NUMERICAL ANALYSIS AND EXPERIMENTAL MEASUREMENT OF EIGENFREQUENCIES OF ACSR POWER LINES

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1. Introduction

Vibration of overhead power lines is a very complicated problem because it can cause damage of overhead power lines, armatures, insulators or failure of the whole transmission system. Overhead power lines are very often exposed to dynamic loads (for example air flow around the power lines cross-section, ice-shedding, etc.) in addition to static loads (markers, icing, etc.). Power line is a 3D system from the mechanical point of view, so it can vibrate in 3 directions (longitudinal, horizontal and vertical direction). At highest forced vibrations the torsional vibrations are possible too. For calculation of eigenfrequencies and eigenmodes the numerical methods (for example the finite element method) are the most effective. For the modal analysis the beam finite element is preferable.

In the presenting contribution the comparison of the numerical simulation and experimental measurement are presented. The results of modal analysis are obtained using a commercial finite element software ANSYS and by a new 3D finite element [1]. An experimental measurement were done to verify and to compare the effectiveness and accuracy of numerical models of AlFe power line.

2. Modeling of the ALFE power line

For the numerical simulations and experimental measurements the single power line with the length of the span L = 19.9 m and the height difference between the points of attachment (A and B) y_h = 0.8 m has been considered (Fig. 1a).

The symmetric power line marked as AlFe 42/7 which is constructed from 1 steel wire in the centre of the power line and 6 aluminium wires (see Fig. 1b) has been used. The diameter of the steel wire is d_{Fe} = 3 mm and the diameter of the aluminium wires are d_{Al} = 3 mm. The rated tensile strength (RTS) of the chosen power line is F_{RTS} = 15.27 kN [2].

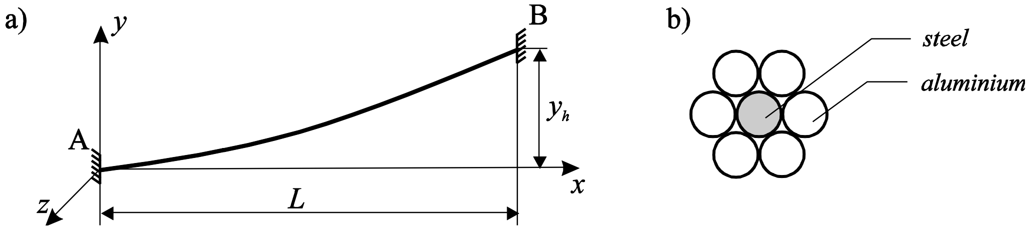


Fig. 1. *a)Model of overhead power line, b)cross-section of the used AlFe power line*

For this case (short length of span and low weight) the maximum deflection of the power line [3, 4] was insignificant and therefore was not calculated. Numerical calculations and experimental measurements were done for three different axial force: $F_{H1} = 2$ kN, $F_{H2} = 4$ kN and $F_{H3} = 6$ kN.

Material properties of the material from which the power line is made are [5, 6]: Steel: the elasticity modulus $E_{Fe} = 207000$ MPa, the Poisson's ratio $\nu_{Fe} = 0.28$, the mass density $\rho_{Fe} = 7780$ kg.m-3; Aluminium: the elasticity modulus $E_{Al} = 69000$ MPa, the Poisson's ratio $\nu_{Al} = 0.33$, the mass density $\rho_{Al} = 2703$ kg.m-3.

3. Numerical simulations and experimental measurements

For numerical simulations a simplified model was used. For simplifying the model of the power line the homogenized material properties have been calculated [7, 8, 9].

The effective cross-sections of the power line parts are: $A_{Fe} = 7.07\ \text{mm}^2$, $A_{Al} = 42.41\ \text{mm}^2$ and the effective cross-sectional area of the whole power line is $A = 49.48\ \text{mm}^2$. The effective quadratic moments of inertia of the power line cross-sectional area are: $I_z = I_y = 218.68\ \text{mm}^4$. The effective circular cross-section of power line is constant with diameter $d_{ef} = 7.94$ mm. The effective material properties of the used power line are:

$$E_L^{NH} = 88714.29\ \text{MPa}, \quad E_L^{M_yH} = E_L^{M_zH} = 40704.43\ \text{MPa}, \quad G_{L_y}^{H} = G_{L_z}^{H} = 34120.91\ \text{MPa},$$

$$G_L^{M_xH}(x) = 27503.49\text{MPa}, \ \rho_L^{NH} = 3460.49\ \text{kgm}^{-3}, \ \rho_L^{M_xH} = 2795.31\text{kg.m}^{-3}, \ \nu_L^{NH} = 0.323$$

where 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. $G_{L_y}^{H}, G_{L_z}^{H}$ is the effective shear modulus, $G_L^{M_xH}(x)$ is the effective elasticity modulus for torsion, ρ_L^{NH} is the effective mass density for axial beam vibration, $\rho_L^{M_xH}$ is the effective mass density for torsional vibration and ν_L^{NH} is the effective Poisson ratio. These calculated effective material properties have been used in the modal analyses of the single power lines.

