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Development of a New Spring Type Tensioning Device for Shinkansen

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The wheel type tensioning device used in the Tohoku and Joetsu Shinkansen lines of JR East requires much time and labor for maintenance including wire replacement and oil application. Further, parts become superannuated and in need of periodic replacement very quickly. So we found it necessary to develop a new type of maintenance-free tensioning device.

To accomplish this, we have been making efforts since 1999 to develop a new spring type tensioning device for Shinkansen, making effective use of the spring type balancer technologies used in the narrow gauge lines, where the major target is to develop a maintenance-free tensioning device. Thus, fairly satisfactory development results have been attained. This paper introduces and discusses this development.

● Keyword : Tensioning device, Shinkansen

1 Tensioning device

The tensioning device is designed to pull the contact wire straight at all times. Pulling a contact wire straight ensures that smooth contact is maintained at all times between the contact wire and pantograph of an electric train, and this makes it possible to ensure a stable supply of electricity to the train. Normally, tensioning device are installed at two positions over a distance of 1 to 1.6 km per line. Fig. 1 shows a conceptual view of the relationship between the contact wire and pulley type balancer.

The tensioning device can be broadly classified into the two types; the wheel type tensioning device that pulls the contact wire by concrete or iron weights and the spring type tensioning device that use the force of a spring to pull it. Fig. 2 shows the wheel type balancer, while Fig. 3 represents the spring type balancer. The spring type tensioning device comprises a spring and a sleeve for accommodating the spring. Only the sleeve portion is visible to the outside.

The wheel depends on gravity acting on the weight to produce tension, so it is possible to pull the contact wire at an almost uniform force, regardless of the height of the weight. In the spring type

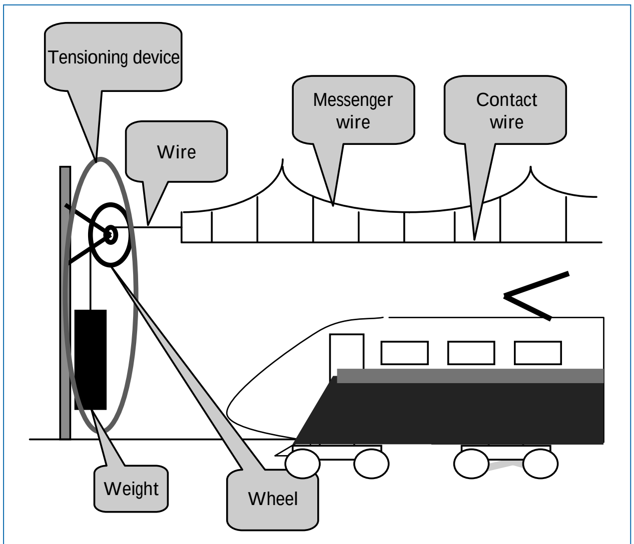

Fig. 1 Relationship between contact wire and wheel type tensioning device (This is a conceptual view. It may not faithfully reflect the actual equipment.)

Fig. 2 Wheel type tensioning device

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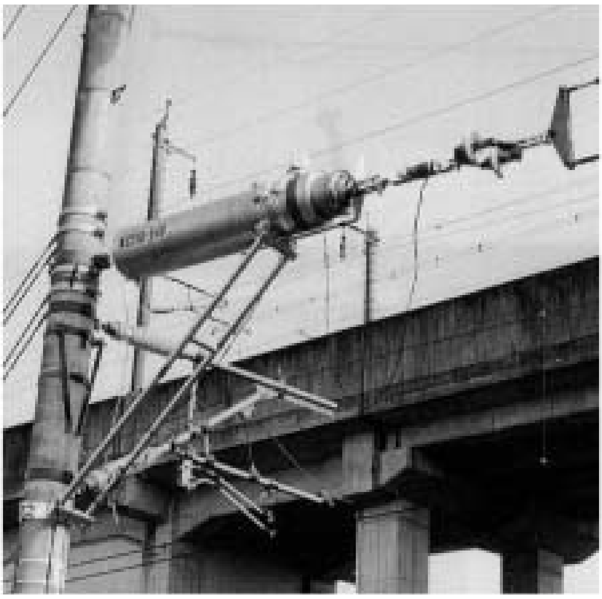

