BrushBot: Designing a Toothbrush Tester

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Abstract

Companies devote a large amount of time and money to developing new products. Colgate-Palmolive, a company that manufactures toothbrushes, is interested in automating their toothbrush testing procedure. We designed a robot that can simultaneously test the effectiveness of two toothbrushes at removing plaque and rendered it in a 3D CAD program. To achieve a circular brushing movement, the robot relies on a system of rotating gears, rods and adjustable clamps that holds the toothbrushes. We describe significant design decisions for determining the optimal mechanisms to simulate brushing motion and environmental conditions. Finally, we include the results of the stress and dynamic simulations.

1 Introduction

Many everyday products, such as toothbrushes, undergo months of development and testing before being released on the market. Colgate-Palmolive is a corporation that makes various household goods and is most prominently known for dental care products. It has a 32.2 percent manual toothbrush national market share. [3] Currently, Colgate relies on third parties for clinical testing of their toothbrushes. However, they are looking to expand their on-site testing capabilities and improve efficiency by way of automation, therefore gaining an advantage over their competitors. To this end, Colgate has commissioned a design for a robot that can compare the effectiveness of their toothbrushes against their generic brush.

The major obstacle lies in reducing a complex human motion to a purely mechanical procedure. People can brush with sideways, up-and-down, and circular motions, applying varying speeds and pressures. The robot must be able to accommodate the variations in brushing technique among target groups, while addressing the physical differences among toothbrush models.

2 Background

2.1 Current Toothbrush Testing

Colgate currently tests their new toothbrush designs by relying on third parties, who conduct clinical trials and laboratory tests on Colgate’s toothbrushes. These testing methods are not automated, and because people normally brush only twice a day, it takes weeks or months for results to come back.

However, automated toothbrush testing is not a novel idea. One company, Mecmesin, sells a machine that has adjustable clamps similar to our BrushBot’s, and tests the stiffness and durability of toothbrush bristles at speeds around 200 mm/min. [1] However, Colgate is interested in a machine that will test the comparative effectiveness in removing plaque, not the durability of bristles. Igus, a plastics company, has also developed a toothbrush testing machine. [2] Both the Mecmesin and Igus systems implement linear motion; however, the circular motion in our design more accurately represents teeth brushing. The BrushBot is the only robot that is specifically targeted to meet Colgate’s
2.2 Gear Overview

Given the fixed motor speed, the speed of the toothbrush can be adjusted by using gears with different numbers of teeth. By adjusting the speed of a store-bought motor, it is possible to obtain the 300 brush strokes per minute that the average person employs. Additionally, the circular motion of the rotating gears translates easily to circular brushing motion.

2.3 Requirements

Our design is built around Colgate’s specific needs. Colgate continually develops new toothbrushes that need to be tested. We are designing a robot that will compare the effectiveness of their brushes by offering the option of testing new models under different conditions. People apply varying amounts of force when brushing their teeth. Previous research on toothbrushes and plaque has measured brushing force between 100 g and 500 g. The average person applies roughly 330 grams of force, but the BrushBot is capable of exerting up to 500 grams to simulate the most aggressive brushing methods. The robot uses circular motion, the best method for removing plaque in toothbrush testing. In order to measure cleanliness, we used dye to represent plaque and to determine the effectiveness of the brush.

3 BrushBot Design Process

3.1 Brushing Mechanics

To simulate the complicated brushing action, we considered the speed of the toothbrush, the pressure exerted on the teeth, the shape of the toothbrush handle, the motion of the brush head and the environment in which the brushing was taking place. We based the mechanism driving the circular brushing motion on locomotive wheels. While the main driving wheel rotates, it turns a rod that sets into motion the other wheels. In our design, the locomotive wheels are the rotating gears and the rod holds the toothbrush.

Circular motion is the best method for removing plaque in toothbrush testing. In order to measure cleanliness, we used dye to represent plaque and to determine the effectiveness of the brush. Dye is useful for representing plaque because it provides a qualitative method to determine how much plaque is removed. If the toothbrush is effective, then the colored dye should be harder to detect.

Although we initially considered using a pulley system, we settled on a gear system. Pulley systems could potentially slip, especially in the presence of water and toothpaste. Gears are also more efficient because they occupy less space.

The motor we used for our robot has a speed of 128 revolutions per minute. Each revolution of the toothbrush is equivalent to two brushstrokes. To reach 320 strokes per minute, we needed to scale up the speed to 160 rpm. Therefore, we needed a gear system that would give us a 5:4 ratio, so we used one 16 teeth gear, one 20 teeth gear and four 60 teeth gears. The relation between the number of teeth and gear speed is defined as:

\[
\text{Ratio of teeth on gears} = \frac{k}{\text{Ratio of rpm}} \tag{1}
\]

\[
\frac{5}{4} = \frac{160}{128} \tag{2}
\]

After achieving the desired number of brush strokes per minute, we attached larger gears to the same axle. One end of the rod that holds the toothbrush was attached to the larger gear. The rod has a slit that allows it to slide forward and backward. At the other end, the toothbrush moves in a circle of a diameter roughly the size of two adult teeth.

