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Study on Structure of Drum Type Transmission Tower Based on Modal Analysis

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Abstract. Based on the theory of dynamics, this paper takes a certain drum-type transmission tower as the research object, performs parametric modelling based on the actual size, and performs modal analysis on the tower structure through the finite element method. The frequency and mode of the first 20 steps of the transmission tower were extracted. The results of modal analysis show the dynamic characteristics and structural characteristics of the drum-type transmission tower, providing a theoretical basis and foundation for studying the earthquake resistance, wind resistance and other environmental incentives of the transmission tower structure.

1. Introduction

With the rapid development of national power construction, the safety issue of high-voltage transmission lines has also received more and more attention. Transmission towers, as the backbone of the safe and stable operation of the power grid, have poor working conditions and are generally located in the geographical environment of the wild, mountains, and suburbs. With the continuous increase in the voltage level of transmission operation in recent years, the parameters such as tower height, span, and safety distance in high-voltage and UHV transmission lines have also increased, making the transmission lines more vulnerable to wind, rain, and snow. Thunder and other natural factors. Especially under the action of wind, earthquake and other dynamic loads, the transmission tower is a kind of high-lattice lattice structure, its vibration effect is very significant, and the structure is easily destroyed and collapsed.

To optimize the structure of transmission towers and reduce transmission risks, this article takes a 220kv line drum transmission tower as an example to demonstrate the basic dynamic characteristics of the tower structure through the finite element analysis method. It provides a theoretical basis and foundation for studying the earthquake resistance, wind resistance and other environmental incentives of the transmission tower structure.

2. Overview of Finite Element Analysis Theory

Finite Element Analysis (FEA) is a numerical technique that seeks to approximate the numerical problem of boundary partial differential equations. Decompose physical quantities into smaller, simpler units, and then use a limited number of units to interact to simulate a real-world system. The principle is to decompose and solve the overall complex system and then merge, and finally get the overall accurate solution.

The birth of finite element analysis is due to the practical problems and the complexity of the system, making it difficult to describe with simple calculations. Finite element calculations can adapt to a variety of complex shapes and thus become effective engineering analysis tools. For the mechanical analysis of transmission lines, the prototyping towers are expensive and have long experimental periods, and are affected by environmental factors. With the rapid development of computer technology, the accuracy and depth of finite element analysis have become higher and higher, and it has gradually become the tool of choice for mainstream structural analysis and multiphasic coupling analysis.

A typical finite element working method includes: (1) Divide the problem domain, divide into sub-domain collections, and each sub-domain represented by a set of meta-equation. (2) The reorganization meta-equation represents the overall system of the final calculation. Combining all the meta-equation equations yields the characteristics of the overall system. For the object of this study, the structure of the transmission tower is divided into small units through the finite element mesh, and the force conditions are calculated respectively. Finally, the overall dynamic characteristics of the transmission tower are obtained.

The basic equations for calculating the dynamics of ANSYS are:

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{F\} \quad (1)$$

$\{u\}$ ---Node displacement

$\{\dot{u}\}$ ---Nodal speed

$\{\ddot{u}\}$ ---Node acceleration

$[M]$ ---Overall mass matrix

$[C]$ ---Overall damping matrix

$\{F\}$ ---Total external load of the structure

ANSYS provides two general mass matrices: a consistent mass matrix (default) and a lumped mass matrix. The overall mass matrix is generated by the density parameter, so the density must be entered when performing the kinetic analysis. Equation (1) is the basic equation of transient dynamics. Three methods can be used in ANSYS to solve the basic equations of dynamics: complete method, modal superposition method and reduction method. Method manner fully reduced and direct method belong to solve the integral transient kinetic equilibrium equation, i.e., the use of HHT method and Newmark improved. The amount of calculations required by the complete law is too large to apply to small-scale engineering calculations. The modal superposition method uses coordinate transformation to decouple equation (1) and start solving.

