TO: Valued New Engineering Employee
FROM: *ChopShop* Engineering team
RE: Design Problem #1: Automatic Chop Saw Pivot Arm Static Design
Due by 11:59 pm, 6 October 2023

We're glad to finally have another mechanical engineer join the staff at *ChopShop*! Now we can really cut to the chase! While your senior colleague can give some top-level guidance, we've really been needing someone to handle the detailed design of the mechanical parts while they work on other details.

We're developing our design for a new entry into our **automatic cut-off saw** product line for cutting metals. The general operation is what you'd expect from the title: A workpiece made of steel will advance toward the saw, which will then be pushed downward by an actuator to cut through the piece. The actuator will then lift the chop saw and the process will repeat. The raised and lowered position of the system are shown in Figure 1.

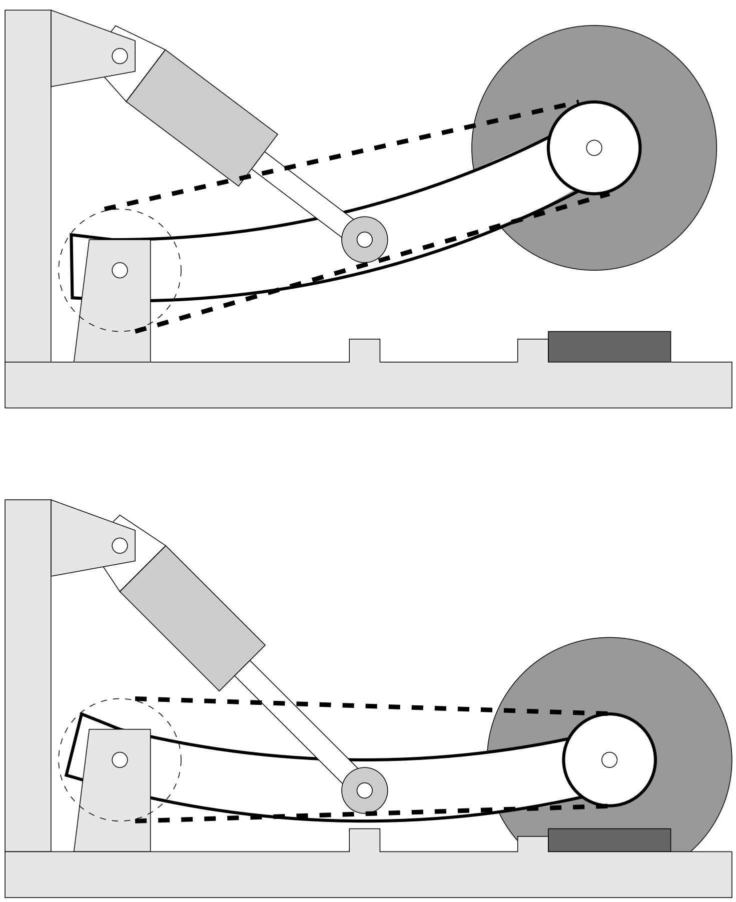

Figure 1: Raised and Lowered Position of the System (not to scale)

The conceptual design (Figure 2) works as follows: The **base** of the saw provides vertical and lateral support for the system and the **workpiece** that is being cut. The **blade** is an abrasive disk that spins at high speed (4,600 RPM) to cut through the workpiece. The blade is supported on a **shaft** that is mounted in a (probably cylindrical) **support box** attached to the end of a curved **pivot arm**. The pivot arm rotates about a **pivot pin**, which passes through a **clevis** at the base. The pivot arm is pressed downward, for cutting, and lifted upward, to clear the area for the workpiece to move, by means of a linear **actuator**. The actuator is connected by a clevis at each end, by means of a **mounting pin** at the wall and an **actuator pin** at the pivot arm. To spin the blade with the pivot arm at any angle, the **motor** is mounted to the base so that the **motor shaft** is co-linear with the pivot pin. The **motor pulley** drives the blade via a **V-belt** that turns the **blade pulley**.

