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Design and Development of Formula Student Electric Drive train

Partheeban K
R.M.K. Engineering College, Kavarapettai

Chandran Saran M
R.M.K. Engineering College, Kavarapettai

Charan A
R.M.K. Engineering College, Kavarapettai

Ezhilarasan K
R.M.K. Engineering College, Kavarapettai

***Abstract* - Formula Student Competitions are the competition for undergraduate students. The main goal of these competitions is to help the students to develop engineering skills in a real-time environment. These allow the students to generate concepts, design, fabricate and compete with others. Generally, it will take 6-12 months of designing, fabrication and testing. The best team is selected not only based on the design and built but also checks the cost, marketability and engineering involved in it.**

This document describes the selection of drive train components, design, analysis, manufacturing and assembly of the drivetrain system of a formula student race car. The drivetrain has designed to be simple, lightweight, compact and serviceable. Here, the power is delivered from an Agni 119R Electric motor. The transmission of power is done by a single fixed ratio chain drive. A limited-slip differential and set of equal size axles are used to transfer the power from the transmission system to the wheels. Further, the analysis methods, manufacturing process and the final assembly of the drive train are documented.

Keywords - Drive train Assembly, Motor mount, Differential mount, Floating plate design.

1. INTRODUCTION

There are some qualities that every engineer must possess in their engineering career. They should have wide knowledge in practical engineering, available tools, project management, cost management, time management, etc., but these skills are to be developed during they are an undergraduate. So, to prove their skills, the formula student competition serves as a platform for every enthusiastic engineer.

A. Formula Student Competition

The competitions generally comprise of two sections, they are Static and Dynamic events. The static event consists of Cost Submission event, Engineering Design event, Business Plan Presentation and Technical Inspection. The technical inspection is to ensure the quality, built and safety of the car. The Dynamic events are Acceleration and Brake test, Skid-pad, Auto-cross and Endurance. The team must pass the technical inspection to get into the dynamic events.
The Cost Submission event tests the cost management, purchase of materials for the team. The Engineering Design event tests the level of engineering involved in the car. The Business Plan Presentation helps to prove the marketability skills of the team.
The Acceleration and Brake test, Skid-pad, Autocross test the performance and handling of the car individually. The Endurance is the real test for the car and the driver, the car has to run about 22 km which tests the performance, handling, efficiency and driver skills altogether. This test holds maximum weightage in scoring points.

II SELECTION OF SYSTEMS

A. Design Goals

The drive train design has four major design goals

- Compact
- Light-Weight
- Simple Design

- Serviceable Design

The design is decided to be compact because it occupies less space. The lightweight design makes the car reduce its weight which contributes to better handling and performance. The simple design makes the fabrication process much easier and lowers the cost too. Many teams when they are thinking about the compactness of the design, they forgot about the serviceability of the system. So, we decided the serviceability is also the main factor that has to be taken care of for the designing phase.

B. Requirements

As a first step, we have to list the requirements for a drivetrain system to design it. The following requirements are the major factors that influenced the design of a drivetrain system.

1)Functional Requirements

- The drivetrain power transmission should be highly efficient.
- The drivetrain should improve the acceleration and handling.
- The differential should provide better handling.
- The half shafts should prevent torque steer.

2) Fabrication Requirements

- The parts of the drivetrain to be of lightweight and cheap.
- The machine time should be low and should not require any specialized or costly tools to fabricate the parts.
- It should be done through readily available materials and processes.

3) Assembling Requirements

- The transmission system and differential are to be integrated compactly.
- The drivetrain system should be easily serviceable.

4) Safety Requirements

- All the rotating parts should be covered properly with non-perforated plates.
- Cases and guards should not contain any sharp edges.
- All the lubrication requiring parts should be properly sealed.

C. Transmission System

1) Chain Drive

A single fixed ratio chain drive is selected without any gearbox. Since it is an electric motor, torque and speed can be easily variable. This reduces the cost and weight of the car. At the same time, the chain drive can transmit power with fewer losses during the transmission system.
A chain drive is selected for the transmission system for the following key factors.