Fig. 3 Spring type tensioning device

tensioning device, however, the contact wire tension undergoes a greater change than that of the wheel type tensioning device, depending on the extension/contraction rate of the spring. So the spring type tensioning device cannot be used in an environment where high-precision tension management is required such as in the Shinkansen characterized by extra-high operating speed. This explains why the wheel type tensioning device has been used so far.

The wheel type tensioning device, however, contains a number of moving parts and wearable parts, and requires much time and labor in daily maintenance. It has long been desired to develop a tensioning device based on the spring type tensioning device whose greatest advantage is found in lack of need for maintenance.

2 Goal of development

Based on the current status and problems as described above, we have set up the following the development goals for a new spring type tensioning device to replace the wheel type tensioning device:

① The new spring type tensioning device should have the same level of performance as that of the wheel type tensioning device.
A tension change rate of ± 8% should be ensured at an applicable wire length of 800 meters. (The applicable wire length is defined as the length of a wire that can be pulled properly by the tensioning device in a straight line).

② The new spring type tensioning device should have the same dimensions as those of the wheel type tensioning device.
A cassette type structure is adopted to facilitate replacement work.

③ The service life of the new spring type tensioning device should be the same as that of the wheel type tensioning device.
The approximate service life is 30 years or more.

This paper will mainly discuss the first point - "The new spring type tensioning device should have the same level of performance as that of the wheel type tensioning device." This is technologically the most difficult point, and requires the most time.

A specific commitment in achieving these goals includes improvement of the conventional spring type tensioning device function (reduction in the change rate of tension and sliding resistance).

3 Study of specifications

3.1 Designing the tensioning device

In designing the new spring type tensioning device, it is necessary to study the stroke (the range of the extension/contraction rate of the spring type tensioning device compatible with that of the contact wire due to change in temperature) and the number of springs.

3.1.1 Study of stroke

To determine the equipment conditions used in the calculation of the stroke, we have used the CS simple catenary equipment compatible with high-speed travel that is in use in the Nagano Shinkansen and Tohoku Shinkansen (Morioka to Hachinohe) Lines. For wires, the messenger wire of PH 150 mm^2 (hard-drawn copper stranded conductor) and contact wire of CS 110 mm^2 (copper clad trolley wire) are used. The standard tension is 19.6 kN for each wire. Other conditions includes a temperature change of 60 degrees Celsius, a distance between electric poles of 50 meters as a standard distance, and an applicable wire length of 800 meters, this length being on the same level as that of the wheel type tensioning device.

These numerical values have been applied to equation (1) specified in the JR East Equipment Design Standard. As a result, we get 632 mm as the extension/contraction rate of the wire. Thus, the stroke has been specified as 640 mm (± 320 mm), with consideration given to a margin of safety.

$$\frac{1}{L} = \Delta\theta\alpha - \frac{T_1 \quad T_2}{EA} - \frac{(Mg)^2 S^2}{24}\left(\frac{1}{T_2^2} - \frac{1}{T_1^2}\right)$$

$\Delta\theta$: Change of temperature
A : Calculated cross section
T_1 : Max. tension (N) T2: Min. tension (N)
E : Elastic coefficient (N/m²)
α : Linear expansion (without unit)
A : Cross section (m²)
M : Unit weight (kg/m)
S : Span (standard 50 m)
g : gravitational acceleration (9.80665 /s²)
L : Extension/contraction rate of wire (m)
I : Wire length (m)

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3.1.2 Study of the number of springs

Two change rates of tension, 4% and 5%, were selected in the designing phase. Table 1 shows the result of calculating the number of springs and dimensions of each portion.

