Testing Of Fluid Viscous Damper

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SUMMARY:
The Fluid Viscous Damper is an equipment protecting structure from damage in earthquake or strong wind. Which must be designed a long and strong life, and should be tested extremely strict. In this article the author will discuss how to test the viscous damper in proper and scientific methods, and objectively evaluate the performance and life of the damper, and how to select the appropriate test methods according to different using.

This article introduces the application and developing of fluid viscous damper in China. The author feels worried about the fast developing damper market under the situation there is no national test standard in China. This article introduces the different structures installing dampers according to different using, indicates three types of inspections: type test, factory test, the third-party test. The author summarizes thirteen types of damper tests, proposes the concept of damper power in the heat dissipation test first time.

Keywords: Fluid Viscous dampers, test methods, test types,

1. FOREWORD

In recent twenty years, structure protection systems used in buildings and bridges for energy dissipation and reducing vibration are fast developing. Install fluid viscous dampers in buildings and bridges, use them to reduce displacement, acceleration, help the structure to absorb the energy that earthquake brings, this become an important choice for structure designers. Fluid Viscous Dampers have been rapidly developed in engineering applications.

Throughout the world, there are only several producers designing and manufacturing fluid viscous dampers. Especially in China, the fluid viscous damper for many engineers is still a new thing. Only a few institutions have the damper test equipment and there is still no established national standard of fluid viscous dampers in China. Most engineers do not understand in depth that how the producers test their dampers properly.

2. THE DEVELOPMENT AND APPLICATION IN CHINA

Fluid Viscous Dampers firstly appeared in China in the late 1990s. The retrofit of the famous Beijing Hotel was the first project using fluid viscous damper in China. After that, Chinese domestic producers try to use fluid viscous dampers in the design of buildings, and use them widely in various types of buildings more and more, gradually using dampers become a standard designation. Large-span bridges built after the year 2000 were basically equipped with viscous dampers, which are mainly used to reduce the longitudinal displacement of the bridge, protect expansion joints, and improve seismic performance.

After the 5.12 Wenchuan earthquake in 2008, fluid viscous dampers and other seismic products become an emerging market. Small companies spring up, claiming that they can produce fluid viscous dampers. We are surprised to see that they did not have test equipments, nor any institution can provide damper testing. But they still gradually grow up in commercial operation. The quality of the dampers can not be guaranteed.

Now in China，there are not only famous international producers providing dampers，but also many national companies. We should establish a general, strict, detailed testing standard of Fluid Viscous Damper in China. So we can wash out the poor performance dampers. Also we can see if the quality of the famous international producers' dampers is as good as they claimed.

This article introduced the application and developing of fluid viscous damper in China. The author feels worried about the fast developing damper market under the situation that there is no national test standard in China. This article introduced the different structures installing dampers according to the different using of viscous dampers, indicated three types of inspections: type test, factory test, the third-party test. The author summarized thirteen types of damper tests, proposed the concept of damper power in the heat dissipation test first time. The author suggested the test types for different using and inspections at last.

3. WORK PRINCIPLE OF FLUID VISCOUS DAMPER

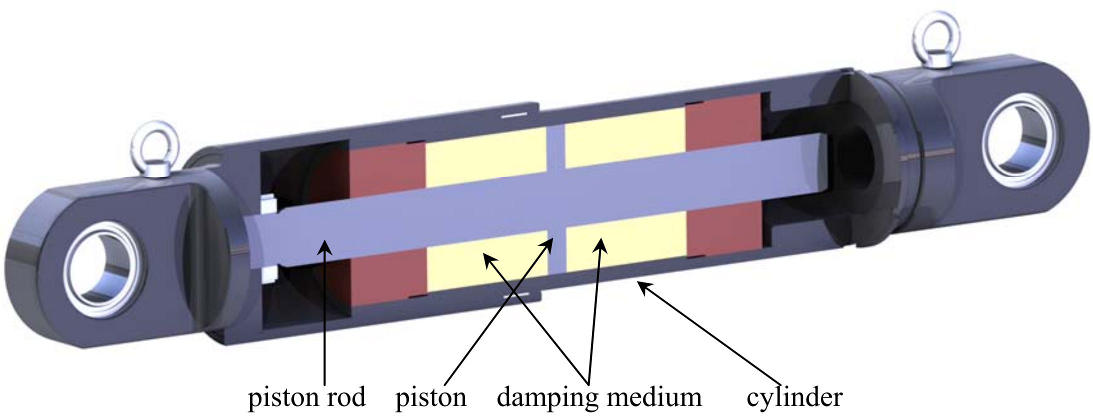

Figure 1. Work Principle of Fluid Viscous Damper

When the damper subjected to external loads to be compressed or stretched, the piston rod with piston will make reciprocating motion in the cylinder to force the damping medium move back and forth between the two cavities separated by the piston. In the process, the friction force occurred between the molecules of the damping medium, the medium and the shaft and piston, the medium and the cylinder, and throttling damping force produced by the damping medium through the piston, all these action work together composed the damping force.

