Design of 3D Printed Steering Wheel for FSAE Vehicle

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Abstract— *The steering action is one of the most important inputs that the driver can use to interact with the race car to control it the way he wishes to. This paper describes the process followed to design and manufacture a steering wheel which abides by the Formula Student rules and compliments the vehicle ergonomics. 3D printing technology allowed us to make a light weight part with design flexibility as well as cost efficiency. To improve the Driver Interface, we have integrated an electronic system onto the steering wheel for the driver to have a better knowledge of the current status of the vehicle. A 3-piece design was finalised to facilitate manufacturing on a 160mm x 160mm printing bed.*

Keywords—Additive manufacturing, prototyping, steering wheel, Driver interface, 3D printing, Fusion Deposition Modelling, formula student, FSAE,

1. INTRODUCTION

Traditionally, steering wheels have been just a tool for the driver to control the steering angle or the direction of the wheel. But with the boom in technology and the need for advanced controls given to the driver, has forced the engineers to be creative and implement various strategies to adapt to these changes

The steering wheel is one of the 3 major inputs that the driver has to vary while driving a race car around a race track. The driver has various other settings that he can control with the help of electronics and mechanical systems such as the brake bias, differential ramp angle, anti-roll bar stiffness and Aerodynamic Drag Reduction System etc. But once the desired set up is achieved, the only interaction that the driver has with the vehicle is through the throttle, brakes and steering, Hence, it is very important that the steering wheel is designed with keeping the driver comfort in mind. For prolonged hours the driver has to use his strength to steer the car through this steering wheel.

In the Formula Student race car, the components are to be manufactured in a very small number. Maybe one set or at max one set of spares. Hence, to manufacture a custom design in such a small quantity for the prototype can turn out to be expensive. Additive manufacturing helps to tackle this issue. Due to the 3D printing technology we get the flexibility in design as well as weight reduction can be implemented. Complex Designs can be manufactured using this prototyping technique without the hassle of complex machining processes and mould preparations.

Due to the rules of Formula Student as per rulebook, no interaction with the driver is allowed using telemetry or over a radio frequency. Hence, the driver is all by himself while on the laps for the endurance run. Hence to give him an idea of the functioning status of the vehicle, we decided to install a Driver Interface system onto our system. This system would give the driver a live update about data such as vehicle speed, Battery voltage (min. And max.), temperature of hottest cell and motor rpm. A suitable position had to be selected for this purpose. Along with the driver interface, the steering would also have the controls for Mark Buttons and Drag Reduction System. An ergonomic test was run to make sure the design of the steering wheel and the positioning of the controls are comfortable for the driver.

Finally, we had to make sure our design was compatible for additive manufacturing.

2. DESIGN FLOW

2.1. Design Considerations and Constraints

i. The competition rules restrict the steering wheel dimensions and shape. It specifies that the steering wheel has to be a continuous perimeter with no concave sections.

ii. It also restricts the dimensions to make sure the drivers' hands do not exceed the topmost surface of the front roll hoop, for safety reasons.

iii. It requires the steering wheel to have a quick disconnect function so that the driver can disconnect the steering wheel from normal driving position with gloves on.

iv. We consider that the driver applies a torque of 10Nm on the steering wheel. This value was calculated by the suspension and steering team.

v. Respective slots and holes were to be made of the exact size in places where external components were to be placed.

