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DEVELOPMENT OF TRANSMISSION POWER WORKBENCH FOR NUMERICAL AND EXPERIMENTAL ANALYSES

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Abstract. *Throughout the last decades, there was a great increased in a production of electricity. The production process is divided into generation, transmission and distribution. The Brazilian energy matrix is based mostly on hydroelectric generation. For the large territorial extensions, is natural that the power plant was be building away from the more important downtown's, and the transmissions systems need be large for ensure meeting the demand at low cost. Therefore, this paper intends to carry out the construction of an experimental model for a transmission tower, in scale, in order to feed the numerical model with data and calibration and show the modal behavior of this equipment. The performed experimental modal analysis provided consistent results for the modal parameters of the constructed tower, allowing the construction of a numerical model still valid and will provide the basis for graduation courses and graduate, as General Mechanics and Experimental Modal Analysis.*

Keywords: *Numerical Analyze, Modal Analyze, Transmission Tower, Workbench, Numeric Model.*

1. INTRODUCTION

Over the past decades, there has been a large increase in the need for electricity production, in Brazil the hydropower matrix adopted by hydropower installed in rivers with high capacity generation. Considering that the plants usually are distant from large consuming centers, and the large geographical size of the country, effective and robust transmission systems are needed to ensure the fulfillment of the demands at low costs.

Because the structural dimensions and the deployment location, transmission towers and cables used are regularly subjected to dynamic forces arising from natural phenomena, the most frequent of these is the action of the winds bend the cables and the structure.

Thus, recent advances in design methodologies and computational analysis through mathematical modeling has allowed a better understanding of the phenomena involved in the transmission of energy. However, it is still common practice among designers restrict the analysis to static and linear aspects considering the behavior of towers and cables separately. Therefore, this paper proposes to build a bench that simulates a transmission tower and validate the model in finite element method based on ANSYS platform and can thus characterize the tower-cable interaction is significant or not in the dynamic behavior of the system.

For Soeiro (2001) the modal analyze is essential for describe a structure in terms of its natural frequencies, damping factors and mode shapes, that is, the dynamic properties of the structure. The variation in oscillation frequencies of a force in a structure generates different responses in the vibration amplitudes at different points in time scale, with an increase of response when the next oscillation frequency of the natural frequency of the structure, and the maximum peak when the frequency oscillation is matched to the natural frequency.

Battista ***et al*** (2003) developed an analytical-numerical model based on the finite element method, in order to investigate the dynamic behavior and response of the one-tower system coupled transmission lines. The wind turbulence was simulated by the auto-regressive method. Considering a transfer of the delta type of tower belonging to a 230 kV transmission line, the first 10 modes of vibration and their mode shapes were calculated. Analysis in the time domain and frequency allowed the authors to conclude that the insulator string functions as double pendulums whose length has great influence on system response coupled transmission lines, towers. This paper was important to determine the mathematical and computational setup that was used in the ANSYS model for this work.

Kaminski (2007) holds in his thesis a thorough analysis about the mechanical model of uncertainties of steel lattice towers of power transmission lines. The author evaluates various mathematical models of increasing order of complexity and detail, assessing them and comparing them to static experimental results obtained in a test station. Three structures like porches transmission towers were subjected to destructive and non-destructive testing. This concluded that the simplest models of static analysis are satisfactory, showing low dispersion compared to experimental results. However, for models considering the flexibility of the link, for example, results presented closer to the experimentally obtained data. Therefore, this job show the utilizations of simplifying hypothesis is valid and very possible, being used as the basis of the assumed computer configurations.

