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# A Study of Countermeasures against Conductor Galloping at full-scale Test Lines

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***Abstract*—Conductor galloping sometimes occurs in our transmission lines and causes some electrical faults and mechanical damages and we have installed 'Inter-phase spacer', 'Eccentric weights' and 'Loose spacer' against the galloping. This paper shows the study of their countermeasures at full-scale test lines.**

## I. Introduction

CONDUCTOR galloping sometimes occurs in our transmission lines and causes some electrical faults and mechanical damages. About 20-30 years ago, the galloping happened mainly in particular mountainous area by in-cloud icing (rime icing), but in latest 15 years we have experienced some galloping in plain area by wet snow accretion. So we have installed 'Inter-phase spacer' to 66 and 154 kV lines against galloping and adopted 'Eccentric weights' to the 275 and 500 kV lines. Moreover, in the latest years, we have installed 'Loose spacer' and 'Inter-phase spacer' to some 275 and 500 kV lines because its weight has become lighter than that of 'Eccentric weights' according to development of polymer insulator and our study. In this paper, we are showing the study of their countermeasures at full-scale test lines. The study shows that their countermeasures have the ability as countermeasures and the effectiveness of 'Loose spacer' depends on their arrangement.

## II. Damage to Transmission Lines Due to Galloping

We have experienced a lot of damages to our transmission lines due to the conductor galloping and the damage includes both electrical influence and mechanical damage. TABLE 1 shows our typical damages in trunk lines due to the conductor galloping. We have been studying about mechanism of galloping and countermeasures against conductor galloping, however, galloping is still one of the most important problems regarding network reliability of power supply.

TABLE 1
TYPICAL DAMAGE TO TRANSMISSION LINES DUE TO GALLOPING

| Electrical Damages | Mechanical Damages |
|---|---|
| - Short Circuit between conductors<br>- Short Circuit Ground Wire to Conductor<br>- Short Circuit between Jumper and Tower Cross-arm<br>- Arc Trail on Conductors and Ground Wires | - Bolt Loosening and Breaking<br>- Iron Member Damaging (Crack etc.)<br>- Jumper Breaking<br>- Insulator Damaging<br>- Spacer Clamps Breaking/Wear |

## III. Countermeasures against Galloping

We have already installed 3 types of countermeasures against galloping according to the condition of the transmission lines such as number of conductors and line voltage (Fig. 1). Their mechanism and features are as follows.

### *A. 'Eccentric Weights'*

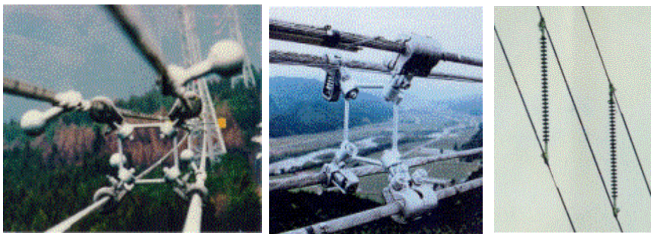
'Eccentric weights' consists of free-rotational clamps and weights on conductor close to spacers. Free-rotational clamps make the deference between the torsional motion and vertical oscillation of bundle conductor in frequency area and heavy weights make the deferent motion in phase area. This device is usually effective but there are a lot of cases that we cannot adopt this to the existent lines or need the reinforcement of towers due to their heavy weight.

### *B. 'Loose Spacer'*

'Loose spacer' has both rigid and free-rotational clamps. The two types of clamps make the deference of snow/ice accretion shape and conductor torsional motion between conductors. So their unbalance aerodynamic and motion make the control of galloping. The device is almost light as same as normal line spacers, so they are widely used in Japan. But it is thought that there might be an ineffective case in a special condition.

### *C. 'Inter-phase spacer'*

'Inter-phase spacer' consists of insulators (ceramic/polymer) and clamps and they keep some distance between conductors when galloping happens. They are most widely used in lower voltage lines and recently in trunk lines. But some reports show that they have some problems with their fitting breaking when galloping occurs in trunk line.



(a) 'Eccentric weights' (b)'Loose spacer' (c) 'Inter-phase spacer'

Fig. 1. Countermeasures against Galloping

## IV. Full-scale Test at Mogami Test Line

Mogami Test Line was constructed in 1979 in the north of Japan and a lot of tests about conductor motion, especially galloping were executed there for the purpose of development of large capacity and high voltage transmission lines.

Around this site there is a special local wind "Kiyokawa Dashi". Thanks to this there are more than 70 windy days (more than 10m/s at 10 minutes average) in every year and the wind direction is almost only ESE that makes our research easier.

