A Mid-Range Cycloidal Gearbox Design

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Abstract

Gearboxes are used for a wide variety of applications in engineering, as they are an efficient means of increasing torque output of a motor. In robotics, cycloidal gearboxes are often used for their minimal backlash and high torque at relatively compact size (Garcia 2020).

However, cycloidal gearboxes generally have a higher cost compared to other types of gearboxes due to their need for precision manufacturing, which makes such designs accessible mostly to well-funded laboratories and R&D departments. Cycloidal gearboxes are also typically extremely heavy and high torque. On the other hand, hobbyists have designed their own cycloidal gearboxes that are able to be manufactured with a desktop 3D printer – which are well-suited for low torque applications and demonstrations. This leaves a gap between the two extremes of cycloidal gearbox use cases and manufacturing that is open. In this area, potential gearboxes could satisfy the needs of makerspaces and labs working on robots not quite suited for industry, but requiring higher performance than those that are entirely 3D printed.

In this project, we present a design for a low-backlash cycloidal gearbox that can withstand at least of 3.3 Nm of torque at input and 56 Nm at output that is easy to manufacture with machines often found in a makerspace. This design is largely made from delrin sheets, steel rods, and commercially available bearings. The total cost of materials is approximately 50 dollars per gearbox.

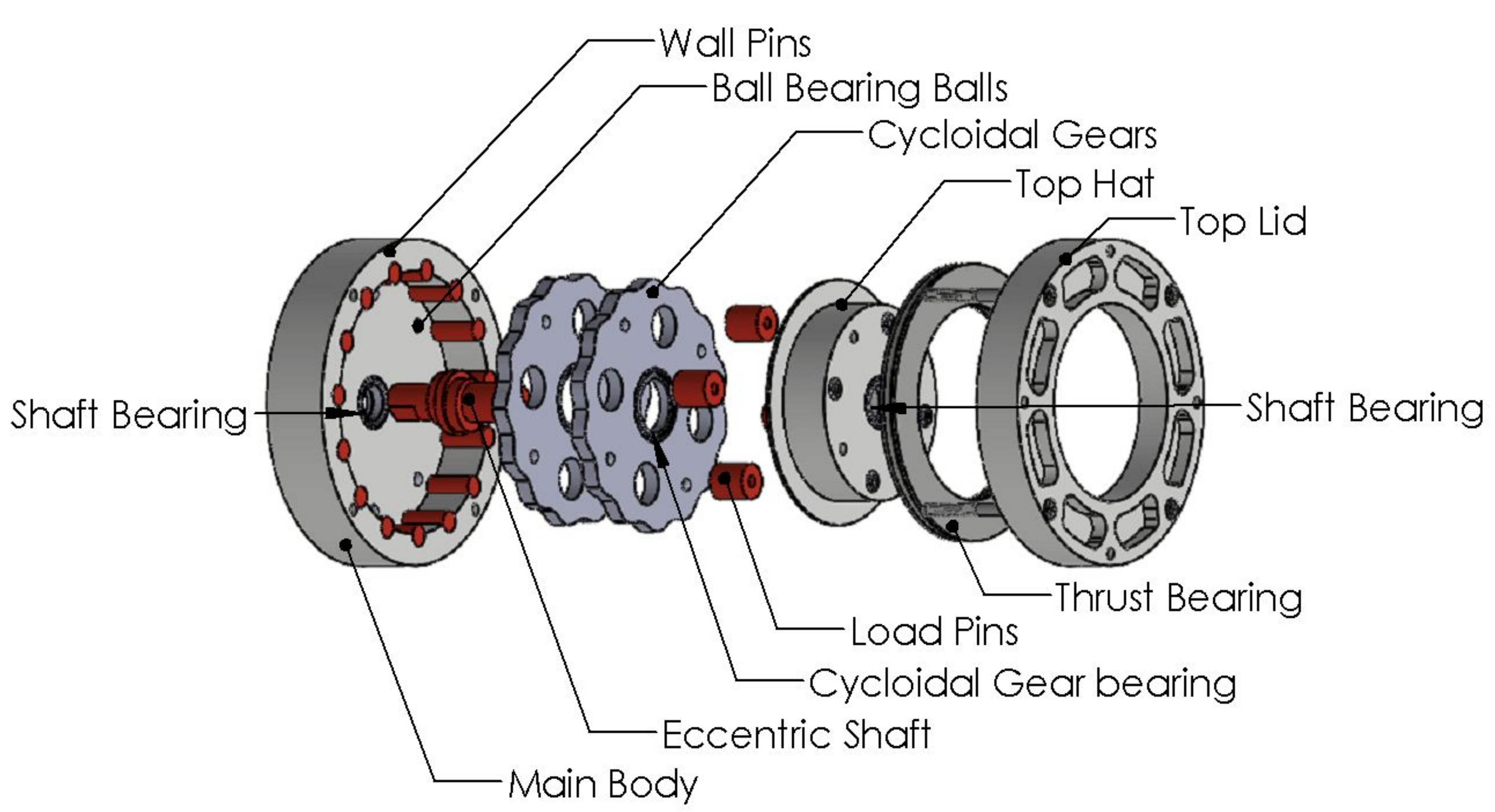

Figure 1. Exploded Cycloidal Gearbox Diagram

Research Gap

- Commercially available cycloidal gearboxes are usually designed for industrial use, which makes them relatively expensive and over-engineered for moderate-performance use cases.
  - Technical specifications are often held behind quotes by manufacturers, presenting an additional barrier to academic, hobbyist, and rapid prototyping use.
- Hobbyists have engineered various cycloidal gearbox designs that can be manufactured just using a desktop 3D printer and relatively inexpensive hardware.
  - While such designs are considerably accessible, they lack the durability and torque potential required for more advanced projects.
- This leaves a clear gap between these two extremes of cycloidal gearboxes.
  - **Labs and student engineering teams often require cycloidal gearboxes more capable than 3D-printed ones, but not as costly and precise as industrial designs**.
- This project addressed this gap by putting forth a mid-range cycloidal gearbox design that offers reasonable torque capabilities, durability, and manufacturability at a relatively low cost

a - dynamic testing *b - static testing*