3. Parametric modeling

Drum type transmission towers are generally used for transmission lines with a voltage level of 220kV and above. They have a wide range of construction and operation scenarios and are suitable for areas with severe ice-coverage. They can effectively avoid the flashover accidents caused by wire jumps when the wire is removed. Considering the complicated structure of transmission towers, modeling efficiency is directly low in ANSYS's Design Modeler module. This article takes a certain drum-type transmission tower as an example, adopts Solidworks software to carry out preliminary parameter modeling of transmission towers, and then connects to ANSYS. Convert to finite element model for analysis. Taking into account the actual situation of the modeling and analysis requirements, in the case of ensuring that the tower structure is intact and unchanged, some of the auxiliary structures that have little effect on experimental data, such as bolts, connecting plates, etc., are properly ignored during modeling. When modeling, it is mainly to ensure that the mechanical properties of the structural part of the main steel of the transmission tower are consistent with the actual ones, that is, to ensure the correctness of the dimensional structure and connection relationship of the main material. Skewed material and auxiliary material of the transmission tower will be ignored. When modeling, the size of each part of the transmission tower is based on the size data of an actual project transmission tower. The detailed steps for modeling are not described here. The final parameterized modeling is shown in Figure 1. Finally, through the ANSYS software interface for data exchange, given its material properties, the finite element model of the transmission tower was obtained.

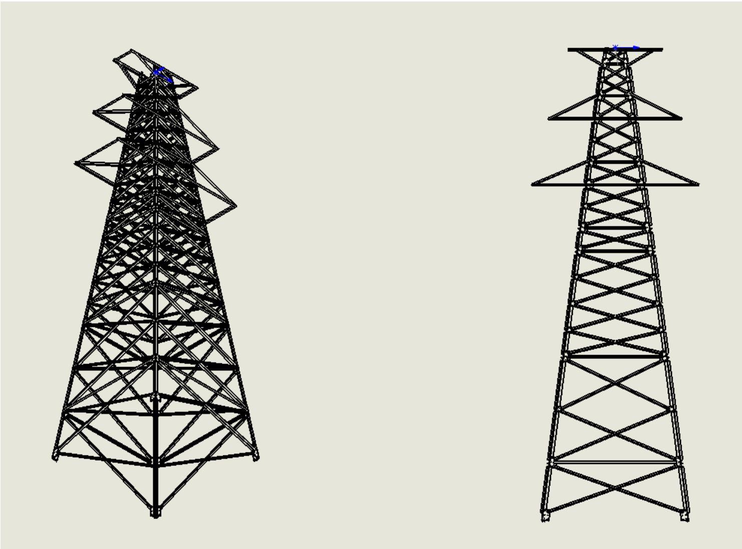


Fig. 1. Transmission tower geometry model

4. Modal analysis pre-processing

Modal analysis is a common method for studying the dynamic characteristics of structures, and it is also the basic application in the field of engineering vibration analysis. The modality represents the natural vibration characteristics of the mechanical structure. Each modality has its unique natural frequency, damping ratio, and mode shape. Modal analysis is the most basic content of all types of dynamic analysis (harmonic response analysis, spectral analysis, transient dynamic analysis, etc.). Through finite element parametric modeling and modal analysis of the transmission tower, the natural frequency and mode shape of the transmission tower model can be accurately calculated, which is of great help to study the dynamic characteristics of the transmission tower. Taking $[C]$ and $\{F\}$ in equation (1) as 0, it is converted into the basic equation of modal analysis:

$$[M]\{\ddot{u}\}+[K]\{u\}=0 \tag{2}$$

ANSYS assumes that the modal analysis is linear, so both the overall mass matrix and the overall stiffness matrix are constant.

