MechE Mixing Maniacs

Topic of Interest: 5 Speed Hand Mixer

Students/Roles:

Student	**Portfolio**
Name	Link to results in student's individual portfolio
Claire Pillar	See canvas
Anna Fulbright	See canvas
Joe Kunken	See canvas
Luis Esquivel	See canvas

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

- Settling time
- Open loop systems
- Steady state behavior
- Disturbance response
- Block diagrams

Abstract:

The system our team decided on is the hand mixer because we have used them before in everyday life and it is interesting to think about how they work. Since we did a dissection, we thought it would be most beneficial if we all worked together throughout the process instead of dividing up tasks so that we could all learn about all the aspects of the mixer. We took apart the mixer to see how different parts fit together and then we used the high speed camera to look at the settling times of the whisk at different power settings and with an added disturbance. We then compared these values to those calculated from a simplified mathematical model.

Dissection/How it Works:

We started the dissection process by taking apart the outer casing (Figure 1). The plastic casing was held together by triangle screws and we were unable to find a correctly shaped screwdriver. Eventually, we used a smaller flat screwdriver to loosen some of the screws, then used a chisel to pry the casing open.

Figure 1. Hand mixer prior to dissection

Inside, we found an electromechanical system with a motor, fan, and coils of wire (Figure 2). One of the two inner plastic casings that holds the whisks in place fell out, but we plugged the device in and watched the whisk spin at the five different speeds. We noticed that it appeared to reach steady state fairly quickly, so we decided to explore this further.

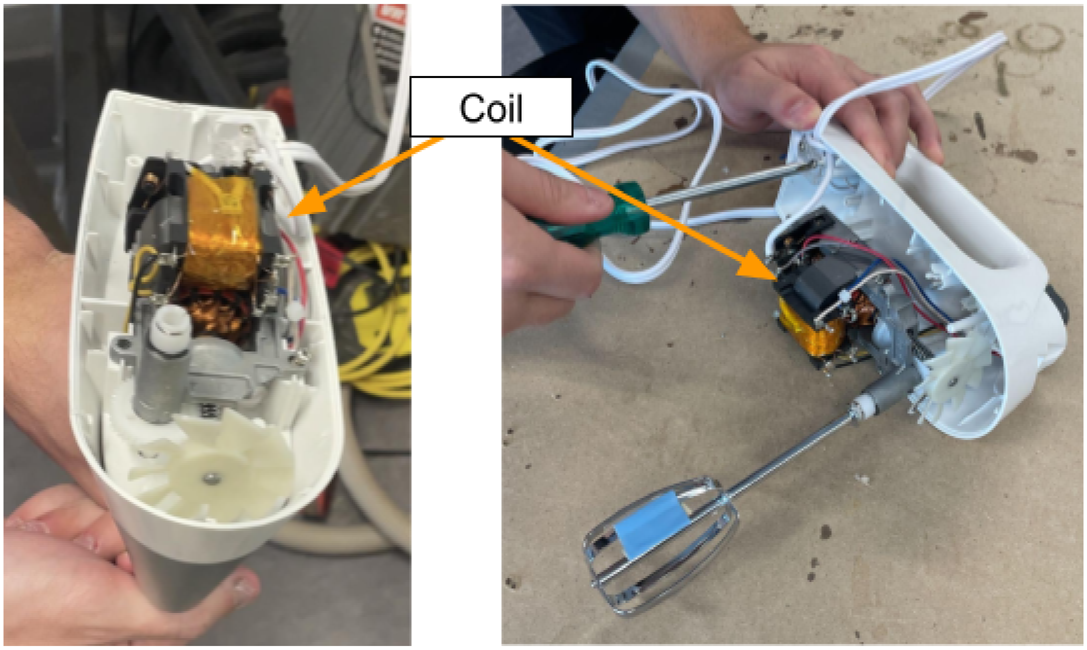

Figure 2. The initial view of the electromechanical system once we removed the lower casing

After our initial observations, we cut open the plastic casing using a handsaw to better understand the electromechanical system. The switch used to turn the hand mixer to different speeds was set into the top handle of the casing, along with a “turbo” button. Unfortunately, as we took the top handle casing off the mechanism for the “turbo” setting fell apart and we were unable to determine how this mode worked. For the rest of the regular five speeds, there are no sensors. Instead, the mixer turns on when the user moves the switch, which completes the circuit (Figure 3). To execute the five different speeds, there are five connection points which correspond to each speed. Each colored wire attaches to the main orange coil in separate locations, allowing flow through varying numbers of turns in the transformer and causing different voltages to run through the system.