We studied about mechanism of galloping in this site, observed the galloping control effect of new devices in basic case and checked the long-term reliability of their products. After these investigations we can introduce their devices to our real lines finally. We have installed 'Inter-phase spacer' to 275 kV lines and 'Loose spacer' to 275 and 500 kV lines after testing there. In this paper the results of their test are described.

Regarding 'Eccentric weights', its study and adoption to real lines had been already completed when the galloping study began at Mogami Test Line.

### *A. Outline of Mogami Test Line*

Fig. 2 shows feature of Mogami Test Line and the artificial snow accretion that is used because there are little wet snow accretion on conductors there. The height of snow accretion is set to the half of diameter of conductor, so it is called 'D/2 triangle shaped'. This shape was based on observation result in real line and snow wind tunnel test. Mogami Test Line has 500kV line (2 spans: 360m+250m) and 1,000 kV lines (1 span: 600m).

Fig. 2. Mogami Test Line and artificial Snow Accretion

### *B. Test Result of 'Loose spacer'*

The test of 'Loose spacer' was done in the span of 360m by using 4-bundled conductor (ACSR410mm$^2$, 1 phase) and 9 spacers was installed to the span. The arrangement of loose clamp is shown in Fig. 3 and the result is shown Fig. 4. Tension variation means the deference between maximum and minimum tension during each 5 seconds.

In the case of no countermeasures, the maximum of tension variation reached to about 5.0 tonf/conductor and the vertical amplitude at this time was about 6.0 m (Note; 1.0 tonf means 1,000 kgf and 9.8kN). While, in the case of 'Loose spacer' the variation was reduced to approximately 2.2 tonf/conductor that is enough to show preventing the short circuits. In the case of 'Loose spacer', there was just only conductor swing by wind and no galloping oscillation. Moreover, there was no deference between the result of Case 1 and Case 2.

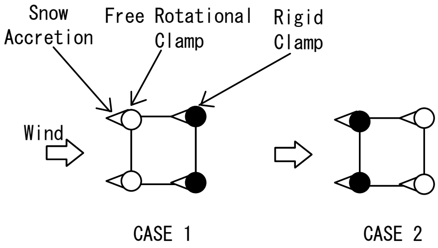



Fig. 3. Test Case of 'Loose spacer'

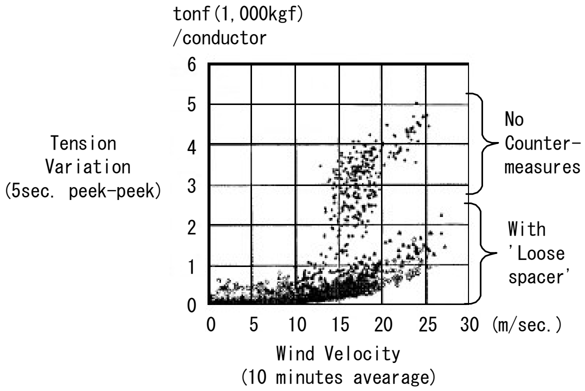



Fig. 4. Test Result of 'Loose spacer'

### *C. Test Result of 'Inter-phase spacer'*

The test of 'Inter-phase spacer' was done in the 360m with 4-bundled conductor (ACSR410mm$^2$, 3 phases). 3 phases were arranged vertically without horizontal offset and the distance between phases was about 7.5m. The polymer insulator was used to the 'Inter-phase spacer' to make its weight lighter.

The case of no countermeasures is same as that of 'Loose spacer'. The maximum of tension variation in the case of 'Inter-phase spacer' was reduced to approximately 2.5 tonf/conductor (Fig. 5.) This value would make no electrical faults such as short circuits, however, there was some galloping with small amplitude in the sub-span between 'Inter-phase spacer's.

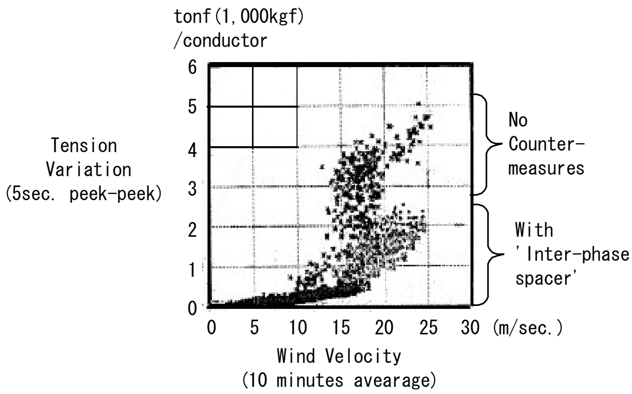



Fig. 5. Test Result of 'Inter-phase spacer'

## V. Full-scale Test at Shikoku Test Line

Shikoku Test Line was constructed in 1998 in the western-south of Japan and Japanese Utilities have researched the conductor motion and the load characteristics to towers when the extremely strong wind happened such as typhoon.