Figure 2. Motor Testing Rigs

Design and Manufacture

- Solidworks 2024 Student was used to design the gearbox. The exploded diagram of the gearbox can be seen in Fig. 1.
- The reduction of this gearbox is 14.
- The main materials used in this project are high-strength acetal (Delrin) and 4140 steel.
  - These two materials were chosen because of their extremely low coefficient of friction (0.1-0.3)
- The **Main Body**, **Cycloidal Gears**, **Top Hat**, and **Top Lid** were lasercut on a Rabbit HX-1920SE laser-cutter out of 3/16" thickness Delrin.
- The **Main Body** and **Cycloidal Gears** required additional machining to create the hemispherical recesses for 3.5mm ball bearing balls.
  - To do this, a ⅛" ball-end-mill on a Grizzly G9901 Mill was used.
- The **Main Body**, **Top Hat**, and **Top Lid** were made by stacking and super-gluing multiple laser-cut layers together.
- The **Wall Pins**, **Load Pins**, and **Eccentric Shaft** were machined out of 4140 steel on a Pratt & Whitney Model C lathe.
  - As the **Eccentric Shaft** included off-center features, additional jigs were made out of aluminum on a mill that facilitated the shaft's fabrication on a lathe.The eccentric shaft also required the use of the mill to create its rectangular input profile.
- The **Bearings**, **thrust bearings**, and **ball bearing balls** were purchased online. For specific information about off-the-shelf components and materials, see Fig. 3.

Testing Rigs

- For both dynamic and static testing, a custom aluminum bracket holding a M8325s 100KV ODrive motor with a ODrive S1 encoder was used (Fig. 2.).
- For dynamic testing, the bracket was held in a mill vise (Fig. 2.a).
  - A Python script was run to accelerate the gearbox at various input torques (up to 3.3 Nm) and gather velocity and time data.
    - A large steel disk of a known inertia was attached to the motor, such that output torque could be calculated from extracting acceleration data from velocity vs. time graphs.
- For static testing, the bracket was held in a robot leg test rig and secured with ratchet straps (Fig. 2.b)
  - Part of a robot leg was attached to the gearboxes output and pressed against a scale to measure force.

Item	Link	Cost	Total Number included in purchase	Amount needed for gearbox	Total Cost
Delrin sheet	https://www.mcn	74.44	24	7	21.71166667
Cycloidal Gear Bearing	https://www.ama	9.59	10	2	1.918
Shaft Bearing	https://www.ama	8.29	10	2	1.658
Thrust Bearing 55ID	https://www.ama	8.79	2	2	8.79
Ball Bearing Balls	https://www.ama	5.69	100	16	0.9104
Wall Pins	https://www.mcn	11.23	25	15	6.738
Output Pin Stock	https://www.mcn	10.13	22	4	1.841818182
Eccentric Shaft Stock	https://www.mcn	16.8	5	1	3.36
m3 nuts	https://www.mcn	2.81	100	12	0.3372
m3x45 screws	https://www.mcn	4.75	25	4	0.76
				Total cost =	48.03

