A Study on Interphase Spacer

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***Abstract*— Galloping is the phenomenon of low frequency, high amplitude motion of conductors associated with icing or snow accretion, and which cause line trip-outs, service interruptions, conductor damage and so on. To mitigate galloping oscillation the use of the interphase spacers, which connect the phases, is increasing. Before the practical use of such spacers, we have studied electrical feature or weatherability of that for many years. Some findings of those studies are briefly mentioned.**

1. Introduction

Interphase spacer was adopted in 1980's for main pool of 275 kV transmission line. Since then, we have not experienced galloping induced line trip-outs with interphase spacers for twenty years except for just a couple of exceptional cases, which provides experimental proof of effectiveness of the interphase spacer. In this paper, studies on interphase spacer and developed findings are described.

2. Background

Galloping of two bundled overhead transmission lines occured in 1980's mainly in southern HOKKAIDO and Sapporo area. Anti galloping dampers were adopted to prevent galloping in southern HOKKAIDO area, although such countermeasure was proved to have limited effects and no effect under strong wind condition.

Interphase spacer was regarded as promising countermeasure to galloping since early stage of galloping-studies. However, the length could be much longer in accordance with power voltage and anxiety of short circuit due to contamination like salt refrained from practical use in those days. The turning point came in 1986. Galloping induced line-trips occurred in the large area around Sapporo which one third of HOKKAIDO population live in, and urged us to investigate the effective and certain measure for preventing galloping. Inevitably, interphase spacers were adopted as temporally, at that time, to prevent galloping limited on one circuit of each transmission line. Since then, electrical instruments like many kind of electrical appliances, PCs in household, and FA in the factory prevailed and almost no brownout is required to the utmost these days. Thus, after large galloping induced trip-outs in 1993 and 1994, interphase spacers are installed both circuits on frequently gallopping-induced transmission lines. Interphase spacers on the main 275 kV transmission line in Sapporo area are shown in Figure 2.1

Figure 2.1 Interphase spacers

3. Light weighted polymeric interphase spacer

Interphase spacer is one of the concentrated mass for transmission line, and cause increased tension loads for supported towers. Thus, strength of members must be checked before installation. In early stage, interphase spacer was composed of porcelain insulators and that sums up to 320 kgf for large size conductors mainly used for Sapporo area, or 250 kgf for small size conductors used for southern HOKKAIDO area. Such heavy concentrated mass could cause so much reinforcement for towers that light-weighted interphase spacer was expected to reduce cost and alleviate installation works.

Expecting way for weight saving was adopting polymer covered FRP core insulator instead for heavy weight porcelain insulator, and began to develop polymeric interphase spacer.

FRP core was considered to sustain serious mechanical condition due to sever winter condition like HOKKAIDO, which lies in far northern part of JAPAN, and adopted 63 mm (2.5 inch) in diameter. Such thick FRP does not seem in other utilities in JAPAN as 275 kV transmission level, and almost no bending in itself observed in galloping motion.

(1) Mechanical Feature

To estimate mechanical characteristics, the bottom of sample FRP core of 63mm in deameter is fixed and horizontal load is added at the top end. Figure 3.1 shows load-displacement curve as a function of each load. FRP does not show perfect linear curve although almost linear property can be figured out on condition of usual usage. Therefore, Young's modulus and acceptable stress was estimated based on the way for metal material.

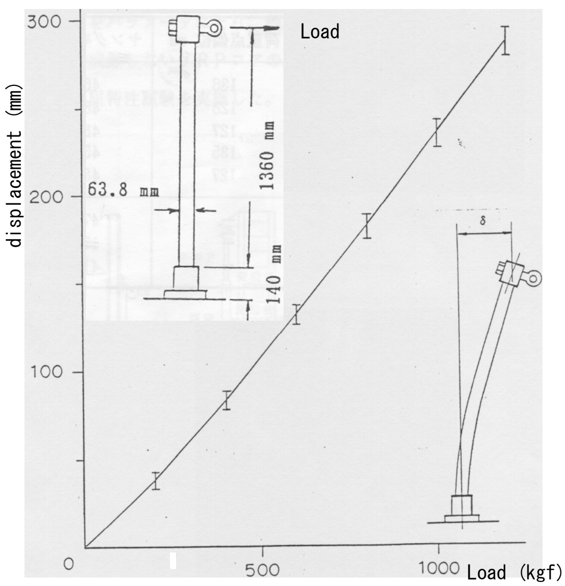


Figure 3.1 Load-displacement of FRP

Table 3.1 shows calculated Young's modulus to each displacement with 600 kgf horizontal load by the relationship between the load and displacement. The adopted Young's modulus for design is 4,200kgf/mm^2 as lower limit of 99 % confidence interval.

