ME 338 – Machine Elements

Final Report

Machine Elements RC Car Research, Design, and Fabrication Team Report

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Project Introduction

This project was to design a RC car. This project provided an opportunity to apply the concepts learned in the Machine Elements course to a hands-on design problem. The goal was to create a functioning product that met a number of design criteria and could complete an entire lap around the race track. The project was completed in a team, and created 2-D sketches of the individual systems, a complete 3D CAD model of the design, and a final physical model.

Our design goals for this project were fairly simple. Our main goal and overall design strategy was to make a relatively simple car. What this means is that we attempted to reduce the moving components on the car, because we believed they were the most likely to have problems. This design strategy really helped us focus our efforts to create a reliable car. Another benefit of this simple design is that it lends itself very well to lightweight designs, as fewer parts can translate to less weight. This really helped when optimizing our car. It allowed us to keep the weight low and the reliability pretty high.

Design Calculations and Predictions

Chassis and Axle Design

We decided to use wood as our chassis because it can easily be laser cut to meet our exact design and it would be easy to mount components onto using bolts and screws. Also, our FEA analysis proved that this material would be strong enough to withstand external forces that could be experienced on the track. With our top end speed of roughly 31mph we have a peak impact force of 14.33kN. To gain a more general idea of the forces and stresses on our chassis for a large impact we utilized an FEA simulation. To find the force experienced, we applied a representative distributed load to the chassis to simulate a head on collision. From the FEA simulation, we found the maximum deflection of the chassis. From there, we utilized the maximum deflection and the representative load, to find the chassis stiffness by treating it like a spring and using Hooke's Law. Now that we had an estimate for the chassis stiffness, we could back out the actual impact force and stresses for our model at the max velocity. The final stress value was found to be roughly 15MPa which is lower than the yield strength of the chassis material, birch plywood. Example calculations of this process can be found in Appendix 4. The second component of this design check was to come up with an axle design. For our axle design, we chose to use a rear axle to drive the car, which would sit below the chassis and connect to the wheels by running through bearings.

Steering Design

We decided to go with an Ackerman steering system due to the simplicity of its design, staying true to our design ideology. For the steering system we used two separate steering braces, one on each side of the front chassis, that would connect to each other via linkage allowing us to use a single servo to rotate both braces simultaneously, as seen in Figure (1) in Appendix 2. Through the use of a second linkage we are able to use the servo to rotate both steering brackets. This second linkage attaches straight to the servo head from an offset distance on the right side steering bracket, seen on Figure (2) in Appendix 2, the offset distance depended on the amount of turn angle we desired as well as the location of the servo on the chassis. In our case we went with a 30° turn angle and located the servo near the front end of the chassis.

As a part of the steering analysis we also calculated the turn radius. Our design criteria for the turn radius was that we wanted a car that could easily turn around completely within the width of the track (in case we collide with other vehicles or move off of our desired path around the track). Since the track is approximately one meter wide we wanted our turn radius to be well under twenty inches. For our calculations we chose to estimate the turn radius for the outside wheel since that is the most directly relevant parameter to indicate if our car can maneuver around the track and not exceed the one meter width boundary. To estimate this parameter we used the following equation:

$$r = \frac{W}{tan(\alpha)} \tag{1}$$

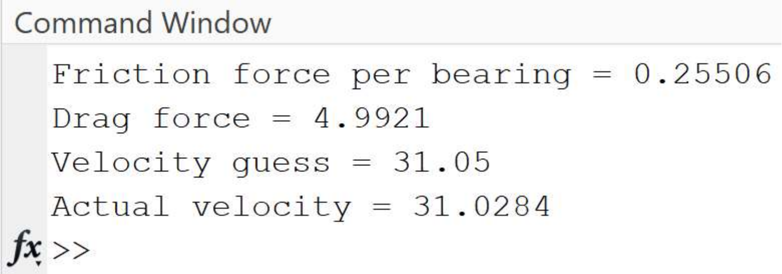
In equation (1) “r” is the turn radius, “W” is the wheelbase, and alpha is the turn angle executed by the servo motor. For our RC car, the wheelbase was 8 inches and we trimmed our steering control to allow for a maximum turn angle of 30°. With these base parameters we calculated a turn radius:

$$r = 13.86\ in$$

This value falls well within our design criteria of less than twenty inches, and we estimated that it would fit the race track and allow us to respond to vehicle collisions quite well.

