DESIGN & ANALYSIS OF STEERING AND UPRIGHTS OF FSAE CAR

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Abstract—The aim is to achieve a perfect steering Geometry for the FSAE Car. The chosen Geometry for the car is Ackerman Steering Geometry. According to the FSAE Competition, the steering mechanism must be mechanically connected to the front wheels, i.e. “steer-by-wire” or electrically actuated steering of the front wheels is prohibited. The steering system must have positive steering stops that 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 the suspension, body or frame members during the track events. Allowable steering system free play is limited to 7° total measured at the steering wheel. The Steering must be attached to the column with a quick disconnect. The driver must be able to operate the quick disconnect while in the normal driving position with the gloves on. Keeping the above rules in consideration, the suspension analysis to find the perfect rack length is done on Solid Works Software. The above Geometry designed is in accordance with Ackerman Geometry. The displacement from the front axle on the upright design is found again in Solid Works Software. The analysis is done in ANSYS software.

Keywords—Solid Works Software and ANSYS software.

I. INTRODUCTION

The steering system is the mechanism which has the purpose to turn the guidelines wheels making that the pilot can guide his car along the desirable trajectory. In order to carry out this task the pilot receive a lot of information by their eyes and the brain send a stimulus to their hands which are the elements in contact with the first part of the steering system, the steering wheel. Now the human work has finished it is the time to the mechanism work. The steering system work is to transmit the angle made by the pilot on the steering wheel across the different elements until the steering wheels. Steering system elements:

- Steering wheel
- Quick disconnect mechanism
- Steering column
- Universal joint
- Steering box (rack-pinion)
- Tie rods
- Ball-and-socket
- Steering arms
- Upright
- Pivot

In our project we will study the theoretically knowledge that has influence on the steering system and basing on these fundaments we will design and describe the steering system elements.
II. DESIGN PROCESS

Elements of the car that have influence on the steering system design

2.1. The cockpit

The criterion to design a cockpit is to create a comfortable place to the driver. The cockpit must be sufficiently spacious to allow the necessary movements of the pilot to have a good control of the car. By other hand the cockpit must not be excessively big because this fact decreases the aerodynamics capacities and the acceleration due to the car is heavier.

![Fig1; Cockpit](image1)

In our project we design the steering system so the design of the cockpit is not our responsibility, being a task of a project in which the chassis of the car is designed. However, this part of the single-seater has influence on the steering system design so we will do a study of a rough estimate measures that could have a Formula S.A.E. car based on a possible pilot measures, without give much details of the cockpit design.

![Fig 2; Arms Movement for A Seated Man](image2)

The size of the cockpit depends directly of the measures and the position of the driver. This position also will have influence on the gravity center of the vehicle. The position of the pilot is based on different aspects: the comfort to the pilot as much as possible, to improve the features of the car principally decrease the weight and the car has good aerodynamics conditions. Bear in mind all of this considerations we choose a normal position of the driver to this kind of competition. The pilot will be situated near to the floor, with the legs stretched out on the front direction. By other hand the pilot will be situated so back as possible in the cockpit in order to allow the movements of the driver arms. As regards with the knees and the arms, will be not totally extended. The arms will be with an angle bigger than 90º degrees with the steering wheel and a little bit curved. The knees will form an angle nearly to 180º degrees with the horizontal of the vehicle. Summing up a really like position that in a formula one.

In order to calculate the approximately measures of the cockpit we will make a study of the measures for a possible driver. We will mesh different parts of the body of different people and finally we will do an arithmetic mean of each measure.
Distances:
- Floor to knee: 55 cm
- Knee to waist: 50 cm
- Shoulder to elbow: 31.5 cm
- Elbow to knuckles: 34 cm
- Waist to head: 76 cm
- Shoulder to head: 29 cm

Widths:
- Waist: 34.5 cm
- Shoulder: 42 cm
- Chest: 28 cm

Weight: 71 kg

Also, we will take into consideration the angles between the back of the driver with the vertical of the cockpit, the angle of the knees with the floor of the cockpit, and the angle of the hands with the wheel, so also the angles of the arms.

Angles:
- Back with vertical of the cockpit: 20º degrees
- Knees with the floor of the cockpit: 180º - 30º - 30º = 120º degrees
- Hands with steering wheel: 90º + 15º = 110º degrees
- Arms: 15º degrees with the perpendicular of the steering wheel

So we are going to calculate the approximately measures of a possible cockpit which will be designed in detail in other project about the design of the chassis.

