OVERVIEW

This semester I designed the Diff Cylinder for OD13. The diff cylinder is used in conjunction with the cutting brakes as a separator between the differential and the axle shaft. Its purpose is to ensure that the cutting brakes don't grind and/or destroy the gears in the differential. This year the primary focus was to transfer the cutting brakes from being lever actuated to being paddle actuated. The first 90% of the semester was dedicated to designing a diff cylinder that would be attached to the steering column. A last-minute decision was made to return to the lever actuated diff cylinder because we were unsure whether the paddle system would work. More research was needed and we were under time pressure. This decision was made with the intention of returning to the design of the paddle actuated diff cylinder next semester after building the lever system which we know is functional. Another design that was considered was a mechanical cable system rather than a hydraulic system. This would have eliminated bleeding and leaking issues that are usually prevalent in the brake system. Ultimately this idea was postponed due to time constraints, but will also be taken into consideration next semester or next year.

PADDLE SYSTEM

This year the team decided to focus our attention on performance improvements rather than weight reduction. Part of this new approach was a paddle actuated cutting brake system which would allow the driver to use the cutting brakes without having to remove his/her hands from the steering wheel. This would improve handling, especially in the maneuverability event where there are sharp hairpin turns. Moving the cutting brake system to the steering column would also encourage the driver to use them more frequently with ease during the endurance event and other events where they would be useful. This would also boost our design score significantly. As of now, the paddle system should be our focus for future models, so this report will go into more detail on the paddle design rather than the current lever design.

FIGURE 1-PADDLE ACTUATED CUTTING BRAKE SYSTEM

The diff cylinder is mounted to the top of the steering column on the opposite side of the cutting brakes. This is to ensure that the diff cylinder is actuated simultaneously with the cutting brakes. This is crucial: if the diff cylinder unlocks the diff too late, then the cutting brakes will grind the gears. If it is too early, then there will be some slippage before the calipers actuate. Tuning can be difficult because the diff cylinder and the cutting brakes displace different amounts of fluid. To reduce compatibility complications, we decided on an angle (22 degrees) that the paddle would rotate, and based our design off that.

DESIGN CONSIDERATIONS

PUSH ROD HEAD

One of the challenges I was presented with was making the diff cylinder function independent of the direction in which the paddle rotates. On the cutting brake side, pulling the paddle with your left hand would activate the left caliper, and vice-versa. I designed a push rod with a wide head (blue part in figure 2) that can displace fluid by applying a force on its corner.

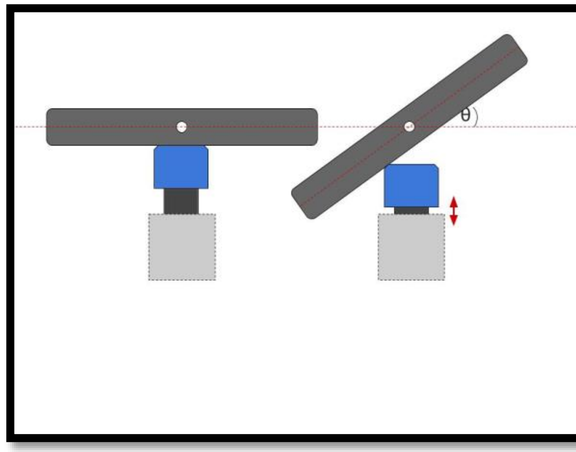


FIGURE 2-PADDLE ACTUATED DIFF CYLINDER DEMONSTRATION

LEVER DESIGN

I found an interesting relationship between the fluid displacement, force, and width of the push rod head. By increasing the cross-sectional area of the diff cylinder housing, you decrease the amount of travel needed to displace the right amount of fluid: $\Delta V = (displacement)(Area)$. If you decrease the displacement, you also decrease the width of the push rod head: $displacement = (width)\sin\theta$. Therefore, we are left with an inverse relationship between the cross-sectional area and the push rod head width. Initially I was concerned that increasing the cross-sectional area would increase the force required to actuate the diff cylinder: $P = \frac{F}{A}$. The inverse relationship between Area and width allows to say: $P \propto Fw$ where 'w' is the width. As the width decreases, the force on the pushrod increases due to the moment from the driver pulling on the lever (or paddle). This relationship allows us to consider the stress on the pushrod and the weight of the diff cylinder independently of the moment and force on the pushrod. I optimized the design to reduce the moment on the push rod head which will reduce the stress at the junctions. I initially went for a cylinder with a 1.5-inch boar, which is much larger than any other piston assembly in the brakes system. This was to reduce the moment in the head. We also have an inverse relationship between the cross-sectional area of the diff cylinder housing and its height. This is important for weight considerations. After running the design through Ansys I reduced the boar size to 1.25-inches which simultaneously made the piece lighter.

