Fluctuating Stresses Pre-Lab

Please Note: Your answers to the questions in this document must be submitted by way of an online quiz posted on the class lab Moodle site (www.moodle.umn.edu). Look for the “Fluctuating Stresses Pre-Lab Quiz”.

You must submit your quiz responses on-line no later than 15 minutes before the start of your lab section to receive credit for the pre-lab. You will have up to 45 minutes to complete the quiz, assuming that you start it at least one hour before the start of your lab section.

You will be allowed only one attempt at the quiz. However, you are allowed up to three attempts on each question on the quiz. A penalty of 25% will be assigned every time you repeat a question. You will be given immediate feedback as to whether each of your answers is correct, partially correct, or incorrect.

You must do the quiz on your own. Enlisting the help of others while taking the quiz, or asking others who have taken the quiz before you for correct answers, or providing answers to others after taking the quiz yourself, constitutes cheating. Please don’t do it.

Please read all of the additional on-line documentation for the lab prior to the start of your lab section.

Background

Assume that you are designing a new bicycle crank set. Alternately, maybe you would like to design a new type of bicycle transmission. In either case, you will need to design the crank so that it does not break, as failure of the crank could cause severe injury of the rider. However, you do not want to “over-design” the crank either, as that would cause the crank to be heavier than it has to be. This would damage the appeal of your product in the highly competitive cycling market.

Your design would likely begin by modeling the stresses in the crank set to ensure that the stresses do not reach a level that could lead to failure. However, simply designing the stresses to fall below the static failure strength of the crank material will not suffice. This is because the stresses in the crank vary significantly every time the crank is rotated 360°. As you will learn in the ME 3221 lectures, when stresses change with time, parts are likely to fail due to “fatigue”. Materials fail in fatigue at stress levels that are a small fraction of their static strength. Since mechanical engineers must often deal with parts where stresses change with time, they must understand fatigue failure.

This lab has three goals. The first is to give you practice calculating stresses in a real part, a bicycle crank shaft, subjected to real-world loads. This will be done in this pre-lab. The second, and most important, is to help you visualize how stresses fluctuate in an application where fatigue failure analysis is required. This is done both during data collection in the lab session itself and while processing your data following the lab. The third is to demonstrate how you can use your stress model to figure out how much force that the rider is applying to the crank, which in turn can be used to estimate how much power the rider is putting in to the bicycle, among other useful measures. This is done in the scope of the lab report.
We can use some results from the first goal to help achieve the third goal. Specifically, we can develop a scaling factor to deduce the force that the rider is applying to the pedal from the stresses that we measure in the lab. We accomplish this by calculating the stresses that would be produced at some point on the crank shaft, for two convenient positions of the crank, if the rider applied a force of 1 N to the left pedal.

This may seem odd at first, since the pedal force will normally be much higher than 1 N. However, this logic provides us with the scaling that we seek. For example, let’s assume that we determine that a 1 N force on the left pedal, at a position where the pedal crank is parallel to the ground, creates a stress of 7 MPa at a point where we measure stresses on the crank shaft. (This is not an accurate result; it is only used as an example.) Then, if we actually measure a stress of 350 MPa at that point when we run the lab, we know that the force applied at the pedal is:

\[
350 \text{ MPa} \times \frac{1 \text{ N}}{7 \text{ MPa}} = 50 \text{ N}
\]

**Pedal Crank Instrumentation and Geometry**

You will pedal a real bicycle that is mounted to a fan trainer during the lab session. This bicycle has sensors attached to the crank shaft which enable you to measure the stresses in it while you are pedaling. The stresses are recorded using a “data acquisition system”, or “DAQ”.

The sensors that are mounted to the crank shaft are called “strain gage rosettes”. For simplicity, we will refer to them as simply “strain gages”. Actually, they measure strains on the surface of the crank shaft rather than stresses\(^1\). However, we can interpret those strains to figure out normal and shear stresses at the points where the gages are mounted. The required conversion factors have been programmed into the DAQ for you in advance. Therefore, the DAQ will read out stresses. Specifically, we can measure two types of stress at two different points on the crank: normal stresses that are attributable to bending, and shear stresses that are a superposition of shear stress due to torsion and shear stress due to transverse loading\(^2\).

