Wind Turbine: Gearbox Design

ME 35401

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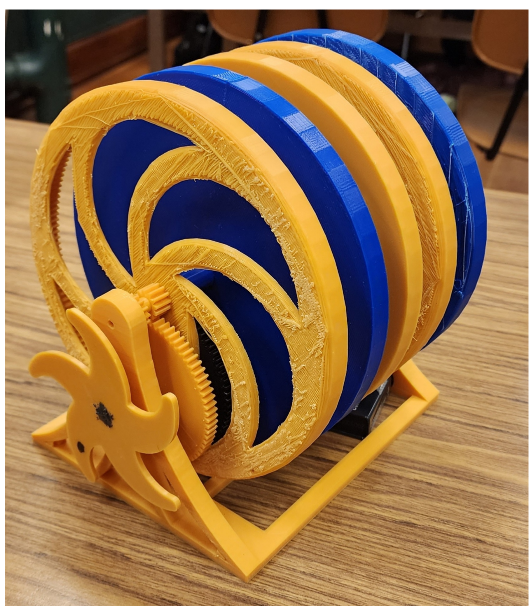

Submitted to: Joel Kong

1 Introduction

1.1 Design Information

The goal of this design project was to create a generator system to simulate the way power is created by a wind turbine. In a typical wind turbine, the oncoming wind is converted to rotation by the turbine blades. This low-speed rotation is then transferred to the main shaft, at which point the angular velocity is increased using a gearbox. Finally, this high-speed rotation is transferred through the high-speed shaft to a generator, which converts the rotational energy to usable electricity. This high-speed input to the generator ensures efficient energy creation.

Since we are unable to use a consistent source of wind to drive the turbine blades, our design challenge utilizes a backward approach, attempting to create a low-speed rotation of the output blades from a high-speed input from a motor using a gearbox. Therefore, in this design project, the most important aspect is converting the motor speed to a low-speed output shaft, with an efficient design of turbine blades playing a minimal role, serving only as an indicator of output speed.

The design constraints of this project were as follows:

▪ All components of the design must fit within an 8” x 8” x 8” cube

▪ All gears will be 3/8” thick at maximum

▪ Cardboard/construction paper/cardstock is not an acceptable design material

▪ Designs must be self-supported, meaning nobody can be touching the turbine in any way during testing besides to attach leads/power

▪ Teams are expected to make their own gears, shafts, gearbox, and turbine blades

▪ Each group should supply their own battery pack

▪ Motors and bearings will be provided by TAs

These constraints played a large role in the design process, as the space restrictions necessitate the maximization of gear reduction per unit volume. Therefore, the design presented in this report takes an unorthodox approach compared to the typical side-by-side gears present in many wind turbine and student project designs, instead electing to use a series of large internal ring gears attached to small spur gears that transfer torque to an intermediate gear and then the ring gear of the next set. By maximizing the number of teeth of the ring gears and minimizing the number of teeth of the attached small spur gears, this design generates a highly space-efficient gear reduction. Due to the small diameter of the spur gears, the design uses a thin shaft that constrains the rotation axis as the ring-spur combinations rotate around it. This design is also created with repair in mind, with minimal fixed components that allow for easy assembly, part replacement, and disassembly. This is important to both the troubleshooting and optimization process of this design project, as well as to the evaluation and repair of gear components in actual turbine gearboxes, as repair costs of these components can make up a large share of the operational costs of wind turbines (*Ukonsaari*).

1.2 Supporting Literature

Stacked gear ratios can be calculated by relating the number of teeth of the input gear to the output gear. In cases where a transfer gear is needed to create a gear train, the transfer gears cancel out in the gear ratio calculation as they serve as input and output gears ("Steps to calculate a gear ratio"). Moreover, it is important to note that gear ratios do not increase linearly as more gear couples are added to a gear train. With every addition of a gear couple component, the total gear ratio increases exponentially by many magnitudes. On the contrary, increasing or decreasing the number of teeth between gears in a couple increases their ratio linearly. Thus, this means that it is beneficial to reduce the size of the gears if it means more gear couples can be fit within the constrained space as this exponentially increases the gear ratio at the expense of smaller gear couples ("Steps to calculate a gear ratio").