Drive Design

For our drive design we wanted to calculate the top speed of our RC car to ensure we had an appropriate balance between acceleration and a large enough top speed to move around the track quickly. We wrote a MATLAB program to calculate the max velocity because it involves guessing a speed and checking the output in an iterative process. Below is an image of the command window in MATLAB after the program has solved for the velocity.



```
Friction force per bearing = 0.25506
Drag force = 4.9921
Velocity guess = 31.05
Actual velocity = 31.0284
>>
```

The code effectively works by looping over velocity guesses beginning with 1mph and increasing by 0.01mph until the actual velocity and guessed velocity are equal. To begin, once a velocity value is guessed, the program calculates the drag force based on a scaled model of an F1 car in a wind tunnel. Then it calculates the friction in each bearing given a mu of 0.2, a mass of 1.3kg, and gravitational acceleration of 9.81 m/s^2. These two negative forces are summed, divided by two, and then multiplied by the wheel radius of 0.03175m to find the required torque at each wheel. Then, the program multiples the required torque at the wheel by the efficiency to get the motor torque. From the linear equation for the torque speed curve the motor angular output speed, Wm, can be found, and after using the transmission ratio the program backs out the angular wheel speed which can be multiplied by the radius to find the linear velocity. Finally this value is compared to the guessed value and when the two are equal the program loop stops.

In addition to the max velocity, we also wanted to calculate the ideal maximum acceleration using Newton's second law on the acceleration force. The acceleration force was calculated through a force balance which considers the force acting on the wheels due to the motor and forces acting against the wheels (used same forces from velocity calculations, i.e. friction, drag, etc.). The final value for the ideal acceleration was about 7.3 meters per second squared. We found the ideal acceleration to be reasonable and were satisfied. The full calculations can be found in Appendix 3.

To determine the optimal train ratio, the track length and type was considered. In this case, the track contained two semi circular turns and two relatively short straightaways. For this reason, we felt that top speed was less of a priority than acceleration. In addition, the motor itself already spun at a relatively high angular speed. Taking these factors into account, to prioritize acceleration, we chose a train ratio of 13/36 which equates to a torque ratio of about 2.76. These ratios seemed reasonable and were similar to those of standard RC cars.

For our drive train design, we decided to use a belt system rather than gears because we decided a belt would be more stable and go with our design goal of being simple. With hits and external forces, gears are more likely to become misaligned, while the belt material can take vibrations and forces and not fail. We decided to go with a timing belt instead of a flat or v belt because of the higher efficiency due to the teeth on the belt, and again, it is more likely to stay on. Also, not much tension is required for a timing belt, which helps make manufacturing easier. Once we determined our desired torque ratio, we found a timing belt on Amazon that met our requirements.

Manufacturing

Our car manufacturing process was designed to align with our design goal of being simple. Our plan was to start manufacturing early, build the car exactly as planned, and then have time to make last minute adjustments if necessary. We were able to execute this well.

The chassis was built using the laser cutter in the Texas Inventionworks. We simply designed the chassis in solidworks, made a vector in the laser cut software, and cut a piece of wood to make our chassis. We ended up doing this twice to make design improvements on our chassis.

The components we assembled by creating mounts for each component and then screwing/bolting the mount to the chassis. Each mount was designed in solidworks and printed in the Texas Inventionworks using a 3d printer. We use settings on the printer to make the print as strong as possible to avoid failure. 3-d printing allowed us to easily make mounts that fit the components perfectly. We obtained the necessary bolts, screws, and washers from Breed & Co.

