A wind tunnel study on unsteady forces of Ice accreted transmission lines

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ABSTRACT: This paper describes the unsteady aerodynamic forces on a single conductor and four-conductor section model of ice-accreted transmission lines. The unsteady aerodynamic forces were measured by using an apparatus that can forcedly oscillate the model with large rotational amplitude in the wind tunnel. The unsteady aerodynamic forces of ice-accreted single conductor and four-conductor bundled transmission lines are different, and both are affected by the angular velocity of motion. The expression unsteady moment of four-conductor based on single conductor is difficult.

1.0 INTRODUCTION

The large amplitude wind-induced motion of ice-accreted conductor transmission lines, which is conventionally called galloping response, is generally a coupled torsional and vertical motion, may cause flashover that results in the shut down of the lines. It has been studied for decades and effective countermeasures have been sought. To perform realistic transmission line galloping simulations, it is important to define accurate aerodynamic coefficients of ice accreted transmission lines. Kimura[1] pointed out that in galloping response analysis, the unsteady aerodynamic force should be used instead of quasi-steady aerodynamic force. However, almost all of the transmission lines have multi bundled conductors. It is necessary to clarify the relation in the unsteady forces of single conductor and multi bundled conductor transmission lines. However, the understanding about the dependence of bundled conductor number on unsteady forces as well as experiments' database seem to be not enough.

In this study, the authors conducted a series of wind tunnel experiments using a single conductor model (1D) and four-conductor bundled model (4D) with artificial accreted ice. The unsteady aerodynamic forces acting on a forcedly oscillated section model of an ice-accreted 1D and 4D were measured under rotational motion, and their characteristics were compared. The effects of the unsteady characteristics were not very significant for unsteady drag and lift forces comparing to unsteady moment force. Because of the limit of number pages, the discussion about unsteady drag and lift force are omitted in here. The unsteady moment forces are discussed.

2.0 EXPERIMENT PROCEDURE

The unsteady experiment was conducted at the wind tunnel of Mitsui Engineering and Shipbuilding Company Limited in Tokyo, Japan. For the basic comparison, the quasi-steady experiment was also done at the wind tunnel of University of Tokyo. Two section models were used (Fig. 1,3). The accreted-ice configuration of the single conductor model (1D) and 4-conductor bundled model (4D) are shown in Figures 2 and 4 respectively.

The amplitudes of the rotational forced motion

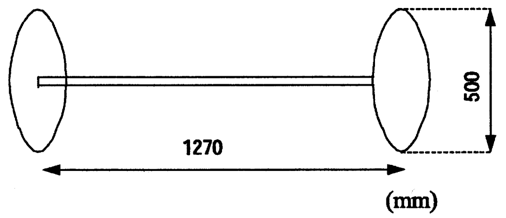

Figure 1. Section model of 1D

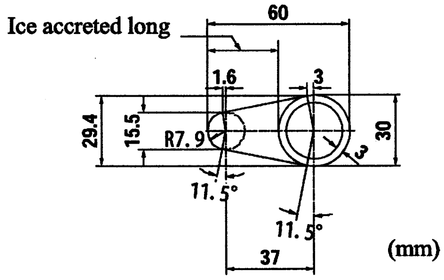

Figure 2. Accreted ice configuration of 1D

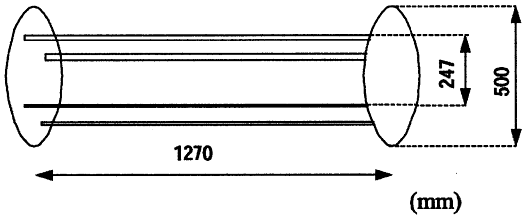

Figure 3. Section model of 4D

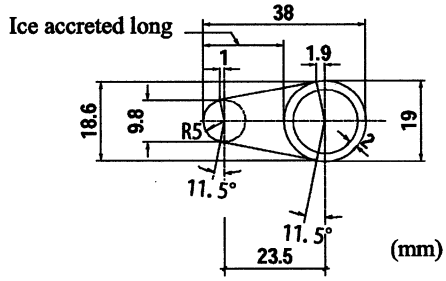

Figure 4. Accreted ice configuration of 4D

were ±5°, 10, 20, 30, 40, 55°. The angle of attack was chosen to be 0°. The measure of the unsteady aerodynamic forces was made with the forced oscillation frequency 0.3Hz. The wind speed was 10m/s.