2. MATERIALS AND METHODS

2.1 Reduced scale transmission tower construction

Initially, a data collection was performed in electric energy transmission lines with bigger use in the Amazon region, and by knowledge and partnerships from previous studies, transmission towers in Tucuruí-Vila do Conde were chosen with its operator, the Eletronorte. Through the analysis of topographical collection and structural plants, the interspace that crosses the Tocantins River, at the dam downstream of the Tucuruí Hydroelectric Power Plant, at the Tucuruí city, in Para. The choice was made due to its considerable suspension towers height (116 m), which naturally are very sought for strong winds, due to the size of its interspace (1325 m) and the fact that the interspace is located at the crossing of the river, which is one of the windiest situations provided by NBR 6123. The support towers of this interspace are the freestanding suspension ones, with 500 kV double circuit, SOD-E-500 model.

From the completed project, the Transmission tower construction began in reduced scale based on the Tower mentioned above. The constructed tower have 1.5 meter of height, with pyramidal body based on the tower model SOD-E-500, two kinds of aluminum structural profiles, with 18x18x1 mm and 12x12x1.4 mm dimensions, where its central bars in the pyramidal body have bigger cross section area then the other constituent bars. In Fig. 1, it is possible to compare the constructed tower with the CAD platform projected model.

Lastly, a concrete base with approximately 80 kg was built, in order to obtain a reasonable setting condition in the tower feet. Since the structure total weight has 3.54 kg, it may be considered that the constructed base has a bigger inertia than the tower.

Figure 1. Constructed tower with the CAD platform projected model.

2.2 Numerical model analysis.

After the tower construction and with the computational modelling, the creation step began with the creation of a finite elements model using the ANSYS platform. The beams were modelled using the beam element BEAM 189. This element is based in a Timoshenko beam, including, therefore, the shear effects. In the analysis, it has 6 liberty degrees by node, being 3 of translation and 3 of rotation. Presented in figure 2.

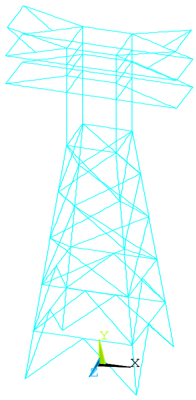

Figure 2. Bars modelled using the BEAM 189 element.

For the finite elements construction model, some simplifying hypothesis were assumed:

- The fixation elements were disconsidered in its geometry and the parts they act were drawn as single parts;
- No components like screw-nuts, screws and other fixation parts were inserted;
- The numerical model construction preoccupation is not in the drawing quality, but in its real model proximity, which helps not to have great rigidity differences (geometrical properties) and its components mass, since this can interfere directly in the results.

From this, the modal analysis was carried out aiming to obtain the mode shapes structure characteristics using the template lines with element BEAM 189 (Figure 3).

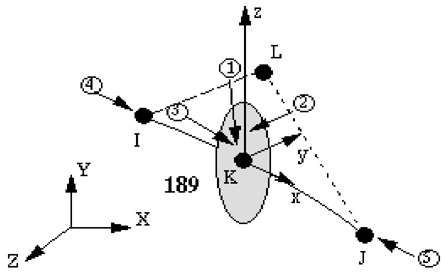

Figure 3. Geometry of BEAM 189 element.

To perform a modal analysis of the structure based in the finite elements theory, the structure was enchased in the base nodes, not allowing any sort of movements in neither directions in the base. The inserted material data were arbitrary aluminum alloy values in Poisson coefficient, Young module and alloy density, not having a great concern about the correct data, aiming a future model update, where these project variables will be optimized.

The chosen modal extraction method was the Block Lanczos one, the most used for complex models where beam, shell and solid elements are found, with efficient extraction modes in a determined frequency range. This method presents good rigid bodies data management. Therefore, this method was the best choice to be used.

In addition, a model adjustment program was created based on an objective function method, which seeks to maximize the correlation between experimental data and analytical models. Foi criado também um programa de ajuste de modelos pelo método da função objetivo, que busca maximizar a correlação entre os dados experimentais e analíticos do moledo. It is worth mentioning that this methodology seeks the adjustment of the model natural frequencies. Therefore, the modal forms were not used as state variables, but as a search for inertial properties and rigidity adequacy of the studied system.

