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Impact of increased temperature of lower end-fitting of a composite long rod insulator on its mechanical strength under variable loads

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Abstract: This paper describes results of tensile mechanical strength testing of two types of composite suspension line insulators from two manufacturers. In order to take into account the operation of composite insulators in overhead transmission lines with high-temperature low-sag (HTLS) conductors, the testing of their static and fatigue strength was performed at both ambient and elevated temperatures. The results showed that the static mechanical strength of composite insulators decreased with an increase in the temperature of the lower end fitting of the insulator, and proved that it followed a third-degree polynomial function. Calculations performed demonstrated that a significant cause of reduction in strength was the increase in the radial stress following the temperature increase in the crimped glass-epoxy resin core of the insulator. The results of the fatigue strength testing demonstrated that the increase in the temperature of the lower end fitting of the insulator up to 85°C degree had a little effect on the fatigue strength of the tested composite insulators.

Key words: composite suspension line insulators, high temperature low sag (HTLS) conductor, mechanical insulator strength, material fatigue, insulator tests, cyclic load, changing load

1. Introduction

The application of temperature-resistant materials (mainly aluminum-zirconium alloys) has led to development of conductors with a considerably higher working temperature, called high-temperature conductors. Nowadays high-temperature conductors usually mean high-temperature low-sag conductors; these are generally designated with the acronym HTLS (High Temperature Low Sag) [1–3]. Amongst them are conductors with admissible operating temperatures of 230–250°C. Growing interest among transmission and distribution lines operators in using HTLS conductors arises from their advantages, primarily including their very high current carrying capacity and their capability of working in overload while maintaining the sag within acceptable limits [4–6].

The increase in temperature of insulators caused by hot conductors is a relatively new area of research [3–5] and affects both porcelain and composite insulators. For this reason, issues associated with the use of high-temperature conductors in overhead lines and their impact on the operation of insulators are a subject of research and studies at CIGRE [4–6]. The method of testing presented therein consists of measuring the temperature of the end fitting and housing of an insulator heated from the conductor side. During the testing, an appropriately selected current flow produced a conductor temperature of 200°C, even reaching approximately 280°C. It was found that the temperature of the end fittings of the tested composite insulators increased by less than 30°C above the ambient temperature during testing. However, it has been noted that there may be many instances when the increase in the end fitting temperature will be higher, e.g. due to very high sunlight exposure or "shorter" fittings connecting the conductor to the insulator. At the same time, it was recommended that while using the HTLS conductors it should be checked that, as the result of the insulator being heated by such a conductor, the lower end fitting temperature does not exceed the admissible safe operation value assumed at a level of 80°C. However, no documents were indicated to justify such an assumed operating temperature limit of the composite insulators. It should be noted though that in the standardized design tests of composite suspension line insulators provided in the literature [8] the maximum temperature value in thermal mechanical tests is +50 ± 5°C.

In the CIGRE publication, there is no information as to whether the elevated temperature of the composite insulator's lower end-fitting impacts its mechanical strength or if – possibly – it does not lead to a decrease in strength, which in turn might lead to a shortening of the expected failure-free operational life of the insulator. Therefore, in the recent IEC technical report [7] an important recommendation has been given for the installation of suspension line insulators in HV lines with HTLS conductors. It is stated there that always before the installation is taken up, it is recommended to check the effect of increased temperature produced by an HTLS conductor on the insulator being installed. Therefore, the objective of the tests performed and described in this paper was to evaluate the strength of composite suspension line insulators at elevated temperatures of their lower mounting node, both under static and cyclic loads.

2. Methods and objects of the tests

The tested items comprised models of two types of composite suspension line insulators from two manufacturers, designated with symbols A (in papers [9] and [10] this manufacturer was designated with symbol D) and B (in papers [9] and [10] this manufacturer was designated with symbol B) for the purpose of this publication. The assembly length of both types of models was approx. 1.3 m, while the diameters of their glass-epoxy resin cores were comparable – differing by not more than 4%. The tested models differed from typical insulators for 220 kV or 400 kV lines in their length only. Other parameters, such as the core diameter and end fittings remained unaltered, i.e. made in the same way as in typical insulators. This had no influence on the mechanical properties of the tested models but simplified the installation and preparatory work on the test stand. Since 2001, the Institute of Power Engineering (IEN) has performed testing of ceramic and composite insulators on this test stand, both under static and – mainly – changing (cyclic) loads [9–13]. The test stand with an insulator installed for the tests is shown in Fig. 1.

