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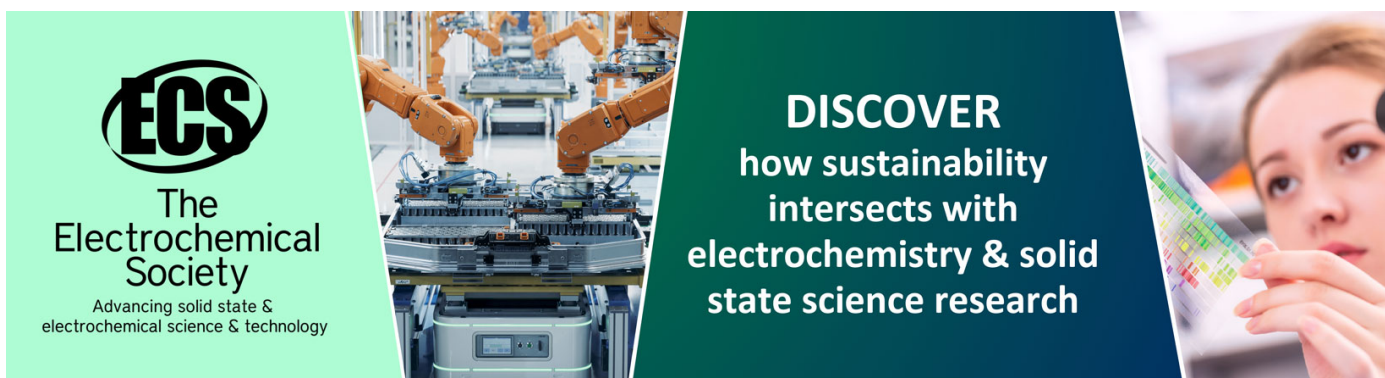
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The modal analysis of the GIS pipe shell

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Abstract. With the help of modeling by ANSYS and application of finite element method, 3D static analysis of GIS pipe shell, the self-vibration analysis of the whole structure are carried out in this thesis. The basic principles of modal analysis in ANSYS are introduced. After establishing the integral finite element model considering the self-weight of GIS pipe shell in ANSYS, the structural model analysis is carried, the top 30 order models are obtained, and the former five-order vibration mode are listed in this thesis. The analysis about the free vibration characters of the GIS pipe shell structure shows that the lateral stiffness in two direction of the structure is relatively uniform, and the structure is comparatively regular, with small torsional rigidity. Also it suggests that the stiffness of side force resistance and torsion resisting stiffness should be improved during the design process.

1. Introduction

The GIS pipe system of substation bears the comprehensive action of various loads. If the strength is not enough, it is easy to cause the deformation and damage of the cylinder and cause SF₆ leakage. At present, the abnormal outage maintenance caused by SF₆ leakage accounts for a high proportion of all kinds of accidents caused by GIS fault. SF₆ leakage threatens the safety of equipment, personnel and environment, and causes great losses to industrial and agricultural production. Gas leakage seriously affects the reliability of power supply [1], which has become one of the core problems to be solved urgently.

In this paper, the GIS pipeline of a substation is taken as the research object, and the finite element model of GIS pipeline is established by using the large-scale general finite element analysis software ANSYS to analyze the natural vibration characteristics of the whole structure. The stress and deformation characteristics of GIS shell are studied, and the operation rules of equipment under different working conditions are mastered.

2. Modal analysis

2.1. Theory of modal analysis and calculation

Modal analysis is the basis of structural dynamic analysis. It mainly calculates two basic parameters of natural mode of structure: natural frequency (period) and mode shapes, so as to analyze the natural vibration characteristics of the structure and prepare for the future dynamic analysis.



For the multi degree of freedom system with n degrees of freedom, in addition to the n natural frequencies with the same number of degrees of freedom, there are also corresponding natural mode shapes, i.e. vibration modes. The motion equation of typical undamped structure free vibration is as follows [2-4]:

$$[M]\{\ddot{X}\} + [K]\{X\} = \{0\} \quad (1)$$

Where $[M]$ is the mass matrix, $[K]$ is the stiffness matrix, $\{\ddot{X}\}$ is the acceleration vector and $\{X\}$ is the displacement vector.

Make $\{X\} = \{\varphi\} \sin(\omega t + \phi)$, then $\{\ddot{X}\} = -\omega^2 \{\varphi\} \sin(\omega t + \phi)$. Substituting them into the equation of motion, we can get the following results:

$$([K] - \omega^2 [M])\{\varphi\} = \{0\} \quad (2)$$

The above formula is called the characteristic equation of structural vibration, and modal analysis is to calculate the eigenvalue $\{\omega_i\}$ ($i=1,2,3 \dots, n$) and its corresponding eigenvector $\{\varphi_i\}$ ($i=1,2,3, \dots, n$). They constitute a complete modal set, and the dynamic characteristics of the structure are represented by the modal set.

