FORMULA SAE - SUSPENSION SYSTEM

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ABSTRACT

The suspension, system includes; steering, braking, front and rear suspension systems. The system divided into modules, these modules were designed independently. Although designed separately the entire system had to operate effectively hence there was a great deal of interfacing between sections.

The steering system was designed so that the final design was compact, light, easy to adjust, cost effective and maintained Ackermann geometry as required for this type of vehicle. The braking system had to be designed with dual circuitry with readily accessible components to provide a balanced, reliable and effective system. The rear suspension system had to interface with power transmission and braking. The rear suspension also had to provide reliable set up, adjustablity and ease of manufacture. The front suspension had to interface steering and braking. As more space was available at the front of the vehicle there was a greater degree freedom given to the front suspension. As a result a close to ultimate set up could be achieved for the front suspension given cost, rule and time constraints. The final tyre selection was a compromise of several factors due to the unique nature of the Formula SAE vehicle.

KEYWORDS: Formula SAE, Suspension, Braking, and Steering.

1.0 STEERING SYSTEM

1.1 Introduction

The rack and pinion steering gear is considered to be the most suitable gear system for Formula SAE race cars. Rack and pinion steering has become increasingly popular, most small and downsized vehicles use a rack and pinion system, the pinion gear on the end of the steering shaft meshes with a flat rack of gear teeth in the rack and pinion system. This type of steering system provides good geometry, compact design and a minium of parts to become a useful, accurate lightweight system.

The steering geometry is important to obtain the correct amount of steer. The steering geometry includes caster angle, mechanical trail, kingpin inclination, bump steer and Ackerman geometry. The final design of the steering geometry is detailed later in the paper.

1.2 Design Specification

The steering system must affect at least two wheels to operate effectively. The steering system must also have positive steering stops, which prevent the steering linkages from locking up. The stops may be placed on the uprights or on the rack and must prevent the tires from contacting suspension, body, or frame members during the track events. Allowable steering free pay will be limited to 7 degrees total, measured at the steering wheel. The steering system must not exhibit any bump steer characteristics. The steering wheel must round in shape and the top of the steering wheel must lower than the front hoop of the chassis. The steering wheel must be removable for quick driver exit of the car.

1.3 Selection of Steering System

There are advantages of choosing the rack and pinion steering gears over other types of steering systems. The rack and pinion steering gear is compact and it uses fewer parts. Therefore, it requires lesser space for installation. With a rack and pinion steering gear, the rack is connected by linkage directly to the upright. It does not require complicated linkage to change the rotary output of the steering shaft to back and forth movement of the wheels. Therefore, the rack and pinion steering gear system is relatively light. The simple steering linkage gives sharp steering response, hence the road feel is improved.

1.4 Final Design Specification

The design of the steering geometry is based on 5^o of caster, 8^o of kingpin inclination and a tyre size of 515mm x 178 mm and wheel size of 330mm. The mechanical trail is 22.5mm, which is reasonable to avoid a large steering force. The tie rod is placed at the front and above the wheel centre to simplify the design of the upright. The distance between tie rod location and upper ball joint is 102.6mm. The tie rod is placed at 86mm above the wheel centre. The track rod is located parallel to the suspension linkage to avoid the variation of position at the wheel [2]. Since Formula SAE race cars are required to turn sharp corners, perfect Ackerman geometry is desired [3]. In order to achieve perfect Ackerman, a straight line is constructed from the tie rod end to the kingpin axis, extended and then intersecting at the centre of the rear axle.

2.0 BRAKING SYSTEM

2.1 Specification Requirements

To design a brake system for a vehicle of mass of approximately 300kg, maximum speeds of 120 km/hr and average speed of 60km/hr. The brake system must give high performance braking efficiency and stability during operation. The weight and the dimension of the brake system must be as small as possible because of the unsprung weight and inside wheel diameter limitation. Finally, the safety of the vehicle occupant is also a primary concern.

2.2 Selection of System

A disc brake system is used in the front and rear of the car. A dual brake system was used at the front (Outboard) and single brake system was used at the rear (Inboard). Floating-Calliper disc brake system with 2 pistons in each calliper was used at the front and the Fixed-Calliper disc brake with 4 pistons per calliper was used at the rear. Two ventilated brake discs with an diameter of 203mm was used at the front and one ventilated brake disc with 292mm diameter was used at the at the rear brake. Two independent master cylinders and an additional balance bar are used in the system.