Additionally, as mentioned earlier, the easy disassembly of this design relates significantly to its application as a wind turbine gearbox, as minimizing operational costs is paramount to making this form of energy generation sustainable. By allowing easy access to the internals of the gearbox, and making replacing parts as simple as possible, the theoretical application of this design to real-world wind turbines would reduce repair times (ie turbine downtime for repairs) and through very particular material selection, the parts could repair in very specific and predictable ways, further reducing repair times, and reducing repair part costs. This is important, as downtime costs, direct repair labor costs, and repair part costs make up a large portion of the operational costs of wind turbines (*Ukonsaari*).

2 Design Process and Justification

2.1 Design Process

The first step in our design process was finding and understanding the problem. We were tasked with creating the most optimal wind turbine. In practice, however, we were going to be creating the least optimal fan contained in a specified space. Once the problem was known, we started researching. This included learning how turbines worked, finding ways that similar problems had been solved, and manufacturing processes available. Next, we started to brainstorm and develop solution ideas. Once we had created a viable list of solutions we made a decision matrix and ranked each design. From here we created a 3D model of our selected design utilizing Autodesk Inventor and calculated the resulting gear ratio. Our team then went through an iterative process of testing different prototypes of our model and its components. Once this phase was complete we were able to determine our final solution and began to assemble it. Once assembled, a few minor details were fixed and our design was complete.

2.2 Final Design

The final design starts with a small driver gear. This then drives a large internal ring gear. Along the same axis, there is another small gear that is constrained to rotate along with the internal ring gear. This small gear then rotates another internal ring gear with the use of a transfer gear and the cycle continues. Once the end is reached, a fan is attached to the transfer gear by an axle and spins the output speed.

2.3 Results

This design resulted in a gear ratio of around 2063355:1. When the design was being tested there were a few gears that were off-centered or wobbled during the operation of the contraption. This was a concern going into the final demo; however, some final alterations to the design allowed it to perform perfectly. Some of these alterations included adding shims to the motor mount, adding spacers to the design, and reprinting an internal ring gear, all of which improved stability and performance due to improper tolerances.

2.4 Gear Design

The initial driver gear was chosen because the smaller the driver gear, as compared to the driven gear, in any gear system, the smaller the gear ratio becomes. The team decided to use internal ring gears as from our research phase, it was determined that this was the best way to utilize the limited space provided for this project. Due to the gears being on the inside, this allowed for the internal ring gears to be created at a larger diameter and thus creating a better gear ratio. The assembly of a standard gear couple can be seen below in **Fig. 2.1** below.

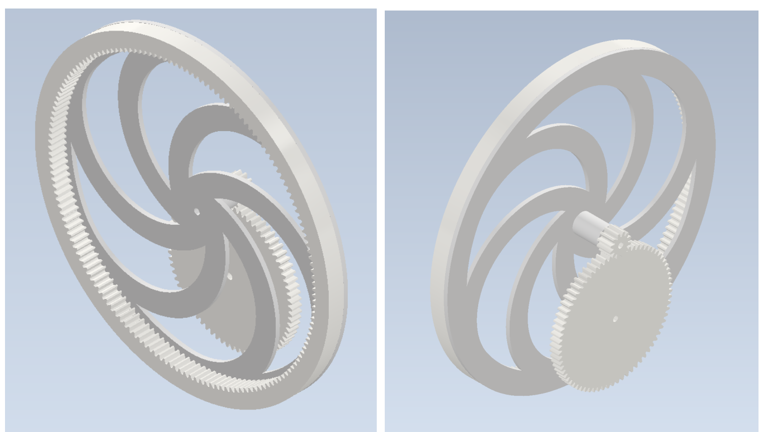

Fig. 2.1: Gear Coupling Assembly

2.5 Blade Design

The blades were designed to be lightweight, have low friction, and be thin. This is to ensure that the gears successfully rotate and fit within the size requirements. The fan was also designed to have press-fit holes to ensure that the fan rotates with the output gear shaft. The blades were modeled to represent a wind turbine, but for the purposes of this project's deliverables, the blade was optimized for its size. This design of blades worked very well as it offered no hindrance to the friction of the system or the size constraints. This design was also optimal for this project, as the primary form of manufacturing was 3D printing. As such, this blade design allowed for minimal supports and a quick manufacturing time.