Lateral measures of the cockpit

With the following values for the angles:
- \( \alpha = 20^\circ \)
- \( \beta = 20^\circ \)
- \( \theta = 15^\circ \)

Horizontal measures:
- \( \cos 20 = \frac{X_1}{55} \rightarrow X_1 = 47.6 \text{cm} \)
- \( \cos 20 = \frac{X_2}{50} \rightarrow X_2 = 43.3 \text{cm} \)
Sin20 = X3/76 → X3 = 26cm
Cos15 = X4/34 → X4 = 33cm
Cos15 = X5/31.49 → X5 = 30.4cm
Sin20 = X6/29.23 → X6 = 10cm

**Vertical measures:**
Cos20 = Y1/76 → Y1 = 65.81cm
Tan20 = 10/Y1’ → Y1’ = 27.47cm
Y1” = Y1 – Y1’ = 43.94cm
Sin20 = Y2/55 → Y2 = 43.3cm

**Front measures of the car**
This measure is determined with the width of the waist and the shoulders in order the drive is comfortable at the time to drive but the most limited possible with the purpose to make the car lighter and more aerodynamic.

**The seat**
As regards with the seat of the pilot the most used on this kind of competition. It is a really good option because is light, around 2 kg and is cheap. The seat is manufactured by hand so it will be adapted to the cockpit measures.

![Fig 6; Seat](image)

**III. DESCRIPTION OF THE STEERING SYSTEM ELEMENTS**

In this chapter we be able to see the elements which to made up the steering system of one car and more in detail which are used in a competition vehicle.

The weight of the car has importance on the performance of the car since depending of the weight the car has a different performance on the road. So we can distinguish in two parts different elements of the car: The elements which belong to the hang weight and the other that belong to the not hang weight. The not hangs weight: is the part of the total weight of the car which is not support by the suspension. This weight supports all the disruptions of the road so we try to reduce this weight the much as possible

- Rims
- Upright
- Brakes
- The bearings, springs and shocks absorbers (elements of the suspension)

The hang weight: Is the weight that is supported by the suspension. This part is the heavier part of the car.

- Steering box
- Steering column
- Steering wheel
- Chassis, engine, driver, fuel, bodywork and one part of the Suspension.
Steering column
This torsion bar joins the steering wheel with steering box through the quick disconnect mechanism. This bar only support the torsion effect produced by the turn of the steering wheel so it is not necessary a high quality steel. Also appears short compression efforts when the pilot leaning on the steering wheel, but are insignificant.
In order to do the design of the steering column we will see the Formula S.A.E. rules and the effort analysis.

According with the Formula S.A.E. rules the steering column cannot be one bar with only one direction due to different aspects. One of this is the safety of the driver since in case of accident, on a front crash, if the steering column only has on direction it will be easy that go out in direction to the pilot being very dangerous. The other aspects depend on the design for the comfort of the driver. Using a universal joint we can join two parts of the steering column making an angle allowing increase the distance between this element and the legs of the pilot and also increase the entry pinion angle into the steering box.

Steering box
Is the part of the steering system defining as the joint of gear assemblies that convert the torque transmitting by the steering column on a horizontal force. In other words, in the steering box the rotational movement transmitted by the steering column is converted on a rectilinear movement. At the same time the rack and pinion produces a decrease on the effort executed by the pilot from the turn of the steering wheel until the turn of the wheels avoiding on this way the extreme tiredness of the driver. The effort necessary to turn the wheels is higher when the vehicle is stopped and decrease in accordance with the increase of the velocity. However, we can say that this effort depends mainly on the resistance made between the wheels and the floor due to the friction which is function of the velocity and the weight of the vehicle.

The Rack and Pinion
Before the appearance of the car the use of the rack and pinion was limited only to small vehicles because the steering proved too heavy and the improvements were not sufficiently suitable so it was necessary to make a lot of turns with the steering wheel in order to guide the wheels on the desirable trajectory. Nowadays this problem has been solved with the power-assisted steering.
Actually the rack and pinion is very used by the fact that is cheap and the assembly is simply allowing the incorporation system that help on the driving as the power-assisted steering.
Tie rod
In our case in which we have chosen the rack and pinion for our steering box the tie rods are the bars which join the rack with the steering arms. The join is made through ball-and-socket joint. The connection between the ball-and-socket join and the steering arms is thread, making possible the variation of the distance from the end of the rack to the end of the steering arms. Then the joint secures through with nuts and locknuts. This is used to adjust the parallelism between the wheels. The tie rods must be made of alloyed steel since must be support the knocks to come from the wheels through the upright and the steering arms.