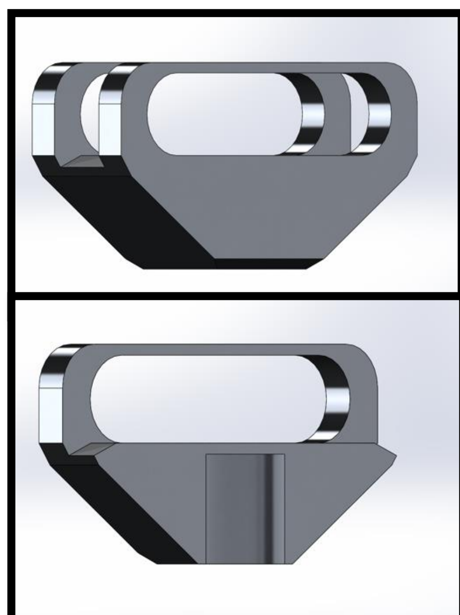


FIGURE 3-OPTIMIZED PUSHROD HEAD + CROSS SECTION CUT

INTERNALS

The internal grooves and reservoir port in the diff housing prevent back pressure from building up in the cylinder. I positioned two holes at the reservoir port so that external fluid from the reservoir can access both chambers in front and behind the piston without disrupting the fluid displacement needed to unlock the diff. The reservoir nipple is press fit onto the housing. The circular channel in the housing shown in the bottom image of figure 4 allows the fluid to flow past the piston and into the back chamber. This design also includes a groove in the piston (not shown) that allows fluid to flow past the piston. The reservoir port is then connected to an external fluid reservoir that is positioned above the cylinder. In the paddle system, the diff cylinder is on top of the steering column with the reservoir on the steering wheel. This was to prevent air from entering the system which would occur if the reservoir were upside down.

