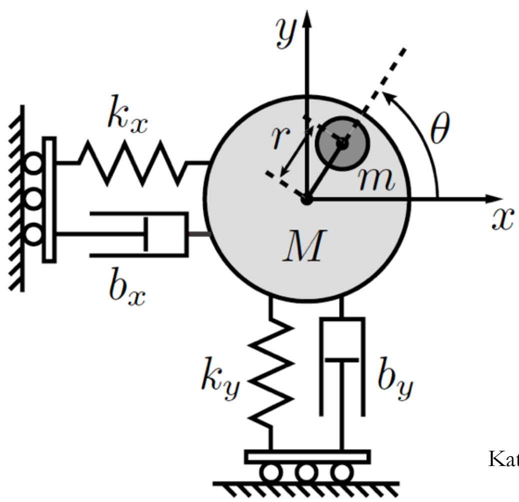
Assignment 3:
Tactile Devices

PDF file due on Canvas by 11:59 pm PDT on Thursday, April 30, 2020
Please write clearly or type your responses.

1. Modeling of an eccentric rotating mass vibration motor

The following schematic shows a simple model for an eccentric rotating mass (ERM) vibration motor. In this model, you will assume that the horizontal and vertical degrees of freedom operate independently such that they result in two separate (decoupled) equations of motion. *If you need to brush up on your dynamic systems modeling, you can check you undergraduate dynamic systems notes, e.g. ME 161, collaborate with other students in the class, or ask the teaching team in office hours.*



(image courtesy
Katherine Kuchenbecker)

A. Develop the independent x and y equations of motion for this system in terms of all the constants and variables shown. Assume angular velocity $\dot{\theta}$ is **constant**.
   i. Find x and y accelerations of the eccentric mass: $\ddot{x}_m$ & $\ddot{y}_m$
   ii. Draw a free body diagram for both the large mass (M) and the eccentric mass (m)
   iii. Write the equations of motion for the combined system and put in the form:
   $$a\ddot{x} + b\dot{x} + cx = d$$
   &
   $$e\ddot{y} + f\dot{y} + gy = h$$
   Where x and y give the position of the large mass (M) and a, b, c, d, e, f, g, h are scalars (though not necessarily constants).

B. Call the non-homogeneous (forcing function) term in the x direction f_x, and the non-homogenous term in the y direction f_y (these were d and h, respectively, in part A). Compute the vector inertial force $f = \sqrt{{f_x}^2 + {f_y}^2}$, and show that the vector force is independent of eccentric mass angle, θ. (However, it will be dependent on the angular velocity, $\dot{\theta}$.)

C. Solve for the natural frequency (ω_N) and damping coefficient (ζ) for our system. Use $k_x = k_y = 500$ N/m and $b_x = b_y = 0.5$ N-s/m for the human skin (from Matsuura et al. 2014[1]), as well as $M = 1.5$ g, $m = 0.3$ g, and $r = 1.5$ mm to represent a typical ERM motor (from Kapur et al. 2010[2]). Note that these are the same for both the x and y directions, so beginning with this part of the problem, we will only look at the x-direction.

D. The steady state solution to our equation of motion takes the following form:

$$x_{ss} = B * sin(\dot{\theta} * t + \phi)$$

with B defined as follows:

$$B = \frac{\frac{m * r}{m + M}}{\sqrt{\left[\left(\frac{\omega_N}{\dot{\theta}}\right)^2 - 1\right]^2 + \left(2 * \zeta * \frac{\omega_N}{\dot{\theta}}\right)^2}}$$

Plot the amplitude of the steady-state response (B) against the ratio ($\dot{\theta}/\omega_N$) as the ratio varies from 0 to 6.

Use MATLAB Grader via the no-credit Canvas assignment "Assignment 3 MATLAB Grader" (or use MATLAB elsewhere if you have access to it) to create the plot, demonstrating the interdependency of the amplitude and vibration frequency of the ERM. Include the plot in your pdf solutions. (Here, MATLAB Grader is just a "sandbox" for you to use for MATLAB calculations if you don't otherwise have access to MATLAB.)

2. Application of a vibration motor for haptics

A. If we want to maximally stimulate the Pacinian Corpuscles, the mechanoreceptors most sensitive to vibration, the vibrations should occur at 240 Hz. Given the skin and device properties described in Problem 1, how well would this work? Show any calculations and describe your conclusion in words. You can use the no-credit Canvas assignment "Assignment 3 MATLAB Grader" if you need access to MATLAB to perform calculations.

B. Another perspective is that we could try to apply vibrations the maximally displace the skin in order to stimulate other mechanoreceptors. For this, we want to vibrate the system at the resonant frequency of the skin, which was measured to be about 14 Hz for the forearm in a paper by Shull et al. 2019[3] Given the skin and device properties described in Problem 1, how well would this work? Show any calculations and describe your conclusion in words. You can use the no-credit Canvas assignment "Assignment 3 MATLAB Grader" if you need access to MATLAB to perform calculations.

[1] https://doi.org/10.1007/978-3-662-44196-1_38
[2] https://doi.org/10.1109/HAPTIC.2010.5444606
[3] https://doi.org/10.1109/TOH.2019.2917072