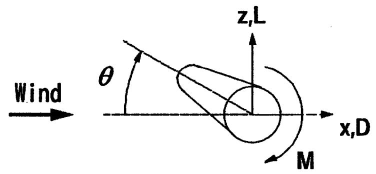

Figure 5. Coordinates of aerodynamic forces

3.0 CHARACTERISTICS OF UNSTEADY AERODYNAMIC FORCES

3.1. *Aerodynamic force coefficients*

Aerodynamic force based on the wind axis(x,z) shown in Figure 5 can be formulated by the definition of the aerodynamic coefficients with the relative among wind speed, angle of attack, the rotational angular velocity as follows:

$$M = 0.5\rho ABU^2 C_M(\theta, \dot{\theta}B/U) \quad (1)$$

where U: wind speed, ρ :air density, A: projected area ($= 2DL = 0.04826mm^2$ for 4 conductors; D: conductor diameter, L: length of the model), B: separation distance of the conductors(=0.247mm for 4 conductors), θ: relative angle of attack, equals to rotational displacement of the model in this study, $\dot{\theta}$: rotational angle velocity. C_M: moment coefficients.

For the comparison with four-conductor bundled model in advance, four single conductors(1D-4) were used, the force coefficients of 1D-4 were obtained as the four times of the force coefficients of 1D.

The quasi-steady moment coefficients (moment coeff.) mean the moment coefficients obtained from quasi-steady forces. The unsteady moment coefficients mean the moment coefficients obtained from unsteady forces.

3.2. *Unsteady forces on 1D*

The time series of the unsteady moment forces under the harmonic rotational forced motion (±55°, 0.3Hz) of 1D were shown in Figure 13. The time series of the unsteady moment force seemed to agree with the quasi-steady moment force. The unsteady moment coefficients did not changed

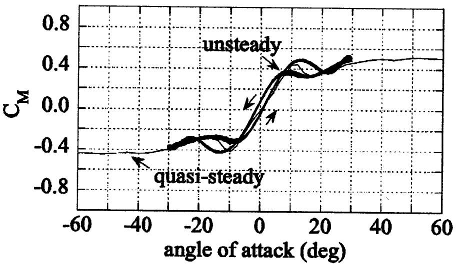

Figure 7. Moment coefficients of 1D-4 (amp=±30°)

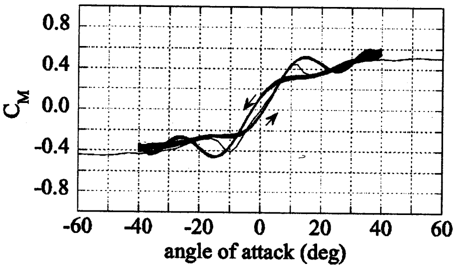

Figure 8. Moment coefficients of 1D-4 (amp=±40°)

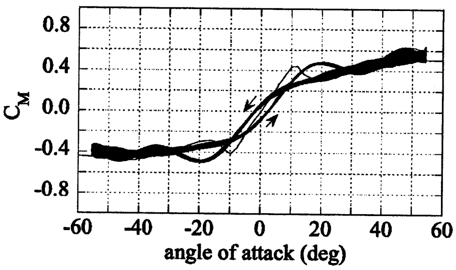

Figure 9. Moment coefficients of 1D-4 (amp=±55°)

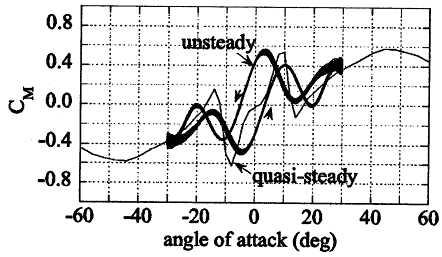

Figure 10. Moment coefficients of 4D(amp=±30°)

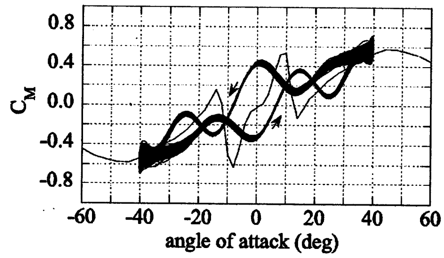

Figure 11. Moment coefficients of 4D(amp=±40°)

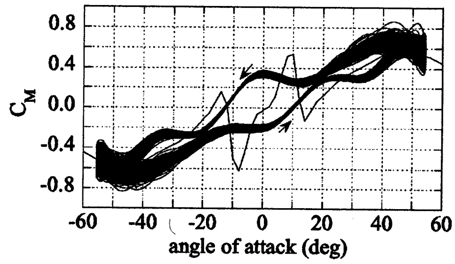

Figure 12. Moment coefficients of 4D(amp=±55°)

much by the varieties of rotational amplitude (Fig. 7,8,9). When the rotational amplitude increased, the unsteady moment coefficient seemed to be extended, and its slopes decreased slightly.

3.3. Unsteady forces on 4D

The time series of the unsteady moment forces under the harmonic rotational forced motion (±55° ,0.3Hz) were shown in Figure 14. The phase of the unsteady moment was slightly behind the quasi-steady moment. The difference was obvious by comparing them as coefficients (Fig. 10,11,12). When the rotational amplitude increased, the unsteady moment coefficients were extended. The peaks seemed to be gone, and the slopes decreased significantly compared to the quasi-steady moment coefficients.

