Field Observation and Analysis of Wind-Induced Vibrations in Four-Bundled Conductor Transmission Lines

Hong-Kwan Sohn*, Hyung-Kwon Lee*, Jang Hee Chu, Dong-Il Lee*** and Eun-Woong Lee******

Abstract - This paper presents observations made on four-bundled conductor transmission lines concerning the behavior of conductors under the effect of natural winds. To know the wind-induced vibration status and how to control it, wind-induced vibrations have been recorded and analyzed from the real transmission lines. From the field observation and analysis results, subspan oscillation was found to be the main type of vibration. In addition, the data also revealed some common characteristics of the observation sites with high maintenance rates. The results will be used in controlling the subspan oscillations and protecting the conductors.

Keywords: Subspan Oscillation, Aeolian Vibration, Wake-Induced Oscillation, Spacer Damper, Transmission Line

1. Introduction

Wind-induced vibrations are known to cause damage to conductors and related hardware through fatigue, clashing of the bundled conductors, and bolt loosening. Generally, three types of wind-induced vibrations are considered: aeolian vibrations, wake-induced oscillations, and galloping. Galloping is related to the presence of ice on the conductors and will be omitted from this paper. Aeolian vibrations are caused by vortex shedding and occurred in all transmission lines [1]. This vibration induces mainly vertical movements of the conductor at a frequency related to the wind velocity V and the conductor diameter d [2]. Velocities below 7 m/s are propitious conditions for such vibrations to occur. In the case of the four-bundled conductors, aeolian vibrations are not a severe problem due to the low amplitude [3]. Moreover, spacer dampers can control aeolian vibrations on bundled conductors.

Wake-induced oscillations have been known since the advent of bundled conductors in the mid-1960s. They are caused by aerodynamically unstable forces acting on the leeward conductors in the wake of the windward conductors. They take the form of vertical galloping, horizontal galloping (snaking), or rolling (twisting), in which case all subconductors move together in unison, and they are called rigid body mode oscillations. They can also take the form of subspan oscillations, which appear as elliptical motions of the subconductors moving out of phase, mainly in the horizontal plane within a subspan. The range of the wind velocity at which subspan oscillations occur is usually 4 to 18 m/s [1]. The critical wind velocity is highly dependent on the bundle configuration and installation of the spacer dampers [1,2]. Four-bundled conductors, in particular, are very susceptible to subspan oscillations due to the bundle configuration.

In this work, the aeolian vibration and subspan oscillation in four-bundled conductor systems in Korea were investigated to know the status of the wind-induced vibrations for four-bundled conductor transmission lines.

2. Aeolian Vibration Measurement

Aeolian vibration amplitude and frequency in four-bundled conductors were measured for about a month using the Kochang test line to determine aeolian vibration status. Field measurements of aeolian vibrations and subsequent data analyses have been standardized in CIGRE [4]. According to CIGRE, conductor displacement should be measured relative to the suspension clamp at a distance of 89 mm from outermost point of contact between the clamp and the conductor (Fig. 1), Conductor displacement is also called bending amplitude. Aeolian vibration amplitude and frequency of four-bundled conductors are as

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shown in Fig. 2, which shows the very low amplitudes at the point of the suspension clamps. Vibration amplitude data shown in Fig. 2 were recorded and analyzed with the VIBREC-300 (SEFAG, Switzerland), a special instrument for measuring aeolian vibration amplitudes and made in accordance with the CIGRE standard.

