Vibration-Dampers for Smoke Stacks

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Abstract: - Vibration dampers are commonly used to reduce the shedding-induced response of chimneys. In this paper, principle of the damping system is discussed. Mass and stiffness of the damper are calculated. Amplitude of the top of chimney during vortex shedding is calculated treating chimney as a single degree of freedom system. Dimensions of dampers are discussed. For example for a steel chimney of height 50 meter & diameter 1.5 meter, mass of damper is 169 kg. Finally, some examples of damping systems are presented.

Key-words: - Vortex shedding; Critical damping; Scruton number; Strouhal number; Resonance frequency; Degree of freedom; Stiffness

Notation

C_{cr} : critical damping
k_1 : stiffness of chimney
k_2 : stiffness of damper
$m(z)$: mass per unit length at height z
m_1 : effective mass of the chimney
m_2 : moving mass of the damper (about 10% of m_1)
S_{cr} : Scruton number
$Y(z)$: mode shape of the chimney
Y_{max} : top amplitude of the mode shape
μ : damping between chimney and damper mass
β : ratio of the damper mass and effective chimney mass

1 Introduction

After being assured of a chimney's ability to perform its required function, its owner will primarily be concerned with its safety. This implies that it should have an adequate factor of safety against collapse, either along wind, in response to fastest gust it is likely to experience, or across wind, in response to vortex shedding [1]. In addition, they will wish to avoid violent movements of chimney, even if consequent chimney stresses are acceptable.

Such large deflections not only pose a threat to the safety and integrity of the structure, but also affect sensitive equipment and human occupants. To alleviate this problem, within economic constraints, concept of structural control has become inevitable, which can be implemented if considered early enough in the design process. Structural control may be implemented through a set of vibration dampers. These dampers generate an opposing force that counters the motion of the basic structure to which it is attached. In this paper, some of the efforts towards controlling the vibrations in chimneys using vibration dampers are presented.

2 Principle of Damping

The movements of the chimneys in cross wind direction are caused by vortices. The forces due to these vortices can have the same frequency as the chimney and resonance can easily occur. The amplitude and stresses of the chimney can become large and can cause fatigue of the steel. A damping structure can reduce the movements considerably, because of counter forces with the same frequency. The theory of damping system is illustrated in figure1.

The vertical axis shows the ratio between the dynamic X_{ml} and the static Δ_{st} movement of the chimney. On the horizontal axis is the frequency of loading divided by the resonance frequency of the chimney. The dotted curve in figure1 is the

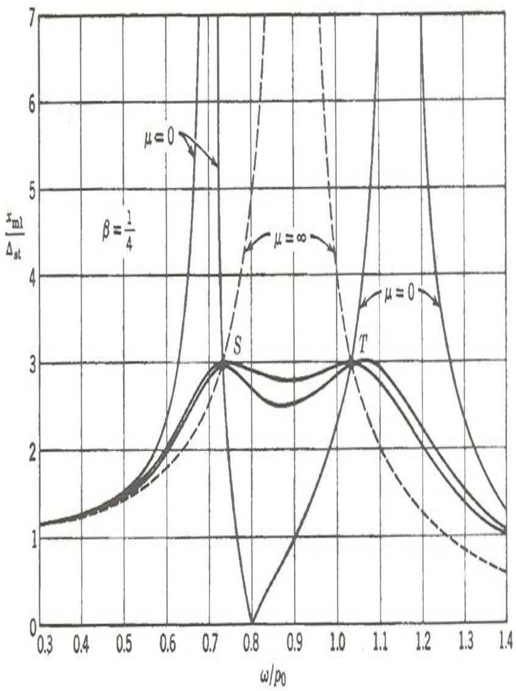


Fig1 Dynamic response of system with and without a damper

dynamic behaviour of the chimney without a damper. The amplitude becomes very large if the frequency of the load (ω) becomes equal to the frequency of the chimney (ρ_o). If the damping structure has been an optim designed, then the amplitude is restricted t the curves with a horizontal tangent at the points S and T. The amplitude will not go three times the static amplitude [2]. This can be considered as an excellent reduction of movements and stresses or an increase of the damping. The conditions for changing the single degree of freedom system of the chimney without a damping structure into the system with maximum amplitudes of S and T are [3]:

