MODAL ANALYSIS OF OVERHEAD POWER LINES AT DIFFERENT AMBIENT TEMPERATURES

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1. Introduction

Overhead power lines under certain conditions are exposed to dynamic loads (ice-shedding, wind-induced vibrations of conductors) in addition to static ones, which can cause elastic vibrations. If a frequency of the harmonic dynamic loads is equal to the eigenfrequency of the line, the resonance vibrations can arise, which can result in mechanical damage of the power line. Therefore, the modal analysis, by which the eigenfreqeuncies and eigenmodes are stated, is needed. The analytical methods are not much effective for the general spatial analysis. The more effective are the numerical methods, over all the finite element method. Weather conditions affect the temperature in the transmission lines. The changes of the ambient (power line) temperature impact to the axial forces and the deflection of the power line, also it made changes of the eigenfrequencies of the power line.

Aluminium Conductor Steel Reinforced (ACSR) are multi-wire conductors commonly used in overhead power lines. The outer strands of ACSR are aluminium, chosen for its excellent conductivity, low weight and low cost. The center strands are of steel for the strength required to support the weight without stretching the aluminium due to its ductility. This gives the power line an overall high tensile strength. So, the material of the ACSR is inhomogeneous, therefore a simplified models obtained by homogenization of material properties are used.

In the presenting contribution the modal analysis of two different ACSR power lines at different ambient temperature is presented.

2. Model of ACSR power line

The symmetric power line marked as AlFe 240/39 and AlFe 445/74 [1] have been considered – Fig. 1. The parameters of the power lines are shown in Tab. 1.

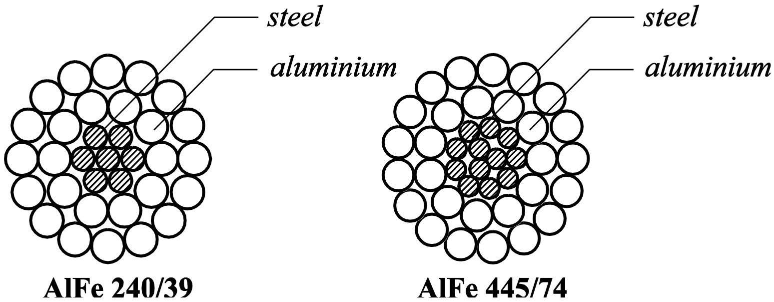

Fig.1. *Heterogeneous cross-section of the used ACSR power line.*

Tab. 1. *Parameters of the used power lines*

Power line type	AlFe 240/39	AlFe 445/74
Number of *Fe* wires/diameter [mm]	1+6/2.65	3+9/2.80
Number of *Al* wires/diameter [mm]	10+16/3.45	11+17/4.50
Power line diameter [mm]	21.75	29.63
Power line cross-section [mm^2]	289.66	519.20
Guaranteed tensile strength [kN]	75.70	139.95

Material properties of the material from which the power line is made are [2, 3]:
steel – Young's modulus E_{Fe} = 207000MPa, Poisson's ratio ν_{Fe} = 0.28, material density ρ_{Fe} = 7780 kg.m^{-3}, the thermal expansion coefficient α_{Fe} = 11.5x10^{-6}K^{-1}; aluminium – Young's modulus E_{Al} = 69000MPa, Poisson's ratio ν_{Al} = 0.33, material density ρ_{Al} = 2703 kg.m^{-3}, the thermal expansion coefficient α_{Al} = 23x10^{-6} K^{-1}.

For simplifying the model of the power line the homogenized material properties were calculated for both AlFe power lines and they are shown in Tab. 2 [4]. Here E_L^{NH} is the elastic modulus for tension, $E_L^{M_yH} = E_L^{M_zH}$ is the elastic modulus for bending about axis *y* and *z*, respectively. $G_{Ly}^H = G_{Lz}^H$ is the effective shear modulus, $G_L^{M_xH}(x)$ is the elasticity modulus for torsion, ρ_L^{NH} is the mass density for axial beam vibration, $\rho_L^{M_xH}$ is the effective mass density for torsional vibration ν_L^{NH} is the effective Poisson ratio and α_{TL}^H is the effective the thermal expansion coefficient.

Tab. 2.*Homogenized material properties of the power lines*

Power line type	AlFe 240/39	AlFe 445/74
E_L^{NH} [MPa]	87916.09	88639.14
$E_L^{M_yH} = E_L^{M_zH}$ [MPa]	45756.06	47929.78
$G_{Ly}^H = G_{Lz}^H$ [MPa]	33813.88	34091.98
$G_L^{M_xH}(x)$ [MPa]	27411.57	27688.99
ν_L^{NH} [-]	0.323	0.323
ρ_L^{NH} [kg.m^{-3}]	3455.31	3482.75
$\rho_L^{M_xH}$ [kg.m^{-3}]	2786.52	2813.05
α_{TL}^H [K^{-1}]	19.3 x10^{-6}	19.2 x10^{-6}

3. Numerical simulations

In the numerical analyses of the single power lines according to Fig. 2 two different length of the span have been considered - L = 250 m for AlFe 240/39 and L = 300 m for AlFe 445/74. Modal analyses of considered power lines has been done for different ambient temperature (temperature of the power line).