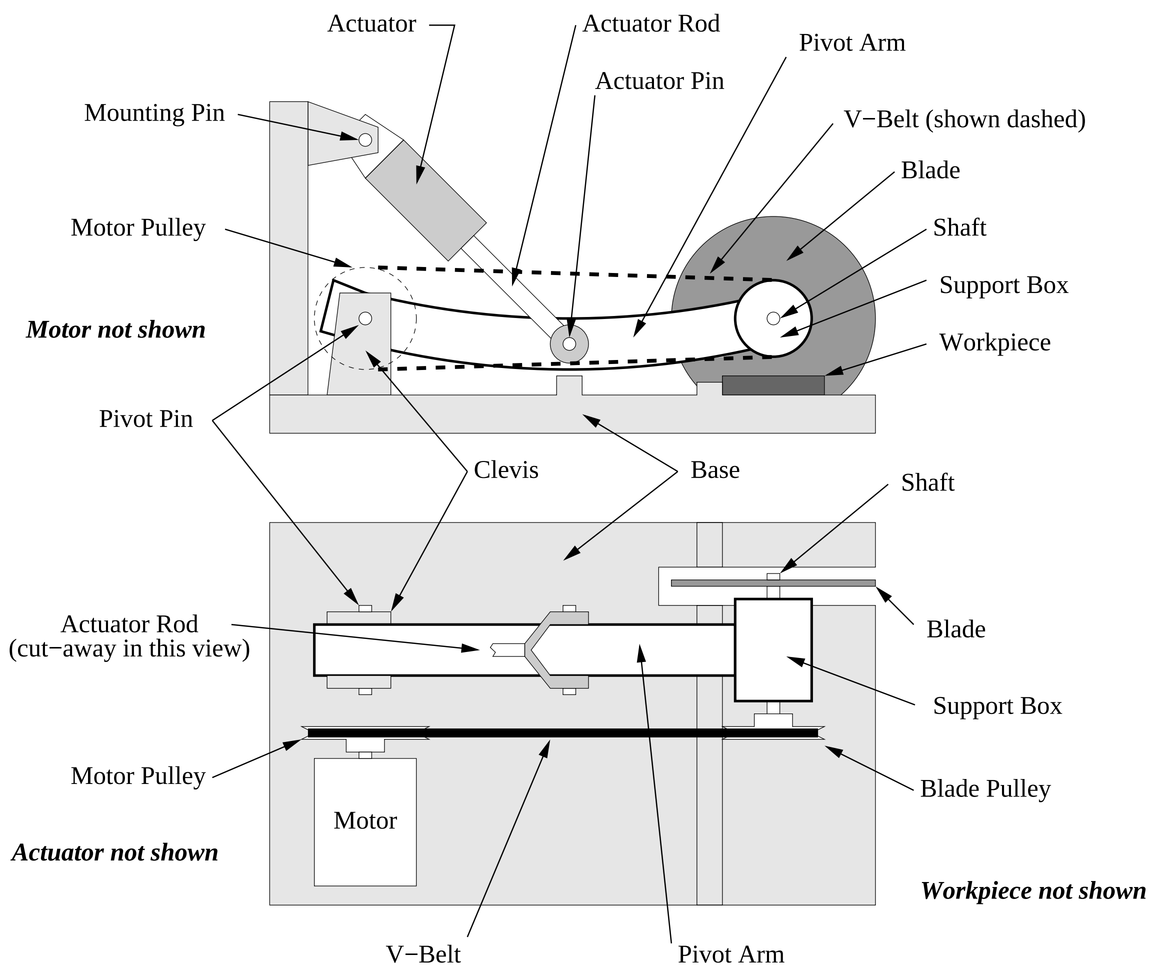

Figure 2: System Layout (not to scale)

For now, we need you to design the **curved pivot arm** and the **pins**. The coordinates and critical dimensions are shown in the detailed view below (Figure 3). Unless otherwise indicated, the units are millimeters.

