

MEEN 2210 Electromechanical Engineering Systems Spring 2011
Problem Set #7 Due April 13, 2011 Design Problem

Introduction:

The pure and ideal viscous damper is mathematically ideal, but not necessarily functionally ideal, i.e., while it gives equations that are analytically solvable, its functional performance is not always the best that might be achieved. In this design exercise, you will show that for a certain class of damping applications, the linear damper is far from optimum and that an optimum damping form can be derived and practically implemented.

Problem Statement:

Consider a mass M of weight 100 lbf, containing sensitive instruments, moving along a frictionless surface with a certain initial velocity v_0 of 5.0 ft/sec. It is desired to decelerate this mass to zero velocity in the shortest possible time and distance, under the constraint that the damping force exerted on the mass should never exceed 200 lbf. This limit on the maximum damping force is necessary to protect the instruments from overstress, excessive impact noise, etc. If the maximum damping force is stipulated, it is clear that the damper should exert this same force for its entire stroke, if we want to stop the mass in the shortest time. That is, if we are allowed to use a certain maximum force, we should apply this force all the time. If we do this, there is no possible faster way to decelerate the mass.

Requirements:

1. Show that the pure and ideal viscous damper will not satisfy the design requirements.
2. Will a nonlinear damper that “increases its B (damping coefficient) value” as the mass slows down meet the design requirement?
3. An optimum damper that maintains a constant force as velocity decreases could be constructed in various ways. Can you propose one?
4. Consider a damper where the damping is obtained by forcing a damping liquid through a small orifice. If this orifice were of fixed size, the damping force, while nonlinear with velocity, would still drop off as velocity decreased – not what we want. We need an orifice that gets smaller, in exactly the right way, if we want an exactly constant force, as the stroke proceeds and the velocity drops. What is this needed relation? First, some basics.

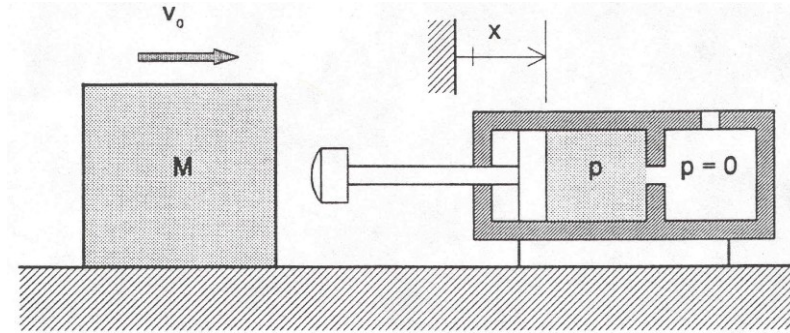
$$q = C_d A_o \sqrt{\frac{2\Delta p}{\rho}} = K_{or} \sqrt{\Delta p} = \text{volume flow rate through orifice}$$

C_d = orifice discharge coefficient (dimensionless)

A_o = orifice area (in²)

Δp = pressure drop across orifice (psi)

$$\rho = \text{fluid mass density} \left(\frac{\text{lbf} \cdot \text{sec}^2}{\text{in}^4} \right)$$



Since the liquid is treated as incompressible, the rate at which volume is displaced by the advancing piston must equal the volume flow rate through the orifice at every instant. Also, the piston velocity must decrease linearly with time since we insist on a constant decelerating force, which gives a constant deceleration a , which in this case equals 64.4 ft/sec^2 (2 g's).

$$q = K_{or} \sqrt{p - 0} = A_p (v_0 - at)$$

$$p = \left(\frac{A_p}{K_{or}} \right)^2 (v_0 - at)^2$$

Now the pressure p times the piston area A_p is the decelerating force, so this must equal the mass times the acceleration, allowing us to eliminate p from our equations:

$$K_{or}^2 = \frac{A_p^3}{Ma} (v_0 - at)^2$$

Now for a motion with constant deceleration a , we know that the displacement x is given by:

$$x = v_0 t - \frac{at^2}{2}$$

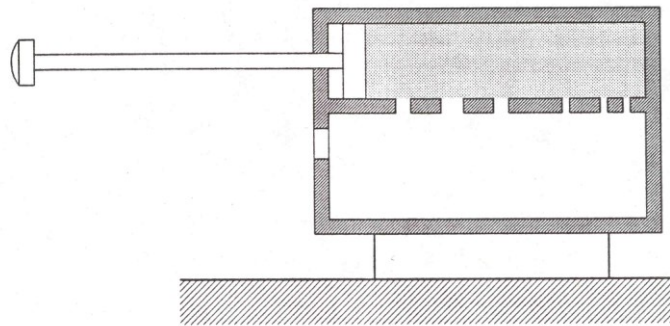
Solving for t:

$$t = \frac{v_0 - \sqrt{v_0^2 - \frac{4ax}{2}}}{a}$$

Therefore

$$K_{or}^2 = \frac{A_p^3}{Ma} (v_0^2 - 2ax)$$

The definition of K_{or} shows that the only practical way to vary it is by changing the orifice area. Commercial shock absorbers approximate the smooth area variation needed by using a sequence of drilled holes. As the stroke progresses, the total orifice flow area reduces in a stepwise fashion which approximates the ideal smooth curve.



5. Build a MatLab/Simulink simulation that compares the performance of 4 different dampers:

- A fixed linear (viscous) damper
- A fixed nonlinear (single-orifice) damper
- A perfect optimum damper
- A stepwise-approximate (use 5 holes) optimum damper

Use a piston area of 0.0015 ft^2 . Submit the Simulink simulation diagrams plus plots of velocity vs. time, position vs. time, and force vs. time for each of the 4 cases. Discuss your results.