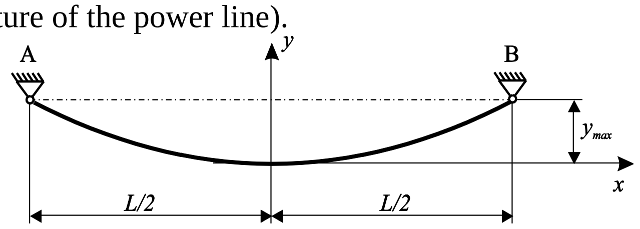

Fig.2:*Modal analysis model of the single power line*

The axial forces and deflection of the power line for each ambient temperature were calculated using the equation of state [2]:

$$\sigma_{H1}^3 + \sigma_{H1}^2 \left[\frac{\gamma^2 E}{24} \left(\frac{z_0 L}{\sigma_{H0}} \right)^2 + \alpha_T E(\vartheta_1 - \vartheta_0) - \sigma_{H0} \right] = \frac{\gamma^2 E}{24} (z_1 L)^2 \qquad (1)$$

where σ_{H0}[MPa] is the horizontal mechanical stress in the state 0, σ_{H1}[MPa] is the horizontal stress in the state 1, z_0 [-] is the weather load factor in state 0, z_1 [-] is the weather load factor in state 1, ϑ_0 [°C] is the ambient temperature in state 0, ϑ_1 [°C] is the ambient temperature in state 1, α_T [°C^{-1}] is the thermal expansion coefficient of the power line. The equation of state has been calculated numerically in software MATHEMATICA [3].

The maximal mechanical stresses and the maximal axial forces in the power line at the points of attachment (A and B) calculated by equation (1) are in Tab. 3 and Tab. 4 The maximal deflections for each ambient temperatures are shown in Fig. 3[8].

Tab. 3 *Maximal mechanical stresses and axial forces in AlFe 240/39 at different ambient temperatures*

Teplota [°C]	**-30**	**-10**	**-5**	**0**	**20**	**40**	**60**	**80**
σ_{max}[MPa]	41.2	38.1	37.4	36.8	34.3	32.3	30.6	29.1
N_{max}^{II} [N]	11469	10742	10542	10351	9670	9097	8609	8187

Tab. 4 *Maximal mechanical stresses and axial forces in AlFe 445/74 at different ambient temperatures*

Teplota [°C]	**-30**	**-10**	**-5**	**0**	**20**	**40**	**60**	**80**
σ_{max}[MPa]	57.3	52.2	51.1	50.0	46.2	43.1	40.5	38.2
N_{max}^{II} [N]	29732	27096	26517	25965	24005	22375	21003	19834

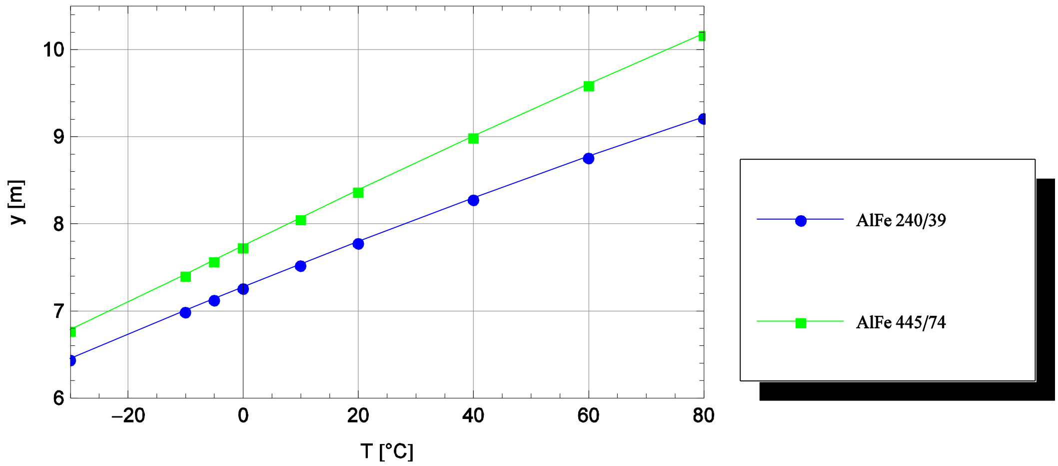

Fig.3:*The maximal deflection of the power lines at different ambient temperatures*

The first five flexural eigenfrequencies *f* [Hz] of AlFe 240/39 and AlFe 445/75 power line in plane *xy* (vertical) and in the plane *xz* (horizontal) have been found. For the AlFe 240/39 power line a mesh of 1000 of BEAM188 elements and for the AlFe 445/74 power line a mesh of 1200 of BEAM188 elements of the FEM program ANSYS [10] have been used. The same problem has been solved using the new 3D beam finite element (3D

NFE) for modal analysis of composite beam structures [4] with a mesh 80 of 3D FGM elements for both power line (the calculation is performed using the software MATHEMATICA [11]) The calculated eigenfrequencies of the power lines at the ambient temperature $T = 20$ °C are shown in Tab. 5 and Tab. 6.

