2012-2013 University of Wisconsin-Platteville Formula SAE Design Report

Introduction

The 2012-2013 University of Wisconsin-Platteville Formula SAE Team is competing in Formula SAE, Nebraska, for the second year. Before going to Formula SAE Nebraska, our team competed at Formula SAE Michigan. Our hard-working and dedicated team has been in existence since 2003. Drivability, reliability, ergonomics, and manufacturability were chosen as specific areas of improvement for this year’s team. In the development of the 2012-2013 competition vehicle, a strong emphasis was placed on the car’s suspension geometry and powertrain to make the vehicle more driver friendly. This powertrain focus is mainly to help improve the overall car drivability and reliability year to year.

Design Goals

Drivability:
The engine must provide maximum torque from 7000 to 9000 RPM.

Reliability:
The vehicle must complete all dynamic events and place overall in the top 50 percent at Formula SAE Nebraska.

Manufacturability:
The vehicle must be designed such that manufacturing of the vehicle is timely, simple, and cost-effective.

Powertrain

This year, the team focused on improving the overall performance of the powertrain over the 2012 car. The primary goal was to better understand the system while increasing performance. The secondary goal for the system was for a target horsepower of 52.2 kw while maximizing the torque between 6000-9000 RPM to improve acceleration out of the corners.

Engine Selection:
For 2013, the team is using a 2007 Yamaha R6 engine. The team chose this engine to keep things consistent from year to year and to utilize the knowledge about the intake, exhaust, cooling and oil systems gained over previous usage of the 2006 Yamaha R6 engine.

Electrical:
The electrical system design incorporates an AEM EMS-4 ECU, which is lighter, smaller and more capable than our previous ECU. This improves the tuning abilities from only fuel tuning to adding timing tuning capabilities. Tuning was done on a Mustang Eddy Current Chassis
dynamometer. Injector pulse widths and ignition advance were adjusted at set RPM and varying load intervals until desirable fuel ratio and horsepower values were achieved. Fuel and ignition tables are based off manifold absolute pressure and RPM to enhance the drivability over last year. The engine is tuned for improved fuel economy under low loads and for maximum torque under high loads. Enrichments for cold starts, air temperature and air pressure were programmed for varying ambient conditions.

**Intake and Exhaust:**
The intake and exhaust are a crucial part of the goal of increasing drivability. The intake manifold geometry is designed to be compact, yet still give even air flow across all cylinders of the engine. The design went through many design iterations using Star-CCM+. The simulations were steady state with approximately half open throttle and the engine under moderate load. This lead to the decision to incorporate a converging diverging nozzle within the plenum to help with pressure recovery after the restrictor. We also included a flow splitter that allows 25% of the flow below it and 75% above it based on flow area.

The intake is designed for maximum power in the 8000 RPM range. This resulted in runner lengths of 184.6 mm. The chosen plenum volume is 1200 cc, two times the engine displacement, which results in a balance between throttle response and steady state power. The intake was Rapid Prototyped from Alulon using SLS making it lightweight and durable. This manufacturing process also allows the design to incorporate complex geometry without compromising manufacturing time, along with a bolt-on design.

Continuing the team’s goal of improving drivability, the exhaust system was tuned to 8000 RPM. A 4-1 runner design with equal length runners was chosen to maximize ease of packing for the system. A runner length of 500.38 mm was chosen to maximize volumetric efficiency at 8000 RPM.

**Fuel System:**
The fuel tank is designed with internal baffles to prevent fuel from sloshing during cornering, which can cause starvation. As they have proven effective in preventing leaking in the past, all fuel lines are connected with simple barb fittings to keep things cost effective and light. The fuel tank is placed behind the seat and mounted in the center for better side to front and side to back weight transfer. The fuel system utilizes a lightweight welded fuel rail to further reduce the overall weight of the system.

**Drivetrain**
The 2013 car improves upon last year’s open differential with a TORSEN differential. The TORSEN differential is a torque biasing differential that allows both tires to receive power. The entire drivetrain assembly provides a significant weight savings of 1.8 kg over last year’s design. In line with our goal to improve the drivability of the car, the TORSEN differential will improve traction during cornering. In addition, a new mounting system was designed using 6061-T6
differential brackets to reduce the weight of the system and improve rigidity over last year. The system was analyzed using Solidworks Simulation and verified by running tests of similar components on last year’s car.

**Frame**

The frame for 2013 incorporated four key dimensional changes and material design changes. The front nose was lengthened by 101.6 mm for better driver ergonomics. The center section was lengthened by 50.8 mm to aid in packaging the components. The front roll hoop has been raised by 25.4 mm to aid in driver egress. Finally, the main roll hoop was narrowed by 101.6 mm to reduce weight and aid in packaging the radiator. Square tubing was added in the rear box frame and the front suspension mounts to reduce tolerance stack-up and to speed up manufacturing. In addition to these key changes, the front suspension mounting bars were spaced farther apart by 25.4 mm to improve the camber curve in the suspension geometry.

