CMDT3 Suspension Guide

Once the decision had been made to use the rear wheel and swing arm from the motorbike, this meant the suspension for the back wheel was already determined. It was decided to use a double wishbone suspension system for the front of the vehicle.

The design of the front suspension system was a complicated matter, because each design decision affected the other decisions that needed to be made. A rack and pinion was acquired from a scrap yard from a rear wheel drive Ford Sierra. The width of this set a minimum width for the wishbones. For safety reasons we felt it was important to have some of the car frame in front of the drivers feet position to absorb some of the energy in the event of a crash. The plan of the car was designed in AutoCAD before any manufacture began. Figure 1.1 shows the vehicle frame designed in CAD with the driver in position.

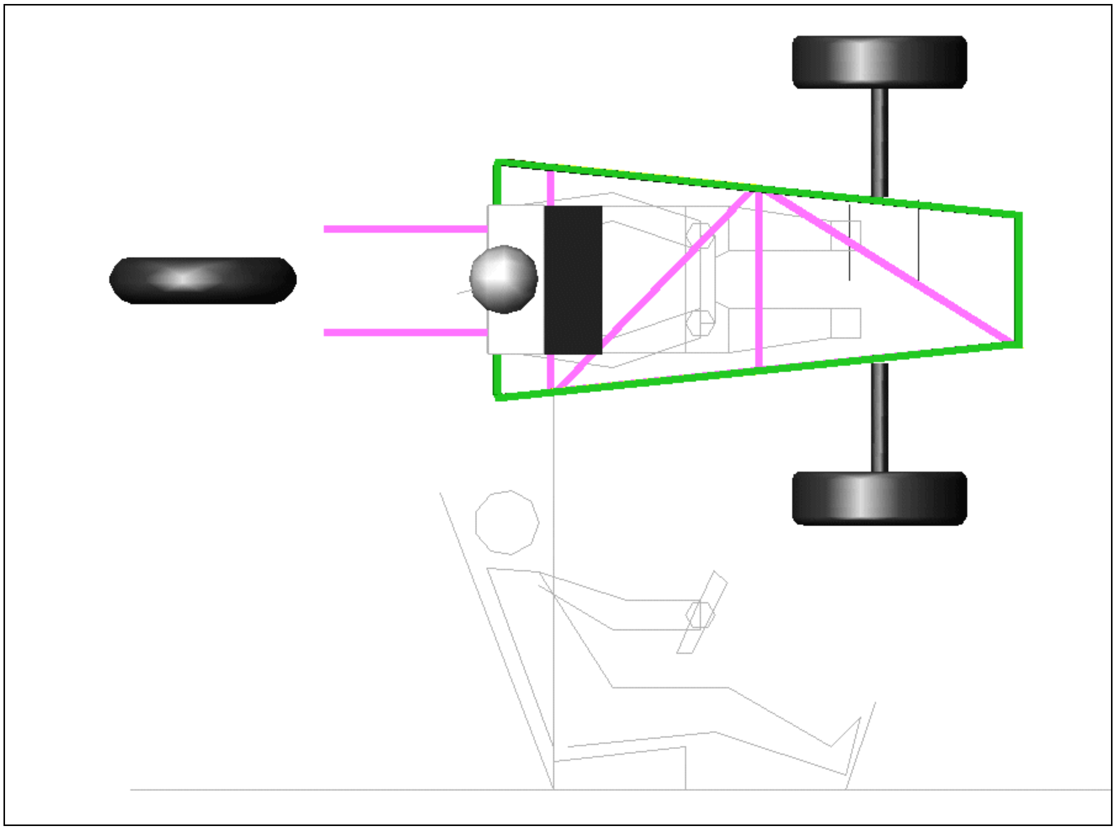


Figure 1.1 – Frame Design

The width of the bottom wishbones at the point of joining with the frame was 400mm. The wishbones were joined to the frames using brackets. The brackets were made by bending steel strips. The sides of the vehicle are not parallel and therefore the angle of the brackets needed to be manufactured such that the axis of the right and left wishbones were parallel, as shown in figure 1.2. To ensure a smooth motion of the wishbones, brass bushes were made, such that the brackets clamp to the bushes leaving the wishbones free to rotate.

Figure 1.2 – Wishbone Mounting Brackets

It was desired to make the wishbones out of seamless steel tubing approximately 20mm in diameter. However, the local steel supplier did not have any seamless tubing in stock, therefore seamed steel tubing was used, but a larger diameter (27mm) was used to increase the strength.

