Study on Dynamic Amplification Factor of UHV Pillar Equipment

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Abstract: In the research of UHV pillar equipment, the dynamic amplification factor of bracket is a key parameter. This paper mainly focuses on the relationship between the dynamic amplification factor of ceramic equipment under the condition of seismic acceleration response spectrum when the structural parameters of the bracket are the same. In this paper, the stiffness of the bracket is changed by altering the elastic modulus of the steel. The dynamic amplification factors of the speed, displacement, stress and acceleration of the bracket in the two kinds of overall structures are compared and analyzed by numerical simulation. At the same time, the relationship between the bracket frequency and the steel consumption is compared by calculating the steel consumption of different bracket structures. Based on the results of simulation analysis and considering the seismic design of porcelain electrical equipment in UHV substations and converter stations, it is suggested that the dynamic amplification factor, the envelope of displacement and stress amplification factor of 1.40 should be adopted, thus providing a theoretical basis for the design of UHV bracket equipment.

1. Introduction
As an important part of lifeline engineering, once the power system is damaged, it will cause serious disasters and incalculable economic losses. Power interruption not only seriously affects the normal production and life and earthquake relief work, but also may cause secondary disasters such as fire, which seriously threatens people’s lives and property safety. In the power circuit system, because the bracket can amplify the seismic load transmitted to the electrical equipment, especially for the UHV electrical equipment. When the bracket structure design is unreasonable, the amplification caused by the bracket is easy to make the equipment fail. Therefore, whether the bracket dynamic amplification factor of the equipment is reasonable is very important in the seismic design.

There are two codes for seismic design of electrical equipment in China: Code for design of seismic of electrical installation and Technical specification for seismic design of ultra-high voltage porcelain insulating equipment and installation/ maintenance to energy dissipation devices. The former is for electrical equipment with voltage class of 750kV and below, and the latter is for UHV 1000kV porcelain electrical equipment.

Steel lattice bracket is commonly used in electrical equipment of higher voltage grade. When steel lattice bracket is used, its height is generally between 3m and 10m. Studies have shown that the dynamic amplification factor of the bracket is related to the structural form, the material and the height of the bracket, the type of equipment, the earthquake input, the site type and other factors.

Porcelain electrical equipment is fragile, and has advantages of low cost, simple process and convenient processing, which is widely used in the electricity industry. At present, there are few specifications and research on the dynamic amplification factor of UHV equipment, especially for
1000kV and ±800kV\(^6\) electrical equipment. This paper mainly focuses on the relationship between the bracket frequency, equipment-overall structural frequency of the bracket and the seismic amplification factor in UHV 1000kV porcelain equipment. Through numerical analysis method to study the change rule of the bracket stiffness (the relationship between the frequency of different bracket structures and steel consumption) and the influence of bracket frequency on the dynamic amplification factor of bracket velocity, acceleration, displacement and stress \(^7\), the purpose of this paper is to reduce the influence of supports on seismic response of electrical equipment.

2. Finite element numerical simulation

2.1. general introduction

In the UHV circuit system, 1000kV porcelain arrester and 1000kV porcelain CVT transformer, which are typical pillar electrical equipment in AC substation and DC converter station, are selected for analysis because of the representative pillar equipment. The structural parameters of the equipment are shown in Table 1.

| Table 1. Equipment structural parameters |
|------------------------------------------|
| Equipment name  | LA  | CT  |
| Equipment weight (kg) | 9649 | 5079 |
| Elastic modulus (×10¹⁰Pa) | 11 | 11 |
| Poisson's ratio | 0.3 | 0.3 |
| Equipment height (m) | 10.65 | 9.41 |

For the sake of simplicity, lightning arrester equipment is abbreviated as “La” and current transformer is abbreviated as “CT”. In the overall structure, the upper root span is 1.2m×1.2m and the lower root span is 0.8m×0.8m. The specifications of circular steel tube used for the mainly auxiliary materials of the brackets are Φ194 ×12mm and Φ83 ×8mm respectively. The total height of the overall structure is 18m, and the height of the bracket is that the total height minus the height of the equipment.

2.2. Finite element modeling

The accuracy of the numerical model is directly related to the accuracy of the analysis results. Especially for the power facilities, when the numerical model is established, various elements should be used as much as possible to simulate the structure shape so as to reflect the mechanical behavior of the structure itself more truly, accurately and intuitively. In this section, ANSYS is used to establish two kinds of finite element model of the overall structure of the equipment-bracket. The finite element model of ceramic special high voltage electrical equipment is shown in Figure 1, and the total height of the overall structure is consistent.

In the process of building model, according to the structural characteristics, the main and auxiliary materials of equipment and bracket are simulated by space beam element. The upper panel of lattice and strut brackets adopts plate element and shell element. The voltage equalizing ring and electromagnetic unit on the equipment adopt concentrated mass unit. And the establishment of simulation flange is partly based on the equivalent formula of rigidity of the flange system. Due to the porcelain set of umbrella not participate in the structure, this part is ignored in the modeling, which the height direction of the device is Z direction in the numerical model.
2.3. Analysis method

At present, seismic numerical analysis methods used in engineering mainly include seismic acceleration response spectrum analysis and time-history analysis. Although time-history analysis can more truly reflect the dynamic characteristics of the structure, it often requires complex calculation work, more detailed site conditions, and long calculate time. Therefore, the seismic acceleration response spectrum seismic analysis method is used to calculate the dynamic response of structures.