- The chain drive is a positive drive
- Has efficiency up to 95%
- An easy and cheap transmission system
- Easily serviceable

2) Electric Motor

The chain drive specifications should be decided based on the motor characteristics (Fig. 1&2). Based on our estimation of torque and power [1][2]required we have chosen the AGNI 119R (PMDC) motor has our drive [3]. The motor delivers the maximum torque of 64 Nm and a maximum power of 24 KW.
The transmission ratio is 3.34 and to achieve that the chain drive contains 15 teeth in pinion and 50 teeth in wheel sprockets. The chain used here is 528 chains. It must be noted that a higher the pitch of the chain can carry more load [4]and lower the pitch of the chain can give you more speed.

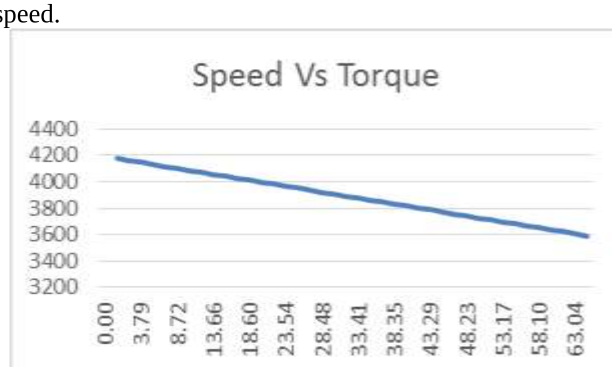

Fig. 1
Speed (RPM) vs Torque (Nm) Characteristics

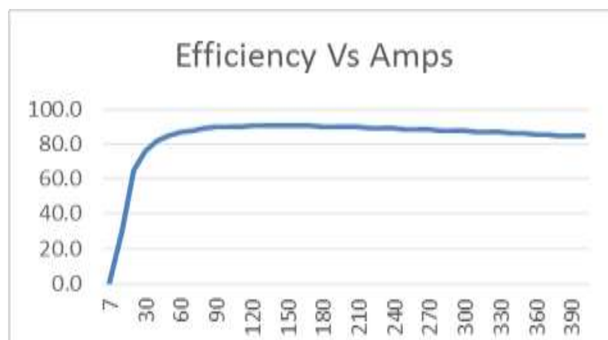

Fig. 2
Efficiency graph

The selection of chain here is optimized between the speed and torque that the motor delivers to the car [5][6].

D. Differential

The differential is a component in the drivetrain system that allows the inner wheel and outer wheel to rotate at different speeds and avoids the slip of the car. This allows the car to have better handling during cornering[7][8]. There are many types of differential namely,

- Open differential

- Limited slip differential
- Locking differential

The limited-slip differential QDF7ZR from Quaife is selected due to the following key factors

- Automatic torque biasing unit
- Since it is a single packed unit. There is no need for any special casing required for differential which reduces the cost
- The delivery time is quicker than the locking differential types and comparatively, the cost is lower than the locking type.

It also to be remembered that the limited-slip differential provides better handling than the open type differential.

E. Drive Axle

The Constant Velocity (CV) axles are selected due to

- Provides better handling
- Have high efficiency

The CV axles are equal in size to avoid torque steer and the weight distribution of the differential is also easy.

III DESIGN

The design of the drivetrain starts with positioning of the motor and connecting it with a transmission system [9].

A. Motor Mount

The motor is in a cylindrical shape that can easily mount over a flat surface. So, the mount which supports its shape is designed. It does not provide rigid support to the motor as well as it also gives an aesthetic appeal. To support the motor and as per the designgoal, it makesit more serviceable.

Fig. 3
Motor mount (front part)

Fig. 4
Motor mount (rear part)

The front part (Fig. 3) holds the motor on the front side and the rear part (Fig. 4) holds the motor on the rear side, in other words, the motor is sandwiched between two mounts and does not allow the motor to move or shake in any of the direction.

B. Differential Mount

The differential is supported on either side with the mount (Fig. 5). That will be connected to the frame of the car using bolted joints.

Fig. 5
Differential Mount

The differential fixed with the mount with the help of RLS12 bearings and allow the differential to rotate.

