Topic: Strength Analysis and Design of Bicycle Frame

1. Introduction

Bicycles have a long history since 1690 and have been a fascinating human-powered transportation tool that is most widely used today by human beings (twice as many as motorcars). The analysis and design of a bicycle frame will allow a student apply the knowledge learned in Statics and Strength of Materials to a practical engineering problem.

2. Background Knowledge

2.1 Bicycle Design

Fig. 1 illustrates a typical bicycle with all its main components labeled. You need to be familiar with the names of these components and use these names in your project report and communication with others.

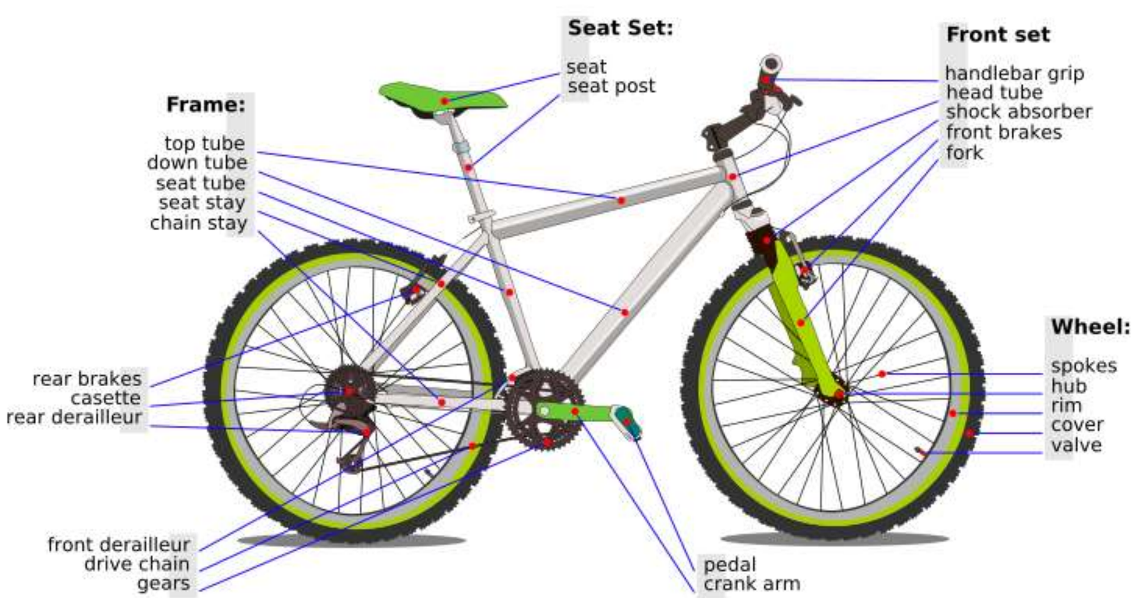

Figure 1 Components of a representative bicycle [1].

The design of bicycle involves many disciplines and many issues. As a traditional mechanical device, one needs to consider the design from perspectives of power generation, power transmission, aerodynamics, dynamics, strength, mechanisms, and materials [2]. Modern bicycles integrate electronic devices to monitor bicycle performances and rider's physical conditions. Therefore these bicycles gradually become a mechatronic device, requiring knowledge on electronics, computer and software, and integration of all these aforementioned disciplines. Future bicycles might use electronic devices and intelligent control to improve traditional mechanical components such as brakes, transmissions, etc.

For this project, we will focus on the strength aspect of the bicycle frame design. Even though the project simulates the real engineering design, you are cautioned that this project is only a small portion of the entire design task of a bicycle. Therefore any conclusion drawn from your project needs to be carefully examined under the lights of other design aspects, and subject to rigorous physical testing.

2.2 Bicycle Frame

A bicycle frame includes head tube, fork, top tube, down tube, seat tube, seat stay, and chain stay. Fig. 2 shows a bicycle frame with these components. We will constrain our project to the frame only. Even though usually the spokes and axles tend to fail more often than the frame, the frame provides the main structure of a bicycle; its strength is thus of high importance. The frame, on the other hand, provides more possibilities for innovation and exciting new bicycle designs.

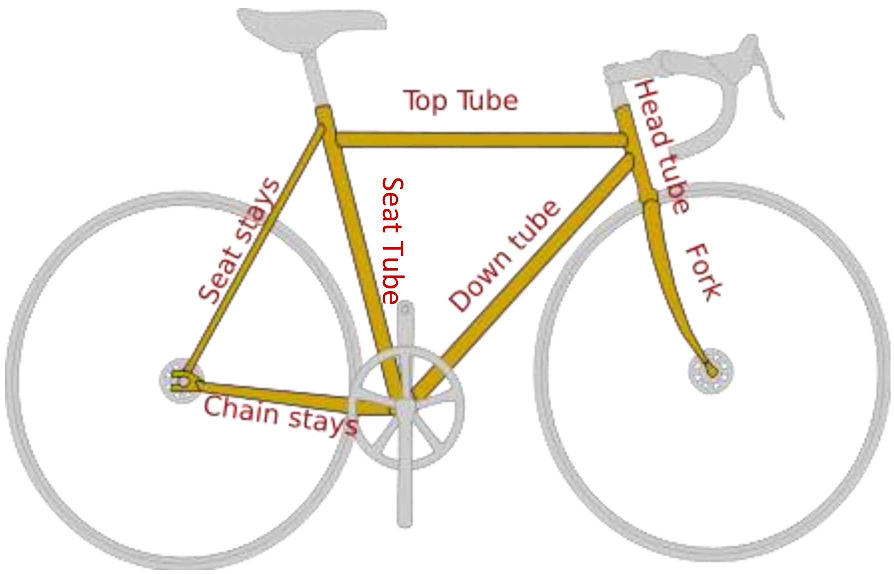

Figure 2 Components of a bicycle frame [1].