ANSYS has powerful modal analysis function. It provides several modal extraction methods, and in this analysis, the modal analysis of GIS pipe shell is carried out by using block Lanczos method with the higher accuracy.

2.2. Modal order extraction

From the process of obtaining the required modes, it is necessary to solve the eigenvalues and eigenvectors of the system. For the continuous medium objects with thousands of degrees of freedom in practical engineering, it is very troublesome to carry out such calculation even by computer. Especially for those structures with complex structure, if the theoretical calculation results are not confirmed by experiments, then the reliability is low. The modal analysis method does not need to find all the eigenvalues and eigenvectors, that is, the natural frequency of the structure and its corresponding vibration mode, but only solves the modal of the required order to establish the corresponding calculation model, which has sufficient reference value for engineering application [2].

Generally speaking, the first several natural frequencies of structural system contribute most to structure. Therefore, in the actual calculation, as long as the contribution of those modes is considered, it can meet the needs of practical engineering, which will greatly reduce the amount of calculation.

2.3. Construction of finite element model

The material of GIS bus pipe wall is 20g boiler steel, the wall thickness is 10mm, and the total length of model section is 15000mm. Considering that the thickness of the pipe wall is very small relative to the axial length and diameter of the pipe, and the material of the pipe wall is isotropic, the stress change of the pipe perpendicular to the pipe wall can be ignored. Therefore, the actual modeling is based on the actual size of the pipe wall, and the shell element is used to replace the pipe wall. The finite element model of pipe wall and its support is shown in the following figure:

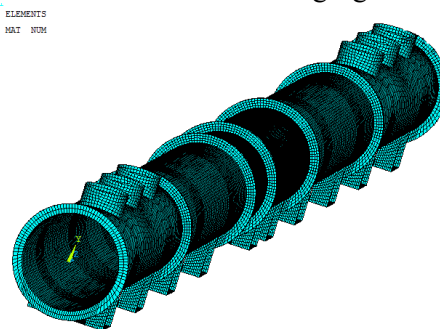


Figure 1. Finite element model of the GIS structure

The first six order natural frequencies of GIS tubular bus shell are shown in Table 1, and the corresponding vibration modes are shown in Figure 2.

Table 1. The first five natural frequencies of GIS pipeline shell structure.

Order	Frequency(Hz)
1	72.459
2	73.407
3	73.524
4	76.333
5	96.365
6	103.19

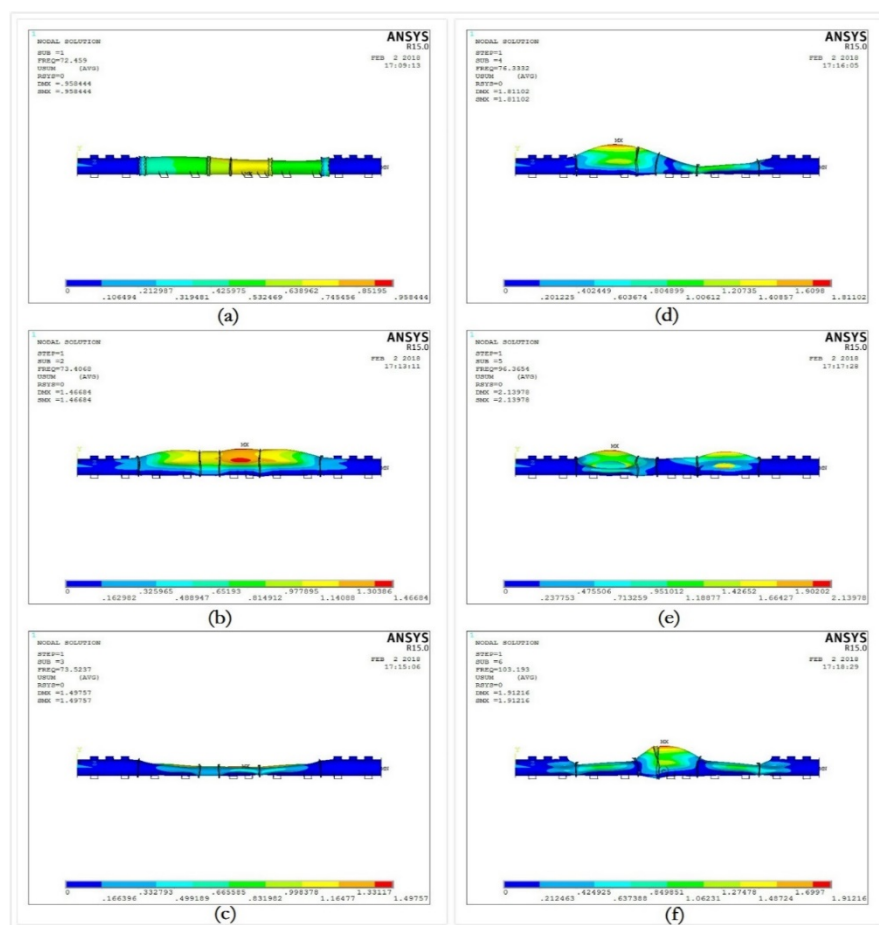


Figure 2. First six order array diagram of tubular busbar (a ~ f corresponds to the first six modes)