Tab. 5. *Flexural eigenfrequencies of the single power line AlFe 240/39*

f **[Hz]**		**ANSYS**	**3D K.P.**	**Δ [%]**
1st	*xz*	0.1984	0.1981	0.1767
2nd	*xy*	0.3951	0.3945	0.1442
3rd	*xz*	0.3966	0.3961	0.1277
4th	*xy*	0.4954	0.4942	0.2524
5th	*xz*	0.5896	0.5885	0.1845

Tab. 6. *Flexural eigenfrequencies of the single power line AlFe 445/74*

f **[Hz]**		**ANSYS**	**3D K.P.**	**Δ [%]**
1st	*xz*	0.1913	0.1910	0.1440
2nd	*xy*	0.3813	0.3809	0.1034
3rd	*xz*	0.3824	0.3821	0.0769
4th	*xy*	0.4181	0.4178	0.0694
5th	*xz*	0.5699	0.5732	-0.5695

The influence of the changing ambient temperature (temperature of the power line) to the eigenfrequencies of AlFe 240/39 power line is shown in Fig. 4 and to the AlFe 445/74 power line is shown in Fig. 5.

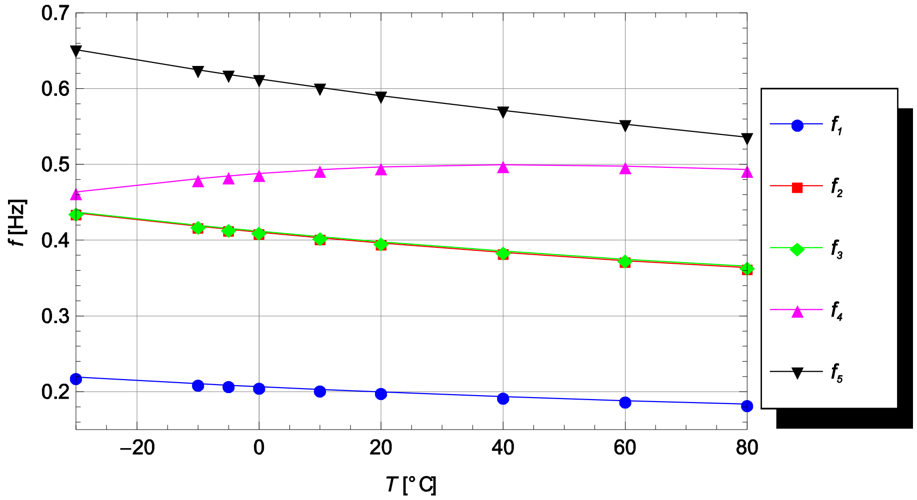

Fig. 4. *Dependence of the first five eigenfrequencies of the AlFe 240/39 power line on the ambient temperatures*

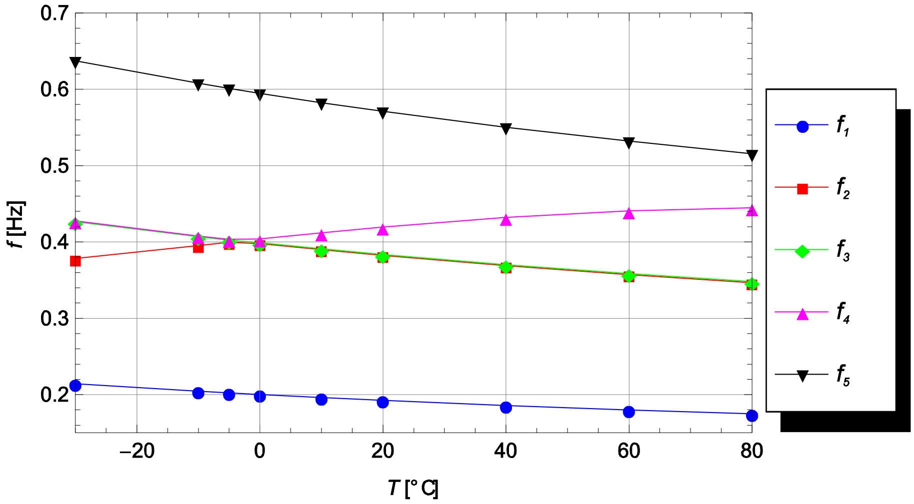

Fig. 5. *Dependence of the first five eigenfrequencies of the AlFe 445/74 power line on the ambient temperatures*

4. Conclusion

In the proposed contribution, the modal analysis of overhead power lines at different ambient temperatures is presented. In the numerical analysis the influence of the ambient temperature (temperature of the power line) to the flexural eigenfrequencies of the AlFe power line has been studied. For numerical simulation our new beam finite element and the commercial FEM software ANSYS were used. From the numerical simulation the following results are obtained: by increasing of the ambient temperature (temperature of the power line) decreases the axial forces and increases the deflection of the power line. By decreasing of the axial forces also decrease the eigenfrequencies of the power line.

Acknowledgement

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