The role of the fluid viscous damper is to transform mechanical energy caused by earthquakes, winds or other structural vibrations into inner energy of the damping medium. The dampers use the increasing temperature of damping medium to temporary store energy. The heat is ultimately consumed by natural cooling. In this way, the dampers protect the structure from damage.

In the course, the damping force should follow the formula:

$$F = C v^{\alpha} \quad (2.1)$$

F: damping force
C: damping coefficient
v: velocity of piston relative to cylinder
α: damping exponent varies from 0.1 to 1.

4. LIFE EVALUATION OF DAMPER IN DIFFERENT USE

Now in China, the design life of viscous damper is different. 35 years for the general buildings and 50 years for bridges. Life evaluation methods shall have different priorities based on their use.

Dampers installed in buildings maybe not work frequently. When evaluating the dampers' life, we should put more notification on how much energy they can absorb, and if they can still work in the smaller earthquakes after a large one.

Dampers installed in bridges make a very slow reciprocating motion everyday and receive some small and medium impact loads. These dampers, considering the strong earthquake and aftershock, shall also consider if they can still work after being installed a long time. Bridge dampers shall be focused on its long-term life evaluation.

Life evaluation of this damper in the laboratory shall focus on whether the heat can effectively distribute, and cool down fast enough in frequent working. According to the state of these dampers in frequent works, the author proposes a concept of heat dissipation ability of viscous damper, simply called the damper power.

5. INSPECTION TYPES OF VISCOUS DAMPERS

The inspection of viscous dampers includes: the type test, the factory inspection, the third-party inspection. Type test is carried out when product modeled, it includes more programs, they are not only to ensure the dynamic mechanical properties of products, but also to ensure product reliability, verifying the life of product. Factory inspection is the quality inspection when the producer provides products in real project. Test programs ensure that product performance meets the design parameters, and performance consistency of products. Third party inspection is an independent third-party authority to verify the producer's test results.

6. GENERAL PROVISIONS OF DAMPER TESTS

1) “Every batch of products” is defined as all those dampers meet the same damping formula, but can be in different strokes. “A complete cycle "is defined as the movement of the damper piston from the middle point 0 to +d, back to 0, then 0 to -d, at last back to 0. The “d” is the achievement of the absolute maximum displacement value in the cycle. The movement must be continuous.

2) A continuous record of force, displacement, temperature, shall be recorded based on time axis in every test process. It is necessary to record the values at least 200 data points in each complete cycle, and more data points can be increased according to the requirement.

3) Structural engineers should give the structure fundamental frequency “f”, the maximum design stroke “A” under design earthquake. When tests using a sine-wave, the velocity should be calculated as $v = 2\pi Af$. The theoretical energy “E” brings by the earthquake should be calculated according to damping force & earthquake displacement.

4) The number of test samples should be based on the damper use and work environment. The test types should be selected according to the damper use and work environment. The tests should be taken in normal temperature (22 ± 3℃), and in normal atmosphere. Considering the large amount of energy imposed on dampers in the tests. The dampers should be ensured never overheat. A test include many cycles can be separated to several test cycle groups. When each group completed, should allow the damper cooling to normal temperature. Test groups should be based on: the total energy imposed to the damper in each group should not exceed 1.5 times of the design earthquake energy.

5) Test should stop when the damper temperature is higher than the value specified by producer. At least temperatures of three locations need to be monitored, where marked by producer. In all tests, no visible leakage or signs of physical deterioration or degradation in performance shall be observed.

7. TYPES OF DAMPER TEST AND DETAILS OF TEST METHOD

7.1 Stroke Verification Test

The purpose is to ensure that the damper is able to accommodate the design stroke.

One full-stroke cycle shall be applied to the damper. The damper need not be filled with fluid. Can be performed by pulling machine, human power if the test equipment has no enough stroke.

The requirement is that the damper shall be able to accommodate a stroke at least equal to the design value within a tolerance of 1 mm.

7.2 Pressure Test of Damper Cylinder

Where applicable, an internal pressure shall be applied to each damper cylinder that shall be equivalent to 150 % of the maximum damper load. This pressure shall be maintained for 180s. During this time the pressure shall not drop more than 10%.

The requirement is that no visible leakage or signs of physical deterioration or degradation in performance shall be observed.

7.3 Low Velocity Test

The purpose is to evaluate the damper's axial force resistance under simulated thermal movements.