It can be seen from Table 1 and Figure 2 that the first mode frequency is 72.459hz, and the deflection of the middle busbar tube is the largest, which shows the y-direction bending, and the structural failure mode is the sealing failure of the support insulator and flange; the second-order mode frequency is 73.407hz, which shows the symmetrical Y-direction bending of the middle bus tube, and the structural failure mode is the bus barrel bending deformation; the third-order mode frequency is 73.524hz, showing the middle wave. The results show that the corrugated tube is bent in X direction and twisted around the axis, and the structural failure mode is the flange seal failure at the bellows expansion joint; the fourth mode frequency is 76.333hz, which shows that the bus tube on the west side of the middle bellows is bent in Y direction and twisted around the axis; the structural failure modes are failure and deformation

of the sealing flange at the joint of the bus tube and bellows expansion joint, and the top of the bus barrel on the east side of the middle bellows is depressed along the Y direction. The second mode frequency is 96.365Hz, which shows that the East and west sides of the middle bus tube bend in Y direction and twist around the axis. The structural failure mode is the bending deformation of the bus tube and the sealing flange at the joint of the bus tube and the bellows expansion joint; the sixth mode frequency is 103.19Hz, which shows the z-bending of the middle bellows and the Middle East bus tube, and the structural failure mode is the support at the bellows expansion joint. The support insulator is detached.

3. Influence of structure type on dynamic characteristics

3.1. Structural type change

On the basis of obtaining the first six modal parameters of GIS tubular bus shell structure, the first six modal parameters of GIS tubular bus shell under different structural types are obtained by changing its design structure type for modal analysis, and the influence of structural types such as tubular bus span on modal parameters is studied.

Figure 3 shows that according to the solid structure diagram of GIS pipe bus, each section of pipeline is numbered as 1-6, and each support is numbered as a, b, c..., The span of sliding support d and e is 760 mm, and the span between other support is 1500 mm.

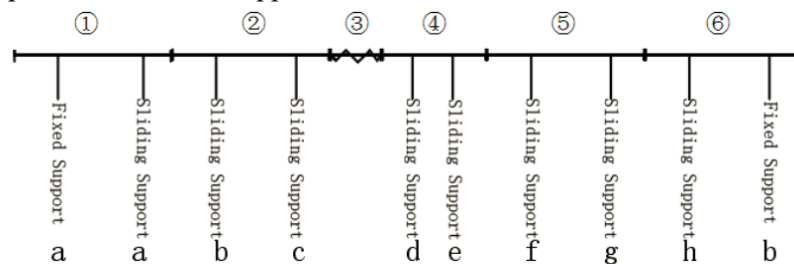


Figure 3. Design structure type of GIS pipeline type(15m)

The following changes are made to the pipe structure type:

(1) Structure type 1: increase the span between fixed support a and sliding support a by 100 mm, from 1500 mm to 1600 mm, and treat sliding bearing a and B; sliding bearing B and C; fixed bearing B and sliding bearing h; sliding bearing h and G; span between sliding bearing g and f.

(2) Structural type 2: On the basis of structure type I, the two sliding supports D and E on the bus barrel of section ④ are changed into one sliding support, and they are moved to the middle position of the bus tube of section ④. As shown in Figure 4.

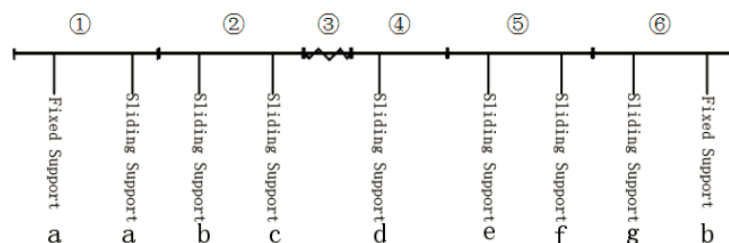


Figure 4. Structure type 2 of GIS pipeline

(3) Structural type 3: increase the span between fixed support a and sliding support a by 200 mm, from 1500 mm to 1700 mm, sliding bearing a and B; sliding bearing h and fixed bearing B; the span between sliding bearing h and G shall be treated the same, and the original sliding bearing C and f shall be removed and renumbered, as shown in Figure 5.