The first eight flexural eigenfrequencies f [Hz] in plane xy (vertical) and in the plane xz (horizontal) have been found with a mesh 200 of BEAM188 elements of the FEM program ANSYS [10]. The same problem has been solved using the new 3D beam finite element (3D NFE) for modal analysis of composite beam structures [1] with a mesh 60 of 3D FGM elements (the calculation is performed using the software MATHEMATICA [11]).

Fig. 2. *Piezoelectric accelerometer attached on the power line (left), attaching of the tensometer to sensing the axial force in power line (right)*

For experimental modal analyses two IEPE piezoelectric accelerometers with range of 50g (Fig. 2 left) were used to determine the flexural eigenfrequencies. For scanning the signals from the accelerometers and 2 way oscilloscope with USB connection to the PC was used. The range of the oscilloscope is 20 MHz. The tension in power line is measured with one tensometer with sensing range F_{max} = 10 kN (Fig 2 right), which is close of the power line attachment point.

For experimental measurements two types (new and used) of AlFe 42/7 power line were used. Difference between the new and the used power lines are shown in Fig 3. There it can be seen, that the wires of the new power line were smooth and the wires of the used power line were oxidized.

Fig. 3. *Detail of the new and the used AlFe power line*

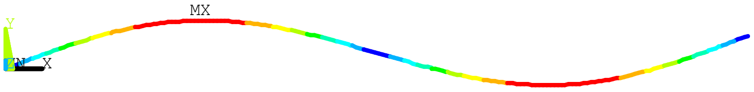
To obtain the frequency spectrum from the measured data, the Fast Fourier Transformation (FFT) was realized by software LabView [12]. The flexural mode shapes were evaluated using software ANSYS.

The first eight measured and calculated eigenfrequencies of single power lines at tension F_H = 4 kN are shown in Tab. 1.

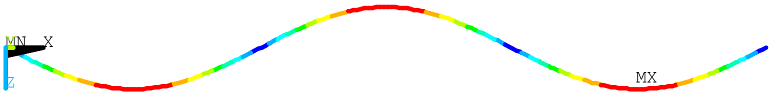
Tab. 1. *Flexural eigenfrequencies of the single power line in the xy and xz planes*

eigenfrequencies *f* [Hz]		**Measured**	**ANSYS**	**3D NFE**	**Δ_{ANS} [%]**	**Δ_{3D} [%]**
1st	***plane xz***	3.41	3.88	3.85	13.76	12.99
2nd	***plane xy***	3.43	3.89	3.86	13.39	12.67
3rd	***plane xy***	7.84	7.76	7.71	-1.03	-1.70
4th	***plane xz***	7.64	7.76	7.71	1.56	0.87
5th	***plane xz***	11.35	11.64	11.56	2.56	1.86
6th	***plane xy***	11.32	11.64	11.56	2.83	2.14
7th	***plane xy***	15.04	15.52	15.42	3.22	2.51
8th	***plane xz***	15.08	15.52	15.42	2.95	2.24

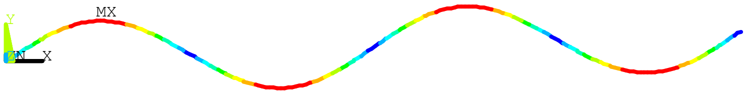
The 3rd, 5th and 7theigenmodes of single power line for tension F_H = 4 kN are shown in Fig. 4.



a) 3rd eigenmode



b) 5th eigenmode



c) 7th eigenmode

Fig. 4. *Eigenmodes of the used power line for tension F_H = 4 kN*

For comparison, the first eight measured eigenfrequencies of the new and used single power line for the tension F_H = 6 kN are shown in Tab. 2. This comparison can be made because of the insignificant difference of deflection (short length of span and low weight) of the new and used old power lines.

Tab. 2. *Measured flexural eigenfrequencies of the new and used single power line*

eigenfrequencies *f* [Hz]		**NEW power line**	**USED power line**	**Δ*f* [Hz]**
1st	***plane xz***	4.16	3.97	0.19
2nd	***plane xy***	4.09	3.87	0.22
3rd	***plane xz***	9.58	8.80	0.78
4th	***plane xy***	9.54	9.00	0.54
5th	***plane xz***	13.93	13.20	0.73
6th	***plane xy***	13.77	13.14	0.63
7th	***plane xz***	18.57	17.33	1.24
8th	***plane xy***	18.35	17.14	1.21

From the results we can see, that the eigenfrequencies of the old power line are smaller, than the eigenfrequencies of the new, and it is caused by changes of the material properties.

4. Conclusion

In this contribution the comparison of numerical simulation and experimental measurements of AlFe power line is presented. Results from experimental measurement realized on a new power line confirm suitability of the numerical models, effectiveness and accuracy of numerical calculations of our new beam finite element.

Because the short length of span and selected AlFe power line the deflection of the new and used old power lines is insignificant. Therefore we can compare experimentally measured value of the eigenfrequencies for the same value of the axial force. From the measurement results we can see that there are differences in eigenfrequencies for new and used power line. This is caused by changes of the material properties. For better comparison a numerical model of the used power line have to be considered. For creating such numerical model it is needed to do new measurements of material properties to recalculate the effective material properties of this power line.

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[11] S. Wolfram Mathematica 5, Wolfram research, Inc., 2003.

[12] National Instruments Corporation, LabView, 11500 Mopac Expwy, Austin, 78759-3504 Texas.