/MAE 3260 Final Group Work: Exploring a System of Interest

Report

Title: Studying the massage gun as a system

Topic of Interest: Massage Gun

Abstract: We are going to analyze the system response of a massage gun because, as students with aching muscles, our closest confidant is the massage gun. We expect it to be a second-order vibrational ODE system with a disturbance input coming from the interaction with the muscle and a step response coming from different speeds/modes that the massage gun may have. We will evaluate whether it is an open-loop or closed-loop system, as massage guns can be both, and we will have to evaluate which one this particular massage gun is. By making a block diagram, identifying the controls, and testing out different settings, we will be able to estimate the output.

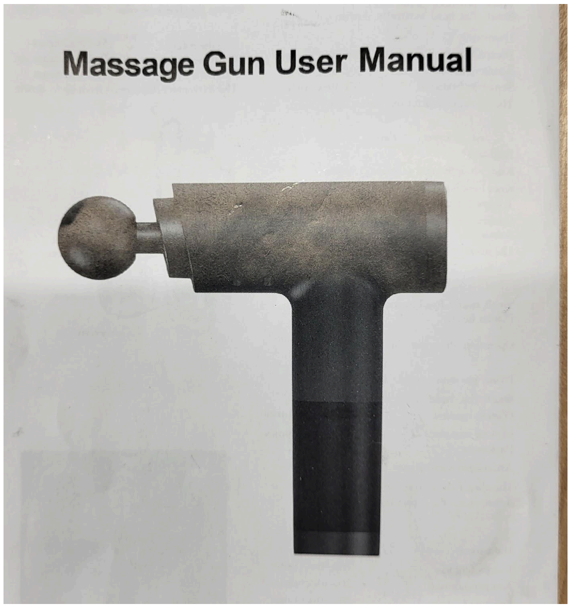
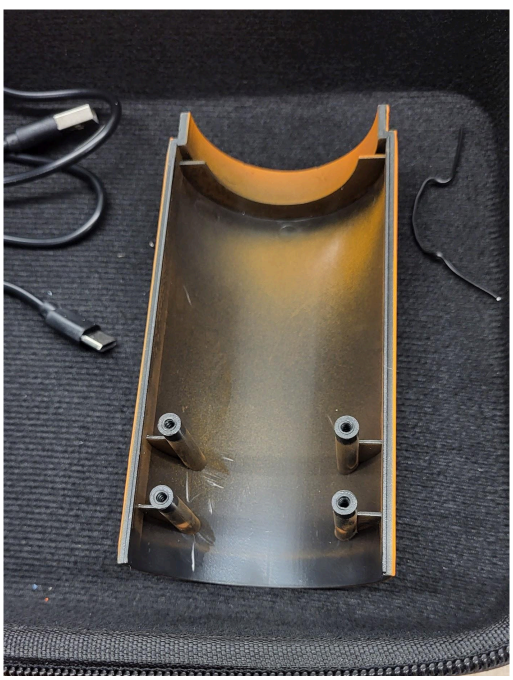
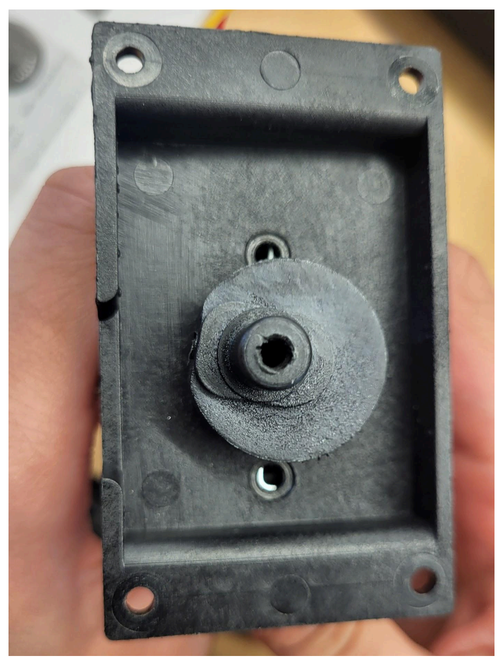
Students/Roles:

Student	**Task/Role**
Apurva, Yunxi, Iris	Together as a group we thought of how to proceed with the dissection, and talked through components of the block diagram in order to fully understand the system.

