

2018 MET Basic Utility Vehicle (BUV) - Senior Design Project

Brake System

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science

University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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April 2018

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Abstract

The BUV competition was founded in 2000 by a man named Will Austin from the Institute of Affordable Transportation (IAT). He sought to create a competition where students would compete to make the best design of a vehicle to transport large sums of water in areas where water is not easily accessible. The idea is to design a lightweight, affordable, and durable vehicle that can be used to transport water in third-world countries. The competition has requirements for the vehicles, set out by the IAT, so that everyone is operating on a level playing field. I, as well as four others, chose to take on this task of designing this vehicle for our Senior Project.

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Introduction

Problem Statement

This vehicle is to be designed for a specific group of people so for this application it was very important to keep the end user in mind throughout the design process. The people who would be using this vehicle would not have access to complex tools or mechanics to do a repairs for them so the design needed to be simple to fix if something were to brake as well as durable enough to function properly in the off-road conditions it would be performing in. Throughout our design we will be focusing on keeping the vehicle lightweight, affordable, durable, and easy to fix and operate.

Responsibilities

There are five main parts of the vehicle that need to work together to get the vehicle to function properly. Those different areas include the irrigation system, chassis and frame, front suspension, drive train, and the brake system. Within our group the areas were split up as follows:

- Irrigation System – El Hassane Kamagate
- Chassis and Frame – Paul Kowall
- Front Suspension – Chris Saranita
- Drive Train – Cole Rardon
- Brake System – Brad Sackett (me)

Research and Background

Requirements

The requirements and specifications set out from the IAT for the brake system, in no particular order, are:

1. Dual or more brake system.
2. Brakes must lock at the wheel, not the drive line.
3. With three wheel vehicle, a front brake is not required.
4. Parking brake is not considered a redundancy.
5. Hydraulic systems may use reverse for brakes.

After talking with the instructor for the BUV team (Dave Conrad) and reading past BUV reports there were a few key points that I concluded. The designs that worked the best in the past used flexible hose for the rear connection along the axle because of the compression of the rear axle that happens when the vehicle is loaded. They successful designs also had flex eye joints that were used for the connection from the pedal to the master cylinders. This can help greatly because when using a flex joint this allows the threaded bolt that extrudes from the master cylinders to always be compressing the cylinder perfectly straight as the pedal is moved down.

Previous Designs Researched:

Figure 1: 2017 UC BUV Club



This year's team decided to do a dual brake system with floor mounted cylinders. I did not like the floor mounted design because I thought it took too much space that could be utilized for other drive train mechanisms.

Figure 2: 2014 UC BUV Club



The team who designed this brake system only has one brake pedal which does not allow for the dual brake system to really be utilized to its full potential. If the pedal fails there is not back up to prevent from a serious problem. It also doesn't allow for torque turning which can only be done with two brake pedals engaging their respective brakes at different times.

Analysis from Research

After looking at many different designs I knew I wanted to go with a two-pedal system which creates the safest environment as well as can help you get out of the mud if you are stuck with torque turning. Torque turning can also be utilized to turn tighter around sharp turns. I also knew I wanted to

mount the cylinders to the frame directly under the hood of the vehicle to allow for maximum space available in the engine housing.

Design Selection

In my design selection I started with just looking at the basic design between a hydraulic or mechanical system. In a hydraulic system you are using hydraulic cylinders and hoses to put the force on the brake pads so that they create friction on the wheel to stop the vehicle. In a mechanical system you are just using a rigid rod which pulls a spring in puts the force on the brake pads to stop the vehicle.

Basic illustrations of the two systems are shown in Figures 3 and 4.

