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JSSI MANUAL FOR BUILDING PASSIVE CONTROL TECHNOLOGY PART-3 PERFORMANCE AND QUALITY CONTROL OF OIL DAMPER

Yasuo TSUYUKI[1], Yoshihiro GOFUKU[2], Fumiya IIYAMA[3] and Yuji KOTAKE[4]

SUMMARY

Recently, oil dampers have been used abundantly for reducing response of building vibration against earthquake. The oil damper is a kind of high performance energy dissipation device. This paper presents about the performances and quality control of the oil damper. It is explaining about the fundamental principle, applications, and dynamic characteristics of the oil damper. And this paper describes various dependencies about damping, durability, limit condition for use, the way of evaluation, quality control method and examination as well how to use the oil damper.

INTRODUCTION

This paper deals with the principle of the oil damper, dynamic characteristic, examining method, and quality control.

PRINCIPLE AND COMPOSITION OF OIL DAMPER

The oil damper is an equipment which makes resistance force produced by the resistance pressure controlled by mechanical valves, and dissipates energy. This resistance force is called damping force and it’s characteristic depends on velocity. A principle and composition are explained below.

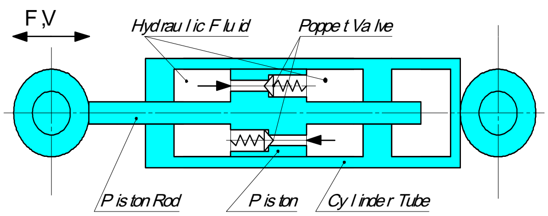
[1]Kayaba Industry Co.,LTD,Tokyo,105-6111,JAPAN E-mail：tsuyuki-yas@kyb.co.jp
[2]Tokico LTD, Kanagawa 252-1121,JAPAN E-mail：gofuku@sg.tokico.co.jp
[3]Sanwa Tekki Corporation,Tokyo 140-8669,JAPAN E-mail：iiyama@tekki.co.jp
[4]Hitachi Metals Techno, LTD,Tokyo 135-8363,JAPAN E-mail：yuuji_kotake@po.hitachi-metals.co.jp

Principle

A piston and a piston rod expand and contract with velocity V by the inner side of the cylinder in which oil is filled. Then, oil spouts from the valves prepared in the piston to the opposite side room. A proportional valve controls pressure according to flux. And the damping force which is proportional to velocity V is obtained and expressed as equation (1),(2).

$$F = C \cdot V \tag{1}$$

$$C = \frac{\rho \cdot A^3}{2 \cdot Cd^2} \cdot \frac{V}{Ax^2} \tag{2}$$



F : Damping force

A : Area which receives the pressure of a piston $(\frac{\pi}{4} \cdot D^2)$

ρ : Density of oil, Cd : Orifice damping coefficient

V : piston velocity, Ax : Opening area of valve

Fig.1. Structure of Oil Damper

Composition

The fundamental composition of the oil damper is shown in Table 1.

Table 1. Composition of oil damper

Function	Parts
Transfer of resisting force	Both rods cylinder structure
Pressure room	Cylinder, Piston
Damping force generating	Damping valve mechanism
Oil tank	Reservoir tank (accumulator) mechanism
Seal of oil	Fixed part packing, Piston rod seal mechanism
Connection to structure	Flexible joint mechanism

One example of outline is shown in Fig.2. It principally consists of the oil, the piston that have the valves, the piston rod, the cylinder, the accumulator and connecting crevices which have flexible joints.

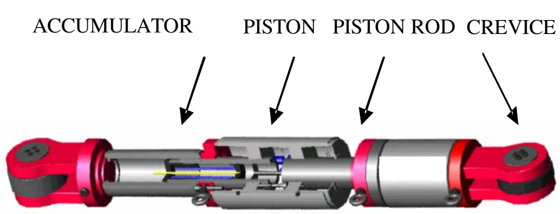


Fig.2. Outline of Oil Damper

THE DYNAMIC CHARACTERISTIC OF THE OIL DAMPER

Various conditions for use

Operating condition of the damper is shown in Table 2. The value of a table is a benchmark and each value must be directed with each design specifications.

