MECH 326 Assignment 1

Scenario

Figure 1 shows a preliminary design of a shaft for a mass-produced portable wire spooling machine. End A of the shaft is cantilevered such that a removable spool can be fit onto the shaft, wound with wire, and then removed. The shaft is to be supported by Bearings B and C. The system is driven by a motor, coupled to a second parallel shaft, and connected using a timing belt between pulleys D and E. The motor connects to the second shaft through Coupling J, and belt tension is maintained using a system with two springs, H and I, pushing against the housings of bearings F and G, respectively. By pushing up on the shaft at E, the springs can be compressed and the belt can be removed for replacement, as depicted in Figure 2.

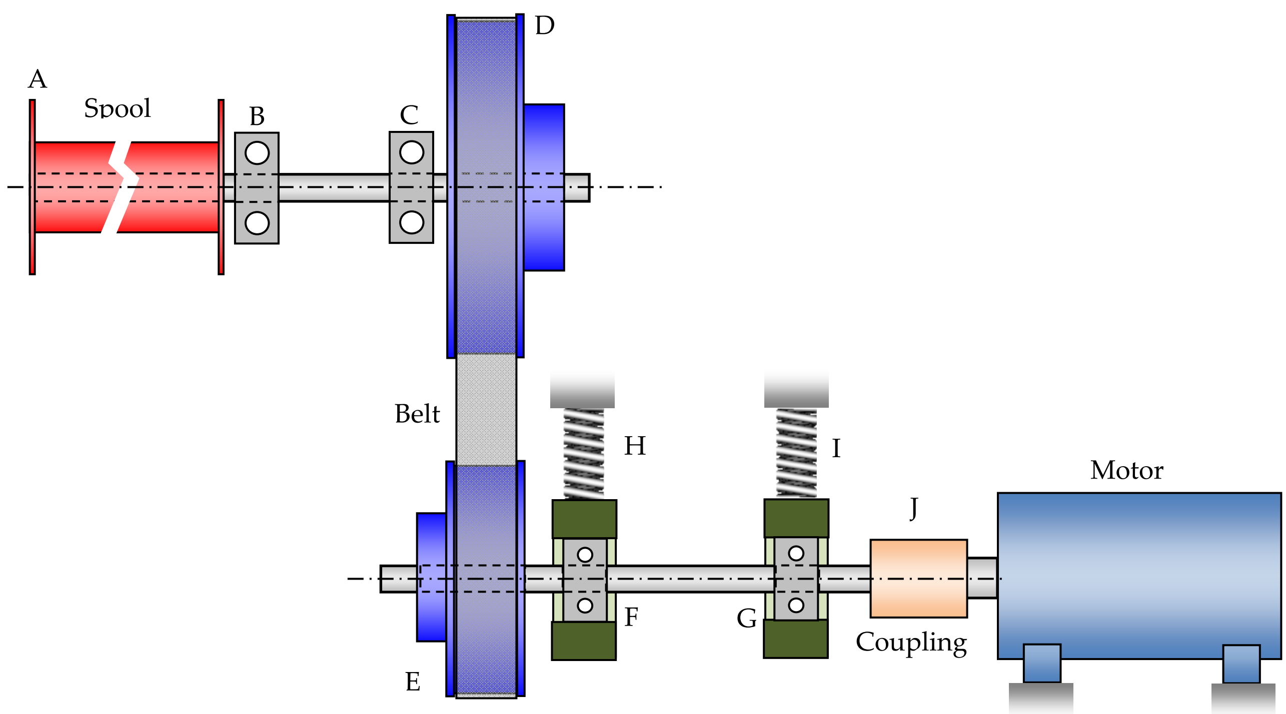

Figure 1: System Geometry. The shaft diameters are not shown to scale, and shoulder and other locating features are not shown.

Your task is to design suitable shafts ABCD and EFGJ. As the machine is to be mass-produced and portable, low cost and low weight are desirable. Your objective is therefore to minimize the product of cost and upper shaft mass. The performance metric is:

Performance = (cost · mass)$^{-1}$ [(\$·kg)$^{-1}$]