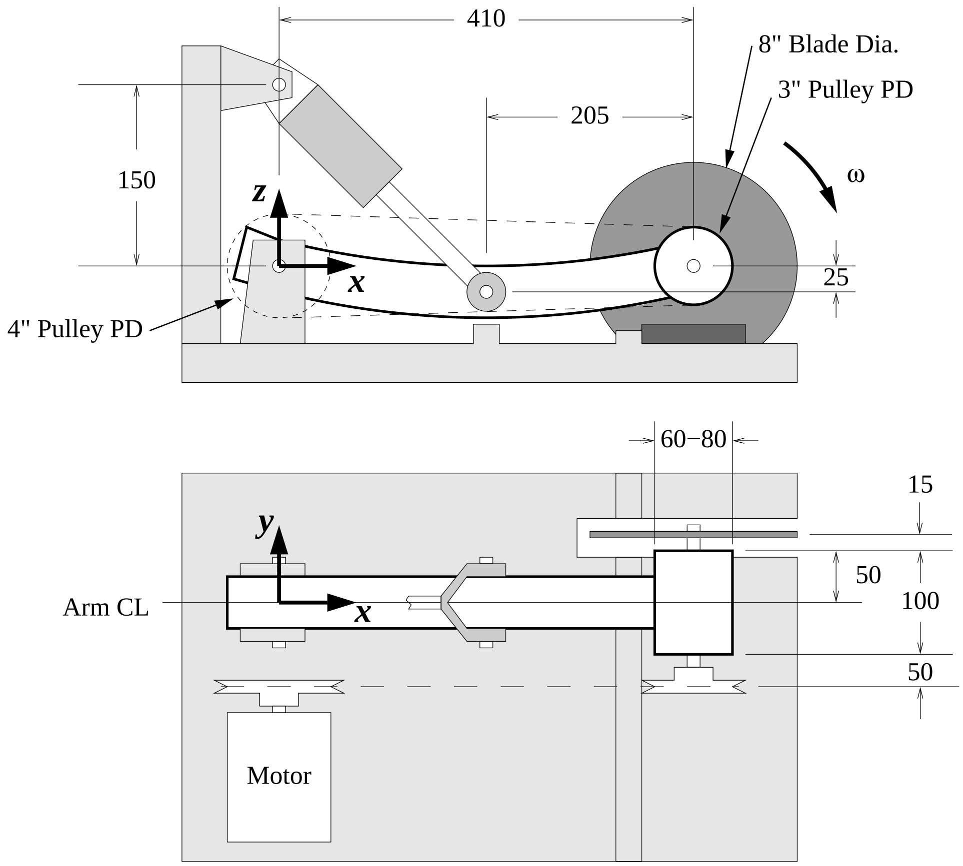

Figure 3: Layout and Dimensions (not to scale)

As shown in the figure, the origin is located at the intersection of the center plane of the curved pivot arm and the centerline of the pivot pin. The pivot arm, which must have a circular (or hollow circular) cross-section, rotates about this pivot pin at one end. The centerline of the blade shaft is 410.07 mm from the pivot pin centerline. To lift and lower the pivot arm, the actuator connects halfway along the length. To provide a proper interface with a motion stop on the base, the actuator pin connection to the pivot arm must be located 25 mm below the center-to-center line between the pivot pin and blade shaft. This will be accomplished by bending the pivot arm into an arc. Because of the details of the actuator rod and connection (not shown here), the actuator acts as a pure truss member between the mounting pin and the actuator pin, though it can, of course, change length to move the arm.

The blade shaft will be mounted within a (nominally cylindrical) support box, which is expected to be about 60–80 mm across (diameter) and 100 mm along the length of the shaft. Under normal operating conditions, the motor spins at 3,450 RPM. Since the 8" diameter abrasive cutting disk (the 'blade') must spin at 4,600 RPM, a belt system is employed to increase the speed. Specifically, the motor pulley has a 4" pitch diameter and the blade pulley has a 3" pitch diameter.

Requirements

The initial requirements, in no particular order, are given below. Any clarifications will be posted on *Canvas* or *Piazza*. **You are responsible for any changes posted there.**

1. The cutting disk (the blade) must deliver 1 HP at 4,600 RPM.
2. The pivot arm must be made from a single piece of a stock cross-section available from McMaster-Carr. It must have a circular or hollow-circular cross-section. You may assume that our shop can bend the stock into the final curvature required for the arm before we drill the holes for the pins and that they will provide a support box that allows the end to be flat and perpendicular to the local cross-section (no unusual cutout geometry required to match the shape of the support box).
3. For this design, the motor pulley has a pitch diameter of 4" and the blade pulley has a pitch diameter of 3". That is, the motor spins at 3,450 RPM.
4. The blade spins clockwise viewed as in the front view of Figure 3 (about the $+y$ axis).
5. The center distance is set by a standard A42 V-belt.
6. The pre-load in the belt drive system will be such that the side of the belt under the **least** load will have a total tension of 45 N under operating conditions. When the system is not cutting, both belts have a tension of 32.5 N.
7. The spinning blade shaft assembly (blade, shaft, support box, and blade pulley) has a mass of 2 kg with its center of gravity approximately at the center of the support box. When it is cutting at full power, in addition to the tangential cutting force on the blade (which you may assume happens at the bottom of the abrasive disk when the blade shaft is directly on the x axis), the vertical resistance force from the material can be assumed to be 40 N.
8. For all pins, no interference fits are allowed, as this would restrict free motion of the system during raising and lowering.
9. For all pins, the minimum spacing between any free edge of the pivot arm and the center of the mounting pin hole must be at least two times the diameter of the hole.