C. Chain Sprockets

The sprocket with 15 teeth (Fig. 6) is going to sit in the motor shaft and the wheel sprocket of 50 teeth is going to sit in the differential [10].
The pinion sprocket requires the features of key slots and through-hole to fix in the motor shaft.

Fig. 6
Pinion Sprocket

To decrease the weight of the wheel sprocket (Fig. 7) the cut-outs have been given, which removes some material in the sprocket.

Fig. 7
Wheel Sprocket

D. Drive Axle

The drive axles contain a tripod joint at the ends of the shaft which allows the transmission of power even at an inclined angle. The diameter of the shaft is calculated based on the amount of torque that is going to transmit from the differential to the wheels and the factor of safety. Here a 22mm solid steel shaft is used and the tripod joints are filled with moly-based grease to increase the efficiency of axles. There are also some other joints like Ball joint, Rzeppa joint, Weiss joints, etc., to transmit torque at variable angles.

E. Analysis

Once the design has been concluded the model has to be testified with the practical objectives.

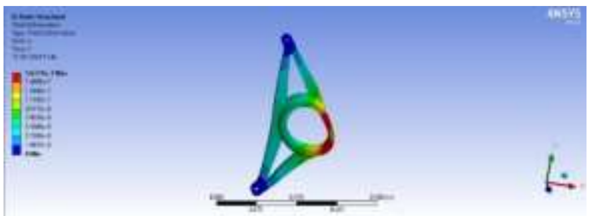

Fig. 8
Analysis of Differential mount

To do that, ANSYS software provides us to check whether our designed model will fit in that system or had to be modified. ANSYS results give accurate results in comparison with other analysis platforms. ANSYS gives accurate results of stress, strain, total deformation, etc[11].

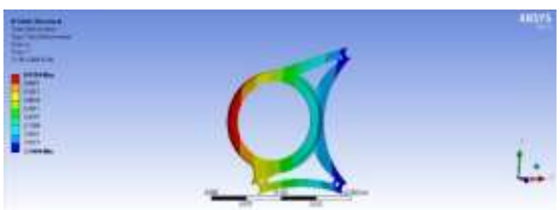

Fig. 9
Analysis of Motor mount (rear)

The analysis involves the differential mount (Fig. 8) and motor mounts (Fig. 9&10) under Structural analysis. To get accurate results fine meshing is done on the mounts. Fig. 8 shows the analysis of differential mount showing stress variations on it [12].Similarly, Fig.9&10 shows the motor mount stress variation.

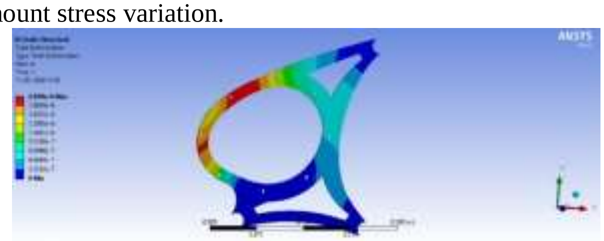

Fig. 10
Analysis of Motor mount (front)

IV MANUFACTURING

Once the analysis phase is completed and got the desired results, the fabrication of parts can be done. The differential mount is fabricated using Aluminium 6061[13]. This aluminium alloy costs comparatively lower than other aluminium alloys and it is proven that it can withstand the load from the analysis reports. If some higher aluminium alloys are used to fabricate, it involves more cost but it offers less weight than aluminium 6061. Hence a trade-off between the cost, weight and strength helps you to decide the suitable material.

The motor mount is fabricated using the 5mm thick MS plate which is very easy to get the shape of our design. The laser cutting process **[14]**is a bit high to produce but you can get the shape of your design precisely with cuts and curves. The ring enclosed in the rear part of the mount can be done through the rolling process and weld it to the rear mount plate.

The sprockets either you can fabricate entirely from mild steel, aluminium, etc., or can use the sprockets that are readily available in the markets, and a machining process can be done on it to fix it in our system. It is also recommended to give some coatings on the sprockets which will avoid rusting and lower the chances of damages to the tooth.