2.3 Reasons of Selection

The advantages of disc brake system are its stability to enable more consistent fictional behaviour to be obtained from the front brake. It also has given a better braking performance at high speed to overcome fade associated with the high temperatures developed. On the thermal side, disc brake systems can lose heat very quickly because air can reach the discs every time the brakes are applied. Also, pad wear adjustment is automatic, renewal of pad is quick and easy, and the condition of pad wear can be checked without dismantling the brake system. The reasons for using dual brake system at the front and single brake system at the rear is because of the weight and cost saving. During the running of the car, most of the load will be transferred to front of the car when braking. Thus, a stable brake system must design at the front of the car.

Floating-Calliper disc brakes have good braking forces and braking stability. This is due to the action of the callipers during application of the brakes. During application the force of the callipers cause the inboard pads and the outboard pads push against each other in order to clamp the disc with equal and opposite force.

Because of the safety reasons, dual braking systems or two independent master cylinders are required in this brake system. The main advantage of this design is; if one of the systems (either front or rear) fails, the one (either rear or front) that remain operation can stop the car.

2.4 Final Design Description

Table 1: Final Design Description of Braking System

Final Design Description	**Front**	**Rear**	**Final Design Description**	**Front**	**Rear**
Type of Brake System	Disc	Disc	Number of Pistons in calliper	2	4
Number of Brake System	2	1	Disc Diameter (mm)	203	292
Type of Calliper	Floating	Fixed	Mater Cylinder Pressure	7.7 MPa	7.7 MPa

3.0 FRONT SUSPENSION

It was decided to use double wishbone suspension with inboard springs and dampers operated by pushrods and bell cranks. An anti roll bar was also incorporated into the front suspension to provide the additional roll stiffness required.

The geometry of the front suspension was mostly determined by the requirements on roll centre location, track width and steering geometry. A short upper arm and a long lower arm (SLA) were used to limit roll centre migration during wheel travel. The front of each arm initially came out from the chassis at an angle close to perpendicular to the centre line of the vehicle to try and maximise the wheel track. Concerns of wheel contact with the rear of the arms caused a change so that the front and rear of the arm came away from the chassis at similar angles allowing more clearance. Initially no side view geometry was included, however to improve fitment to a changed chassis, a small amount of anti dive geometry was included (less than 1%). To be able to sufficiently react the suspension loads it was not possible to give the required virtual swing arm length. To circumvent this problem a longer virtual swing arm was settled for and two degrees of negative camber included.

It was decided that the wishbones be made of mild steel due to its appropriate properties for manufacture and service. Initial calculations showed that 0.5” tube would be suitable however an increased safety factor led to the use of 0.75” tube. The pushrods are also to be made of 0.75” tube.

The instillation ratio of the spring and damper was found to rise in bump. This is a desirable condition. The dampers are small gas SPAX units, which the helical spring locates on the outside of. This type of coil over damper allows adjustment of ride height and damping. It also allows relatively easy exchange of springs.

4.0 REAR SUSPENSION

Generally, rear suspension consists of three major components, which include; uprights, wishbones and spring and shock absorber unit. For the Formula SAE racing vehicle, it was found that the front uprights taken from a Morris Mini were appropriate to be used for the rear uprights with some machining. Whereas the short-long arm (SLA) independent type of wishbones would be the desired ones to be used because this system keeps the wheels perpendicular to the road under any combination of bump, rebound and roll, and the lateral sliding travel at the central joint is less than half an inch. For the spring and shock absorber unit, the spring is made according to the calculated spring rate while the shock absorber is an oil-operated type.

4.1 Uprights

Uprights play an important role in connecting the drive shaft to the wheel and also holding the wishbones and spring and shock absorber unit. The uprights used exist Mini front uprights. They are made of cast iron and weigh approximately 5 kilograms. The main reason of using the Mini uprights is that they have extremely similar vehicle geometry and secondly, using an existing part will always be cost effective. For the safety purpose, the bearings inside the hubs are replaced and some extra parts have been machined to fit into the wheel and for weight reduction purpose.

4.2 Wishbones

The wishbones used are of a SLA independent type, also known as Double A-arm type with a toe link. The reasons for choosing independent type are camber characteristics that changes with both vertical suspension movement can be archived and are less complex thus increasing the ease if manufacture. The wishbones and toe links are made of 19 millimetre circular hollow Mild Steel Grade C250 so that they can withstand a maximum force of 25-kilo Newton. The steels are attached to triangular steel bars with an angle of 66 degrees and 51 degrees respectively for the upper and lower arms. Spherical rod ends are attached to the other end before the arms are bolted to the brackets in order to provide some clearance to the wishbones when the vehicle bumps or rebounds. This is to prevent the wishbones from cracking or breaking due to sudden impact.

