<u>Model Of The Total Torque Produced By Damper To Be Used For Inceptor</u>

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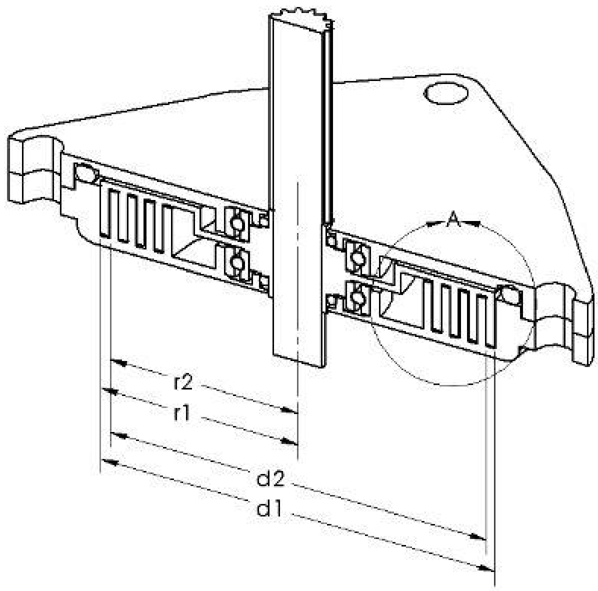
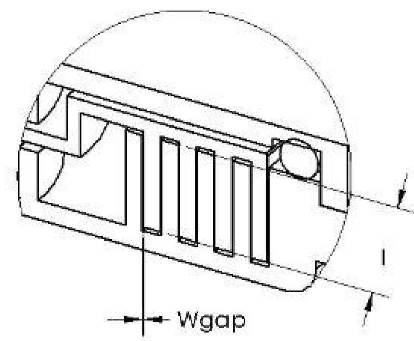




DETAIL A
SCALE 4 : 1

Introduction:

The inceptor for an aircraft needs to have spring centering to allow the pilot to feel the degree of command input. The spring centering combined with the inertial mass of the stick can result in a mechanical system that can oscillate if let go. A damper can be added to the inceptor axes to dampen this oscillation and to dampen inputs that are quicker than desired. Any added damper must not reduce the fidelity of control. The most common and worst characteristics that a damper can add are friction and deadband. Friction can make it harder to move the stick in the very small inputs that are needed for smooth control. Deadband can ruin the linear feel of the stick, making it hard to move the stick with smooth, continuous motion. A common type of damper that can be made with significant damping that is nearly completely viscous, with very low friction and with little to no deadband is described and analyzed here. This damper consists of a plate that rotates on a shaft, within a sealed housing. The plate has a number of concentric cylindrical fins of depth l and width w_{fin} with grooves between them of width w_{groove}. These concentric fins interleave with matching fins on one side of the stationary housing. The fins on the housing have the same depth, width and groove width. The fins and grooves are sized such that between each fin on the moving disk there is a very thin gap, w_{gap}, to the wall's corresponding groove. The damper configuration to be discussed has four fins with four corresponding grooves. The following discussion includes an analysis of the effect of machining tolerances and temperature on the range of torque values produced by the damper.

Overview:

The damping force contributed by each gap in the damper model is proportional to the angular velocity and the damping coefficient. Understanding that the damping coefficient is equal to the dynamic viscosity of the silicone fluid multiplied by the interface area and divided by the gap size, damping force can be written as:

$$f_d = c_r \cdot \omega = \frac{\mu \cdot A}{gap} \cdot \omega \qquad (1)$$

Where ω is the angular velocity, *A* is the interface area, and μis the dynamic viscosity of silicone oil in centipoise. Dynamic viscosity is equal to a fluid's kinematic viscosity multiplied by its density. The reason this property is used in this equation rather than kinematic viscosity is that by including the density of the fluid, dynamic viscosity gives information about the force necessary to make the fluid flow at a certain rate, whereas kinematic viscosity only shows how fast a fluid is flowing under the force of gravity.