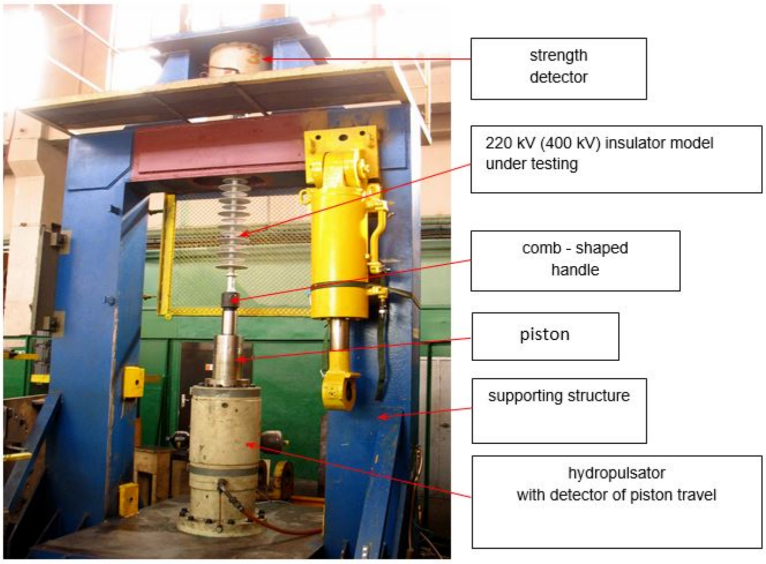

Fig. 1. Servo-hydraulic machine for insulator testing at ambient temperature

The tested models of the insulators came from two renowned manufacturers (A and B), whose composite insulators (both suspension line and station type) had been already tested at the Institute of Power Engineering (IEN) in previous years [9–11], and the results attested their high quality.

Moreover, the curves of the fatigue characteristics determined for these composite suspension line insulators indicated they had good strength under cyclic loads. The insulators from these manufacturers, therefore, complied with the selection criteria developed by the Institute of Power Engineering (IEN) on resistance for this type of load (currently these criteria are also included in the specifications of PSE S.A. for composite insulators [15]).

The 220 kV (400 kV) composite insulators (models of insulators), designated for current testing, had mechanical properties similar to those of the previously tested insulators [9, 10] due to a similar core diameter and the size of the end fitting. Prior to the mechanical tests, each insulator was subjected to a visual inspection and basic dimensional checks. Each mechanical strength (destructive) test was in turn preceded by a test load of SML value maintained for 60 s. After this period the load was set at an initial value (not more than 2 kN) and any permanent changes in the assembly length or deformation of the end fittings were evaluated. The results of testing with the test load raised no issues. The testing of the static mechanical strength of the insulators (models) was performed according to the method indicated in the standard [8] (p. 10.4.2.1). The load was increased steplessly from zero to 75% of the expected value that would cause mechanical damage to the insulator, and then within 30 s to 90 s the damage to the insulator occurred. Figure 2 shows an example of the recorded course of the load and elongation during the mechanical strength test of one of the tested insulators (at ambient temperature).

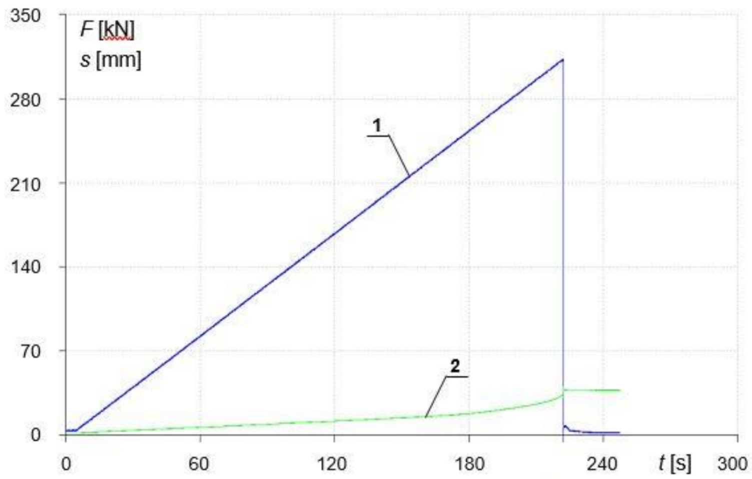

Fig. 2. Typical record of composite insulator loading with static tensile load (on the axis 0–y in [kN]) versus time (on the axis 0–x in [s]) (1), typical record of elongation (on the axis 0–y in [mm]) of composite insulator under testing versus time (2)

Three insulators from each manufacturer were used for the static strength tests at ambient temperature (20°C); the tests were also carried out at temperatures of 70°C and 85°C. One insulator from each manufacturer was tested at temperatures of: 50°C, 100°C, 115°C, 130°C, 150°C and 200°C.