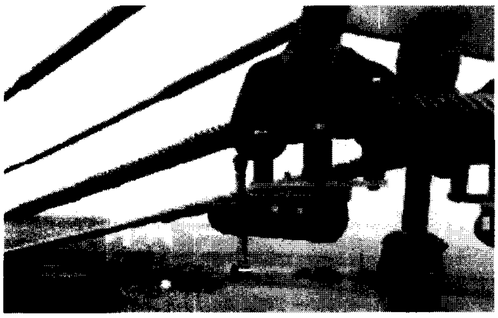
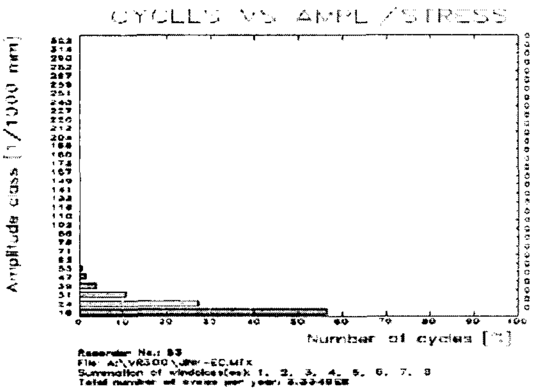
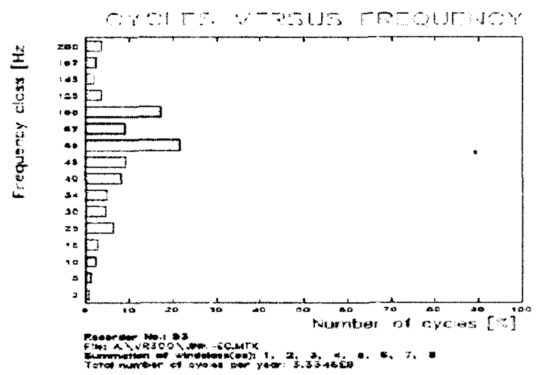


Fig. 1 An aeolian vibration recorder (VIBREC-300) attached to a suspension clamp.



(a) Aeolian vibration amplitude



(b) Aeolian vibration frequency

Fig. 2 Measured aeolian vibration amplitude and frequency of Kochang test line.

Maximum safe bending amplitude of the ACSR Cardinal and Rail conductor is 0.23 mm [1]. To use the conductor safely during its lifetime, aeolian vibration amplitudes must be lower than the safe bending amplitude at the suspension clamp point or support point. Aeolian vibration amplitudes and frequencies of four-bundled conductors are as shown in Fig. 2.

3. Selection of the Observation Sites

There are a lot of four-bundled conductor transmission lines in Korea. Knowing where subspan oscillations occur frequently is very difficult. The observation sites can be selected by analysis of the maintenance data [5,6]. Information related to oscillation problems, such as bolt loosening and damage to the conductors and spacer dampers, can help with the selection of good positions or spans to observe the oscillation. Maintenance items related to oscillations are generally divided into bolt loosening, cutting of a subconductor (Fig. 3), damage to the spacer damper body (Fig. 4), and a free conductor from the clamp.

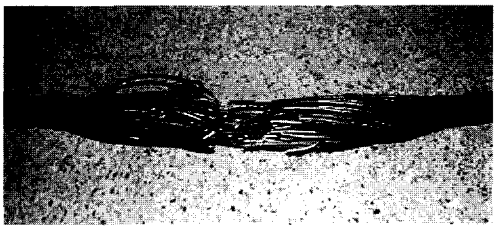


Fig. 3 Wearing of a conductor caused by oscillation.

Fig. 4 Damage to a spacer damper clamp.

Table 1 Maintenance rate related to the line oscillation

Line	Total No. of installed SD (SET)	No. of Spacer Damper maintenance (SET)				maintenance rate (%)		select
		(a)	(b)	(c)	(d)	all	(b+c+d)	
In-Seo	300		4	6		3.3	3.3	○
Boryung	3.564	320	2	5		9.2	0.2	
Young-Po	12.178	937	93	63	30	9.2	1.5	○
Sin-Kimjae	4.158	46	52			2.4	1.3	○
Ul-Young	7.884	357	69	20	1	5.7	1.1	
Sin-Kangjin	6.648		65	11	3	1.2	1.2	
Seo-Incheon	5.346	189	54	6		4.7	1.1	
Sin-Yangsan	2.067	20	22	1		2.1	1.1	
Youngkwang	6.549	240	48	14		4.6	1.0	○
Others	191.383	5.665	316	216	31	3.3	0.3	
Total	240.077	7.774	725	342	65	3.7	0.5	

(a) bolt loosening, (b) free conductors from the clamps, (c) wearing of conductors, (d) damage to a spacer damper body

Maintenance data from the sites were collected and analyzed as shown in Table 1. The average maintenance rate for all spacer dampers installed on four-bundled conductor transmission lines is 3.7%. Bolt loosening accounts for 87% of all failures related to oscillation problems. The observation lines were selected as shown in Table 1, and site condition and operation history were also considered.

4. Observation and Measurement

4.1 Characteristics of the observation sites

In-Seo T/L is located on seaside of the west Incheon. The line also has double circuits and was built on a flat terrain close to the sea. Wind direction and speed data have been collected and analyzed by online systems for a year. Fig. 5 shows that about 46% of the wind direction is perpendicular to the line. But no high wind speeds were observed (see Fig. 6), even though subspan oscillations were observed frequently.

