MAE 3260 Final Group Work: Exploring a System of Interest

Report

Outline (two examples given below, there could be others):

Option #1: one report, same grade for all	Option #2: separate sections/grades for each
Page 1: cover page **Pages 2-9**: any format you want in these pages, just include a few section headings in this outline) **Page 10:** References	**Page 1:** cover page **Page 2-3:** Student A technical summary **Page 4-5:** Student B technical summary **Page 6-9:** Ella and Reggie **Page 10:** References

Title: Shock Absorber Dissection

Topic of Interest: Shock Absorber

Abstract: One paragraph summarizing the project. Include the system, why you decided on this project, what aspects you plan to study, etc. See the list below or the provided project description examples for some ideas of possible aspects to study. Choose the aspects that make the most sense for your system.

Students/Roles:

Student	Task/Role	Portfolio
Name	1-3 sentence summary of student's work and key take-aways	Link to results in student's individual portfolio
Reginald Harris	I assisted in the dismantling of the shock absorber, as well as being responsible for calculations of the damping coefficient and modeling the system as an ODE + TFs	https://cornell-mae-ug.github.io/portfolio-rdh252/
Ethan Hernandez	Assembly	https://cornell-mae-ug.github.io/fa25-portfolio-emh236-dotcom/
Ella Johnson	My role was experimentally finding the spring constant as well as creating a state space model of the system. This is in the last section of our report, entitled Modeling the System. I also assisted in dismantling the shock absorber.	https://cornell-mae-ug.github.io/fa25-portfolio-ellabellaboo54/
Aahil Ali	Background & Dismantling components	https://aahil24108.github.io/cornell-mae-ug.github.io-portfolio-aaa387/

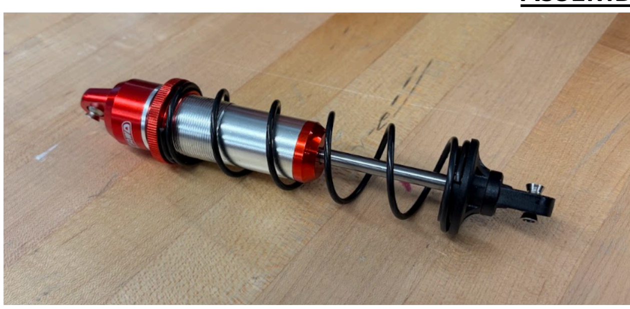
List of MAE 3260 concepts or skills used in this group work:

- Forced spring-damper systems
- State space modeling
- Transfer Functions
- Bode Plots

Pages 2-9 include two pages for each student:

- Summarize technical work, including figures
- For references, use numbers/brackets (e.g. [1]) in text with list - IEEE citation format.
- Students can combine sections (i.e. 4 pages for students A and B), but will get the same grade

ASSEMBLY



We started taking apart the shock absorber by prying the black holding piece on the bottom end of the spring out. After prying the bottom end, we were able to access the main body of the shock absorber and retrieve the spring.

After prying the black end off, we screwed off the red cap at the top of the shock absorber to access the inside of the silver metal tube. The silver metal tube is the damper housing.

With the red cap removed, we were able to access the main ram rod. This inner chamber was also filled with a small amount of oil. The oil was likely used for lubrication and sealing purposes, the inside of the chamber was filled with air.

This chamber is a damper used to resist bouncing within the suspension. The spring holds the weight, while the damper resists motion and prevents the spring from bouncing up and down. The damper wo 10rks by creating an airtight seal with the black ram rod. This airtight seal cannot compress the hydraulic fluid in the chamber easily, and therefore creates resistance that slows the motion of the spring. It is likely that although the chamber is filled with air, the black ram rod forces oil through the valves to create the damping effect.

The dissection went smoothly, we made some key observations on the way the shock absorber was made:

- The top and bottom of the shock absorber have a rolling ball that can pivot freely so that the suspension can handle loads that are moving around. A suspension that can only move on one axis would be useless, so the rolling ball allows the shock absorber to absorb a load in multiple directions.
- The circular red piece shown in the above photo is an adjustable screw to tune how compressed the spring is. When the spring is compressed, it changes how much force it takes to make the spring start moving. This will make the system more responsive.
- Much of the body and parts of the shock absorber is made of Aluminum in order to withstand high stresses and temperatures.
- The hydraulic fluid in the damper is different from a normal fluid. The hydraulic fluid is more viscous than normal fluids, meaning the fluid is more resistant to flow, which gives the damper a higher damping force.