The ball joints for the top and bottom wishbones were sourced from local scrap yards. Ball joints from a Ford Sierra were used for the bottom wishbones, and larger track rod end ball joints were used from a Ford Transit for the top wishbones. A mounting plate was made to hold the bottom ball joints. The bottom wishbones were supported in a specially made wooden jig, and then TIG welded together.

The size of the bottom wishbones obviously affects the size of the top wishbones. In designing the top wishbones, once the ball joints were acquired, the next decision was how to mount the ball joints to the hubs. The wheel hubs were from a Ford Sierra, and therefore are designed to hold McPherson strut suspension units. An extension unit was made to fit in the mounting for the McPherson struts and hold the ball joints at the other end, as shown in figure 1.3. The length of the extension would determine the angle of the top wishbone.

Figure 1.3 – McPherson Strut & Ball joint

The vehicle needs to be designed such that when the car is fully laden the suspension system is in the desired position. The ideal position of the wishbones in the fully laden position is such that the bottom wishbones are level and the top wishbones angle down inline with the mounting point of the ball joint and hub on the bottom wishbone on the opposite side of the car, as shown in figure 1.4.

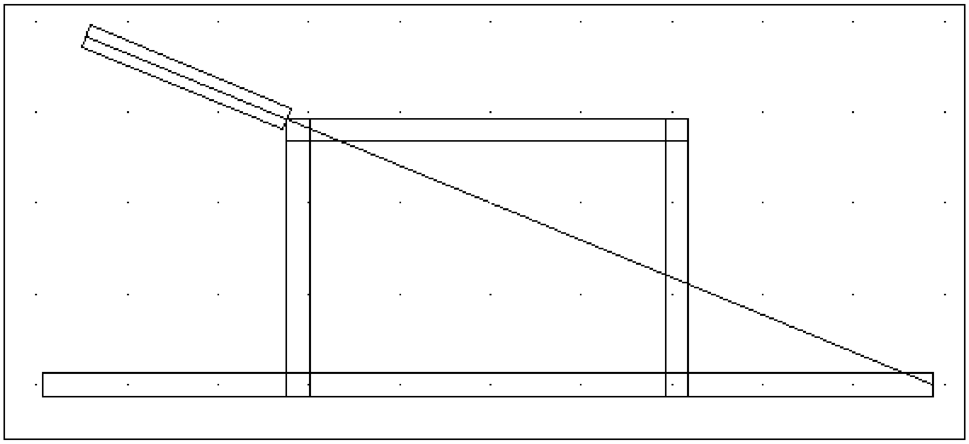


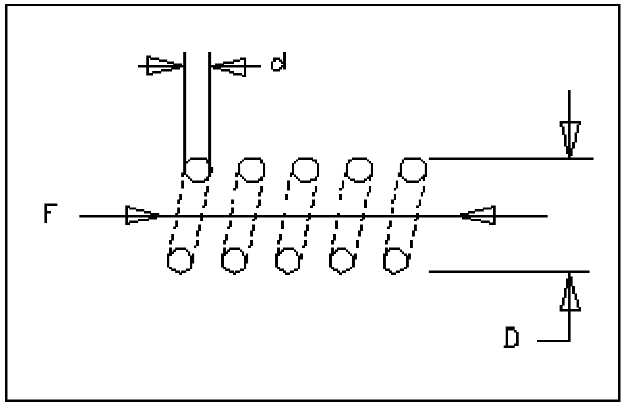
Figure 1.4 – Ideal Loaded Front Wishbone Position

Therefore the mounting point of the top wishbones on the frame also had to be decided. To reduce the forces in the suspension system, it is desirable for the distance between the top and bottom wishbones at their external points to be as large as possible. However, the greater this height is, the higher the top wishbones need to be mounted on the frame. For aesthetic reasons it was decided we didn't want the wishbone mounting points sticking out of the bonnet, therefore they were placed as high up on the frame as possible without protruding above the line of the bonnet. This then generated a line from the opposite lower wishbones through the mounting points and thus defining both the length of the upper wishbones and the extension struts.

The final aspect of the wishbone suspension design was which spring and damper units to use, and where to position them. The first approach was to look around scrap yards, however, most modern cars use McPherson suspension struts which were not suitable. A few older sports cars were found using coil over spring and dampers, but these generally looked in very bad condition and difficult to remove. A new set of suitable springs for a car would cost around £300, so we looked for a cheaper option. The single spring from the back of motorbike suspension systems seemed suitable. However, acquiring two springs from separate bikes in a similar condition seemed unlikely second hand, and new they were upwards of £70 each. Some bikes use two springs for their rear suspension, and we were able to acquire a set new, but at a discount rate of only £40 for the pair. The next issue was to calculate the stiffness of the springs.