While at ambient temperature the insulator required no additional preparation, at the elevated temperatures it was necessary to heat the lower end fitting prior to testing (insulator in a vertical position). The strength test (both under static and cyclic loads) was started after the entire lower end fitting was heated to a set temperature maintained with a defined accuracy during the assumed length of time. This temperature was maintained (stabilized) during the entire duration of the test. The crimped part of the insulator end fitting is the key to its mechanical strength, therefore, the temperature measurement was taken in three zones of its cylindrical part: at the top (by the flange), in the middle (between the upper and lower crimped part), at the bottom (just before the clevis eye). Thermocouples were mounted on the cylindrical part of the surface with metal clamps – Fig. 3.

The testing was not concerned with the end fitting or the clevis eye itself, which was assumed to have suitable dimensions and strength to ensure the rated mechanical properties of the insulator, but with the cylindrical crimped part, as it is crucial to the integrity of the insulator. Increasing the temperature of the clevis eye to the test values that were assumed in the testing program had no significant impact on the strength of the fittings, which was confirmed by the tests.

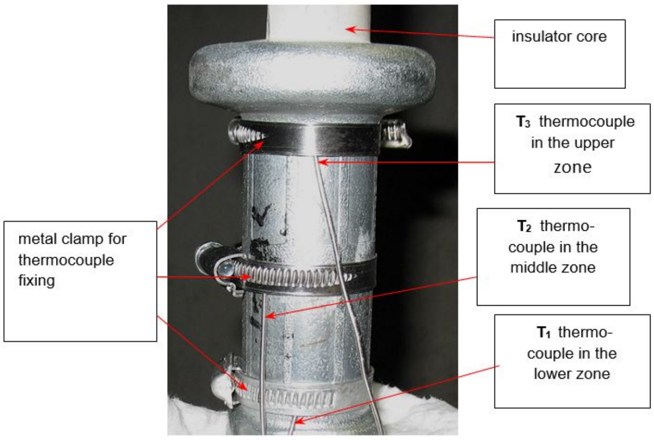

Fig. 3. Thermocouple fixing on surface of cylindrical part of lower end fitting

A toroidal resistance heater (500 W, supplied from a 230 V AC source) was used to heat the cylindrical part of the end fitting with the glass-epoxy resin core crimped inside – Fig. 4.

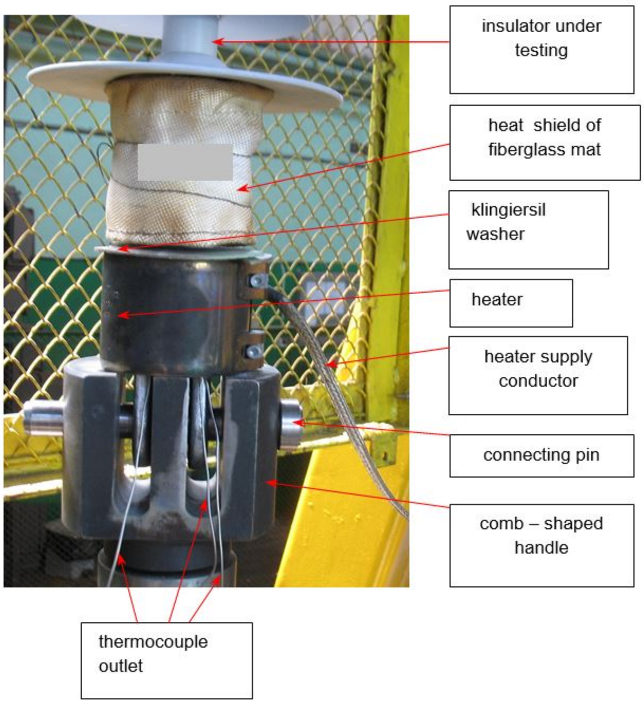

Fig. 4. View of lower part of composite insulator ready for test of its mechanical strength at elevated temperatures

In operational conditions, the heating of the lower end fitting of the insulator starts from “the bottom”, i.e. the clevis eye. Therefore, it was assumed that during the heating process, the temperature of the upper part of the end fitting (in the area of the end fitting flange) should not be higher than in its lower part (the area of the cylindrical part of the fitting shifting into the clevis eye), while also maintaining the assumed deviations from the stabilized temperature value. A maximum ±5°C deviation was assumed to be justified – such a temperature deviation was assumed in the standard [8] during the performance of the thermal mechanical test. A custom-designed and manufactured automatic temperature control system ensured maintaining the temperature with an accuracy of ±3°C, which complied with the adopted assumptions. The control system was checked on the ongoing basis for a difference between the set and the measured temperatures. It was also based on the determined value of the difference and the rate of temperature increase of the end fitting, adjusting the duration time of the pulse controlling the heating unit.

