WIKI

Drivetrain Department

Summary

1 - Rules 2
- 1.1 Fasteners 2

2- The Drive Axle 2
- 2.1 Types 2
- 2.2 Fixed Axle 2
- 2.3 Half Shaft Axle 2

3- Constant Velocity (CV) Joints 4
- 3.1 Purpose 4
- 3.2 Tripod Joints 4
- 3.3 Rzeppa Joints 5
- 3.4 Boots 6
- 3.5 Lubricants/Grease 6
- 3.6 Parts Lists & Catalogues 6

4- Spool and Differential 6
- 4.1 What is a Spool? 6

5- Bearings 8
- 5.1 What are bearings? 8
- 5.2 Bearing Selection 8

6- Sprockets 9

7- Drive Calculations 10

8- Gear Changing Systems 11
- 8.1 Purpose 11
- 8.2 Mechanical 11
- 8.3 Pneumatic 11
- 8.4 Electronic 12

9- Chain Tensioners 12
- 9.1 Purpose 12
- 9.2 Automatic Solutions 12
- 9.3 Manual Solutions

10- Brake mounts 13
10.1 Current Design 13
10.2 Brake Disc 13
10.3 Brake Calliper
11 - TLDR Resources 14
11.1 Research Papers 14

1 - Rules

1.1 Fasteners

See the paper written by Justin Lebowsky, he covers the drivetrain rules in great detail at the start of his paper.

2- The Drive Axle

2.1 Types

The axle which is being directly driven by a chain (or driveshaft) in a vehicle is the drive axle. This is the axle which allows the vehicle to move. There are two main types of axle:

- Fixed axle
- Spool/Differential axle

2.2 Fixed Axle

A fixed axle is essentially what it sounds like, a solid bar that connects both wheels together. The wheels operate as one unit, meaning that if one side of the axle is raised or lowered (e.g. going over a bump), the other side will also feel this effect, This also means that the wheels also turn at the same rate. This is further explained in the Differential section of this document,

Fixed axles are only really used in go-karts and other low power vehicles due to the poor handling and understeer.

2.3 Half Shaft Axle

An alternative, and more common set up is to divide the axle into multiple parts. When a Spool or Differential is used (See section XXXX), half shafts are needed to connect the wheels to the central Spool/Differential. Half shafts are usually hollow steel tubes but other materials are also used. The half shafts are usually splined at each end to allow for CV joints (See section 3).

Depending on the setup, the half shafts may be either bought or made, Many vehicles use half shafts so there are many available to purchase. The difficulty is that these are specifically sized for the vehicle they come from. Datasheets for these parts are also difficult to find. This means that unless you know the exact dimension or already own the half shaft, designing for pre existing ones can be difficult. Compatibility with different joint types will also depend on what is available for that halfshaft.

The other option is to design one from scratch. This allows for greater flexibility since you can decide the length and diameter. In order to assure that the shafts will work as intended, simple calculations are required.

The most important stress to consider is the torsional load on the shaft. In order to calculate this you can assume the shaft to be a hollow cylinder, fixed at one end with a torque applied at the other. This could be imagined as the car starting from rest, the chain pulls on the axle causing the torque but the other side of the shaft is fixed because of the friction between the wheel and the ground. This causes the shaft to twist. The shear stress experience must not exceed the torsional yield strength of the material. It can be

2.4 Mounting Mechanisms

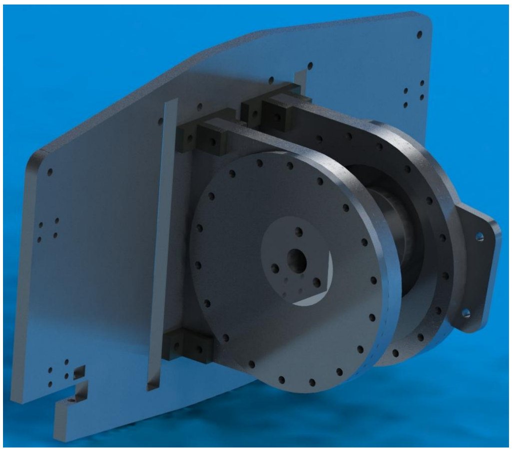
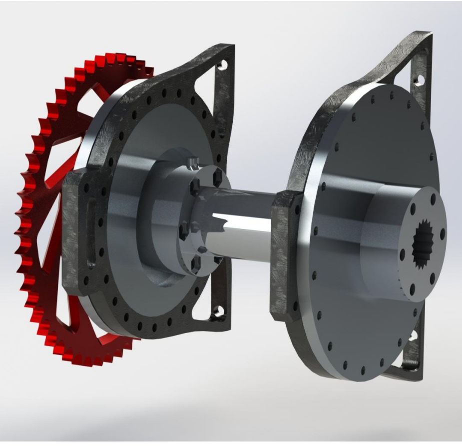
Fig.1: 