The ratio of the resonance frequencies $f_{chimney}$ of the main system and the damping system f_{damper} as in figure 2:

$$\frac{f_{damper}}{f_{chimney}} = \frac{1}{\sqrt{1+\frac{m_2}{m_1}}} \tag{1}$$

$$m_1 = \frac{\int_0^h m(z)Y^2(z)\,dz}{Y_{\max}^2} \tag{2}$$

The stiffness of the support of the damping mass is:

$$k_2 = k_1 \cdot \frac{1}{1+\frac{m_1}{m_2}} \tag{3}$$

The damping

$$c_2 = \frac{c_{2cr}}{1+\frac{m_2}{m_1}}\sqrt{\frac{3m_2}{8m_1}} \tag{4}$$

$$c_{2cr} = 2\sqrt{m_2 k_2} \tag{5}$$

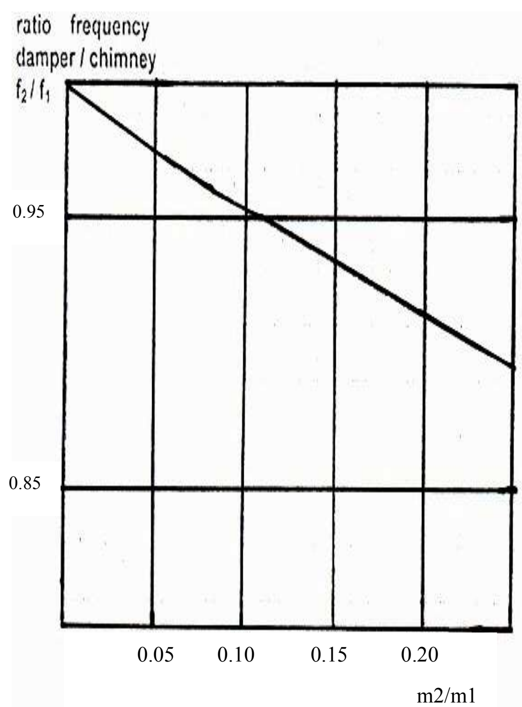


Fig 2 Frequency of the damper

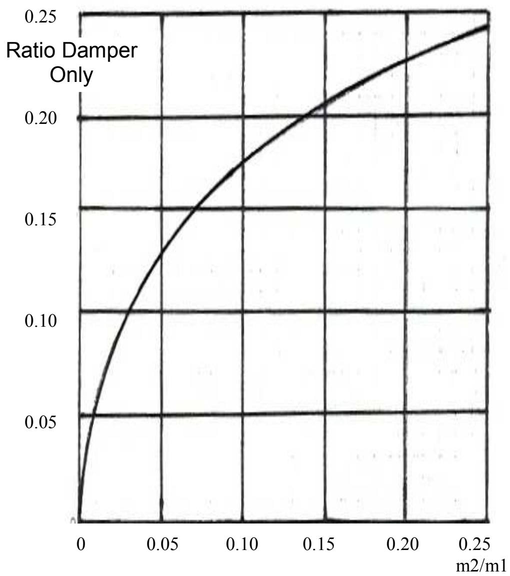


Fig 3 Damping of the damper

m_2 and k_2 are mass and stiffness of the damper as shown in fig 3.
This damping ratio of a dynamic system with on degree of freedom is explained below:

- If the ratio is 1, then the movement of the mass after displaced will go back to the rest situation, without passing this position.
- If the ratio is 0, then there is no damping and the mass will go over the rest situation to the same distance on the other side. The movement will continue.
- If the movement is only 50% of the starting value after n cycles, then the damping ratio is 0.11/n. This is a simple way to determine the damping ratio of a single system of freedom: move it out of the rest situation and count the number of movements until the movement is reduced by 50%. The damping ratio is then 0.11/n.

