ME 342 Design of Machine Elements
Summer 2023 Team Project

Semester Project. Design of a Two Stage Reverted Speed Reducer
The purpose of this exercise is to give you hands-on experience with the design of a two-stage reverted speed reducer (Figure 1). The following description details the requirements specific to your project.
Please read carefully!

Big Picture:

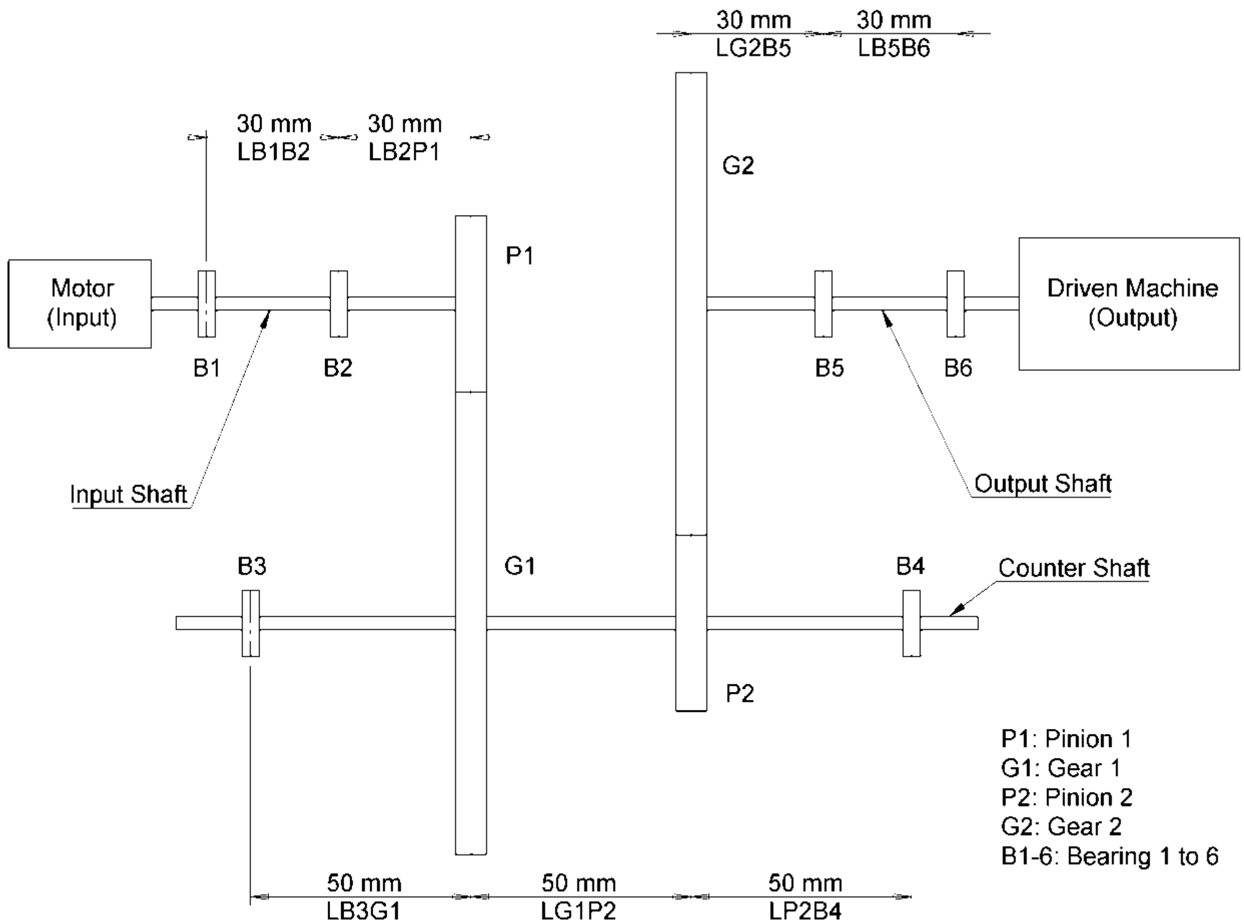

Figure 1. Schematic of a Two Stage Reverted Speed Reducer

Please, carefully read and follow all instructions.

Brief Problem Description

General design requirements:

a) Shafts: steel, lengths, input, and output shafts are inline and overhung, and countershaft is straddle mounted (see Figure 1)
b) Standard Spur Gears: steel, full-depth teeth, all gears have the same module
c) Bearings: Deep Groove Ball Bearings, metric, purchased from Motion Industries.
d) Costs will be assigned for weight, volume (bounding box), material removal and precision machining.
e) All materials other than bearings (shaft, gears, snap rings set screws, etc) from McMaster Carr.
f) Teams will need to propose two solutions to meet the given criteria.

Table 1. Design Parameters

General Parameters		**Group-specific Parameters**	
Gear Pressure Angle	*20 [degree]*	Motor Power	
Life	*14000 [hours]*	Motor Speed	
Shaft Length	*Figure 1*	Speed ratio	
Component Locations	*Figure 1*	Gear module (m)	
Static Analysis	*DET*	Number of Teeth on the P1 (N_{p1})	
		Single stage efficiency	
		Application	

Each team will be provided initial module and initial number of teeth on P1. When optimizing weight and size, many teams will have to change both of these parameters.

