to the fixing force, it is also known that the proportional relationship sometimes does not hold. This non-proportionality can lead to mis-estimation of the fixing force, in turn causing malfunction of the switch due to the high fixing force. In order to solve this problem, we clarified the mechanism and causes of the mis-estimation related to contact between rails. The results of field investigations and motion simulation using a flexible multibody model of switch, were used to developed maintenance methods and a measurement tool for avoiding mis-estimation.

Key words: opening force, fixing force, closure between rails, switch, point machine

1. Introduction

Closure between the stock rail and tongue rail of a turnout is highly related to running safety of vehicles passing through a turnout. Therefore, the locking devices and locking mechanism of a point machine have to tightly fix the tongue rail (blade) against the stock rail. This fixing between rails occasionally loosens due to lateral displacement of the stock rail and the tongue rail. When this occurs, lock rods of the point machine detect this insufficiently fixed condition as a locking malfunction. The detection of this malfunction ensures the safety of a train passing through the turnout but disrupts train operations. It is therefore important to reduce the frequency of this malfunction to ensure operational stability. Thus, the fixing between rails should be checked by periodical maintenance and the actual method for checking the fixing status is also important.

Since most electric point machines in Japan have internal locking mechanisms, the status of the fixing force acting between the tongue rail and the stock rail is generally used to indirectly manage the closure and fixing status. The fixing force is supported by the point machine and acts on the switching bar of the turnout. The fixing force can be measured as the strain of devices between the throw bar on the point machine and the switching bar. It has been established empirically that the fixing force is proportional to the tongue rail opening force. Although the method for measuring the strain for a permanent monitoring device had been developed, this method has not been used yet commercially in Japan because of the need for periodical calibration of the strain sensors. Therefore, the fixing force between the rails is measured indirectly during periodical maintenance work on point machines by using the tongue rail opening force. The maximum and minimum strength range of the tongue rail opening force is stipulated in a maintenance rule. The indirect measurement of the fixing force using the tongue rail opening force normally gives the appropriate fixing force to be set in most turnouts. However, it has also been shown empirically that anomalous characteristics, i.e., non-proportionality, is exhibited between the fixing force and the opening force in some turnouts. This characteristic may cause the switch to malfunction, since the fixing force is adjusted to be larger than the switching force of a point machine, even if the opening force is normal. That is one of the problems related to the difficulty of maintaining point machines.

This paper reports on the results of experimental investigations and analyses the relationship between the tongue rail opening and fixing forces and its effect according to the type and condition of a turnout. We also report that the anomalous characteristics of the forces are affected by a contact position between the stock rail and the tongue rail. Moreover, we propose a new measurement tool and method, to avoid mis-estimation of the fixing force.

2. Fixing force and tongue rail opening force

2.1 Fixing force

The fixing force acts on a tongue rail as the elastic force in a switch adjuster and switching bar to ensure the tongue rail is tight against the stock rail. It is responsible for maintaining the position of the tongue rail so that the gap is closed between rails when a lateral force acts from wheels. To achieve this, the fixing force is empirically adjusted to 1 kN in a hinged heel switch. The fixing force can also be adjusted to be stronger. However, a strong fixing force exceeding the maximum switching force of the point machine may cause the switch to malfunction, and a strong fixing force may also wear of parts in the point machine and the rods. Accordingly, it is important to adjust the fixing force to within a proper range.

Figure 1 shows the fixing force action and related forces on the point machine and the rods including the switch adjuster and the switching bar. The internal locking mechanism of the electric point machine and the escapement crank in switching mechanisms for large turnouts, including high-speed rail turnouts, maintain a relative position against the stock rail because they are locked into position with fixing bolts and plates. The fixing force is affected by elasticity of the rods and tongue rail between both fixed ends, which are the switching bar in an electric point machine and the contact
point on a stock rail. The strength of the force is mainly adjusted with the distance between one end of switch adjuster rod, which connects with the point machine or the escapement crank, and the adjustable nut facing to the arm connected to the switching bar. The fixing force can be measured as strain of the switch adjuster rod and the jaw pin. A jaw pin with strain sensor for testing of switch and permanent condition monitoring methods of the fixing force and switching load [1] had been already developed. However, these methods have not been used yet in commercial permanent monitoring systems because of problems related to periodical calibration and durability of sensors.