The observation span of the Young-Po T/L crosses the Hyungsan River from the south to the north with 587 m span length. The probability that wind direction is perpendicular to the line was about 86% (see Fig. 7). In view of the oscillation occurrence, this site is in poor transmission line condition. The wind speeds were higher than In-Seo T/L as shown in Fig. 8. The Young-Po T/L had the highest maintenance rate due to vibration problems.

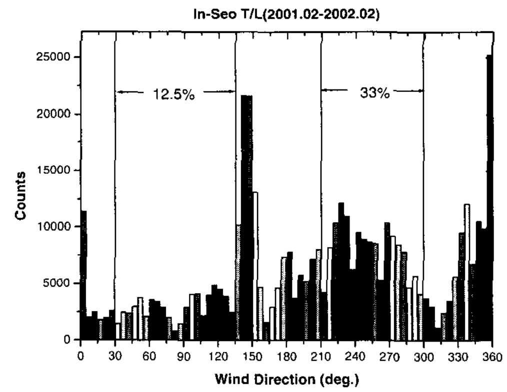


Fig. 5 Distribution of wind direction in In-Seo T/L.

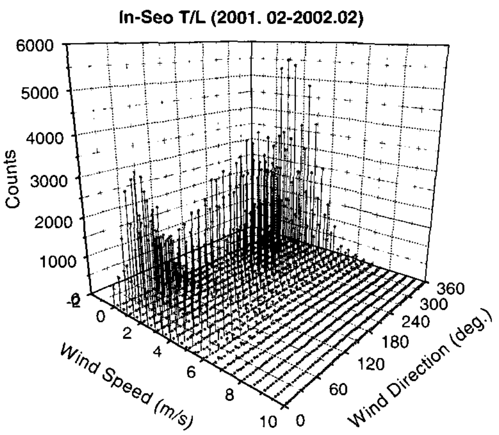


Fig. 6 Distribution of wind direction and wind speed in In-Seo T/L.

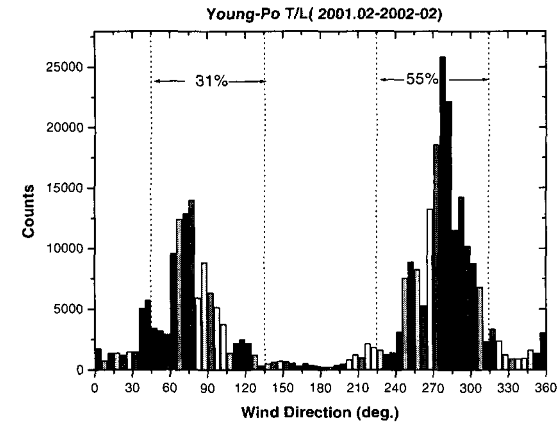


Fig. 7 Distribution of wind direction in Young-Po T/L.

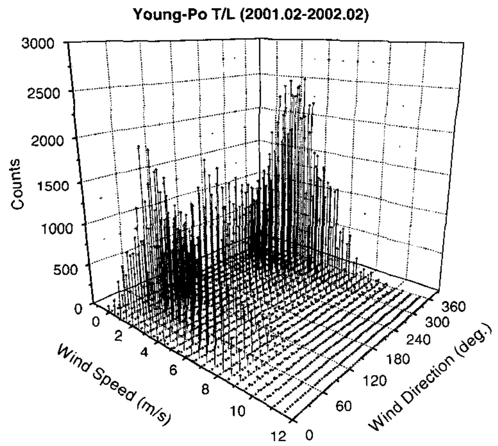


Fig. 8 Distribution of wind direction and wind speed in Young-Po T/L.

The observation span of the Youngkwang T/L is located in Jeon-Buk Province and was built on the rice fields and the flat terrain. Therefore, the site can be affected by winds easily.

The observation span of the Sin-Kimjae T/L crosses the Mankyung River, was built on flat terrain, and has a 754m-long span. So these observation sites can be easily affected by winds like the Young-Po T/L.

4.2 Recording of subspan oscillations

Because installing accelerometers or displacement sensors, anemometers and wind direction meters on energized lines is very difficult, on-the-spot recording method was adopted. Wind-induced oscillation, including wind speed and direction, was recorded directly under the lines and under optimal weather conditions.