The motor and battery were simply mounted onto the chassis using 3d printing mounts and screws from Breed & Co. Each was strategically placed to balance the weight on the vehicle and allow for connectivity between the components. The 3d printed motor mount allowed the motor to be screwed into the mount, while the battery was zip tied down onto the mount and chassis to keep it secure.

The chassis was built so that the servo could sit in a hole towards the front of the chassis and drive the steering system to lower the center of gravity and keep the components contained. The servo simply screwed down into the wood chassis.

The acrymen steering system was one of the harder parts to assemble. Two different wheel mounts were created for the front wheels. Both were secured by bolting onto the chassis so they could freely turn, but one was designed differently to allow the steering linkages to affect the wheel direction from the servo. These linkages were 3d printed and screwed tight enough into the system to not fail, but loose enough to allow the steering system to pivot freely.

The wheels were connected to each wheel mount using 3d printed hubs that bolted to the wheels. These hubs spinned freely in skate-board bearings that fit tight in the wheel mounts. Each wheel needed to be bored out a little bit with a drill so that the proper bolts would connect the hubs to the wheels. This resulted from the lack of preciseness in 3printed components. The rear wheel mounts were screwed onto the wood chassis.

The drive train was assembled by wicked-machine-shop-master Jake Hyland, who cut down and tapped our axle on the ends to allow the rear wheels to screw tightly. He also jerry-rigged a diagonal set screw for the belt pulley in the machine shop so that the belt would turn the circular axle.

Race Day Performance/Results

On race day our car performed very well. All of our systems functioned properly and our car completed a whole lap for credit and went on to win our heat of the racing competition. Our chassis held up even when it suffered a large impact load before the race, due to a receiver error, while we test drove the design, which aligned with our FEA predictions of a high speed collision. Our steering system functioned flawlessly and the turn radius fit the track better than expected. We were able to maneuver around other vehicles when there were obstructions, or backmarkers, just like we predicted. We had good top end speed and acceleration as well as having a very good weight distribution which allowed the car to handle incredibly well and be very responsive. Our car then performed very well for another 3 laps without any necessary adjustments during our second round of racing, before being demoted to third after finishing second. Overall we believe that our design performed very close to how we wanted it to.

Discussion

During this project we learned many lessons about project management and engineering design. I think one of the largest lessons we learned was to not procrastinate. That sounds like it should be really simple, but trying to meet deadlines becomes stressful and doesn’t allow us too much time to make sure everything is correct. With greater foresight and time management we could have focused on perfecting our systems rather than simply getting them operational. Another lesson we learned is to always have a backup plan in case things don’t workout. We had our axel go missing in shipping and had to make lots of design changes due to that issue. It would have been wise to begin working on a backup axle design earlier to make deviating from our original plan easier. We also learned that part tolerance is very important. Lot’s of our 3D prints didn’t come out to size meaning we had to modify them at a later time to fit the car.

Overall I think that our approach to this design challenge was very well suited for the competition. Our simple, but robust design proved to be very successful. I think a change we could have made is planning out hardware before producing parts, rather than the other way around like we did. This would hopefully allow us to have better fitting parts, and do less guessing and checking with the fitments. One last thing we might do differently if we were to do it again would be to change our belt system. The gear ratio was very good, and the system itself was pretty usable. The issues we had were the large pulley had no set screw, making it hard to attach, and the belt it came with was way too small, meaning we had to find another one that is compatible. Overall the belt was a good idea, but needed a better execution.

Sustainability

As per ABET requirements we looked into the sustainability of our design. Using wood for our car chassis enhanced the sustainability of our design since wood is a renewable resource. In contrast, using aluminum for our rear axle detracted from the sustainability of our design since aluminum has a high energy content, and because we laser cut a chassis before we finalized the chassis design, we ended up needing to laser cut two chassis instead of just one, which wasted material. If we had more time we could have creatively determined a different material to use for our rear axle or we could have waited to finalize our chassis design before laser cutting so we did not have to print an extra one. The potential impacts on the global environment from this redesign would be to save energy which would lower emissions from energy production, and to save the extra wood material which decreases the volume of work for recycling centers, which helps with overall recyclability.