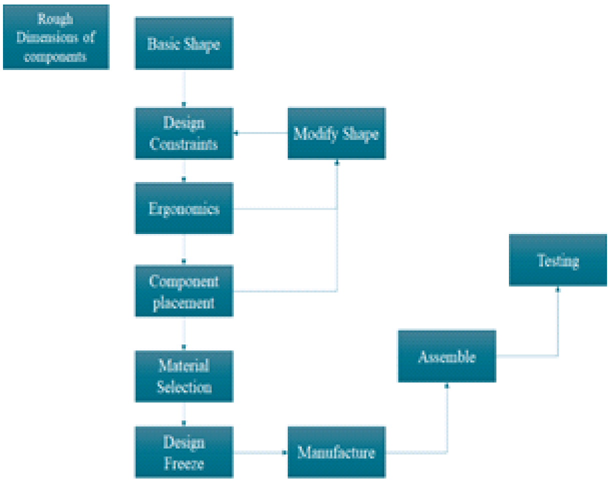

Figure 1: Design flow

2.2. Ergonomic Considerations

Driving a race car is a demanding task. For an endurance event, the driver has to be seated in the vehicle for around 30 mins and during the 11 km run the driver has to bear an immense amount of force. These forces in our vehicle, as per our previous logged data, can be up to 2G's on certain corners. Hence the driver positioning is very critical to avoid any discomfort to the driver. Hence along with the Ergonomic set up for the driver seat and chassis structure, ergonomic tests were carried out for the steering wheel shape, size and accessibility of on-board controls.

The ergonomic set up had a provision to change the following parameters with respect to the steering wheel -

i. Steering column angle

ii. Steering wheel distance from driver

iii. Steering wheel inclination

iv. Steering wheel lock-to-lock motion

v. Steering wheel shape

vi. Steering wheel width and height

vii. Placement of on-board controls

For a particular set up, the driver was made to sit in the set up for 10-15 minutes with continuous steering from lock - to - lock to emulate racing conditions to let the driver get a feel of the race fatigue. This would allow him to notice pressure points or discomfort zones. To replicate the steering forces, a spring was added to the set up. This would emulate the steering forces. This brought the ergonomic set up close to real race scenarios.

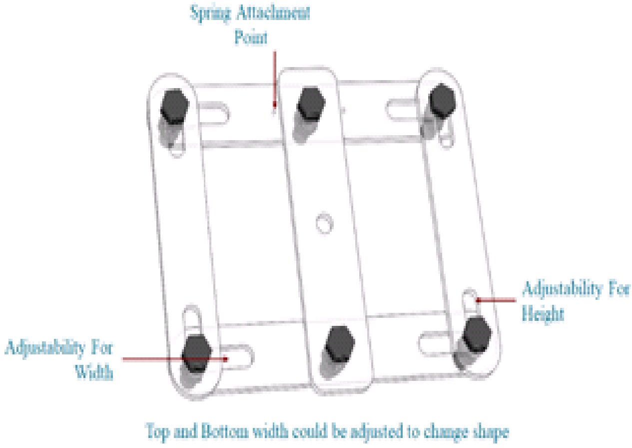

Figure 2: adjustable steering for ergonomics

Figure 3: Ergonomics set up

Figure 4: Use of springs to replicate steering effort

Different placements for the electronic components were made and the driver feedback was noted. This included the placement of the main reset and RTD buttons, LCD display, DRS & Mark buttons, SLM and emergency kill switch.

Figure 5: Accessibility of cockpit controls on steering and dashboard

Design Iterations

i. The first step was to make an initial circular sketch to replicate the boundary condition for the steering wheel. This covers the constraint of the driver's hands being under the front roll hoop in all steering positions.

ii. The dimensions of the hand rest and other dimensions are replicated from the Ergonomic readings taken.

iii. Different shapes and dimensions of thickness are iterated keeping in mind driver comfort, manufacturability and mechanical strength. A thumb rest was also provided as per driver comfort.

iv. The holes for the Quick release mechanism are made in the centre of the steering wheel.

v. Once the basic dimensions and shape is finalised, the components were placed and sufficient space was left out for wiring and assembly ease. The LCD, connectors, Driver Interface PCBs and the buttons are placed.

Once the design was finalised, it was iterated for mechanical strength with various materials