Fig.2: 

The rear spool, the heart of the rear axle, is attached to the backplate of the chassis through chassis mounts as shown above. These mounts are either attached to the plate in 2 parts (fig.1) or as a single piece (fig.2). When in two parts, female clevises are used to secure the axle mounts to the backplate. In this scenario the bolts securing the mounts are in double shear. When a one part mount is used, there is the benefit of cheaper production and a lower part count. However, in this case, the bolt is in single shear, which is less preferable to double shear, but the forces present should not make this an issue if the bottles are sufficiently strong.

The rear mounts are either mounted to the axle directly, sitting on bearings, or indirectly through a chain tensioning system called the eccentric. We can mount the axle directly if we are using a chain tensioning system that is not an eccentric system. For more information on eccentrics and chain tensioning systems, refer to (insert eccentric wiki link here).

As well as the mounts, a cage (an example is pictured below) can be added to the system here to provide more rigidity to the mounts. This reduces the lateral forces on the bolts to the rear plate and eccentrics, as well as improving the overall rigidness of the rear axle. The possibility of using a cage will depend on the location of the sprocket and brake disc, whether they are inside or outside the mounts. This should be taken into consideration when designing a cage.

3- Constant Velocity (CV) Joints

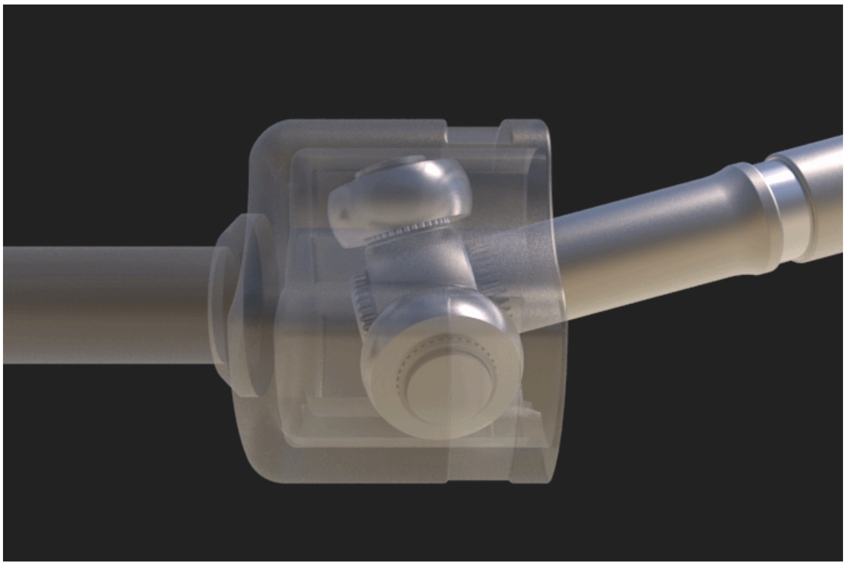
3.1 Purpose

The main purpose of a constant velocity joint is to allow for slight variations in the angle of a rotating axle. When a wheel of a vehicle moves over a bump or dip, a fixed axle would tend to tilt to one side. The suspension of the vehicle will try to keep the ride smooth. CV joints will allow portions of the axle to move up and down with the suspension while still transferring rotational movement to the wheels. There are a variety of different CV joints, each with their own pros and cons.

The link below is to a short video showing full disassembly of both a Tripod Joint and a Rzeppa Joint as seen on most cars. - https://youtu.be/auQ65qno2Eo

Here is a link to an article by Pat Clarke explaining why one doesn't use universal joints.