You will be expected to make reasonable assumptions and design decisions for:

a) Safety factors and reliability for shafts, gears, pinions, and bearings
b) Shafts: steel alloys (from Appendix in text), diameters, shoulders, fillets, keyways, and grooves for snap rings
c) Standard Spur Gears: steel alloys (from Appendix in text) and face widths

Table 2. Parameter and Applications

Example	 *Awesome* Racing Go Kart	 *Practical* Moped	 *Amazing* Lawn Mower
Parameters / Application	**World class racing car (F1, Indy, etc)**	**Production automobile**	**Agriculture Equipment**
Motor Power (hp)	15.0	4.0	1.0
Motor Speed (rpm)	12,500	6,000	1,250
Cost	Somewhat	Yes	Yes
Weight	Yes	Somewhat	No

These assumptions will need to be chosen based on the assigned application. Each team will be assigned one application. Three example applications are included in the table above and emphasize their critical characteristics.

Expectations for Software Use

This project will require analytical calculations, and computer-aided design drawings in order to successfully design the shafts, gears, and bearings.

For analytical calculations: EES

1. You should plan on about 600 lines of code to fully optimize the design of this speed reducer.

2. Please use a clear naming convention for your variable names and document these calculations thoroughly!

3. Comment your code thoroughly and completely. This makes it much easier for one teammate to seek help from a TA. Imagine this conversation between a student and a TA:
   "Why do you have two tangential forces in this equation but one tangential and one normal in that equation?"
   "I don't know. I didn't write this part of the code."

   Not very productive.

4. It is strongly recommended that your team has two independent sets of EES code written independently by two members allowing you to cross-check your results. It helps you significantly to get your results correct in your first submission.

For computer-aided design drawings: SolidWorks

Grading and Accurate Work

It is imperative that your force analysis in Part A is correct. If any of your force calculations are incorrect at the time of submission, you will need to correct them. We will give you up to 50% of your corrected points back for your effort (e.g. 75% → 87.5%). The same applies to Part B (Static Stress Analysis).

You are also expected to include a cover page and a comprehensive conclusion in each report. The cover page must include your team name, team members, instructor's name, and the date. The conclusion must resemble that of a professional report, which briefly yet thoroughly summarizes the work done in the body of the report, and your takeaways from the analysis.

Please fill out the team points distribution very carefully, since your grade on each project is directly proportional to your contribution, literally. For example, in a group of three, the ideal situation is everyone gets 33.33 points. However, if you are awarded only 20 points, and your report scores a 92%, your grade on the report will be 20/33.33*92% = 55.2%. However, if you get more than 33.33 points, you still only get 92% (don't go solo). Therefore, the only way to win is to work together and contribute equally.

Some notes:

- Neglect the weights of the motor and the load. Treat the power transmission as a pure torque.

- The spacings between the two bearings on the input and out shafts are small, but still needs to provide enough moment. Think of P1 and G1 as being cantilevered by the two bearings.

Overview of Due Dates (tentative)

Project Part	Component to submit	Date due
Part A	Force Analysis	Jul 02
Part B	Shaft Static Stress Analysis	Jul 09
Part C	Gear Analysis	Jul 21
Part D	Shaft Analysis, Fatigue, and Ball Bearing selection	Jul 31
Part E	Final Project Presentation	Aug 11

Part A: Force Analysis
Due: Sunday, Jul 02, 11:59 pm

Complete a force analysis of all components to determine:

- Shaft loading on all three shafts: input, counter and output
- Gear and Pinion tooth loading
- Bearing loads

Your Progress Report A should include

1. Diagrams (of all three shafts)
    a. Free body diagrams
    b. Shear diagrams
    c. Bending moment diagrams
    d. Torque diagrams.

    Diagrams should be drawn using some sort of computer too. Andy would use Adobe Illustrator or Inkscape, Alston would use MS Word[1] and Josh would probably use Python.

2. Create a table (or tables) to summarize the results of your force analysis. Indicate the torques and moments for each shaft at each gear location, the tangential and radial forces on each gear, and finally the reaction forces at each bearing.

3. Answer the following questions:
    a. Which components are subjected to the highest loads?
    b. What is the effect on bearing loads by mounting cantilever shaft (input and output) vs a straddled gear shaft (counter shaft)?

4. Assuming all of Part A took 100 units of effort, please briefly summarize which team members contributed what parts of the report and how many “effort units” they contributed to the overall report.

    For example:

Alston	30 pts	EES code, tables, and grammar
Josh	30 pts	EES code, FBDs, formatting report
Zhiyi	30 pts	Shear and bending diagrams, (checking FBDs)
Dress	10 pts	Ordered pizza, submitted report on Canvas

5. All assumptions with their justifications. Some good examples of detailed assumptions can be found in the example problems in the Spur Gears chapter in the Juvinall textbook.