2.2 Tongue rail opening force

The tongue rail opening force is the force acting on a tool when the toe of a tongue rail is opened from the stock rail. Since the opening force is known to be empirically proportional to fixing force, the fixing force is determined by the measured opening force. There are many kinds of measurement and methods for determining the opening force. Some inspectors use measurement devices, while others measure the force manually. On the other hand, maintenance rules for railway operators specify a range for the measured strength of adherence, which indicates when the points can be considered to be in good condition.

Figure 2 shows an example of a method for measuring the opening force using a measurement device. Inspector A operates the device for measuring the tongue opening rail force to open the toe of tongue rail, and inspector B measures the opening width between the tongue rail and the stock rail using a thickness gauge. Inspector B checks the opening width by inserting a thickness gauge between the rails or a pull-out from the rail of the thickness gauge. Inspector A confirms an indicated opening force on the device at the moment when the opening width reaches the thickness of the gauge. The thickness of the gauge is 1.0 mm in case of hinged heel switches and 0.5 mm in case of flexible switches. Although the range of the opening force differs from railway operators and the type of turnout, it is normally specified as 2.0 kN to 2.7 kN maximum.

2.3 Problems in fixing force management using opening force measurement

To identify problems in fixing force management using opening force measurement, a questionnaire survey was conducted among maintenance companies doing measurement works of the opening force. Table 1 shows the results of a survey to identify difficulties encountered by inspectors. The results indicate that inspectors believed that same turnouts had different opening force and the opening force was influenced by the measurement devices, inspectors, method of measurement and season when inspections were conducted. Moreover, it was reported that for some turnouts it was difficult to satisfy the specified range of opening force and specified clearance between the tongue rail and the stock rail at once. In case of such turnouts, the fixing force was strongly adjusted to satisfy the specification of clearance of rails.

In addition, it has been shown that some turnouts present anomalous characteristics where the opening force is empirically smaller than the expected force on the basis of the relationship between the normal fixing force and opening force. This anomalous characteristic may induce a switching malfunction in a turnout even when the opening force is adjusted to satisfy the specified range, because the fixing force exceeds the switching force of the point machine.

These issues and characteristics are problems for fixing force management based on opening force.

3. Experimental investigations

In order to clarify actual states of the problems managing the fixing force based on opening force measurements, we experimentally investigated the relationship between the forces and other parameters.

3.1 Investigation methods

Table 2 shows numbers of the turnouts investigated in the field by type and shape of turnouts. These turnouts were measured and investigated in the field for opening force, fixing force and gaps between the rails. The opening force was measured with the same opening force measurement device used by railway operators. The fixing force was measured with the strain gauge equipped with a jaw pin, which was a normal jaw pin taken from one end of a switch adjuster. The characteristics between the fixing force and the open-

<table>
<thead>
<tr>
<th>Table 1 Result of questionnaire survey (selected)</th>
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<tr>
<td>Type of measurement device</td>
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<tr>
<td>----------------------------</td>
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<td>(N=19, multiple responses)</td>
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Maintenance works related problems:

a) Differences depending on who is inspecting and conditions of front rod
b) In some locations, the guard (check) angle makes inspection difficult
c) Results influenced by different gauge insertion methods and positions
d) With some switches, when the opening force is within the specified range, the rail gap fails to meet requirements.

Fig. 1 Fixing force and tongue rail opening force

Fig. 2 Example of method for measuring tongue rail opening force
ing force (referred to below as FOC) were measured by adjusting the fixing force at the switch adjuster nut. Gaps between a tongue rail and a stock rail were measured to investigate the effect of the contact position of the rails on the FOC. These measurements were normally done in both directions of a switch (Normal and Reverse). The opening width at the toe of a tongue rail at the opening force measurement is 0.5 mm for flexible switches and 1.0 mm for hinged heel switches normally. Note, if an opening occurred at the toe of the tongue rail before measurement, the width before opening was added to the measurement width.

