Vehicle Differentials

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Abstract

Utilizing the core concepts taught in the Computer Science 285 course we produce a physical model of a vehicle differential that can be used as a pedagogical tool.

1 Introduction

I realized that gears assemblies were a natural choice while exploring ideas for a final project which would touch upon the core concepts of the course, yet still be tractable given the time constraints. Gear systems are built around the idea of symmetry, which lends to procedural design directly; additionally, their physicality touches upon the need for accurate solid modeling with rapid prototyping allowing for real world testing as well as haptic interaction. I have a particular interest in performance motorsport and the key differentiator (excuse the pun) between vehicles of high caliber is the design of the differential assembly, so I decided that this was the type of gear assembly I would pursue.

Vehicle differentials allow for a common power source to apply varying torque to many outputs, usually two for rear wheel drive or four for all wheel drive. This varying torque and resulting rotation is present at any point in which the vehicle is turning (given the different rate at which an inner and outer wheel must turn in order to remain in contact with the ground) or when a wheel is 'slipping', meaning it has lost complete or partial contact with the ground and is now unloaded.

The core of a differential is a planetary gear system, with a planet gear per axle and one or more sun gears to drive the motion from the power source. Many advanced

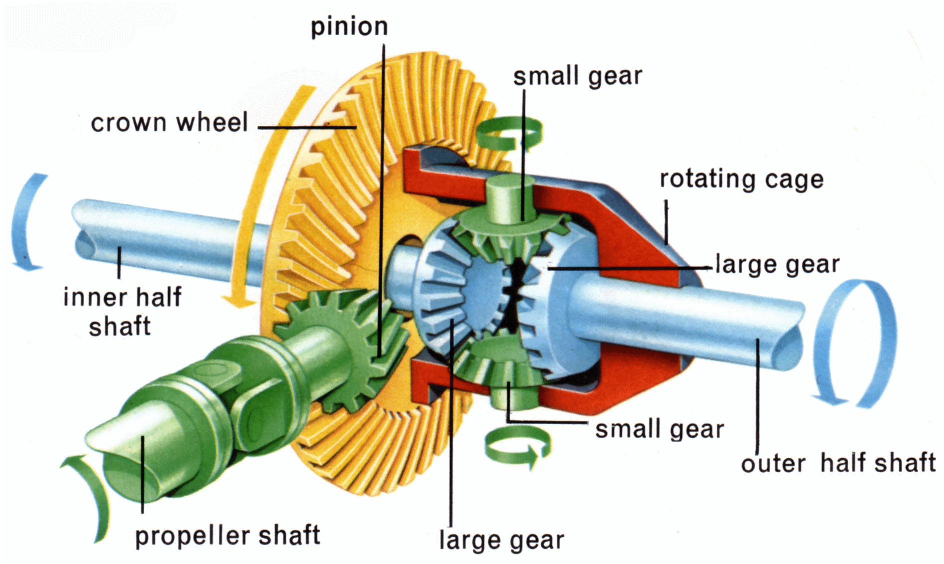


Figure 1: An open differential

designs (limited slip and Torsen differentials) exist that allow for specific types of power transfer as well as optimization, but given the time constraints, I chose to pursue the simpler but still effective open differential design (which has regained popularity recently when used in conjunction with computer braking systems). This open differential has two sun gears driving two planet gears arranged in a square as seen in Figure 1.

2 Background

Gear design asks for intermeshing teeth and a constant velocity ratio between the gears in question. There are many gear tooth profiles; two that are commonly used are the involute and the cycloid, the involute being easier to design was the determinant factor in this project. The involute also allows for a single contact point along the Pressure Line which results in smooth turning.

The determinant in gear tooth sizing is clearance for the top land to fit into the bottom land, as well as the addendum to fit maximally into the dedendum. Often the tips of teeth are clipped to allow for ease in manufacturing. These aspects are illustrated in Figure 2.