Table 3.1 Young's modulus to displacement

Sample	Displacement (mm)	Young's Modulus (kgf/mm2)
A	136	4,548
B	128	4,833
C	127	4,871
D	135	4,582
E	127	4,871
Mean Value(X)	130.6	4,741
Stdev(σ)		162
X-3σ		4,256
Young's Modulus for Design		4,200

Table 3.2 shows breaking load and stress for each samples. Acceptable stress is 60 kgf/mm^2 as 80 % of lower limit of 99 % confidence interval of breaking stress.

Table 3.2 Breaking stress for each sample

Sample	Breaking Load (kgf)	Breaking Stress (kgf/mm2)
A	1,560	83
B	1,760	94
C	1,700	91
D	1,660	89
E	1,700	91
Mean Value(X)	1,676	89.4
Stdev(σ)		3.9
X-3σ		77.6
Acceptable Bending Stress (X-3σ)×80%		60

Long term reliability was tested after 10^6 times cyclic axial force of -500kgf to 500kgf with 1 Hz . This result proved no deterioration of mechanical characteristics, Young's modulus and allowable stress, mentioned above.

(2)Weatherability

As polymer is one of the organic compound, some kind of deterioration due to ultra violet rays exposure and else was concerned. Therefore, composite test as shown in table 3.3 had been carried out for years. This test begun in 1992 with two sets of samples and added two more samples in 1996.

Table 3.3 Condition of accelerated test

Item	Condition
UV rays	6mW/cm^2 Continuous Radiation on Upper Side
Temperature	-20℃～60℃ 12 hour Cycle
Precipitation	90mm/h 1 hour (at 60℃)
Bending Load	Maxmum 30kgf/mm^2 Continuously
Electric Load	AC 70 kV Continuously (equal to 275 kV for 4 units)

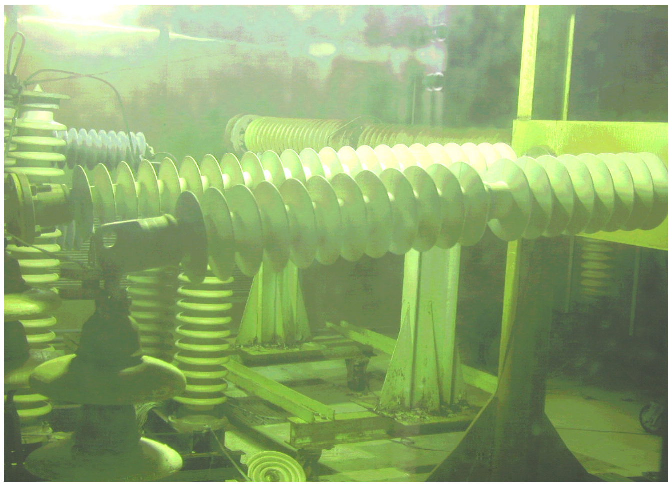


Figure 3.2 Samples under accelerated test

The durability especially against weatherability-related stress of polymeric insulator was estimated by using accelerated test data and field data. Figure 3.3 shows the sequential trend of hardness of test and field data as a function of elapsed years, and each trend line is approximated by least squares as logarithmic function. (Eqs. 3.1 and 3.2) Eight-year accelerated test sample had sufficient electrical strength evaluated by withstand voltage test with contaminated, salt and all the rest, atmosphere, and also had water-repellent quality which is almost equal to brand-new one, shown as Fig. 3.4. (Water-repellent surface improve antipollution quality) Estimated durability was calculated by estimating the elapsed time in the field which is equal to the accelerated test period of 7.8 years. The estimated period is 105 years, and durability of polymeric insulator is proved to be sufficient to the life-time usage of transmission lines.

However, conducted test was focused so mainly on UV ray damage that another view point might be required for the adoption in much contaminated area because leakage current may probably induce some damage like erosion or tracking.