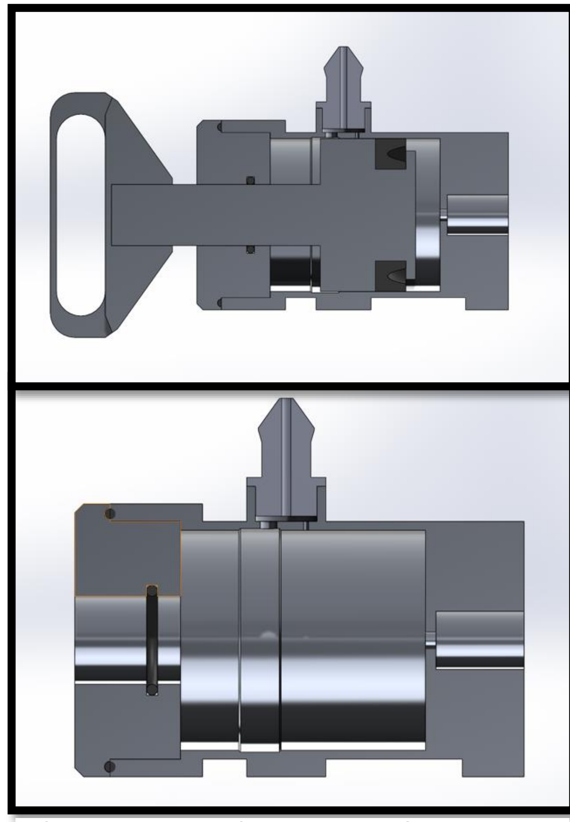


FIGURE 4-LEVER MOUNTED DIFF CYLINDER CROSS SECTION

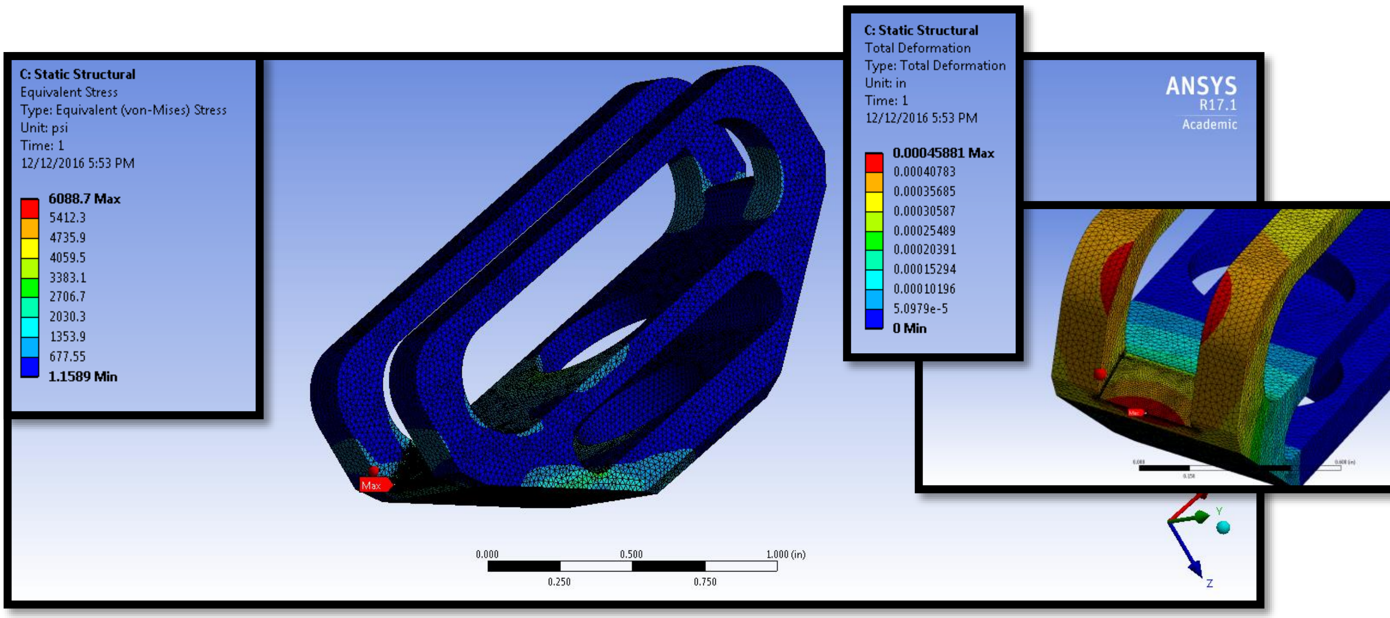
As can be seen, this system presents room for error. After designing the diff cylinder, I considered the idea of making the pushrod as wide as the cylinder boar (1.25-inches), which would eliminate the backpressure caused in my current design. This would add some weight, but this added weight would replace space that would otherwise be occupied by DOT-4 fluid which is roughly half as heavy. Due to time constraints, I didn't explore that idea further, but I encourage the consideration of this idea in future designs. Since the diff cylinder displaces so little fluid (~0.5in^3), the added weight would be a minor drawback compared to the great simplification in design.

Furthermore, I reduced potential leakage by adding a crush O-ring between the cylinder cap and the housing. The cap is now aluminum instead of delrin, which it was last year. This is to account for the perpendicular force applied by the lever that didn't exist on last year's model.

ANSYS

My main concern was that the perpendicular force applied by the rotating lever could cause deflections in the cap and housing that would introduce leakages. I ran both components through Ansys to ensure that the deflections weren't severe enough. I also ran the push rod head through the same analysis.

Push Rod Head



Supports:

  Fixed support on bottom face of pushrod.