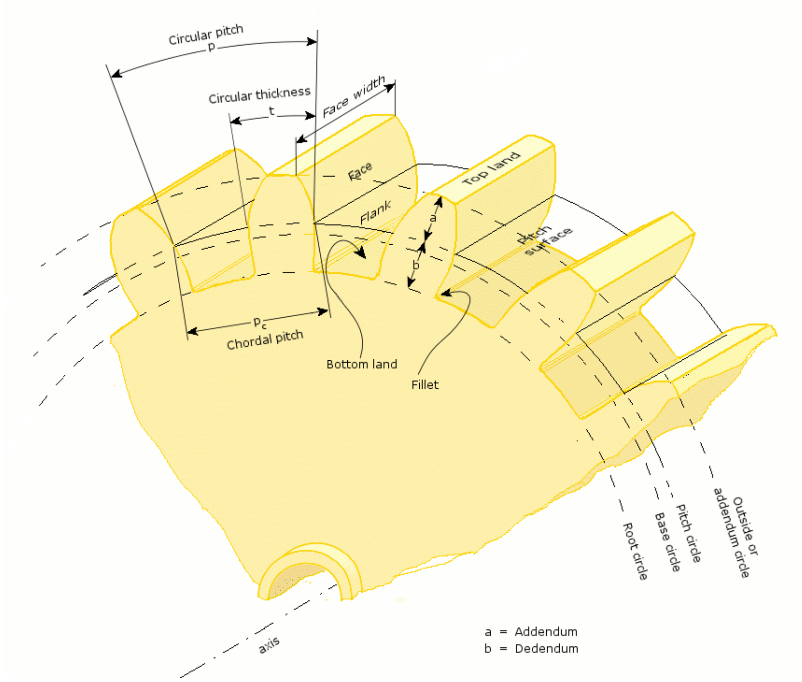


Figure 2: Gear Terminology

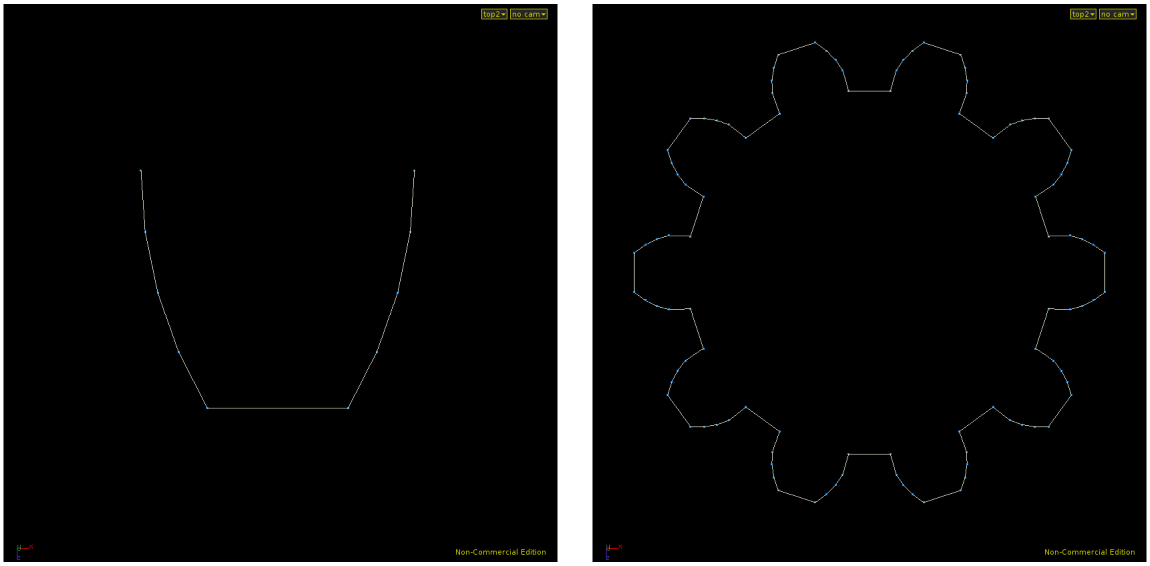
3 Process

To take advantage of the inherent symmetry that gears provide, it was obvious to start with the 'tooth' of the gear. In order to model the tooth, a involute curve profile needed to be drawn. This profile can be generated by the following parametric equations:

$$x = a(\cos t + t \sin t)$$

$$z = a(\sin t - t \cos t)$$

The curve was sampled at five points; this discretization was deemed sufficient for FDM fabrication. This curve was then mirrored and joined to produce the tooth, as seen in Figure 3(a). The tooth was then instantiated on points arranged in a circle, and then oriented to face outwards as seen in Figure 3(b). The gear face was then duplicated, scaled, and transformed to provide two surfaces to loft between as seen



