TO: Valued Engineering Employee
FROM: *ChopShop* Engineering team
RE: Design Problem #3: Blade Shaft Bearings and Gear Design
Due by 11:59 pm, 1 December 2023

While we review your blade shaft design, we have a new assignment for you. Good news! Using your recommendations for improving the shaft layout details, we've been able to broaden the acceptable range for the shaft diameter so that anything 3/8" (~9.5 mm) or larger will work for the stresses and fatigue life of the blade shaft. However, we just realized we still need someone to select suitable bearings and make sure they are adequate for the axial and radial loads.

In other news, our marketing group is worried about a competitor's new 'superior gear-driven design', so they want to make a new version of our product. The blade rotational speed must be the same as before (4600 RPM) at the required 1 HP, so the operating torque at the blade shaft is still 1.548 Nm. Our advanced-technology motor is compact, but can efficiently produce the required power over a speed range of 3000–3500 RPM. We need you to design/select a set of gears to make the necessary speed conversion.

A side view of the revised layout (not to scale), is shown in Figure 1 below. As shown in the figure, the major differences from the previous design layouts are that the **motor** is now mounted directly to the **support box**. The **motor gear** drives the **blade gear**. The remainder of the system is the same as in your previous design problem, with the two identical **bearings** (one in the **front plate** of the support box and the other in the **back plate**) supporting the shaft.

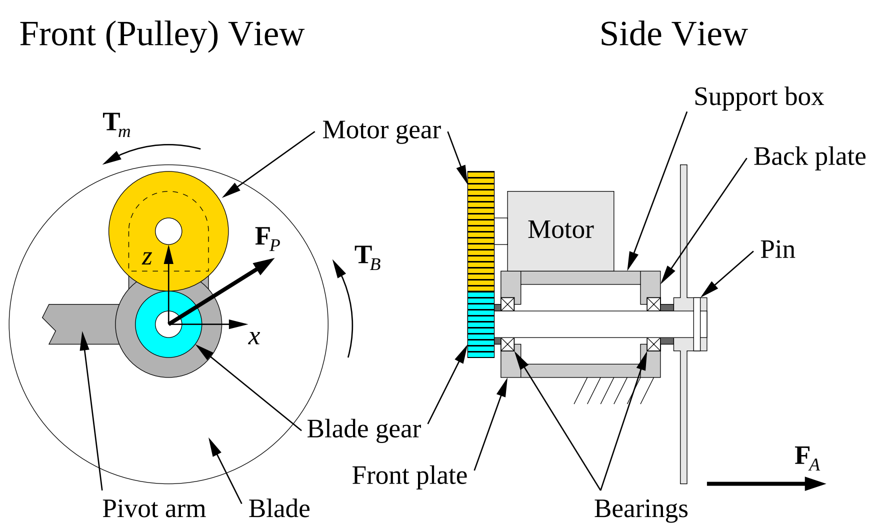

Figure 1: Geared Design Layout

You must design/select ball bearings for the blade shaft and perform the complete design of the two gears. *As with DP1 and DP2, you will also be required to type in summary data into a Canvas quiz.* For this design problem, we are interested in the bearings and gears, so **no calculations are necessary for the new pivot arm, the shaft, the shaft connection hardware, or the motor.** Required dimensions (in millimeters, unless otherwise indicated) are shown in Figure 2.

