Team 7110X

Vex Robotics Competition

“Make It Real” CAD Challenge

01 December 2020

Compact Planetary Transmission

ABSTRACT

The Compact Planetary Transmission (CPT) is an adaptive, variable-ratio gearbox designed using Autodesk Fusion 360. It takes 2 inputs: One high-strength axle input into the sun gear, and one standard-strength axle input into the reinforced carrier assembly. By varying the relative speeds of these elements, the output gear ratio can be manipulated to allow for optimum drivetrain performance across a wide range of speeds.

TASK

First, we established our design criteria. Transmissions (primarily differential-based designs) have been used in VRC in the past, however, they have fallen out of favor due to their relative lack of efficiency, added complexity, and bulk. Therefore, our design needed to be efficient, practical, and easy to implement; compact, yet robust. Most importantly, the design needed to be able to outperform statically geared drivetrains while preserving internal space on the robot.

BRAINSTORM

No one on our team had previous experience with CAD gear design, so plenty of brainstorming and research needed to be done. Initially, our team did not favor an epicyclic design, due to added complexity. However, the versatility of an epicyclic gearbox proved to be incredibly useful in the prototyping process, so our team began to brainstorm how a planetary gear set could be used to create a transmission.

FUNCTION

The method our team settled on is fairly intuitive. Typically, in an epicyclic gearbox, one of the three inputs is fixed (i.e. sun is driven, ring is fixed, carrier is output). We decided to take two inputs to our gearbox. This allows us to either power or fix different inputs, depending on the desired drive mode. When high torque wasn't needed, the sun and carrier would spin in opposite directions. This resulted in a 160% increase in top speed compared to ungeared drivetrains, but more importantly, distributed the workload between two motors. Thus, the robot could be driven both more aggressively for a longer duration, with a lower risk of a motor overheating.

However, when torque was needed (such as in a push-battle or plowing through field elements), the carrier motor would fix its position using a hold command. This allowed the sun gear to multiply its torque across the planet gears, resulting in 170% greater torque performance at the wheel than standard ungeared drivetrains. A downside of this is that since only one motor is doing active work, that motor could be subjected to additional heating compared to the static motor. Also, the speed of the robot in this "torque mode" would be significantly limited, since only one motor is doing work on the robot. These were judged as acceptable sacrifices, as this lower speed would only be necessary for very short time intervals.

COMPUTER ASSISTED DESIGN

After completing a general design plan, prototyping began in CAD. We began with a simple, loose-tolerance gearbox that was designed using Ross Korsky's helical gear Fusion 360 plugin. This "herringbone" gear structure was used because it greatly improved the structural stability of the gearbox. The chevron-shaped teeth served to lock the gearbox together, so the resulting assembly can be printed as a single part. Additionally, the gears stay coplanar without extra support. Though this makes the design less adaptable, and arguably less Vex-friendly, this was judged as a superior choice due to the weight, size, and simplicity of a one-piece gearbox.

The prototype began as a stand-alone, Vex-independent part. However, after prototypes were printed on Makerbot PLA printers, significant frictional heating between the gearbox and casing caused parts to fuse after prolonged use. This problem was solved by integrating steel axles into the carrier assembly to act as bearings for the significant loads the gearbox would be experiencing from the motors. Later, we encountered problems with torque multiplication and gear skipping; our design wasn't sturdy enough. We fixed this problem by adding a fourth planetary gear, adding 4 teeth to each planet, and subtracting 8 teeth from the sun gear. This effectively tripled our stall torque by increasing the theoretical max torque, as well as providing a larger contact area to support that extra torque. A final prototype was established using an integrated, modified Vex 24-tooth sprocket as the output. This was accomplished by importing the Fusion 360 CAD files from the Vex website and adapting the sprocket to fit around the output ring.

Finally, animations were created of the epicyclic gear train to show that the gears were capable of meshing correctly. This was done by creating joints around all applicable rotation axes and modifying the rotation constants to prove that the prototype rotated freely.

PRACTICALITY

Our design team used our first prototype to conduct a feasibility study, investigating whether the design could be successfully implemented in practice. Initial results were less than effective, with significant efficiency losses due to poor tolerances and frictional heating. Later prototypes, however, tackled this problem by using existing Vex-standard parts, in addition to distributing were far more successful and fully accomplished the task.

LESSONS LEARNED

Before this season, no one on our team knew how to use CAD software. This challenge provided an avenue to learn invaluable engineering skills, including CAD, but our team also gained an appreciation for the value of an early prototype. One of the mistakes we made was we waited until our research was complete until we began our first print. This proved to be a mistake, as we had many issues with the design in the early stages that additional research likely would not have prevented.

Additionally, we learned that there are often simple solutions to complex problems. One of the issues we were having in the early stages was how to quickly model geometrically accurate helical gears in Fusion 360. We struggled with this problem for a while, before we realized that this was not a unique problem, and were able to download a simple plugin that did most of the brute force work for us. This tool made our prototyping process much more rapid, allowing changes in gear size to be made in relatively little time.

Participation in this CAD challenge was a highly beneficial and educational experience for everyone involved. I'm sure our team will continue to use CAD in our future as a prospective team of engineers, and every one of us is grateful for the hands-on experience this challenge has given us.