Maintaining the set end fitting temperature within the assumed limits required additional use of heat shields made of fiberglass or mineral wool mats. In comparison with testing the insulators for fatigue strength at ambient temperature, for tests under cyclic load at elevated temperatures it was necessary to employ the additional mounting of a heating element. Mounting of the heater was supplemented with elastic elements; these additional elastic elements pressed the heating element (heater) against the comb-shaped handle, to avoid any possibility of vibration or displacement during cyclic changes in the load.

3. Test results

3.1. Results of the tests of the mechanical strength of the insulators under static load

During the testing at elevated temperatures, the insulators were mounted on the test stand: as shown in Fig. 1, in addition to the heating system shown in Fig. 4. After achieving the set temperature and making any correction to the setpoints, the end fitting was “heated” for at least 1 hour, after this period the strength testing started.

Similarly to the tests carried out at ambient temperature, in these tests the tensile load was also increased according to the method specified in the standard [8], (p. 10.4.2.1). Each test was continued until destruction of the insulator occurred. The destruction of the insulator at the elevated temperatures usually consisted in diagonal rupturing of the glass-epoxy resin core in the crimped zone inside the lower end fitting and longitudinal fragmentation of the core [9, 10]. The results of the strength tests are compiled in Table 1.

The results of the static tests compiled in Table 1 were plotted on a coordinate system according to the principles:

- values of the abscissa (0–x axis) – lower end fitting temperature t [°C] value – according to column 2 in Table 1 and Fig. 5,
- values of the ordinates (0–y axis) – relative value of the static strength at a given temperature (failure load F_z as percentage of SML) ,
- according to column 3 (insulators from manufacturer A) and column 4 (insulators from manufacturer B) in Table 1 and Fig. 5.

An attempt was then made to approximate the points plotted on the coordinate system according to Table 1 using various functions: linear, power, logarithmic, exponential, and polynomial.

Table 1. Compilation of the results of the tests of the static mechanical strength of the composite insulators for 220 kV (400 kV) lines, determined at different temperatures of the lower end fitting of the insulator

Relative number of consecutive insulators	**Temperature of the insulator's lower end fitting**	**Failure load in relation to SML F_z/SML [%]**	
		Insulators from manufacturer A	**Insulators from manufacturer B**
1	**2**	**3**	**4**
1	20°C (ambient)	145%	128%
2		139%	122%
3		142%	143%
4	50°C	127%	Insulators from manufacturer B were not tested at a temperature of 50°C
5	70°C	129%	145%
6		127%	145%
7		136%	126%
8	85°C	115%	127%
9		108%	128%
10		108%	137%
11	100°C	118%	120%
12	115°C	117%	118%
13	130°C	91%	116%
14	150°C	72%	100%
15	200°C	44%	64%

SML – specified mechanical load,
F_z – failure load (in kilonewtons)

The best approximation accuracy was achieved for third degree polynomial functions, which in this paper were designated as:

$y_{t\mathrm{Astat}}(x)$ – for insulators from manufacturer A,

$y_{t\mathrm{Bstat}}(x)$ – for insulators from manufacturer B.

For the relative values of the static strength on the 0–y axis, i.e. F_z/SML in percent, they assumed the form of (R^2 – coefficient of determination):

$$y_{t\mathrm{Astat}}(x) = 4E - 0.6x^3 - 0.0028x^2 - 0.0876x + 144.29 \qquad \text{at} \quad R^2 = 0.9296, \tag{1}$$

$$y_{t\mathrm{Bstat}}(x) = 1E - 0.5x^3 - 0.0075x^2 + 0.6726x + 120.82 \qquad \text{at} \quad R^2 = 0.88. \tag{2}$$

No rounding up in the function formula was introduced, and it was presented in the form generated by Excel software. The graphical presentation of these functions is shown in Fig. 5. It is noteworthy that very good accuracy of the empirical data image was achieved by the approximating function, expressed by the coefficient of determination R^2. Based on the obtained results it may be stated that these tests of the static strength of the insulators at ambient temperature confirmed the mechanical properties declared by the manufacturers, and were verified through standardized methods. Although a more important objective of this phase of testing, was to check the static strength of the insulators with elevated temperatures of the lower end fitting.