The wind-induced oscillation data recorded by videotapes was analyzed according to the following methods.

• First, the type of wind-induced oscillation was analyzed.

• The video camera recorded 30 frames per second on videotape. Distances between the upper and lower subconductors were directly measured from the monitor every two frames.

• Oscillation amplitudes can be directly measured from the monitor by comparing with wind speed. After converting the measured values, oscillation frequency, amplitudes, and waveforms were analyzed.

5. Analysis Results

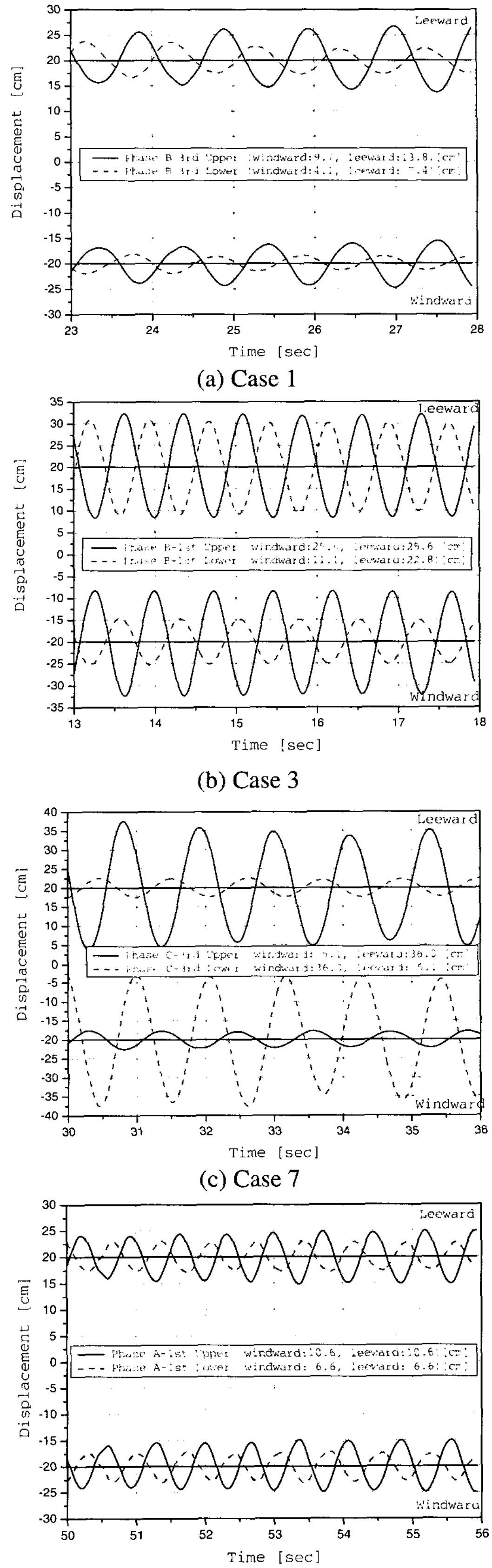
The observed wake-induced oscillations were mostly subspan oscillations, which oscillate in the horizontal plane within a subspan. No rigid body mode oscillations were observed; only subspan oscillations were observed.

Subspan oscillation amplitudes depended on tension, subspan length, and wind speed. Maximum amplitude of 43 cm (peak to peak) was found from the records. Clash between two conductors is possible in a view of the subconductor's distance. Most papers reported that subspan oscillations have minor effects on conductor fatigue. Nevertheless, subspan oscillations can have an effect on the conductor's fatigue and clash in four-bundled conductors.

Table 2 Analysis results of subspan oscillations

Site	Case	Span length (m)	Wind speed (m/s)	Frequency (Hz)		Amplitude (peak-peak) (cm)			
						Upper		Lower	
				Upper	Lower	Wind	Lee	Wind	Lee
YP	1	367	4	0.95	0.95	9.7	13.8	4.1	7.4
	2	420	4.0	1.39	1.36	12.5	12.5	20.9	20.9
	3			1.36	1.36	25.6	25.6	11.1	22.8
	4	587	5~7	1.09	1.10	18.0	18.0	16.3	16.3
	5		6~8	1.06	1.07	25.5	25.5	16.7	16.7
	6		8~11	1.03	1.04	9.5	9.5	5.7	5.7
	7	363	5	0.91	0.91	5.1	36.0	36.0	5.1
	8			0.94	0.91	14.7	42.4	12.1	12.1
IS	9	444	6~7	1.40	1.44	10.7	10.6	6.6	6.6
	10			1.39	1.42	10.5	10.5	10.4	10.4
SK	11	754	5	0.84	0.83	12.8	38.3	28.0	9.3
	12		8	0.83	0.80	3.6	27.2	23.1	41.7
	13		5	0.95	0.95	13.4	13.4	23.9	23.9