Table 2. Operating conditions of the oil damper

Condition	Item	Value assumed
Vibration	Period	Fundamental period of building T 1= 1～4 sec The 2～3rd cycles T2=* T3=**
	Amplitude	① Earthquake response ±2～40 mm ② Strong wind response more than ±0.2 mm
	Velocity	① Earthquake response 6～250 mm/sec ② Wind response more than 0.6 mm/sec
	Number of cycles	① Number of cycles assumed from earthquake response ② Number of cycles assumed from strong wind response
Environment	Range of temperature	Indoor attachment 0～+40 ℃, Outer wall attachment －5～+60℃
System configuration	Vibration-control structure	Brace-type, Share-link-type
	Junction method	Flexible pin joints

* and ** are based on the characteristic of each building

Basic characteristic equation

The characteristic of the oil damper is expressed with *F-V* line of linear characteristic and *F-X* loop diagram.

Linear characteristic

The relation between velocity and damping force is expressed as *F-V* line in Fig. 3.
Moreover, the hysteresis diagram of *F-X* loop showing the relation between damping force and displacement is expressed as an ellipse formula, and is shown in Fig. 4 .

$$F = \pm C \cdot \omega \cdot \sqrt{a^2 - X^2} \tag{3}$$

ω : Angular frequency, a : Amplitude, X : displacement

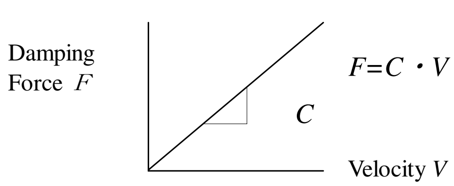


Fig.3. F-V line of linear characteristic

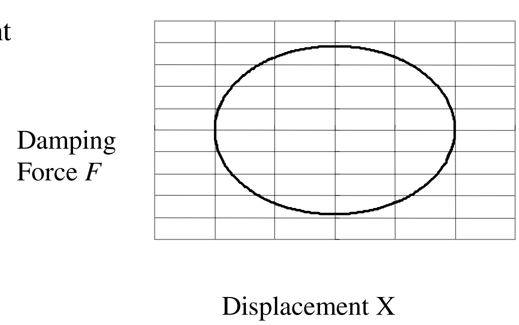


Fig.4. F-X loop of linear characteristic

Bi-linear characteristic

The bi-linear characteristic is expressed with the following equation. It is obtained by two kinds of valves with the different characteristic. One is a proportional valve, another is a relief valve. At one or less velocity (V_1), the proportional damping valve for low velocity(V) products the linear characteristic of damping coefficient (C_H). If it becomes velocity (V_1), relief valves operates, and velocity products the characteristic of damping coefficient C_L called post-relief damping coefficient. It is shown by the equation (4) and (5).
F-*V* line of bi-linear characteristic is shown in Fig.5. *F*-*X* loop of bi-linear characteristic is shown in Fig.6.

$$V < V_1$$
$$F = C_H \cdot V \tag{4}$$
$$V > V_1$$
$$F = C_H \cdot V_1 + C_L \cdot \left(V - V_1 \right) \tag{5}$$

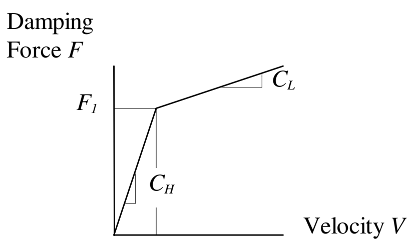


Fig.5. F-V line of bi-linear characteristic

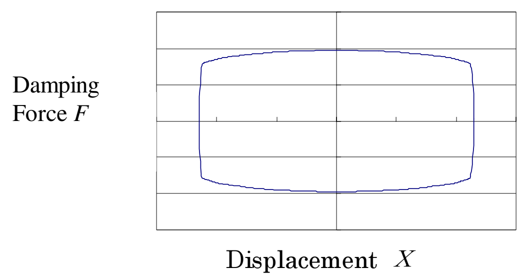


Fig.6. F-X loop of bi-linear characteristic

The equivalent damping coefficient of the bi-linear characteristic can be obtained by the following equation (6).

$V < V1$; $Ceq = C_H$

$V > V1$; $Ceq = \dfrac{1}{\pi \cdot V} \cdot \left[2 \cdot (C_H - C_L) \cdot Ve + \pi \cdot C_L \cdot V \right]$

$$Veq = V_1 \cdot \sqrt{\frac{V^2 - V_1}{V^2}} + V_1 \cdot a \cdot \sin\left(\frac{V_1}{V} \right) \tag{6}$$

Dependency

Various-dependencies affect the performance of the oil damper. We should take into consideration especially about the influence of compression stiffness of operation oil.