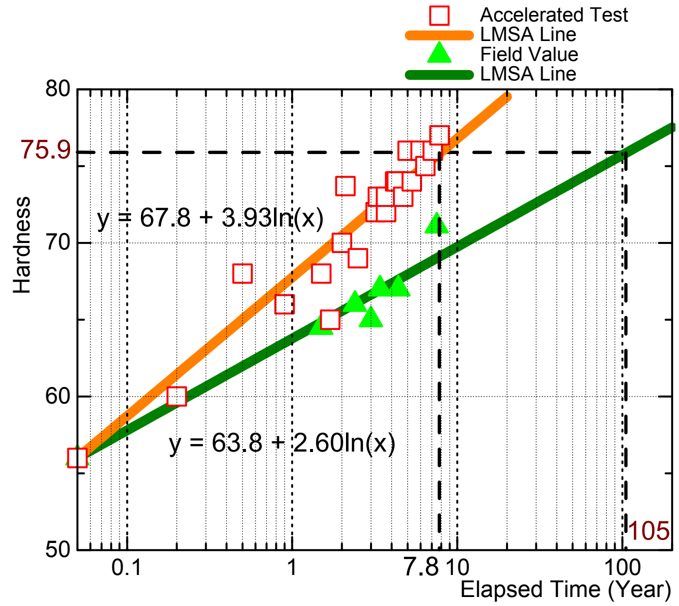


Figure 3.3 Sequential trend of hardness

[least squares equation]

accelerated test data $y = 67.8 + 3.93\ln(x)$ (3-1)

field data $y = 63.8 + 2.60\ln(x)$ (3-2)

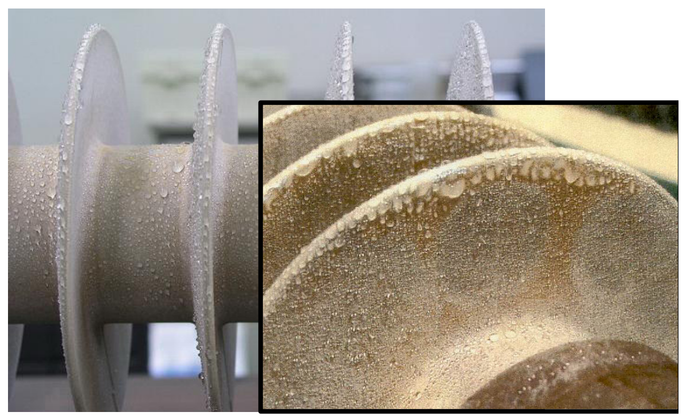


Figure 3.4 Water-repellent quality after 8-year accelerated test

(3)Anti Snow or Ice Accretion

HOKKAIDO suffers with the most cold winter and has much snow compare to other Japanese prefecture, although amount of snow fall depends on the district in HOKKAIDO. In view of such climate, snow or ice accretion resistance of polymeric insulator was tested. Polymer material has an advantage of easiness in forming any type of shapes, so three types of samples, shown in Fig. 3.5, are tested.

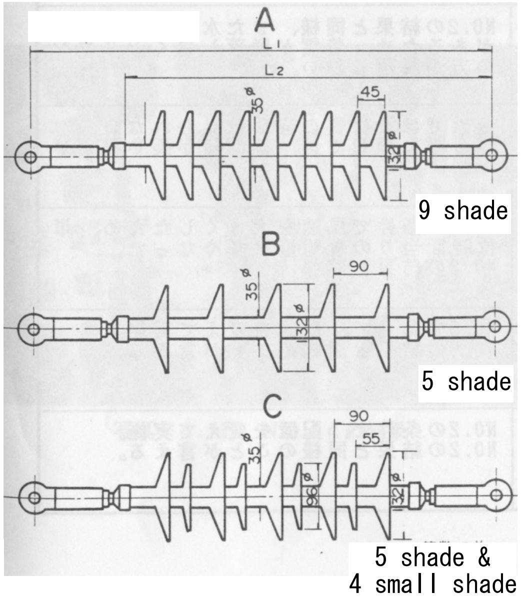


Figure 3.5 Samples (A to C)

Temperature was remained between 0 to 2 C, which is conceived as suitable temperature for snow accretion, and stocked snow with steamed water was breezed by electric fan in a laboratory with constant temperature and humidistat. (Snow with steamed water has relative density of 0.5) Figure 3.6 shows snow accretion to of sample B and C, made from EPDM and silicone, and figure 3.7 shows icing of these same samples. Test results are summarized as below:

(1) Sample B is superior to sample C in anti-snow-accretion characteristics.
(2) Both sample B and C have almost same quality in anti-icing characteristics.

