VIQC Elementary School - Reverse Engineering Online Challenge

Exploring the Inner Workings of Dirt Devil Total Power Pet (Model # BD10167)

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Summary Report

Our team managed to find an old cordless phone, a handheld vacuum, a VHS camcorder, and an RC car for this project. We chose the vacuum because it was simpler than the camcorder, the parts/work seemed more easily divisible than the RC car, and it seemed more interesting than the phone. Also, we were told that the vacuum didn't work well, which made us want to see if we can find ways to improve it.

During deconstruction, we found that the vacuum has the following main parts: a switch/circuit board, batteries, a motor, filters, and a front attachment. The switch turns the vacuum on and off. The switch is on a circuit board, which helps direct the flow of electricity to the system. The batteries provide energy to the motors. The motor then converts electrical energy to mechanical power, moves the fan, and creates suction. After the dirt is sucked in, the filters separate the garbage from the air, and leave the garbage in the dust cup. The front attachment is an optional tool that has a claw to scrape the surface and a smaller motor that rotates the brushroll to dislodge and pick up dirt.

Through our own experience, we identified two major issues with the vacuum. First, the motor needs more suction power. To improve it, we could replace the main DC motor with a more powerful motor. Second, the nickel-cadmium batteries that it uses have a short life and cannot sustain a typical length of cleaning job. They also charge very slowly. Lithium-ion batteries would be a better option because they recharge faster and last 2-3 times longer.

We learned many things through this online challenge, specifically, about teamwork, the research process, and how a handheld vacuum works. The teamwork skills we used in this project were similar to building our robot in many ways. Having the extra meetings for the online challenge made us more comfortable working with each other. Having to meet on the weekends and online and communicating through e-mail and chat improved our communication skills.

Another thing that we learned was that to research, you might need to look at several different websites, patents, videos or even books, before you get the answers to the questions. Even just getting the manual was difficult for this discontinued product. We had to contact Dirt Devil's customer service to have one e-mailed to one of the parents.

Lastly, we learned about how different parts of a vacuum work and different ways to make some parts better. This project made us think about the challenges of making a cordless, handheld vacuum, or portable versions of other larger devices. The company would need to condense key features into a much smaller size, and also with a cordless vacuum, you need to think about adding batteries, which can add to the weight and the size, and probably the cost, of the device.

(485 words)