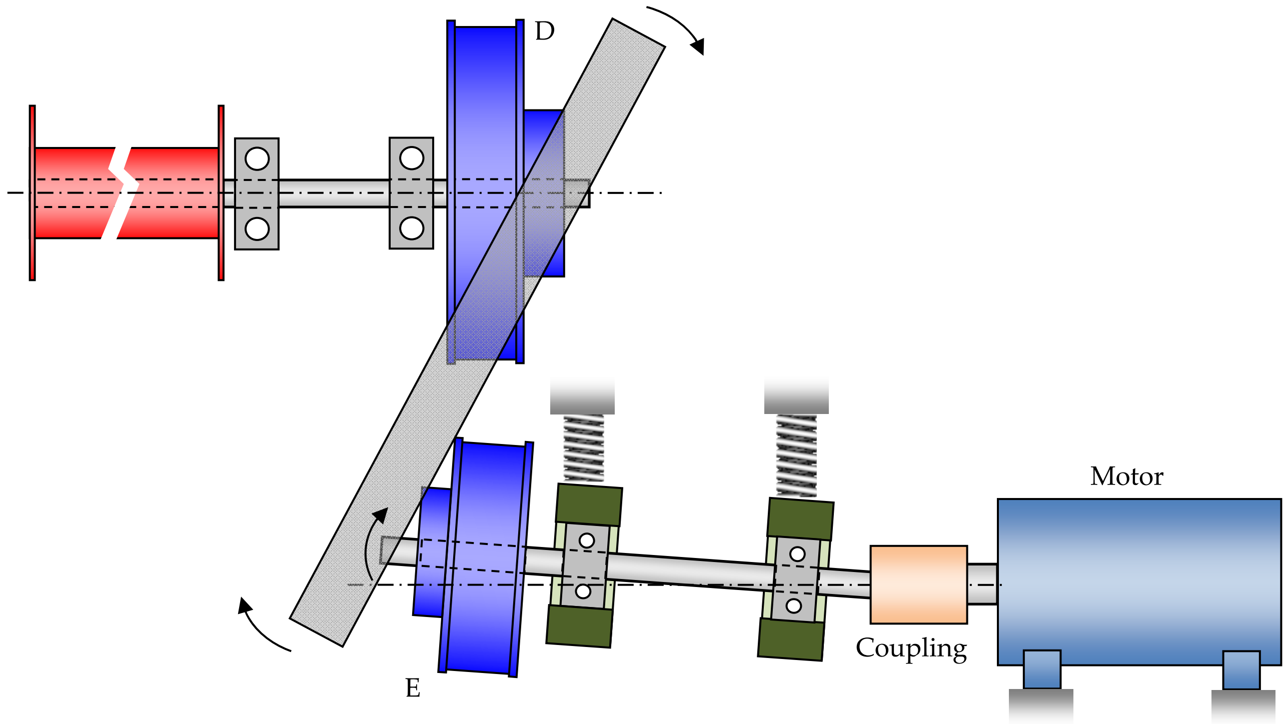

Figure 2: Belt Removal Process. The shaft at end E is lifted (it pivots about the coupling and compresses the springs), and then the belt is removed from pulleys D and E.

Details on how cost is computed are outline below. Your design must also satisfy the strength and stiffness constraints detailed in the following sections.

Application Details

Bearings (B, C, F, and G)

Both sets of bearings are single row 02-series deep groove ball bearings as described by Table 11-2 in Shigley. Assume that bearings B and C are 35 mm inner bore and are to be mounted against a 6 mm shoulder on Shaft ABCD. Bearings H and I are 20 mm inner bore and are to be mounted against a 5 mm shoulder on shaft EFGJ. Bearings are axially restrained using a retraining ring, with a circumferential groove in the shaft.

Drive Motor

The drive motor has a peak power output of 1.0 kW. At load, the motor rotates at 1000 rpm and the upper shaft rotates at 600 rpm. The motor shaft is 12 mm (but it connect to a ½″ bore shaft coupling)

Belt and Pulleys (D and E)

When properly tensioned, the combined radial load from the belt on the pulleys can be approximated to be 500 N. Assume that the 20 mm wide belt is 94% efficient. The pulleys have a 20 mm hub (for keys or setscrews, for example), and can be right- or left-mounted, making the total pulley width approximately 40 mm. The pulley is available in bores from 10 mm and higher, in 2 mm increments. Assume pulleys are mounted to the shafts using gib-head keys (see Shigley Figure 7-17). Specify the locations of the pulleys on the two shafts.

In order to remove the belt, pulley E must be moved upward by at least 10 mm at the mid-belt position on the shaft. The maximum force that can easily be applied by the maintenance workers to the end of the shaft at E is 800 N.

Spool A

The 300 mm long wire spool is to slide onto the shaft at A. A 20 mm long spline at the end A is used to transmit torque and interfaces with a female spline of appropriate size in a steel insert press fit into the spool. The empty wire spool has a mass of 3 kg and holds 47 kg of wire when fully wound. Wire is wound onto the spool beginning at a radius of 8 cm and extending to a radius of 12 cm. During winding, the orientation of the incoming wire is horizontal (i.e. the wire passes out of the page in Figure 1). The wire tension is adjusted during winding in order to maintain a constant shaft rotation rate. Axial forces on the spool due to the wire are negligible, but axial positioning of the spline is important.

Shaft ABCD and Shaft EFGJ

The shafts is to be made from solid stock AISI 1050 cold-drawn steel (assume properties for ∅30 mm stock apply). The following requirements must be observed in the shaft design:

- The allowable shaft deflections at the pulley and wire spool centres are 1 mm, with maximum slope of 0.008 rad.
- The allowable maximum shaft slope at the bearings is 0.001 rad.
- All sections of the shaft receiving shaft elements must have a machined surface.
- The shaft is to be designed for infinite fatigue life.