Ultimately, C type sample was adopted for practical use in consideration of the long leakage length which affect insulation performance, although B type sample have apparently superior to C type in anti-snow-accretion performance.

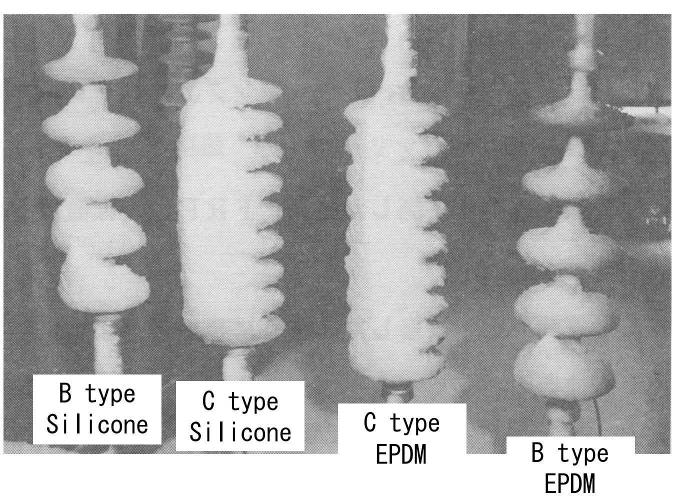


Figure 3.6 Snow accretion of each sample

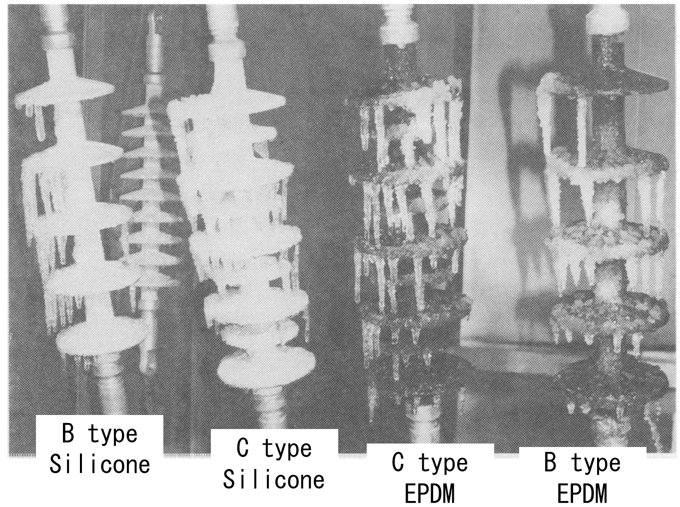


Figure 3.7 Icing of each sample

4. MECHANICAL CHARACTERISTICS

There is a possibility that actual behavior and simulated one are somewhat different because in respect that the FRP core is not absolute linear structure. Therefore, dominant frequency and mechanical property are analyzed by using field observed data for years. Summarized specification of observed transmission line is shown in table 4.1 and Fig. 4.1.

Table 4.1 Specification of observed transmission line

Voltage, Span	275 kV, 380 m
Conductor	TACSR 610mm^2 (Bundle)
Interphase spacer	Polymer insulator Length: 9 m waist breadth: 73 mm FRP core breadth: 63 mm

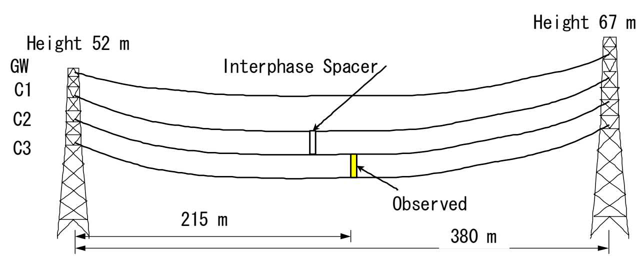


Figure 4.1 Observed interphase spacer

(1) Predominant Frequency

Conductors and interphase spacers mentioned as above were modeled to be FEM elements and predominant frequency was calculated to be 1.10 Hz by CAFSS, a FEM code developed by CRIEPI which can consider geometrical non-linear model. The predominant frequency of 1.10 Hz of polymeric interphase spacer is comparably lower than porcelain's one of 1.5 to 2.0 Hz because its flexible bending property, although the weight is much less than porcelain one.