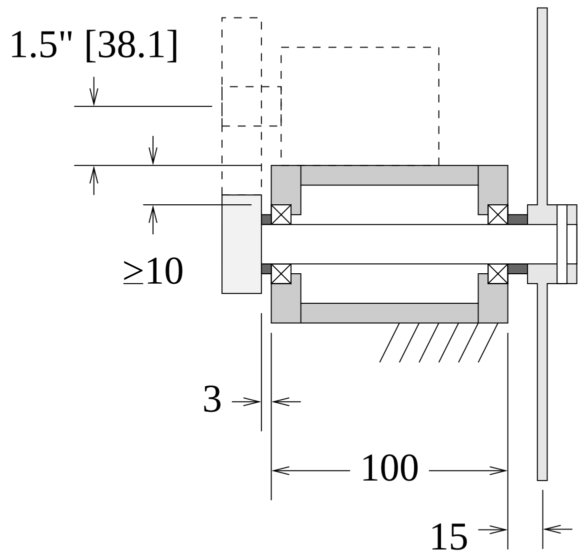

Figure 2: Geared Design Dimensions

Assumptions and Requirements

1. As in the previous design problem, the blade torque (T_B) is equal and opposite the torque applied to the blade gear (1.548 Nm) and the blade force (moved to the intersection of the shaft centerline and the midplane of the blade) is $\mathbf{F}_P = 15.62\hat{\mathbf{i}} + 39.85\hat{\mathbf{k}}$ N. The axial force is $\mathbf{F}_A = 10\hat{\mathbf{j}}$ N, acting at the bottom of the 8" diameter abrasive cutting disk (blade).
2. Due to the improved shaft layout, you may assume that the blade shaft can have whatever standard diameter you choose, as long as it is at least 3/8" (∼9.5 mm). Of course, the shaft diameter you choose must be suitable for the gears and bearings you select. The motor is mounted directly onto the support box and can be assumed to have a vertical dimension from the mounting flange to the motor centerline of 1.5" (38.1 mm).
3. The support box can be assumed to be fabricated from 6061-T6 aluminum ($S_y = 35$ ksi or 240 MPa).

4. Since this machine is intended for commercial use, the blade shaft bearings are expected to operate for 20,000 hours. Additionally, no material (liquid or solid) is permitted to pass through the bearings. Since they are replaceable, and because of the definition of bearing failure, it is sufficient for the bearings to have 90% reliability at this life and a factor of safety of 1.2.
5. Your gears must be spur gears with 20° pressure angle and must be sourced from McMaster-Carr. Any of the gears in their catalog with 20° or 14.5° pressure angle are acceptable, but **please assume that all of the gears listed are available at the same price with a 20° pressure angle** (so that you have the tables you need). Assume that all of the gears have all been manufactured by a hobbing process.
6. The desired minimum factor of safety in the design of the gears is 2.0.
7. For the desired gear reliability (99.9%), our past experience with the supplier indicates that, for brass gears, the allowable bending stress (S_t) is 7.5 ksi (52 MPa) and the allowable contact stress (S_c) is 30 ksi (210 MPa). The steel gears from this supplier are made from different alloys and have varying levels of quality control, strength, and hardness, but you may assume that they have S_t and S_c of 30 ksi (210 MPa) and 110 ksi (760 MPa), respectively. **All of these gear strengths already include the increased reliability**. These values assume that there is no undercutting in the teeth. Due to past quality issues, you may not use the stainless steel gears from this supplier.
8. The final layout of the gears must leave at least 10 mm (∼3/8") in the front and back plates of the support box around the hole that you bore for the OD of the bearings (Figure 2).
9. When uploading your single PDF to Gradescope, you must assign the relevant pages to each part to assist in grading. In addition to submitting your work to Gradescope, please also complete the Canvas quiz data summary.

Design Assignment

Gearbox Kinematics, Layout, and Components (2 points)

1. State the diameter of the blade shaft that you have assumed for your design.
2. Design the gear train kinematics, stating your final gear reduction ratio (input divided by output) as well as the number of teeth on each gear.
3. State the pitch/module and the resulting nominal center distance between the gears.
4. Provide the McMaster-Carr part numbers and costs for the two gears.
5. State the outer diameter for the ball bearings you have selected and the outer diameter you are using for the front and back plates of the support box.
6. Provide the McMaster-Carr part numbers and costs for the bearings.

Bearing Design Calculations (3 points)

1. Determine the required static load rating for each of the blade shaft bearings.
2. Determine the required basic dynamic load rating for the blade shaft bearings. **Justify your design with complete calculations**. No credit will be given without sufficient supporting calculations.
3. State the minimum thickness for the support box front plate (based only on the bearing and shoulder thickness), the hole size and tolerances for installing the bearing, and the dimensions (thickness, inner diameter, and tolerances) for the through-hole of the shoulder. Cite any sources.

Gear Design Calculations (4 points)

1. Determine the forces on the gear teeth (radial, tangential, and, if applicable, axial).
2. If we had a supplier that could provide **any** face width we wanted at no additional cost, what **minimum** face width would be necessary for the gears to meet the required factor of safety? **Justify your design with complete calculations**. No credit will be given without sufficient supporting calculations. Your selected gears must have at least this face width.
3. If we wanted to try out a new supplier, what minimum Brinell hardness would you specify for these gears (and why)?

Acceptable and Economically Viable Design (1 points)

Your total cost will be based on two bearings, the motor gear, and the blade gear. If your bearing and gear design are both fully acceptable, you will earn 0.25 points. If the final cost (for the gears and bearings only) is within 50% of the nominal design cost, you will earn an additional 0.25 points. Finally, if the cost is within 25% of the nominal design cost, you will earn the final 0.5 points.