3D-PRINTED GEARS

MODULAR - VERSATILE - OPEN SOURCE

Engineering Project (Mechanical)/Design 1 - DE6399 and MG6136
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INTRODUCTION

Gears are an essential part of mechanical engineering, allowing speed to be exchanged for torque and vice versa. However, due to gears' demanding operational conditions and often-complex, precise geometry, 3D-printed gears of adequate performance are challenging to design, fabricate and refine.

PROBLEM STATEMENT

Our project goal is to design a family of gears and gearbox assemblies that are optimized for 3D-printing regarding accuracy, ease of use, strength and hardiness, efficiency of print time and materials, and acceptably low-loss performance, with the hope of increasing the available knowledge pool on 3D-printed gears within the open-source community.

CONSTRAINTS

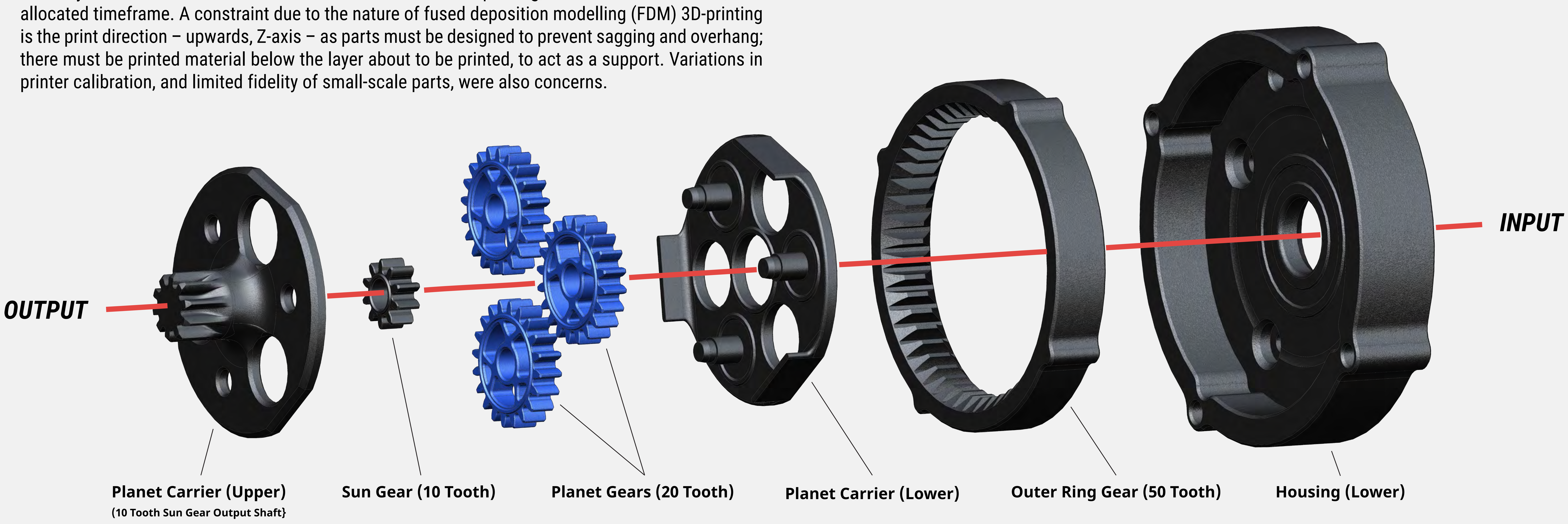
Our major constraints are limitations of the medium of 3D-printing, client needs as stated, and allocated timeframe. A constraint due to the nature of fused deposition modelling (FDM) 3D-printing is the print direction – upwards, Z-axis – as parts must be designed to prevent sagging and overhang; there must be printed material below the layer about to be printed, to act as a support. Variations in printer calibration, and limited fidelity of small-scale parts, were also concerns.

PROJECT CLIENT

This project is commissioned and overseen by Professor Martin F. Hohmann-Marriott of United Scientists, an open-source collective of scientific and engineering professionals seeking to foster creative research endeavours towards widely reusable and accessible engineering and software solutions.

CLIENT NEEDS

- Designed using the metric system, within a 10mm grid.
- Able to mesh with every other gear (same module.)
- Open-source, and saved in a suitable open-source format (.STL).
- Fun, with the ability to generate enthusiasm when tinkered with.
- Simple and intuitive to use and assemble.



Exploded View: Planetary Gearbox - 6:1 Ratio

The planetary gearboxes are designed specifically for a NEMA 17 stepper motor, and are currently offered with three different reduction ratios of 3D-printed Polylactic Acid (PLA) gears, as well as two output shaft options. Compared with other gearbox designs, the compact epicyclic construction delivers substantial power density and high torque output in a small form factor.