Table 4.2 Specification of modeled interphase spacer

Total length	8.966 m
Weight	167 kgf
Composition	Polymer insulator×4 (FRP core 63 mm) center pipe 101.6 mm, colona ring etc.

(2) Frequency in the Field

Figure 4.2 shows observed frequency of bending moment as a function of vertical acceleration. Observed frequencies of across-line movement is dispersed around 0.3 Hz, 0.6 Hz, 0.8 Hz and 1.0 Hz, while along-line's ones are concentrated around 1.2 Hz. In other words, the frequencies of across-line movement are depends on the predominant frequencies of across-line oscillation of conductors while along-line's frequencies are depends on the predominant frequencies of the interphase spacer itself. Figure 4.3 describes this concept. Thus, it is strongly possible that the bending motion of interphase spacer is vulnerable to be brought into resonant vibration mode, and mechanical design mainly considered on along-line bending motion is of the most importance.

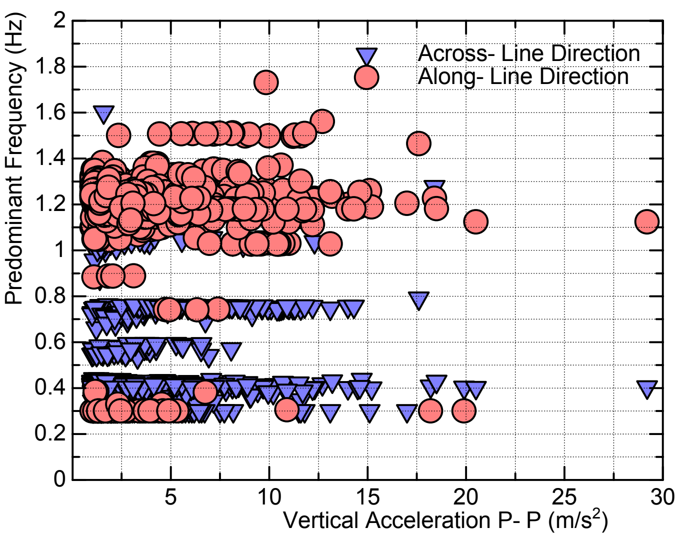


Figure 4.2 Predominant frequency of bending moment

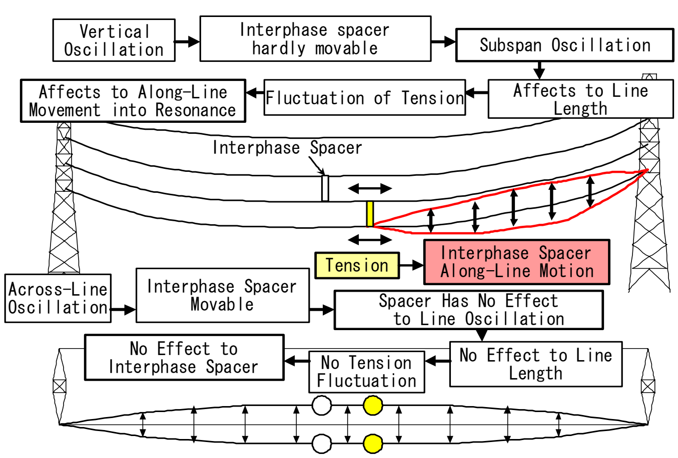


Figure 4.3 Description of interphase spacer's oscillation

(3) Bending Moment

Figure 4.4 shows bending moment of interphase spacer as a function of its acceleration. Theare is a relatively strong correlation between across-line acceleration and bending moment of same direction, while along-line bending moment has also positive correlation to the bending moment. A theoretical fomula, assuming bending shape of interphase spacer as primary mode, which derives along-line bending moment from its acceleration was thought up as shown in Fig. 4.5 and Eqs. 4.1. Along-line bending moment values tend to converge to theoretical line as its acceleration increases, so derived Eqs. 4.1 is considered to be near valid in this respect. In the meanwhile, predominant frequencies of across-line direction bending moment are widely dispersed according to horizontal line oschilation itself, and the hypothesis, assuming bending shape as primary mode, is not applicable. Thus, another discussion is needed to analyse across-line bending momoment with its acceleration theoretically.