For a linear system, the solution of equation (2) is:

$$\{u\}=\{\phi\}_i \cos\omega_i t \tag{3}$$

$\{\phi\}_i$ ——Corresponding Mode Shape Characteristic Vector of Mode *i*

ω_i ——Natural frequency of mode *i* (rad/s)

t ——time(s)

Substituting equation (3) into equation (2) results in:

$$\det\left|([K]-\omega_i^2[M])\right|=0 \tag{4}$$

For the transmission tower structure, it belongs to the problem of small deformation line elasticity, and the modal superposition method is completely applicable. In the modal analysis pre-processing section, the standard structural steel in which the transmission tower member material is isotropic is defined; fixed constraints are applied to the bottom of the tower leg to simulate the fixed effect of the foundation on the transmission tower, and to constrain the six degrees of freedom. For grid division of a complex structure such as a transmission tower, considering the grid quality and computational efficiency, Relevance Center selects Medium, and Element Size selects Default. If the mesh quality is insufficient, add the On Proximity And Curvature option to the Advanced Size Function to increase the accuracy of the local meshing.

Using tetrahedral elements, the transmission tower model was eventually divided into 131 147 meshes, containing 268 501 nodes. The local meshing situation is shown in Figure 2.

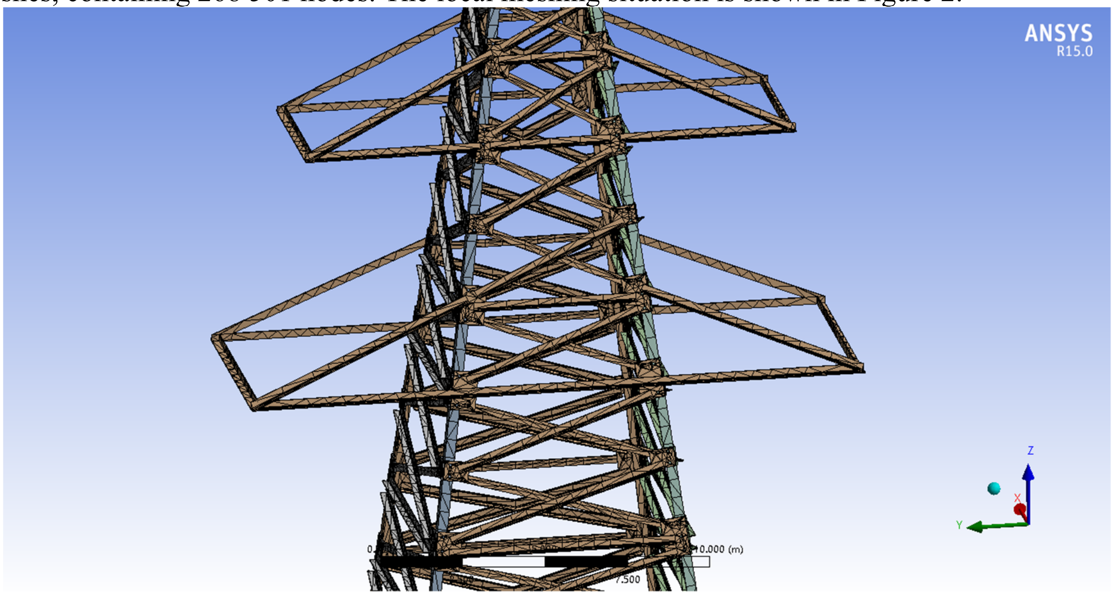


Fig. 2. Transmission tower Local meshing

5. Modal data solution and analysis

Complete the above three parts in the preprocessing module. That is, material definition, meshing, and constraint loading. Solving through the ANSYS solver, the natural frequencies and cycles of the first 20 analysis modes of the transmission tower model are shown in Table 1.