In the case of the objective function, it was necessary to obtain an equation to be minimized or, in other words, a function that tends to zero. However, with error considerations at 10% maximum, once it is practically a total convergence based on the experimental data. Based on this, it is admitted that the objective function is minimized and the best-obtained results will be the ones that are in the margin of error with the minor objective function value.

2.3 Modal experimental analysis

After the tower construction, a modal experimental analysis was performed to determine the main modal parameters and to characterize the tower dynamic point of view. In this way, the structure nodes were numbered in every screwed joint, in a total of 76 nodes. The experimental modal analysis was made with a commonly used technique in which a vibrations shaker (B&K 4809) exciter is fixed to the structure and the accelerometer is positioned in every other nodes, wherein the tip of the exciter, connected to the structure, an impedance head (B&K 8001) which consists in a cell charge and an accelerometer. This setup is showed in the Fig. 4.

As interface software with signal analyzer, the Pulse® Labshop® 12.1 was used, which was configured to provide the answer functions in frequency, coherence and each measure phases.

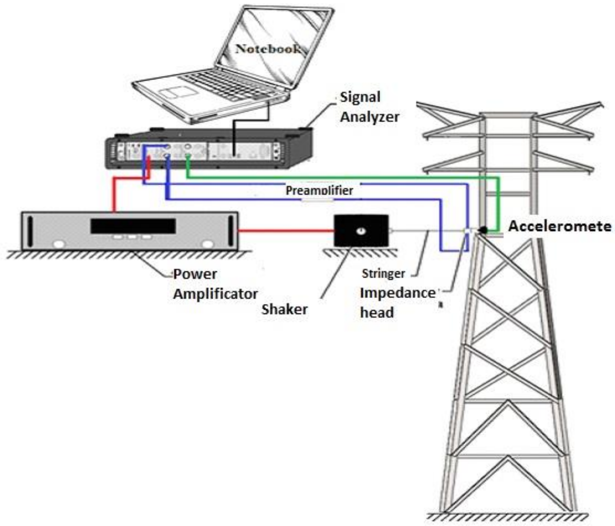

Figure 4. Setup of experimental analyze with Pulse® Labshop®.

The input and output signals were analyzed by the Pulse 3560C, and the transference then calculated because it is a tridimensional structure, each node was excited in more than one direction, unless when the node configuration prevented it.

The Pulse analyzer was configured to generate a white noise, which is featured by a signal that in the frequency domain presents a constant energy amount in every frequencies. This generated frequency is amplified and then sent to the shaker, then exciting the structure. The impedance head locked to the stinger needs pre-amplifiers, because it does not have on-board electronics.

The answer and force in the application point of the excitation are measured with the impedance head (punctual), and in their other (transference) points the answer in frequency is measured with a high precision accelerometer. This way, it is possible to measure the answer functions in frequency (FRFs) in the points. Shown in Fig. 5.