2.6 Shaft and Housing Design

For the housing design, we decided to have an open housing concept with the base consisting only of supports and connecting beams, as seen below in **Fig. 2.2**. We chose this as it led to easier changes between iterations of the project. This also allowed for less material to be used for housing as only the necessary parts were included. As for the shaft, our team went with a 3mm stainless steel rod purchased from Amazon. There were many options available; however, this seemed the most viable option for many reasons including strength, durability, and friction reduction. This reduction in friction allowed us to forgo the use of bearings in our shaft, allowing the design to maintain the small diameter and number of teeth of the spur gears.

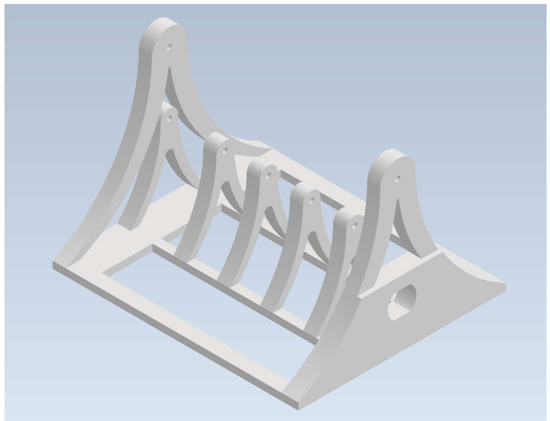

Fig. 2.2: Base Assembly

3 Conclusion and Improvements

3.1 Comparison to Other Turbines

There are many different factors that go into the best project design. This includes gear ratio, stability, durability, creativity, and many other factors. This design was near the top of the class for gear ratio, however, there were many other projects that had better durability and stability. As for creativity, this design was one of the more unique ideas which also performed at a very high level. As compared to actual turbines, which have an average gear ratio of 90:1, this design well outperforms this with a ratio of around 2000000:1 (“Gears & Gearboxes 101”). Again there are many different aspects that go into an actual turbine, many of which were not accounted for in this project. Thus this design lacks or falls well below the acceptable threshold.

This design also performs comparably to the seemingly most common student design, which emulates the common wind turbine gearbox design of side-by-side spur gears. In some cases however, this design outperforms the design presented in this report, as it is very space efficient. While each set of ring and spur gears on the presented design may have a higher gear ratio than an individual gear of the common design, the small size of the gears in that design allow more gears to fit. Since the relationship between number of gears and gear ratio is exponential, the high number of gears allows the common design to generate very large gear ratios when connected in series. However, the drawback of that design compared to the design presented in this report is the number of gear connections. Since the presented design uses significantly fewer (but larger) gears, it minimizes the total friction, which is inherent in each gear connection.

3.2 Potential Future Improvements

There are many ways that this design can be improved. To start, where the design has a sufficient gear ratio it lacks the stability that would be preferred. To improve this, the spacing between each gear should be more accurately measured as well as the supporting rods more tightly secured. The motor in this design is also very loose and should have a better fit so that it does not wiggle when running. As for the design of the gears themselves, the initial driver gear and the small gear on the back of the internal ring gear could have been made smaller. This, along with the maximized internal ring gear diameter, would create the most optimal gear ratio for the space provided. Finally, the gear thickness themselves could have been minimized so that they were durable but at the same time took up less space. In doing these few things, this design could have had a much larger gear ratio as well as been much more secure.

3.3 Application of Concepts from Previous Labs

This design utilized many of the concepts that were learned throughout the semester. Specifically, gear-related concepts from Lab 1, the mixer lab, as well as shape-synthesis rules that were observed in Labs 3 and 4. Lab 1 was used as a basis for the research that was done on gears during this lab. Shape synthesis was used during the designing and printing of the design. This included the material removal principle on many of the large gears, the triangle principle on the supports, and force flow from the transfer gears to the supporting structures of the shaft.