Moreover, the FOCs were measured when contact positions between the rails were changed for a hinged heel turnout with 50 N rail [2] in RTRI to investigate the effect of the contact position of the rails on the FOC. On the same turnout, the FOCs were measured to investigate the influence of different inspectors and opening force measurement methods, which was claimed by inspectors to influence the opening force, including insertion position of the thickness gauge and insertion angle of the measurement device.

3.2 Effect of types and shapes of turnout

Figure 3 shows the field investigation results for the FOC on hinged heel switches and flexible switches. Since measured results of hinged heel switches are highly dispersed, it is difficult to think that the opening force of all measured hinged heel switches are proportional to the fixing force. However, it is possible to contend that the FOC of each turnout is proportional to the fixing force, focusing on the result of each turnout A to E. Since slopes of hinged heel turnouts and y-intercepts are different for each turnout, the opening force does not appear to be proportional to the fixing force.

Figure 4 shows the FOCs of hinged heel turnouts by shapes of turnouts, size, rail types and configurations of switching rods and cranks. These results confirmed that turnout shape, size and rail type do not affect the FOC. Meanwhile, the FOC with the configurations using two cranks differed from the FOC with the other configurations: in the configuration using two cranks, the opening force was the same, but the fixing force was stronger than in the other configurations.

Figure 5 shows configurations of switching rods and cranks for large turnouts. A configuration with two cranks shown in Fig. 5 (a) fixes a tongue rail to a stock rail by two switch adjuster rods. For this configuration, a fixing force of the second switch adjuster is transmitted from second crank to first crank and first switch adjuster directly, because a normal crank has no locking function to hold fixing force by itself. It is possible to contend that this transmission of fixing force from second switch adjuster relates to a special tendency of the FOC of 1:16 turnouts shown in Fig. 4 (b). The FOC of this configuration without the effect of a fixing force of a second switch adjuster is shown in Fig. 4 (d). It was confirmed that this FOC is as same as the FOCs of the other configurations. Furthermore, since an escapement crank holds the fixing force itself, the FOC of the configuration shown in Fig. 5 (b) is as same as the others.

3.3 Effect of contact position of rails

In order to investigate the effect of the contact position of the

<table>
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<th>Table 2 Types and numbers of field investigations</th>
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<tr>
<td>(Numbers)</td>
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<tr>
<td>-----------</td>
</tr>
<tr>
<td>Simple turnout</td>
</tr>
<tr>
<td>Symmetrical turnout</td>
</tr>
<tr>
<td>Asymmetrical turnout</td>
</tr>
<tr>
<td>Curved turnout (same direction)</td>
</tr>
<tr>
<td>Curved turnout (opposite direction)</td>
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tongue rail and the stock rail on the FOC, FOCs at two different contact positions A and B were measured at the same turnout. Figure 6 shows the FOCs at contact positions A and B. Contact position A, which is the position between toe of tongue rail to a switching bar, is considered to be a “good contact position.” On the other hand, contact position B, which is the position behind a switching bar, is normally considered to be a “bad contact position.” The results show that for contact position A, FOC increases with the fixing force, but for contact position B, FOC has little correlation with the fixing force.

This tendency is also true for the results of the field investigation shown in Fig. 3. The characteristic that increases with increasing fixing force of the FOC in turnouts B to E, where the contacts are behind the rolling rods, is smaller than in the case of turnouts A and F. Table 3 shows the average, median and standard deviation of y-intercepts and the slopes, when FOCs of each flexible switches are linearly approximated, for each type of contact. The slopes and y-intercepts have some dispersion in each turnout. However, focusing on median, it is found that the slope of the cases for contacting on the position behind the switching bar is smaller than other results. Meanwhile, no significant difference was found at y-intercepts. This tendency may explain why the dispersion of y-intercepts is not affected by contact positions and structures of turnouts.