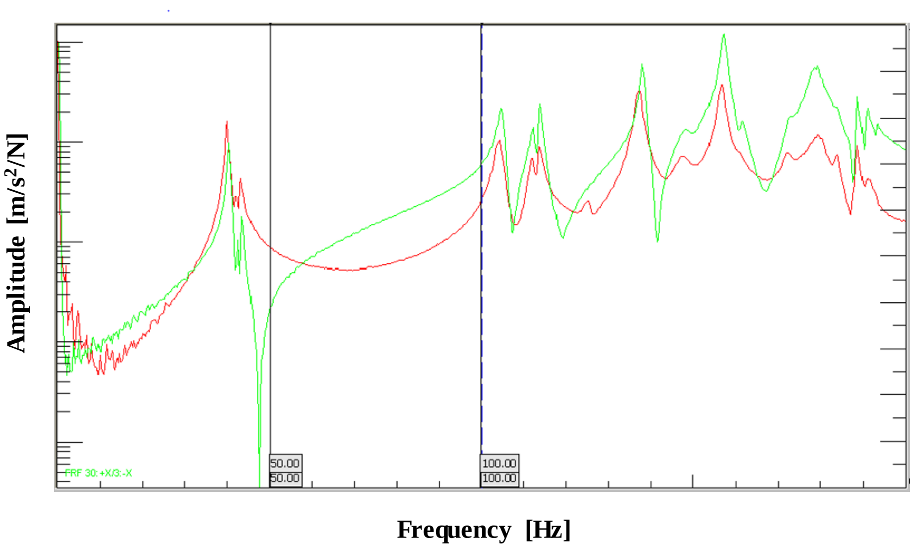

Figure 5. Example of FRF diagram obtained in the Pulse® Labshop® software.

3. RESULTS

3.1 Modal forms numerically obtained

The numerical analysis was performed aiming to find the first four modal forms in 0 to 200Hz range. The results of the numerical modal analysis were obtained for future comparisons with the modal experimental analysis, seeking to realize if the same modal forms were obtained and with which natural frequencies. These results are showed in Fig. 9 A to D. Even knowing that it would have discrepancies, since it is practically impossible to insert in the numerical model some variables such as geometrical discontinuities, metallic material porosity, among others, that certainly are present in the real tower model. Therefore, it is possible to reduce this margin of error using model adjustment techniques for natural frequencies optimization. The numerical results show the following vibrations models below.

