Investigation on seismic and shock absorption experiments of UHV arrester

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Abstract. In this article, seismic and shock absorption experiments of ultra-high voltage (UHV) porcelain arrester is carried out to investigate a seismic withstand ability for UHV porcelain equipment. To ensure the seismic safety of UHV equipment, tensile and compressive cyclic loading tests of metal dampers for arrester were conducted. Test results showed that hysteresis curves are full, and energy dissipation characteristics are significant. The mechanical characteristics meet Wen constitutive model. The shaking table test found that the shock absorber increased damping ratio of arrester structure and extend the characteristic period of arrester, which improve the dynamic characteristics of the electrical equipment. Under seismic action, the metal plastic deformations in the damper dissipate seismic energy, which reduce stress and acceleration of arrester. The damper significantly inhibits seismic response to improve the UHV arrester seismic safety. In the 0.3g level earthquake, stresses of UHV arrester with dampers and without dampers were 26.56 Mpa and 43.28 Mpa respectively. The safety factor of damper-added arrester structure meets the requirements. This paper provides technical support for the ultra-high voltage electrical equipment applied in the high-intensity seismic zone.

1 Introduction

Low-carbon energy supply and clean energy system optimization is continuing long-term trends. 1000 kV UHV AC project is of great significance in promoting the sustainable development of the power industry, optimizing energy allocation, and saving efficiency.

China is a country that is prone to earthquakes. In the previous earthquake, substations were seriously damaged, which affects the electricity supply, the security and stability of the grid. It results in a huge social and economic loss. As an important substation lightning overvoltage protection device, Arrester has been seriously damaged in the previous earthquake [1-3]. Frequency of arrester structure is within the seismic predominant frequency range, which belongs to sensitive structures for seismic action [4]. Arrester porcelain material strength is low, with small damping, so energy storage and energy dissipation capacity is weak. The root of the arrester porcelain is easily destroyed due to the bending moment caused by earthquake. UHV arrester is higher and heavier, and withstands greater moment under earthquake. Consequently, the seismic safety issues are more prominent. H. Matt [5], D. Kong [6] and M. Fahad [7] conducted seismic tests for ceramic electrical equipment and results show that the strength of the material is one of key factors to control the seismic performance.

Applying damper to electrical equipment is an effective way for seismic safety of electrical equipment [8]. Damper can absorb seismic energy thereby reducing the seismic response of the equipment. It becomes an important method to improve the seismic performance of High voltage substation project in high intensity zones [9].

In this paper, the mechanical properties of the damper for UHV arrester are investigated. In order to analyze the damping effect of damper, the shaking table test of 1000 kV arrester was carried out. It provides a reference for solving design and construction problems of UHV project in the high-intensity seismic zone. It also provides technical support for the safe construction of UHV projects.

2 Mechanical properties of the metal damper

UHV arrester is a typical strut-type equipment, such structure towering height is generally 10 ~ 15m, weighing up to nearly 10 t. In addition, length-diameter ratio is great, and center of gravity position is high. Bending moment is large under the earthquake. The following table 1 shows the dynamic characteristics test results of several UHV arresters produced by major domestic manufacturers. As shown in table 1, the frequencies of typical UHV arresters are lower than 2.3Hz, and damping ratio do not exceed 3%. It demonstrates that UHV arrester structure is flexible, with small damping. Additionally, energy storage and energy dissipation capacity is weak. Therefore, it is not conducive to against the seismic action.

Table 1. typical dynamic characteristics of 1000 kV arrester

Code of arrester	Code of manufactures	frequency（Hz）	Damping ratio（%）
1	L	2.28	-
2	L	2.08	2.80
3	X	1.56	2.10
4	X	1.71	3.00
5	F	1.18	2.12
6	F	1.40	1.73
7	N	1.66	2.70
8	N	1.59	2.59

Arrester shock absorber use metal dampers. Plastic deformation of metals is one of the most effective consumption mechanisms for seismic input energy [10]. The increase of relative displacement of the metal damper results in increase of energy capacity accordingly. Therefore, the metal dampers are ideal for UHV arresters that are flexible strut-type electrical equipment. In the strong earthquake, metal damper gets into energy consuming working condition prior to the main structure. Then the damper produces a great damping and dissipates large amounts of seismic energy input to electrical equipment, which can rapidly decay of the dynamic response of the equipment. The damper effectively protects the main structure of the device and makes it from damage and destruction.