### 3.4 Effect of measurement method of tongue rail opening force

The opening force was measured by two inspectors who normally use an opening force measurement device and a thickness gauge, respectively.

One inspector operates the device to open the toe of the tongue rail, while the other checks the opening width between the tongue rail and the stock rail using a thickness gauge. They confirm an indicated opening force on the device at the moment when the opening width reaches to the thick of the gauge. However, details of the measurement method, such as a measurement method of the opening width by the thickness gauge, measurement position of the width, were not specified in the working procedure. To clarify the relationship between the measurement methods and the dispersion of the measured value, we experimentally studied the effect of changing the conditions of the inspectors and measurement methods on the opening force measurement result using the same turnout.

Figure 7 shows effects of inspectors A to E on FOCs. All inspectors who worked on this test were researchers of RTRI, and the same turnout and device were used. Figure 7 (a) shows the effect of an inspector who used same measurement device on FOCs, and Fig. 7 (b) shows the effect of an inspector who uses same thickness gauge. The dispersion of the opening force when measured with the same measurement device used by different inspectors on the same fixing force was within 0.4 kN which is as near as the result of a same inspector of 0.2 kN. Meanwhile, the dispersion of the opening force measured by different inspectors using a thickness gauge on same fixing force was 1.0 kN maximum, however dispersions of the opening force when a same inspector used the thickness gauge was normally within 0.2 kN. By the results of this test, we confirmed that measured opening force was related to different inspectors using a thickness gauge. We also confirmed that the maximum difference of 1.0 kN had a non-negligible effect on the strength of the fixing force, which is around 1.0 to 3.0 kN.

Figure 8 shows effects of measurement methods on the FOCs. Figure 8 (a) shows the effect of insertion positions of the thickness gauge, and Fig. 8 (b) shows the effect of the insertion angle of the measurement tool. These tests confirmed that the measurement method affects the values of the measured opening force, and we also confirmed importance of specifying the measurement method of the opening force on a working manual.

### 4. Causes and effects of contact position of rails against the tongue rail opening force

In order to experimentally clarify the causes and effects of anomalous FOC relating to the contact position between rails shown in section 3.2, a dynamics model of the switch considering the relationship between the fixing force and the opening force was developed. Moreover, the relationship between the FOCs and contact position of the rails was calculated using this model on a dynamics simulator for a turnout and switching devices developed by RTRI [3].

#### 4.1 Modeling of mechanisms of the fixing force and the opening force

Figure 9 shows the relationship between the forces acting on a turnout and switching devices from when the rails is fixed by the fixing force to when the tongue rail is opened by the opening force. The relationship suggests that the fixing force of the rails relates to a constraint force on the end of the tongue rail (a), an elastic force of the tongue rail (b) and an elastic force of the switch adjuster (c). In addition, this relationship also suggests that the opening force re-

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**Figure 6** FOCs by contact position between tongue rail and stock rail

**Table 3** Slopes and y-intercepts of linear approximation of FOC by contact position

<table>
<thead>
<tr>
<th>Contact Position</th>
<th>Slope of OFC</th>
<th>y-intercept of OFC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td>Contact at toe</td>
<td>1.13</td>
<td>1.01</td>
</tr>
<tr>
<td>Good contact</td>
<td>0.91</td>
<td>0.83</td>
</tr>
<tr>
<td>(Toe is closed, contact is available at a section between toe and switch bar)</td>
<td>0.7</td>
<td>0.69</td>
</tr>
<tr>
<td>Contact behind switch bar</td>
<td>0.36</td>
<td>0.33</td>
</tr>
</tbody>
</table>
lates to the fixing force acting on the switching bar, an internal force (d) and friction forces (e) between the tongue rails and bed plates on the sleepers. The internal force relates to the opening width of the tongue rail and contact point between the rails. If the tongue rail has no contact point, the relationship between forces can be defined as an elastic deformation of a static beam [3]. Since, in a real turnout, one or more contact points are occasionally found on the tongue rail, and positions and numbers of the contact points move dynamically, it is difficult to analyze the relationship of the forces using a static beam model. To solve it, we modified the multi body dynamics model and simulator for a turnout and switching devices developed by RTRI which considers the forces relating the fixing force and the opening force. Moreover, the effects of the contacting position of the rails on the FOCs, motion of rails and related forces were computed using the model and simulators.