BACKGROUND INFORMATION

A shock absorber is built from a few key parts that work together to control how the suspension moves. On the outside there is the main tube or "body" which holds the oil. Inside that body is a piston connected to a metal rod, and the rod sticks out the top of the shock and connects to the chassis. The bottom of the shock mounts to the suspension arm. As the suspension moves, the shock is pushed and pulled by the arm, driving the piston up and down through the oil. There are also seals to keep the oil inside and keep first out.

All of these parts make sense when you look at how the shock behaves as one system. When the wheel hits a bump, the suspension compresses, and the piston is forced into the oil. The only way the oil can move is through small holes and passages in the piston, or through little spring-loaded valves. Those openings are tiny, so the oil has to squeeze through them, and that slows the piston down. The harder or faster the suspension tries to move, the more the oil resists. That resistance is what we call damping. It turns the motion of the suspension into heat in the oil instead of letting the wheel and chassis bounce up and down over and over. The body, piston, rod, oil, and seals all work as one unit: they let the suspension move enough to absorb bumps, but not so freely that the car feels floaty or unstable. This results in better grip, a smoother ride, and a car that's easier to control.

MODELING THE SYSTEM

Shock absorbers can be modeled as a forced spring-damper system. For our shock absorber, the movement of an ATV provides a downward force on the shock absorber, which is counteracted by the spring to reduce the effect of the force on the entire vehicle. There is also a piston with hydraulic fluid that acts as a damper to slow the effects of the force and the spring, allowing for a smoother ride.

To model the system, we had to find both the **damping coefficient** and the **spring constant.** Because we did not realize there was a damper in the system until after taking our shock absorber apart, we were unable to calculate the damping coefficient experimentally. If we had done it experimentally, we would have collected data on how much the system compresses under a specified force and then compared that to the spring on its own to discover the damping coefficient. Instead, we estimated the damping coefficient by combining the measurements of the cylinder/pistons with a couple of simplifying assumptions and values found online to get a ballpark number.

Assuming that the piston was responsible for the damping, we modeled the force of the piston as proportional to the damping coefficient multiplied by the velocity of the system. Also knowing the the force of a piston is equivalent to the change in pressure drop across the cylinder times the area of the piston, we set the two relations equal to solve for c. Using Hagen–Poiseuille[1] relation to solve for change in pressure, and μ=0.63 Pa/s[2] as the estimated shock oil viscosity, we plugged in our piston measurements we took with calipers to get a final value of c = 245.7 N*s/m.

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[1] Descirbes pressure drop across a cylinder filled with fluid in laminar flow, which we assumed describes how the position moves through the oil in the cylinder in the shock abosrber

[2] Found online from shock oil viscosity tables

$$F_{piston} = c*\dot{x} \ \& \ F_{piston} = \Delta P * A_{piston}$$

So

$$c = (\Delta P^3 * A_{piston})/\dot{x}$$

$$c = (8\mu_{oil}L_{hole}A_{piston}{}^2\dot{x})/(\#_{holes}\pi(d_{hole}/2)^4)\dot{x}$$

$$c = (128(.63 \text{ pa/s})(.00447 \text{ m})(.000304 \text{ m}^2)^2)/(8(\pi)(.001524\text{m})^4$$

$$c = 245.7 \text{ n*s/m}$$

Unlike the damping coefficient, we were able to figure out the spring constant experimentally. Since the force exerted by a spring is directly proportional to the spring constant and the change in length of the spring, we used that relationship to calculate the spring constant. We first used a caliper to find the unstretched length of the spring. We then found the mass of some weights in the lab, attached them to the spring, and used the caliper to find the stretched length of the spring. We then used the following equations to calculate the spring constant.