Figure 1. The mechanical test of mental damper

Once earthquake occur, Arrester will rock back and forth to produce a moment in the equipment root, which helps the damper make axially reciprocating tension and compression piston movement to consume energy. Therefore, tension and compression cyclic loading test can simulate the damper working conditions and obtain the mechanical properties of the damper. Test device is shown in Figure 1. Before testing, connecting rods are welded on the top and bottom of the damper. testing machine grips these two connecting rods during test. One is fixed, and another side bears cycle load. The hysteresis curve of damper with 1,2,3, and 4mm is shown in Fig. 2.

At the beginning of loading, stress is proportional to strain. However, as the strain continues to increase, the damper reaches the yield when displacement reaches about ±0.3mm. The yield bearing capacity is about 53 kN. With the post-yield displacement increases, resistance slowly grow, post-yield stiffness is far less than yielding stiffness, ultimate bearing capacity of about 58 kN. When unloading, resistance declines sharply. When unload to 0, the residual displacement is obvious, then the load reverse. Hysteresis curve is full and substantially symmetrical in the tension and compression direction, which exhibits good energy dissipation characteristics.

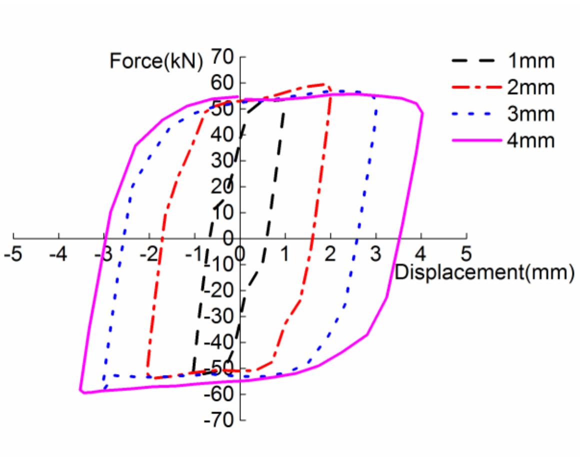


Figure 2. Hysteresis curves of metal damper

Obviously, force-displacement curve of damper is consistent with typical metal plastic constitutive, so it can adopt Wen model [11]. As shown in Fig. 3, force - displacement equation of Wen model can be written as follows:

$$f = rkd + (1-r)F_y z \tag{1}$$

Where *f* is the Wen unit resistance. *d* is Wen unit deformation. *k* is stiffness before yield. *r* is the ratio of yield stiffness and original stiffness. F_y is the yield strength. z is internal hysteresis factor, and it controls hysteresis curve shape. it can be determined by the following differential equation:

$$z' = \begin{cases} \frac{k}{F_y} d'(1-|z^a|), & d'z > 0 \\ \frac{k}{F_y} d', & \text{else} \end{cases} \tag{2}$$

Where *z*' is the derivative of the coefficient of *z*. d' is the derivative of the unit deformation amount *d* and the coefficient. *a* is related with the unloading behavior. for the metal damping device, it takes a value of the 2; z is between 0 and 1.

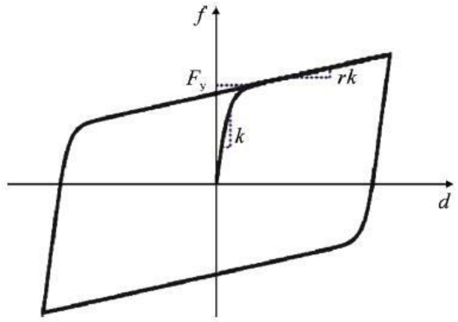


Figure 3. Wen hysteresis model

3 Shaking table test of UHV arrester

Shaking table test is an important method to assess the seismic performance of electrical equipment [12]. By shaking table test of 1000 kV arrester, the seismic performance of UHV arrester can be assessed and the damping effect of the damper can be verified.

3.1 Test equipment

The number 2 porcelain metal oxide surge arrester in Table 1 was selected in the test. Arrester height is about 11827mm, weighs is 9774kg, and the grading ring is on the top. Porcelain tube number is 4. The elastic modulus of porcelain is 90 Gpa. Failure stress is 60Mpa. Metal damper is ordered at the bottom of equipment annularly in shock absorber test.