Introduction

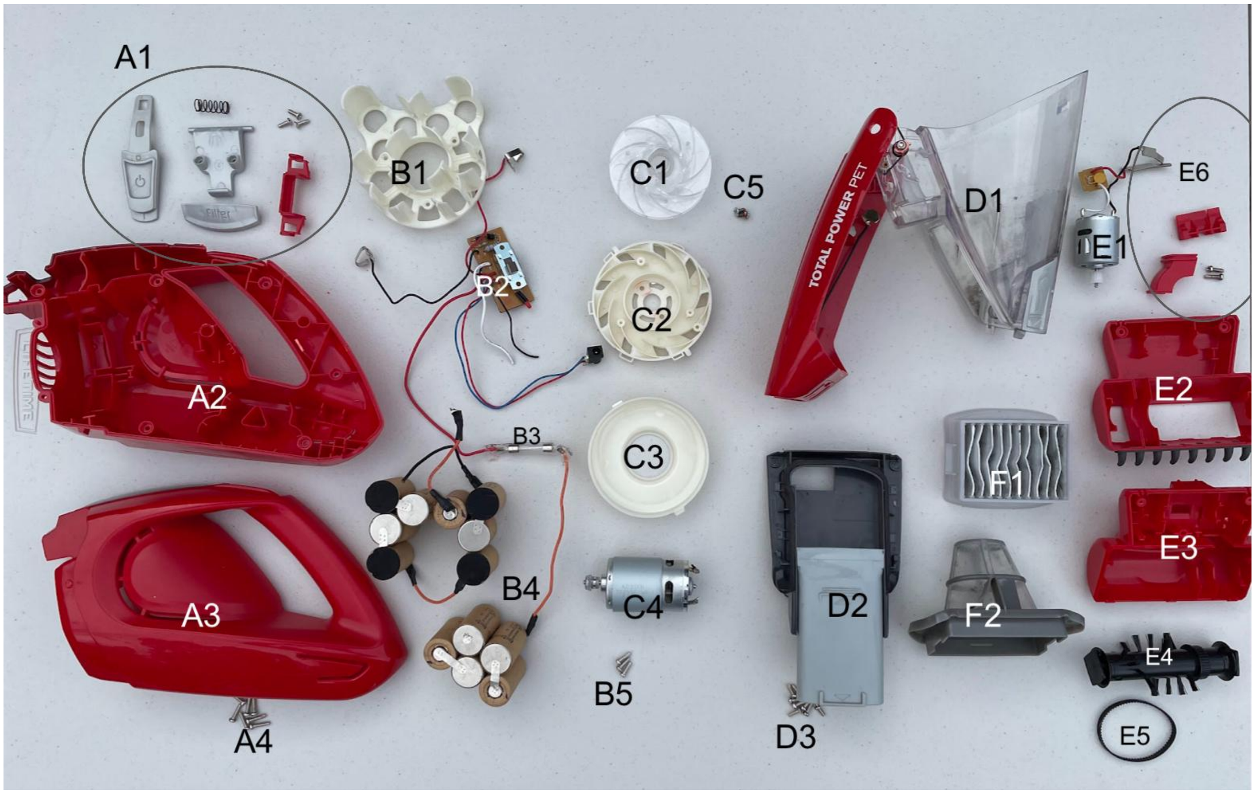
Device Description

The electronic device we chose to take apart and research was the Dirt Devil Total Power Pet Cordless Hand Vac with TurboClaw Stair and Upholstery Tool (Model # BD10167). It was manufactured in April of 2015. This model of vacuum by Dirt Devil has been discontinued since then.

Approach

Our group first met on 11/19 after school to review the rules of the challenge and discuss what we could bring to disassemble. At the next meeting on 12/3, we decided on the Dirt Devil handheld vacuum and made a schedule. On 12/4, we disassembled the vacuum. While disassembling, we took notes and pictures of our disassembly process. After that we met every Friday after school, some Saturdays, and occasionally on Google Meet to discuss tasks, progress, problems and give each other feedback. We stored individual work and common resources, like pictures and other documents, on a shared folder on Google Drive.

Parts List



A1 - Power on/off button & Filter access button
A2 - Case side 1
A3 - Case side 2
A4 - Case screws

B1 - Battery case
B2 - Switch
B3 - Fuse
B4 - Batteries
B5 - Battery screws

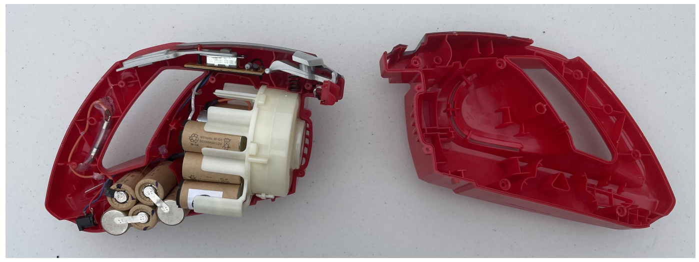
C1 - Fan
C2 - Fan case
C3 - Fan case
C4 - Motor
C5 - Fan case screws

D1 - Dust cup
D2 - Telescoping nozzle
D3 - Accessory tool screws
E1 - Accessory tool motor
E2 - Accessory tool case (bottom)
E3 - Accessory tool case (top)
E4 - Brushroll
E5 - Gear Belt
E6 - Accessory tool case screws and pieces
F1- Pleated filter
F2 - Screen filter

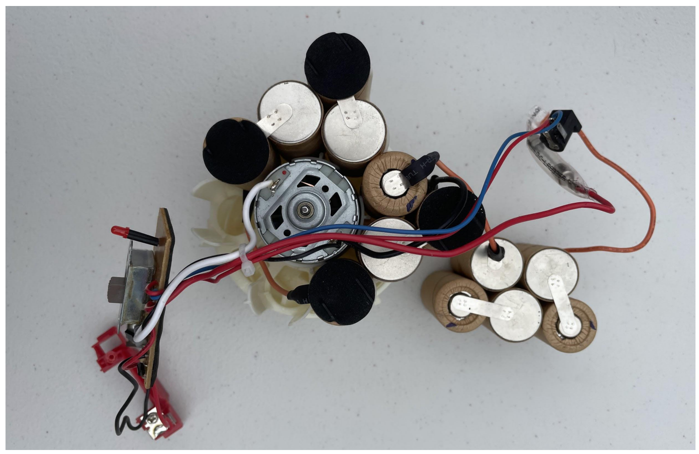
* When possible, part names were taken from the product manual.

Disassembly Procedure

1. The outside had seven screws in total. We took out the screws one by one. We couldn’t take the shell apart even though it was all unscrewed, so we pried the shell open with force.