A complete cycle with a constant velocity of $0.01mm / s < v < 0.1mm / s$ shall be applied to the damper, in which the stroke is not less than 10% of the design value, while the full-stroke test should be applied when the damper's design stroke above $\pm$ 500mm .

The requirement is that throughout the full displacement cycle the damper shall develop a reaction force less than the 10 % of its design rated force, or a lower value if specified by the Structural Engineer.

7.4 Damper Quality Guarantee Test

The purpose is to verify if every damper is working obey the constitutive law $F = C v^{\alpha}$.

Using the sine-wave loads, impose three complete cycles under the maximum design velocity. For a guarantee of every damper can work properly, the author suggests to add a velocity that is 50% of the maximum design velocity. For very important projects, another velocity 10% of the maximum design velocity should be put in.

The requirement is that all experimental points of the reaction force characteristic curve shall fall within the tolerance envelope of ±15%.

7.5 Velocity Law Test

The purpose is to determine the damper's characteristic force vs. velocity curve, i.e. the parameters C and α, which define the constitutive law $F = C v^{\alpha}$.

Using the sine-wave loads, impose three complete cycles under each velocity. The applied velocity shall include at least the following increments of the maximum rated velocity: 1 %, 10%, 25 %, 50 %, 75 % and 100 %. When apply slower velocity, the input frequency and displacement should be reduced at the same time.

The requirement is the same as “6.3”. The damper’s reaction force F_n at a velocity v_n is defined as the average of the positive and negative intercepts with the force axis of the second hysteretic loop cycle.

7.6 Frequency Law Test

The purpose is to ensure the test force not change too much at same velocity but different frequency.

Using the sine-wave loads, impose three complete cycles under each frequency. The applied frequency shall include at least the following increments of the structure fundamental frequency: 50%, 100 %, 150 %, and 200 %. Or the following values: 25%, 50 %, 75 %, and 100 %.When displacement shall be calculated by the maximum design velocity.

The requirement is the same as “6.3”. At the same time, all test results shall fall within the average damping force of ±5%.

7.7 Displacement Law Test

The purpose is to ensure the test force not change much at same velocity but different displacement.

Using the sine-wave loads, impose three complete cycles under each displacement. The applied displacement shall include at least the following increments of the maximum design earthquake displacement: 50%, 100 %, 150 %, and 200 %. Or the following values: 25%, 50 %, 75 %, and 100 %.When frequency shall be calculated by the maximum design velocity.

The requirement is same as 6.6.

7.8 Velocity Overload Test

The purpose is to ensure the damper can still work under velocity overload.

Using the sine-wave loads, impose three complete cycles under 150% of the maximum design velocity. Displacement and frequency can be selected by the actual condition.

The requirement is the same as “6.3”. Or the test value of damping force not less than the design maximum damping force, when an overload safety device is designed inside the damper.

7.9 Tiny Vibration Response Test

The purpose is to ensure the damper can still work under tiny displacement.

Using the sine-wave loads, impose three complete cycles under the structure fundamental frequency.

Displacement should increase from 0.1mm, with an interval of 0.1mm, until 2 mm or a value the structure engineer indicated. Stop when the test force appeared obey the constitutive law $F = C v^{\alpha}$.

The requirement is that the damping force shall appear obey the constitutive law $F = C v^{\alpha}$ when the displacement not more than 2 mm or the value the structure engineer indicated. Otherwise, the damper's machinery gap is too large and no sufficient response. Producer shall be suggested redesign.

7.10 Energy Dissipation Test

The purpose is to ensure the damper can dissipate the energy brought by earthquake in time.

Using the sine-wave loads, impose five complete cycles under the maximum design velocity. When using the structure fundamental frequency and the maximum design earthquake displacement. More cycles can be required from structure engineer. Group tests can be considered if equipment capacity not enough. Not less than three complete cycles in each group. Each group shall have no cooling time except the time for test equipment to recover the oil pressure.

The above test can only ensure the damper can dissipate the energy brought by one design earthquake. But in the 311 East Japan large earthquake, the main earthquake is super large, after that several large earthquakes occurred. The author suggests a group of this test should be taken. Every group includes five complete cycles. The damper should be cooled to normal temperature after each group test. Group number should be indicated by structure engineer.

The requirement is the same as "6.3". At the same time, all test results shall fall within the average damping force of ±10%. Enveloped area curved by the damping force vs. displacement in each complete cycle is the energy absorbed by the damper. The average value of all enveloped areas shall be larger than 85% of the design earthquake energy.

7.11 Temperature Law Test

The purpose is to ensure the damper can work properly in it's design working temperature arrange.

Using the sine-wave loads, impose three complete cycles under the maximum design velocity. At least three temperatures shall be tested in the minimum, normal and maximum value within the range of the design working value. The damper shall be placed in the required temperature for 24 hours. More velocity and temperature can be required by the structure engineer.

