# Torque Peaking Due to Viscus Damper Deadband

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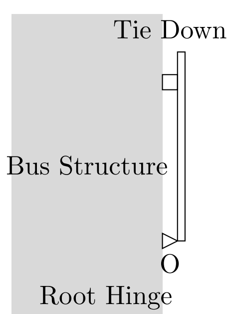
Deployable appendages are typically stowed & launch-locked at tie down location(s) during launch so that they can fit into the fairing of a rocket and survive the rough ride to space. Once the spacecraft has separated from the launch vehicle and has reached its proper orbit, launch locks are released and preloaded torsional springs deploy the appendage. Since successful appendage deployment is often a single point of failure for success of a mission, high margins of safety are required on the deployment torque to overcome friction, parasitic torques, and extreme temperature effects. However, we do not want high speed at the end of the deployment and before hinges latch since high kinetic energy stored in the appendage could results in destructive structural loads at the end of deployment. To resolve this issue, dampers are typically used to slow down the deployment speed. In this article, we discuss impact of deadband angle on the damper shaft torque.

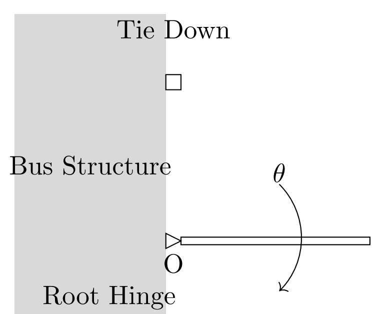
## Deployment Equations

Consider a stowed appendage as shown in Figure 1 where after tie-down release, it will deploy around root hinge O. If inial torque stored the spring is $T_0$ and appendage mass moment of inertia about O is $I_o$, the inital angular acceleration $\alpha$ of deployment becomes:

$$\alpha = \frac{T_0}{I_o}$$




(a) Stowed Appendage




(b) Deployed Appendage

Figure 1: Schematic spacecraft and appendage representation

Now if the damper has an initial deadband $\theta_{db}$ where it has no damping resistance to the torque, angular velocity at the end of deadband becomes:

$$\omega = \sqrt{2\alpha\theta_{db}}$$

Consequently, we compute appendage angular velocity at the end of deadband as:

$$\boxed{\omega_{db} = \sqrt{\frac{2T_0\theta_{db}}{I_o}}}$$

The time that it takes the appendage to travel to the end of the deadband then becomes:

$$\boxed{t_{db} = \sqrt{\frac{2\theta_{db}I_o}{T_0}}}$$

Damping as a function of time for a damper with damping coefficient of $C$ and deadband $\theta_{db}$ can be written as:

$$\boxed{c(t) = C\left[\frac{1}{2} + \frac{1}{2}\tanh\left[\lambda(t - t_{db})\right]\right]} \tag{1}$$

where $\lambda > 1$ is a constant that simulates the deadband step function differentiably.

Equation of motion for the appendage can be written as:

$$\boxed{I_o\ddot{\theta}(t) + c(t)\dot{\theta}(t) + k\theta(t) = k\theta_s}$$

where $\theta$ is angular rotation of appendage about the root hinge axis, $k$ is the torsional spring rate, and $\theta_s$ is original twist in the spring. Solving this second order ODE numerically for different deadband angles we can study peaking effects of damper deadband. Damper shaft torque before latching can be computed as:

$$\boxed{T(t) = c(t)\dot{\theta}(t)} \tag{2}$$

# Numerical Examples

Consider a damper with damping rate of $C = 1000 in.lbf.s/rad$, and a deadband $\theta_{db} = 5°$. Figure 2 shows damping as a function of time for different $\lambda$ assumptions. As this plot shows, the higher the $\lambda$ assumption, the closer Equation 1 becomes to a step function.

Figure 3 shows damper shaft torque as function of time for different deadband angle assumptions (assuming step function penalty factor $\lambda = 10$ in Equation 1). This plot shows damper shaft torque peaking at approximately the end of the deadband when damper resistance suddenly kicks-in. Note how quickly torque peaking increases with increasing deadband angles.