3.4. Discussion on the unsteady aerodynamic force characteristics

The differences between unsteady moment force of 1D and 4D were large as described above. The difference may be explained by the effect of the wake of windward conductors. The agreement is that there is not effect of wake in 1D. On 4D, the wake of conductors swings around the relative wind direction. When the rotational amplitude increases, the “swing” may be large enough to disturb the wind, decrease the peak and delay the phase of the moment coefficient. However, it does not explain the extension of unsteady moment on 1D.

In order to clarify the effects of rotational velocity on the unsteady aerodynamic forces,

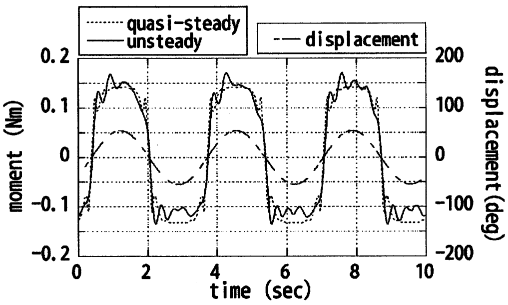

Figure 13. Moment force of 1D (amp=±55°)

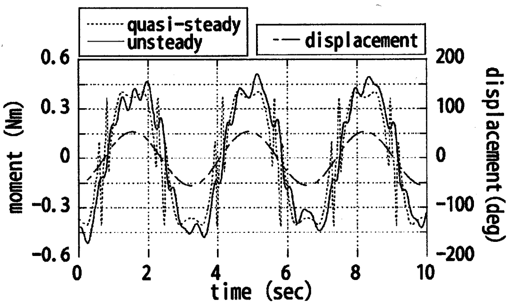

Figure 14. Moment force of 4D (amp=±55°)

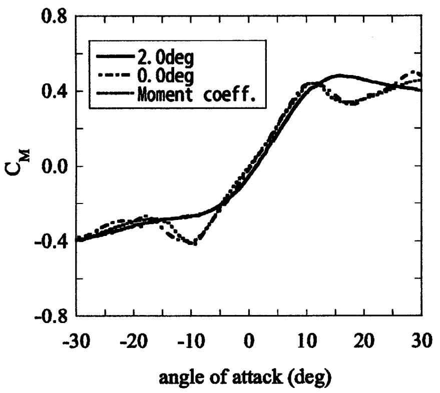

Figure 15. Moment coefficient in $\theta - C_M$ plane of 1D-4

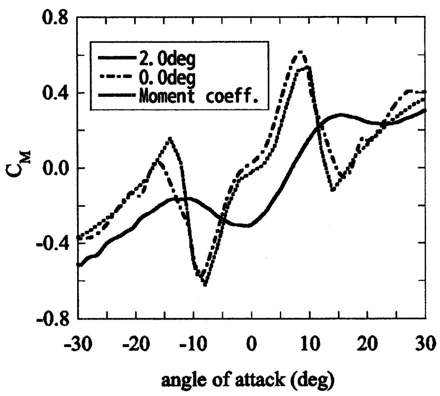

Figure 15. Moment coefficient in $\theta - C_M$ plane of 4D

the authors used the method suggested by Kimura[1]. By interpolating the measurement with rotational frequency of 0.3Hz and amplitudes of ±5, 10,20,30,40 and 50° ,the cross-sections in $\theta - C_{M \cdot z}$ are shown in Fig.15 (1D-4), Fig.16 (4D). With 1D, unsteady moment generally agreed with the moment coefficient ($\dot{\theta}B/U = 0.0\,\text{deg}$). The difference was still not large with $\dot{\theta}B/U = 2.0\,\text{deg}$. However, the unsteady moment coefficient did not agree with the moment coefficient for 4D($\dot{\theta}B/U = 0.0\,\text{deg}$). The difference became greater with large angular velocity ($\dot{\theta}B/U = 2.0\,\text{deg}$).

4.0 CONCLUSIONS

The unsteady aerodynamic force characteristics of unsteady forced rotational oscillation of the ice-accreted singe conductor and four-conductor bundled transmission line were studied, and the following conclusion were obtained:

1. The unsteady aerodynamic forces of ice accreted transmission line were affected by the angular velocity.
2. On the ice-accreted single conductor model, the unsteady moments were not affected too much by angular velocity.
3. On the ice-accreted four-conductor model, the unsteady moment took quite different values from the quasi-steady moment.
4. The expression for the unsteady aerodynamic force of a multi bundled conductors based on a single conductor ice accreted transmission line is difficult and it should to be studied further.

5.0 REFERENCES

[1] Kimura, K. Unsteady forces on an ice-accreted four-conductor bundle transmission line. Wind Engineering into the 21st Century, Larsen, Larose & Livesey(eds). Balkema, Rotterdam (1999), pp 467-472