Table 1 Proposals for balancer specifications

	Proposal 1	Proposal 2
Number of spring steps	3 steps	3 steps
Tension change rate (design value)	± 5%	± 4%
Outer diameter [mm]	Φ435	Φ435
Standard length [mm]	2636	2984
Number of springs used	15	18
Weight [kg]	930	1050

When the change rate of the tension is ± 4%, the weight exceeds one ton. This may cause an increase in sliding resistance due to the increased number of springs. To eliminate this possibility, we have adopted Proposal 1. Figs. 4 and 5 show the overview of the prototype.

The design value tension change rate differs from the measured value. This is due to the following reasons: At the time of measurement, the spring type tensioning device is placed in the same state as when actually used. This makes the spring contact the sleeve of the spring type tensioning device proper due to its own weight. Then a sliding resistance occurs to deteriorate the change rate of tension to below the level of the design value.

It is very difficult to calculate the sliding resistance and change rate of tension. So the final tension change rate is determined in a performance verification test of the prototype.

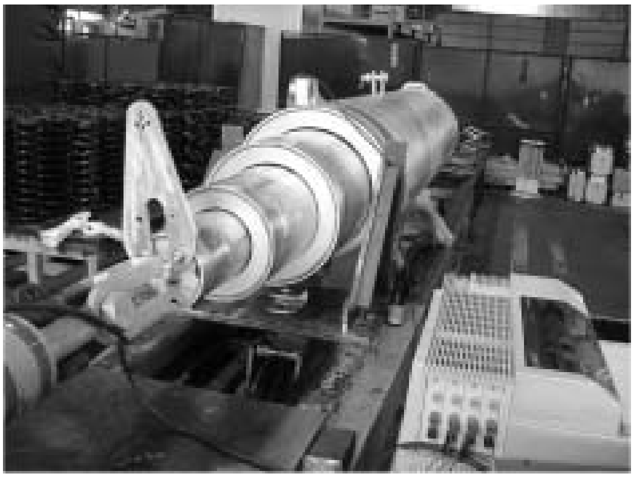

Fig. 4 Overview of prototype

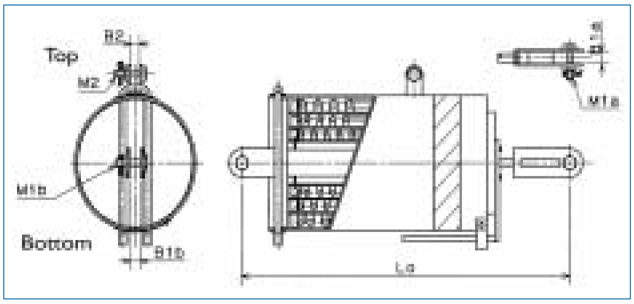

Fig. 5 Overview of prototype

3.2 Study of how to reduce the sliding resistance

Since the basic specifications have been determined, we would like to discuss our efforts to reduce the sliding resistance. Reference will also be made to the expected service life.

3.2.1 Surface treatment of the main unit

The surface treatment of the tensioning device proper is normally provided by hot dip galvanizing (HDZ70). To reduce the sliding resistance, a hot-dip aluminum coating must also be mentioned as a candidate.

Hop dip galvanizing (HDA2: 120g/m2) provides a very hard alloy layer, which is extremely wear-resistant, and is expected to be helpful in reducing the sliding resistance. Since it is also highly corrosion-resistant, a service life of 30 years can be expected. Further, hot-dip aluminum galvanizing has characteristics intermediate between hop dip galvanizing and hot-dip aluminum coating. When compared with the latter, the latter is superior in sliding characteristics.

The developed product is assumed to be used outside of tunnels. So corrosion of aluminum to alkali is not taken into account.

As a result of the above-mentioned discussion, we have decided to adopt hot-dip aluminum coating.

3.2.2 Painting on spring surface

We examined the coating on the spring surface, placing greater emphasis on corrosion resistance and cost reduction, as well as reduction in sliding resistance. Table 2 shows the result of our study.