While in winter, in-cloud icing (rime icing) happens in the site due to the altitude of 1,500 m from see level and geographical feature and location. By using this event, we have studied about the effect of countermeasures in natural icing and looked for better arrangement of free-rotational clamps of 'Loose spacer'.

### *A. Outline of Shikoku Test Line*

Fig. 6 shows feature of Shikoku Test Line and the example of natural icing on 4-bundle conductor. Shikoku Test Line has 2 circuits 500kV line with 2 spans (350m+350m).

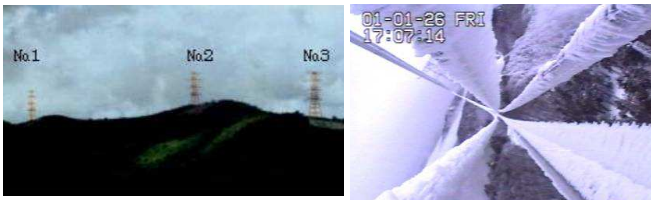



Fig. 6. Shikoku Test Line and in-cloud icing

We should make attention in analyzing of the galloping observed because there are 2 patterns in relationship with wind direction. One pattern is that the wind directions of icing and at galloping are same; the other is that they are different due to the changing of low-pressure system position (Fig. 7.) So we analyzed the observed galloping data in each case.

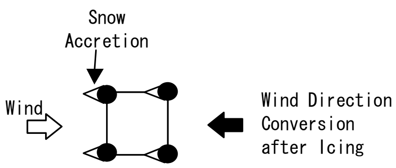



Fig. 7. Wind Direction Conversion

TABLE 2 shows the test case at Shikoku Test Line and all the tests were done in the span of 350m (ACSR410mm$^2$, 4-bundled conductor). Regarding 'Loose spacer', 4 arrangement patterns were tested. The test duration is shown in TABLE 3. The test of 'Inter-phase spacer' was not executed due to its weight, cost and the problems with fitting breaking.

### *B. Test Result of 'Eccentric Weights' and 'Loose spacer'*

The TABLE 3 shows maximum tension variation of each case. The variation of no countermeasures reached to 4.0/3.2 tonf/conductor in the case of without/with wind direction conversion. That of 'Eccentric weights' was reduced to 1.7/1.1 ton/conductor, and this shows the eccentric device is so effective.

While in the case of 'Loose spacer' the variation is a little less than or equal to that of no countermeasures. Although this result seems to show the ineffectiveness of 'Loose spacer', Fig.9 and 10 make us know that 'Loose spacer' is mostly effective because the data plots showing ineffective are not many.

TABLE 2
TEST CASE AT SHIKOKU TEST LINE

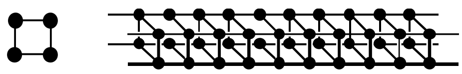
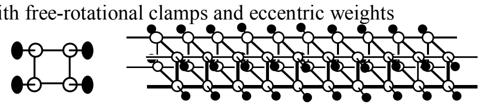
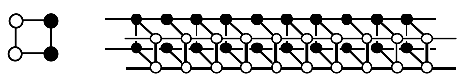
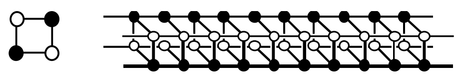
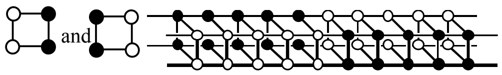
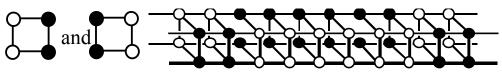
| No. | Type | Arrangement of Countermeasures in Span |
|---|---|---|
| 1 | No Countermeasures | Each spacer has rigid clamps.<br> |
| 2 | 'Eccentric Weights' | With free-rotational clamps and eccentric weights<br> |
| 3 | 'Loose Spacer' | With 2 free-rotational clamps (line symmetric)<br> |
| 4 | | With 2 free-rotational clamps (point symmetric)<br> |
| 5 | | With 2 free-rotational clamps (1 reverse (ration 5:5))<br><br>and |
| 6 | | With 2 free-rotational clamps (2 reverse (ration 2:6:2))<br><br>and |