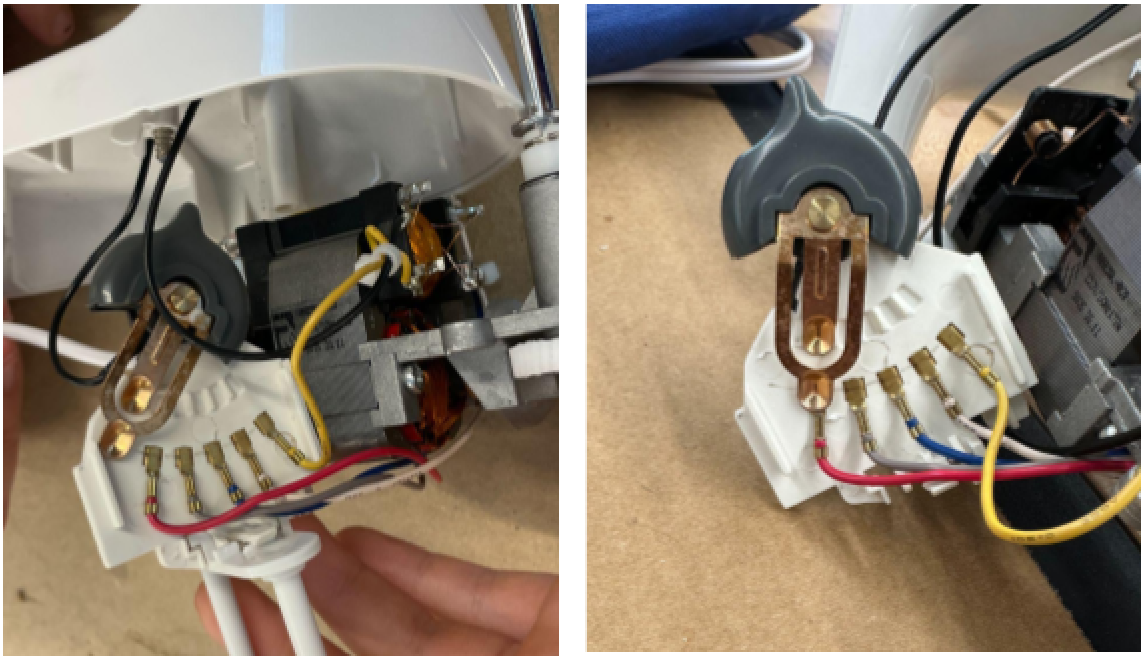

Figure 3. *Left*: the unconnected circuit when the hand mixer is turned off.
Right: when the user moves the switch, the circuit is connected; in this image to the lowest setting

The hand mixer contains a 12-pole motor directly connected to the worm gear and fan, which turns a helical gear. By manually moving the fan and watching the rotations, we found that the motor, worm gear, and fan all have the same rotation rate, and the whisk and the helical gear are directly connected and have the same rotation rate. To find the gear ratio between the worm and helical gears, we used a sharpie to mark a spot on the fan blades and then counted the revolutions of the fan and the whisk. We found that the gear ratio between the worm and helical gears is 20:1, and this is a constant ratio for all of the mixer speeds.