The requirement is the same as "6.3". At the same time, all different temperature test results shall fall within the normal temperature test result of ±10%.

7.12 Seal Wear Test

The purpose is to ensure the damper can work properly after the long-term working.

Using the sine-wave loads, impose full-stroke complete cycles under any low velocity. The total cycles shall be counted according to the damper's design life. A performance guarantee test prescribed in 6.4 shall be taken after this test.

The author believes that the theoretical total distance of the structure traveled during life time can be calculated. And this test should perform not less than 120% of the theoretical total distance. Number of cycles shall be calculated according to the displacement capacity of the equipment or the damper design stroke. The cycles can be grouped. And completely cooling is allowed after each group.

The "6.4" test taken after this test, the results' requirement is the same as "6.3". At the same time, the test results shall fall within the "6.4" test taken before this test' result of ±10%.

7.11 Heat Dissipation Test

The purpose is to ensure the damper can dissipate the high heat brought by frequently work.

Using the sine-wave loads, impose some complete cycles under a velocity. The structure engineer must give the test frequency, the displacement, the number of cycles according to the damper's working situation. A performance guarantee test prescribed in 6.4 shall be taken after this test.

Some parameters here to be considerable: for normal wind, frequency = 0.1~0.3Hz， displacement = ± 5mm， total 2000 cycles; for windstorm, frequency = 0.4~0.6Hz， displacement = ± 5mm， total 4000 cycles; for machinery vibration, frequency = 1~3Hz， displacement = ± 3mm， total 2000 cycles.

Here the author proposes a concept of heat dissipation ability of viscous damper, simply called the damper power. As the author mentioned in "6.10", enveloped area curved by the damping force vs. displacement in each complete cycle is the energy absorbed by the damper in one cycle. Calculate all the energy the damper absorbed in all cycles during this test as "E", the unit is "J". After the test， the average time that the damper needed to reduce its temperature each per 1°C in natural cooling as "t", the unit is "s". The damper power P = E/t, the unit is "W". The structure engineer should calculate the damper power "P" according to the damper's working situation.

The requirement is the damper temperature during this test can not get over the maximum design working temperature. The damper power should meet the structure engineer's demand.

7.12 Other Tests

Some strange test requirements were seen in drawings or technical requirements. For example, ultraviolet radiation resistant, high concentrations of ozone resistant, salt fog resistant, acid proof, alkali proof and even displacement damage test used to test BRB.

The damping medium such as silicon oil is always put inside the damper cylinder, can not be touched by the outer environment through the seal wear. The outer environment can not effect on the damper performance. The author suggests all the above tests related to the environment are unnecessary. But if dampers installed outside the building or on cross sea bridges, the structure engineer could require the damper parts manufactured by high strength stainless steel, or the damper coated by better paint.

8. SUGGEST TEST TYPES IN DIFFERENT USING AND INSPECTION

Table 8.1 Suggest Test Types in Different Using and Inspection

Chapter No.	Test Types	Sample Number	Building	Seismic Isolation	Bridge	Wind or Frequency	Type Test	Factory Test	Third party
6.1	Stroke Verification	1*	★	★	★	★	★	▲	▲
6.2	Cylinder Pressure	All	★	★	★	★	★	★	━
6.3	Low Velocity	>1*	━	★	★	━	★	★	★
6.4	Quality Guarantee	All	★	★	★	★	★	★	★
6.5	Velocity Law	>10%*	★	★	★	★	★	★	★
6.6	Frequency Law	>10%*	★	▲	▲	★	★	━	━
6.7	Displacement Law	>10%*	▲	★	▲	★	★	━	━
6.8	Velocity Overload	1*	▲	▲	▲	▲	▲	━	▲
6.9	Tiny Vibration	1*	★	━	━	★	▲	━	▲
6.10	Energy Dissipation	>1*	★	★	★	★	★	★	★
6.11	Temperature Law	>1*	★	★	★	★	★	━	★
6.12	Seal Wear	1*	▲	▲	★	★	★	━	━
6.13	Heat Dissipation	1*	▲	▲	▲	★	▲	━	▲

★ Tests suggested or must be done;
▲ Tests on structure engineers requirement;
━ Tests not suggested or no need;
* Or due to structure engineer's requirements.

9. CONCLUSION

This article introduces the application and developing of fluid viscous damper in China. The author feels worried about the fast developing damper market under the situation that there is no national test standard in China. This article introduces the different structures installing dampers according to the different using of viscous dampers, indicates three types of inspections: type test, factory test, the third-party test. The author summarizes thirteen types of damper tests, proposes the concept of damper power in the heat dissipation test first time. The author suggestes the test types for different using and inspections at last.

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