TABLE 3
TEST DURATION AND MAXIMUM TENSION VARIATION OF CONDUCTOR

| No. | Countermeasure | Observation Duration | Maximum of Tension Variation of Conductor (tonf /conductor) | |
|---|---|---|---|---|
| | | | Without Wind Direction Conversion | With Wind Direction Conversion |
| 1 | No countermeasures | 5 Winter* | 4.0 | 3.2 |
| 2 | 'Eccentric Weights' | 2 Winter* | 1.7 | 1.1 |
| 3 | 'Loose Spacer' | 3 Winter* | 4.0 | 2.7 |
| 4 | | 4 Winter* | 3.4 | 2.7 |
| 5 | | 3 Winter* | 3.9 | 3.8 |
| 6 | | 5 Winter* | 3.1 | 3.2 |

* Winter is defined as from November to April.

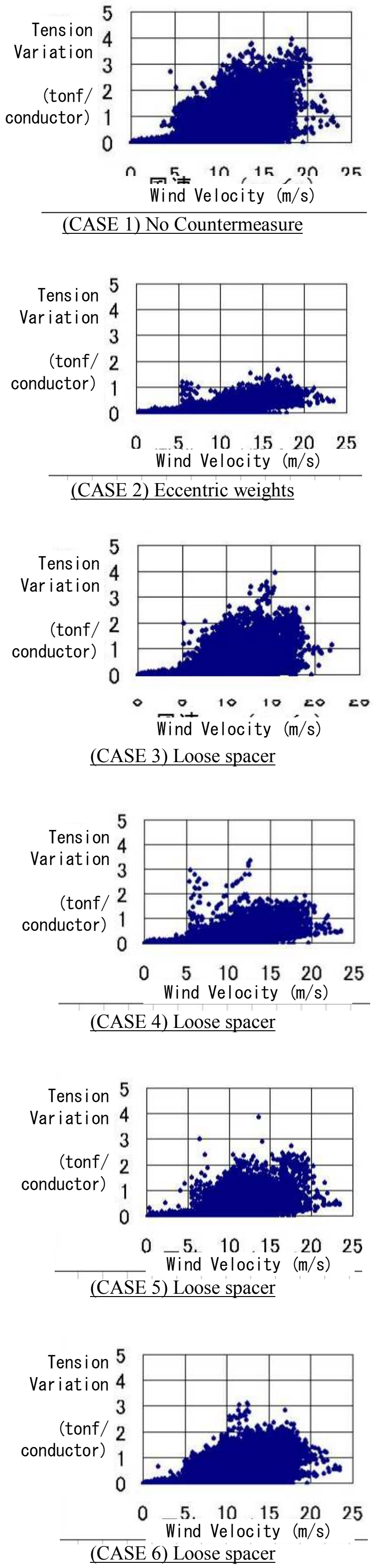



Fig. 8. Tension Variation (5 seconds peek to peek) to 10 minutes average wind velocity without wind direction conversion after ice accretion.

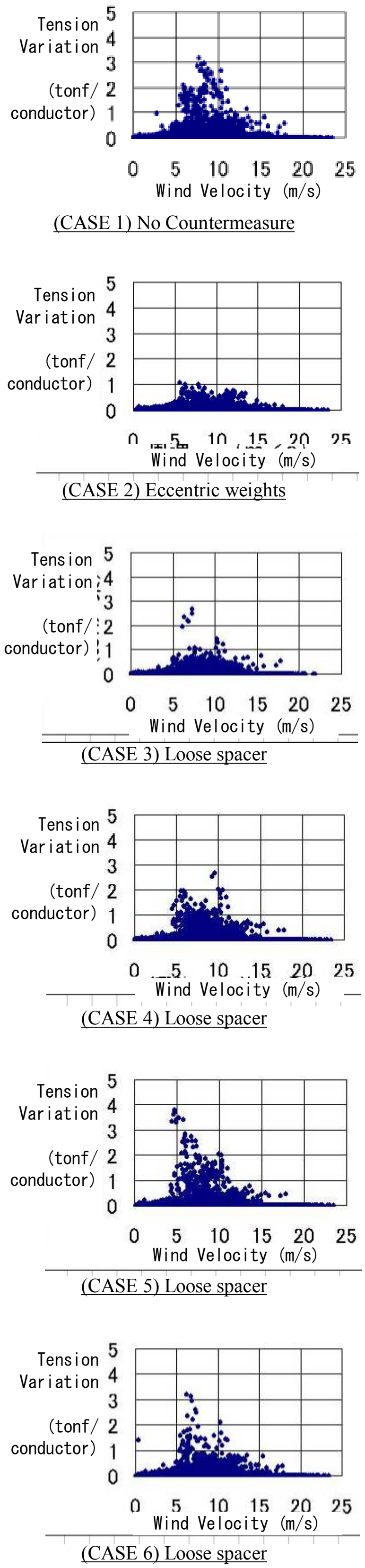



Fig. 9. Tension Variation (5 seconds peek to peek) to 10 minutes average wind velocity with wind direction conversion after ice accretion.