[1] A word processor to make an illustration. Interesting.

Part B: Static Shaft Stress and Strength Analysis
Due: Sunday, Jul 09, 11:59pm

Complete static strength analysis (using the Distortion Energy Theory) for all three shafts (input, counter, and output) to determine minimum shaft sizes and material. You must choose your shaft material from the round allow steel stock available from OnlineMetals.com or McMaster Carr. You may start with oversized stock and turn it down with a lathe, but this will get expensive later in the project.

Note: You aren't buying a "shaft". You are buying a chunk of metal. For example, from McMaster, go to:

Raw Materials > Metals > Steel > Multipurpose Low Carbon Steel > Rod and Disc

Your Progress Report B should include

1. Create a table (or tables) to summarize the results of your static strength analysis. Indicate the properties of the materials you choose, and minimum diameter, equivalent Von Mises stress, and safety factor for each shaft at each gear and each bearing location.

2. Answer the following question:
    a. How does your material choice address the design considerations: strength, environment, machinability, weight, and cost?

3. All assumptions and their justifications.

4. Assuming all of Part B took 100 units of effort, please briefly summarize which team members contributed what parts of the report and how many "effort units" they contributed to the overall report.

Part C: Gear Tooth and Face Width Analysis
Due: Friday, Jul 21, 11:59 pm

Using both the gear-tooth bending and surface fatigue analysis (Recommended Procedures in Juvinall), calculate the face width of gears necessary to avoid yielding with appropriate safety factors.

Your Progress Report C should:

1. Create a table or tables to summarize the results of both gear analyses for each gear.

2. Justify all safety factors, correction factors, assembly decisions and assumptions.

3. Assuming all of Part C took 100 units of effort, please briefly summarize which team members contributed what parts of the report and how many “effort units” they contributed to the overall report.

Gear specs: Given the limited selection of gears available from McMaster-Carr, you may design your own gear. You can specify module, number of teeth, bore and keyway. Remember: Any changes to gears will result in a new force and static analysis.

Gears face widths should be between 9*m* and 14*m*. If the design parameters assigned to your team results in non-integer values for gear teeth, you may round up or down accordingly. You may also adjust the module, but you must stay as close as possible to the assigned total gear ratio (2.5 can become 2.532 if necessary).

You should also limit your safety factor to less than 2 to limit the required face width of your gears and avoid overdesigning. Remember, weight is always a significant performance damper.

Given your parameters and safety factors, you may use materials for the gears that are substantially harder than those available for gears online, such as the McMaster Carr website (do not invent your own materials though).

Case hardening: You may use case hardened 1018 steel. Assume that you can case-harden the gear sufficiently that the minimum face width necessary for surface fatigue matches the minimum face width necessary for bending fatigue. You may only employ this method if you cannot achieve a desired safety factor for surface fatigue.

Part D: Shaft Analysis, Fatigue, and Ball Bearing Selection
Due: Monday, Jul 31, 11:59 pm

Design the shafts with necessary shoulders, keyways, snap rings, etc. to mount all bearings and gears. Complete fatigue strength analysis for all three shafts to determine new minimum shaft sizes and material (from OnlineMetals.com). Choose deep groove ball bearings for all shafts based on force analysis and minimum shaft diameters. Update your initial static strength analysis using the new dimensions determined after the fatigue strength analysis and bearing selection.

A few notes:

- Straight shafts are not allowed. While you would save some money on machine time, your bearings would be grossly oversized. This is VERY expensive. You must step your shaft diameter down to fit the correctly specified bearing.
- Safety factors should be reasonable.
  - Any safety factors over 5 need a detailed explanation
  - Any safety factors over 10 need a convincing justification
- You can design your own gear. Specify module, diameter, number of teeth and internal bore. You can also specify a shoulder, keyway and bore radius.
- The base radius of a retaining ring should be 1/10th of the groove width. McMaster has a large selection of retaining rings.
- Keys should have the lowest safety factor of the entire speed reducer. Key length, *l*, should also be at least 3 times the width. You may have to use a key with $w < d/4$ to achieve this.

Your Final Report should include:

1. Describe (pictures, diagrams, tables, etc.) the manufacturing process of your shafts.

2. Create a table or tables to summarize the results of your fatigue analysis. Indicate the properties of the materials you choose, and stress concentration factor, minimum diameter, and safety factor for each critical location.

3. Create a table or tables to summarize the results of your bearing selections. Indicate all the product details and critical dimensions of the bearings.

4. Update the static analysis tables from Part B with new diameters.

5. Develop a fully dimensioned engineering drawing of your three shafts (you do not need to include any of the other components – bearings, gears, keys etc.).

6. In your report answer the following questions:

    1. How does the minimum shaft diameter compare between the initial static

analysis, the fatigue analysis, and the bearing selection?

   2. Is static strength, fatigue strength or bearing capacity the most critical?

7. All assumptions and justifications.

8. Assuming all of Part D took 100 units of effort, please briefly summarize which team members contributed what parts of the report and how many “effort units” they contributed to the overall report.