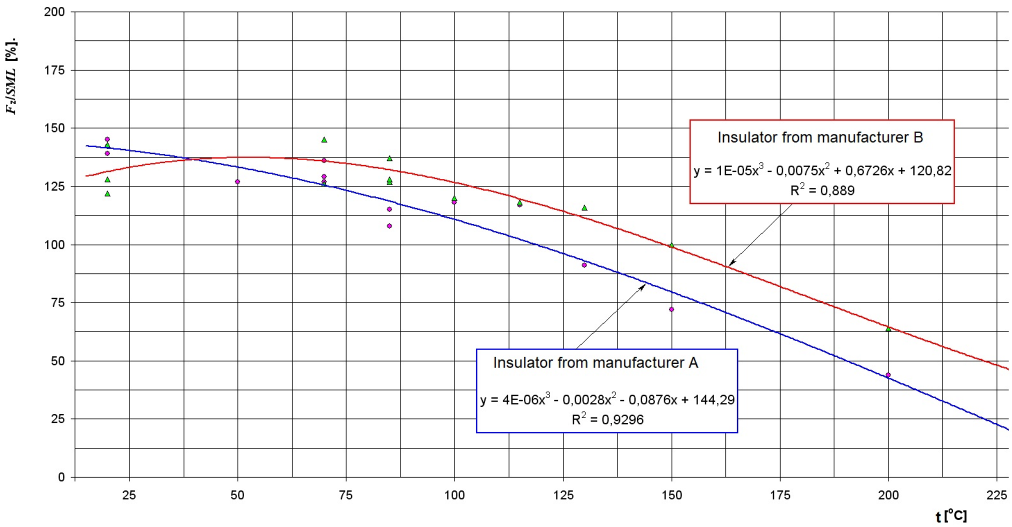

Fig. 5. Relationship between mechanical static strength of composite insulators and temperature of their lower end – fittings

While analyzing the results of the static strength of the tested insulators in conditions of elevated temperature of the lower end fitting (Table 1 and the diagrams in Fig. 5), it could be observed that as the temperature of this end fitting increased, the strength reduced. The functional correlation, insulator static strength–end fitting temperature is similar for both types of insulators (third degree polynomial function), although the "intensity" in the reduction of the strength is different (Fig. 5).

For the insulators from manufacturer A, the failure load approaches the SML value at a lower end fitting temperature of approximately 120°C, whereas for manufacturer B, the failure load approaches the SML value at a lower end fitting temperature of approximately – 150°C. It could be then preliminarily assumed that the temperature indicated by CIGRE as 80°C (see p. 3.2.) is the limit of safe operation of composite insulators. Therefore, for these insulators, this temperature can be allowed in the long term for static loads occurring in the line without any additional risk. However, there is no basis for assuming that a temperature of 80°C – as the highest admissible operating temperature – also applies to the composite insulators operated in changing load conditions.

3.2. Results of the mechanical strength tests of the composite long rod insulators under cyclic load at ambient temperature and increased temperatures of their lower end-fittings

The strength of composite insulators under cyclic load (fatigue load) and the criteria of its assessment are significant elements of selection of these insulators to meet expected operational conditions. The knowledge of the fatigue characteristics also enables mechanical properties of insulators to be compared, in terms of their equivalent normalized properties [8–15].

Similarly to long-rod ceramic insulators, composite suspension line insulators are usually subject to complex mechanical stress conditions during operation, and parameters of the stresses are usually dependent on a structure of the string; that is the manner of the arrangement and connection between its individual elements. The vibrations of the conductors are transferred to the insulators through the fittings. The main source of the vibrations of insulator strings in overhead lines are the so called aeolian vibrations of the conductors, which cause changing (cyclic) stress conditions in the insulators [16, 17].

In fatigue tests of suspension line insulators, a combination of the static load F_m (constant component, average load) and the cyclic load F_a (harmonic) is assumed to represent the changing mechanical load (stress) to which the insulator may be subjected during operation. With such an assumption, the variable tensile force F (tensile load) applied to the insulator during the fatigue test can be simplified as:

$$F = (F_m \pm F_a), \tag{3}$$

or, assuming a uniform uniaxial loading state varying over time t, as:

$$F(t) = F_m + F_a \sin \omega t. \tag{4}$$

According to the methodology of the fatigue tests of composite insulators developed by the Institute of Power Engineering and the adopted evaluation criteria of their strength under variable (cyclic) load [9, 10, 12], the amplitude value of the test load during each test was set as the equivalent of 25% of the average load:

$$F_a = 25\% F_m\,. \tag{5}$$

Fatigue tests at ambient temperature were performed on four composite insulators from both manufacturers. The insulators were installed in the handles of the testing machine in the same manner as the tests under static load (Fig. 1).

Each of the four insulators from the given manufacturer was subjected to a test at a different maximum load level, the test continued until destruction of the insulator. The four results obtained determined the points for approximation (determinations of fatigue characteristic), which were then mapped to a coordinate system according to the following principles:

– Abscissa values (axis 0–x) – number of cycles N until destruction of the insulator (Table 2, Figs. 6 and 7).
– Ordinate values (axis 0–y) – relative value of the maximum cyclic load ($F_{\max}$ in relation to SML, in percent, Table 2, Figs. 6 and 7).