10. You may assume that the clevis plate thicknesses are 0.25" and that they have sufficient strength that they will not fail before the pivot arm or the pins.
11. Your design for any component must have a factor of safety of at least two (2) with respect to the yield strength of the material.
12. To ensure a clean cut and low vibration, the total deflection of the bottom of the blade when cutting (compared to when not cutting) must be $\leq$0.1 mm. This deflection specification is based only on the pivot arm stiffness, so you may assume that everything else (blade, shaft, support box) are rigid for purposes of this calculation.
13. Similarly, the twist angle in torsion of the pivot arm must be $\leq 0.01°$.

Design Problem

Determine the Loads (3 points)

1. What is the blade torque required by these specifications?
2. There are many forces, moments, and reactions acting on the pivot arm. Provide a table of the **locations** (coordinates) of all forces and moments on the system that affect the design of the pivot arm, along with the vector components of the corresponding **forces and moments**. Use the world coordinate system shown in Figure 3.
3. In that same world coordinate system, what are the reaction forces and moments acting at the centerline of the pivot pin and actuator pin?
4. In a local coordinate system (x', y', z'), rotated so that x' is tangent to the curved pivot arm, y' is still the pivot pin axis, and z' is defined by those two axes according to the right hand rule, what are the equivalent forces and moments acting at the origin?
5. In the world coordinate system, what are the loads at each pin at each side of the pivot arm that the pin passes through in this design?
6. What is the magnitude of the peak axial load, the peak bending moment in each direction, and the peak torque on the pivot arm, and where does each occur?

Provide your Design of the Pins (2 points)

1. Select an appropriate pin that would be suitable for use at **all** of the pinned connections. That is, the pins must be identical. Justify your selection with appropriate calculations. Provide a McMaster-Carr part number and cost for the pins.
2. Specify the hole diameter and tolerance you require for these pins. **NOTE:** depending on your experience in your CAD class, you might need additional information on holes and tolerances. You are expected to use your resources to make an appropriate design choice and to cite your sources.

Provide your Design of the Pivot Arm (4 points)

1. Design the pivot arm, choosing your cross-section to meet the strength and deflection requirements. In your design, you may ignore any possible stiffening or strengthening effects of the support box.
2. Show calculations to justify the strength performance in terms of the local stresses at the pin connections, the overall axial, bending and torsional stresses, and any other important effects. **NOTE:** as a new engineer, it is unlikely that you ever studied bending in curved beams. You are expected to use your resources to make this calculation and to cite your sources.
3. Show calculations to justify the performance in terms of the deflection of the blade shaft support point and the twist angle of the pivot arm. **NOTE:** for purposes of this initial deflection calculation, you may make the approximation that the pivot arm is straight, rather than curved.
4. Produce a CAD drawing of the pivot arm, including dimensions and tolerances, suitable for quote/fabrication and appropriate for official documentation.
5. Provide a McMaster-Carr part number for your selected cross-section. Your selection must be the shortest available part that is still long enough to use in making the curved pivot arm. Give the cost for that part number (do not reduce the cost if your length is shorter than the stock piece).

Economically Competitive Design (1 point)

1. Provide a summary table for your bill of materials, including the total cost of materials for the pivot arm and the pins. Since everyone will have to bend the pivot arm and drill nearly the same holes, you do not have to provide a machining estimate.

If your final procurement cost is within 25% of the cost of the best acceptable design (either my solution or the best practical design produced by the class, **whichever is better**), you will receive one (1) point for this section.

If your final design is within 50% of the cost of the best acceptable design, you will receive a half (0.5) point for this section.

Designs outside this price range and designs that fail to meet all of the specifications will receive no points for this section.