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M3 Design Product Teardown
Sonicare Toothbrush

Why do the product teardowns?
Part of the product development process is to apply knowledge gained from prior experience during the concept development and design phases. Some experience comes from actively designing something in the past while other experience is gleaned from more indirect sources. It is this indirect product development experience that we gain via product teardowns.

Teardowns are different from reverse engineering
Reverse engineering is nothing more than figuring out the design and manufacturing methods of a product, typically for copying. Conversely, M3 Design views product teardowns as ways to gain insight into the design to become better product developers. We focus on "why" questions.

• Why did the designer make the choices they did?
• Why were specific construction techniques chosen?
• Why were certain features included and others left out?
• Why was the particular design approach chosen?

This serves to gain more in depth understanding into the product's design rather than a superficial once-over.

How does M3 Design approach product teardowns?
Our teardown process is a rigorous approach to carefully catalog the product's deconstruction in both pictures and written descriptions. This procedure serves two purposes:

1. It forces the deconstruction team to carefully investigate the product pieces and learn as much about the design details as possible.
2. It provides a detailed record of the process for future reference by other designers.

The end result of this meticulous process is the beneficial expansion of applicable knowledge regarding product designs. We employ the lessons and insights garnered from these teardowns during brainstorming, design, prototype development, and troubleshooting. This method of obtaining indirect product development experience is just one of many important tools that sets M3 Design apart from other product development firms.
Overview
How do you improve the ubiquitous toothbrush? M3 set out to answer that question with its latest teardown project, a Sonicare rechargeable toothbrush. The manufacturer states that the product uses “sonic technology” to create a “high frequency and high amplitude bristle motion”. Furthermore, the toothbrush operates at 31,000 brush strokes per minute – pretty fast for a mechanical system. The M3 team was very curious to find out how this was possible.

External Construction
The toothbrush is encased in an aesthetic over-molded plastic housing. The white plastic shell provides its structure, and a rubber over-mold creates a non-slip user grip. Additional molding was added for the on/off and mode selection pushbuttons. The mode selection button is rigid plastic with a rubber base that allows the button to translate. A bottom cap with O-ring seal completes the assembly. A vapor seal is also used in the bottom cap to prevent water from entering the assembly, while allowing water vapor to pass to prevent condensation from building within the toothbrush. Considering the wet environment the toothbrush is used in, these design features make perfect sense.
Systems
The user manual actually explained how to open the unit. This is was to instruct the user on how to recycle the battery, but the information saved the teardown team from having to resort to the band saw! Once the cap was removed the driver assembly slid out easily. The driver assembly consists of a lithium-ion rechargeable battery, an induction charging coil, an electromagnet, a moving permanent magnet, and the controller PCBA.
The toothbrush head driver consists of a fixed electromagnet, a moving permanent magnet, and a bearing structure to support the permanent magnet. These three components are contained in a sheet metal shell which is spot welded together after assembly. The bearing structure is triangular shaped, constraining the permanent magnet’s range of motion. The electromagnet is a U-shaped stacked laminate assembly with the coils of wire wound in opposite directions on each leg.
When the toothbrush is powered on, the permanent magnet vibrates very slightly. The team initially thought that the magnet was moving linearly back and forth. However, the mass of the magnet is fairly large and its attraction force to the steel laminations is probably larger than any repelling force the electromagnet could generate. Upon further inspection the team discovered that the magnetic poles were on the top and bottom of the permanent magnet, not on the faces adjacent to the electromagnet. A quick brainstorm determined the likely operation of the magnet. When the current through the electromagnet creates a north pole on one leg and a south pole on the other leg, the permanent magnet rotates to align its north and south poles appropriately. When the current reverses, the electromagnet poles also switch and cause the permanent magnet to rotate in the opposite direction. Further inspection of the bearing assembly revealed that the triangular shape was not to guide the permanent magnet linearly, but rather to allow it to pivot like a see-saw. The final clues were the signal being sent to the electromagnet and observing the actual motion of the permanent magnet. An oscilloscope showed that the current was reversing at 258 Hz. A picture of the moving magnet showed a blur of motion in the rotational direction. Case closed!
Electromagnet state 1: CCW Rotation

Electromagnet state 2: CW Rotation

End view of moving permanent magnet and fixed electromagnet during pole reversal

Scope capture of fully-reversing electromagnet drive signal
Inductive Charging Coil

The inductive charging coil is a multi-turn loop of wire connected to the lithium-ion battery and the microcontroller system. The user manual states that the LED battery gauge flashes during charging, indicating that the microcontroller must be powered to run the LED logic. The coil itself was small, so the amount of current induced by the charging circuit is likely very small. The user manual states that the toothbrush requires 24 hours to recharge fully, further supporting this observation.
Other Observations
The team found a few other items worth mentioning. First, the PCB has 24 test pads apparently for signal testing. There are indentations on each pad so it appears that the unit was tested and/or repaired at the factory. There are also larger pads marked $V_{\text{batt}}$, Gnd, Rx, and Tx. We believe this makes it likely that un-programmed chips are assembled onto the board and final programming is performed after assembly or perhaps the serial interface is provided for test or updating purposes.

Another observation was the use of thread locker on many of the screws. This would be a reasonable precaution due to the constant vibration this product endures during operation. We also noticed that product used nuts to fasten some items. In most products, self-tapping screws are used to secure parts for cost and assembly reasons. It may be that vibration levels this product sees may cause self-tapping fasteners to fail.

The toothbrush was in our “teardown” pile because the brush head bent over too far during use and the device made loud grinding noises when powered on. When the device was inspected the team discovered that the connection between the brush head and the permanent magnet assembly had broken. The resulting de-coupling allowed excessive movement of the brush and left the broken part to rattle around inside the toothbrush. The small part looked to be die cast or metal injection molded and failed around the screw hole, possibly due to poor grain structure in this area.

Our final task was to understand how the product claim of 31,000 brush strokes per minute is achieved. First some simple math. 31,000 brush strokes over 60 seconds equates to 516.6 Hz. However, the team measured ~258 Hz with the oscilloscope, so clearly the toothbrush can't possibly be going as fast as claimed, right? Absolutely! Our conclusion is that this is yet another example of clever marketing. In this case, an engineer would state that the vibration is measured in full cycles, which in this case would be about 15,500 per minute. However, the marketing perspective is that each brush stroke is in one direction only. Therefore, there are 2 brush strokes per cycle, or 31,000 brush strokes per minute. Brilliant!

Conclusions
The team found many instances of clever engineering inside the product. The design and manufacturing of the outside case is well-suited for the user and the product’s operating environment. Clearly this product has had much thought put into it, considering the age of the product line and its premium price tag. The electromagnetic drive system seems to provide adequate power and amplitude for cleaning teeth. The only non-premium item we discovered was that there is no isolation between the driver and the outside case. This is probably due to cost constraints. It could also be that users require the product buzzing in their hand to give them the feedback they need to let them know that the toothbrush is really working. What do you think?