Assume that Shaft EFGJ is to have a length of 40 cm.

Coupling J

Assume coupling J is suitable for the deflection required to remove the belt for pulley E.

Springs H and I

The springs are compression springs, as depicted. You may assume that the bearing housings at H and I are designed such that spring compression is purely axial with the housing surface remaining perpendicular to the spring axis. The springs have a rate (i.e. linear force to deflection relationship) of k = 37.8 kN/m. Both springs have a free length (uncompressed length) of 100 mm and a solid length (minimum compressed length) of 20 mm.

Design Cost

The goal is to design the two shafts with the smallest product of final mass and overall cost. Mass is based on shaft masses only (i.e. ignore bearings, pulleys, springs, the spool, etc.).

To simplify your work, cost is to be determined by the following model:

- **Stock shaft** can be bought for \$13/kg in diameters of 9 mm and up in increments of 2 mm.
- **Shaft machining** costs \$50/kg of removed material. To illustrate, for a 3 kg shaft before machining with 0.5 kg machined off, the cost is: $\left(\$13/kg \times 3kg\right) + \left(\$50/kg \times 0.5kg\right) = \$64$.
- **Shaft additions** add \$240 for the cost of retaining ring grooves at the bearings, keyways for the pulleys, and the shaft spline at A. (This will be the same cost for everyone.)
- Other components, including pulleys, bearings, retaining rings, couplings, etc.) do not need to be specified or included in the cost estimate.

Reporting Requirements

There are three graded elements for this assignment: a report for formal marking (75% of mark), your assessment of the designs of two other teams in the class (15%), and the performance of your design relative to others in the class (10%).

Report

Each team will submit a report in two formats:

- A paper (hardcopy) version of the report is due at the beginning of class on Nov 13
- A .pdf (softcopy) version of the report is due at 8:00am on Nov 13 to the assignment drop box on Connect

Important: you must submit both the hardcopy and the softcopy versions of your report!

Your report shall consist of:

- A **title page** with the assignment number, your group number, and names and student numbers for all team members.
- A **summary** of your approach to the problem, your assumptions and methods, your final design, and the design and performance information requested below. Point-form writing, tables, and figures are all encouraged. **The summary must not exceed 2 pages and text should be computer-generated.**
- An **appendix** outlining your detailed calculations. The appendix can be hand-written or computer-generated, and should be clearly organized and easy to follow.

The report must contain the following design and performance information in the summary (supporting calculations must also be provided, either directly in the summary or in the appendix):

- A profile drawing of both shafts, showing all lengths, diameters, features (e.g. keys, grooves, etc.), and locations of components (e.g. bearings, pulleys, springs, etc.)
- V, M, |T| diagrams of the shafts (axial forces F are minimal, show torque magnitude |T| only)
- A summary of critical locations. Provide a table that summarizes the following:
    - maximum bending and shear stresses (MPa), with corresponding safety factors
    - maximum linear deflection (mm) and angular deflection (slope in rad)
- A summary of the costs
    - cost of raw shaft material
    - cost of machining at $50/kg of removed material
    - total cost ($)
- Mass of finished shaft (kg)
- Performance metric from Page 1: $(\text{cost} \cdot \text{mass})^{-1}$ $[(\$\cdot\text{kg})^{-1}]$

Your Assessment of Other Designs

The .pdf versions of the reports will be posted to Connect and you will be randomly assigned two teams to review. For each team you review, you should analyze the work in terms of:

- A critique of overall design and design decisions (e.g. is the overall design a good one or a bad one? Why? Are there errors, omissions, or unreasonable assumptions?)
- Analysis of the calculations and work (e.g. are the diagrams correct? Do you compute the same shaft stresses and deflections reported?)

Each of your assessments should be roughly one full page. Be sure to identify the teams you are evaluating on your assessments. Include a title page with your assessments (with the same information as the report title page) and submit everything as one document at the start of class on November 27.

Performance Relative to Class

The top performing team (i.e. the team with the design with the highest performance metric that satisfies all design requirements and constraints) will receive the top performance mark on the assignment. Performance marks for the rest of the class will be determined by the instructor using either a linear or non-linear scaling. A working design will at minimum receive a performance mark of 50%.

Addendum

After reviewing other teams' designs, if your team feels that your report could be improved substantially due to oversights, you may submit a 1-page, 12-pt font addendum with clarifications and/or amplifications. This can be handed in as a hardcopy to the Mech Office (CEME 2054) or emailed as a .pdf file but must be received by Dr. Ostafichuk no later than 8:00am on, November 27. This is not intended as an opportunity for you to completely change your design. Any extra points gain in the addendum will be worth ½ of their value had they been provided in the original report.