3.4 Biggest Takeaway

Throughout this design process, the team was continuously reminded of the importance of an iterative design process. With every test, new problems were discovered. The solution to each issue also had the potential to bring about new problems. For example, 3D printing tolerances were difficult to master due to the nozzle diameter of the printer and cooling of the PLA leading to shrinkage and thus improper tolerances. Another example was when we added spacers in the shaft stack-up to increase the compressive bolting load along the shaft to ensure that all the gears maximize their contact with each other. Doing this increased the pressure between gears and caused the driver gear to press too tightly against the motor and increase binding. To alleviate this, shims were added below the motor to reduce the contact pressure. Similarly, many other problems were addressed but their solutions led to more problems. Thus, an iterative design process of continuous testing, evaluation, and changes in designs was important to account for ahead of time by creating a malleable design that had room to grow and change. Along with this, recognizing these issues early on ensured that the team had sufficient time to plan for any unforeseen design changes.

References

1. Steps to calculate a gear ratio. (2019). Retrieved 6 April 2023, from https://clr.es/blog/en/steps-to-calculate-a-gear-ratio/#:~:text=The%20gear%20ratio%20is%20calculated,i%3D%20Ze%2F%20Zs).
2. Ukonsaari, J., & Dvorak, P. (n.d.). *The effect of wind turbine gearbox maintenance on present and future designs*. Windpower Engineering & Development. Retrieved April 6, 2023, from

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3. Zipp, K. (2012). Gears & Gearboxes 101. Retrieved 6 April 2023, from https://www.windpowerengineering.com/gears-gearboxes-101/

APPENDIX:

A final assembly of the design can be seen below in **Fig. A.1**:

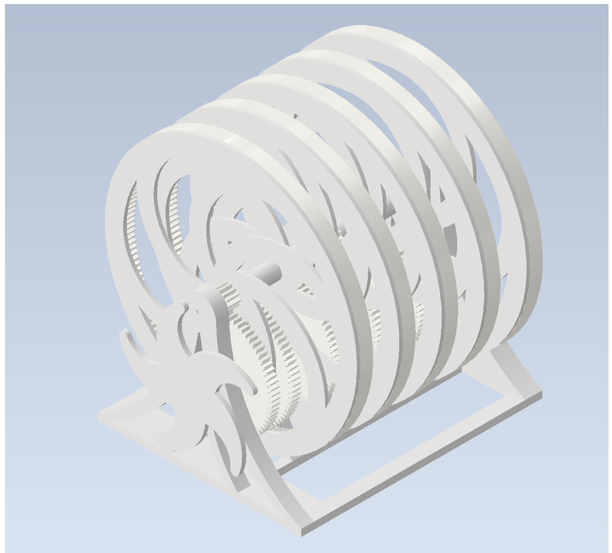

Fig. A.1: Final CAD Assembly of the Model (Back).

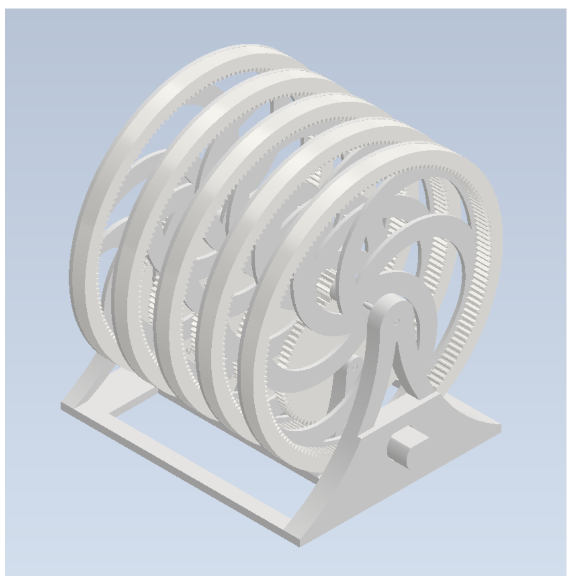

Fig. A.2: Final CAD Assembly of the Model (Front)