ME 328 – Machine Design
Spring 2020, Homework Set 6

1. ***Educational purpose****: this problem demonstrates the application of impact analysis in the context of automotive suspension design. This is a starting point for other problems on this assignment where you will analyze the displacement and acceleration as a function of time.* (5 pts) A small off-road vehicle has a total mass of 400kg, including the driver. After it goes over a jump, it strikes the ground with a vertical velocity of 4.4 m/s. Its suspension system uses springs with a rate of 13kN/m. Assume each wheel carries one-fourth of the total vehicle mass and all four wheels strike the ground simultaneously (you may model this as a mass spring system with m=100kg, k=13kN/m). State all assumptions.
   a) Draw an appropriate free body diagram and kinetic diagram showing this as a mass-spring problem.
   b) Determine the undamped natural frequency of the system.
   c) Determine the maximum displacement assuming no shock absorber is used.
   d) Determine the static deflection due to the 400kg load (100kg per wheel).
   e) Show that the critical damping constant is 2280 N-sec/m.

The next problems on this assignment are meant to be so simple freshmen could do them, yet so challenging juniors will have difficulty. I know you can punch buttons on a calculator to solve complex equations – but no one is going to pay you to do that. These problems push you beyond calculator solutions. They are meant to make you aware of the fact that you can solve far more complex problems; problems that begin to resemble real engineering problems for which you will be paid to solve. They require integration of basic concepts learned in physics (hence "simple enough that a freshmen could do it") to solve non-trivial engineering problems (which may give you a headache).

Being able to solve new problems in unique ways is an important skill for engineers. Practice makes perfect (or at least closer to perfection).

Educational purpose*: this problem demonstrates the application of impact analysis and vibration analysis in the context of automotive suspension design. In problem 1 you developed the appropriate hand calculations. This next problem goes beyond that and uses basic kinematic equations to allow "time marching" analysis (numerical method). This determines the oscillatory motion as a function of time. Problem 3 uses problem 2 analysis to solve a design problem.*

2. (10 pts for the graphs, 1 pt each for a, b, c, d) DESIGN PROBLEM: A small off-road vehicle has a total mass of 400kg, including the driver. After it goes over a jump, it strikes the ground with a vertical velocity of 4.4 m/s. Its suspension system uses springs with a rate of 13kN/m. Assume each wheel carries one-fourth of the total vehicle mass and all four wheels strike the ground simultaneously (you may model this as a mass spring system with m=100kg, k=13kN/m). Use Excel to create plots of the displacement and acceleration (one graph each) as a function of time (zero to 2.0 seconds, use time increments of 0.01 seconds). Include in both plots four different damping factors ($\zeta = 0$; $\zeta = 0.25$; $\zeta = 1.0$; $\zeta = 2$). The

initial conditions at the instant of impact are: x_0=0 m, v_0 = 4.4 m/s (downward). To determine the displacement, velocity, and acceleration use the following approximate kinematics equations (which *incorrectly* assume constant acceleration):

$$x_{i+1} = x_i + 0.5*(v_i + v_{i+1}) * \Delta t \; ; \quad v_{i+1} = v_i + a_i * \Delta t \; ; \quad a_i = -(k/m)*x_i - (c/m)*v_i - a_g$$

From the graphs:

a) What is the natural frequency with no damping?
b) For the damped systems, what is the displacement after oscillations have died out?
c) Show that the sum of all forces (including weight) equals the *inertial* term (mass*accel) at all times (at least from zero to 1.0 seconds for the case of $\zeta = 0.25$). Note, "*inertial*" is not the same as "initial".
d) Comment on the validity of the displacement graph. Why **and** why not might it be "accurate enough" to be relied upon for engineering decisions?

3. (5 pts – but you need the software in problem 2) DESIGN PROBLEM: Create a Design Increment Document for the following problem (*hint, if you developed the spreadsheet in problem 2 properly, it should be very useful in this design problem*). See link on course web page for DID description. Note – DID's really aren't any different than the standard homework format – other than you should add comments from time to time explaining what/why it is you are doing. So this may sound more complicated than it is.

   Problem statement: determine spring constant and damping constant to satisfy the following criteria:

#	Criterion	Priority	Description
1	Total mass	Essential	Total vehicle mass is to be 400kg (100kg per wheel)
2	Max total displacement	Essential	When dropped from 2 meter height, the max allowable displacement is 300mm from the "unloaded" height (spring is fully extended).
3	Ride feel	Important	To prevent oscillating motion, the system should be critically or over damped.
4	Minimize impact force	Important	Deceleration forces should be minimized.

4. For the past several decades, one of the primary questions NASA, as well as others, have been working on is "what is the effect of long-term space flight on humans". Many experiments have been done in orbiting space stations (such as the ISS) to evaluate effects of exercise and diet on human health. NASA would like a way to measure the "weight" of astronauts (actually, their mass – they weigh zero in zero gravity). Sketch and explain device that NASA could use to achieve this. (hint – this may be something that already exists…it would not be "cheating" to google it, but if you do, be sure you understand it).

5. There are several links on the course web page (and copied here). I think you will find most of these interesting. A few of these will discuss or use Fourier transforms – a mathematical way of showing the frequency content of a signal. Fourier transforms are very powerful and

very useful for analyzing vibrations and other oscillating signals. There is nothing to turn in for this so it is your decision to watch none, a few, or all. We may have watched a few in class – but if we haven't yet, we probably won't.

Vortex sheading (the real cause of Tacoma Narrows Bridge oscillation) (3:45min)
2nd mode cantilever beam (a few seconds)
Wine Glass - time warp (4 min)
Wine glass with water (1.5 min)
Overtones, square wave (1 min)
youtube: overtone chant (2 min)
Applet (play around with it for a few minutes)
Oldie but very Goodie -Fourier Series(3 min)
Frequency analysis for troubleshooting (5 min)
Guitar overtones (7 min)
Slow motion string vibration) first 10 seconds is enough
Music - good vibrations (6 min)
Dan Russel's Penn State web page (really cool stuff, music, bats, vibration demo's

THE BATTLE OF THE X-PLANES is now available on the ME328 Moodle page (right side of screen, scroll down to Activities>Resources. **If you have not yet watched it, please do so before the end of spring break.**

6. No homework "credit" will be given for this part of the assignment – nothing to turn in. We be discussing after break. It is a 2 hour documentary very well worth watching in regards to engineering design **even if you have no interest in aerospace**. **Pay attention to:**
    a) **Any discussion about "thermosetting vs. thermoplastic composites."** Boeing bets the whole project on thermoplastic composites to save weight, but how can thermoplastic composites save weight? We'll discuss that later, because it isn't clear how from the video.
    b) Pay attention to a meeting of a few dozen engineers trying to determine which of two different design they should pursue. **There are two important lessons demonstrated**: 1) the fact that engineers must often make decisions without having all the facts and data needed and 2) engineers need to have confidence in their professional opinions in order to make significant contributions to engineering decisions.
    c) Listen for the name Dennis Muilenburg. He went on to become Boeing's CEO from 2015 to 2019, when he was fired after the two 737-Max accidents.
    d) Don't forget the popcorn: https://www.youtube.com/watch?v=Y_WPLeDmU6o