Table 1. Top 20 analysis modes of transmission tower model

Modal order	Frequency (Hz)	Cycle (s)
1	2.4478	0.40853
2	2.5276	0.395632
3	3.0254	0.330535
4	3.4646	0.288634
5	3.5818	0.279189
6	3.6472	0.274183
7	3.6861	0.271289
8	3.6987	0.270365
9	3.7497	0.266688
10	3.9552	0.252832
11	4.0764	0.245314
12	4.2051	0.237806

13	4.3088	0.232083
14	4.3340	0.230734
15	4.4704	0.223694
16	4.5522	0.219674
17	4.6573	0.214717
18	4.8763	0.205074
19	4.8795	0.204939
20	5.0196	0.199219

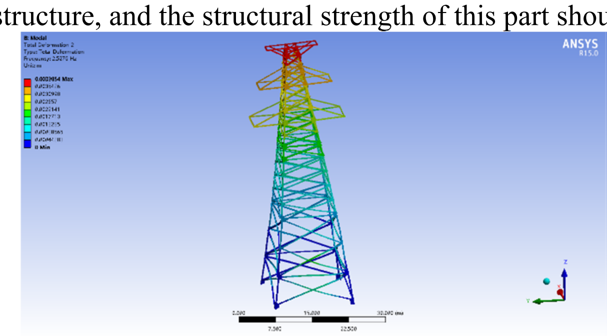
In the process of structural design of transmission towers, the results of the calculation of the fundamental frequency should mainly be considered. The overall stiffness of the transmission tower and the type of materials selected will affect the fundamental frequency. Based on experience summarization and theoretical deduction, the power sector of China has given the formula for the first natural vibration period of the transmission tower as follows:

$$T_1 = 0.034\frac{H}{\sqrt{b+B}} \qquad (5)$$

B--Root width； *H*-- Tower height； *b*--Width of tower head

According to the formula, the theoretical first self-vibration period of the drum tower is 0.399 s, corresponding to the first-order vibration frequency of 2.506 Hz, and the finite element calculation error is about 3%, which proves that the modal analysis results of this drum tower are more accurate. Fig. 3 and Fig. 4 are the modal vibration modes of the transverse vibration and the partial structure vibration of the transmission tower, respectively.

Combined with the results of the modal analysis chart, it can be seen that the first vibration mode of the drum tower is the overall transverse vibration; the second stage is the overall longitudinal vibration; the third stage is the overall torsional vibration; the fourth and fifth stages are The overall horizontal and vertical bending vibrations; the sixth to the 20th order are all manifested as the local oblique material bending vibration, and the similarity is high, only the direction and location are different. The vibration of local oblique material and auxiliary material may be a dangerous part of the structure, and the structural strength of this part should be strengthened in the design.



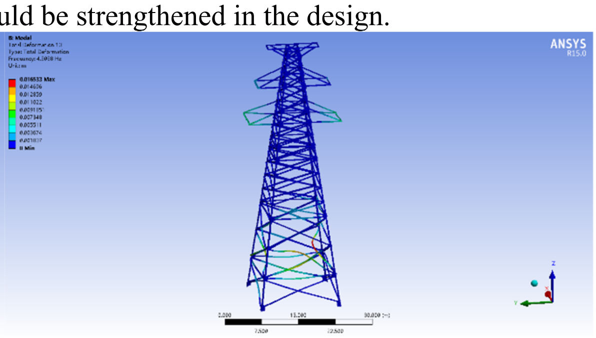


Fig. 3. Transmission Tower Cross Vibration Fig.4. Transmission Tower Local Vibration

6. Conclusion

The structural safety of transmission towers is the key point for the safe operation of transmission lines. The structural characteristics of the drum transmission towers obtained by modal analysis in this paper are as follows: The frequency difference between neighboring natural vibration frequencies of drum-type transmission towers is small and close, which is in line with its square symmetry. The structural features of the arrangement; the skewed material of the tower of the drum tower is the key part of the local vibration, and the bending force of the joint between the tower head and the tower body is relatively large, and it is easily damaged. In the design, the necessary reinforcement is needed to eliminate the potential. Threats and hidden dangers to ensure tower safety. The experience of modelling and analysis of drum-type transmission towers can also be applied to other similar structures of high-voltage transmission towers, such as wine cup-type transmission towers and cat-head transmission towers. This paper does not consider the dynamic characteristics of the transmission tower after the line is loaded. Whether or not the dynamic characteristics of the transmission tower are qualitatively changed requires further study.

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