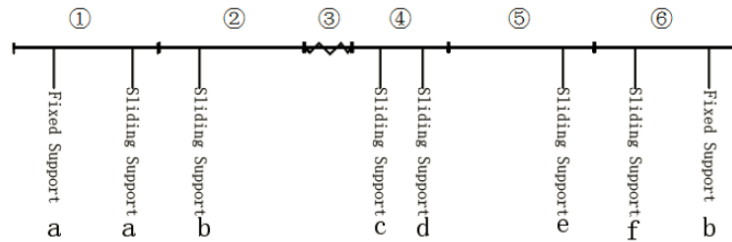


Figure 5. Structure type 3 of GIS pipeline

(4) Structure type 4: the calculation of modal parameters is based on the actual structure drawings, and a section of pipe bus with a total length of 15m is intercepted. For the convenience of comparison, a model is established to calculate the 8 m of the right part of the structure.

3.2. Influence of bearing span on dynamic characteristics

The natural frequencies of the first six modes of these structural types are shown in table 2.

Table 2. Calculated modal parameters of different structural types

Order	Frequency(Hz)			
	Design structure	Structure type 1	Structure type 2	Structure type 3
1	72.459	68.363	67.593	66.146
2	73.407	72.024	72.762	67.947
3	73.524	75.521	73.765	71.134
4	76.333	78.889	77.638	73.455
5	96.365	97.169	95.927	88.286
6	103.19	100.76	99.876	97.683

It can be seen from table 3 that, by comparing the modal natural frequencies of the design structure and structural type I, the first two natural frequencies are reduced by 5.65% and 1.88%, and the third to fifth order natural frequencies are increased by 2.72%, 3.35% and 0.83% respectively when the span is only increased by 100 mm; by comparing the structural type I and structural type II, the first six natural frequencies are reduced by only one support. The second-order parameters in the ratio increased by 1.02%, and the other natural frequencies decreased by 1.13%, 2.33%, 1.59%, 1.28% and 0.88% respectively. By comparing the natural frequencies of the design structure and structural type III, the parameters of each order were significantly reduced with the increase of span and the decrease of one bearing. The natural frequencies of the first six orders were reduced by 8.71%, 7.44%, 3.25%, 3.77%, 8.38% and 5.34%, respectively. After analyzing the changes of the above modal parameters, it can be seen that the first and second order natural frequencies, which have great influence on the normal operation of the structure, are reduced after the structural type changes.

3.3. Influence of structural length on dynamic characteristics

The calculated natural frequencies of 15m long structure and 8m long structure are shown in table 3.

Table 3. Calculated modal parameters of different structural types

Order	Frequency(Hz)	
	Design structure	Structure type 4
1	72.459	88.921
2	73.407	100.49
3	73.524	126.81
4	76.333	132.02
5	96.365	139.9
6	103.19	141.45

It can be seen from table 3 that by comparing the modal parameters of the original design structure with that of the structural type IV, the natural frequencies of the first six modes of the structure type IV are significantly higher than those of the original design structure, and the natural frequencies of the first six modes of the structure type IV are increased by 22.72%, 36.89%, 72.47%, 72.95%, 45.18% and 37.08%, respectively. It shows that the natural frequency increases with the decrease of the length of the pipe, and the increase is large. It can be seen that the long tube bus shell structure is more prone to resonance in operation.

4. Conclusion

(1) The first six natural frequencies and vibration modes of the original structure are obtained by calculating and analyzing the dynamic characteristics of the original structure. The first few modal parameters of structures are generally focused on. The first mode frequency is 72.459hz, and the deflection of the middle bus tube is the largest, which shows the y-direction bending, and the structural failure mode is the sealing failure of the support insulator and flange; the second-order mode frequency is 73.407hz, which shows the symmetrical Y-direction bending of the middle bus tube, and the structural failure mode is the bending deformation of the bus barrel; the third mode frequency is 73.524hz, which shows the x-direction bending and axial torsion of the middle bellows The structural failure type is the flange seal failure at the bellows expansion joint

(2) By changing the structure type, including support span and structure length, the structural dynamic characteristics are analyzed, and the first six natural frequencies and vibration modes are obtained. The frequency of each order of the structure decreases obviously with the increase of bearing span. By comparing the modal parameters of the original design structure and the short pipe system structure (structure type 4), the natural frequency of the first six modes of the short pipe system structure is significantly higher than that of the original design structure, and the natural frequencies of the first six modes are increased by 22.72%, 36.89%, 72.47%, 72.95%, 45.18% and 37.08%, respectively. It shows that the natural frequency increases with the decrease of the length of the pipeline, and the long tube bus shell structure is more prone to resonance in operation.

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