The locations where the strain gages are mounted on the crank are illustrated in Fig. 1. One of the gages is aligned with the left pedal crank. The second is mounted 90° clockwise from the first, so that it is perpendicular to the pedal crank.

A scaled drawing of the crank geometry is provided in Fig. 2. The origin of the coordinate frame is located at the center of the right crank shaft bearing. The \(z\)-axis points from the crank set to the front of the bicycle. The left crank shaft bearing is at \(x = 52 \text{ mm}\). The strain gages are located at an axial position of \(x = 64 \text{ mm}\). The diameter of the crank shaft at this position is \(d = 16 \text{ mm}\).

\(^1\)The strain gages are bonded to the surface of the crank shaft. Tiny deformations in the surface of the crank cause tiny changes in resistance in extremely fine wires inside the strain gages. These wires are connected to an electronic “bridge circuit”, where the tiny changes in resistance are converted to measurable voltages. If you would like to learn more about how strain gages work, we suggest [http://www.ecourses.ou.edu/cgi-bin/ebook.cgi?doc=&topic=me&chap_sec=08.3&page=theory](http://www.ecourses.ou.edu/cgi-bin/ebook.cgi?doc=&topic=me&chap_sec=08.3&page=theory). You can learn about strain gage bridge circuits at: [http://www.allaboutcircuits.com/vol1/chpt9/7.html](http://www.allaboutcircuits.com/vol1/chpt9/7.html)

\(^2\)Transverse means perpendicular to the shaft axis. See Juvinall & Marshek Sec. 4.7 for further information.
The largest chain sprocket, to be utilized in Lab #1, is located at $x = -31$ mm. The force on the left pedal will be assumed to be applied at $x = 166$ mm. We will assume that the pedal force is always applied vertically.

The pitch radius of the largest sprocket is 97 mm. The crank radius is 175 mm. The angle of the crank set, $\theta$, is measured counterclockwise positive from the $+y$–axis.

Figure 2: Scaled drawing of the bicycle crank set utilized in Lab #1.
Pre-Lab Questions

*Important Note:* You must enter your final answers for the four questions included below in a moodle on-line quiz. If the actual stresses are in the direction opposite to that shown on the sample stress elements provided below, input them as negative numbers. Include shear stresses caused by transverse forces if any exist at the point being analyzed. Input your answers accurate to at least three significant digits. If a stress does not exist, please indicate that by inputting a magnitude of zero. The stresses should be input in units of KPa.

1. Assume that the pedal angle $\theta = 90^\circ$ and that the force on the left pedal is 1 N (see Fig. 3). Input the magnitude of all stresses acting on a stress element under the first strain gage (see Fig. 4(a)).

2. Assume that the pedal angle $\theta = 90^\circ$ and that the force on the left pedal is 1 N (see Fig. 3). Input the magnitude of all stresses acting on a stress element under the second strain gage (see Fig. 4(b)).

![Figure 3: Right side view of the crank set when $\theta = 90^\circ$.](image3)

![Figure 4: Stress elements at the strain gages when $\theta = 90^\circ$.](image4)

(a) Stress element at first strain gage  
(b) Stress element at second strain gage
3. Assume that the pedal angle $\theta = 180^\circ$ and that the force on the left pedal is 1 N (see Fig. 5). Input the magnitude of all stresses acting on a stress element under the first strain gage (see Fig. 6(a)).

4. Assume that the pedal angle $\theta = 180^\circ$ and that the force on the left pedal is 1 N (see Fig. 5). Input the magnitude of all stresses acting on a stress element under the second strain gage (see Fig. 6(b)).

![Figure 5: Right side view of the crank set when $\theta = 180^\circ$.](image)

![Figure 6: Stress elements at the strain gages when $\theta = 180^\circ$.](image)

(a) Stress element at first strain gage. (b) Stress element at second strain gage

*Note:* The element is being viewed from the top; e.g., you are looking at it through the crank shaft (so that the crank shaft would block your view of it in real life).