### C. *Evaluation of Arrangements of 'Loose spacer'*

TABLE 3, Fig. 8 and 9 are not useful for evaluating the arrangements of 'Loose spacer', so we made the data accumulation curve of effectiveness (Fig. 10.) Horizontal axis of Fig. 10 means the ratio of tension variation (tension variation of countermeasures / tension variation of no countermeasures at the same time only when the latter is more than 1.0 tonf/conductor as galloping). The value of data accumulation at the ratio of tension variation 1.0 means the effective percentage of countermeasures against galloping.

TABLE 4 shows the effective percentage of each countermeasures and 'Eccentric weights' is most effective. Concerning 'Loose spacer', Case 4 or Case 6 would be selected as better arrangements and we would the best arrangement by evaluating risk of galloping with wind direction conversion.

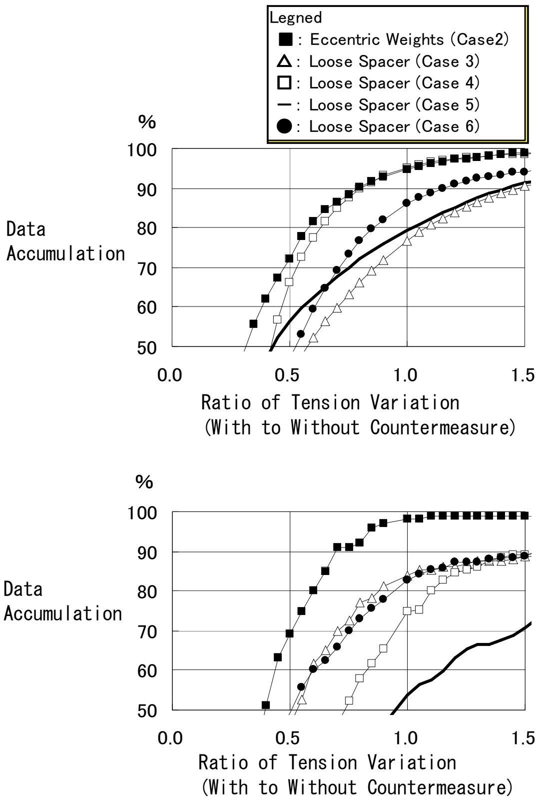



Fig. 10. Accumulation Curve of the Ratio of Tension Variation

TABLE 4
EFFECTIVE PERCENTAGE OF EACH COUNTERMEASURE

| No. | Type | Effective Ratio (%) (At Tension Variation Ratio 1.0) | |
|---|---|---|---|
| | | Without Wind Direction Conversion | With Wind Direction Conversion |
| 2 | 'Eccentric Weights' | 95 | 98 |
| 3 | 'Loose Spacer' | 76 | 83 |
| 4 | | 95 | 75 |
| 5 | | 81 | 54 |
| 6 | | 86 | 83 |

## VI. CONCLUSION

The conductor galloping by ice/snow accretion sometimes occurs in our transmission lines and causes some electrical faults and mechanical damages. So we have been studying about the effectiveness of several types of countermeasures by using full-scale test line.

According to the result of Mogami Test Line, the effectiveness of 'Loose spacer' and 'Inter-phase spacer' were shown in basic case with 'D/2 triangle shaped' artificial snow accretion.

According to the result of Shikoku Test Line, the effectiveness of 'Loose spacer' and 'Eccentric weights' were shown in natural icing condition. In addition of them, 'Eccentric weights' is most effective than 'Loose spacer', and the degree of the effectiveness of 'Loose spacer' depends on their arrangements of free-rotational clamps.

Finally, the galloping is still one of the serious problems in Japan, so we have to continue the research and development regarding galloping by real line observation, full-scale test and simulation etc.

## VII. REFERENCES

[1] H. Haji et al., "Field Test Results of 'Loose spacer' for galloping," *IEEJ National Spring Conference 7-025*, March 2000.

[2] H. Mitsuzuka, Kozo Takeda and Ryoichi Shishido, "Field Test Results of 'Loose spacer' for galloping -2," *IEEJ National Spring Conference 7-029*, March 2001.