Figure 4 shows damper shaft torque vs angle. In this application, 90° is the end of deployment where solar array hinge latches. These plot show that torque at the end of deployment is the same regardless of the damper deadband angle. Table 1 summarizes max torques for different deadband scenarios.

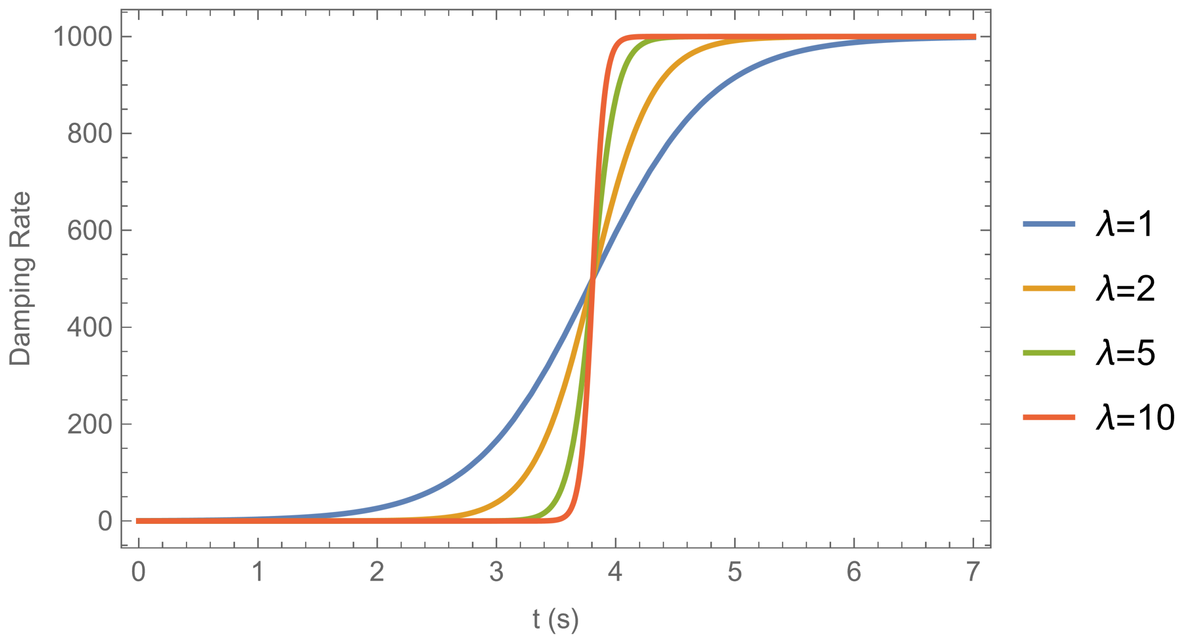



Figure 2: Damping vs time for 5deg deadband angle for different $\lambda$ penalty factor assumptions