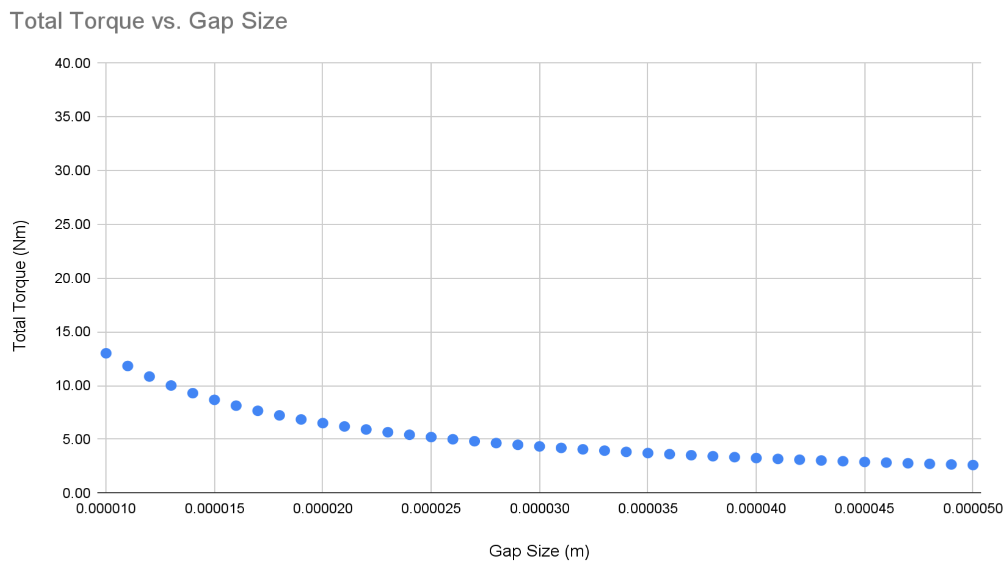
Inserting the computation of interface area into Eq. 1 yields the equation for damping force of each gap:

$$f_d = \frac{\mu \cdot \pi \cdot d^2 \cdot l}{2 \cdot w_{gap}} \cdot \omega \qquad (2)$$

Here, *d* is the diameter of the inner ring and *l* is the depth of the gap. Finally, to achieve torque Eq. 2 is multiplied by the moment arm which acts at the center of the gap for each gap. This can be calculated as the radius to the gap, or *r*:

$$f_d = \frac{\mu \cdot \pi \cdot d^2 \cdot l}{2 \cdot w_{gap}} \cdot \omega \cdot r \qquad (3)$$

The total torque is then calculated by adding the torque produced at each gap, and can be plotted against fluctuating gap size to produce the following model:

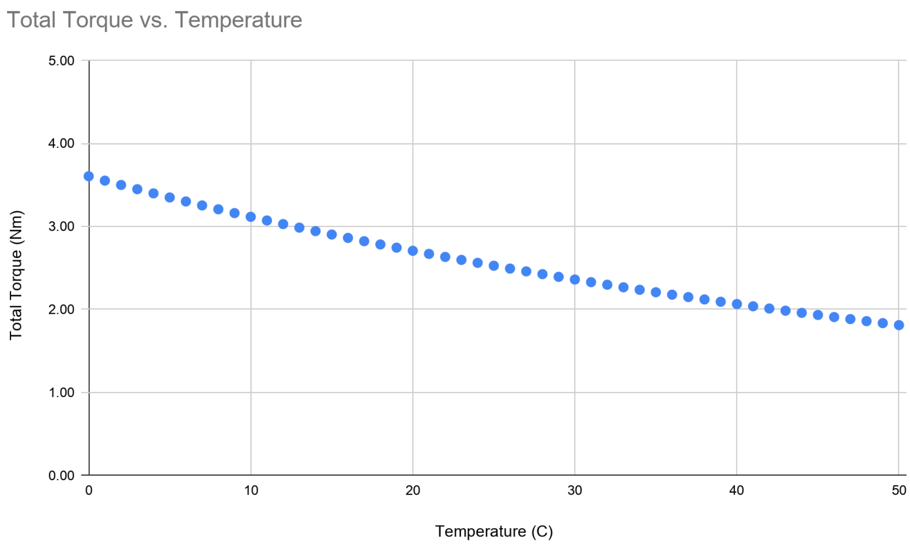


In this chart it is clear that as the nominal gap size decreases, the slope of total torque increases and is most steady at higher nominal gap sizes. Therefore it can be concluded that considering machining tolerances of around 8 microns, the tightest range of torque values will be achieved at a nominal gap size of around 50 microns. This range in torque values is slightly less than 2x.

Total torque can also be modeled as a function of temperature. Change in temperature affects the viscosity of the fluid, therefore the dynamic viscosity which is used to calculate damping force. The manufacturer from which the silicone oil will be sourced provides a temperature coefficient of 0.61 that fits the model to a roughly linear fit under a logarithmic scale. Viscosity can be modeled as a function of temperature approximately fitting the following equation:

$$v = v_0 \cdot 10^{\frac{763.1}{273+t} - 2.559} \tag{4}$$

Where v_0 is the initial viscosity. After calculating viscosity at each temperature within the appropriate range, the dynamic viscosity can be calculated based at each temperature and sequentially the damping force and torque. Total torque is plotted against temperature in the following graph:



From the plot it can be seen that for a temperature range from 0 to 50℃, the range in torque values goes from about 1.81 to 3.61. These values were calculated using a constant gap size of 40 microns.

References:

(1)

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(2)

Zhai, S.; Song, L.; Lv, X. Measurement and Analysis of Silicone Oil Characteristics and Viscosity-Temperature Index. *IOP Conf. Ser.: Earth Environ. Sci.* 2019, *330*, 032049. https://doi.org/10.1088/1755-1315/330/3/032049.

(1)

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