3.2 Tripod Joints



Tripod joints are three pointed metal joints. Each of the three points has a cylindrical portion that can rotate. Many cars implement tripods in their driven axles for a number of reasons.

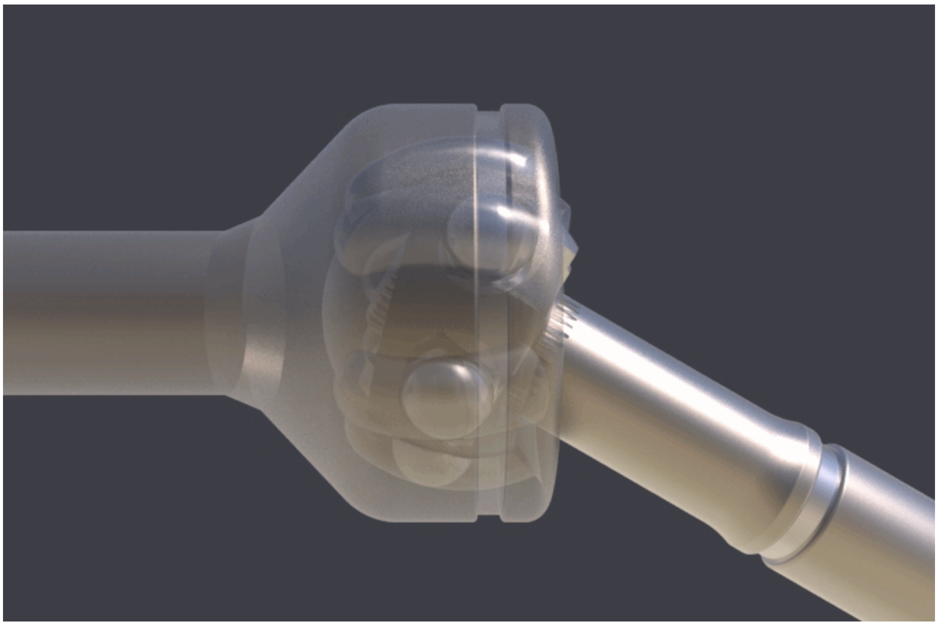
Firstly, it is usually the simplest and cheapest to implement. This is because a tripod joint only has 3 main parts; A driving axle, the tripod unit, and the tripod housing (or hub). The axle will usually have splined teeth on which the tripod unit sits.

There are also many different types of tripods with different shapes and sizes to suit different setups.

There are mechanical losses when using a tripod setup. This is due to the fact that the cylindrical wheels of the tripod need to slide within the housing to support different angles. This can lead to frictional losses. However due to the large contact area between the tripod and housing, the efficiency of this joint is quite high.

A downside of a tripod joint is the angles at which it can operate. Tripod joints cannot operate at very large angles, roughly at most 26 degrees, at least when compared to other CV joints such as Rzeppa joints. For this reason they are often used as inboard joints at the differential/spool, where the transmission angle would be lower.

3.3 Rzeppa Joints



*Note this looks like a “Cross Grove” CV Joint

Rzeppa joints are another common type of CV joint, commonly referred to as just CV Joints. These are essentially made up of ball bearings pushing against groves to allow rotation.

The efficiency of these joints are lower compared to tripod joints due to the smaller contact area between the balls and the grooves.

However the angle of operation is much higher, between 40-55 degrees. For this reason they are often used on the outboard of an axle, at the wheel hubs. The suspension of a vehicle will often allow the wheels to move up and down, but also can also rotate the pitch slightly.

These joints can also be slightly bigger than tripod joints, but that depends on the exact model. The more complex design also means that Rzeppa joints can be more expensive to implement.

3.4 Boots

Boots are rubber covers that go over CV joints to prevent any dirt or debris from getting into the joint during operation. They are usually held in place at both ends with Jubilee Clips. Boots also prevent lubricants needed for the CV joint from spilling out.

3.5 Lubricants/Grease

CV joints need some kind of lubricant to allow for smooth operation of the joint. It is usually a thick grease of some kind. GKN produces grease for tripods and CV joints.