  Cylindrical supports where the piston and cap are positioned

Load

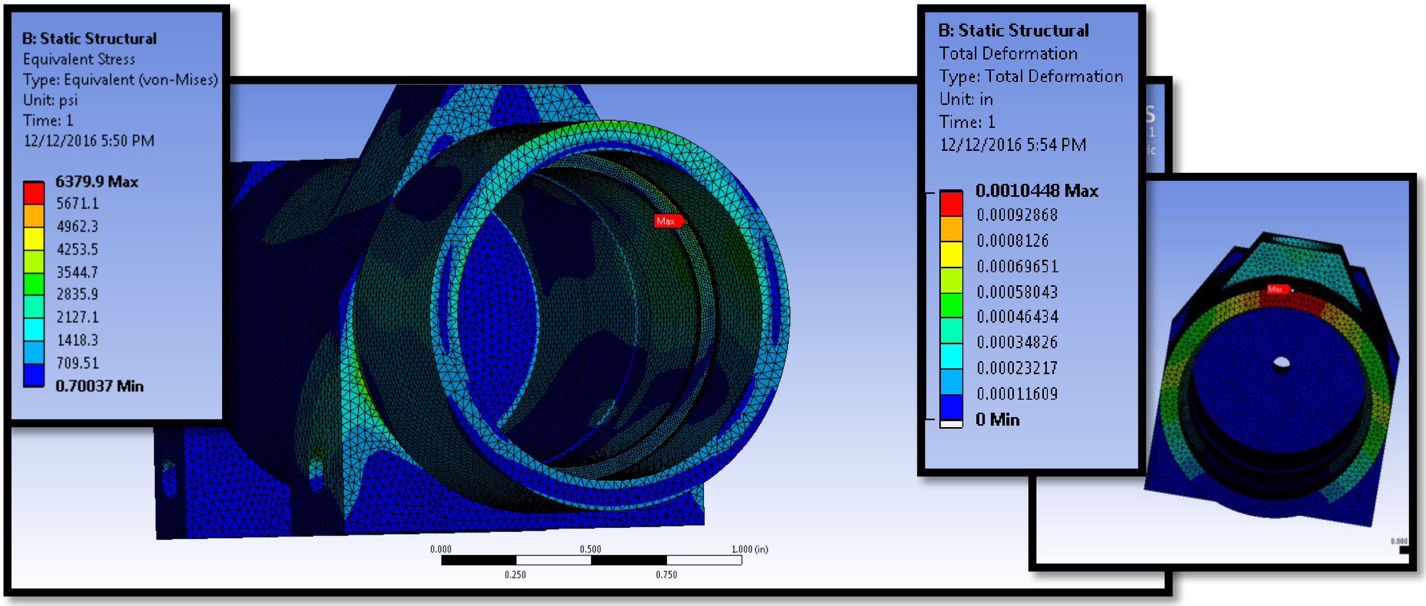
  Load is applied on the corner of the pushrod head

  I added a 50lb load in the z direction due to vibrations in lever

Contacts

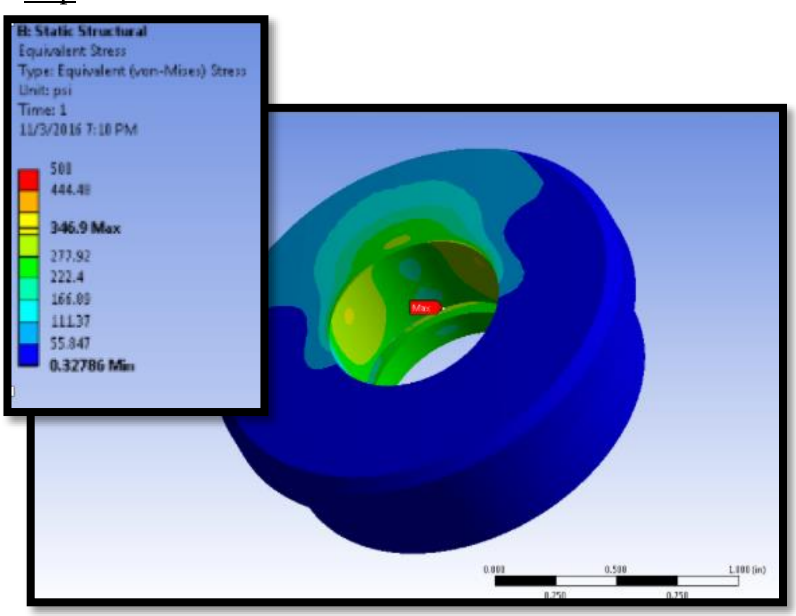
  Threading is bonded

Diff Housing



Supports:
Fixed support on bottom face (where floor bar is)
Cylindrical supports at tab holes
Load
Bearing Load applied horizontally where the cap is
Contacts
Threading is bonded