(a) Involute Tooth

(b) Involute Gear

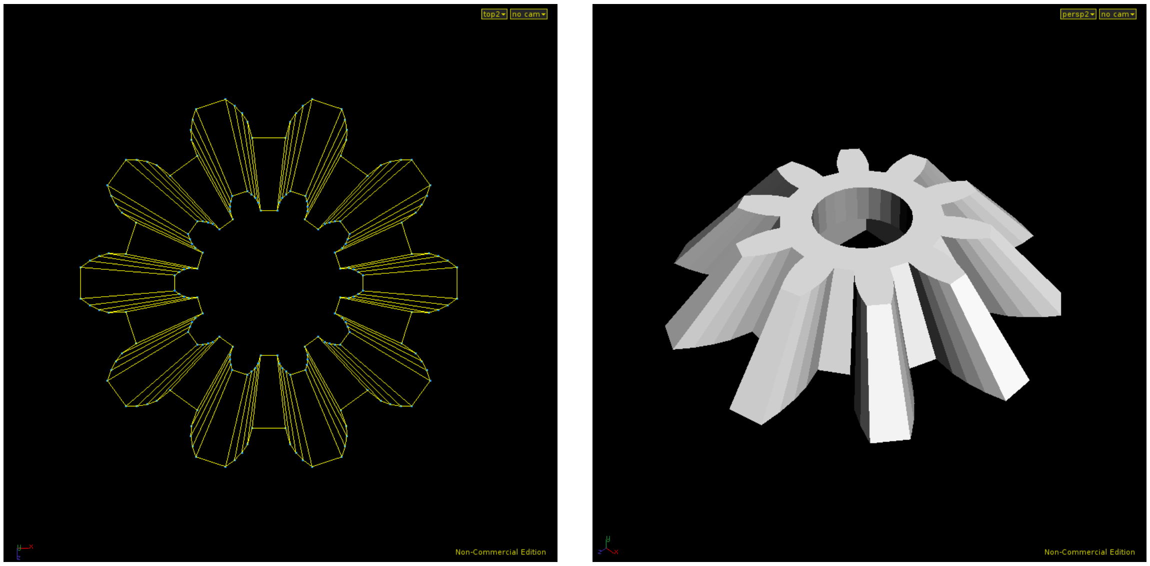
Figure 3: Procedural Design

in Figure 4(a). Some CSG operations were necessary to accomodate the shaft and rod assembly parts; the final gear can be seen in Figure 4(b).

Finally, STL files were exported for FDM from the 3D application through a small python program.

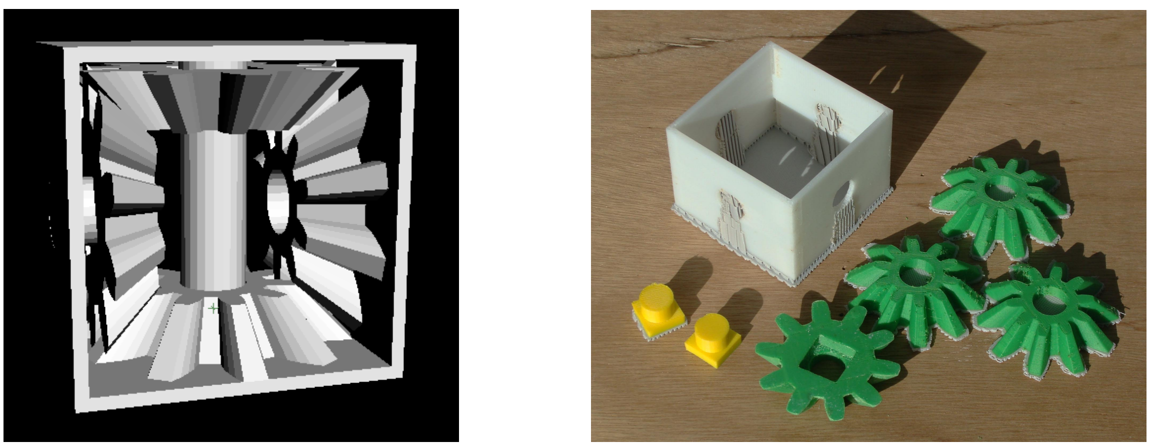
4 Results

As you can see in Figure 5(a), the final assembly of the differential gear is made up of four of the gear shapes as well as a cage and some connecting rods and shafts that allow the assembly to function. The final FDM parts are shown in Figure 5(b); the yellow parts are the shafts connecting the planet gears to the cage. Additionally, a final procedural animation was also created to demonstrate the motion of the final differential assembly.



(a) Lofted Geometry (b) Final Gear

Figure 4: Gear Design



(a) Viewport render (b) FDM parts

Figure 5: Final Results

Acknowledgments

Thank you to Professor Sequin for the tip on involute teeth.