Parameters assuming a hinged heel 1:8 simple turnout, were used for the simulation. In the simulation, motion and forces were calculated when the turnout switched its direction and when the tongue rail was opened 1.0 mm by the opening force measuring device, to confirm the relationship between the FOCs against fixing forces and contact positions.

4.2 Result of simulation and effect of contact position on the FOCs

We simulated the FOCs and geometry of the tongue rail with two different contact positions between the tongue rail and the stock rail. One of them was a contact at the toe of the tongue rail which is a normal contact, and the other was a contact at 0.6 m behind the toe of the tongue rail which is behind the switching bar. Figure 10 (a) shows the simulation results of the FOCs, and Fig. 10 (b) shows the simulation results of the gap between the rails also showing of the geometry of top view for the tongue rail. The simulation results showed that the anomalous FOC is confirmed when a contact exists behind the switching bar, and this tendency is as same as the investigation results. Moreover, the simulations also calculated the opening force and related forces such as the elastic forces and the fixing force. When the toe of the tongue rails is opened in 1.0 mm for measuring the opening force, the fixing force directly acts on the opening force at the case of a normal contact, because there is no supporting point of the force on the tongue rail except for the toe. On the other hand, the fixing force acts on the toe of the tongue rail and the contact point, when the contact point is available behind the switching bar. Since the fixing force is supported at those two points, the opening force is smaller than normal contact even if in same fixing force. By this mechanism, it is considered that increasing of the FOC is smaller than increasing of the FOC of the normal contact when a contact point of the rails is available behind the switching bar.

4.3 Results of simulation and effect against geometrical inertia of moment of tongue rail

Parameter studies using the simulator showed that a lateral geometrical inertial of moment (referred to below as LGIM) of the tongue rail relates to the FOC, because a LGIM relates to a geometry of the tongue rail and the contact points. Figure 11 shows the simulation results of the FOCs against LGIMs and the geometries of the tongue rail. On the simulations, a contact point is set at the toe of the tongue rail. However, it was confirmed that the slope of the FOC decreases when LGIMs are 25% and 50% of that of the 70S rail used in 50N rail turnouts. The results shows that low LGIM tongue rails tend to come into contact with the tongue rail behind the switching bar when the opening force is measured, since low LGIM rails bend easily.

These results showed that a main cause of the anomalous FOC is an effect of the contact position of the rails behind the switching bar. Moreover, we also confirmed that the contact position is affected by the geometry of the tongue rail, width between the tongue rails

a) Change for measurement device operator b) Change for thickness gauge operator

Fig. 7 Effects of inspector against FOCs

(a) Insert position of thickness gauge (b) Insert angle of measurement device

Fig. 8 Effects of measurement method against FOCs

Fig. 9 Relationship between forces acting on a turnout and switching devices

Fig. 10 Simulation results of effect of contact points
task was added, which is to check for contact between rails before measuring the opening force. To reduce the dispersion of measurement results due to individual differences between inspectors and measurement methods, we proposed clarifications to the method used to measure the opening force, such as how the device should be inserted, the position of the thickness gauge, and type of measurement device.

For turnouts with a gap on the toe of the tongue rail before opening, the problem is that the opening force is often found to be weaker than in normal turnouts. The problem occurs because the opening width of the tongue rail, defined by thickness of the gauge, is affected by the pre-opened gap, and becomes smaller than specified opening width of 1.0 mm or 0.5 mm. To avoid this problem, the thickness of the gauge was adjusted in our investigations using relative displacement as the specified width. The modified maintenance method shown in Table 4 suggests adding the gap width before measuring to avoid this problem.