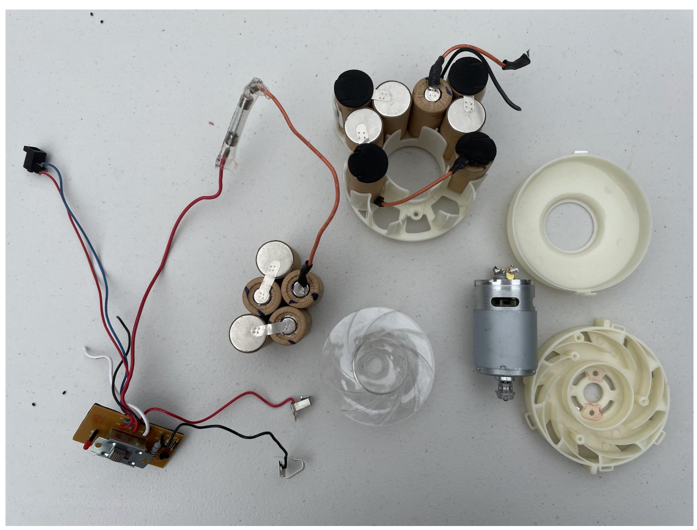


2. We took out the wires first, since the wires were connected to the battery. Then, we took out the battery.



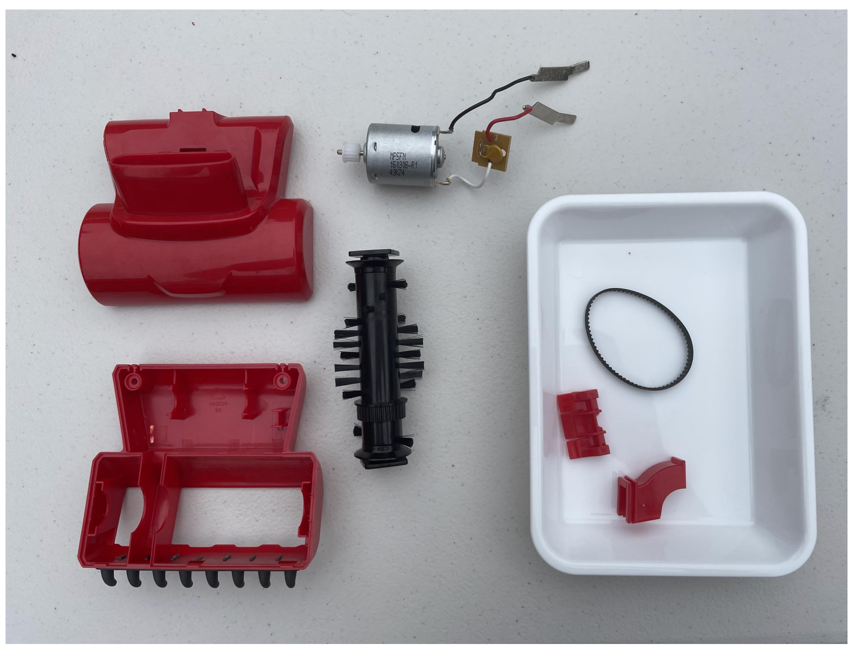
3. Then, we took out the motor because the motor was connected to the battery. The batteries were inside of a case which made it hard for the batteries to be shown bare, so we cut some wires.

4. After this, we took the motor apart from the fan. We broke the fan apart from the motor using brute force.



5. The Dirt Cup had a couple of filters. To access the wires and the telescoping nozzle, we broke apart the Dirt Cup Door. The Dirt Cup Door had rivets, which weren't coming out, therefore we had to break the plastic frame.

6. To take apart the Powered Brushroll Attachment, we took the screws off first. Once it was opened, we took out the Brushroll, then we took off the belt. Finally we took out the motor and the wires. While we were taking this apart, we found two other screws that were not the same kind as the ones we found on the outside.



Component Analysis: Motor

The DC motor (direct current motor) in the vacuum moves the fan to suck in all the dust. We did not take the motor apart for my own safety.

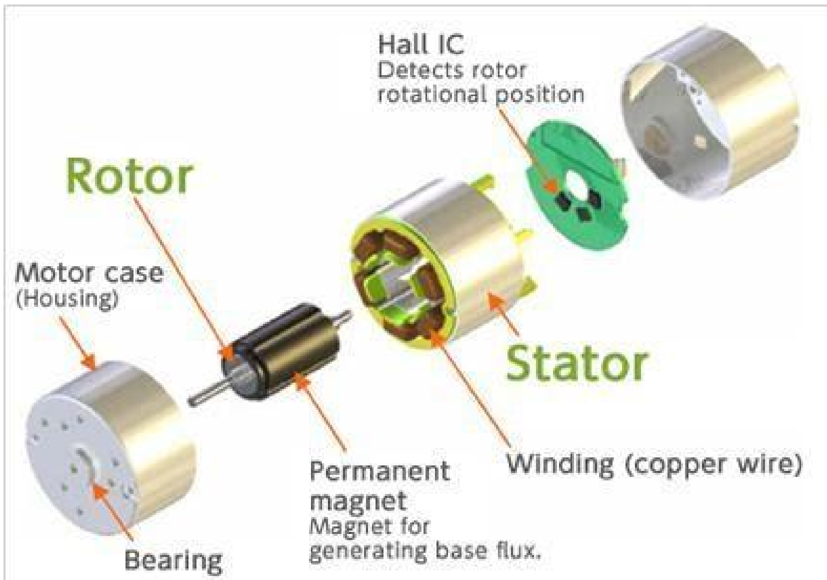


Figure 1 : Parts of a typical DC Motor

A DC motor is an electrical machine that converts electrical energy into mechanical energy. The components of a typical DC motor (Figure 1) are a rotor (magnets), a stator (coils), a Hall IC, and a motor case.

A typical DC motor rotates when you put a coil with electrical energy flowing through it, in a magnetic field. When the magnets are in the motor, one of the magnets is facing north and the other is facing south, which creates a magnetic field. When the coil with electrical energy is in the magnetic field, the coil is also creating a magnetic field, the two magnetic fields are not attracted to each other because both of them are south and south or north and north, therefore making the coil spin.