Table 2 Type of spring coating and comparison

Type	Characteristics	Example of practical use
Aminoalkyd resin plus Alkycoat	• General painting, much experience • Baking finish is used.	Conventional spring balancer
Epoxy based paint A	• Mixed with lubrication additives • Thermosetting liquid • Superior in corrosion resistance, lubricity and wear resistance.	Axle trunion joint and spring

Epoxy based paint A is characterized by being mixed with lubrication additives and the friction coefficient is very low. It is also superior to other general epoxy based paints in corrosion resistance. It is used in a great many cases and is highly reliable.

Based on the above survey, we have decided to use epoxy-based paint A for the coating of the spring surface.

4 Fundamental test

Based on the above-mentioned study, we built prototypes of the new spring type tensioning device. Then to verify the performance of the prototypes, we conducted an fundamental test. The following discusses this point. We built three prototypes.

4.1 Load carrying test

The prototype was subjected to tension 2.5 times the tension equivalent to 105 percent of the standard tension (19.6 kN) for three minutes. Then we checked the prototype to see if there was any trouble. Fig. 6 shows the overview of the test.

4.2 Repeated load test

Tension is gradually applied to the prototype until the stroke reaches the maximum value of +320. Then the prototype is extended until the stroke reaches the minimum level of -320. This procedure is repeated. Tension is measured at the maximum and minimum specified strokes at the end of the 10th, 20th and 30th steps. The outline of the test is the same as that shown in Fig. 6.

4.3 Creep test

The prototype is extended to the maximum limit including the spare stroke into the maximum limit in addition to the maximum specified

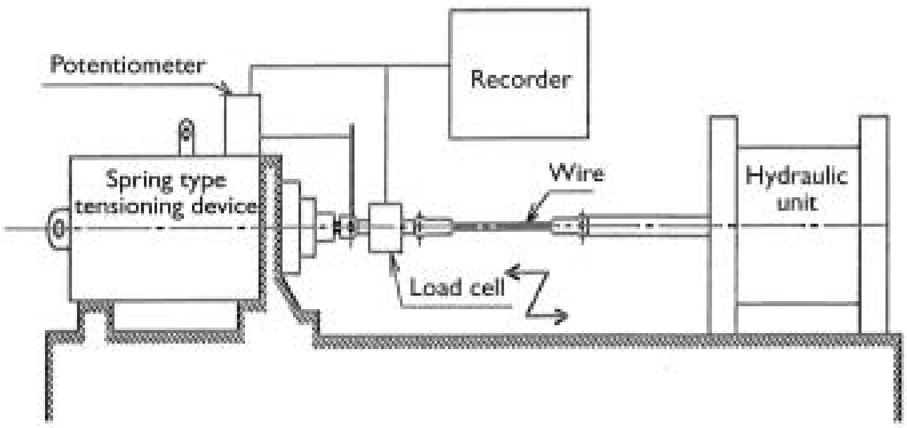

Fig. 6 Overview of load carrying test

stroke, and is retained under that condition for 30 minutes. Then the above-mentioned repeated load test is carried out to check if the performance has been degraded due to settling of the spring.

Further, settling of the spring and degradation of performance are checked when the retention time is extended to as long as four weeks.

5 Test result

5.1 Load carrying test

Table 3 shows the result of the Load carrying test. Table 3 indicates that there was no problem with any of the three prototypes after the load-carrying test.

Table 3 Result of load carrying test

Prototype	Test load for three minutes [kN]	Test result
1	102.90	No problem
2		No problem
3		No problem

5.2 Repeated load test

Table 4 shows the result of the repeated load test and Fig. 7 is a graph representing the changes in tension.