3.6 Parts Lists & Catalogues

Below are links to useful sites to find CV-Joints. The link in brackets is an explainer for the names of CV-Joints on the GKN Automotive site.

https://catalog.febest.eu/en/

https://www.gknautomotive.com/en/AftermarketMotorsport/aftermarket/online-catalogue/

(https://www.gknautomotive.com/en/AftermarketMotorsport/aftermarket/our-products/cv-joints/

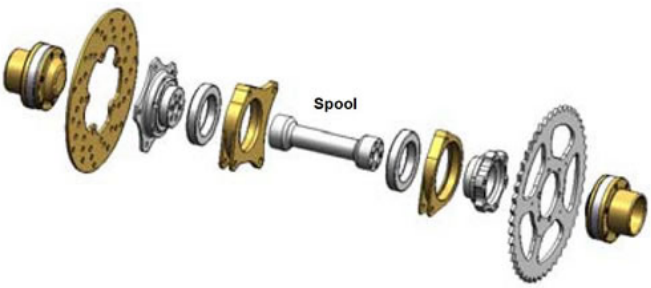
https://twitter.com/gkn_plc/status/943108510702764032

https://www.vsm.skf.com/int/en/search-parts?market=eu&vhits=12&phits=10&l=en

4- Spool and Differential

4.1 What is a Spool?

It is a locked differential. This essentially makes one solid, fixed axle between both drive wheels. Thus, equal power goes to both wheels and they rotate at the same rate.



4.2 Spool: Pros and Cons

Pros

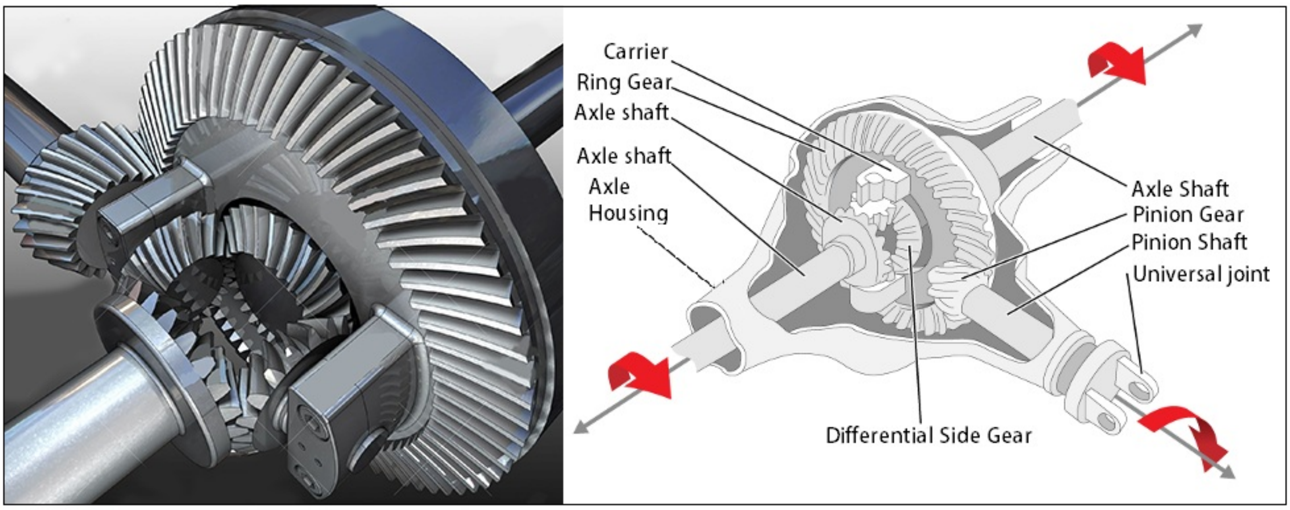
- The spool is easier to service, with less parts to go wrong
- The spool is cheap, since it consists of a lot less parts than the differential, this leads to less R&D time, less production time and easier production as well. In both time and money, the spool is more efficient.
- It is also lighter (under 1kg); the spool is a simple mechanism connected straight to the driveshaft. This means there is very little weight added to the car, so little that it is almost negligible.
- Can be made in-house if needed
- Cost of buying a spool? Don't, there's no point. It's too easy to make.