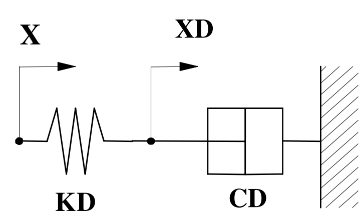


Fig .7. Maxwell model

Oil compression spring model and performance dependency

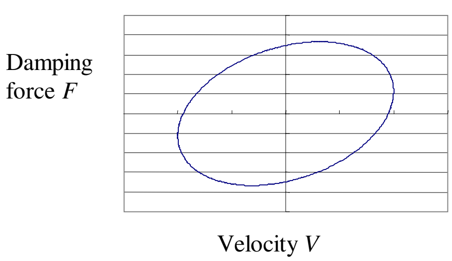
When the spring constant of oil compressibility is taken into consideration, as shown in Fig. 7, it becomes the model called Maxwell model, which has a spring (*Kd*) in series, and the performance has the frequency- dependency.
Equation (7), (8), and (9) calculate (*Ceq*) and (*Keq*).

$$F = \pm\ Ceq \cdot \omega \cdot \sqrt{a^2 - X^2} + Keq \cdot X \tag{7}$$

$$Ceq = \frac{C_d}{\left(\dfrac{C_d \cdot \omega}{K_d}\right)^2 + 1} \tag{8}$$

$$Keq = \frac{K_d}{\left(\dfrac{K_d}{\omega \cdot C_d}\right)^2 + 1} \tag{9}$$

(*Ceq*) is called equivalent damping coefficient and (*Keq*) is called equivalent spring stiffness. The load hysteresis of the oil damper inclines aslant and comes to show the spring characteristic.
Damping depends on stiffness (*Kd*), the pure damping (*Cd*) in Fig.7 and angular frequency (ω).
As expressed in hysteresis figure, the hysteresis diagram of linear characteristic shows a slanting ellipse like Fig. 8.
As shown in Fig. 9, the maximum damping force of bi-linear characteristic is restricted by relief valve operating.



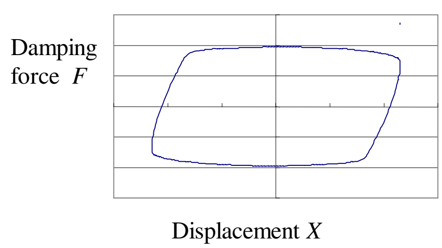


Fig.8. F－X loop of linear characteristic **Fig.9. F-X loop of bi-linear characteristic**

Maximum value of (*Ceq*) depends on frequency (f) and the spring constant (*Kd*) . This is shown in equation (10).

$$Ceq\ \max = \frac{K_d}{4 \cdot \pi \cdot f} \tag{10}$$

Environmental temperature dependency

Performance of the oil damper is little influenced by viscous change caused temperature change in the usual operating condition. So, the temperature-dependency can be neglected for regular use. The temperature limit and performance-dependency of the damper are judged from examination data. An examination example of temperature is shown in Table 3 and Fig. 10.

Table3. Temperature dependency examination

Examination article1000kNtype		C =250 kN・sec/cm
Condition of vibration	Period	4.5seconds
	Input wave	Sinnsoidal
	Amplitude	Single-sided amplitude a ＝20 ｍｍ
	Velocity	2.8cm/sec
	Circumference temperature	－20～80 ℃

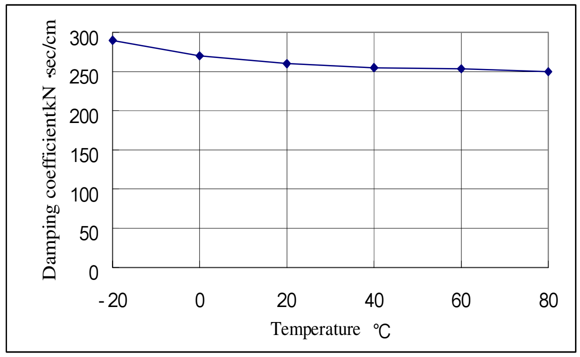


Fig.10. Temperature dependency of damping coefficient

Durability

The oil damper must be evaluated about durability of aging and number of cycles.