Table 4: Result of repeated load test

Test item	Stroke	One-way stroke		Return stroke		Reciprocal stroke %
	mm	kN	%	kN	%	
10th step	-320	37.73	-3.75	35.67	-9.00	16.50
	0	39.98	2.00	38.02	-3.00	
	320	42.14	7.50	40.77	4.00	
20th step	-320	37.53	-4.25	35.28	-10.00	17.25
	0	39.98	2.00	37.73	-3.75	
	320	42.04	7.25	40.47	3.25	
30th step	-320	37.53	-4.25	35.67	-9.00	16.00
	0	39.98	2.00	37.93	-3.25	
	320	41.94	7.00	40.47	3.25	

The tension change rate rose to 17.25 percent in the 20th test step. As the repeated load test continued, the rate was reduced to 16% in the 30th step. With the progress of the repeated load test, the tension change rate exhibited a gradual reduction, and a stable state was observed at a change rate of approximately 16%.

5.3 Creep test

Table 5 shows the result of the creep test when retained for 30 minutes. Fig. 7 is a graph representing the tension change, as mentioned above. Good results were recorded in all of the three prototypes.

In the creep test for a retention period of 40 days, a load test was carried out upon termination of the creep test. No spring settling was observed. Good results were recorded in all of the three prototypes without any degradation in performance.

Table 5 Result of load test after creep test

No.	Stroke	One-way stroke		Return stroke		Reciprocal stroke %
	mm	kN	%	kN	%	
1	-320	37.24	-5.00	35.38	-9.75	16.00
	0	40.08	2.25	37.73	-3.75	
	320	41.65	6.25	40.47	3.25	
2	-320	37.53	-4.25	35.87	-8.50	15.75
	0	39.79	1.50	38.12	-2.75	
	320	42.04	7.25	40.67	3.75	
3	-320	37.93	-3.25	35.77	-8.75	16.00
	0	39.89	1.75	38.02	-3.00	
	320	42.04	7.25	40.67	3.75	

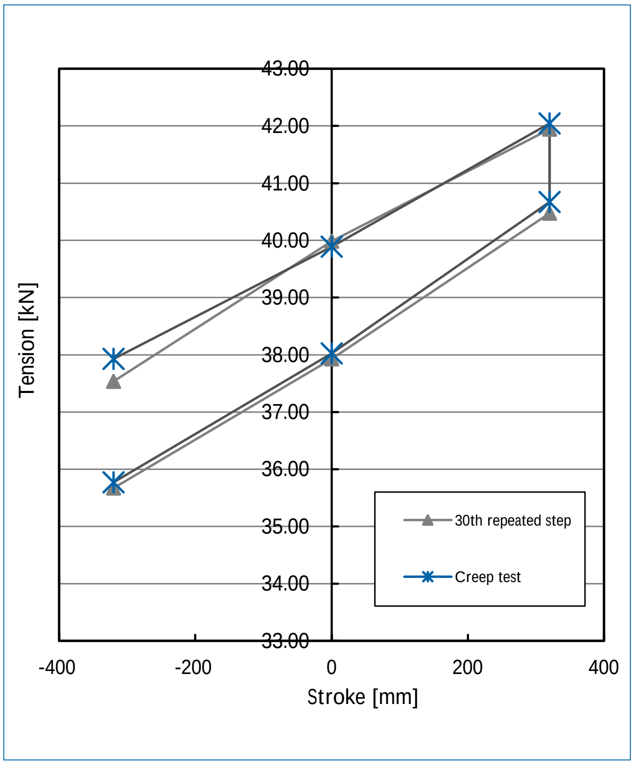

Fig. 7 Hysteresis chart

6 Consideration of in-plant test

6.1 Load carrying test

No problem was found in the test result. It has been made clear that the prototype meets the performance requirements in normal use under all conceivable environmental conditions.

6.2 Repeated load test

Table 6 shows the relationship between the number of repeated load tests and reduction of sliding resistance.