IV. STEERING GEOMETRY

Ackerman Steering Geometry
It is a geometric arrangement of linkages in the steering of a car or other vehicle designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radius.
It was invented by the German carriage builder George Lankensperger in Munich in 1817, then patented by his agent in England, Rudolph Ackermann (1764–1834) in 1818 for horse drawn carriages.

Ackermann geometry mainly focuses on avoiding the need for tires to slip sideways when following the path around a curve. The geometrical solution to this is for all wheels to have their axles arranged as radii of a circle with a common centre point. As the rear wheels are fixed, this centre point must be on a line extended from the rear axle. Intersecting the axes of the front wheels on this line as well requires that the inside front wheel is turned, when steering, through a greater angle than the outside wheel.
This arrangement enhances controllability by avoiding large inputs from road surface variations being applied to the end of a long lever arm, as well as greatly reducing the fore and aft travel of the steered wheels.

V. UPRIGHTS

Upright is that part which contains the wheel hub or spindle, and attaches to the suspension components. It is variously called a steering knuckle, spindle, upright or hub, as well.

5.1 Design
To begin the design process of the front upright, the front suspension of the car was disassembled so accurate and thorough dimensions could be recorded for the upright and the accompanying components. The design was then modeled in Solid Works (Dassault System’s Solid Works Corporation, Waltham, MA).

5.2 Meshing UL
The designed model of upright was imported in ANSYS software and meshing was done to find the number of nodes and elements. Meshing is probably the most important part in any of the computer simulations; because it can show drastic changes in results you get (have a first-hand experience of this). Meshing means you create a mesh of some grid-points called 'nodes'. It's done with a variety of tools & options available in the software. The results are calculated by solving the relevant governing equations numerically at each of the nodes of the mesh. The governing equations are almost always partial differential equations, and Finite element method is used to find solutions to such equations. The pattern and relative positioning of the nodes also affect the solution, the computational efficiency & time. This is why good meshing is very essential for a sound computer simulation to give good results.

5.3 Analysis
The uprights must be able to withstand a variety of forces including, braking, steering, lateral loading, and supporting the weight of the car through the turns. The maximum stresses on the upright will be when the car is turning in the direction opposite of the side of the car in which the upright being examined is installed. There will be a load transfer from the wheel on the inside radius of the
turn to the outside due to the centrifugal force of the car making the turn. In addition to the load transfer there will be a lateral force at the tire contact patch resisting the centrifugal force and forcing the car to turn. Finally, there are braking and steering forces applied to the upright. As the car negotiates the course the upright must be able to withstand these forces simultaneously. The upright also has to handle these stresses with a factor of safety of 3 or greater to withstand emergency situations and crashes.

VI. RESULT

Equivalent Stress

![Equivalent Stress Image]

**Fig 13; Analysis on Equivalent Stress**

Total Deformation

![Total Deformation Image]

**Fig 14; Analysis on Total Deformation**

VII. CONCLUSION

The elements rack and pinion, tie rods, steering arms and the upright were determined by Jeantaud trapezium & Ackerman Geometry and we have obtained the connection between the turn angles of the front wheels with the wheelbase and the tracks. According to Ackerman Geometry we have design the elements in order to the extensions of the lines that join the end of the tie rods with the point where the steering arm is joined with the upright finish on the center of the rear track in order to achieve a good performance of the vehicle.

To situate the steering wheel and the steering column we have make a study between seven people in order to achieve the measures of a possible pilot. Once finish this task, we have calculate the position of the steering wheel achieving that the pilot drive in a good position avoiding an extreme tiredness and respecting the SAE rules that say the top of the steering wheel must be no higher than the top-most surface of the front hoop.
For the uprights we have designed and analyzed it using Ansys and SolidWorks. Meshing and analysis such as stress and total deformation were done. The loads applied on the uprights were static loads which are according to the rules of FSAE

REFERENCES