Cons

- The spool mechanism does not allow for differing rotational speeds of the wheels when cornering. This can lead to understeer. But if a corner is entered correctly by the driver this can be minimised. The head design judge also said that for starting teams, this is a worthwhile payoff if the funds cannot be secured.
- The spool also does not allow torque transfer between wheels. This is more minor than the other con, but still comes into effect depending on the weather on the day.
- Can cause damage to the driveshaft on repeated hard use.

4.3 What is a Differential?

Mechanical device that enables both wheels to operate at different rates. Wheels are attached to two different axles, in turn these axles are connected to the diff. Watch this excellent video to explain how this works.



4.4 Differential: Pros and Cons

Pros

- Allows for optimal torque transfer between wheels with differing grip
- Enables wheels to rotate at different rates, greatly increasing the driveability through corners

Cons

- Very expensive, in the region of 2k+ for a simple limited slip differential, which is what most well-funded teams use. An open differential is cheaper, but still expensive and still has the following problem
- The weight of the differential is substantial. It adds a lot of weight for driveability in corners, sacrificing a percentage of straight-line speed. (in region of 7kg)
- Cannot be manufactured in-house, whatever you say. This part needs to be manufactured by a 3rd party, who are looking to profit, so therefore the mark-up will be large.

5- Bearings

5.1 What are bearings?

A mechanical part that allows relative motion between two parts with minimum friction. For further information, see page 564 in “Design of Machine Elements” by VB Bhandari, found on the drive. The function of bearings are:

- Ensures free rotation of axle/shaft
- Supports the axle/shaft and holds it in position
- Takes up the force acting on the axle/shaft and transmits it to the housing/frame

5.2 Bearing Selection

Use the bearing selection excel file found in the drivetrain drive. For further understanding of this selection process, see unit 15.12 on page 573 of “Design of Machine Elements” by VB Bhandari.

6- Sprockets

6.1 What are sprockets?

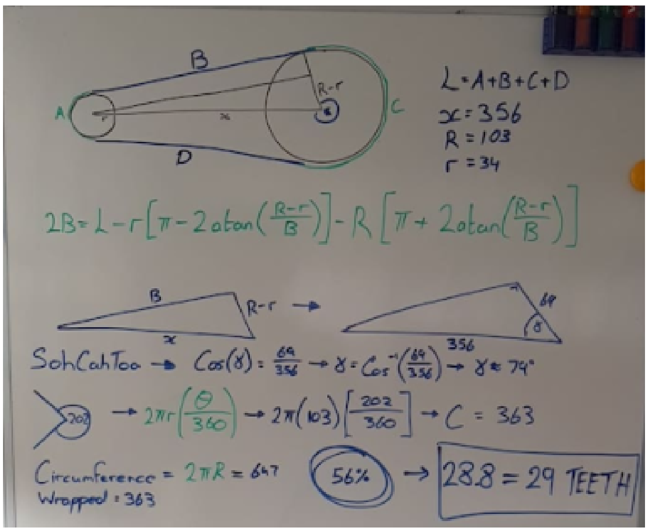
A sprocket or sprocket-wheel is a profiled wheel with teeth, or cogs, that mesh with a chain. By combining sprockets by connections through their teeth or via a chain, different torques are achieved.

6.2 Designing and Drawing a Sprocket

Full instructions into drawing a sprocket can be found in “Designing and Drawing a Sprocket - Gears Education System” PDF in the drive.

6.3 Position of and Force Acting on each tooth

When analysing the effectiveness of a designed sprocket. The force acting on a given tooth is paramount. This can be calculated using matlab. Such a programme has already been coded and can be found as “Force_On_Each_ToothV2.m”.