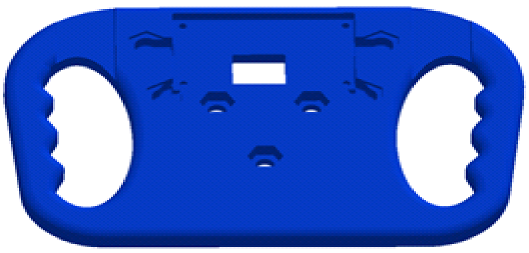

Figure 6: Final Design of steering wheel

Table 1- Placement of components

Sr. No.	Component	Placement	Reasoning
1.	LCD Display	On Steering wheel	The display has to be visible to the driver in all steering positions. Placing it on the dashboard makes it difficult to view when steering at 90 degrees
2.	SLM	On Dashboard	SLM is easier to view than the LCD screen because it only has coloured LEDs to be interpreted by the driver. Hence it can be placed on the dashboard to save space on the steering wheel.
3.	DRS Button	On Steering wheel	DRS button has to be accessed without leaving the steering wheel for better handling while accelerating through a straight.
4.	Mark Buttons	On Steering wheel	Mark buttons act as a pointer to signify any activity that the driver has observed and wants to notify to be discussed later. Hence it is placed in close proximity to the driver's thumb so that it can be accessed without leaving the steering wheel.
5.	Indication Lights	On dashboard	Lights are easily viewed on the dashboard, hence they are not placed on the steering wheel.
6.	Main Reset & RTD button	On dashboard	These buttons are used to start or restart the vehicle. Hence these buttons are to be operated with the vehicle on stand still. Hence it is acceptable to leave the steering wheel while operating these buttons.
7.	Emergency Kill Switch	On dashboard	Emergency kill switch has a minimum diameter as specified by the rules. Due to the space constraints on the steering wheel it has to be placed on the dash board.

Figure 7: Final placement of components

3. Material Selection

The materials that were considered for the manufacturing of the steering wheel were

1. Acrynotrile Butadiene Styrene (ABS)
2. Poly Lactic Acid (PLA)
3. Polyethylene Terephthalate Glycol (PETG)
4. Polycarbonate (PC)

The materials were compared on the parameters that were important to our usage which are Fatigue Resistance,

Printability, Weight, Durability, Stiffness and Ultimate Strength.

Though ABS was lighter, the stiffness and ultimate strength was lower than the other materials, hence it was eliminated. Subsequently, PC was eliminated due to the printability issues.

Finally looking at the other properties, PETG was finalised for the printing material.

The detailed decision matrix can be visualised in the radar plot shown below.

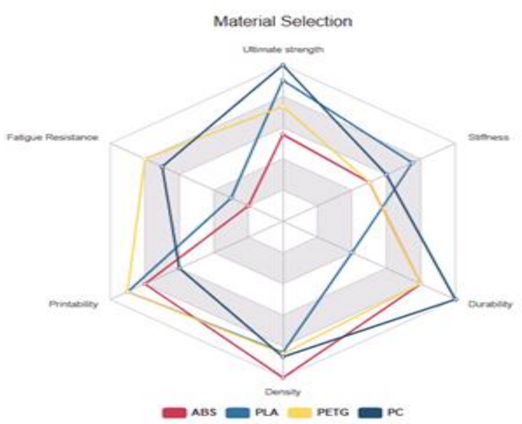

Figure 8: Material selection chart

4. Manufacturing

4.1. Manufacturing Constraints

The steering wheel had to be printed in the 3D printer available in the college campus. This machine had a circular bed with a diameter of only 160mm. Hence to make the full steering in a single run would not be possible. Hence we decided to split the design in more than one part and then mechanically join it to achieve the steering wheel as per the final design.

We had the option to split the steering wheel into 2 parts but that would cause the parting line to be in the middle of the steering wheel and would pass through the attachment points of the Quick Disconnect attachment. There would be the maximum load at the attachment points hence it was avoided to have a parting line at that point. The parting line could not be moved to any one side so as to avoid any asymmetry in design.

Hence, we decided to split the steering wheel in 3 parts to overcome the above 2 mentioned issues. This helped us to move the parting lines away from the attachment points as well as keep the final design symmetric about the central axis.

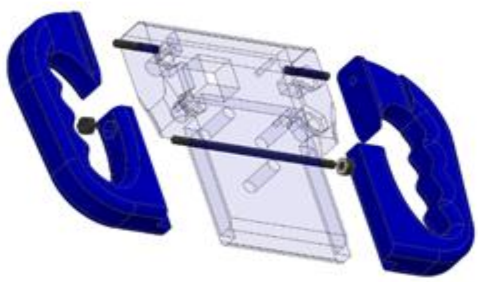

Figure 9: Final 3-piece design

It was decided to stick the adjacent parts with a structural glue which was compatible with our printing material.