According to standard[2] and site conditions, the response spectrum of UHV standard seismic acceleration with basic peak acceleration of 0.2g and characteristic period of 0.9s is selected to calculate and analyze the dynamic amplification coefficient of electrical equipment bracket, so as to study the variation law of dynamic amplification coefficient of different equipment. The mode analysis is carried out for two kinds of electrical equipment and brackets, and the frequency is extracted. At the same time, under the earthquake load of 0.2g, the equipment is simulated and calculated. The maximum stress, the maximum displacement value, velocity value and acceleration value of the equipment are extracted, and the dynamic amplification coefficient of each parameter is calculated, and the calculation results are compared and analyzed. Figure 2 shows the response spectrum curve of seismic acceleration of the structure. When the response spectrum analysis of equipment or equipment model with bracket is carried out, consolidation method is adopted for equipment or its bracket-equipment bottom.
3. Results analysis
The bracket of electrical equipment can be designed into different structural forms. The change of stiffness has a certain impact on the mechanical properties of the whole structure. By changing the elastic modulus of the bracket steel, different bracket stiffness can be obtained. The elastic modulus of steel varies from 10 GPa to 1010 GPa, and the difference between adjacent elastic modulus is 5 GPa. A total of 200 elastic modulus values are taken. In the process of analysis, the fundamental frequency variation range of single equipment, bracket and overall structure is shown in Table 2. Due to the height of each equipment bracket is not the same, it will lead to the difference of the overall structure frequency of equipment-bracket.

| Equipment name | Equipment name | Brackets structure | Overall structure | Range of change |
|----------------|----------------|--------------------|------------------|----------------|
| P-CA           | 2.61           | 4.25~34.87         | 1.26~2.57        | -51.72%~1.53%  |
| P-CT           | 1.84           | 3.37~27.67         | 1.32~1.83        | -28.26%~0.54%  |

### 3.1 The relationship between bracket frequency and steel consumption
Because the steel consumption used in the bracket can affect the structural frequency of the bracket, it is related to the steel consumption used in the bracket when the elastic modulus of steel is selected in the range of 10GPa ~ 1010GPa. When the elastic modulus of the bracket steel is 206GPa and the total height of the bracket is 6.3m, the relationship between the frequency of different bracket structures and the steel consumption used can be obtained by changing the structure of the bracket. In the simulation, 5 lattice brackets and 2 strut brackets are selected for calculation and analysis. The upper and lower root opening of lattice bracket, the outer diameter / wall thickness of main and auxiliary materials, and the outer diameter / wall thickness of steel pipe of strut bracket are shown in Table 3, which also lists the structural fundamental frequency and steel consumption of different brackets. Figure 3 shows the design drawings of different bracket structures. From left to right, for lattice bracket, the upper and lower root opening sizes change from 800 mm×2400mm to 600mm×600mm, the main material specifications change from 194mm×12mm to 140mm×4.5mm, the auxiliary material specifications change from 83×7mm to 60mm×3mm, and for steel pipe bracket, the steel pipe specifications change from 400mm×8mm to 300mm×7mm. From bracket structure 1 to bracket structure 7, the fundamental frequency value and the steel consumption decreases gradually.

| Serial number | up/down(mm) | Main material (mm) | Auxiliary materials (mm) | fundamental frequency (Hz) | Steel consumption (kg) |
|----------------|-------------|--------------------|--------------------------|-----------------------------|------------------------|
| 1              | 800/2400    | φ194×12            | φ83×7                    | 27.67                       | 2920                   |
| 2              | 800/1200    | φ194×12            | φ83×7                    | 19.64                       | 2613                   |
| 3              | 800/800     | φ180×8             | φ76×5                    | 14.55                       | 1838                   |
| 4              | 600/800     | φ159×4.5           | φ70×4                    | 12.90                       | 1300                   |
| 5              | 600/600     | φ140×4.5           | φ60×3                    | 10.41                       | 1134                   |
| 6              | --          | φ400×8             | --                       | 8.24                        | 1061                   |
| 7              | --          | φ300×7             | --                       | 5.23                        | 903                    |
Figure 4 shows the curve of bracket frequency and steel consumption. It shows that the bracket frequency and steel consumption change nonlinearly. When the bracket frequency increases gradually and changes from bracket 7 to bracket 1, the steel consumption of the bracket increases gradually. Compared with the strut bracket, the lattice bracket can increase the bracket frequency when the steel consumption has a little increase. But after the root opening adjustment, the lattice bracket can increase the bracket frequency. With the increase of steel consumption, the frequency changes slowly.