Figure 3: Hydraulic System

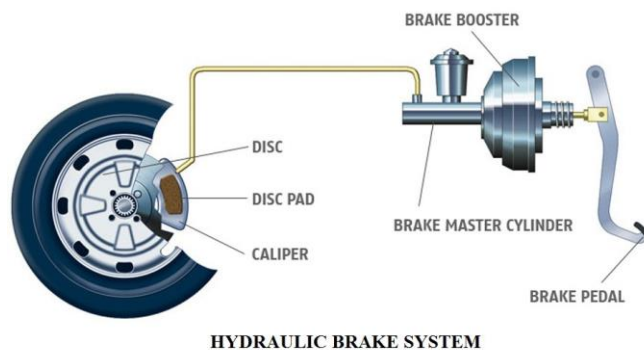
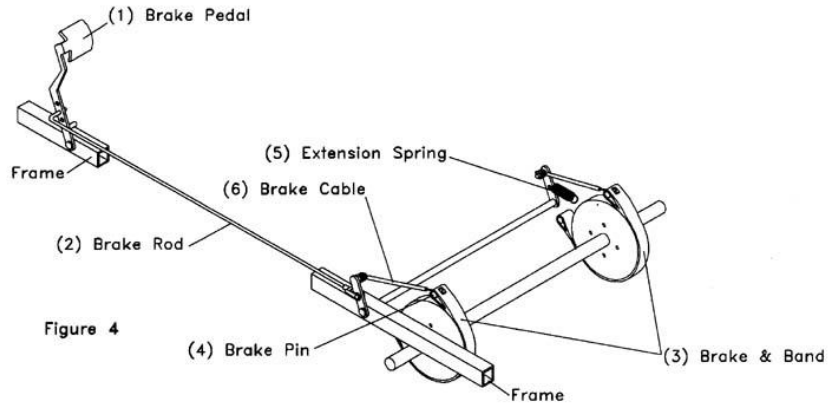


Figure 4: Mechanical System



My analysis between these two systems is shown in the following table.

Table 1:

Brake Selection		Concept Alternatives			
		Hydraulic System		Mechanical System	
Criteria	Importance	Rating	Weighted Rating	Rating	Weighted Rating
	Weight (%)				
Brake Efficiency	20	4	0.8	1	0.2
High reliability	30	3	0.9	1	0.3
Low maintenance	10	3	0.3	4	0.4
Low cost	25	2	0.5	3	0.75
Light weight	10	2	0.2	3	0.3
Weather resistance	5	4	0.2	2	0.1
Total	100	NA	2.9	NA	2.05
Rating		Value			
Unsatisfactory		0			
Just tolerable		1			
Adequate		2			
Good		3			
Very Good		4			

In this analysis my conclusion was that a hydraulic system will be the best for this application. The main things that factored into this was the much higher stopping power (brake efficiency) and the higher reliability for our application. In the terrain we will be working in there will be a lot of much and that can get caught up in the mechanical system and cause it to fail.

Once I had determined that a hydraulic system would best fit our application I had to select the type of hydraulic system I wanted. There are two main types of system on the market today. Those two systems are a drum brake system and disc brake system. In a drum brake system you have brake pads that push outward on a brake housing that is fixed on the wheel which causes the friction to stop the wheel from rotating. With a disc brake system you are using the pressure from the hydraulics to squeeze two brake pads together onto a rotor that is fixed to the wheel to stop it from rotating. Basic diagrams of these two systems are shown in figures 5 and 6.

Figure 5: Drum Brake System

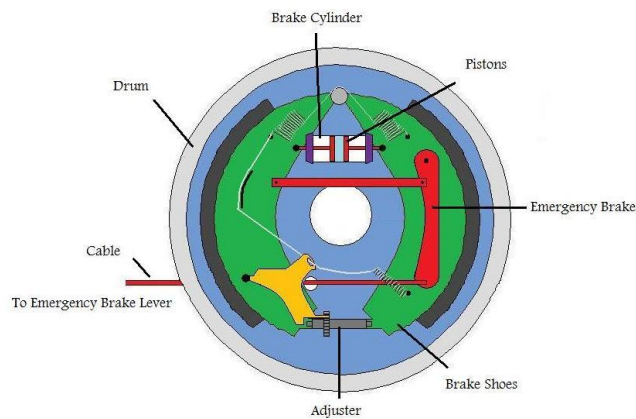
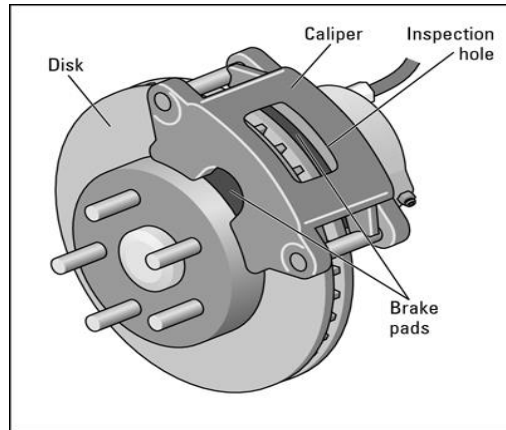


Figure 6: Disc Brake System



My breakdown of how well these two systems would vary in their performance is shown in the table below. The same criteria were considered as well as the importance of each.