Approximating the points mapped to the coordinate system with a power function, the following functions were obtained, which were marked for the purpose of this paper as:

$y\mathrm{A}zm(x)$ – for the insulators from manufacturer A,

$y\mathrm{B}zm(x)$ – for the insulators from manufacturer B.

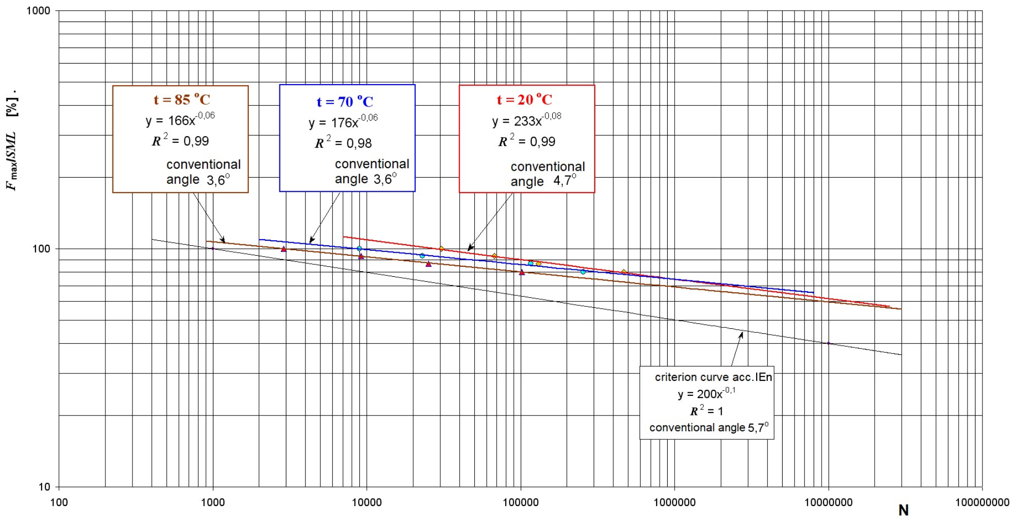

Fig. 6. Fatigue characteristics of composite insulators of manufacturer A, for the 220 kV (400 kV) lines, determined at different temperatures of lower end-fitting

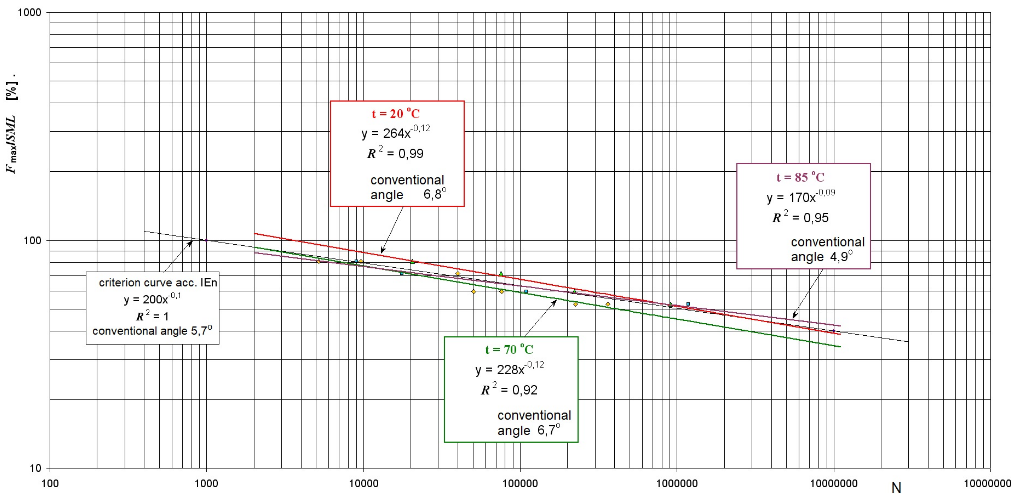

Fig. 7. Fatigue characteristics of composite insulators of manufacturer B, for the 220 kV (400 kV) lines, determined at different temperatures of lower end-fitting

Fatigue tests of the mechanical strength of the insulators at an increased temperature of their lower end fitting were performed at two temperatures:

– 70°C–30°C higher than the maximum ambient temperature adopted in the standard [14], recognized as part of normal environmental conditions.

– 85°C–5°C higher than the permissible operating temperature of a composite insulator indicated by CIGRE, and at the same time taking into account the use of HTLS conductors with a higher operating temperature than in CIGRE tests.