In our vacuum, when the motor (Fig 2, D) is spinning the fan (Fig 2, C) at a certain angle, the fan is sucking the air from the vacuum chamber (Fig 2, A and B), causing low air pressure. Since the air pressure is low, the vacuum is trying to fill the low air pressure with the air pressure from the outside, therefore causing the suction motion.

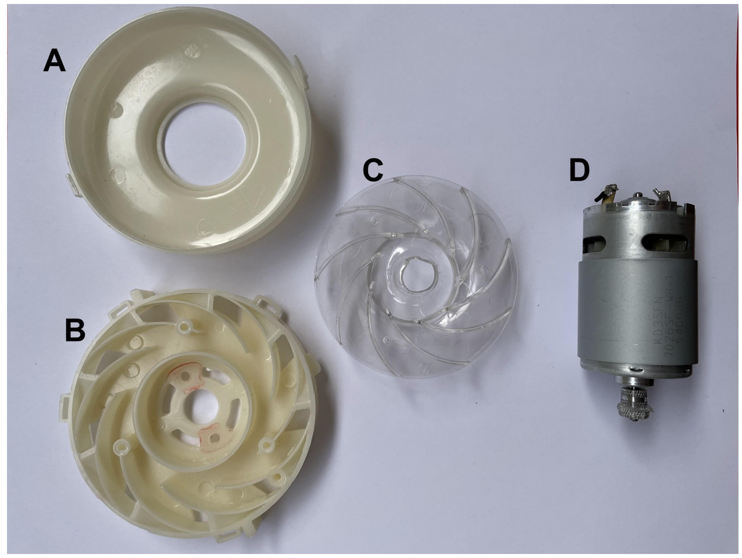


Figure 2: Motor and fan assembly consisting of fan casing (A, B), fan (C), and a DC motor (D).

In a vacuum, the fans that are used are typically Axial fans, we believe that is the best fan to create suction. We believe that we can use more powerful motors to make our vacuum's suction more effective.

Component Analysis: Batteries

The batteries are needed to power the motors, or store energy for later use.

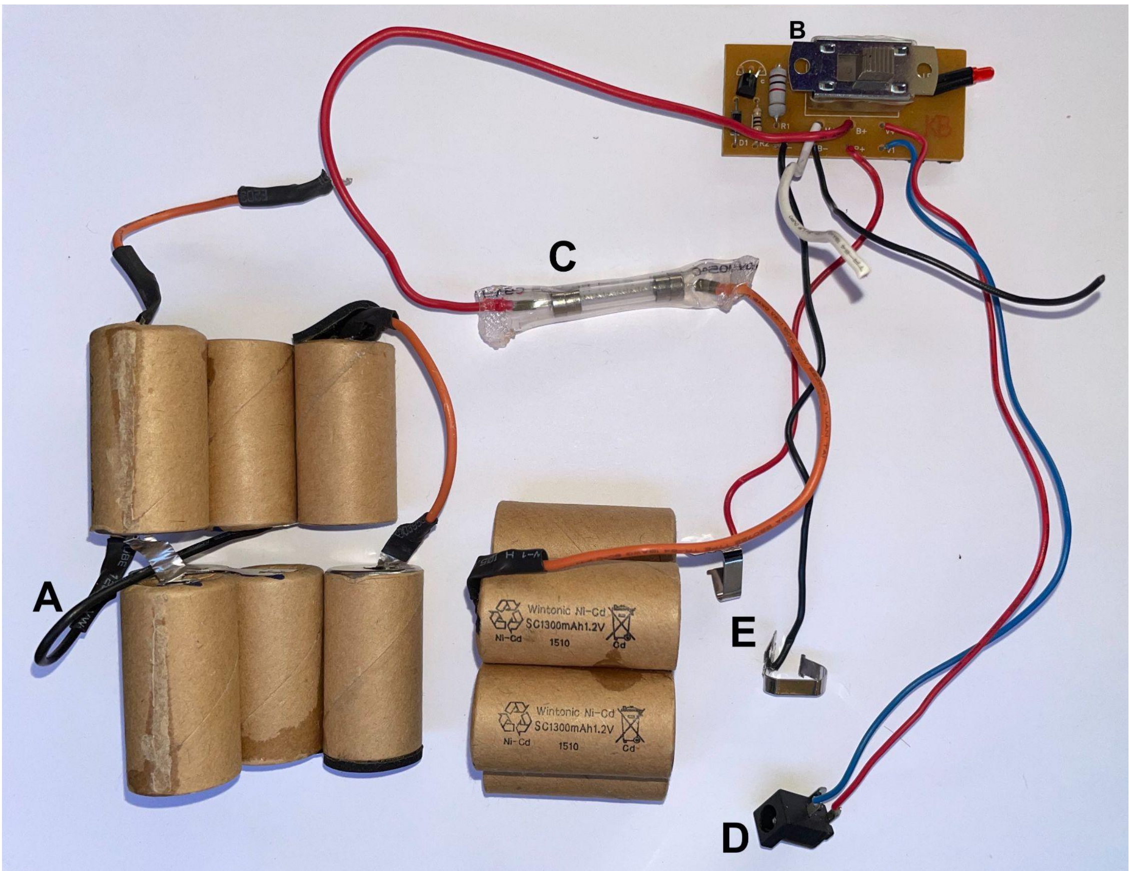


Figure 3: Thirteen 1.2V Ni-Cd batteries (A) are connected to the switch/circuit board (B), fuse (C), charger port (D), and accessory tool (E).