Table 2:

Brake Selection		Concept Alternatives			
		Disc Brake		Drum Brake	
Criteria	Importance	Rating	Weighted Rating	Rating	Weighted Rating
	Weight (%)				
high brake efficiency	20	4	0.8	3	0.6
high reliability	30	3	0.9	4	1.2
low maintenance	10	3	0.3	4	0.4
low cost	25	2	0.5	3	0.75
light weight	10	3	0.3	3	0.3
weather resistance	5	3	0.15	2	0.1
Total	100	NA	2.95	NA	3.35
Rating		Value			
Unsatisfactory		0			
Just tolerable		1			
Adequate		2			
Good		3			
Very Good		4			

The conclusion I made here was that a drum brake system would be the better route to go in this case. It had a higher reliability and a lower cost which were the two highest weighted criteria and resulted in it getting a better overall score.

Calculations

To understand how the calculations work it is important to understand how the brake system itself works. To help visualize the flow of the system view the diagram below.

Force on Pedal → Master Brake Cylinder → Hydraulic Pressure from Hose → Brake Cylinder at Wheel → Force Applied to Brake Shoe/Drum

When doing the calculations you can work in the direction of the flow chart if you have a desired pedal ratio. In our case we are going to have to calculate the pedal ratio needed so we will have to work backwards on this flow diagram. In table 3 you can see this given variables (Left) and the calculations (Right) using those given variables that led me to the desired lever ratio of the pedal.

Table 3: Calculations

Given	Calculations
Average Force on Pedal: 150 lbs	Max Brake Force to Lock Wheel = $3000 \text{ lbs} / (2 * 0.5) = 750 \text{ lbs}$
Tire Radius: 13 in	Torque Needed by Drum Brake = $750 \text{ lbs} * 13 \text{ in} = 9750 \text{ in*lbs}$

Shoe Radius: 4.75 in	Force Needed by Brake Cylinder = $9750 \text{ in} \cdot \text{lbs} / (4.75 \cdot 2) = 1026.3 \text{ lbs}$
Bore Area of Brake Cylinder: 0.4417 in ²	Hydraulic Pressure Needed by Brake Cylinder = $1026.3 \text{ lbs} / 0.4417 \text{ in}^2 = 2323.5 \text{ psi}$
Bore Area of Master Cylinder: 0.994 in ²	Force Needed by Master Cylinder = $2323.5 \text{ psi} \cdot 0.994 \text{ in}^2 = 2309.6 \text{ lbs}$
Weight of Vehicle +500 lbs: 3000 lbs	Lever Ratio Needed = $2309.6 \text{ lbs} / 150 \text{ lbs} = 15.4$
Ground Coefficient= 0.5	
Assume no pressure drop between master and brake cylinder	

Fabrication and Assembly

The basic assembly of a brake system can be separated into three parts. There is the pedal assembly which will be attached to the master cylinders, the brake line assembly which connects the master cylinder to the brake cylinder, and the drum brake assembly which is the connection between the brake cylinders to the wheel and stops the vehicle.

The Chevrolet S10 frame that we obtained fortunately already had a drum brake system in place. After looking over the parts they looked to be in good condition and after testing later we concluded that all of the parts of that assembly will still be useable. Because of this it was not needed for me to assemble anything on the drum brake system so I will not be reporting on that.

Pedal Assembly

The pedal assembly consists of two square plates welded to ½” square tubing with holes drilled in the sides of the tubing to create a slot for the flex eye joint that connects to the master cylinders.

There are also two lock nuts on the ends of the threaded rod that protrudes from the master cylinders to prevent the pedal from slipping back and coming unhooked. The lock nuts can also be threaded off too allow for the pedals to be lifted up which makes it easier to work behind the whole system. This overall design worked very well because it did not clog up the engine housing with the brakes and allowed a lot of room for other things such as our battery, inverter, all the wiring, and our switch plate.

A picture of the pedal assembly can be seen in figure 7.