Table 2. The summary of the fatigue characteristics determined for composite insulators for 220 kV lines (400 kV), under cyclic load 7 Hz and amplitude of 25% of medium load at temperatures of 20°C, 70°C and 85°C

Item	**Tested insulators (models of insulators)**	**Temperature of the insulator's lower end fitting**	**Fatigue characteristic (approximating function)**	**Coefficient of determination R^2**	**Coventional angle**
1	**2**	**3**	**4**	**5**	**6**
1	Manufacturer A	20°C	$y_{\mathrm{A}zm}(x) = 233x^{-0.08}$	0.99	4.7°
2		70°C	$y_{\mathrm{A}zm70}(x) = 176x^{-0.06}$	0.98	3.6°
3		85°C	$y_{\mathrm{A}zm85}(x) = 166x^{-0.06}$	0.99	3.6°
4	Manufacturer B	20°C	$y_{\mathrm{B}zm}(x) = 264x^{-0.12}$	0.98	6.8°
5		70°C	$y_{\mathrm{B}zm70}(x) = 228x^{-0.12}$	0.92	6.7°
6		85°C	$y_{\mathrm{B}zm85}(x) = 170x^{-0.09}$	0.95	4.9°

NOTES
1. The table contains fatigue characteristics determined under a relative value of the cyclic load on the ordinate axis (Figs. 6 and 7)
2. The analytic form of the fatigue characteristics adopted rounded numeric values

For a better comparison of the results obtained at ambient temperature with the results at increased temperatures, the levels of the maximum load and the other parameters of the cyclic load of the insulators were adopted as in the tests performed at ambient temperature, applying the same test method. After installing the insulator at the test stand and conducting the test under static test, the heating of the lower end fitting was started. After stabilization of the assumed temperature, the end fitting was "heated", similarly to the tests under static load. Then a test under tensile cyclic load was started; each test was continued until destruction of the insulator occurred. The results of the fatigue tests were mapped to a coordinate system and approximated with a power function according to the same principles as at ambient temperature. The determined fatigue characteristics were indicated on a joint graph on Figs. 6 (insulators from manufacturer A) and 7 (insulators from manufacturer B), and in Table 2. Analyzing the accuracy of the model's fit (approximating function) of the fatigue strength of the tested insulators to the measurement data (Table 2 and Figs. 6 and 7) it may be noted that, for each test of the temperature of the insulator's lower end-fitting, the accuracy, specified by the coefficient of determination, is very high: for each fatigue characteristic the coefficient of determination R^2 is not lower than 0.92. Whereas for the insulators from manufacturer A it is not lower than 0.98, so the approximating function nearly overlaps with the empirical data.

4. Discussion. Analysis of the stresses in the end fitting of the composite insulator

A technology that is used to join the glass-epoxy resin core with metal end fitting, which is applied through compression in composite suspension line insulators, develops stresses in the assembly nodes that are created in this way. They are strictly associated with the strength applied when the end fitting is clamping on the core. The value of the strength must be high enough to ensure a connection with the appropriate mechanical strength. At the same time the strength may not exceed too high value because it may surpass the stress that is permissible for the core. Exceeding this stress would already damage the core at this stage of manufacture. The strength of the compression must be carefully selected because it is of key importance for the strength of connection.

The presence of the stress field is associated with a deformation field. This means that during compression, aside from creating stress, the compressed segment of the core is also deformed which decreases its diameter. From the viewpoint of mechanics, this problem is known as Lamé's problem and it is applied to calculate the thick-walled pipes or spinning discs [18]. In the analyzed case there is the connection of the bushing (end fitting) and the compressed bolt (core) – Fig. 8, which is additionally subject to temperature changes. Taking into account the difference between the coefficients of thermal expansion for resin and steel, the influence of the temperature on the stress in compressed elements should be also taken into consideration.

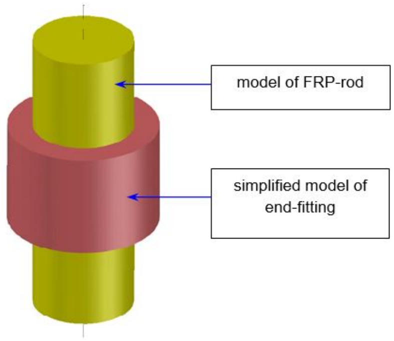

Fig. 8. Simplified presentation of essence of a composite insulator end-fitting structure

The relation between the stress and the deformation does not only depend on the elasticity (Young) modulus and Poisson's ratio, but also on the coefficient of thermal expansion (linear). Taking into account the difference between the coefficients of thermal expansion for resin and steel, the influence of temperature on the stresses in the compressed elements should be also taken into consideration.