The batteries in our vacuum are Wintonic Ni-Cd SC1300MAH with 1.2 voltage types. The Ni-Cd stands for nickel-cadmium, which is the type of material to make the battery.

The batteries were connected to other components, and to each other, by copper wires. The batteries were directly connected to the main DC motor and the on/off switch through a fuse (Fig 3, A, B and C). The on/off switch fits on the on/off button, which is used to turn on and off the vacuum. The blue and red wires from the switch were connected to the charging port (Fig 3, D). The charger is plugged in here to charge the batteries. The black and red wires from the switch were connected to a piece underneath the filter access button to provide power to the Powered Brushroll Attachment (Fig. 3, E).

Here is the electrochemistry of Ni-Cd batteries. A fully charged nickel cadmium cell usually contains: a nickel oxide-hydroxide positive electrode plate, a cadmium negative electrode plate, a separator, and an alkaline pelectrolyte (potassium hydroxide). The chemical reactions at the cadmium electrode during discharge are:

$$\mathrm{Cd} + 2\mathrm{OH}^- \rightarrow \mathrm{Cd(OH)}_2 + 2\mathrm{e}^-$$

The reactions at the nickel oxide electrode are:

$$2\mathrm{NiO(OH)} + 2\mathrm{H}_2\mathrm{O} + 2\mathrm{e}^- \rightarrow 2\mathrm{Ni(OH)}_2 + 2\mathrm{OH}^-$$

The net reaction during discharge is

$$2\mathrm{NiO(OH)} + \mathrm{Cd} + 2\mathrm{H}_2\mathrm{O} \rightarrow 2\mathrm{Ni(OH)}_2 + \mathrm{Cd(OH)}_2.$$

When the battery recharges, the reactions go right to left.

Nickel-cadmium (Ni-Cd) batteries are rechargeable, but they are bad for the environment. The U.S government even classifies the battery type as “hazardous waste.” Ni-Cd batteries self discharge approximately 10% each month, and 20% at higher temperatures. Another shortfall about the Ni-Cd batteries is that they are not efficient. One positive feature about the Ni-Cd batteries is that people have been using them since the 1900s, so they are very reliable.

A better option is to use Lithium-ion (Li-ion) batteries. Li-ion batteries last 2-3 times longer between each recharge than Ni-Cd batteries. Although Ni-Cd batteries can be used for more than 1,000 cycles (one cycle is from fully charged to no energy), and Li-ion batteries can only be used for 700-1,000 cycles, Li-ion batteries can charge 2 times faster. Therefore Ni-Cd batteries are not nearly as efficient as Li-ion batteries. Also, Li-ion batteries have virtually no self-discharge. This means you can store lithium batteries for months, without worrying about them losing usage time. The government classifies Li-ion as “non-hazardous waste”, essentially meaning they don’t harm the environment. But, lithium batteries are 2-3 times more expensive. A third option is Sodium-ion batteries which have similar advantages as Li-ion batteries, but sodium is more common than lithium, which makes sodium-ion batteries cheaper.

Component Analysis: Switch/circuit board

The purpose of the switch is to turn the vacuum on and off. The switch is part of a circuit, which takes electricity from the wall outlet (power source) into the batteries. This switch also distributes the power to the accessory tool.

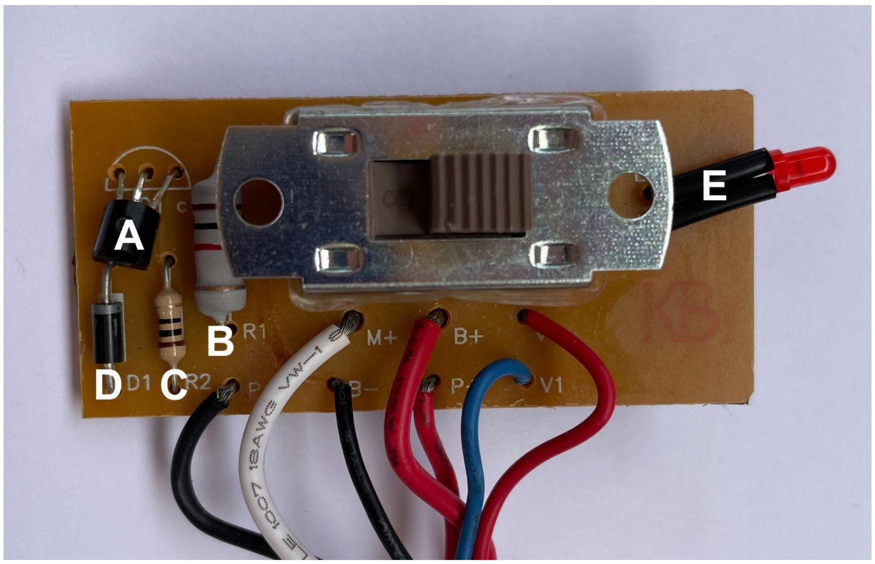


Figure 4: Switch/circuit board has a transistor (A), two resistors (B and C), diode (D) and an LED indicator light (E).