V ASSEMBLY

A. Motor Assembly

Finally, the front motor mount is bolted with the motor and the ends of the mount are welded to the frame of the car. The rear mount only holds the motor at the backside, the motor sits into that ring on the rear mount. But the rear mount is not welded to the frame, instead, it is bolted to the clamps. These clamps are welded to the frame. Hence, the motor can be easily serviced. The pinion sprocket is tightened on the motor shaft (Fig. 11).

Fig. 11
Motor Assembly

B. Differential Assembly

Fig. 12
Differential Assembly

The differential is first fitted with the wheel sprocket using bolts and nuts. Then either side of the differential is fixed with the differential mounts. These are fixed to the frame of the car using clamps that are welded in the frame (Fig. 12)

C. Final Assembly

The final assembly (Fig. 13&14) of the drivetrain is very simple, which is the motor assembly has to fit in the inner side of the frame and the differential assembly is fitted outer side of the frame.
Therefore, can establish a transmission system from motor to differential by connecting a chain. Further, the axles carry the power from the differential to the wheels. The inner CV joint is fitted inside the differential and the outer CV joint at the wheels.

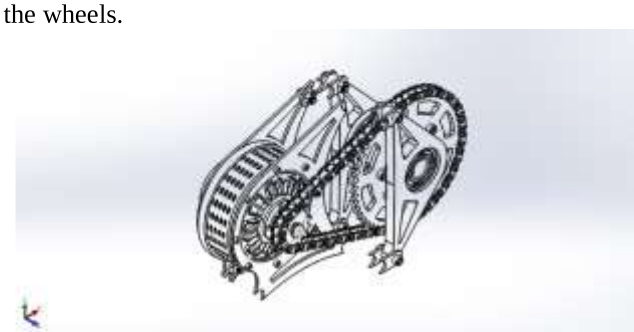

Fig. 13
Final Assembly

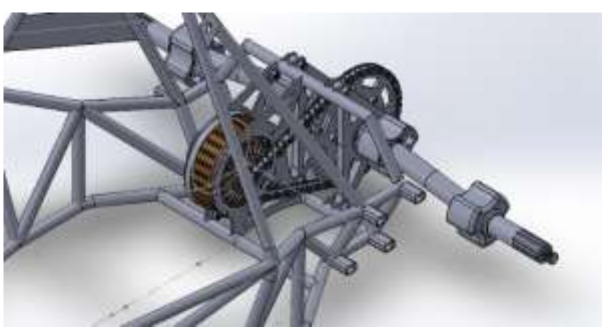

Fig. 14
Final Assembly with the frame

VI CONCLUSION

This drivetrain design is one of the simplest designs, compact, lightweight and without compromising the serviceability of the drivetrain system. The efficiency [15]of the drivetrain is about 91%.
Efficiency of chain drive – 0.95
Efficiency of roller bearings –0.99 (2 bearings)
Efficiency of drive axle – 0.99 (2 drive axles)
Total Efficiency = 0.95x0.99x0.99x0.99x0.99 = 0.91
This drivetrain design in fact started with the concept of floating plate design (Fig.15) where many teams implemented it successfully.

Fig. 15
Floating plate design (reference)

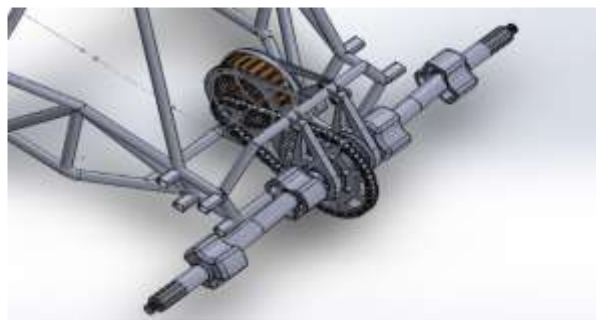

Fig. 16
Final Drivetrain Design

But the main disadvantage of that design is that the complex design and the huge cost and time involved in it. If the team is at beginner level then it will be more crucial design for them. The Hexagonal plate (Fig 15) in the floating plate design is replicated in the frame of the car itself (Fig 16). Hence, the individual fabrication of the floating plate is not required. This saves the huge cost and time.Therefore, our drivetrain design serves as an alternative for the floating plate design concept(Fig. 16) especially maintains the same level of compactness and a simple design for electric formula student car.

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