This paper has addressed the following question, among other things: how significant is the contribution of the thermal stresses in relation to the stresses caused by compression, and which of them is more responsible for the strength of insulators at increased temperature. Analyses of the problem were carried out on the basis of Lamé's equations, taking into account – aside from the slight deformation introduced by the compression – the deformation of the connections caused by the change in temperature. The results of the calculation indicate that the additional stresses calculated for different temperatures in the end fittings of the examined insulators of manufacturer A and manufacturer B do not differ significantly.

Heating the insulator's end fitting to a temperature of 85°C introduces additional thermal stress which do not exceed 20% of the stress created by the compression and in principle it overlaps with the empirical data in this range of temperatures. The results of the calculations also indicate that at higher temperatures, exceeding 100°C, additional (thermal) stress increases (to almost 50% of the stress caused during crimping), which surely had an impact on steady decrease of the static strength of the insulators during the tests carried out at higher temperatures – Table 3.

Table 3. Calculation results of the stress in the compressed part of the glass-epoxy resin core of the tested composite insulators depending on the temperature of the end-fitting

Item	**Tested insulators (models of insulators)**	**Temperature of the end-fitting**			
		70°C	**85°C**	**100°C**	**200°C**
		Increase of the radial stress in the compressed glass-epoxy resin core in relation to the stress, introduced during crimping at ambient temperature			
1	**2**	**4**	**5**	**6**	**7**
1	Manufacturer A	+13%	+17%	+21%	+47%
2	Manufacturer B	+13%	+17%	+21%	+48%

The calculations are approximate, as they have not taken into account a change of the structure of the glass-epoxy resin core under the influence of temperature, for example softening, nor the existence of the glass fibers in the core. The impact of similar phenomena is very difficult to determine as the core is influenced by the compressing stress that increases with the temperature. Epoxy resin in such the case behaves differently than if treated as a separate object. This is confirmed by the fact that at a temperature of 200°C, the insulators still supported a tensile load in the range of 50% SML.

5. Summary and conclusions

The composite insulators from both manufacturers that were tested, were not significantly different in terms of construction and – within the scope that could be confirmed by a visual inspection – the manufacturing technology. Both types of insulators had the same normalized size of clevis eyes in the end-fittings and a core in the end fittings was crimped in a similar manner. Tests of the static strength of the insulators at ambient temperature, performed with normalized methods, confirmed that the mechanical properties declared by the manufacturers have a sufficient factor of safety (Table 1 and the graphs in Fig. 5).

It has been proved that as the temperature of the lower end fitting increases, the real strength of the insulators decreases. The decrease in the static strength occurs in accordance with a third-degree polynomial function (see Eqs. (1) and (2)). The decrease in the static strength of the insulators becomes significant only after the fitting is heated to a temperature above 100°C (for manufacturer B – even higher); then the mechanical strength starts to approach the SML value and – with further increase the temperature of the fitting – the strength decreases more and more. Taking into account the currently used HTLS conductors, the heating of the insulator's end fitting of the conductor to a temperature of 100°C or higher is unlikely. However, such an increase in the temperature of the fitting cannot be ruled out, especially when it comes to the implementation of new designs of conductors with increasingly higher operating temperatures. It seems that the temperature of 80°C indicated by CIGRE as the limit of the safe operation of the composite insulators may be currently allowed in the long term for the tested types of insulators and this should not have an impact on their strength in terms of the temperatures and static loads predicted for their operation.

Analyzing the fatigue characteristics indicated by the increased temperatures (Table 2 and Figs. 6 and 7) it may be concluded that – in the range that is interesting from the view point of operation – the fatigue characteristics of the insulators of both manufacturers are acceptable for every test temperature. It should also be noted that the fatigue characteristics for a temperature of 85°C are at significantly smaller angles in relation to the axis 0–x than the ambient temperature, so it is more favorable. It can be assumed that the resistance to vibration of those insulators at the increased temperature of the insulator's lower end-fitting of 85°C should not be a problem when it comes to operation. It should also be noted that the temperature increase of the fitting causes an increase in the radial stress in the compressed part of the glass-epoxy resin core. This increase, within the range of 20% in relation to the stresses at ambient temperature, may have an impact on the operational durability of composite insulators based on "hard" glass-epoxy rods and "hard" end fittings [9, 10].

The results of the tests of the composite insulators carried out under cyclic load were well correlated. As a result, this influenced the very high accuracy of the representation of the empirical data by approximating the power function. The method of testing the composite insulators under a variable load developed by the Institute of Power Engineering (IEN) not only enables the insulators to be more widely evaluated when it comes to their mechanical strength, but also enables the properties of the insulators, which equally meet the normalized requirements, to be compared and differentiated. As a consequence, this facilitates the proper selection of composite insulators for specific operational conditions.

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