**Material:**
The frame is constructed using chromoly 4130 tube steel. Primary benefits are ease of manufacturability, high tensile strength, and the reduced cost of the steel resulted in the selection of the spaceframe design. The team aimed for a frame weight of 40.8 kg or less compared to last year’s 42.5 kg. This was accomplished through careful consideration of member placement and component packaging.

**Pedals:**
The pedal system for 2013 was designed to be a robust, light, and adjustable set of pedals. The design started as a single pedal tray, but after preliminary FEA using Solidworks Simulation, the team designed separate trays for the gas pedal and another for the brake pedal. Previous competition vehicles did not accommodate the wide range of driver heights on our team, so designing pedal tray adjustability was a necessity. The design was optimized through many iterations of FEA to determine a safe design made from 6061-T6 Aluminum that will withstand a braking force of 2000 N with a factor of safety of 2.0.

**Body and Aerodynamics:**
The undertray was designed using Star-CCM+ CFD software. The vehicle was placed in a wind tunnel and the final design was based upon the best coefficient of downforce that was simulated. The design started as a simple 7 degree angle diffuser and was eventually optimized using EES to a parabolic shape that includes tunnels running past the rear of the chassis to ten inches behind the rear wheels. The angle of the lower front plane of the nosecone was optimized to reduce the Coefficient of Drag using Star-CCM+ while still being able to cover the standard impact attenuator used for competition. A few different angles were tried and the final design was decided upon before optimization of the diffuser and undertray occurred.

**Suspension**
The suspension is designed with low weight in mind. At the expense of adjustability, the team designed the suspension to be cost effective, durable, and lightweight. Testing results were balanced with theoretical design to produce the final suspension geometry. This resulted in reducing the wheelbase of 1778 mm from the 2012 car to 1676.4 mm for the 2013 car.
The 2013 car has 4-way adjustable shocks which aid in the rebound compression rates and suspension travel. Suspension geometry was designed to accommodate a negative 1.5 degree camber angle at static ride height and maintain less than 1 degree change through a 3 degree body roll. Mounting points for the suspension are similar to the 2012 car with the exception of the rear which was modified to be similar to the front of the 2012 car for consistency. Also, this change allowed the force vectors from the pushrods to be coplanar with the rocker arms and the shocks reducing the moment created by last year's rear suspension.

For the 2013 car, laser cut tube ends were designed to accept spherical bearings in order to increase the range of motion available and to decrease the stress concentration generally found with rod-end type A-arms. These components also incorporate the pushrod mounting points, thus bringing the line of action closer to the spherical bearing and reducing the bending moment on the A-arm.

**Uprights:**
With weight and strength in mind, the uprights were designed as single piece components. This also reduces dependency on multiple pieces and the possibility of breaking fasteners.

**Steering:**
The steering system uses a manual rack-and-pinion mounted to the base of the frame. The rack is bottom mounted to lower the center of gravity of the rack, pinion, and tie rods. The chosen rack housing is designed to optimize steering responsiveness, allowing minimal steering wheel input to steer the car. The bottom-mounted rack and the placement of the brake calipers resulted in the team using a steering arm behind the wheel center with a 50% Ackermann steering geometry. The addition of a custom steering wheel design improved driver ergonomics.

**Brake System**

**Rotors:**
As the energy of vehicle motion is converted to heat the rotors are required to dissipate a large amount of very heat quickly and efficiency. This heat transfer is achieved through drilled 6.35 mm thick mild carbon steel rotors on the front and rear of the vehicle. The team chose steel because it is resistant to warping and provides adequate heat transfer properties. The rotors are drilled to provide better pad bite and conditioning as well as to reduce weight as much as possible.

**Calipers and Master Cylinders:**
In order to provide adequate braking power, Wilwood Dynalite floating calipers were used in both the front and rear. Aluminum calipers were chosen because they are lightweight and have a relatively low profile when compared to similar open wheel calipers. The car is designed to couple Dynalite calipers with a set of AP Racing 19 mm bore master cylinders front and rear. Together with a Tilton bias adjustment bar, and 4.8:1 pedal ratio, the system easily provides the required braking force to bring the 317 kg car and driver to a stop.
Figure 1: PR13 Top View

Figure 2: PR13 Front View

Figure 3: PR13 Side View
Figure 4 AEM Fuel Map

Figure 5 AEM Ignition Map
Figure 6: Custom SLS Alulon Intake

Figure 7: One Piece Upright
Figure 8: Full Car CFD simulation to optimize down force and drag