2.3 Failure Modes of Bicycle Frames

As one might have seen that in a circus 10-15 men are carried by a commercially available bicycle, the safety factor in bicycles is high for normal loads that result from smooth-road riding conditions. The failure of a bicycle often is not caused by this normal condition, but rather caused by following factors or a combination of these factors.

1. Low-cycle fatigue (LCF). LCF is defined as fatigue involving 2-50,000 cycles. Bicycles are found to fail predominantly due to LCF, as compared to high-cycle fatigue (HCF) when the number of cycles is in millions or higher. A useful choice for the maximum stress in a particular material is the stress that causes failure after 3000-6000 cycles, which can be defined as σ_{LCF}.
2. Stress concentration. Hole and fillet stress concentrations can increase a stress by a factor of six or more. Other stress concentration could be due to improper manufacturing, heat treatment, or weak joints.
3. Loads due to impacts (e.g. bumps), start-up, or swerving are far more severe than normal loads encountered in general smooth pedaling.

It is also observed that handlebars frequently break, and sometimes the front forks fail, which causes serious safety consequences.

3. Project Details

3.1 Loading Condition

Given the complicated use (or sometimes abuse) of bicycles, to define the actual service loads a bicycle endures is a difficult task. The principal information needed for a more analytical approach is a collection of loading data gathered from actual bicycle use by a wide variety of people over at least a year [2]. From this regard, physical testing that simulates various loading conditions is performed in industry to test and guide the bicycle design.

For this project, we assume only one loading condition from many for the exercise.

Loading condition: the rider jumps onto the bicycle to start. Assume that two times of the rider's total weight is on the seat due to the impact; and a quarter of his/her weight is on the handle. The weight of the rider can be assumed to be around 180 lbs.

3.2 Failure Criteria

Due to complexity of finding σ_{LCF} , we use the endurance limit of the material S_{FL} as our design criteria. S_{FL} can be calculated using the following equation

$$S_{FL} = S_f'*(NFL)^b$$

Where S_{FL} stands for the fatigue stress, S_f' is the intercept and b is the slope of the stress-cycle curve; NFL is the number of loading cycles, 10^6 is taken for steels and 10^7 for aluminum. One can find the value of S_{FL} by using the following URL http://www.fatiguecalculator.com/constamp/stresslife.htm

You need to first click the "Material Property Finder," and then "Material Property Estimator" to find the S_{FL} for commonly used materials. You can ignore the rest of the info on the webpage for this project. For your project, assume a safety factor > 3.0 is a safe design.

3.3 Project Tasks

1. Identify a bicycle (one that belongs to you, your family members, friends, etc.) and obtain the geometric measurements of the bicycle frame; find the material of the tubes (or best estimation)
2. Approximate your bicycle frame by straight bars.
3. Apply the loading condition, assuming all forces are vertical and the two tires are statically balanced similar to the "roller on a smooth surface" condition.
   a. Assuming all joints are pin joints and the entire structure is a truss structure, calculate the forces and stresses in each bar, and find the safety factor for each bar.
   b. Assuming 1) the top tube is removed and, 2) the seat stay and chain stay are trusses but 3) the rest of the three bars are beams, calculate the stresses in each bar and verify if the design is safe.
   c. Assuming all the bars are beams (actual case), use the given Finite Element Analysis (FEA) program (refer to the course CANVAS page to download the program "TrussBeam-2D-2017.zip"; read its Introduction_GW.docx first) to calculate the stresses in beams, and verify if the frame is safe.

4. Compare the results from a), b) and c) and make comments
5. Based on the results of c), answer following questions:
    a. Is the frame safe under the given loading conditions?
    b. Which bar is most risky?
    c. What are your suggestions to improve the current design?
    d. What if weight is to be reduced, what are your suggestions to change the design?
6. Propose a design change, e.g. dimension, material, tube cross-section, configuration of the frame.
7. Repeat Steps 3-c)
8. Compare your suggested design with the current design and report your findings
    a. Is the new design better or worse?
    b. In which way it is better or worse?
    c. If you are asked to design it again, what are the changes that you plan to try?
9. Report what you have learned through this project.

Project Report

The project should follow guidelines of technical report as in Ref. [3]. Additional specifics are as below:

1. The title page should have signatures of the authors, which will be used for assigning marks.
2. The main text of the report (excluding title page, letter of transmittal, table of contents, list of figures and tables) should NOT be longer than 5 pages (1.5 space, 12 pt fonts).
3. Put all the detailed analysis in the Appendix and only present main results in the report
4. Remember to cite your analysis in the Appendix in your main text

References

1. Wikimedia Foundation, Inc., URL: http://en.wikipedia.org, Last Access: Oct. 30, 2008.
2. Wilson, D.G., *Bicycling Science*, 3d Edition, The MIT Press, Cambridge, Massachusetts, 2004.
3. URL: https://writing.colostate.edu/guides/guide.cfm?guideid=88, last access Nov 26, 2017.