Figure 3. Bill of Materials

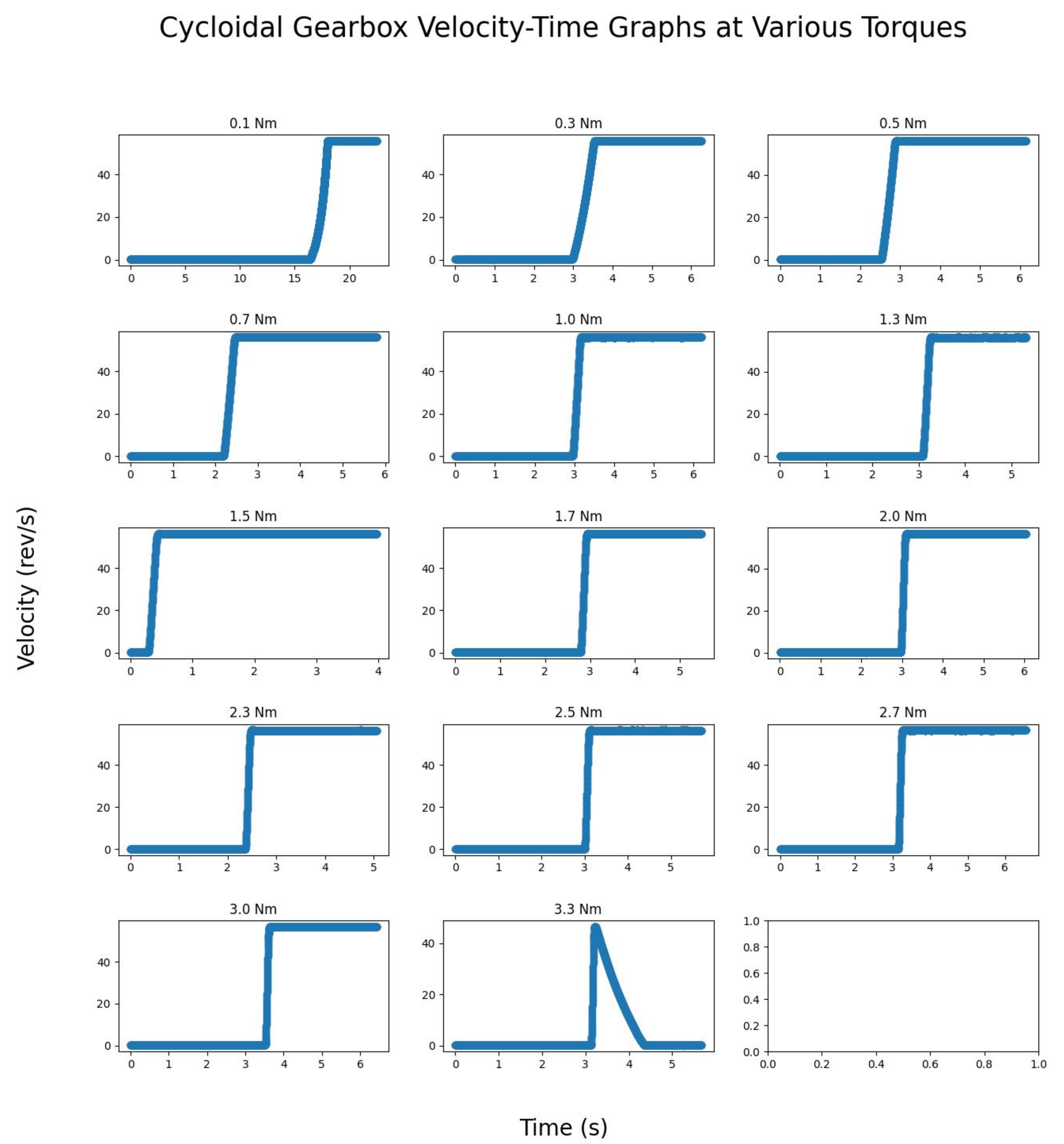

Figure 4. Velocity-Time Graphs

Continuation

- The testing rigs were used to collect static and dynamic (fig. 4) testing data, however, suspected issues with the ODrive Motor calibration resulted in unreliable data.
  - The motor bracket used to hold the gear motor assembly was significantly over-constraining the motor – which likely resulted in encoder magnets becoming misaligned.
  - We could not remedy this within our time frame, but are aiming to redesign the motor bracket and repeat dynamic and static testing.
- Aside from redesigning the motor-holding bracket, we also want to further develop the gearbox itself.
  - Although we do not have efficiency data at the moment, we want to find methods to reduce internal friction even further and eliminate existing backlash.
  - FEA tests can also be run to determine which components need reinforcement, and from which mass can be removed.
- This gearbox is a subproject under the Carnegie Mellon Robotics Club's quadruped robot project, which will utilize a total of 12 cycloidal gearboxes.
  - Gearbox efficiency data will be used to run simulations in Gazebo and test walking controller and robot design.

Sources

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