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# IDENTIFICATION OF MODALS PARAMETERS OF TRANSMISSION LINE CABLE

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***Abstract.*** *The dynamics of electric transmission lines cables are induced by the action of the wind. Cyclic stresses not only lead to failure of the cables, but also of the structures and accessories installed on the lines. This way, it is important to analysis the dynamic behavior of the system. Dynamic and structural test using three different cables: Greeley, Phosphorus and Tern with 54 meters span were conducted in an automatic testing bench using an impact hammer for system excitation and five accelerometers for obtaining the vibration data. At the same time, mathematical models obtained by the Finite Element Method were used to obtain corresponding numerical modal data. The modal parameters were identified using modal analysis and the Rational Fraction Polynomial Method (RFPM) and were compared with numeric data obtained with linear and nonlinear mathematical models. The results showed that the linear model presents errors mainly when the cable span is large and with low mechanical traction (errors in the order of 20%), where the catenary is the large. The nonlinear model shows a better agreement between numerical and experimental results (errors in the order of 2.5%) for the entire range of mechanical traction variation used and for the three cable types. Best damping factor results were obtained by tuning the response individually for each vibration mode.*

***Keywords:*** *Transmission line drivers, self-damping, modal analysis, FEM, nonlinear model.*

## 1. INTRODUCTION

The main consequence of the vibrations of the cables of the transmission lines induced by the wind is the appearance of damage by fatigue of the aluminum wires, often in points close to their insertions in the suspension brackets or anchors due to the additional alternating voltages to those provided for in the project. This problem has been studied in various parts of the world with solutions and applications of the most varied possible. This has allowed the increase in the size of the cables and the mechanical loading of these lines with a consequent increase in energy transportation and life of drivers and accessories. Therefore, simulation and validation of computational models is most wise way in order to reduce costs on new projects and on operational maintenances in existing lines.

Barbieri, *et al*., 2003, 2004, 2008 developed and applied linear and nonlinear, models obtained through the finite element method for dynamic analysis of transmission line cables.

Spak, *et al*., 2013 was recent survey of the cable dynamics. The authors reviewed models of helical cable behavior with an emphasis on recent models and they concluded that damping through inclusion of friction forces, viscoelastic shear effects, or bending stiffness, as a function of cable curvature and wire properties, must be included to produce a realistic cable model.

This paper tries to validate a numeric model that which describes the behavior of the three different cable samples.

## 2. MATHEMATICAL MODELS

Barbieri's linear and nonlinear models was applied, in order to validate the models, experimental data were obtained in an automatic test bench for electrical transmission line cables. The modal analyses took into account the variation of the first five vibration modes for different axial loads and sample lengths.

### 2.1 Linear Analysis

The linear physical model on Barbieri, *et al.*, 2004 is similar to a beam under the action of an axial load. This model is usually used to evaluate the behavior of the cable submitted to the action of an external load (such as the excitation due to the wind) and to an axial load (mechanical tension of project). The differential equation of cable dynamics is:

$$EI\frac{\partial^4 w(x,t)}{\partial x^4}+\rho A\frac{\partial^2 w(x,t)}{\partial t^2}-P\frac{\partial^2 w(x,t)}{\partial x^2}=f(x,t) \quad (1)$$

where $f(x,t)$ is the external load, $P$ the axial load, $\rho$ the specific mass, $A$ the cross-sectional area, $w(x,t)$ the transversal displacement, $x$ the position along the sample, $t$ the time variable and $EI$ the flexural stiffness.

### 2.2 Nonlinear Analysis

Even for geometrically non-linear problems with large displacements, the equilibrium conditions between internal and external forces have to be satisfied. If the displacements are approximated with the conventional finite element method by a finite number of nodal values $q=\{q_1,q_2,...q_n\}^t$, the equilibrium equations are obtained by using the principle of virtual works on Barbieri, *et al.*, 2008.

If $\Psi(q)$ represents the sum of the internal and external generalized forces, the equilibrium can be expressed as being:

$$\Psi(q)=\int_V B^t\sigma dV-f=0 \quad (2)$$

where $f$ is the external force vector and $\sigma$ is the stress tensor.
where the matrix $B$ is defined from the strain definition as:

$$d\varepsilon=Bdq \quad (3)$$

After manipulations it is possible to obtain:

$$d\Psi(q)=[K_0+K_L+K_\sigma]dq=K_t dq \quad (4)$$

where $K_0$ matrix is the usual stiffness matrix for small displacements; $K_L$ is the matrix associated to large displacements and it depends on $q$, and $K_\sigma$ matrix is known as the initial stress matrix or geometric matrix. The eigen behavior was obtained by using the $K_t$ matrix of Eq. (4), after static convergence for the nonlinear model.