Table 6 Number of repeated load tests and reduction of sliding resistance

Number of repetitions	Prototype 1	Prototype 2	Prototype 3
1st	17.25%	16.75%	17.50%
30th	16.0%	15.75%	16.0%
Reduction of sliding resistance (%)	-1.25%	-1.00%	-1.50%

Table 6 shows that the maximum difference in sliding resistance among prototypes was 0.75% in the first step in the repeated test. It declines to a maximum of 0.25% in the 30th step, exhibiting a substantial reduction. The sliding resistance of each prototype reached a plateau in the 20th through 30th steps in the repeated test, although this is not illustrated. Generally, the sliding resistance was smaller in the 30th step in the repeated test than in the first step. The percentage of reduction is 1.0 to 1.5% after the 30th step in the test.

When consideration is given to the fact that the tension change rate is 15.75 through 16% for the three prototypes, it will be possible to achieve commercial use when the required performance is equivalent to a tension change rate of within ±9%. However, it will be difficult to achieve the target of ±8 %.

Accordingly, further improvements have been made to achieve the target. This will be discussed in Section 7.

6.3 Creep test

Comparison of tension values after the creep test for a retention period of 30 minutes and after the 30th step in the repeated load test shows that there was no reduction in either the maximum or minimum load. No degradation of performance was observed after the creep test for a retention period of 40 days. This leads to the conclusion that there is no settling of the spring under this condition, and the prototype maintains the required performance.

7 Overview of improvements

As described above, our efforts to reduce the sliding resistance were insufficient, and so we have proposed the following improvements to achieve the target:

Improvement 1.

Grease applied to the spring surface should be changed to one with better lubricity.

Improvement 2.

A groove is formed on the outer periphery of the flange of the inner sleeve to ensure that an adequate amount of grease is supplied at all times.

Improvement 3.

The material of the flange surface should be changed.

Fig. 8 shows how the flange of the spring type tensioning device looks. The flange is located on the end portion of the inner sleeve and is in contact with the closest one of the inner sleeves. It provides space for the spring and ensures a smooth movement between the sleeves when the spring extends or contracts.

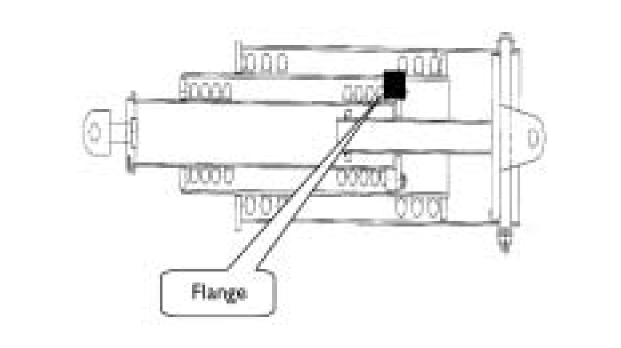

Fig. 8 Spring type tensioning device flange

7.1 Study of grease (Improvement 1)

We have selected new grease characterized by excellent performance in protecting against impact and heavy loads. The outer sleeve of the prototype has a large diameter of 435 mm, and there is a large contact area between the outer sleeve and flange in it. Probably viscous resistance of the grease has occurred.

Accordingly, we have selected the grease characterized by lower viscosity and higher fluidity, thereby reducing the sliding resistance. Further, reduction of viscosity may allow grease to be removed from the sliding surface. Finally, we have adopted extreme-pressure grease that is not easily removed under high surface pressure.

7.2 Study of grease (Improvement 2)

A groove for grease to escape is provided on the flange in order to increase fluidity of the grease for the same reasons as above. Fig. 9 shows the overview of a grooved flange.