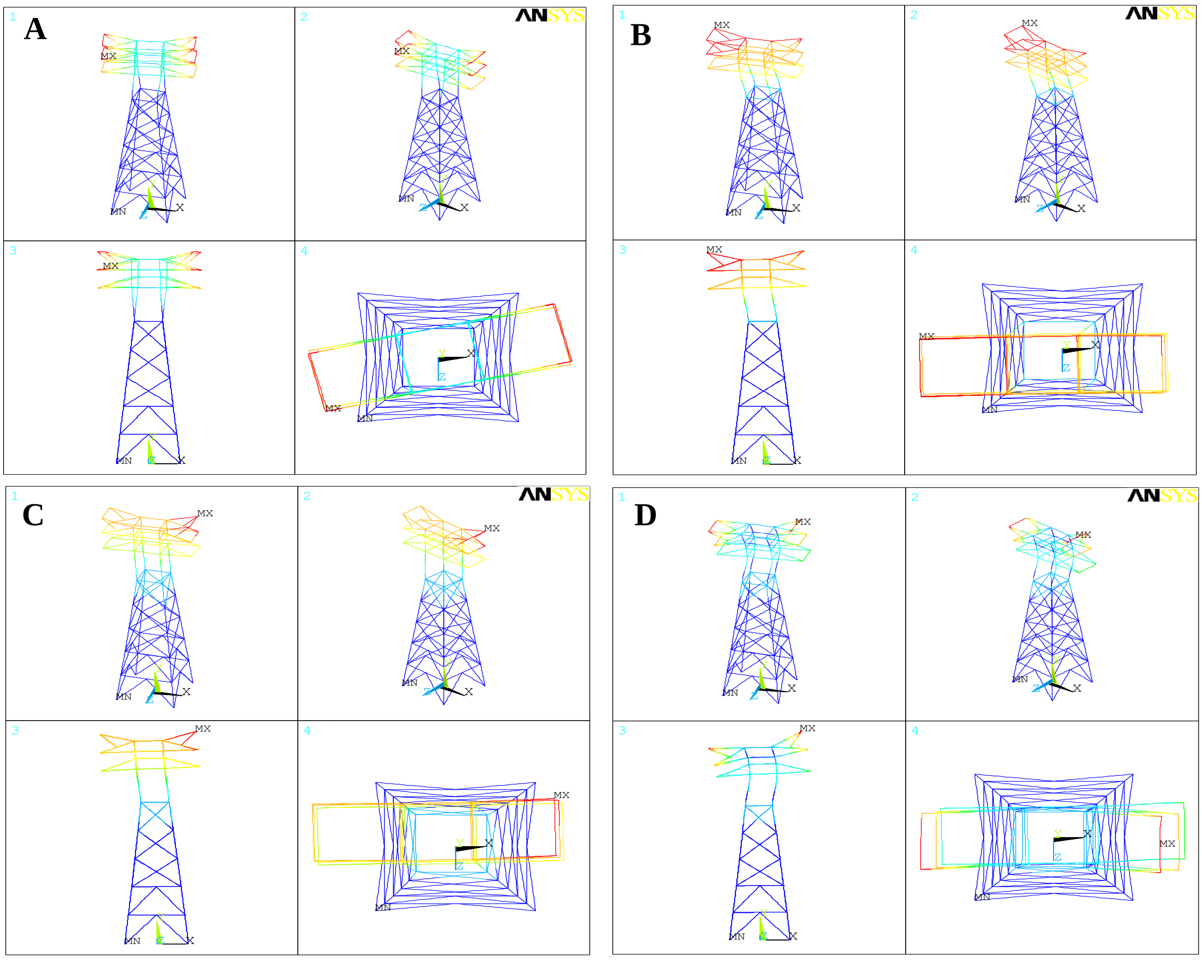

Figure 6. Diagram of shear modulus versus frequency at 303 K

The first vibration mode, shown in Fig. 6A, exhibits torsional deformation along Y-axis. Such analysis is important in case of a sudden rupture of one of the conductors. The second vibration mode, shown in Fig. 6B, represents bending about Z-axis. This mode has great modal participation in the most common crosswind excitation case. The fourth vibration mode, presented in Fig. 6C, is associated with torsion along Z-axis. The fifth vibration mode, shown in Fig. 6D, presents a bending mode about X-axis. I can be seen yet a slight inclination towards the front plane to the left.

3.2 Experimental results and optimization.

The model adjustment program was divided in three files. The first one is the ANSYS model construction, modelling e numerical modal analysis solution. The second on, the adjustment parameters are informed, such as tolerances, experimental frequency values and the objective function. In the third file, the state variables are defined, as well as the admitted tolerances in file 2, the optimization time, and some basic configurations for the convergence beginning. The three files are presented in the appendix section of this paper.

To perform the optimization, the convergence process begins until the objective function is reached. With the adjusted results for material properties, the optimized frequencies can be extracted. The table 1 show the comparison between the experimental and optimized simulated frequencies and the results are very close, validating the experiment and mathematical simplifications adopted.

Table 1. Comparison between the optimized and experimental frequencies.

Natural Frequency	Optimized	Experimental
First	36.883	39.976
Second	39.284	41.938
Third	54.090	43.015
Fourth	169.55	103.660

4. CONCLUSIONS

When evaluating the modal experimental analysis results, the presence of four tower modal forms, using 1 to 120Hz range. However, the first three modes are in very close natural frequencies, what turned to be extreme difficult to extract the correct modes with precision. When comparing with the finite elements model, it was observed that the convergence of modal forms, only with slightly difference from which the first experimental modal form is confused with the second numerical modal form, which is plausible due to great proximity among these frequencies. Due to these differences between the data obtained experimentally and numerical data, there was the need to perform the model adjustment.

To obtain the adjusted result, it was necessary to define the material properties as project variables. Besides, the informed intervals adjust the sequences of the modal forms to stay as those shown experimentally. There was convergence in the technical utilization, and the first three natural frequ encies stayed with an error below 10%. However, since the fourth experimental natural frequency is significantly higher, the convergence became difficult, towards the first three that are all found in 30 to 50 Hz range. Then, the convergence was only succeeded in the fourth modal form, however this fact becomes acceptable, since in the structural project, the first modal forms in relatively low frequency are the most important to be determined and the ones to be considered, since the resonance would be initiated below the 100Hz. This result is in accordance with the showed in the referen ces utilized.

This work was then expected results regarding the model fits between experimental and numerical results and, determining simulation variables for the materials used.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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