### 2.3 Modal Analysis

Three different transmission line cables were used, Tern (CAA), 1120 and 6201 (alloy) with a mechanical load variable (7 to 36% of the ultimate tensile strength (UTS)).

The Table 1 shows the specifications of the three samples used.

Table 1 – Specifications of the tested cables.

| Item | Description | CAA Tern | CA 1120 | CA 6201 |
|---|---|---|---|---|
| 1 | Cable code | Tern | Phosphorus | Greeley |
| 2 | Cable stranding (*wires*) | 45 Al / 7 Steel | 37 Al | 37 Al |
| 3 | Diameters (*mm*) | 27,00 | 26,53 | 28,14 |
| 4 | Modulus of elasticity (*GPa*) | 64,47 | 64,00 | 61,78 |
| 5 | Tensile strength (*kN*) | 98,05 | 91,20 | 135,00 |

The sensors used to obtain the vibrational data for the three types of cables are accelerometers PCB model 352C33 and 338C04. The external force was applied by impact hammer PCBI 291M55 at a distance of 0.5 meter from the end.

The accelerometers were placed at positions L/16, L/8, L/4, 3L/8 and L/2 in the length L of the sample. The Rational Fraction Polynomial Method (RFPM) is used for experimental modal analysis.

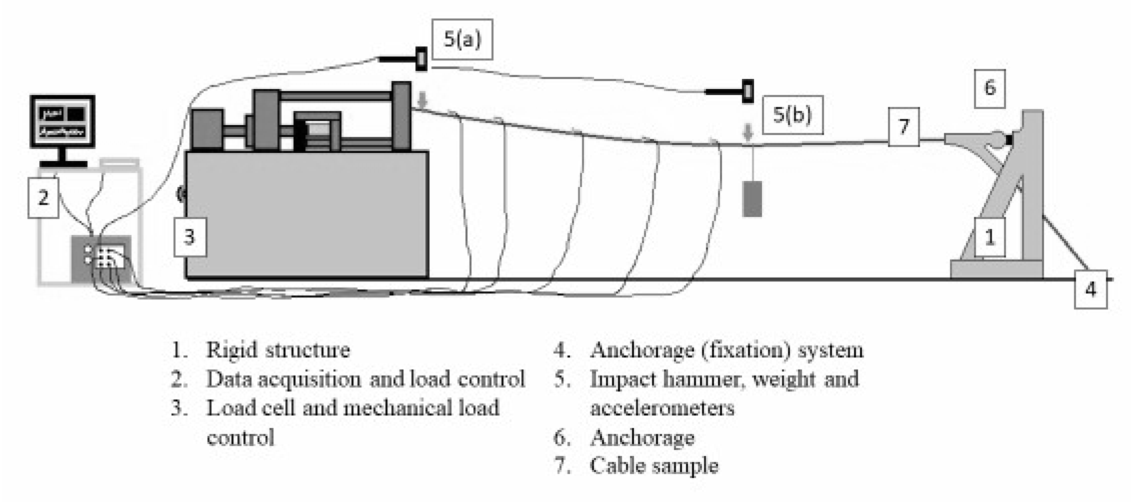


Figure1: The vibration test bench.

Figure 1 shows the system excited by impact hammer and weight. In the system excited by a weight, the hammer is substituted by a suspended rope in the middle of the span. The system was excited by cutting the rope and letting the cable vibrate freely.

## 3. RESULTS

Experimental natural frequency behavior of the first vibration mode using excitation systems with impact hammer and suspended weight, and the numerical values using linear and nonlinear models were evaluated.