Figure 7: Brake Pedal Assembly



Brake Line Assembly

For the brake line assembly my main goal was to keep it out of the way of everything so that the hoses would not be hit and potentially damage or break. This also allowed for maximum space for other components. For this system it started with two Wilwood 3/4" Diameter Bore Master Cylinders. These

cylinder were recommended many times in the past. These were mounted to holes in the top of the engine housing with bolts so they would not come loose. The brake lines coming from the master cylinders are 3/8" which were connected to the master cylinder with a 1/8" to 3/8" pipe fitting. They run out the back of the cylinders and immediately to the left edge of the engine housing and down to the frame itself. (See in Figure 8)

Figure 8: Master Cylinders and brake lines.



From here they run along the frame and clipped in until they are connected to the flexible brake hose that runs to the rear axle. The flexible hose is then run to a hydraulic plug which serves a junction point for the flexible hoses to then connect to hard brake lines and the run to their respective drum brake systems. This junction can be seen in Figure 9.

Figure 9: Flexible brake hose junction with rigid brake lines.



Testing Method

For testing my system there were two things I needed to make sure worked correctly. The first test is to check whether the system is sealed and there are no leaks anywhere in the system. For this test all that we need to do is to push the pedal down hard for 15-20 seconds and make sure we don't feel any pressure loss in the system. If you push down at first and then it feels as if it is getting easier and easier to push then you have a leak somewhere in the system.

The second test makes sure that the whole system was going to hold up to my calculations and actually stop the vehicle. For this test we rolled the car at very minimal speed and hit the brakes and at

this point the car should stop immediately. We then went upped the speed in small increments to make sure the car would stop at a decent rate as the speed increased. We started slow then increased by increments of 5 mph until we hit max speed.

The brake system performed very well in both of these tests and I determined the brake system was sound and competition ready.

Overall Results

Unfortunately we were not able to compete in the competition this year. We ran into a huge road block in the beginning of the semester when trying to obtain the Chevy S10 frame that we were looking for. This road block set us back many weeks and we were not able to finish every part of the vehicle before the competition date. We did get everything functioning eventually and the vehicle seemed to perform very well.

Conclusion

Even though we did not get to compete in the competition I still think the project was a success overall. We accomplished our goal as a team to get all of the different parts working together and the vehicle to run effectively. We met the requirements set out by the IAT and if we would have been able to compete I think our vehicle would have done well.

For future vehicles I would suggest using a brake system design similar to the one I used. It was effective in meeting its requirements and it maximized accessibility and was a compact design which allowed maximum space for other components.

As a team, if we could go back to the beginning we would definitely do some things differently though. Some suggestions I have for future vehicles would be to start your fabrication as early as possible

because time gets tight towards the end of the semester. Also some components were given to us from past years vehicles but it is very important to double check that all of those parts are still available. We were originally under the impression that we had a frame to use and it turned out we didn't which set us back dramatically. The last thing I would say is that it is very important to get as much prior knowledge of this project before you jump into it. Go to tech expos and check out previous vehicles, look at previous reports, and talk with everyone and anyone who you think could be of help to you.

Supplementary Information

Figure 10: QFD

Bill of materials	November 11 th 2017	November 11 th 2017
Detailed design	November 16 th 2017	November 16 th 2017
Completed design in CAD	December 30 th 2017	December 30 th 2017
Layout scheduling for manufacturing	January 1 st 2018	January 1 st 2018
Presentation Proposal	January 26 nd 2018	January 26 nd 2018
Order parts	January 31 th 2018	March 7 th 2018
Design modifications/manufacturing	February 1 st - 26 th 2018	March 8 th 2018
Start Testing	March 1 st 2018	April 10 th 2018
Spring break	March 12 th -18 th 2018	March 12 th -18 th 2018
Testing modifications	April 1 st 2018	April 18 th 2018
Final test	April 15 th 2018	April 22 nd 2018
Competition / Final Presentation	April 20 nd 2018	

Figure 12: Proposed vs. Actual Budget

BUV Section	Estimated Cost	Estimated Cost
Chassis	\$1,060.00	\$310.00
Braking system	\$360.00	\$130.00
Irrigation	\$160.00	\$300.00
Steering/Suspension	\$460.00	\$85.00
Drive Train	\$560.00	\$210.00
Total Cost	\$2,600.00	\$1,035.00

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