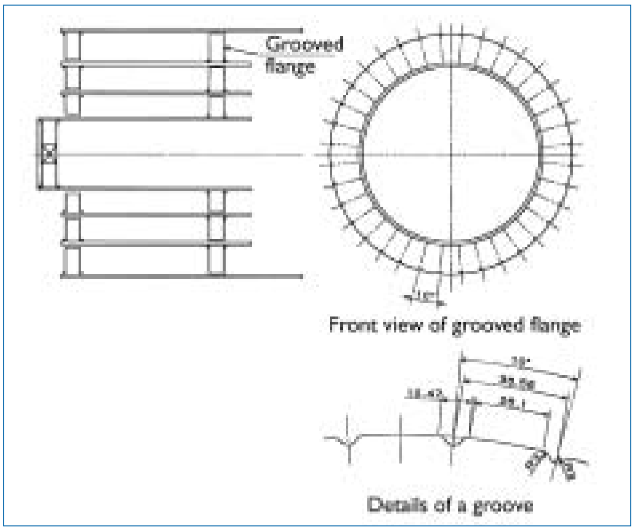

Fig. 9: Overview of grooved flange

7.3 Study of grease (Improvement 3)

Both the flange and pipe are provided with hot-dip aluminum coating, and components made of the same materials are made to slide on each other. Generally, components made of the same materials are said to result in increased sliding resistance. So we have changed the flange material to reduce sliding resistance. We have selected a hard material (SUS) and a soft material (FB series). The FB has a surface profile similar to that of the aluminum plated one. We have selected it since it has high surface pressure.

8 Fundamental test and test result

An improved prototype was subjected to a repeated load test.

8.1 Test result for the prototype of the alternate grease

Table 7 shows the result of the repeated load test (test repeated in 10 to 30 steps) after the grease was changed. The tension change rate was deteriorated down to the level of 18.25% after 30th step of the repeated load test.

8.2 Test result after changing flange profile

In the repeated load test, the tension change rate further deteriorated as compared to the case after the above-mentioned change of grease.

8.3 Test result by change of flange material

Increased number of repeated steps in the test caused a deterioration in the tension change rate.

Table 7 Test result after changing grease

Test item	Stroke	One-way stroke		Return stroke		Reciprocal stroke
	mm	kN	%	kN	%	%
10th step of repeated operation test	-320	37.24	-5.00	34.79	-11.25	19.50
	0	39.89	1.75	37.34	-4.75	
	320	42.43	8.25	40.38	3.00	
20th step of repeated operation test	-320	37.24	-5.00	34.59	-11.75	19.00
	0	39.59	1.00	37.14	-5.25	
	320	42.04	7.25	40.18	2.50	
30th step of repeated operation test	-320	37.34	-4.75	35.18	-10.25	18.25
	0	40.18	2.50	37.24	-5.00	
	320	42.34	8.00	40.38	3.00	

9 Consideration of proposed improvements

9.1 Change of grease

The test result after changing the grease shows that the tension change rate deteriorated to the level of 18.25%. This is because grease has entered the rough skin of the tensioning device sleeve surface due to reduced viscosity of grease, and the grease does not function properly.

Accordingly, grease of a higher viscosity (equivalent to the currently used grease) is considered to be adequate.

9.2 Changing the flange profile

In the test of flange profile modification, the plan was to form a groove on the flange to ensure the smooth flow of grease. As a result, however, contact surface pressure increased, and the tension change rate deteriorated as compared to the case where only the grease was changed.

Accordingly, as for flange profile modification, it has been revealed that grooving is not effective. Further, it has been shown that the flange should have a profile that tends to reduce surface pressure.

9.3 Change of flange material

When SUS was used as flange material, the tension change rate deteriorated in proportion to the number of load test steps. This is because scoring has occurred to the flange due to the protrusion on the inner surface of the pipe.

In the case of FB, the tension change rate was about 16%. This is a good result as compared to other cases. Since the polygonal line representing the relationship between stroke and tension exhibits a smooth figure, the sliding characteristics of the flange are considered to be improved by the current flange profile (groove-free flange).

Accordingly, better results cannot be easily obtained despite various changes in profile. It has been revealed that there is no particular need for changing the profile. Since the tension change rate in the case of a normal flange profile when treated by HDA2 (hot-dip aluminum coating) is about 16%, the performance is considered to be about the same as that of the FB.

10 Checking for impact on the power supply to electric trains (current collection performance)

From the above-mentioned test result, it has been shown that the tension change rate of ±9% has been realized, but the target of ±8% could not be achieved. We examined the possible impact of this difference of 1% upon the power supply to electric trains (generally called current collection performance), when the actual facilities are mounted with consideration given to commercial operation.