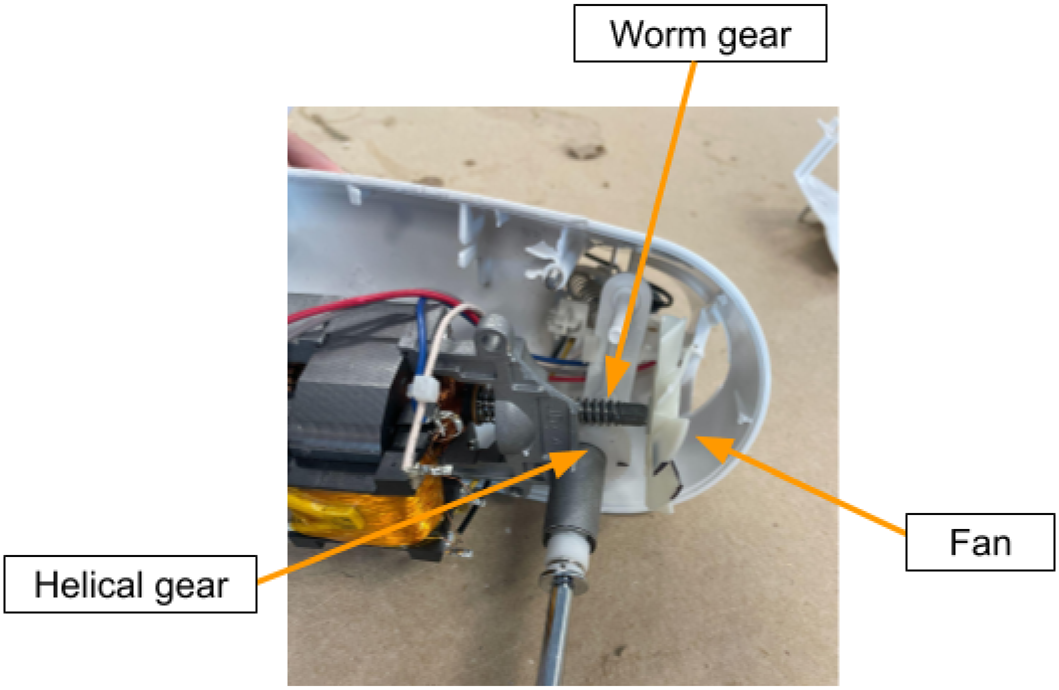

Figure 4. Annotated photograph of inner system, including how the motor connects to gears that turn the whisks.

Settling Time Exploration:

In order to analyze our system with the high speed camera, we decided to attach only one whisk blade so as to not clutter the frame. We attached a blue piece of tape to one side of the whisk in order to count each rotation. We analyzed three separate instances with the high speed camera. In the first instance, we ran the hand mixer at speed setting 1. Next, we ran the hand mixer at speed setting 5. Finally, we ran the mixer at speed setting 5 and added a disturbance. The results of these tests can be found in Table 1.

While analyzing the high speed camera information at speed setting 1, we observed that the mixer was able to perform about 3 rotations in the roughly 1 second clip we recorded. The first of these three rotations was completed in 90 milliseconds, while the second and third were completed in only 30 milliseconds. We believe this means that the system reaches steady state by its second rotation which occurred after 90 milliseconds.

At the max speed setting, we once again observed the mixer performing 3 rotations in a 1 second clip. During this time, the first rotation was completed in only 30 milliseconds, while the second and third each took 20 milliseconds. We again interpreted this as meaning the system reaches its steady state after completing the first rotation at 30 milliseconds.

For the last trial with the added disturbance, we took our data from three rotations directly after a disturbance was applied. It took a little bit longer to complete its first rotation at 40 milliseconds, however, it quickly returned back to completing the second and third rotations in 20 milliseconds each. From what we observed, the disturbance only added an extra 10 milliseconds for the system to reach steady state and did not affect anything else in any critical way.

Speed Setting	**Time for rotation 1**	**Time for rotation 2**	**Time for rotation 3**	**Whisk Steady state angular velocity**
1	90 milliseconds	30 milliseconds	30 milliseconds	209.44 rad/s
5	30 milliseconds	20 milliseconds	20 milliseconds	314.16 rad/s
5 + added disturbance	40 milliseconds	20 milliseconds	20 milliseconds	314.16 rad/s

Table 1. Rotation times and steady state angular velocities for different speed settings

Model:

We modeled our system as a DC motor, since most hand mixers use universal motors [3], which can operate with AC or DC current but function like DC motors. One of the main advantages of a DC motor is that they can have very high rotational velocities, up to 30,000 rpm

[1]. From our dissection, we learned that the mixer is an open loop system, so disturbance decreases the velocity but there isn't any feedback. This means that disturbance to the mixer (such as mixing in a viscous fluid) would be an input to the system in addition to voltage. To simplify the system, we didn't include the transformer in our model. Our block diagram is shown below.

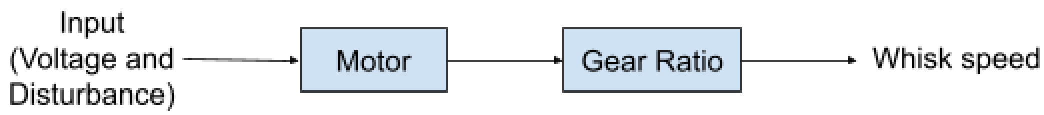

Figure 5. System block diagram

Using our notes [2], we found the ODEs and state space of the system.

$$I_m\dot{\omega} = k_T i_a - T_L - \omega c \qquad \dot{\omega} = -\frac{c}{I_m}\omega + \frac{k_t}{I_m}i - \frac{1}{I_m}T_L$$

$$v_a - i_a R_a - \frac{di_a}{dt}L_a - k_b\omega = 0 \qquad \frac{di}{dt} = -\frac{k_b}{L_a}\omega - \frac{R_a}{L_a}i + \frac{1}{L_a}V_a$$