The switch sits on a tiny circuit board (Fig 4). The tiny circuit board has a variety of different components. First, the transistor (Fig 4, A). It essentially acts like a valve. There are three metal legs on the transistor. The current flows through the first leg, goes across the middle, and finally comes out the other leg. The middle leg controls the amount of current that flows between the two legs, when the switch is on or off. Next, are the two resistors (Fig 4, B and C). The function of resistors is to limit the amount of electric current going through the wire to the batteries. The gray resistor (Fig 4, B) limits the amount of current from the power source, so the batteries don't charge too fast when they are completely discharged. Lastly, there is a diode (Fig 4, D). The function of a diode is to let electricity flow in one direction, but not the other; changing Alternating

Current (AC) into Direct Current (DC) to charge the batteries. Finally, there is an indicator light that turns on during charging (Fig 4, E).

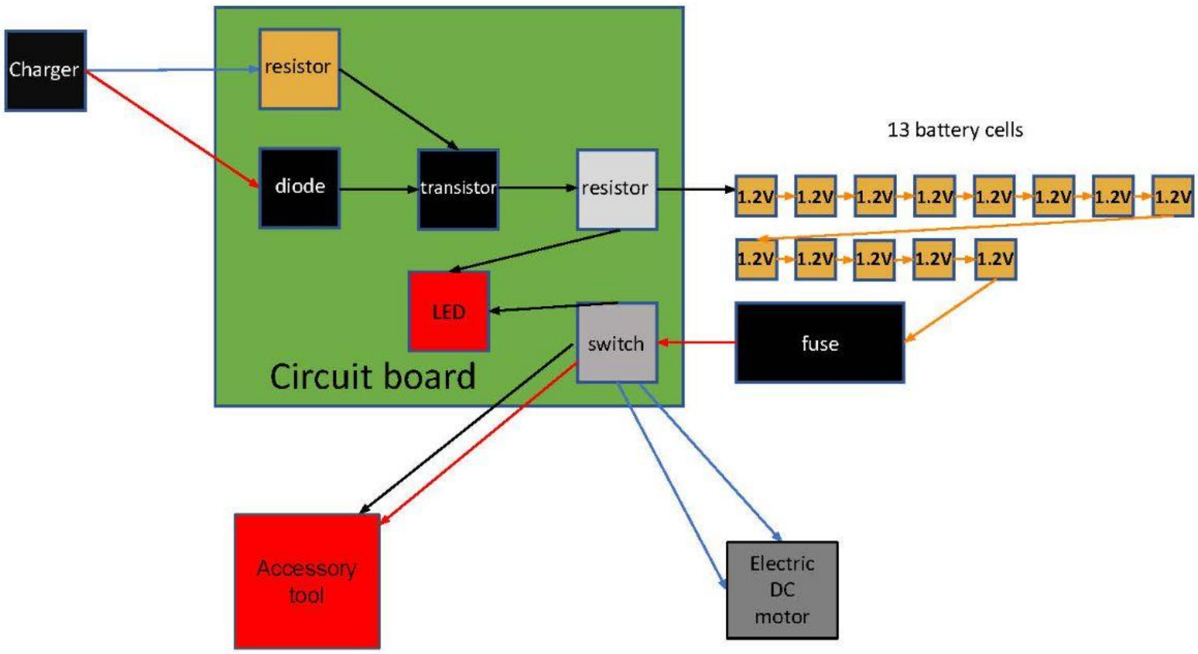


Figure 5: Schematic diagram of circuit board. Colors in the diagram correspond to the colors on the actual circuit board.

Charging the batteries (switch is off)

Figure 5 is a schematic diagram of the circuit board. The circuit starts flowing when electricity enters from the charger through the red and blue wires. The blue wire feeds electricity into the brown resistor, which then goes into the transistor. The red wire goes through a diode, and then into the transistor. The red wire directs the flow of electricity through the diode. The blue wire tells the transistor how much to reduce the current flowing through the red wire. When the batteries are almost full, less electricity will come out of the transistor into the batteries, and when the batteries are completely empty, more electricity comes out of the transistor and into the batteries. The output from the transistor goes into a gray resistor. The gray resistor slows down the flow of electrons into the batteries, so the batteries don't overheat. A red LED turns on when the batteries are charging. When the batteries are done charging, the LED light turns off, because the electric current from the transistor has stopped flowing, and there is no more electricity going into the LED light.

Powering the vacuum (power adaptor is unplugged and the switch is on)

When the switch is turned on, the electricity starts flowing from the batteries to the motor and the accessory tool, if attached. The 13 batteries are connected in series (13 x 1.2V = 15.6V), and the output of those 13 batteries goes through a fuse. The fuse is an added safety measure so that the batteries don’t overheat and catch on fire. If there is too much electricity flowing through the fuse when the vacuum is in use, it will burn out instead of the batteries.