Attached to the rod, there is an adjustable clamp that adapts well to different kinds of handles. The clamp is a U-block with bolts that can be tightened. It will adjust itself to the different handles and at the same time hold them in place tightly enough to be tested. This way we can test differently shaped
toothbrushes without having to create a new clamp for each one.

3.2 Environmental Simulation

To accurately compare the effectiveness of a new toothbrush model against the generic brush, we tested both brushes under the same conditions to eliminate confounding variables. Identical gears connected to the same axle, which ensures the same brushing speed, drive the two toothbrushes.

Methods that have previously been used to simulate plaque include dry erase ink, mixtures of food and condiments, and dyes. [8] We settled on dye because it will stain but can easily be removed. Because the dye is colored, it will be easier to see how effective the toothbrushes are at removing a plaque-like substance. Unlike food mixtures, dye will not pose the risk of clogging the pump.

We needed to be able to test the toothbrushes in different environments: dry, water, and toothpaste with water. To imitate the moist environment of the mouth, the teeth can be submerged under water. In addition, a water pump will recycle the water that will be used for brushing.

3.3 Measuring Force

A spring scale is the most economical instrument to measure the force exerted on the teeth. The teeth plate is positioned at different distances away from the toothbrush to simulate how forcefully people press the bristles against their teeth. We used the spring scale to calculate the distances at which the toothbrush will exert 300 grams and 500 grams of force, and indicated them as presets. By pressing the toothbrushes closer to the teeth, we can adjust the amount of pressure on the teeth.

3.4 Technical Approach

We used SolidWorks to design a model for the BrushBot. The model underwent dynamic and stress simulations, which highlighted weak and strong constructs. This allowed us to analyze how the robot would respond to pressure.

To power the motor, we constructed a circuit with a 555 timer to set up pulse-width modulation and regulate the motor output. Each of the eight pins of the timer had its own function. Pin 1 was connected to the ground, and Pin 8 directly to the power source to create a potential difference to allow current to flow. Pin 2, the trigger, was also connected to the ground through a 100 nanofarad capacitance, labeled C1, to the ground. Since we did not have a capacitor with the value of 100 nF, we achieved an equivalent value by placing two 50 nF capacitors in parallel. Pin 3, the output, was attached to a 250K Ω potentiometer to vary the resistance in the circuit.

To restrict the current flow to one direction, we inserted a diode on each side of the potentiometer. Then, we connected the two diodes to the trigger pin. Pin 4 was the reset, which shorts to the power source when not in use. Pin 5 is the voltage control, which is grounded through a 100 nF capacitance, C2, which we also constructed with two parallel 50 nF capacitors. Pin 6 was the threshold pin, which we also connected to Pin 2. Pin 7, the discharge, led to the negative output of the motor, and pin 8, the positive voltage, to the positive. To adjust the
power of the motor, we would just change the value of the potentiometer.

4 Results and Discussion

The following figures illustrate parts of our assembly under stress simulation. The blue areas represent strong points in our design, while other colors indicate higher levels of stress. However, these areas do not present a massive concern to our entire assembly.

As seen in Figure 1, the fillet on the motor mount shows a higher level of stress than other sections. However, it was not necessary to change the design of the motor mount because the part will not experience much load when in use.

Overall, the rod holding the gears in place is very strong. No gears are attached to the points where the stress simulation indicates weaker points in the design.

The frame barely exhibits stress. Although the areas surrounding the holes show some stress, the rest of the frame provides sufficient support.

Figure 1: Stress distribution of motor mount

Figure 2: Stress distribution of rod holding the gears

Figure 3: Stress distribution of frame

5 Conclusion

Colgate-Palmolive requires a machine that will allow them to test their toothbrushes under different situations; variables include pressure, environment, and toothbrush handle shape. This robot allows them to compare the effectiveness of their toothbrushes in a more efficient way than the current testing procedures. Implementing an automated toothbrush tester will speed up Colgate's research and design process, thus giving the company a competitive edge. Our work offers a solution to the inefficiency in current toothbrush-testing procedures.

After completing our research, we rendered a 3D model in SolidWorks. This model showed the position of the gears, motor, clamp, and water pump. We verified the durability of our design through SolidWorks stress simulation. We successfully designed a robot that would test toothbrushes, adjust to differently shaped handles, and simulate different environment.

5.1 Future Work

There are many other features we would recommend for future work. Another design might implement a more accurate system of gauging brushing force, perhaps by building pressure sensors into custom teeth plates. We also realized that manually changing the toothbrushes each time would become tedious and therefore should be automated with a loading mechanism. Also, in our current design, the effectiveness of each brush is approximated by eye. We could implement a system that would scan the teeth plates and more precisely analyze what percentage of plaque was removed by each brush. These additional features would make the testing
process even more efficient and automatic.

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