Large high-performance three-axis shaking table test system produced by British SERVOTEST company was used in the test, including the vibration directions X, Y, Z and 6 degrees of freedom. Shaking table size is 3 mm ×6 mm. The largest weight of specimen is 35 t. The maximum overturning moments is 70 t·m. The maximum rotational torque is 35 t·m. The operating frequency range is 0.1 ~ 80 Hz, technical indicators of shaker table for each axis are listed as table 2.

Table 2. technical indicators of shaker table

Technical indicators	X axis	Yaxi s	Z axis
Maximum displacement（mm）	±150	±150	±100
Maximum speed（mm/s）	±800	±800	±600
Maximum acceleration（g）	±1.2	±1.2	±1.0

Test site is shown in Fig. 4. Arrester bottom was blotted with shaking table.

Figure 4. The shaking table test of 1000kV arrester

3.2 Measuring points

Resistance strain gauges are pasted symmetrically in each section at the bottom of arrester porcelain tubes. Accelerometers were installed on the shaking table, top of the arrester and connecting flange of each tube. Fig. 5 shows a schematic arrangement of the measuring points.

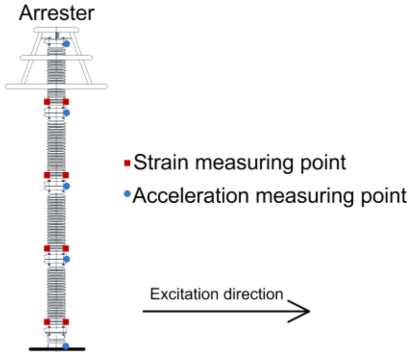


Figure 5. Schematic arrangements of Sensors

3.3 Test conditions

Single horizontal (X direction) seismic test is conducted because the arrester is symmetric electrical equipment. Input seismic wave of shaking table is 0.3g level. For the UHV electrical equipment without the bracket, dynamic magnification factor 1.4 should be considered. The standard input time-history is shown in Fig. 6. First, the seismic test without damper is carried out. After that, the test with metal damper is accomplished to test the damping effect. 0.05g level white noise condition test was carried out before and after the earthquake. The purpose is testing dynamic characteristics of the arrester to determine the fundamental frequency variation within the permissible range and the arrester has not irreparable damage during the test.

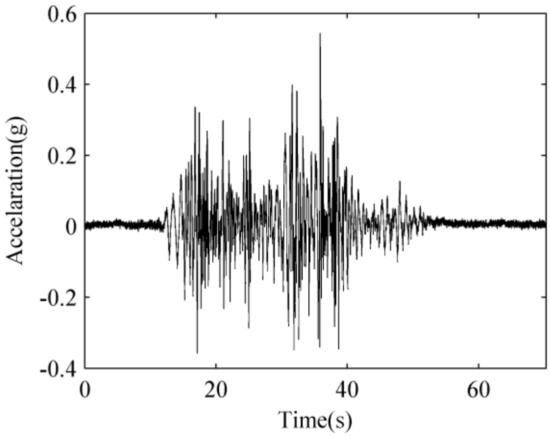


Figure 6. Test input seismic waves

4 Results and discussions

Fig. 7 shows comparison between required response spectrum (RRS) with the test response spectrum (TRS). As can be seen from the Fig. 7, the value of TRS covers basically RRS. Just a small amount of frequency points are below the platform of RRS. It shows shaking table test input is accurate and effective.