Component Analysis: Filters

The purpose of the filters are to separate garbage (small dirt and dust) from air and trap the garbage in the Dust Cup.

The filter assembly is combined into two parts. The Screen Filter (Fig 6, A) comes first in the set of two filters to screen the large and medium particles or matter. Its frame is made out of plastic, while there are a lot of holes in the plastic on top of the filter, all of the surrounding filter is made out of nylon mesh.

A Carbon Infused Pleated Filter (Fig 6, B) sits right behind the Screen Filter in the Dust Cup. The main role of this filter is removing gases, smoke, odors, and microscopic particles from the air that passed through the Screen Filter. It is made from a pliable material, like paper, polyester, and cotton.

These two filters are located inside the Dust Cup. The reason why these filters are positioned inside the Dust Cup is to separate wastes from the intake air and store them in the Dust Cup, in order to avoid the fan and motor malfunctioning due to large particles entering.

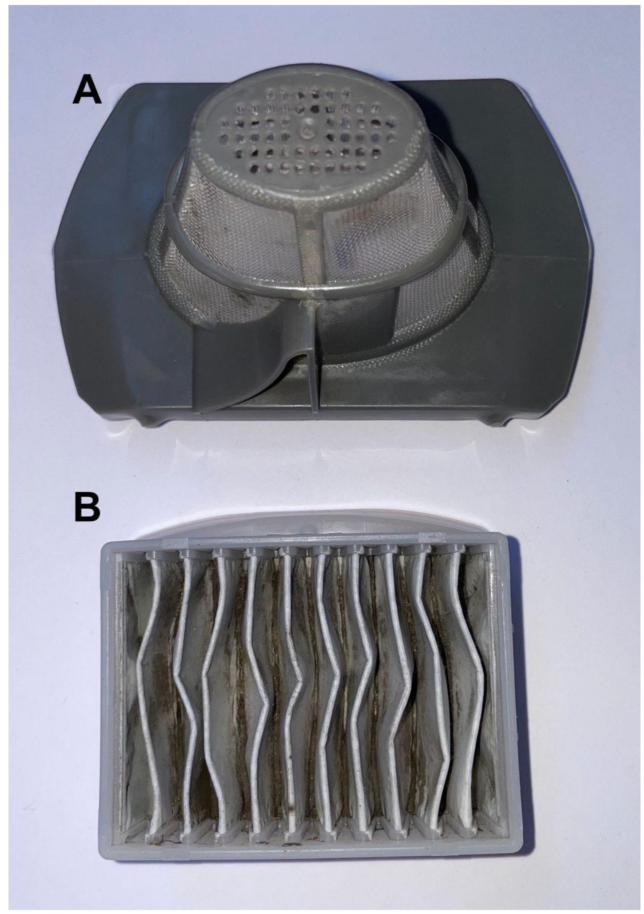


Figure 6: Filter assembly consists of mesh screen filter (A) and a pleated filter (B).

Component Analysis: Dirt Cup & Powered Brushroll Attachment

Dirt Cup

The Dirt Cup, which connects to the main body and the Powered Brushroll Attachment, holds, and filters out all of the stuff the vacuum cleaner sucks up.

The top half of the collecting bin (Fig. 7, A) hinges open on two riveted joints. There are two springs (Fig. 7, B), which keep the Dirt Cup Door open when it is unlatched. There are two latches (Fig 7, C) that hold the two halves together when they are closed. The Telescoping Nozzle assembly (Fig. 7, E and F) is attached to the bottom half of the dust cup (Fig 7, D) and the nozzle slides in and out of its base (Fig. 7, E). Underneath the telescoping nozzle assembly, there are wires (Fig. 7, G) that connect to the accessory tool. The Powered Brushroll Attachment attaches to the end of the Telescoping Nozzle (Fig. 7, F),

Figure 7: All the parts of the Dirt Cup (A-D and G), including the telescoping nozzle (E and F), collectively make up the front part of the vacuum.

and it is also where the dust goes when it first enters the vacuum.

Powered Brushroll Attachment

The Powered Brushroll Attachment attaches to the front of the handheld vacuum. The function of this accessory tool is to dislodge dirt from the carpet.

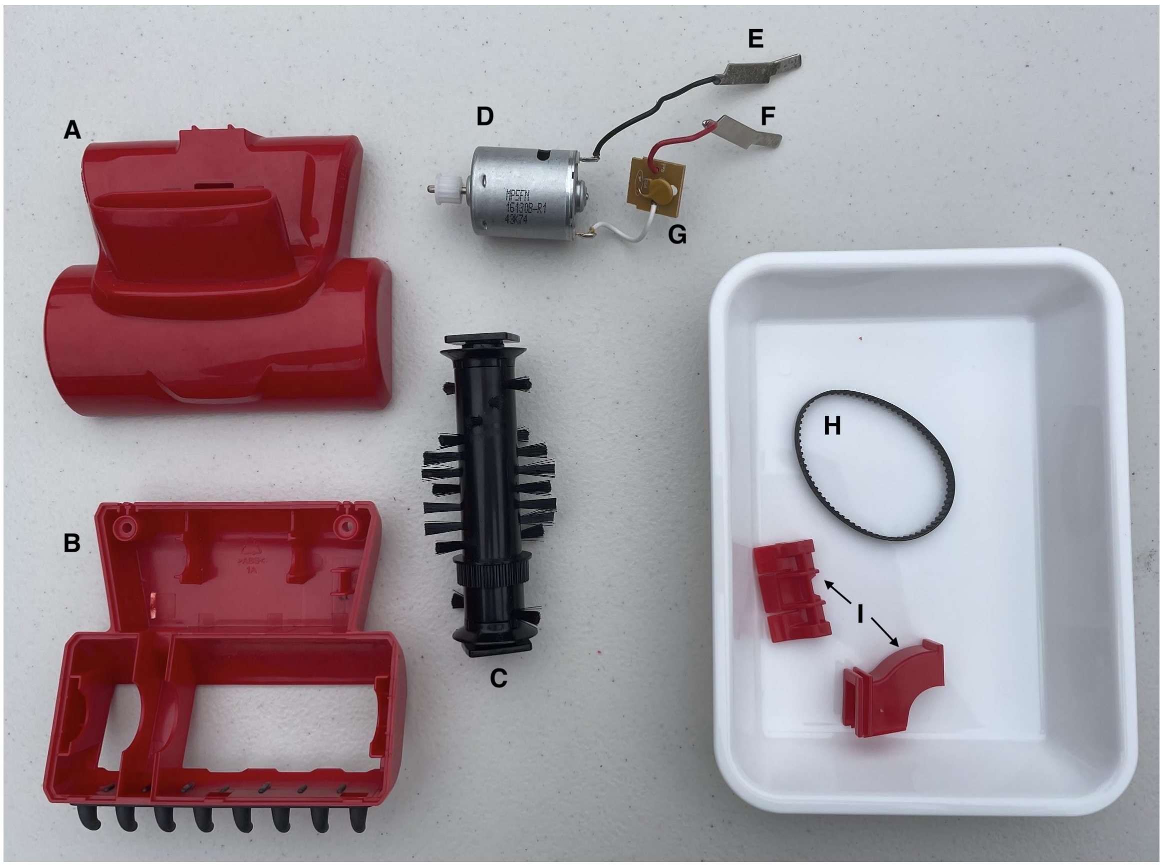
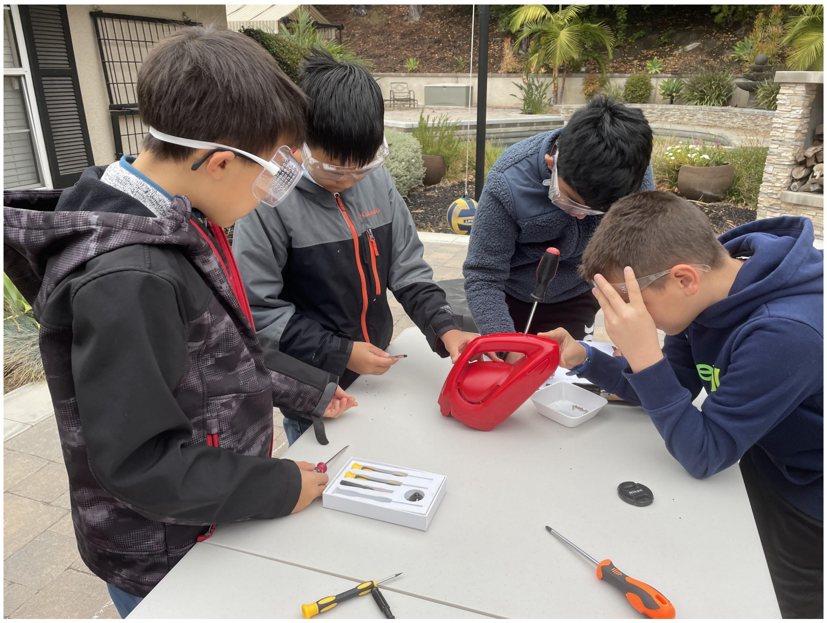


Figure 8: The accessory tool (A-I) contains powered Brushroll (C) to collect dirt.

The brush (Fig 8, C), which fits into the shell (Fig 8, A and B), has a spiral bristle pattern to funnel dirt to the middle of the front attachment. We thought that this design might reduce the cost of the brush, by reducing the number of bristles. It might also reduce the friction between the brush and the ground, by reducing the contact of brushes to the ground, to meet the power constraints of the motor (Fig 8, D). The brush is shaped in a cylinder, which has a notched section on one end for the gear belt (Fig 8, H). This allows the motor to spin the brush. The motor is an electric D.C. motor. The wires connect to the motor (Fig 8, E and F). While one wire goes straight to the metal strip to go to the power supply coming from the batteries, the other one first connects to a resistor (Fig 8, G), which reduces the voltage of electricity to the motor. The two support pieces (Fig 8, I) attach to the upper shell (Fig 8, A), and keep the brush component in line with the motor.

Conclusion

In conclusion, our group really learned how to work as a team, as well as having fun while at it. This experience has strengthened our friendship, and made us a better team.



Citation

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