List of MAE 3260 concepts or skills used in this group work:

- Models:
    - o ODEs
    - o Block diagrams
- Open-loop system:
    - o Parameter estimation (speed of motor)
    - o Step Response (Different settings/speeds on the massage gun)

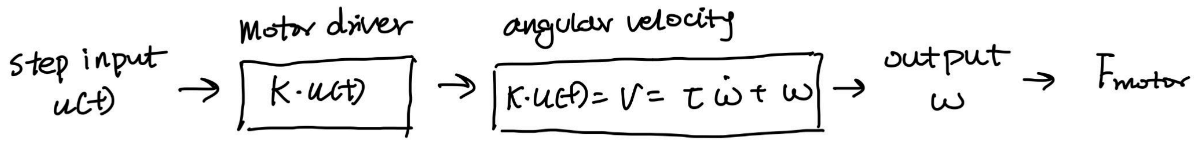
Page 2-3: Take apart + what we learned

How the gun looks before take-apart	Massage gun housing. The wiring leads to rechargable battery
Top casing of housing	Cam attached to motor to actuate linear motion of the piston

 Piston arm with bearing	 motor

After taking apart the system, we quickly realized that the system is an open-loop system with no closed-loop control feedback. The motor's input force directly influences the piston displacement speed. We noticed that there is a cam attached to the motor, which allows for the linear motion of the piston. Below we go into detail on the input and outputs of the system as well as its governing equation

Page 4: Block Diagram



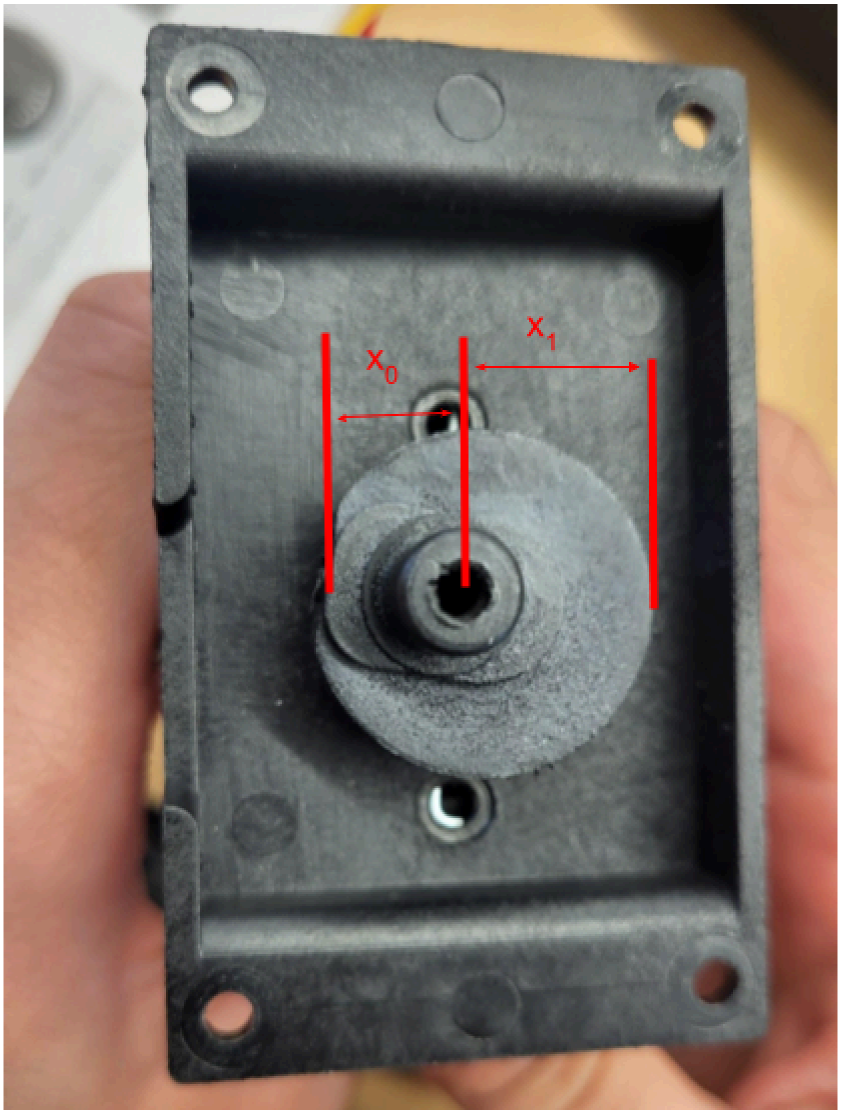
Known from manual of massage gun: voltage: 9V
speed mode one: 2100 rpm