7- Drive Calculations

7.1 Max Acceleration

The below formula, obtained from a trustworthy yet unfindable source (see David Jones for source), helps obtain the maximum acceleration of the car without the wheels slipping. This means that even if the engine could produce unlimited energy, this as fast as the car will be able to accelerate, as the wheels will slip. An excel spreadsheet has already done the manipulation of this formula and can be found on the drive currently as “Drive Calcs 2020”.

$$\left(mass\ of\ car \times \frac{height\ of\ COM}{wheelbase} \times \frac{a_{max}}{g} + weight\ on\ rear\ wheels\right)\mu g = F = ma_{max}$$

7.2 Max Torque

From estimates of weight distribution around the car, a static reaction force acting on a rear wheel (which will be receiving power) can be calculated. Furthermore, an additional weight transfer dynamic reaction can be calculated from the formula below:

$$Weight\ Transfer\ (N) = \times \frac{Weight\ of\ Car\ x\ Height\ of\ centre\ of\ mass\ x\ co-efficient\ of\ friction\ between\ tyres\ and\ r}{wheelbase}$$

Summing both dynamic and static reaction forces acting on one rear wheel, the maximum force before slipping can be found. Multiply this figure by the radius of the wheels being used, and the maximum torque the car can achieve is found. This is also seen in the excel file mentioned in 7.1.

7.3 Drive Ratio and Sprocket Radius

This is the ratio between the sprocket attached to and being powered by the engine, and the sprocket on the spool of the rear axle giving power to the wheels. This can be any number, but can’t be too precise, so generally a max of one decimal place. The drive ratio augments the actual output of the engine’s torque to the rear axle. However, this augmented torque cannot exceed the previously calculated max torque, with a factor of safety. This drive ratio then informs us how much larger the rear axle sprocket is than the gear on the engine, and how many teeth the rear.

For example, if the engine produces 10Nm of torque, the associate sprocket has 12 teeth and a radius of 0.1m, and the max torque before slipping is 28Nm, suggest an appropriate drive ratio and what would the implications of that figure be on the rear sprocket? Disregarding a safety factor for now a ratio of about 2.5 would be fine, which means max actual torque would be 10x2.5 = 25Nm, and 12x2.5 = 30 teeth and 0.1x2.5 = 0.25m radius to the sprocket.

8- Gear Changing Systems

8.1 Purpose

The aim here is to design a gear shifting mechanism that translates from the motorbike-style gear shifting, i.e. using your foot to push down on a lever which returns to its original position which the engine was designed for to a shifting system that is better suited to a seated driver, i.e. a stick shifter.

8.2 Mechanical

A lever is mounted on the left side of the driver. It's attached to a push-pull cable which runs along the length of the car to the transmission or a fixed four-bar linkage system. Whenever the driver pushes the lever, the cable extends at the shifting spline, causing a downshift. Pulling the lever causes the cable to retract, causing the car to upshift.

Pros	Cons
It's the easiest of the options to manufacture and probably the cheapest. It's a very simple, fully mechanical design.	There are delays in the gear shift because the driver has to take their hand off of the steering wheel and push or pull the lever. This causes problems when frequent and rapid shifting is required. It's also dangerous to be making quick turns with one hand off the steering wheel. Due to the stiffness of the lever and cable, a lot of driver's report being tired due to the difficulty of shifting.

8.3 Pneumatic

Pneumatic shifting utilises compressed air for faster mechanical gear shifts. A double-acting cylinder is connected to the gear lever. Instead of having to take a handoff of the steering wheel, there are two buttons the driver can push to move the gear up or down.

By pressing the buttons, the driver sends a signal to a microcontroller which then sends another signal to the solenoid valve that controls the compressed air flow on either side of the piston.

Pros	Cons
The pneumatic shifting builds on the simple mechanical design and solves the issue of having to take a hand off the steering wheel. The automatic system allows for much faster gear changing.	The compressed air canisters add weight to the car. There is also a limited number of shifts that can be made based on the amount of air available. There is also a big risk of the plastic hose tubing chaffing on the hot metal surfaces causing the system to fail.

8.4 Electronic

Buttons/Steel flexures are attached behind the steering wheel within the reach of the driver's fingers. Rocker-type switches are installed on each side of the button/flexure, so when the latter was pressed, the switch would be activated. The flexures return to the original position after the driver deforms them to change the gear.

The activated switch sends a signal to the ECU. The ECU then determines which shift is actuated depending on the switch that was activated. Current is relayed to the electric solenoid that then actuates the shift.