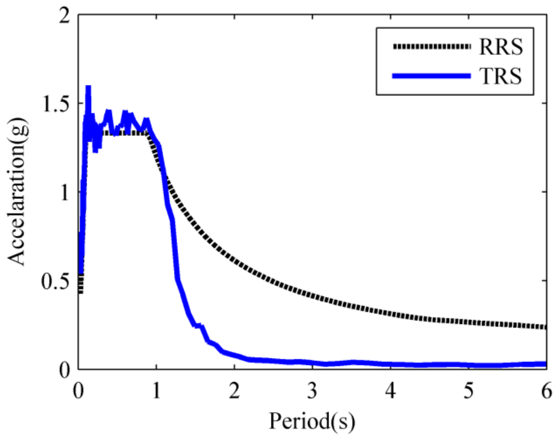


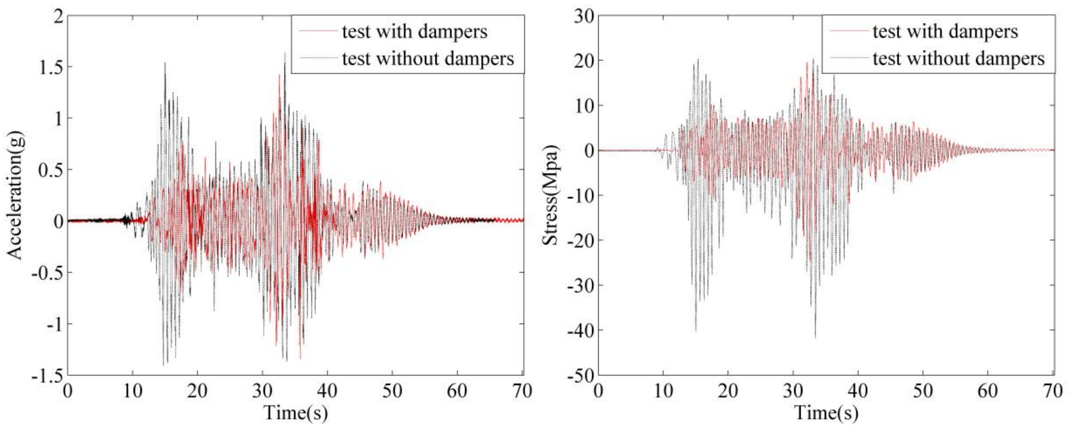
Figure 7. Comparison between RRS and TRS

4.1 Dynamic characteristics of arrester

Testing by the white noise condition, the frequency of arrester without damper before test and after test is 2.08 Hz and 2.01 Hz respectively. After applying dampers, the structure frequency is 1.59 Hz before and after test. It shows the electrical equipment frequency doesn't decrease significantly before and after the earthquake conditions. the damping ratio of arrester with damper are 2.8% and 5% before and after the test, indicating that dampers can reduce the structure frequency and increase the structure damping. It helps the arrester reduce the seismic response.

4.2 Damping effect and seismic performance of arresters

Bottom porcelain stress curves of structures without and with dampers are shown in Figure 8 (a). The absolute maximum bottom porcelain stress of structure without damping absorber is 41.77 MPa, and that with damper is 24.74 MPa. The damping rate of porcelain tube stress is more than 40%. The top acceleration curves of structures without and with dampers are shown in Figure 8 (b). The absolute maximum acceleration of structure without dampers is 1.64 g, while that with dampers is 1.43g. The damping rate of the absolute acceleration on the top of the structure is 12.8%.



(A) Comparison of acceleration response (b) Comparison of stress response

Figure 8. Comparison between results of seismic and shock absorption experiments

Obvious sound emission resulted from connection or material failure does not occur during test. The strain time-history curves recoded by strain sensors are generally symmetrical in positive and negative direction. No structural damage can be seen after test. The fundamental frequency of the arrester is not decreased significantly. In order to accurately examine the seismic performance of the arrester, load combination of wind conditions should be considered on the basis of the seismic test results [13]. The combination stress of arrester without and with dampers is 43.28 Mpa and 26.56 Mpa respectively. The porcelain failure stress is 60MPa, so the stress safety factor is 1.39 and 2.29 respectively. The arrester with metal dampers meets requirements that seismic safety factor not less than 1.67 for the ceramic electrical equipment.

5 Conclusions

In this paper, the mechanical properties of metal damper for arrester are investigated by the tension and compression cyclic loading test. 1000 kV porcelain arrester structures with and without dampers are compared by shaking table test. The results showed that the metal damper can effectively improve the 1000 kV arrester seismic safety.

1) Hysteresis curve of metal damper is full. An energy dissipation characteristic is significant. Force-displacement constitutive relationships comply with Wen model.

2) Metal damper increased arrester damping from 2.8% to 5 %, while reducing the frequency of the structure.

3) Shaking table test results show that top acceleration damping rate reach 12.8%. The stress damping rate of arrester reaches 40% after applying dampers, playing obvious damping effect.

4) Under the peak acceleration of 0.3g level earthquake, maximum combined stresses of the arrester with and without dampers are 43.28 Mpa and 26.56 Mpa respectively. The safety factor of the UHV arrester with dampers meets seismic requirements.

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