The stiffness of a spring can be calculated by measuring the dimensions of the specific spring, using the formula:

$$k = \frac{d^4 G}{8 D^3 N}$$



Where:

k is the stiffness of the spring,
d is the diameter of the wire used to make the spring
G is the shear modulus of the material (usually steel)
D is the diameter of the spring itself
N is the number of coils in the spring

The suspension units comprised two springs in series. The combined stiffness of one unit was calculated to be 9,600 N/m. Simple moment calculations were performed to estimate the forces that would be acting on the suspension. It was estimated the wet vehicle weight (with fluids) would be 350Kg, excluding driver. However, the wheels are self supporting, and estimating 30Kg per wheel, leaves a sprung weight of 260Kg. By estimating the distribution of this weight, the forces acting on each front suspension unit were calculated to be approximately 850N.

The rear axle stiffness was estimated using the standard formula for calculating the stiffness of a spring and mass system:

$$Natural\_Frequency = \frac{1}{2\pi}\sqrt{\frac{Spring\_Stiffness}{Mass}}$$

Using a estimate natural frequency of 1.5Hz. The quoted dry weight of a Kawasaki GPZ motorcycle is 176Kg, therefore adding a rider and fluids take an estimate weight of 280Kg, and assuming the weight is distributed evenly means a load of 140Kg on the back axle. This results in an estimate rear axle stiffness of 12,435N/m.

For a comfortable ride it is desirable to have the rear axle slightly stiffer than the front, therefore a desired front axle stiffness of 11,000N/m seemed reasonable, leaving on each front wheel a stiffness of 5,500N/m.

This desired stiffness can be used with the spring stiffness to calculate what is known as the motion ratio of a suspension system.

$$\sqrt{\frac{Desired\_Wheel\_Stiffness}{Actual\_Spring\_Stiffness}} = Motion\_Ratio$$

This gives a motion ratio of:

$$\sqrt{\frac{5{,}500}{9{,}600}} = Motion\_Ratio = 0.76$$

The motion ratio is used in conjunction with the spring travel to calculate the travel of the wheel. The spring travel was measured to be 65mm, which implies a wheel travel of:

$$\frac{Spring\_Travel}{Motion\_Ratio} = Wheel\_Travel = 86mm$$

The desired stroke length is given by:

$$\frac{Spring\_Load}{Desired\_Wheel\_Stiffness} = Desired\_Stroke\_Length$$

This gives a desired stroke length of:

$$Desired\_Stroke\_Length = \frac{858}{5500} = 156mm$$

Therefore the expected wheel travel was approximately half the required wheel travel, which would mean the suspension would bottom out and hit the limit of the springs.

However, it was noted that the spring units were already preloaded, and by experiment, i.e. pushing on a set of bathroom scales, it was determined the preload in the springs were 130N. Therefore the first 130N of load due to the car on the spring purely took up the preload. This meant the spring load was 130N less, only 728N. This meant the desired stroke length was reduced to 132mm, however still greater than the expected stroke length.

To solve this problem, the preload in the spring was increased, firstly by the manual adjustment on springs, and secondly by adding in a spacer. It was estimate that by increasing the manual preload by 10mm and adding in a 20mm spacer, the preload would increase to approximately 500N, thus leaving a spring load of 350N. This reduced the desired stroke length to 63mm, which is less than the expected available wheel travel of 86mm. Therefore a nylon spacer was produced and inserted into the spring units. The spacer can be seen in figure 1.5 as the white ring with a jubilee clip round it.

Figure 1.5 – Suspension Strut Spacer

Having attained the required stiffness of suspension springs, they still needed to be mounted in a suitable location, such that the motion ratio was achieved, that is the ratio of spring travel to wheel travel is 0.76. There are limitless options for the two ends of the spring to be mounted. Therefore it was decided to fix the position of one end, and then calculate a suitable mounting point for the opposite end. It was decided to mount the bottom end of the spring onto the bracket holding the bottom ball joint in the lower wishbone. Having decided this, using AutoCAD it was possible to locate a position for the upper end of the spring such that the motion ratio was achieved, and that when the vehicle was laden the lower wishbone was flat.

Brackets were made to hold the top and bottoms ends of the springs, using brass bushes in a similar manner to that used for the wishbones themselves to allow freedom of movement. Figure 1.6 shows the fully assembled wishbones.

Figure 1.6 - Front Wishbone Assembly

The calculations and estimations used seemed to have been accurate. The system was tried using the springs without the spacers in place, and the suspension was far too soft. However, with the spacers in place, the laden vehicle sits nicely with the lower wishbones approximately level and the suspension doesn’t hit the limits of the springs if someone stands on the nose and bounces up and down.