10.1 current collection performance evaluation indicator 1)

There are the following three indicators to evaluate the current collection performance when the contact wire tension has been changed:

① *Wave propagation speed and contact break rate*

Wave propagation speed can be defined as the speed of the wave traveling along the contact wire caused by the pantograph while the train is in motion. Wave propagation speed is higher as the tension of the contact wire is higher or the unit weight of the contact wire is lower. The higher this wave propagation speed, the more suited to high-speed running.

Further, contact break rate can be defined as the ratio of the time when the contact wire and pantograph are separated from each other while the train is in motion and normal current collection (supply of electricity) is not carried out, with respect to the total traveling time. To keep the contact break rate to a minimum, the train traveling speed is preferred to be below 70% of the wave propagation speed.

② *Resonance of contact wire in a trainset with multiple pantographs*

The level of resonance of contact wire in a trainset having multiple pantographs is proportional to the speed of wave propagation.

③ *Variation of contact wire height*

The contact wire height varies with the change in tension. It may happen that the contact break rate is increased when microscopic asperities occur to the contact wire that has been horizontal, with the result that the current collection performance is affected.

10.2 Equipment conditions

As described in "3.1.1 Study of stroke," we used Shinkansen CS contact wire simple catenary as the contact wire equipment. Calculation was made under the following conditions:

- Contact wire: CS110 mm2; messenger wire: PH 150 mm2; tension: 19.6 kN.
- Traveling speed: 275 km per hour as the current maximum speed
- Spacing between utility poles: standard 50 m
- Tension change rate: double scale (±8% and ±9%)

10.3 Result of calculation

Table 8 shows the result of calculating the tension change rate and wave propagation speed under the equipment conditions:

Table 8 Change rate of tension and wave propagation speed

Tension change rate	-9%	-8%	–0%	+8%	+9%
Tension [kN]	17.8	18.0	19.6	21.2	21.4
Wave propagation speed [km/h]	497.1	499.8	521.1	541.6	544.1
70% value [km/h]	348.0	349.9	364.8	379.1	380.8

10.4 Reference

① *Wave propagation speed and contact break rate*

The area with lower tension and lower wave propagation speed is less advantageous in terms of current collection performance. Such an area was used for comparison and study.

As a result, the difference in wave propagation speeds when the change rate is -8% and -9% is 2.7 km per hour, and the difference is as slight as 1.9 km per hour even when the value is multiplied by 70%. So there is considered to be no big change in the contact break rate.

Accordingly, there seems to be no impact on the current collection performance.

② *Resonance of contact wire in a train with multiple pantographs*

The change rate of wave propagation is higher in the area having a negative tension change rate. So we made a comparative study of the case where -8% was changed to -9%.

As a result, we got 0.9946 times the change rate. This means almost one time the change rate. There is considered to be no impact on the resonance of the contact wire.

③ *Contact wire height*

We made a comparative study in the area where current collection performance was reduced by loosening the contact wire. As a result, the contact height was lowered one to two millimeters when there was a change in tension.

This study has revealed that changing the contact wire height has no impact on the current collection performance.

10. 5 Summary of current collection performance verification

The above discussion shows that there is no impact upon the current collection performance even if the change rate has changed from ±8% to ±9%.

11 Conclusion

In our research and development discussed in this paper, we could not achieve the original target as viewed from the result. However, when compared with the conventional spring type tensioning device, we succeeded in a substantial reduction in the tension change rate from ±15% to ±9%. Further, we examined the impact on the current collection performance by simulation, and it has been revealed that there is no particular impact. We have reached the conclusion that the new spring type tensioning device can be used for the Shinkansen facilities.

This new spring type tensioning device has already been put into commercial operation on the Shinkansen and has been adopted for the line between Morioka and Hachinohe on the Tohoku Shinkansen.

We at the Technical Center will continue this research and development project in an effort to reduce the maintenance burden and cost.

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