Cap



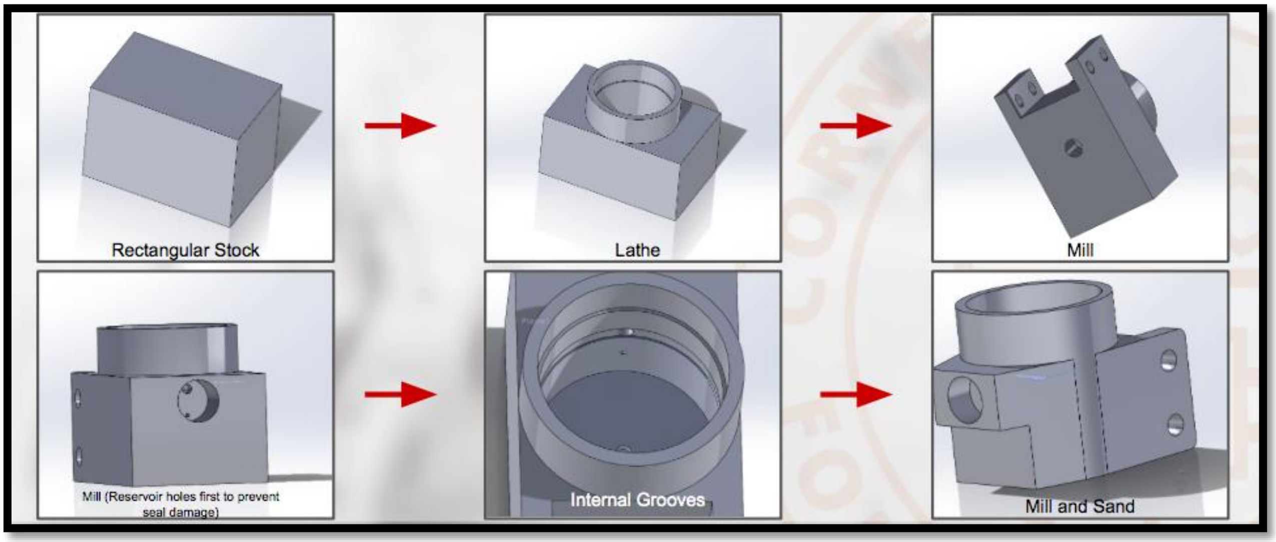
Supports:
Cylindrical supports at threading
Load
Bearing Load applied horizontally on the inner cylinder.
Contacts
Threading is bonded

--The deflection is insignificant.

FABRICATION

Diff Housing-

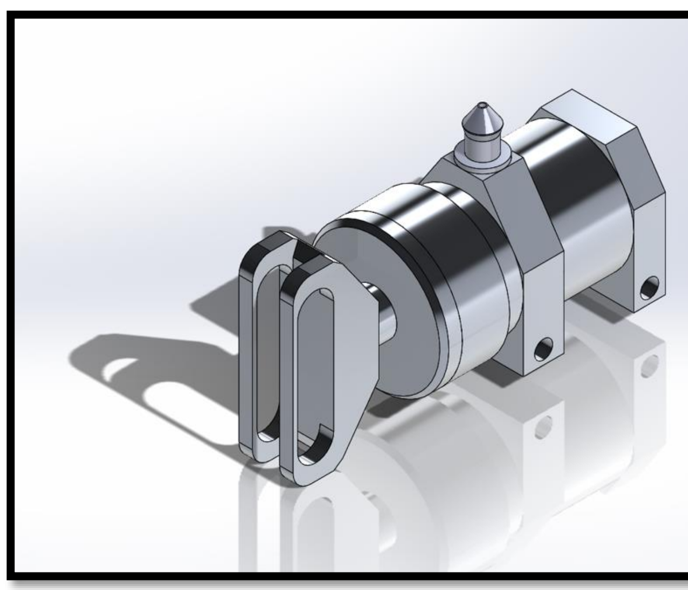
The diff housing will begin as a rectangular AL6061 block and will be made primarily using the Lathe and the Mill. The 1.25-inch boar will be centered in the aluminum block and the internals will be carved using the lathe. The figure below shows the machining process for the 1.5-inch boar paddle actuated diff cylinder that I presented during FDR. The new housing is a bit different, but the machining operations are the same.



The internals are easy to manufacture using the lathe. The push rod head can be made using basic mill operations and a sanding belt.

REFLECTION

The figure to the right is the current diff cylinder. It is designed to function on both the lever and paddle system in case we change to the paddle based system. The new diff cylinder is smaller, lighter, easier to manufacture, and should do a better job preventing fluid from leaking. Because the cutting brakes system is still new to Cornell Baja, I could be very innovative with how I approached my design. We even considered a replacing the hydraulic system with a lighter cable system for a while. This is an idea that is worth investigating in the future. It would eliminate the need for a diff cylinder and leakages.



Throughout the semester the diff cylinder went through many different revisions, so I spent a lot of time in the computer lab revising my part. This improved my ability with Solidworks and Ansys, to the point where I am comfortable using both programs to design and analyze complicated parts. This constant revision was due to the many components involved in the cutting brakes. Kyle, Mark, and I met several times to discuss how we would integrate all our parts. Every time someone changed a dimension, someone else might have had to change something in their part to avoid integration issues. This semester my part is a lot more involved which has greatly improved my engineering skills.