4.3 Spring and Shock Absorber Unit

The main function of the spring is to store varying amounts of energy that are caused by the unsprung and sprung weights. Thus, progressive spring rate has been introduced to reduce the total bump travel for a given energy-absorbing capacity to keep the tires almost upright to the road all the times. This will improve cornering, braking and acceleration. For this project, an outboard type spring and damper is chosen instead of inboard type due to ease of assembly and lowering the risk of failure. The main reason for Formula cars today to use an inboard type is due to aerodynamic effects, which do not have a great effect in Formula SAE types of cars. Basically, coil springs in helix shape and gas-operated shock absorbers are used and orientated in parallel with some angles to facilitate the necessary geometry.

4.4 Final Design Description

For the final design, the uprights to be used will be taken from the Mini with some machining and replacement of bearings. The wishbones to be used will be of a SLA independent type with toe link, made of circular, hollow Mild Steel with spherical rod ends. An outboard type spring and shock absorber unit will be appropriate for this project to keep the design simple and cost effective.

5.0 SUSPENSION GEOMETRY DETERMINATION

Once the type of suspension had been selected, in this case an independent arrangement, the next step was to decided upon roll centre placement, virtual swing arm lengths, ride frequencies, roll rates, track width and wheelbase. To be able to select these variables a computer program was written that gave an indication of vehicle behaviour and performance based on these variables. The outputs of the program were body-roll angle, individual corner weights and suspension travel during cornering. The formulas upon which the program has been based are from Miliken et al [5]. It was necessary to make assumptions about the centre of gravity location, mass of the vehicle, and lateral acceleration to be able calculate the above parameters. The following set of variables gave the best compromise for vehicle behaviour;

Table 2: Final Design Descriptions of Suspension Geometry

Final Design Descriptions	**Dimension**	**Final Design Descriptions**	**Dimension**
Front roll centre height	35mm	Rear roll centre height	80mm
Front ride frequency	2Hz	Rear ride frequency	1.8Hz
Additional front roll stiffness	3000Nm/rad	Additional rear roll stiffness	0
Wheelbase	1.75m	Track width	1.2m

The program with the inclusion of additional rear roll stiffness predicted better performance, however the added complexity proved too difficult to design within the limited time frame. The selection of variables was firstly to optimise cornering behaviour, as it is the most complex and problematic manoeuvre. The ride frequencies were chosen with care to account for irregularities in road surface, braking and acceleration manoeuvres. The wheelbase length represents a packaging compromise, as a shorter wheelbase would have been preferred to improve turn in.

6.0 TYRE SELECTION

At the start of the Formula SAE project Bridgestone Motor sport Australia had offered to supply the Adelaide University team with a set of tyres for the race car. As a result the tyre selection procedure was predominantly restricted to Bridgestone products. Initially it was proposed to use slick racing tyres, after some investigation it was found that the two sizes most suitable would be 13 x 8.5" or 15 x 6" tyres. These tyres were designed for saloon car racing and were of a soft compound. The tyres would have provided good grip and wear characteristics. As the tyres were designed for much heavier cars which travel at faster speeds there was a concern that the tyres may not be able to obtain operating temperature when being used on a Formula SAE car.

Further investigation found a tyre made by Hoosier for Hill climb vehicles. The tyre was designed for lightweight vehicles and did not require warm up to operating temperature. The tyres could be run effectively in their cold condition. Inquiries were in conjunction with Bridgestone to obtain the Hoosier tyres. After the inquires were made it was found that the tyres were not imported in Australia.

The final selection of tyre became the Bridgestone WEC 170/510-13 wet weather racing tyre. This tyre was designed for light touring car use. While the Formula SAE car is considerably lighter than the vehicle the tyres were designed for it was felt that the selected tyre would be a good compromise of available tyres. The WEC tyre will get to its operating temperature quicker than its slick counterpart due to the small tread area contacting the road surface. The resultant reduction in tread surface also reduces the rolling resistance of the tyre. As the Formula SAE car will be driven in dry conditions the use of a wet weather tyre will compensate for the light weight of the vehicle and the resultant combination will provide a car and tyre combination with excellent roadholding capability and good wear characteristics.

7.0 CONCLUSION

Many factors where taken into consideration when designing the suspension system for the Formula SAE vehicle. Some of these parameters were common to all sections such as; safety, weight reduction, reliability, ease of manufacture, cost of components, complexity of design and previous experience with designs of a similar concept. All of the concepts used in the design of the vehicle were chosen due to the simplicity, reliability, cost and availability of existing components as well as compatibility with related systems of the entire vehicle design. Other than the safety of the competitors the major limitation in choosing suspension systems and components was the restrictions placed upon the design due to SAE rules, time constraints and cost.

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