The critical wind velocity [3]: $V_{crit} = c_r fd$ (6)

Where $c_r = 5$ (c_r is the inverse of the Strouhal number)

3 Movement of Chimney

The amplitude of the top of the chimney during vortex shedding can be calculated. Introducing the Strouhal number[3] as 0.2, the maximum amplitude y and the chimney as a single degree of freedom system with stiffness k, mass mh/4 and damping c/c_{cr} loaded by a force F in resonance with the chimney, then the movement of the top is

$$y = F/(2kc/c_{cr}) \qquad (7)$$

The frequency is $$f = \frac{1}{2\pi}\sqrt{\frac{k}{mh/4}} \qquad (8)$$

And the amplitude is $$y/d = \frac{8C_L}{S_{cr}} \qquad (9)$$

$$S_{cr} = \frac{4\pi m \dfrac{c}{c_{cr}}}{\rho d^2} \qquad (10)$$

And m the mass per unit length of the top third.
The velocity of the top of the chimney is given by $v = \omega y = 8.1\pi C_L df/S_{cr} fd$ (11)
The critical wind velocity is given by 5fd. If the Scruton number is larger than 7 the movement of the chimney has an influence on the loading. The load is increased. For Scruton numbers larger than 15, the movements become smaller than 5% of the diameter and the influence of the movements can be neglected. Normally the Scruton number is above 15 if the damping ratio $c/c_{cr} > 3\%$.

4 Features of Dampers

4.1 Dimensions of dampers

- The damper must create a force to compensate for the force of the vortex.
  The force is given by
  $1/2\rho V_c^2 C_L dh = ½*1.25*25*d^3h\omega^2/4\pi^2$
  $= 0.08\omega^2 d^3 h$ (12)
  The force of the damper = $me\omega^2$ (13)
- The force of the vortex is compensated if $me = 0.08d^3h$ (14)

Where m is the mass of the damper and e is the eccentricity out of rest.

- If the movement of the mass is supposed to be close to 0.08m, then the mass in kg must be about
$m \geq d^3h$ (15)

Several types of dampers are available

- A mass which is usually of steel or liquid. Moving water in rectangular buckets will break against the wall and cause a counter force against the vortex induced movement. The mass of steel is much smaller than the mass of water so for large chimneys steel will be used. (e.g. h=50m and d=1.5m, m=169kg)[4]. A spring which can be a rolled steel wire (the KABE damper in fig 4 for a single coil)
The frequency of water moving in a square bucket will depend on the size of the bucket. The length and width of the water box must be about:
$L = \sqrt{(gh)}/2f$
Where f=the required frequency, g=9.81 m/s^2. The direction of the sides may be different from the direction of the movements as in fig 5. For a pendulum or a curved shell is the length of the pendulum or radius of the shell $R = g/(2\pi f)^2$.
- Damping can be obtained from friction in the steel wires or hydraulic shock absorbers can be used in case of a pendulum. The rolling of masses in a shell requires sufficient energy to damp all movements.

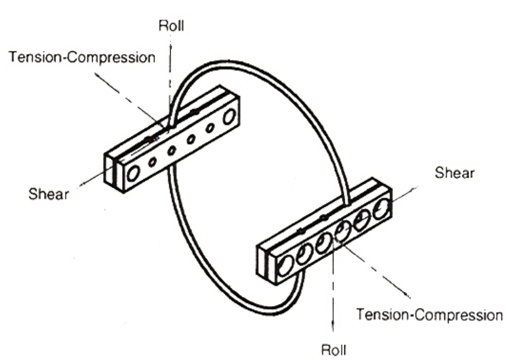


Fig 4 A single coil of the wire rope spring

The dimensions of damping structures are determined by equations (1) & (2). Making mass of the damper of as 10% of the generalized mass on the top of the chimney is a reasonable first guess, but the damping of the chimney has to be calculated. The movements can be calculated by solving the equations of dynamic equilibrium of the system with two degrees of freedom. If the solution for a large chimney with a suspended mass and shock absorbers for the damping is chosen, then the movement between the chimney and the swinging mass has to be limited, because the shock