Moreover, a device assisting the opening width measurement was developed to solve problems related to opening width measurement. Figure 13 shows the developed device which measures relative displacement of the tongue rail and warns the inspector when a measured width reaches a specified opening width. This device is still under development for practical use, and it is expected it will replace opening width measurements using a thickness gauge.

6. Conclusions

We conducted field tests and analyses to investigate the relationship between the tongue rail opening force and the fixing force, and the impact of type and condition of the turnout. On the basis of the results obtained from these tests and analyses, the characteristics

adjusted by the width of the front-rod, and LGIM of the tongue rail. Since LGIM of turnouts normally used in main tracks and sidetracks range between 71% to 214% of LGIM in a 50N turnout, the effect of the difference in LGIM on the FOCs is small (within ±10%). Therefore, a specification of opening force can be applied for different types of turnouts. However, for example, a special turnout having low LGIM characteristics, such as a single tongue rail for dividing direction of the dual gauge track to a broader gauge track and a narrower gauge track, may have an anomalous FOC. Considering these characteristics, it is necessary to specify an opening force range within which the fixing force is considered normal.

5. Proposal for an adjustment and measurement method for opening forces

The procedures and contents of the fixing force using opening force measurement devices were conducted in accordance with railway operator maintenance manuals. An opening force range used for determining the state of health of an opening force and the thickness of the thickness gauge are specified for hinged heel switches and flexible switches, respectively.

Our investigations confirmed the basis of current regulations whereby the FOC is nearly stable regardless of size, shape and type of rail in the turnout. However, we also confirmed the highlighted problems in the current regulation, which are that the FOC is affected by contacts between rails and the position and method used to make measurements.

Table 4 shows the proposed modifications to the measurement methods in the current maintenance manual, based on the investigation described in this paper. Figure 12 shows a flowchart of the maintenance work reflecting our proposal. To avoid strong fixing forces due to adjustment of the opening force to a regulated range for a turnout with rails making contact behind the switching bar, a

Table 4  Current maintenance manual regulations and proposals for modification

<table>
<thead>
<tr>
<th>Current measurement method regulations and proposals from this study (underlined)</th>
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<tbody>
<tr>
<td>● Opening force should be adjusted in following range</td>
</tr>
<tr>
<td>● Hinged heel turnout] X to Y kN in 1.0 mm opening</td>
</tr>
<tr>
<td>● Flexible turnout] Z to W kN in 0.5 mm opening</td>
</tr>
<tr>
<td>● If there is a gap before the measurement in taken, the width of the opening should be added to the gap</td>
</tr>
<tr>
<td>[i.e., gap is 0.3 mm, opening width is 1.3 mm in hinged heel turnout]</td>
</tr>
<tr>
<td>● The device should be inserted N mm behind the toe of the tongue rail</td>
</tr>
<tr>
<td>● Thickness gauge should be inserted, and opening force should be measured if the gauge pulls out</td>
</tr>
<tr>
<td>● The opening force device should be inserted parallel to the rail</td>
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Fig. 11  Simulation results of effect of geometrical inertia of moment

(a) FOC  (b) Gap between rails

Fig. 12  Proposal for work flow of opening force measurement

Fig. 13  Opening width measurement device (Prototype)
of the fixing force and the opening force are summarized as follows.
- The anomalous characteristics of forces are affected by a contact position between the stock rail and the tongue rail. The anomalous characteristics were confirmed when there was contact behind the switching bar.
- The anomalous characteristics were also confirmed when lateral geometrical inertial of moments were 25% and 50% of that of a 70S rail used in 50N rail turnouts.

Moreover, we proposed a new measurement tool and method to avoid the mis-estimation of fixing forces. We hope that the results of this investigation and proposed method and tools contribute to improving maintenance work on switches, point machines and related devices.

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References


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