Motor driver: it converts the step input into a voltage for the motor. A typical step input for a massage gun is likely to be the PWM duty cycle, as different speed modes correspond to different duty values. In a simplified case where we are dealing with one speed mode, step input can be to turn on the battery which would mean V_motor = 9V. (to clarify: V_motor = K*u(t)*V_battery)

Angular velocity: time constant of motor, Tao, determines how fast speed responds to a step input. If we want to measure it, we can apply a step input and record the speed vs time and fit it to curve w(t) = w_0*(1-e^(-t/Tao))

Page 5: ODE + Transfer Function

When we observed the physical system we noticed that the driving action behind the massage motion was created by a motor spinning an elliptical output on the shaft. The difference between the radius on either side of the ellipse creates that displacement that then translates to the end of the massager. This is shown in the picture below where $\Delta x = x_1 - x_0$.



That also means that the amount of displacement the massager exerts on an object, like a muscle, is independent of the speed of the motor, because it's a geometric property. However, the speed at which the massager operates is directly proportional to the speed of the motor and by extension the voltage. This part is an open system, as the motor does not use feedback so the only thing that changes the motor voltage draw is the massager settings. As a result of displacement and velocity being separately controlled we can analyze this as a decoupled system. The mass of the system is the shaft, elliptical output, and the rest of the parts creating the massaging motion because that is the mass that the motor drives.

Equation 1) $F_{motor} = 2 * m * \frac{dx}{dt} * \omega$

Equation 2) $M * \frac{d^2x}{dt^2} = k_{motor} * \Delta x$

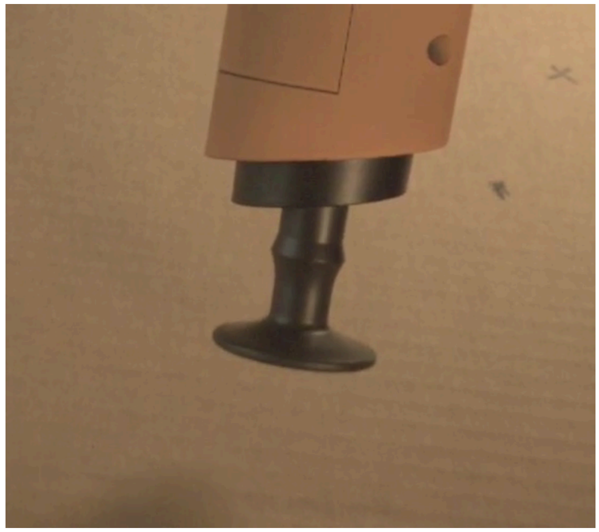
This is the operation of the massager in air, without contacting a muscle. If the massager contacts a muscle, the muscle exerts a reaction force in the direction of the displacement that acts as a dampening force. As a result, we would get equation 2 to be $M * \frac{d^2x}{dt^2} = k_{motor} * \Delta x - b * \frac{dx}{dt}$. Both this and the original equation 2 are vibration equations, with the second version including a dampening factor to it.

Whether ω and $\frac{dx}{dt}$ are related depends on whether the massager experiences feedback from the muscles. When there is feedback the muscle creates more resistance on the shaft of the motor which would cause increased current draw and slower rotation at the same time. So, there would be a correlation between the angular velocity and linear velocity in the form of $\omega R = \frac{dx}{dt}$, where R is the shaft of the motor.

For the electrical system, the voltage and current of the motor, when we choose a setting for speed, give us the desired angular velocity. The ‘u’ is the step input to the motor driver to achieve the desired speed

$\tau * \frac{d\omega}{dt} + \omega = K * u(t)$ [1]

Page 7: Pictures from high-speed video + explanation



This video features the process that the massage gun starts from stationary to the mode one. It finishes the speed-up in one cycle, which means it gets steady state within one cycle of full displacement. In slow-motion mode, we can observe there is displacement vertically happening in the presence of horizontal displacement, by the reflection of light on the surface of the massage gun tip, which was addressed in page 5.

This video features the change from speed mode one to speed mode two, which experiences a very smooth transition process. One observation from this video is that the vibration of the main body of the massage gun gets bigger after transition.

Page 8: References

[1] M. Campbell. MAE 3260. Class Lecture, Topic: “1st Order Open Loop Systems.” College of Engineering, Cornell University, Aug 27, 2025