To improve the bonding and to increase the surface area of the glueing surface, we added opposite steps to the two surfaces. The steps would mate internally to to fit correctly and hence not cause any hindrance in the final design. The steps are shown in the figure.

To further strengthen the bond, aluminum dowels were inserted in the upper part and studs were inserted and bolted in the lower part. This added to the mechanical strength of the bonds.

4.2. Machine Testing

In additive manufacturing we have observed that the dimensional accuracy varies from machine to machine depending on the nozzle temperature, nozzle diameter, layer thickness and the adhesive properties of material between 2 layers. This affects the locations where the dimensional accuracy is critical. Hence to avoid any post processing on the critical dimensions such as fasteners holes and LCD cavity, we made a test sample on the machine on which the final part was to be printed.

We printed a part which had holes with dimensions in the range of +/- 0.5mm with an increment of 0.1 from the bolt dimension which was used as a shaft to determine the best clearance fit for the bolt to pass freely.

It was found out that 3.2mm was the best fit for a 3mm bolt. This was due to the shrinkage of hole due to tha sagging of the innermost layer of the hole. Hence a +0.2mm clearance was given to all holes and critical dimensions so that it wouldn't interfere during assembly.

Any post processing such as reaming or drilling on the 3D printed part can affect the integrity of the inter-laminar bonds between subsequent layers of the print. Hence to avoid any post processing on the final part, these measures were undertaken.

4.3. Design Freeze

As per the manufacturing constraints, the following changes were made to the final design which could be printed.

i. The design was split into 3 parts as shown below. The cuts were made vertically and holes were made to insert studs to increase strength and provide reinforcement at the mating surface.

ii. A step was made at the mating surface to increase the gluing area at the mating surface.

iii. A gap of 0.2mm was left at the mating surface to incorporate the glue while gluing.

iv. The holes were made with a dimension of +0.2mm to get the desired fit after the manufacturing.

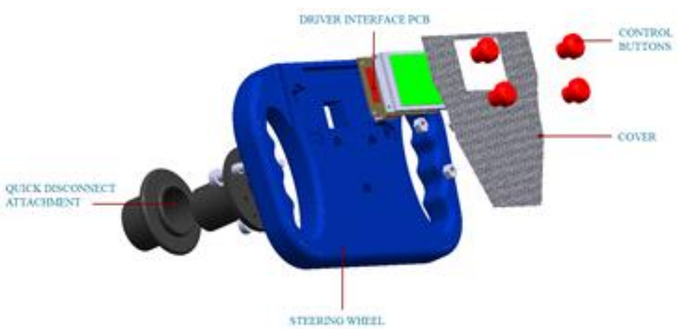

Figure 10: Exploded view of assembly of components

4.4. Manufacturing

The 3D printed parts were manufactured using the 3D printer available in our sponsors' facility. The print was done with a 30% in-fill using gyroid infill pattern. The parts were removed and no finishing was done before assembling the pieces together. No support materials were to be made due to the simplicity of the design. The printer settings were controlled and fed into the system by the operator. The overall print took 4 hours to be completed. The overall weight of the manufactured parts was just 203g.

Figure 11: Manufacturing using FDM method

Figure 13: Assembly and gluing of the 3 parts

4.5. Assembly

The 3 parts were manufactured separately and then assembled using the inner studs and glue. At first the mating surfaces were sanded and the bur from the holes was removed. This was done to clean the surface before the glue was applied. Once the parts were cleaned up, the studs were cleaned with acetone and everything was ready for assembly.

First the studs were fitted into the central piece. The structural glue was applied on one side of the central piece and the corresponding mating surface from the handle. The pieces were mated and carefully held in place. Similarly the second side was glued up. Once done the pieces were clamped and left overnight for curing. Once done the assembly was ready to be passed on to the electronics team for their component assembly.

5. CONCLUSIONS

We were able to achieve the following things by the end of this project.

i. We managed to reduce the weight of the steering wheel from 930g (Aluminium) to a 450g (including electronics). We were also successful in providing on-board electronic driver feedback to the driver using the real - time logged data.

ii. The overall design was simplistic and rule compliant. The manufacturing of the steering could be carried out in a single piece if we had access to a 3D printing machine with a larger bed size.

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