Appendices:

Appendix 1: Turn Radius Calculations

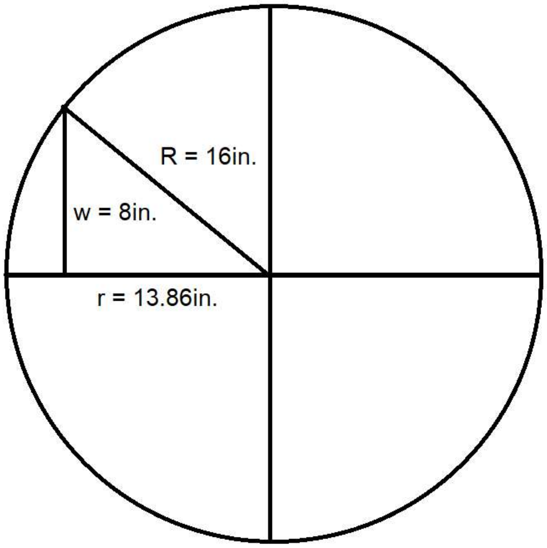
Turn radius equations:

$$\text{Servo angle range: } 60^\circ \Rightarrow \alpha = 30^\circ$$

$$r = \frac{w}{tan(\alpha)}, R = \frac{w}{sin(\alpha)}$$

$$TR = \frac{wB}{tan(\alpha)} = \frac{8in.}{tan(30^\circ)} = 13.86in.$$

Turn radius diagram:



Appendix 2: Reference Photos

Figure (1): Ackerman Steering System, Joint linkage

Figure (2): Ackerman Steering System, servo head mount

Appendix 3: Acceleration Calculations

Force on Wheels

$$F_w = \frac{2T}{D} \tag{1}$$

Stall Torque: 0.196N·m
Wheel Diameter: 65mm = 0.065m
Drive Train Ratio: $\frac{13}{36} \Rightarrow$ Effective Torque = $\frac{36}{13}$
Assumed Efficiency = 0.90

$$F_w = 2\frac{\frac{36}{13}(0.196N \cdot m)(0.90)}{0.065m} \approx 15N$$

Force of Acceleration

Forces against wheel ($F_{against}$): 5.67N

$$\Sigma F = 0 \Rightarrow F_{accelerate} = F_w - F_{against} \tag{2}$$

$$\rightarrow F_{accelerate} = 15N - 5.67N = 9.46N$$

Acceleration

$$F = ma \Rightarrow a = \frac{F}{m} \tag{3}$$

$$m = m_{servo} + m_{receiver} + m_{controller} + m_{battery} + m_{motor} + m_{chasis} \approx 1.3kg$$

$$\rightarrow a = \frac{9.46N}{1.3kg} \approx 7.28\frac{m}{s^2}$$

Appendix 4: Chassis Stress Calculations

Impact Force

$$F = k\delta \Rightarrow K = \frac{F}{\delta} \tag{1}$$

From FEA, F = 150N and $\delta \approx 1.4 \cdot 10^{-4} m$

$$k = \frac{150N}{1.4 \cdot 10^{-4} m} \approx 1.07 \cdot 10^{6} \frac{N}{m}$$

Impact Force:

$$F_i = V\sqrt{\eta m k} \tag{2}$$

Let V = 20mph $\approx 9\frac{m}{s}$, m = 1kg, $\eta = 1$

$$\rightarrow F_i = 9\frac{m}{s} \cdot \sqrt{1(1kg)(1.07 \cdot 10^{6}\frac{N}{m})} \approx 9,316N$$

Stress

$$\sigma = \frac{F_i}{A} \tag{3}$$

Let A = 3in x 0.5in = 9.68 $\cdot 10^{-4} m^2$, F = 9,316N

$$\sigma = \frac{9,316N}{9.68 \cdot 10^{-4} m^2} = 9.63 \cdot 10^{6} Pa$$