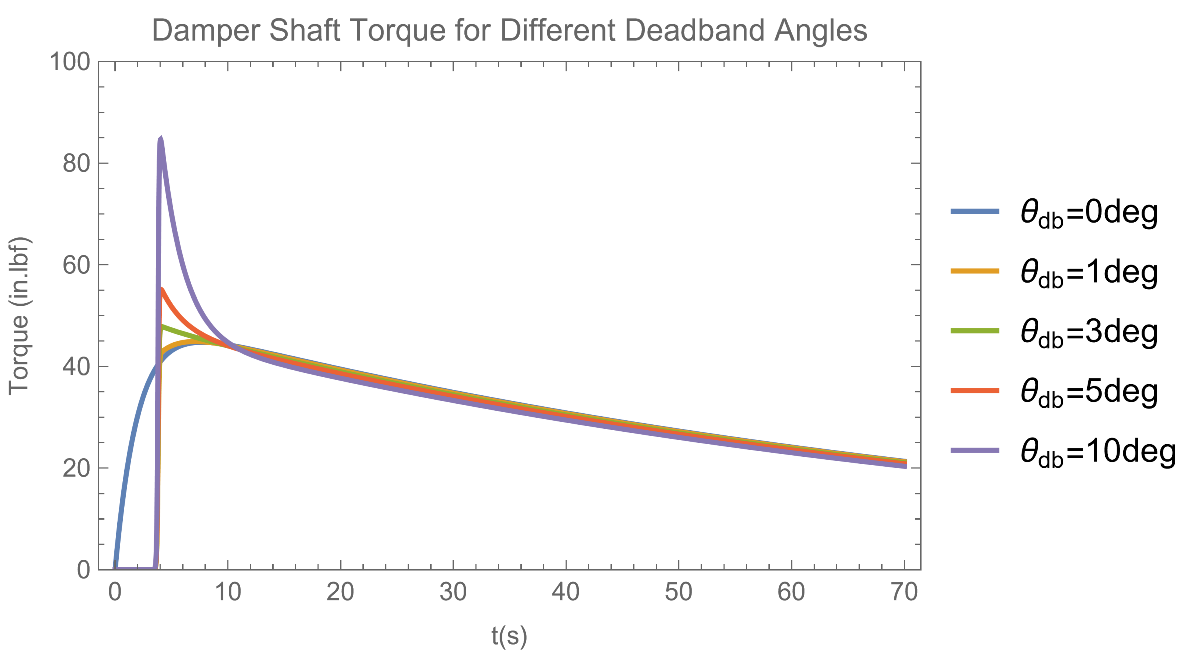



Figure 3: Damper shaft torque vs time for different deadband angles

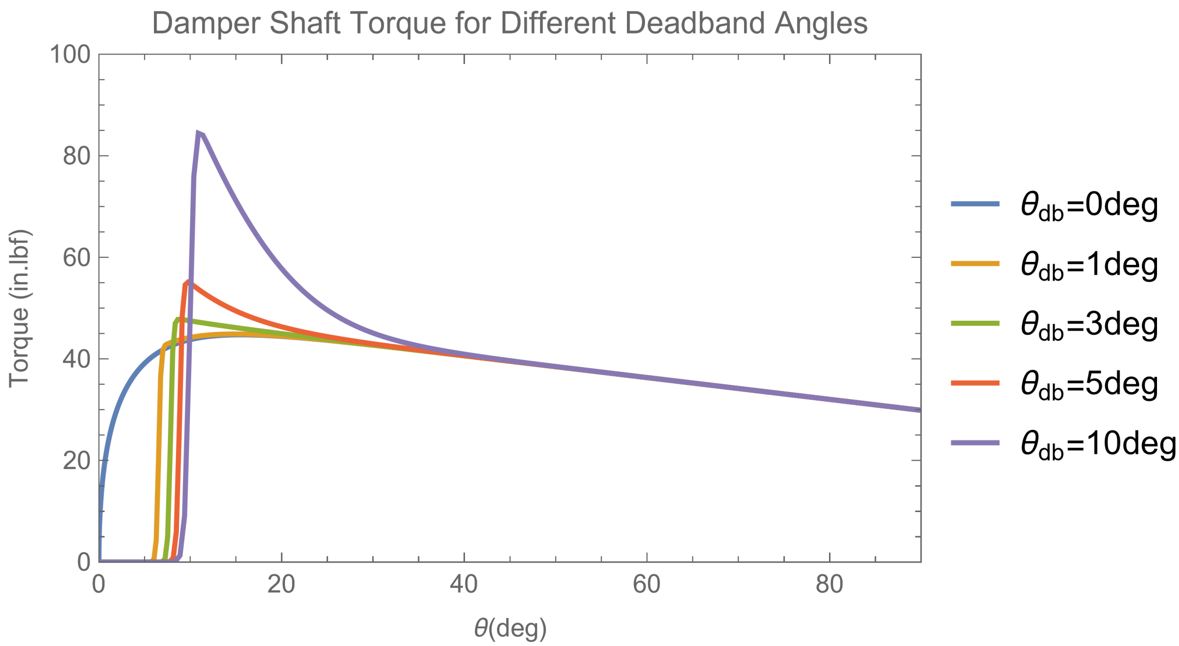



Figure 4: Damper shaft torque vs angle for different deadband angles

Table 1: Damper shaft torques for different deadband angles

| Deadband° | Peak Torque $(in.lbf)$ |
|---|---|
| 0° | 44.75 |
| 1° | 44.90 |
| 3° | 49.55 |
| 5° | 61.90 |
| 10° | 84.67 |