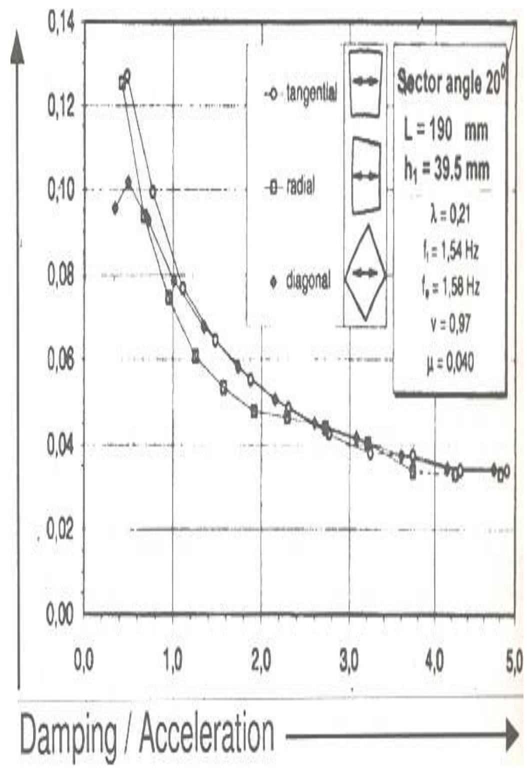


Fig 5 Damping, depending on acceleration for three water boxes

absorbers can move only 100mm in and out or in a special case 150mm in and out. If a damper with a steel ring as mass, suspended by bars with hinges and absorbers is used, then the large steel chimneys can easily be damped. The shock absorbers are produced with damping values of 200-3000 Ns/m, 900-1400 Ns/m and 400-5000 Ns/m. Combination of 2, 3, 4 or 6 absorbers makes it possible to find a solution for all required damping values for any chimneys [5]. A sketch of the damping structure with shock absorbers is shown fig 6.