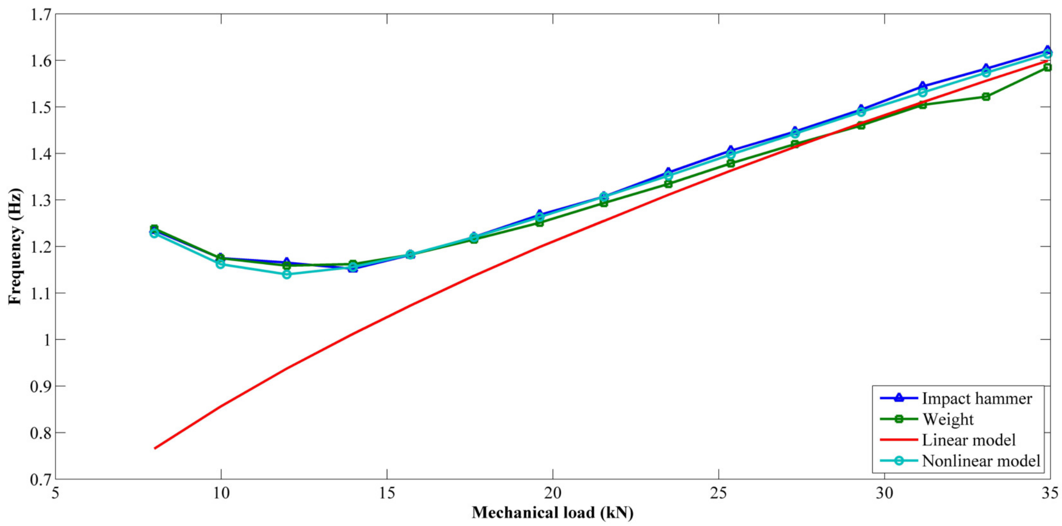


Figure 2: Variation of the first natural frequency for the CA 1120.

Figure 2 shows the curves for the CA 1120 cable. It can be easily noticed that the numeric results obtained using nonlinear model are close to the experimental results. The results obtained with linear model present a large variation in relation to other results. The variations are more accentuated for low mechanical loads and with an increasing mechanical load the errors decrease. The same behavior was observed for the other two types of cables.

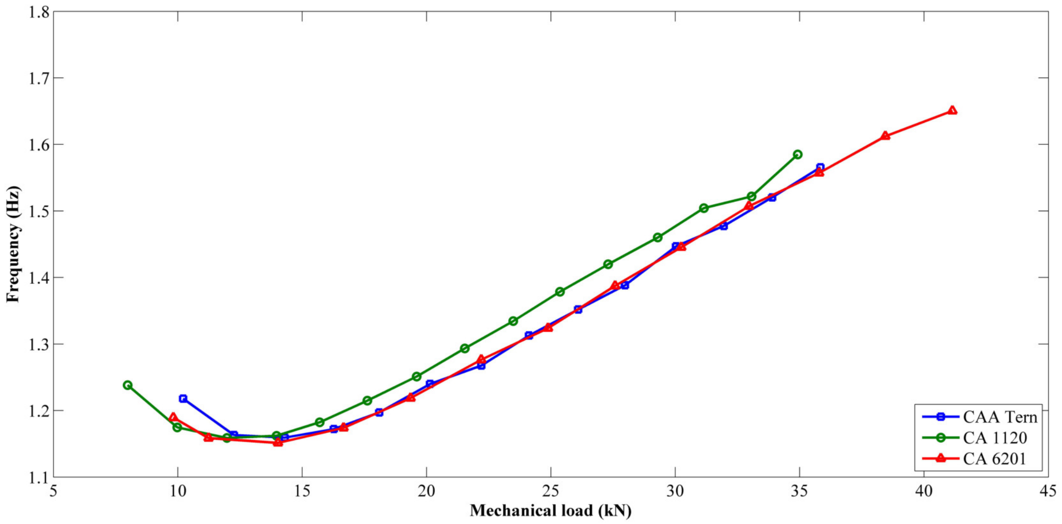


Figure 3: Variation of the experimental first natural frequency of the three cables.

Figure 3 shows the experimental curves of the first natural frequency variations with an increment of the mechanical load. For low mechanical loads, the curves show a tendency inversion, that is, an increase in the frequency with the decrease of the load.