Durability of aging

The main parts of the oil damper consist of the steel parts, which are machined. Since inside is sealed, it is isolated from oxygen. Since there is also little number of cycles of operation, it will not become in high temperature state. Therefore, there is no degradation of oil, no rust of internal parts and no wear of sliding parts and seals etc.
This has been checked from the actual result of the same type oil dampers for structures.

Durability of number of cycles

Durability examination is carried out to the number of vibration cycles as which it is assumed for 60 years. It has been checked that there was no detrimental performance change.

PERFORMANCE EXAMINATION AND EVALUATION METHOD

Performance examination of damping force

As for the oscillating examination, it is common to measure the response to input of sine curve vibration. Performance examination of oil damper is the same.

Evaluation item and appraisal method

In the linear characteristic range, damping force and displacement as Fig 11 can draw a hysteresis diagram. The damping characteristic is estimated by two items. One is the maximum damping force and the another is the equivalent damping coefficient, which are asked from the dissipation energy, the amplitude and the frequency etc. This is shown in Fig.11 and Table 4.

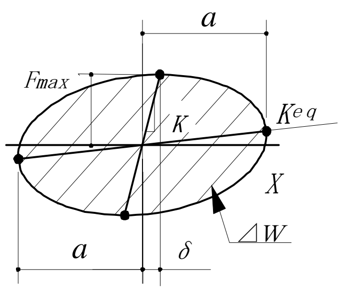


Fig.11. Hysteresis loop of Oil Damper

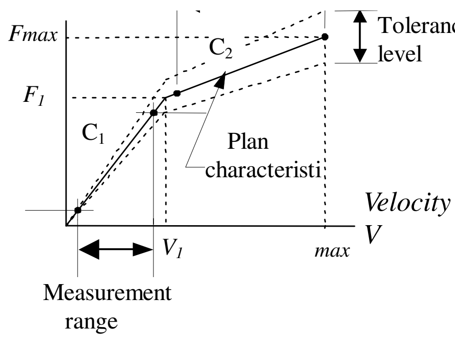


Fig.12. Inspection standard of damping force

Table 4. Evaluation items

Characteristic value	Contents
Maximum damping force F_{max}	Maximum load of extension force and compression one
Equivalent damping coefficient *Ceq*.	$Ceq = \frac{\Delta W}{\pi \cdot a^2 \cdot \omega}$ ΔW : Loop area (dissipation energy of one cycle)

The maximum damping force of one cycle is plotted in F-V diagram of Fig. 12. The relief characteristic is not greatly influenced of stiffness in the range of post-relief damping slope. Therefore, only the maximum damping force of the loop of one cycle is estimated.

Separation of stiffness and damping

The resistance power which the oil damper generates can be divide d into spring power which accumulates energy and the damping force which dissipates one. In the case of the oil damper, damping coefficient is calculated as (*Ceq*) in Table 4. Stiffness is expressed as the equivalent spring constant (*Keq*) calculated from the damping force (*Fa*) at the time of amplitude (*a*) in Fig. 11. It is shown in equation (11).

$$Keq = {Fa}/{a} \tag{11}$$

The spring constant (*Kd*). in Maxwell model is calculated from (*Fmax*) and δ in Fig. 11. It shown in equation (12). $K = {F\max}/{\delta}$

(12)

Calculation of pure damping coefficient (*Cd*) in Maxwell model is based on the following equation.

$$C = \frac{F\max^2}{2 \cdot f \cdot \Delta W} \tag{13}$$

The range of post relief damping coefficient has only little influence of stiffness. Since it can be disregarded, separation is not performed in relief range.

Other examinations

1) Examination of frequency-dependency
2) Examination of environmental-temperature-dependency
3) Examination of small-vibration-dependency
4) Examination of time of cycle-durability of performance
5) Examination of seal-durability
6) Examination of junction part

LIMIT CONDITIONS OF THE OIL DAMPER

Limit of displacement

Limit of displacement is one half of the differences of the maximum extension and the maximum compression length of stroke, which can move mechanically. If marginal value is exceeded, it will get damage, but performance is maintainable to the limit of displacement (±S). It is the total of the maximum response displacement, the error of attachment part and margin (manufacturing error of the damper length is included).
They are based on judgment of a structure designer except the manufacturing error of the oil damper.

Limit of velocity, Limit of damping force

Since the damping force is decided by velocity, t he damping force at the time of limit of velocity is the limit of damping force.
The maximum damping force is specified in design of the oil damper. Generally strength parts have about safety factor 1/1.2 ~ 1/1.5 to power-proof on short-term load conditions.
The velocity at the maximum damping force is the limit of velocity, and it is considered as limit of use.