Figure 6. *Left*: The ODEs of a DC motor *Right:* The equations solved for the highest derivative of each state variable on the left hand side of the equation

$$\begin{bmatrix} \dot{\omega} \\ \dot{i} \end{bmatrix} = \begin{bmatrix} -\frac{c}{I_m} & \frac{K_T}{I_m} \\ -\frac{K_b}{L_a} & -\frac{R_a}{L_a} \end{bmatrix} \begin{bmatrix} \omega \\ i \end{bmatrix} + \begin{bmatrix} -\frac{1}{I_m} & 0 \\ 0 & \frac{1}{L_a} \end{bmatrix} \begin{bmatrix} T_L \\ V_a \end{bmatrix}$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} \omega \\ i \end{bmatrix} + \begin{bmatrix} 0 & 0 \end{bmatrix} \begin{bmatrix} T_L \\ V_a \end{bmatrix} = \omega$$

Figure 7. The state space forms of the ODEs

Next, we found values for the unknown variables (Table 2). Some of them were included in the hand mixer information sheet, others were calculated or extrapolated from internet sources.

Variable	Value (minimum steady state speed possible)	Value (maximum steady state speed possible)
R_a (Resistance)	5 Ω	1 Ω
V_a (Voltage)	175 V	175 V
L_a (Inductance)	0.001 mH	0.001 mH
c (Damping constant)	0.001 Nms/rad	0.0001 Nms/rad
K_b (Back EMF constant)	0.14 Vs/rad	0.038 Vs/rad
K_T (Torque constant)	0.05 Nm/A	0.08 Nm/A
T_L (Back EMF torque)	0 Nm	0 Nm
Motor diameter	0.0254 m	0.0254 m
Motor mass	0.3 kg	0.3 kg

Table 2. Values of constants used in model calculations

Results and Analysis:

We created a MATLAB script with our ODEs and the variables for the values to find the motor and whisk steady state speeds for the low and high speed setting. We also found the settling times within 5% of steady state for the low and high speed setting. As shown in Table 3, the calculated values of both steady state speeds and settling times are much higher than the real-life values we observed. This is likely due to fundamental differences in the real-life model as compared to our mathematical model. When setting up the model, we decided to greatly simplify the system. For example, we did not take into account effects of the transformer and used the moment of inertia of the motor and not the whisk in our calculations. All of the values of constants that we used in our calculations were also taken from the internet and could be inaccurate. We used a voltage of 175 V found from the mixer specifications in our calculations. This number is likely the highest operating voltage and not the actual value of voltage that is used at the mixing speeds. Each mixing speed likely uses a lower voltage, with each successively faster speed using a greater voltage to allow for an increase in the steady state angular velocity of the whisk. Even with these differences, it is still surprising to see how much the mathematical model and the real-life data differ.

Value to compare	**Real-life**	**Model**
Motor steady state speed (low speed)	4188.7902 rad/s	719.4557 rad/s
Whisk steady state speed (low speed)	209.4395 rad/s	35.9728 rad/s
Settling time within 5% of steady state (low speed)	0.12 s	4.6991 s
Motor steady state speed (high speed)	6283.1853 rad/s	4436.3113 rad/s
Whisk steady state speed (high speed)	314.1593 rad/s	221.8156 rad/s
Settling time within 5% of steady state (high speed)	0.05 s	3.6219 s

Table 3. Comparison of results from real-life observations and mathematical model

From our dissection process, we first learned how the different components of the hand mixer fit together. We found that the hand mixer uses an open-loop system to spin at five different speeds plus a turbo speed, and that the settling times of the whisk for both low and high speed settings is impressively low. While the model and results do not accurately represent what happens in real life, formulating the model was still a helpful exercise in understanding the system dynamics of a hand mixer.

REFERENCES:

[1] H. Austin, *Electric Motors and Drives*, 3rd edition. Burlington, MA. [E-Book]

[2] Ritz, Hadas. MAE 3260. Class Lecture, Topic "Introduction to State Space Modeling with Examples." School of Mechanical and Aerospace Engineering, Cornell University, Ithaca, NY.

[3] "Which Motor Used In Mixer", kelimotorgroup.com, Sep. 21, 2023. Available: https://www.kelimotorgroup.com/info/which-motor-used-in-mixer-87515119.html [Accessed Dec. 8, 2025]