Pros	Cons
The electronic method is the safest and most efficient out of the three. There is no need to remove one hand from the steering wheel.	A potential con could be the cost, mainly due to the solenoid. Another thing to consider whether this is something feasible for our ECU.

9- Chain Tensioners

9.1 Purpose

During the life of a chain, it's length will increase by about ??2%??, when and if this occurs it means there is slack in your chain meaning the power being sent from the engine is lost. There are two main solutions to this problem, one is to either buy a prestressed (used) chain or to design and manufacture a chain tensioner.

9.2 Automatic Solutions

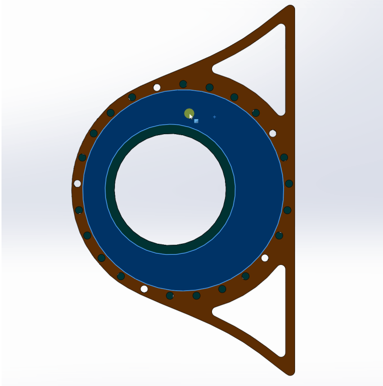
These usually consist of either a small sprocket or a skid/slide mounted to a spring-loaded arm which pushes against the chain to keep it in tension. The spring mechanism can either be a metal spring or a rubber material which is deformed but supplies tension to the chain while trying to undeform.

9.3 Manual Solutions

Here there are two main options: either a small sprocket on a bolt that sits in a slot that can be moved up and down as necessary or an eccentric.

9.4 Eccentrics

The eccentrics partially slide into the drivetrain mounts and then are bolted together will need to have a bearing mounted inside them, which the spool will run through here there are two main options: either a small sprocket on a bolt that sits in a slot that can be moved up and down as necessary or an eccentric.



10- Brake Mounts

10.1 Current Design

2019/2020: Fixed Brake Calliper & Floating Rotor
2020/2021: Fixed Brake Calliper & Floating Rotor

10.2 Brake Disc

For this year's car we have opted for a floating rotor or floating disc design.

The brake rotor (Silver) is designed by Ergonomics only the mount for the rotor (Gold) is designed by drivetrain, also includes the selection of the "buttons" (brake rotor buttons).

10.3 Brake Calliper

If it is decided for an inboard brake calliper then the brake calliper must be mounted to the drivetrain in some fashion. The most noteworthy design element for the designer of this mount is whether or not the team is running an eccentric, if so then it is a must that the brake calliper is mounted to the eccentric in some fashion or can rotate with the eccentric. Also, it is to be noted that the calliper selection is left to Ergonomics so this part must be designed by Drivetrain but in close conjunction with Ergonomics. The choice of a floating caliper would mean the mount would have to be designed in such a way that the caliper can slide along its mounts, whereas a fixed calliper is mounted and can not move this is achieved through the use of a calliper with 2 "Pots" which push from both sides.

(It may, in fact, be possible not to mount the brake calliper to the eccentric but I would not suggest doing this without being able to mechanically and physically test the design as the reduced contact with the brake disk from the calliper will result in reduced braking ability.)

11- TLDR Resources

11.1 Research Papers

Paddle Shifters – Andrew Ajirogi, Ben Aldern, John Odlum & Johnny Chang:

They originally ran a push-pull system but found that too much force was required to change gears and this problem was compounded by the lack of power steering.

~8.8–9Nm was required to move the small bar coming from the engine to be able to shift gears.

They used a solenoid, and switches connected to the ECU, they used something similar to the Kliktronic System but the brand they used was Flat-Shifter.

They did simulations and calculations to find out how flexible their paddles needed to be and that their materials would be able to withstand that bending.

The force required to flex paddle must be less than ~13.5N.

The end of the paper also includes all necessary technical drawings to recreate their parts.

!!!This paper does not discuss the power requirements of such a solenoid and how they did it. !!!

Simplification of the Shift-Clutch Operations for Formula SAE vehicles:

Driving with 2 hands is better than just driving with one.

Paddle shifters are the best-case scenario.

DC motors can be used to shift rather than a solenoid.

Your drivers are armatures so don’t expect much from them.

The lack of power steering means drivers get tired and this then makes a heavy manual shifter more difficult.

The car is already narrow so 3 pedals is too many and will cause drivers to make mistakes.