Limit of environmental temperature

In cryogenic temperature, the limit is decided with the poor performance by viscous change. In high temperature, the limit is decided with the operation oil leak by defect of sealing. The performance gets the little dependence in the range of - 20°C ~ +80°C . Since the oil damper is used in indoor environment, so wind vibration, cryogenic temperature and high temperature state are not considered. Therefore, the high temperature of firing point is temperature limit.

DESIGN WHICH USES THE OIL DAMPER AS RESPONSE CONTROL DEVICE

Recommended analysis model

When the oil damper is installed in a structure, the stiffness must be taken into consideration.
Generally, the Maxwell model is used as shown in Fig. 13.

$$K = \frac{K1 \cdot K2}{K1 + K2} \quad (14)$$

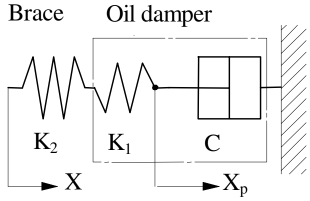


Fig.13. Maxwell model

C : Damping coefficient of the oil damper. (Bi-linear type is C_1 and C_2)

K_1 : Stiffness of the oil damper

K_2 : Stiffness of attachment parts to structure

K_1 and K_2 is calculated by following equation.

Analysis with consideration to the performance error

At the time of shipment, damping-force characteristic of all oil dampers are inspected , and adjusted to ± 10～15% (it is decided by consultation with a structure designer) of the tolerance to the designed value. When we design with using oil dampers, it is safe side to analyze both cases of maximum and minimum standard value.

The equivalent damping coefficient at the case of slant installation

At the time of slant installation, damping coefficient C is converted into a horizontal direction C_h. It is shown in Fig. 14 and equation (15).

$$Ch = C \cdot \cos^2 \theta \quad (15)$$

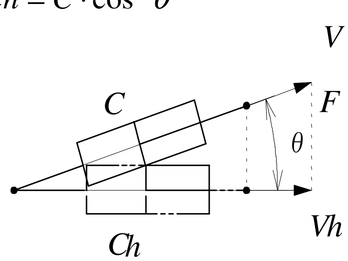


Fig.14. Horizontal force

DESIGN OF ATTACHMENT PART

In order to get design performance, the response value of the attachment part of the oil damper must be maintained below permissible value also used in the state of a limit.

QUALITY CONTROL

Quality control management

In order to maintain the quality of products and to raise, quality control system must be built. And the action about quality, authority, responsibility, or information etc. must be systematized. Inspection items, person in charge, and inspection place is shown Table 5.

Manufacturing process and quality control

At the time of a manufacture of oil dampers, quality is checked with the manufacturing document beforehand described by the builder and the manufacturing maker. Contents of inspection in the factory are shown in Table 6.

Table 5. Inspection items, person in charge and place

Person	Inspection item \ Place	Manufacturer factory	Construction place
Manufacture	Size inspection	√	
	Material inspection	√	
	Damping-force performance inspection	√	
	Full stroke inspection	√	
	Appearance inspection	√	
	(Product carrying in)		√
Designer, Superintendent, and Builder	Receiving inspection	√	Inspection of the result of the data manufacture already checked
	Inspection at the time of construction		√
	Inspection at the time of completion		√

Table 6. Contents of inspection in the factory

Order	Manufacture process	Contents of inspection
1	Materials	Size inspection Material inspection
2	Purchase parts Outside processed parts	Size inspection Material inspection
3	Oil	Material(quality) inspection
4	Machining parts	Size inspection
5	Welding parts	Appearance inspection
6	Assembly	Crack inspection Size inspection Full stroke inspection
7	Performance	Damping-force performance inspection
8	Painting	Paint thickness inspection Appearance inspection
9	Packing	OOS inspection Packing inspection

Various inspection

Performance inspection

All products get performance. Inspection.

Receiving inspection

This inspection carries out on the basis of the result of inspection data manufacture has already checked.

Inspection at the time of construction

It is inspected after equipping with oil dampers.

Inspection at the time of completion

The appearance inspection is carried out at the time of completion of a building.

CONCLUSION

This report has explained the performance of the oil damper, and the quality control as possible as plainly. From now on, we should plan more fully to enrich this paper, and make it complete so that it may become more perfect as a more effective manual.

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