YP : Young-Po T/L, YK : Youngkwang T/L
IS : In-Seo T/L, SK : Sin-Kimjae T/L
Wind : Windward conductor, Lee : Leeward conductor
Upper : Upper conductor, Lower : Lower conductor
Wind speeds were measured on the ground.



(a) Case 1
(b) Case 3
(c) Case 7
(d) Case 9

Fig. 9 Graphs of the observed subspan oscillations

Among the subspan oscillation records, high amplitudes and good oscillation shapes were selected for analysis. Analysis results of the observed subspan oscillations are shown in Table 2. Wind speed of the subspan oscillation is much lower than expected. Subspan oscillation was observed at wind speed 4 m/s on the ground. Oscillation amplitudes are very high in relatively low wind speed. Some sample cases are graphed in Fig. 9. The figure shows the observed oscillations are purely subspan oscillation modes.

Oscillation frequency is a natural characteristic of a subspan and can be calculated as a function a subspan length, tension, and conductor weight per unit length. The theoretical frequencies, f, can be determined from

$$f = \frac{1}{2l}\sqrt{\frac{T}{m}} ,$$

where l is a length of the given subspan and T and m are conductor tension and mass per unit length, respectively. The observed oscillation frequencies were mostly about 1 Hz. They are well in accord with calculated frequencies. A comparison between observed and calculated frequencies is shown in Table 3.

Table 3 Calculated and observed frequency

Site	Tension [kgf] (span length)	Subspan length [m]	Calculated frequency [Hz]	Observed frequency [Hz]
Young-Po T/L	2,040 (367 m)	59	0.96	0.95
	2,000 (420 m)	41	1.36	1.36~1.39
	1,950 (587 m)	50	1.10	1.06~1.15
		53	1.04	1.03~1.04
Young-kwang T/L	2,497 (363 m)	66	0.95	0.91
		65.2	0.96	0.90~0.91
		82	0.76	0.76~0.79

The analysis results and data of the observed wind-induced vibrations described in this paper can be applied to understand the status of wind-induced vibrations in four-bundled conductors and protect conductors and spacer dampers from the subspan oscillations. Even though subspan oscillations are highly dependent on wind velocity, spacer damper installation, bundle configuration, and tension, proper countermeasures can be developed from the analysis results and vibration status in four-bundled conductor transmission lines. In other words, when some lines or sites have a high maintenance rate for the spacer dampers and conductors, reinstallation of the spacer dampers for controlling subspan oscillations may be required. However, no reinstallation is needed for aeolian vibration problems, especially for four-bundled conductors.

Those sites where vibrations were observed shared the following characteristics.

• Two sites cross rivers, with no obstacles to disturb the wind flowing.

• The observation sites are built mostly on a flat terrain.

• Wind direction is apt to be perpendicular to the lines.

From these common characteristics, we now know that special protection measures against subspan oscillations are needed for safe operation of the transmission lines that cross sites like the observation sites.

6. Conclusion

The following conclusions can be drawn from the results of this investigation of wind-induced vibrations.

① Aeolian vibration amplitudes are very low in four-bundled conductors.

② The type of observed wake-induced oscillation is subspan oscillation. No rigid body mode oscillations were observed in our four-bundled conductors.

③ Wind speeds of only 4 m/s caused subspan oscillation, a much lower speed than expected.

④ Subspan oscillation amplitudes were very high in relatively low wind speed. Therefore, when protecting the conductors from the vibrations in four-bundled conductor transmission lines, subspan oscillations should be considered first.

⑤ Common characteristics of the observation sites in Korea were known. The spans that had high maintenance rates are mostly built on flat terrains, cross a river, and frequently have winds perpendicular to the lines. So when sites or lines are built on similar sites, proper protection or control methods will be needed for the safe operation during the lifetime of the four-bundled conductor transmission

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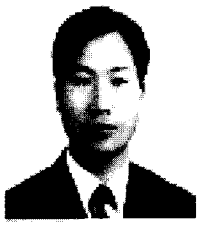

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