$$F = k \times \Delta x \rightarrow k = F \div \Delta x$$

$$F = m \times g = (2.762\, kg) \times (9.81\, m/s) = 27.09522\, N$$

$$\Delta x = |L_0 - L| = |4.728\, in - 4.949\, in| = 0.221\, in \rightarrow 5.6148\, mm$$

$$k = 27.09522\, N \div 5.6148\, mm = 4825.65\, N/m$$

The motion of the system can be described by the second order differential equation $mx'' + cx' + kx = F(t)$, where m is ¼ the mass of the ATV, as there are 4 shock absorbers in

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[3]: $\Delta P = Q\pi d^4/8\mu_{oil}L_{hole}$ & $Q = A_{piston}\dot{x}/\#_{holes}$

it, c is the damping coefficient, k is the spring constant, and F(t) is the external input force acting on the shock absorber caused by the vehicle moving over unsmooth terrain.

One way of modeling this is by creating a state space model. This model has two state variables, the spring's compression (x) and how fast the system is changing (x'). The input variable is the forcing function (F(t)), and the output is the position, as shock absorbers use a changing position to minimize the effects of the applied force on the vehicle. The state space is shown below. For simplicity, numerical values are not shown.

$$\mathbf{x} = \begin{bmatrix} x \\ x' \end{bmatrix}$$

$$\mathbf{u} = [F(t)]$$

$$\mathbf{x}' = \begin{bmatrix} x' \\ x'' \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -k/m & -c/m \end{bmatrix} \begin{bmatrix} x \\ x' \end{bmatrix} + \begin{bmatrix} 0 \\ 1/m \end{bmatrix} [F(t)]$$

$$\mathbf{y} = [x] = [1 \;\; 0] \begin{bmatrix} x \\ x' \end{bmatrix} + [0][F(t)]$$

Another way of modeling this system is through the use of a transfer function. Staring back at the ODE that models the system as a spring-mass damper, we can rearrange and plug in our values for k, c, and m ($m = m_{RC\ car}/4 \sim 11kg$[4]$/4 = 2.75$ kg), as well as model F(t) as the shock absorber's reaction to the road to get this:

$$2.75x'' + 245.7x' + 4825.65x = 245.7y' + 4825.65y$$

From here, we can derive this transfer function:

[4]Mass of the RC Car our shock absorber is apart of is roughly 11 Kg. Given there are 4 in one car we assumed $M_{car}/4$ was an appropriate way to model the mass in this system.

$$G(s) = \text{input/output} = (245.5s + 4825.65)/(2.75s^2 + 245.7s + 4825.65)$$

And this normalized version:

$$(89.345s + 1754.782)/(s^2 + 89.345s + 1754.782)$$

This allows us to easily calculate the natural frequency, damping ratio, and poles of the system, which will all give us key insight into how our shock absorber reacts to uneven terrain.

$$\omega_n = \text{sqrt}(1754.782) = 41.89 \text{ rad/s}$$

$$\zeta = 89.345/2\omega_n = 89.345/2(41.89) = 1.07$$

$$S_{1,2} = -\omega_n(\zeta +/- \text{sqrt}(\zeta^2 - 1))$$

$$S_1 = -60.74$$

$$S_2 = -28.9$$

$$\tau = 1/S_{slow} = 1/|-28.9| = .0346 \text{ seconds}$$

$$T_{settle} \sim 4\tau = .14 \text{ seconds}$$

This tells us that the system is stable and slightly overdamped, meaning that as the shock absorber experiences a disturbance, it returns to equilibrium with no oscillatory behavior. Meaning that after driving over bumps in the road, the RC car doesn't bounce around in response; it simply settles. The poles confirm this behavior. Both are real and negative and demonstrate quick exponential decay, indicating a fast system response time with T_s = .14s in the slowest decay mode, meaning that the car settles after disturbances within a fraction of a second!

REFERENCES

- **Finding Pressure Drop Across Cylindrical Tube Filled With Fluid**

  https://en.wikipedia.org/wiki/Hagen%E2%80%93Poiseuille_equation

- **Shock Oil Viscosity**

  https://www.absolutehobbyz.com/best-shock-oil-for-rc-cars.html?srsltid=AfmBOopVXLPzrr3lO9KK-yn5Tyje0y39MIozg26oCggDKQHNxprlOy0u

- **RC Car Mass**

  https://www.arrma-rc.com/en/product/1-8-kraton-6s-4x4-rtr-brushless-speed-truck/ARA8608V5.html