3.2 Influence of bracket frequency on the overall model frequency
Different bracket frequencies will affect the frequency of the overall model. The relationship between the bracket frequency of different equipment and the frequency of each overall structure is shown in Figure 5. The change trend of the curve in Figure 5 shows that the frequency of the overall model of P-LA and P-CT composed of the bracket equipment is obviously affected by the bracket frequency, especially when the bracket is flexible. The overall structure frequency of the two kinds of equipment increases with the increase of the bracket frequency. The smaller the bracket frequency is, the more obvious the influence of bracket frequency change on the overall model is. With the increase of bracket frequency, the overall model frequency change tends to be stable and gradually close to the equipment frequency.

3.3 The relationship between dynamic amplification coefficient and bracket frequency
On the basis of the elastic modulus of steel stent range, porcelain and composite materials equipment overall structure velocity, acceleration, displacement and stress of the bracket in the amplification coefficient of as shown in figure 6. Fig. 6 shows the numerical relationship between the dynamic amplification coefficients of the speed, acceleration, displacement and stress of the
bracket in each overall structure when the elastic modulus of the material is 206GPa.

![Fig.6 Frequency-dynamic magnification coefficient curve of stent in porcelain equipment](image)

Fig. 6 shows that the three dynamic amplification coefficient curves of velocity, displacement and stress of P-LA and P-CT porcelain equipment. Three curves all decrease with the increase of bracket stiffness in the overall structure, and gradually stabilize at 1.10 and 1.02 respectively when the bracket frequency is 15Hz, in which the displacement dynamic amplification coefficient curve is the largest and the stress dynamic amplification coefficient curve is the smallest. The difference is greatest when the stent was the most flexible. For porcelain equipment, the curves of the acceleration dynamic amplification coefficient of the bracket first increased with the stiffness of the bracket, then gradually decreased, and finally tended to be stable. Moreover, the bracket frequency values tending to be stable for each type of equipment were not consistent.

On the whole, except for the acceleration dynamic amplification coefficient, the relationship between the overall model frequency and the equipment dynamic amplification coefficient of the two kinds of equipment decreases gradually with the increase of the bracket frequency, and finally becomes stable. All the equipment in velocity, displacement and stress of the dynamic amplification coefficient curve, the displacement amplification coefficient of maximum and minimum stress amplification coefficient, namely the stent, the biggest influence on displacement response of the equipment the main reason is in the same bracket structure form, stent plus the equipment level, and basic little impact on the frequency of equipment, increase significantly under the action of the seismic displacement response. For the acceleration dynamic amplification coefficient, the curve variation of each ceramic device is consistent.

In the seismic analysis of the equipment monomer, the ceramic equipment reacts with the softest and stiffest bracket and the actual elastic modulus of the steel material. The dynamic amplification coefficients of velocity, displacement, stress and acceleration of the bracket are shown in Table 4.

| Parameter    | Elastic modulus | P-LA  | P-CT  |
|--------------|-----------------|-------|-------|
| Velocity     | 15GPa           | 1.983 | 1.635 |
|              | 206GPa          | 1.192 | 1.077 |
|              | 1010GPa         | 1.044 | 1.016 |
| Displacement | 15GPa           | 4.057 | 2.251 |
|              | 206GPa          | 1.264 | 1.098 |
|              | 1010GPa         | 1.045 | 1.019 |
| Stress       | 15GPa           | 1.415 | 1.396 |
|              | 206GPa          | 1.160 | 1.064 |
|              | 1010GPa         | 1.043 | 1.016 |
| Acceleration | 15GPa           | 0.993 | 1.159 |
|              | 206GPa          | 1.125 | 1.079 |
|              | 1010GPa         | 1.072 | 1.024 |
Table 4 shows that the dynamic amplification factor of porcelain equipment varies widely. When the elastic modulus of steel is 206GPa, the maximum dynamic amplification factor of porcelain equipment bracket is 1.192. It should be noted that once the bracket is too flexible, the dynamic amplification factor of porcelain equipment bracket will increase rapidly, which will have a greatly adverse impact on the seismic performance of the equipment. The existing codes for seismic design of electrical equipment only require the stress amplification factor of the bracket. According to the simulation results, the displacement amplification factor of the same equipment is higher than the stress amplification factor, and the equipment is connected by wires. The displacement response of the equipment and its displacement coupling effect have a significant impact on the seismic performance of the loop system. Therefore, the dynamic amplification coefficients of displacement, stress and acceleration should also be considered in the design of the bracket.

4. Conclusion
According to the calculation results of velocity, acceleration, displacement and stress amplification factor in simulation analysis, and considering the seismic design of porcelain and composite electrical equipment in actual UHV substation and converter station, the following conclusions can be drawn.
(1) The dynamic amplification factor of 1.40 should be adopted for UHV equipment, so as to envelope the dynamic amplification factor of velocity, acceleration, displacement and stress.
(2) There is a nonlinear change between different bracket frequencies and the steel consumption. Compared with the strut bracket, the lattice bracket can increase the bracket frequency when steel consumption has a little increase. But the frequency of lattice bracket will slow down with the increase of steel consumption after root opening adjustment.

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