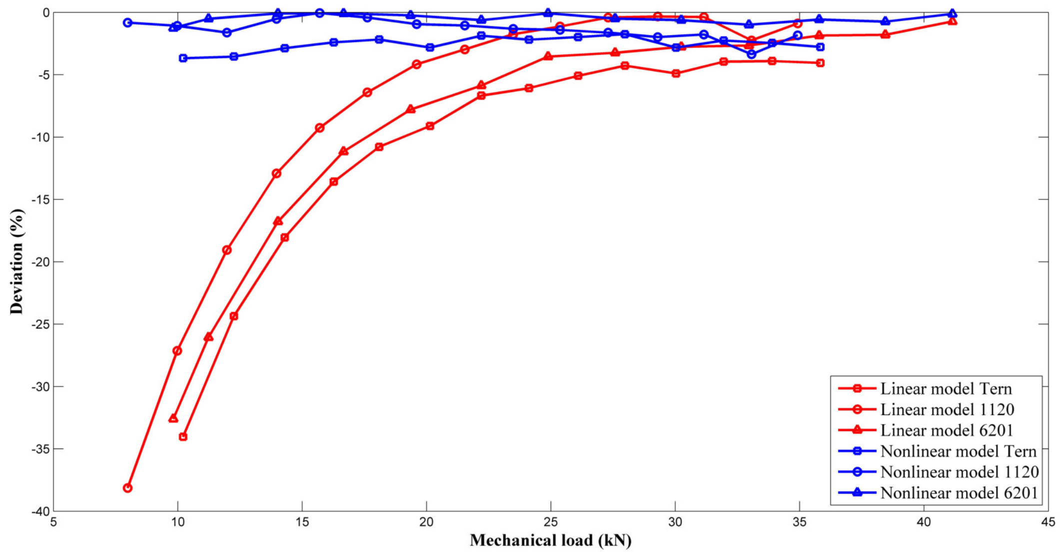


Figure 4: Deviation of natural frequencies using linear and nonlinear models.

Figure 4 shows the relative deviation obtained by comparing the numerical results of first natural frequency obtained with linear and nonlinear models. The linear results show relative deviations above 30% for low mechanical loads.

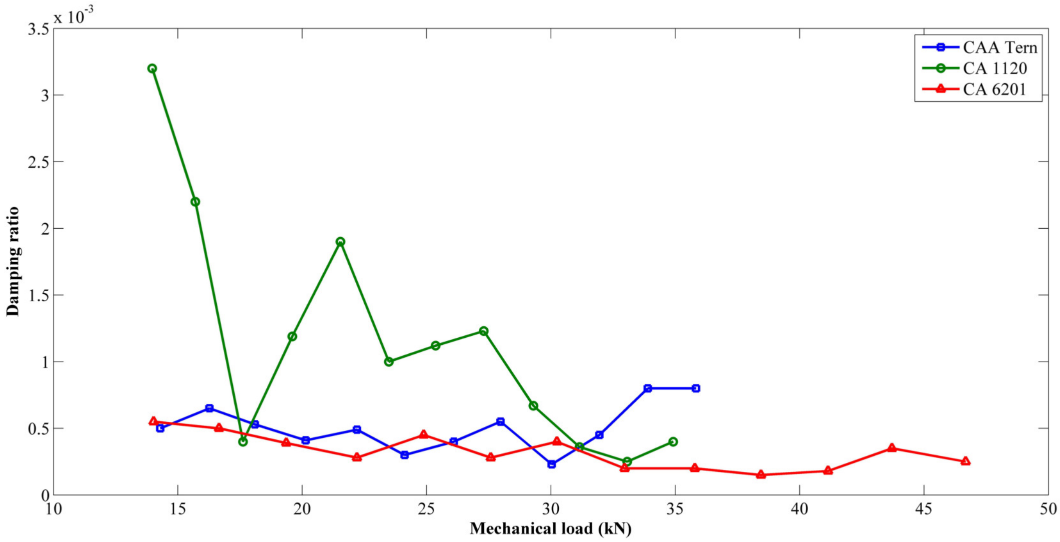


Figure 5: Damping ratio of the three cables.

Figure 5 shows the damping ratio in first natural frequency, it was adjusted using selective filtering of the signal in time domain around the first natural frequency. A Butterworth digital filter of fourth order was used. The modal parameters were found through the adjustment of a time function using a gradient search method using filtered signal.

## 4. CONCLUSIONS

In this work was noted that the linear model for dynamic analysis conductor cable provides good results only for high mechanical cable loads, which is not commonly used in practice. The linear model also shows good results for small samples length. For samples of large length, nonlinear models present better results than linear models mainly for low mechanical loads. This fact is evidenced by analyzing the behavior of the first vibration mode. We used 3 different cables for dynamic analysis and it was noted that the largest percentage deviation of the numerical values of the natural frequency of the first vibrate mode using nonlinear models was around 2.5% for low mechanical loads and the deviation for the linear model was in the order above 30%.

## 5. ACKNOWLEDGEMENTS

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## 7. RESPONSIBILITY NOTICE