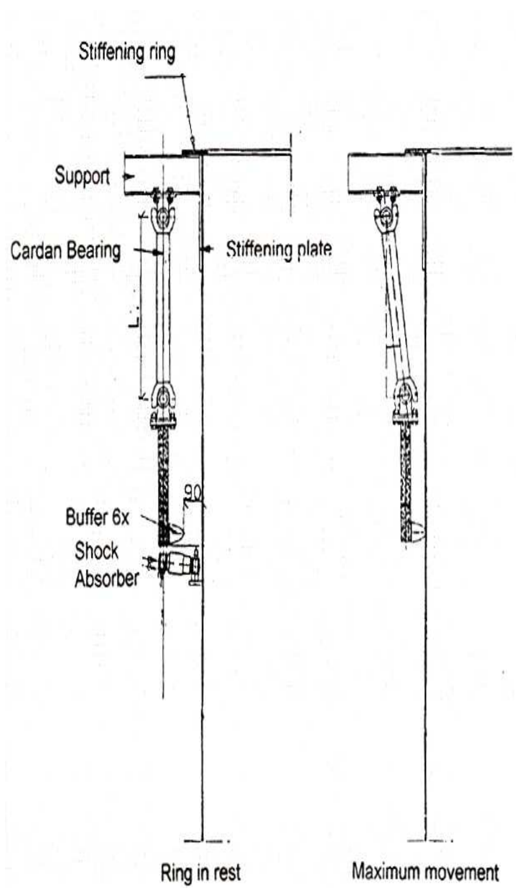


Fig 6 Cross section of a steel ring, suspended at the top of a chimney

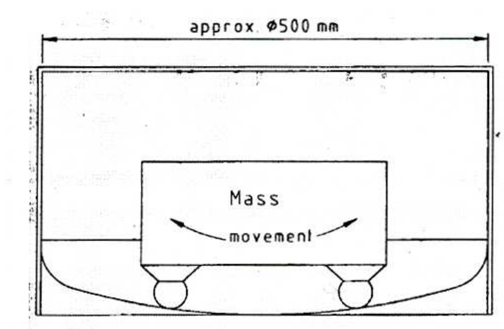


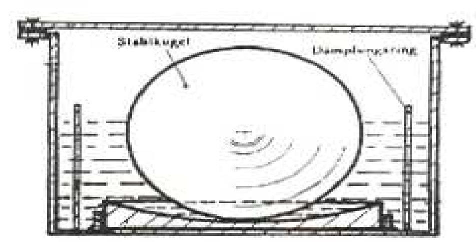
Fig 7 Cross section of a roll box damper

The mass of the damping structure is again about 10% of the effective mass of the upper part of the chimney, but the swinging is obtained by fixing rollers under the mass and placing them in a box. It can be executed as a closed box, called Roll-box damper as in fig 7 or as a ring around the chimney resting on three shells. The size of the shell determines the resonance frequency of the damper and the resistance of the rolls in the shell is effective as damper.

5 EXAMPLES OF DAMPING SYSTEMS

The following damping systems are in the practical use [5]. Each system has it's advantages and disadvantages.

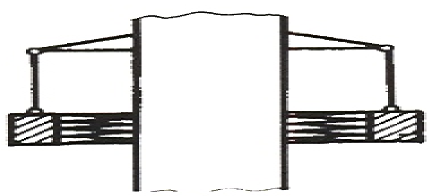
System: Traetner



The system consists of:

- Replaceable calotte
- Steel bowl as damping mass
- Silicon oil as damping liquid
- Damping ring as compensation for the viscosity changes due to
- Temperature fluctuations
- Shielded box against environmental influences

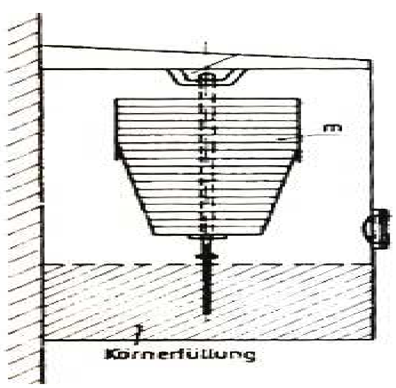
System: Hirsch



The system consists of:

- Gimballed pendulum
- Ring as pendulum mass
- Damping of the pendulum movements through screw spring packages between
- Ring mass and bearing tube

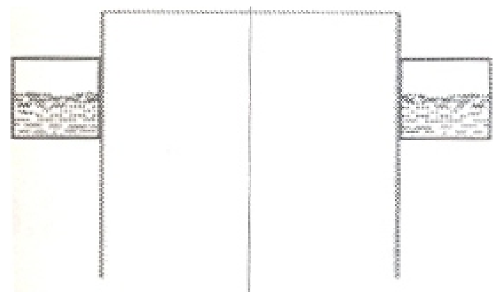
System: Langer



The system consists of:

- Gimballed pendulum
- Oscillating mass
- Damping of the oscillation movement by stiring of the pendulum beam in plastic grains

System: Verwiebe



The system consists of:

- Boxes in form of circular shaped ring pieces
- Filled with anti freeze liquid in a defined height

6 Inaccurate Tuning of a Damping Structure

The tuning of a damper at the optimal frequency and damping is not always possible and the frequency of a chimney and its damping can change. Calculations have been made to find the effect of this accuracy. If the resonance frequency of the damper is 10% outside of the optimal value the damping of the chimney is reduced by 20%. This is not important, because the minimum required damping is 3% of the critical damping. The damping of the damping system must be close to 0.1 to 0.2. If the damping is more than this value the damping of the chimney is hardly changed [5].

7 Conclusion

The minimum required damping to prevent cross wind vibrations is 3% of the critical damping. Dampers made with water need an anti freezing protection. Tall chimneys can be damped by using the non linear coils or hydraulic shock absorbers. Regular tests by measuring the variations of the stresses at the base of the chimney are advised. The tests make it possible to determine the damping and the effect of the damping system [5].

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