3 Reduction Ratios = Many Possible Configurations

SOLUTION

For a mixture of technical and aesthetic reasons – strength, compactness, visual simplicity, more demanding tolerances, novelty – we selected a planetary gearbox as the main test-bed assembly. It comprises a housing, spacers to accommodate the provided motor's shaft length, an inner ring gear, a central sun gear to transmit power from the motor, three identical planet gears, and their rotating carrier, which also carries the output shaft. The shaft has the same outer profile as the sun gear, allowing two identical stages to be stacked to provide a higher ratio.

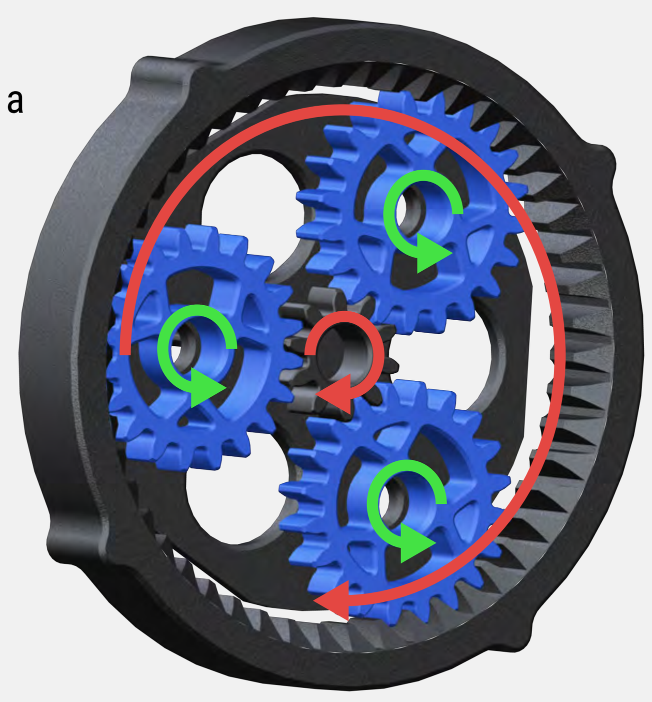
Gear teeth counts and ratios were derived mathematically. For the tooth profiles, an "involute" shape was chosen, as it provides ideal smooth transmission of force and transition of contact area throughout the gear's revolution.

Over many design and print iterations, ideal values for aspects such as print orientation of parts, tolerances, slicer parameters, part Z-height and minimum sizes of 3D-designed features were determined experimentally.

For non-manual operation of this gearbox, a NEMA 17 stepper motor was specified, to be driven by an Arduino Nano and a TMC2130 stepper driver board – reflecting the intended potential application of an axial positioning system e.g., for an open-source 3D printer. Control software was written in C++ for the Arduino, using both standalone and SPI modes, and incorporating such features as a potentiometer-based analogue speed control, a diagnostic LCD screen, or buttons simulating end-stop limit switches intended e.g., for self-calibration of a positioning axis.

IMPORTANT FUNCTIONS

In torque tests, a completed single gearbox stage with a ratio of 6:1 has demonstrated an output of 531.79 N mm as opposed to 101.78 N mm for the same motor ungeared, giving an efficiency of ~87%. It has also been able to run continuously with low noise, low vibration, and little detectable wearing of contact surfaces, all without additional lubrication. Testing two stages in series (a theoretical 36:1 ratio) gave 1685.86 N mm of torque, for a far lower efficiency of 46%, though this is suspected to be compounded by massive friction increases due to the unbalanced nature of the test load and the resulting asymmetrical forces on all components.



AREAS OF IMPROVEMENT

Areas for future exploration and potential optimization include: producing a wider variety of gears and associated systems; greater control of slicer parameters for higher accuracy, consistency and part strength; investigation of the effects of annealing (baking) on printed parts' strength and exact dimensions; integration of the electronics into a SPI-mediated, Klippr-driven multiple-axis-positioning system; and perhaps higher-speed continuous-run wear testing with different, higher-RPM motors.

CONCLUSION

While many refinements of the models, assemblies and processes used were required along the way, the results are encouraging at this point given the measured performance of the completed assemblies. Suitable values for dimensions, tolerances, Z-height, and infill type/quantity of various parts have been determined by experience - as well as assembly designs, such as the multi-stage gearboxes, being functionally validated. While unlikely to replace precision-engineered steel in the most demanding of gearing applications, 3D-printed gears so far appear viable within certain ranges of size and required strength, with ample potential opportunities for further improvement.

Involute Spur Gears: