Solder Qwik Pen™

Prepared for: Dr. Liz Schlemer & Dr. Tali Freed

IME Department
California Polytechnic State University

Prepared by: Katherine E. Robbins

IME 481/482
Senior Project

December 11, 2009

Table of Contents

Abstract

Electronics soldering is a technique used frequently in the manufacturing of Printed Circuit Boards (PCB) to attach small electronic parts or wires together. Often times the need to remove a solder joint arises, this is known as desoldering. Solder wick, fine braided copper wire infused with rosin, is one of the most effective ways to desolder because it results in the cleanest joints. Currently using solder wick involves several time consuming and somewhat awkward steps. This report will cover the process behind designing, manufacturing, and testing a new ergonomic, dispenser for solder wick that can be used with one hand. After coming up with a new design, I made a functional prototype to assist in testing the design. The prototype was made with an ABS plastic material. To determine if the Solder Qwik Pen is a significantly faster method to use compared to a coil of solder wick, an experiment was done. The experiment's results showed that the Solder Qwik Pen did have a significantly faster average time among users than the solder wick coil. Not only is the Solder Qwik Pen an improvement on the old solder wick method of desoldering, it could easily lead to other products being sold as companion products.

Introduction

Electronics soldering is a technique used frequently in the manufacturing of Printed Circuit Boards (PCB) to attach small electronic parts or wires together. An iron is used to melt the solder material (commonly a tin-lead alloy), which hardens once the heat is removed resulting in a strong joint. Electronics soldering is usually confined to a small space and precision is important. Often times the need to remove a solder joint arises, this is known as desoldering. Solder wick, fine braided copper wire infused with rosin, is one of the most effective ways to desolder because it results in the cleanest joints. However, solder wick is fairly complicated to use and cannot be done very quickly because the process involves multiple steps. This report describes the product design process for the development of a new way to dispense and trim solder wick.

Current Process

Currently using solder wick involves several time consuming and somewhat awkward steps. Typically, solder wick is packaged in a small round container (2 in diameter) that contains a coil of wick. The tip of the coil is placed at the solder joint and the soldering iron applied. The coil becomes hot during the desoldering process and the excess solder is absorbed into the wick. After the wick is used, the ruined part must be cut off with scissors or wire cutters. Then the wick needs to be uncoiled and the process starts over.

Problems to Address

- Container is small and difficult to grasp
- Flexible braid is hard to place in exact location
- The heated solder wick must be advanced manually before the next use
- To snip off the end of the wick in between joints, the soldering iron needs to be put down and scissors need to be picked up
- The braid absorbs a lot of heat and can become really hot and potentially burn the user

Project Scope

This report will cover the process behind designing, manufacturing, and testing a new ergonomic, dispenser for solder wick that can be used with one hand.

- The design portion will cover different innovation methods used, and tools used to create a set of specifications that accurately reflect the customer's needs.

- The manufacturing portion will include the different processes and machines used to make a working prototype of the dispenser.
- The testing section will go over the methods used for the design of the experiment and will also analyze the data from the test

IME Courses Needed

- IME 319- Human Factors (anthropometrics & product design)
- IME 326- Engineering Test Design & Analysis (experiment design & data analysis)
- IME 335- Computer-Aided Manufacturing I (Solidworks & CNC prototyping)
- IME 418- Product Process Design (QFD, innovation methods, product design)
- IME 429- Ergonomics Lab (experiment design)
- IME 437-Advanced Human Factors (product design & DFX)

Background

Existing Products

Solder Wick

Solder wick is the most effective tool used for desoldering. It is a roll of finely braided 18-42 AWG copper wires. It is usually treated with rosin solder flux that makes the solder absorb into the braid better. The wick is pressed onto the solder joint that needs to be removed then the tip of the soldering iron is applied. When the braid heats up, the excess solder absorbs into it. The result is a clean joint. The used portion of the braid must be removed with scissors before desoldering a new joint.

Solder Sucker

A solder sucker is another method to remove solder from a printed circuit board. The most common solder sucker is a spring-loaded device that is used to "suck up" unwanted solder from a heated solder joint with a quick burst of air. More high-end models create a constant airflow by using a motor powered vacuum. Solder suckers tend to be fairly effective, however they are difficult to clean, the spring loaded ones can damage components with too much pressure, and the high-end suckers can be pretty pricey.

Desoldering Bulb

A desoldering bulb is very similar to a solder sucker. It is a bulb shaped rubber piece with a small funnel attached to it that works much like a turkey baster.

Past Efforts

No other solder wick dispensers have been created. Most of the efforts have been focused around improving the solder sucker, but none have been very effective because the low-end models can damage the joints and high-quality ones are too expensive.

Importance

This is an important problem to address because a simple effective method for removing solder would greatly impact electrical engineering projects and other jobs that involve detailed soldering. This design should significantly decrease the time to

desolder each joint, and decrease the occurrence of burn and repetitive motion injuries that result from fumbling with the soldering iron and touching hot wick.

Literature Review

When designing any product, many elements are involved in the design process, and there are numerous tools and strategies to aid in effective design. Strategies like concurrent engineering and design for x can assist the product developer in quickly and efficiently producing a quality product without having to backtrack. These methods involve many parts of the design process working simultaneously. Quality function deployment is also a great tool to help insure that the designer incorporates the maximum number of user requirements into the final design.

In the design of a handheld tool, it is important to understand certain specific concepts of product design. In a precision task, ergonomics of the tool are very important to decrease fatigue and increase overall satisfaction with the product.

Ergonomics of Handheld Tools

Over the last 20 years, ergonomists have been focusing on tool design because of the prevalence of Repetitive Motion Injuries (RMI) such as carpal tunnel syndrome. Hand tool design can greatly affect the occurrence of musculoskeletal disorders. The three main guidelines for hand tools are to fit the task, fit the user and hand, and not create injuries. In an external precision grip (or tripod grip), the tool is gripped like a pen, and in a study done in Italy, ergonomists concluded that the tripod grip, a grip consisting of the thumb, index and middle fingers, was chosen by the majority of subjects over the pinch grip, a grip between only the thumb and index finger. (Gentilucci, 2003) Because most people when soldering use the tripod grip, the Solder Qwik Pen will also use the tripod grip in order to keep the user balanced. The most important guidelines for a healthy precision grip are shown below in table 1.

Figure 1: Guidelines for Precision Grip

Guidelines for Precision Grip (Helander, 2006)

- Grip between thumb and fingers
- Grip thickness between 8-13 mm
- Minimum grip length of 100 mm
- Maximum tool weight of 1.75 kg

Other more general guidelines include having a smooth, slightly compressible grip surface, keep the wrist as straight as possible, limit vibration, and make the tool useable with either hand. (Helander)

Quality Function Deployment (QFD)

Quality Function Deployment is a structured method of defining customer needs and translating them into specific product plans that can best meet those needs. QFD uses matrices with collected and developed information to represent the plan for a product. (Crow, 1998) In product design, it is important to completely understand the exact requirements of the intended user so you can create the most effective product for the task. This is a good communication tool that leads to effective decision-making. It provides communication between engineering, marketing, production, manufacturing, and the customer.

The house of quality used in QFD has six sections: customer requirements, competitive assessment, design characteristics, a relationship matrix, a tradeoff matrix, and the target values. (Russell, 1996) The customer requirements section lists different attributes that are important to the customer, and rates them on a scale of 1 to 10, with 10 meaning most important. The competitive assessment section ranks the product against a couple competitor products, on a scale of 1 to 5, with 5 meaning the highest, according to each of the customer requirements. This section is important to see what factors need to be improved on in order to create a better product than the ones already on the market. The design characteristics section translates the customer requirements into measureable design characteristics such as weight, size, etc. These are then related to the customer requirements in the relationship matrix. In most cases the relationships can be + or - , and strong relationship are denoted by a circled plus or circled minus. The tradeoff matrix shows the interrelations of the design characteristics using the same symbols as the relationship matrix. The tradeoff matrix is important because it shows which characteristics impact each other. The final section puts quantitative measurements to the design characteristics and shows what the target values of each should be. (Russell, 1996)

Concurrent Engineering (CE)

In 1988 the Institute for Defense Analysis (IDA) defined concurrent engineering, sometimes called Integrated Product Development (IPD), as "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support." (Stark, 1998) This approach to engineering gets designers/developers to think about all the factors of a product. These factors include conception, quality, cost, user requirements etc. This theory brings multidisciplinary groups together to create a product looking at each of their specific factors simultaneously. Working in parallel gets all the parts of a product coming together accurately as quickly as possible. Often, CE involves only the design engineers and manufacturing. However, sometimes cross functional teams can include people from purchasing, marketing, production, and even the customer

can be involved. All the teams give their input before the product specifications are finalized. This helps to have everyone on the same page and clearly understand what the product requires.

Design for "X" (DFX)

Design for "X" is a concept that involves guidelines to follow in different areas of design. It is one of the best tools used in concurrent engineering. Some examples of design elements that are commonly considered are assembly, manufacturability, form and function, sustainability, etc. (Huang, 1996). Each area of design has guidelines to aid in innovative thought. Examples of some of the guidelines involved in DFA (assembly) are to reduce the number of parts, standardize parts, reduce fasteners, assemble from the top, etc. Each "X" has a detailed list of guidelines, or things to consider, helping in designing for that specific element. It is important to cover all aspects of design when creating a product so that the product excels in as many ways as possible.

Design Process

Brain Storming Product Ideas

After struggling with the standard solder wick dispenser during the construction of a PCB, I decided to brainstorm a better design. I came up with three new product ideas. The ideas are: a disposable solder wick pen, a solder wick pen with solder sticks, and a solder wick pen that has a roller to extract the solder. The first design is a disposable pen that has a wheel to push the solder out, and a small cutting mechanism so the entire tool can be operated using only one hand. The second design is the pen with solder sticks, it would work much like a standard mechanical pencil and use solder sticks similar to pencil lead instead of a roll of solder wick. The third design is a pen that is very similar to the first disposable design, except it has clips on the outer case that allow it to be opened, and reused multiple times.

Product Selection

A product matrix (Table2) was created to aid in choosing the most appropriate design. The first column contains the top three design ideas along with other similar products already on the market. Across the top of the table are the factors that I thought were the most important for choosing a good design. The level of innovation was especially important for choosing a design because my main goal was to create an extremely innovative new device. Manufacturability was chosen as a factor because if it were too hard to create it would not be a sensible design to take on. After ranking each product according to the 7 different feasibility factors on a scale from 1-5 with 5 being excellent and 1 being mediocre I chose the third design, the solder wick pen w/ roller or the Solder Qwik Pen™.

Figure 2: Product Selection Matrix

	EASE OF USE	LEVEL OF INNOVATION	COST TO BUY	MANUFACTURABILITY	COMFORT	SPEED TO DESOLDER	EFFECTIVENESS	**TOTAL**
DISPOSABLE SOLDER WICK PEN	4	4	5	2	4	5	5	29
SOLDER WICK PEN W/ STICKS	3	4	3	2	5	5	5	27
SOLDER WICK PEN W/ ROLLER	5	5	3	3	5	5	5	**31**
SOLDER WICK	1	1	5	5	1	1	5	19
SOLDER SUCKER	4	5	1	1	4	4	3	22
SOLDER BULB	3	2	4	4	2	4	3	22

Customer Survey

I created a short survey and asked the opinions of 30 students familiar with both soldering and solder wick. Thirty is a reasonable sample size to get an accurate sense of the most desirable characteristics for the design. The survey results helped to establish a set of product specifications that would accurately meet the customer's needs.

Solder Removal Survey

1. Which method do you prefer to remove unwanted solder?
   a. solder sucker
   b. solder wick
   c. solder bulb
   d. other

2. Which do you think most effectively removes solder?
   a. solder sucker
   b. solder wick
   c. solder bulb
   d. other

3. If solder wick could be used with only one hand would you prefer it over the other methods?
   a. Yes
   b. No

4. Rate the features of a solder removing device below that are most important to you from 1 to 5 with 5 being very important and 1 being not so important.

_ Fool proof to use
_ Minimal learning curve
_ Effective in removing unwanted solder
_ Long lasting
_ Comfortable
_ Low cost
_ Easy to maintain
_ Minimal number of pieces
_ Space saving

Survey Results:

- 85% said they preferred solder wick over other methods to remove solder
- Of those that preferred other methods, 100% said if solder wick could be used with one hand it would be preferred.
- Being easy to use, effective, and somewhat small were the main concerns of the survey participants
- Long lasting design, low cost, and comfort were other concerns of the survey participants

QFD

I made a QFD house of Quality to help me visualize what features to focus on in the design of the product, and to organize the customer's needs and how they should be executed in the design.

Figure 3: House of Quality

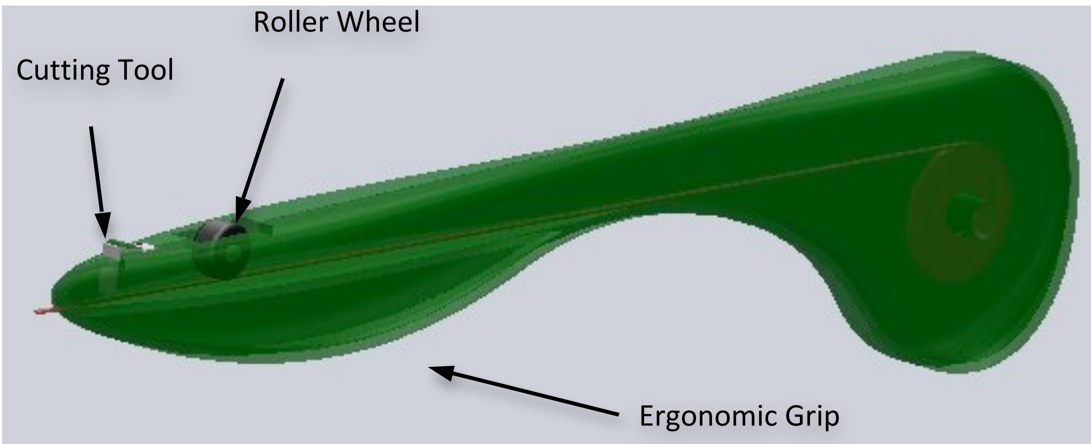
Strong Relationship	***
Some Relationship	**
Weak Relationship	*
No Relationhip	

	Wick Roller to extract wick	Uses Solder Wick	Reusable Design	Bulit- In Cutting Device	Durable Plastic Casing	Size of a Pen	Ergonomic Grip	Low Manufacturing Cost
Wick Roller to extract wick								
Uses Solder Wick	**							
Reusable Design								
Bulit- In Cutting Device								
Durable Plastic Casing	**	*	**					
Size of a Pen								
Ergonomic Grip	*				*	*		
Low Manufacturing Cost					*	**		
Easy Clips to replace solder wick		**	**		*			

Customer Needs	Customer Weights	Wick Roller to extract wick	Uses Solder Wick	Reusable Design	Bulit- In Cutting Device	Durable Plastic Casing	Size of a Pen	Ergonomic Grip	Low Manufacturing Cost	Easy Clips to replace solder wick	Solder Sucker	Solder Bulb	Solder Wick	***Solder Wick Pen***
		Product Features / **Technical Requirements**									**Competition**			
Fool Proof to use	5	**	**		**					**	3	3	4	5
Minimal Learning Curve	3	**	*								4	3	2	5
Effective in removing unwanted Solder	5		***								3	2	5	5
Long Lasting	4			***		***				**	5	4	1	5
Comfortable	3	**				*	**	***			4	2	1	5
Low Cost	4		*	**			*		***		1	4	5	4
Easy to Maintain	2			*		**	*			**	2	2	4	4
Minimal number of pieces	2	*								*	1	5	5	4
Space Saving	5		*				***				2	4	4	4
Raw score		35	72	50	15	45	60	27	36	35				
Rank		6	1	3	8	4	2	7	5	6				

Design Features

Because the user will most likely be using their non-dominant hand to operate the solder wick pen, a simple, easy to use design is crucial for it to be a preferred tool. Some of the key design features of the solder wick pen are the roller wheel, the cutting tool, and the ergonomic grip.



Roller Wheel

The roller wheel's purpose is to push the solder wick out of the case. This feature saves a lot of time compared to the old method of using two hands and manually extracting the solder wick from its case. Because it is a cylinder and similar to the scroll wheel on a mouse, users will find they have a natural instinct for how to use it effectively and immediately. It is made of rubber and has a grip texture to assist in extracting the solder wick. To operate the user simply has to roll it back.

Cutting Tool

The cutting tool's purpose is to cut the solder wick once the undesired solder is removed. This feature saves the most time compared to the old method, because the user no longer has to put down the soldering iron and pick up a pair of scissors in order to perform the cut. It is made of flex steel that is sharpened on one end. It also features a rubberized piece on the top that adds comfort and strength to the design. The tool is located on the pen towards the front end to minimize wasted solder. To make a cut, the user has to apply light, downward pressure to the tool.

Ergonomic Grip

The case features an ergonomic grip that was made considering the proper anthropometrics for the 95th percentile of users. Its sleek design is not only comfortable to use and aesthetically pleasing, it also gives the user a sense of balance because it is similar in size to a standard soldering iron.

Design for "X"

"X" = Aesthetics and Usability

Aesthetics were considered early in the design process. The sleek design will be inviting to users of the product. The roller and cutting system should allow users to clearly perceive how to use and operate the system immediately. With the design of the clip-in system, the case snaps together and opens easily to replace the solder wick roll.

"X" = Manufacturing and Sustainability

A simple design was important for the ease of manufacturability. I decided on an injection-molded casing and rolling wheel, and a cutting device made from flex steel. The case has two axels incorporated into the injection mold, one for the wheel and one for the solder wick. By making the axels part of the original mold the cost is decreased, because it minimizes parts that would otherwise need to be sourced or manufactured separately. I was originally thinking of making a disposable case that could be thrown away after the solder wick roll is finished, but for sustainability purposes, a reusable case makes more sense. Another benefit of making the case reusable is that solder wick rolls that fit the pen perfectly can be sold along-side the pen for additional convenience and profit.

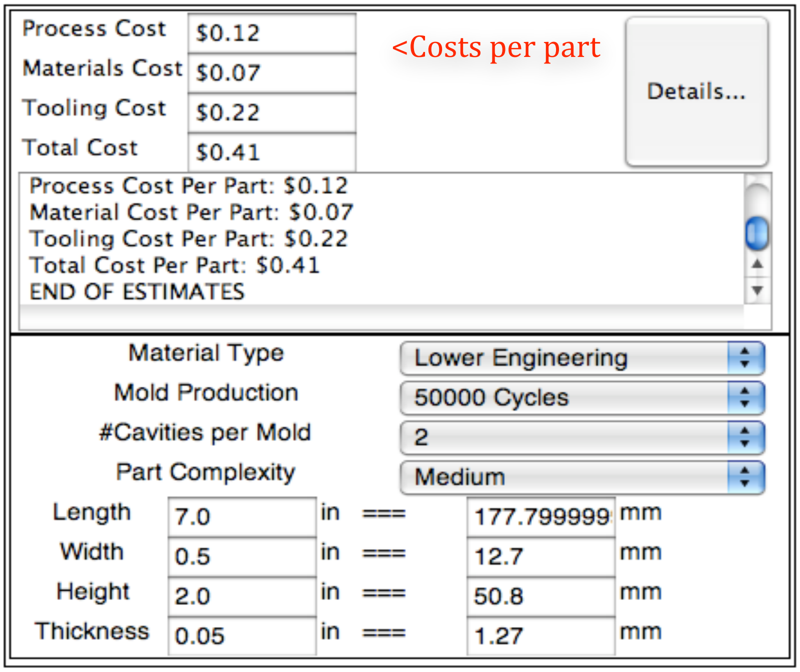
"X" = Maintenance

Based on the survey, customers desired a device that would be easy to maintain along with being user friendly. So unlike the solder sucker, and soldering bulb, this pen will require little to no cleaning. Solder gets stuck in solder suckers and eventually needs to be cleaned out. With the pen, the soiled wick is simply cut away.

Cost Estimates

Figure 4 below shows a complete cost estimate for the injection-molded portion of the solder wick pen. Some important factors in creating this estimate were the type of material, the production quantity, the number of cavities needed, and the overall parts complexity. In my estimate, the total tool cost would be approximately $22,093 and the machine cost would be around $50.58 per hour.

Figure 4: Cost Estimate (for complete list of estimates used refer to Appendix)



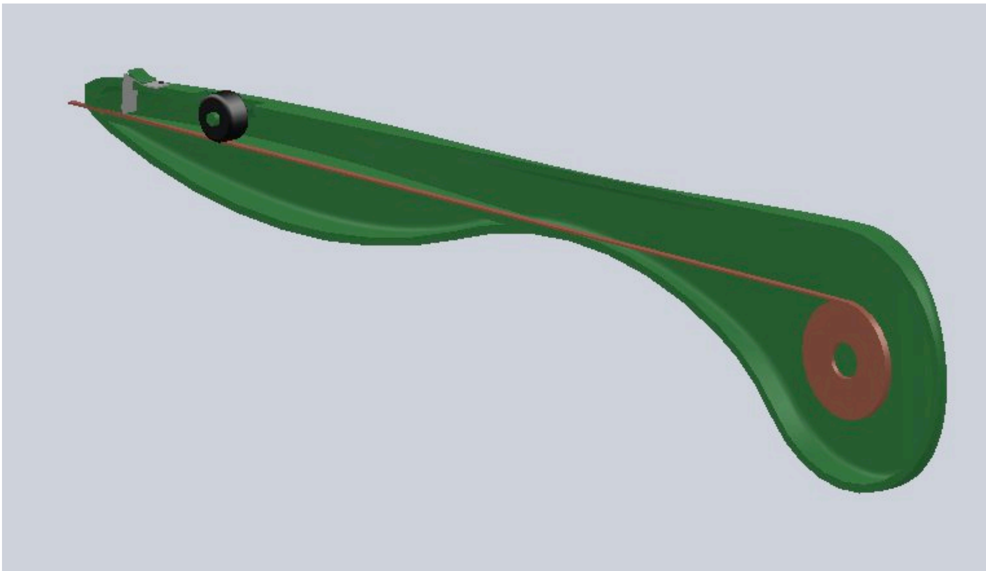
Material Type
I chose a thermoplastic resin (ABS) for the material, because of its good processing and performance qualities. The price of this material is approximately $1.25 per pound.

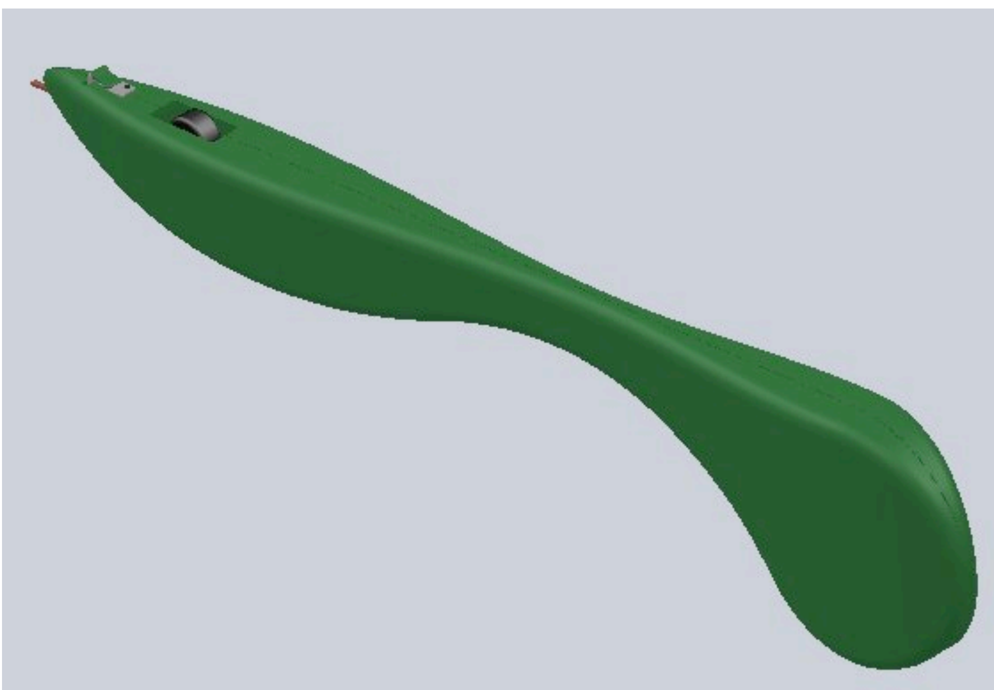
Production Quantity
For the production quantity I thought 50,000 cycles was accurate for cost estimating, because it is about the most that can be done on a tool before the tool needs to be replaced.

Cavities
Two cavities is the standard for small to medium parts, and the more cavities the more economical the production.

Complexity of the Part
Because of the clips, and axels for the wheel and solder wick coil, this part is considered to be of medium complexity.

CAD Pictures



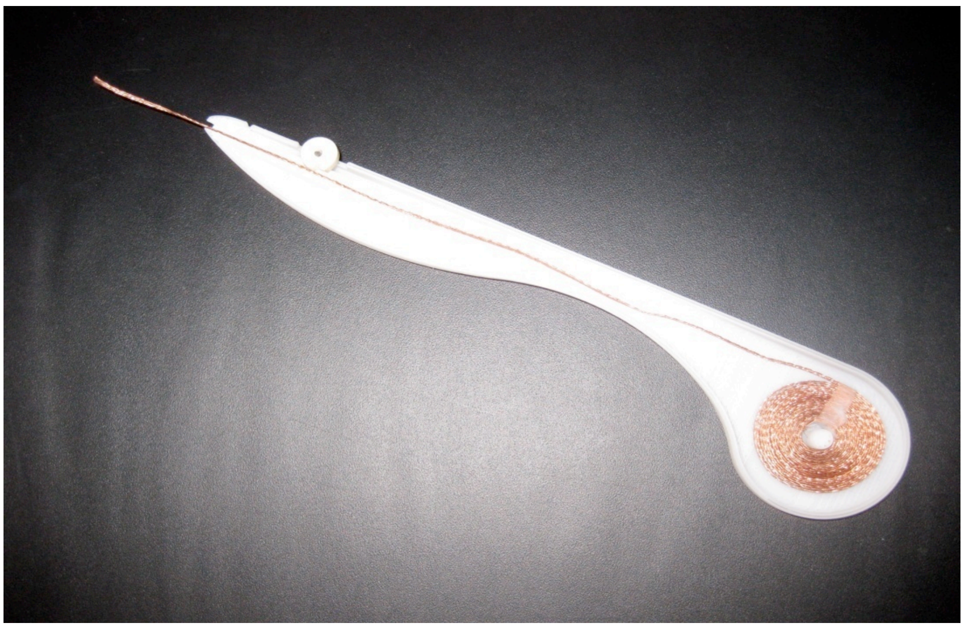


Methods and Experimentation

Prototype

I made a functional prototype to assist in testing the design. The prototype was made using a rapid prototyping machine to the exact specifications of a Solidworks STEP file I created. It was made with an ABS plastic material. I made the roller wheel with foam material wrapped around a thin tube. I did this instead of using the rapid prototyping machine, because it was such a small part and I wanted to resize the Solidworks drawings based off how the foam prototype worked.

Picture of Prototype (section view)



Experiment

Objective

To determine if the Solder Qwik Pen is a significantly faster method to use compared to a coil of solder wick.

Equipment

- Soldering Iron
- Solder Qwik pen
- Solder wick coil
- Wire cutters
- PCB with several similar soldered joints
- Stopwatch

Variables

Dependent: The amount of time it takes to completely desolder a joint, cut the used solder wick and prepare for the next joint.

Independent: Type of desoldering device used

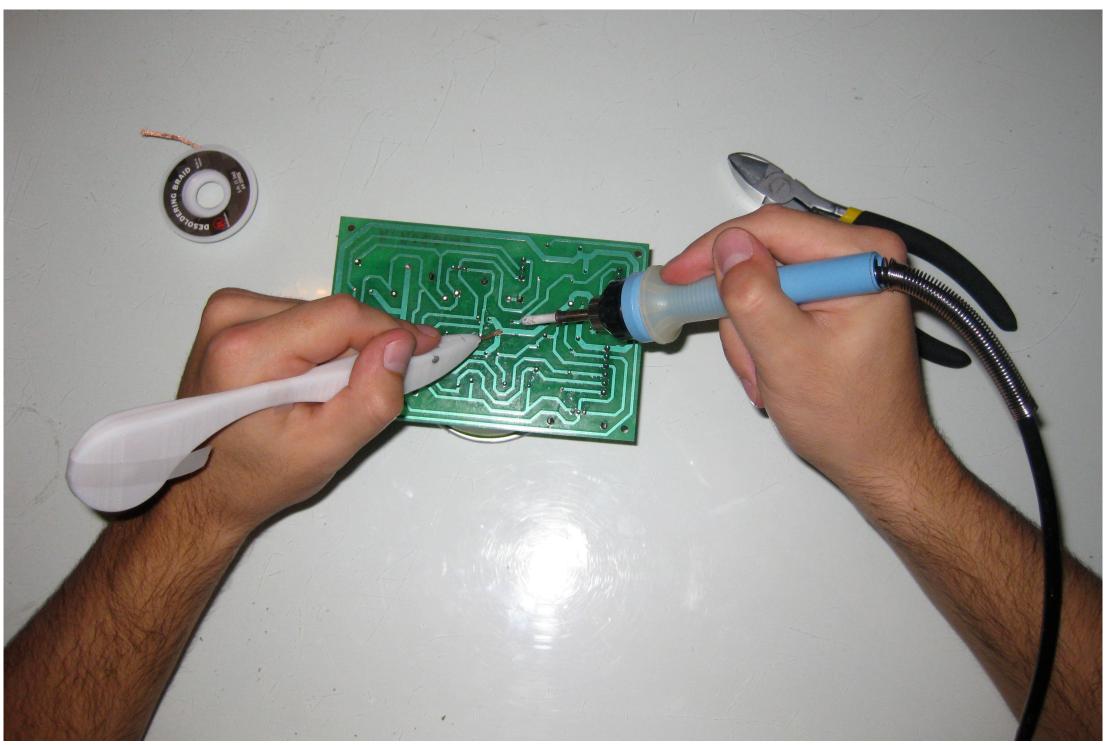
Control:

- Gender
- Subject's experience soldering
- Sitting position
- Initial hand and arm position
- PCB placement
- Brightness of light
- Non-dominant hand used
- Experimental condition order

Hypothesis

Ho: $m_{Coil} = m_{Pen}$ The type of desoldering device does not affect the time it takes to desolder a joint.
Ha: Otherwise

Diagram / Setup Pictures



Subjects

Subjects will be 10 male Cal Poly students between 18-23 yrs who have at least 1 quarter of soldering experience

Instructions given to subject

1. Sit down in chair with correct seating posture
2. Place both wrists on mark,
3. Grasp both instruments with correct placement of hands
4. On command, place wick on a joint and press soldering iron to top of wick
5. Once solder is absorbed into braid snip used wick into the designated bucket
6. Wait for repeat command

Data Collection Procedure

- 2 practice trials, 2 warm-up trials and 6 experimental trials per subject
- 5 subjects used solder wick coil and 5 subjects used the Solder Qwik Pen

Results and Discussion

Data

As shown by the figure 5 below, the Solder Qwik Pen did have a faster average time among users than the solder wick coil.

Figure 5: Comparison of desoldering methods (see appendix for raw data)

SOLDER QWIK PEN		SOLDER WICK COIL	
Subject:	Ave Time (sec)	Subject:	Ave Time (sec)
1	8.165	6	13.508
2	7.590	7	13.895
3	8.367	8	12.882
4	7.842	9	13.563
5	7.587	10	13.337
TOTAL AVE	**7.910**	**TOTAL AVE**	**13.437**

Analysis of Data

Figure 6: Unpaired t-test

Analysis of Data	
Solder Qwik Pen vs Solder Wick Coil	vs
Unpaired t test	
P value	P<0.0001
Are means signif. different? (P < 0.05)	Yes
One- or two-tailed P value?	One-tailed
t, df	t=19.91 df=58
How big is the difference?	
Mean ± SEM of column A	7.910 ± 0.1732 N=30
Mean ± SEM of column B	13.44 ± 0.2170 N=30
Difference between means	-5.527 ± 0.2777
95% confidence interval	-6.083 to -4.971
R squared	0.8723
F test to compare variances	
F,DFn, Dfd	1.571, 29, 29
P value	0.2301

P value summary	ns
Are variances significantly different?	No

To properly analyze the collected data, I performed an unpaired t-test. As shown in Figure 6 above, the means of the data are significantly different because the P value is less than 0.05. This allows me to throw out the null hypothesis, and confirms that Solder Qwik Pen is a significantly faster method for removing solder when compared to a solder wick coil. The R-squared value (0.8723) is very close to 1.0, meaning that this model is a good at predicting trends in the data.

Problems and Limitations of the Experiment

Outliers

For the most part all the experiments went smoothly, however, there was one instance with Subject 9 where the pair of wire cutters was dropped. In that case, I threw out the data as an outlier and ran an extra test.

Design Problems

A big issue that came up was that the material the prototype was made from was not strong enough to support the pressure created by the cutting tool. Because the resources of injection molding a new, stronger prototype were not available to me due to time and money constraints, I chose to use the prototype I had. To account for the time it would take for the Solder Qwik Pen group to cut the wick off, I had a second person snip the used solder wick off. This created a fairly accurate measurement of the time it would take to use the fully working design, because the subject still only needed to make a small movement towards the wick disposal bucket and did not need to put down the soldering iron and pick up the scissors.

Future Predictions

This product could easily lead to other products being sold as companion products to the Solder Qwik Pen. A "name brand" custom fitting solder wick cartridge for the pen could be developed. Another possibility would be to implement one of the competing ideas for this project- the disposable solder wick pen.

Conclusion

The solder wick pen was conceived using the principles of good product design. It can be made cost effectively and is significantly faster to use than a normal solder wick coil. This product has the potential to become the industry standard desoldering tool.

Appendix

Figure 4: Cost Estimate: List of estimates used in determining cost of production

ESTIMATES USED IN COST ANALYSIS (Kazmer, 1995)	
Specific Gravity	1
Number Of Gates	2
Fill,Pack, & Cool Time	10 sec
Ejection Time	8.89 sec
Parts Per Hour	315
Inj. Pressure	103.4 Mpa
Clamp Tonnage	978.237 tons
Tool Cost	$334,613
Machine Cost	$115.22/hr
Material Cost	$1.25/lb
Process Cost Per Part	$0.37
Material Cost Per Part	$0.75
Tooling Cost Per Part	$3.35
Total Cost Per Part	$4.46

Figure 5: Comparison of desoldering methods: raw data

Solder Qwik Pen			**Solder Wick Coil**		
Subject:	Trial #	Time (seconds)	Subject:	Trial #	Time (seconds)
1	Warmup	9.23	6	Warmup	12.54
1	Warmup	10.1	6	Warmup	11.4
1	1	8.65	6	1	13.06
1	2	9.12	6	2	12.21
1	3	8.32	6	3	14.07
1	4	7.02	6	4	16.16
1	5	7.78	6	5	12.8
1	6	8.1	6	6	12.75
1	**ave**	**8.165**	6	**ave**	**13.508**
2	Warmup	6.23	7	Warmup	15.67
2	Warmup	6.74	7	Warmup	14.8
2	1	8.89	7	1	16.89
2	2	7.12	7	2	13.5
2	3	8.32	7	3	12.34
2	4	6.88	7	4	14.64
2	5	7.08	7	5	12.11

2	6	7.25	7	6	13.89
2	**ave**	**7.590**	7	**ave**	**13.895**
3	Warmup	7.5	8	Warmup	14.91
3	Warmup	7.42	8	Warmup	13.77
3	1	7.11	8	1	13.23
3	2	9.48	8	2	13.46
3	3	6.23	8	3	12.76
3	4	8.02	8	4	13.55
3	5	10.2	8	5	11.79
3	6	9.16	8	6	12.5
3	**ave**	**8.367**	8	**ave**	**12.882**
4	Warmup	9.34	9	Warmup	17.91
4	Warmup	9.87	9	Warmup	14.22
4	1	8.28	9	1	12.43
4	2	8.43	9	2	14.22
4	3	7.91	9	3	12.89
4	4	7.12	9	4	13.78
4	5	8.39	9	5	14.76
4	6	6.92	9	6	13.3
4	**ave**	**7.842**	9	**ave**	**13.563**
5	Warmup	10.12	10	Warmup	14.21
5	Warmup	7.32	10	Warmup	12.5
5	1	7.84	10	1	13.52
5	2	7.58	10	2	13.67
5	3	6.19	10	3	12.34
5	4	8.42	10	4	12.8
5	5	8.36	10	5	12.4
5	6	7.13	10	6	15.29
5	**ave**	**7.587**	10	**ave**	**13.337**
	TOTAL AVE	**7.910**		**TOTAL AVE**	**13.437**

Works Cited

1. "Application of the QFD as a design approach to ensure comfort in using hand tools." Applied Ergonomics, 2007
2. Chan, Vincent, Salustri, Filippo, "Design for Assembly." www.deed.ryerson.ca/~fil/t/dfmdfa.html. 2005
3. Crow, Kenneth, "Design For Manufacturability/Assembly Guidelines." www.npd-solutions.com/dfmguidelines. 1998
4. "Design Relationships: Integrating User Information Into Product." Mechanical Engineering-CIME, 2009
5. Gentilucci, M., Exp Brain Res.Epub, 2003
6. Helander, Martin, A Guide to Human Factors. 2nd ed. Taylor and Francis, 2006
7. Huang, George Q., Design For X . Chapman and Hall, 1996
8. "Human experience and product usability." Applied Ergonomics, 2008
9. Kayis, Berman, "Concurrent Engineering Projects." International Journal of Risk Assessment and Management. 2008
10. Kazmer, David O., "Java Injection Molding Cost Estimator." http://kazmer.uml.edu/Software/JavaCost/index.htm 1995
11. "Listo Corporation". http://www.listo.com/plastic.htm 1997
12. "Product Design: Slowly but Surely." Design Weekly. 2009
13. Russell R., Taylor B., "Quality Function Deployment." Operations Management, 1996
14. Selvaraj, P., "An Integrated Approach to Design for Manufacturing and Assembly." International Journal of Advanced Manufacturing Technology, 2009
15. Strasser, Helmet, Assessment of the Ergonomic Quality of Hand-Held Tools. IOS Press, 2007
16. Stark, J., "A Few Words About Concurrent Engineering." www.johnstark.com/fwcce, 1998
17. Vezzetti, Enrico, "Product lifecycle data sharing and visualization." The International Journal of Advanced Manufacturing Technology, 2008