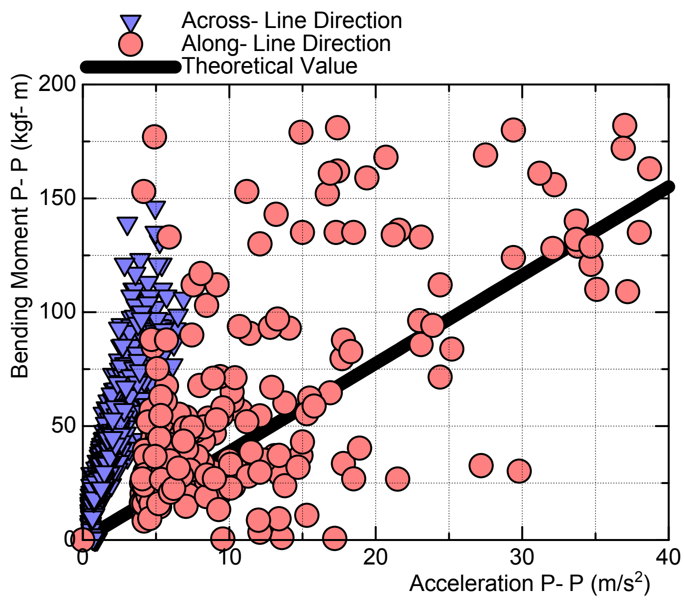
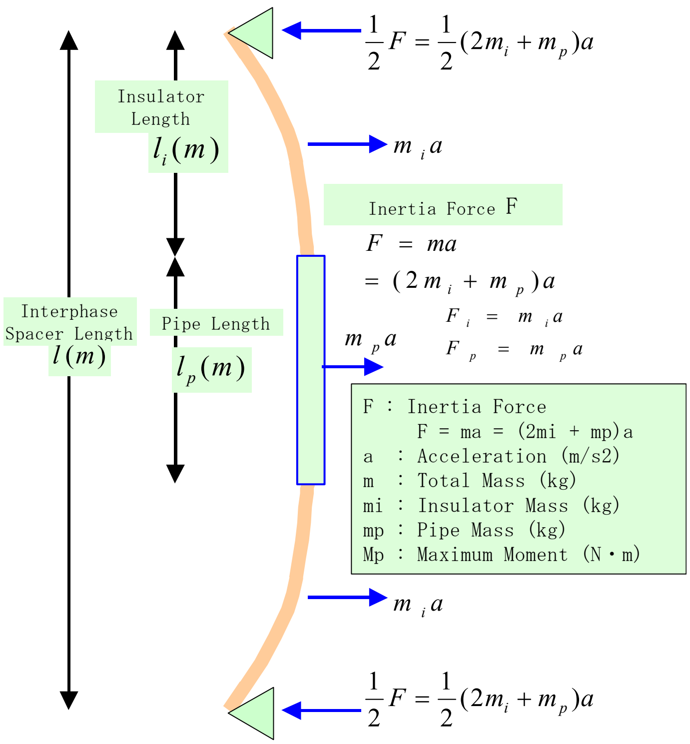


Figure 4.4 Bending moment



$$M_p = \frac{F}{2}\left(l_i + \frac{1}{2}l_p\right) - F_i \cdot \left(\frac{1}{2}l_i + \frac{1}{2}l_p\right) - \frac{1}{2}F_p \cdot \frac{1}{4}l_p$$

$$= \left[\frac{1}{2}m_i l_i + \frac{1}{2}m_p\left(l_i + \frac{1}{4}l_p\right)\right] a \qquad (N \cdot m) \quad \cdots (4.1)$$

Figure 4.5

Theoretical equation was derived from statistically processed two and half year field data, and any kind of analysis for mechanical stress of interphase spacer can be simulated by FEM with CAFSS or equivalent code.

5. Conclusion

Developments of improved interphase spacer and carried studies to determine the specification are mentioned in this paper. No electric or mechanical problem has been identified since 1990 when the first polymeric interphase spacer was adopted to be practical use. It can be concluded that conducted weatherability evaluation research and mechanical design are reasonable and proper in respect to the past performance.

However, interphase spacer will be used in much salty atmosphere area in the future, although previous applications were limited in less severe area. On this account periodic research of the surface condition for every regular inspection is needed to evaluate the weatherability of the interphase spacer in severe salty area. Besides, some cases of brittle fracture of FRP core induced by water influx are reported in overseas. Especially the inspection in recognizing the importance of end fittings of each polymeric insulator is desperately needed in order to prevent water influx into FRP core.

Interphase spacer is under electric and mechanical severe stress because it physically connect phases each other. Therefore, domestic and foreign related technology trends and researches in this field deserve continued attention.

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