Producing and Testing Light Emitting Diode Christmas Light Strands

Benjamin Conrad

Mr. Knudsen

Senior Project

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New applications for technologies are always being developed; the emergence of the energy-efficient Light Emitting Diode (LED) and the relatively narrow range of applications for LEDs motivated me to use them in my project. I also wished to design and build a process to produce my LED application to further my career as an engineer. With these two desires in mind and the proximity of the holidays, I settled on making a machine to produce LED Christmas light strands similar to the familiar incandescent miniature Christmas lights.

As a future engineer, I realize that it is one thing to spend time building one demonstration product, but to be able to do it quickly, repeatedly, and cost effectively is another. Early in the designing process, I thought of a way to eliminate the plastic socket found on most other Christmas lights by directly inserting the LEDs into a wire and covering them with plastic or rubber for protection; this method could make the LED strands less costly than other lighting sets. When I was designing and building the machine, I tried to build the components so that producing one set of lights would be no different than making ten. By doing this, I gave my project a practical application, one that could be refined for a larger production scale.

The main benefit of an LED Christmas light strand over the traditional incandescent variety is that LEDs emit more light for the amount of power that they consume. An informed consumer would realize that they could save money by buying LED strands over incandescent strands while achieving similar levels of illumination. Also, LED strands are safer, they do not shatter and emit very little thermal energy, and they last longer than incandescents do. Therefore, they save the consumer money by using less power and do not require replacement as soon. However, because the benefits of LED strands are mostly long-term, unless LED strands cost less than incandescent ones, consumers will still buy incandescent strands over LED strands for the short term savings. For this reason, I bought the lowest costing parts that I could find without sacrificing form or function.

Hypothesis

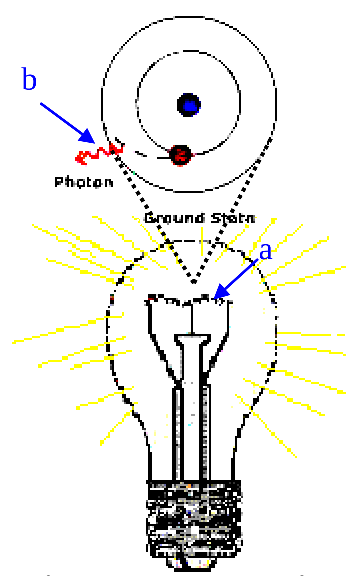
My project would see the production of low cost, energy efficient LED strands as an alternative to the traditional incandescent Christmas lights. A strand of LEDs will be more efficient in terms of power consumption for visible energy outputted than a like strand of filament lamps because of the fundamentally different ways in which each produces light. Furthermore, in LED strand production I would expect no more than a ten percent defect rate from the machine that I built.

Background

In recent years, the LED has allowed for the more energy-efficient and vibrant illumination in many applications where incandescents were insufficient. LEDs can also be much smaller than incandescent lights, leading to the major function of LEDs as indicator lights on electronic appliances. LEDs dominate on the small scale, but almost all applications larger than flashlights are better served by incandescent lights. LEDs are great at producing one color, but when white light is required LEDs need to be combined, whereas incandescents mostly produce white light and need to be filtered to produce colors. Another factor is that the incandescent light bulb has been around for a much longer time than the LED and has enjoyed much more research than LEDs; with further development the LED will undoubtedly be a much closer competitor to the incandescent light bulb. For the time being, LEDs will be used on the small scale, especially when colored light is needed.

LEDs produce light in a fundamentally different way than conventional, incandescent lights do. In 1879, Thomas Edison introduced the incandescent light bulb to mainstream society and allowed the world to easily light their homes when it was dark out. As the light bulb grew in acceptance, it was changed, adapted, and specialized; eventually being miniaturized and used to decorate Christmas trees (See Note 1). These lights work off the principle of incandescence, that a body will emit energy when it resists the flow of electrons (Incandescence). When electricity flows through the filament (Fig. 1a), the filament resists the current. The resistance causes electrons in the filament to excite to a higher state, and when they return to their normal orbit, they release a photon (b). The photons vary in wavelength, which is the distance between the electromagnetic waves that the eye interprets as color. Some of the photons, around ten percent, are visible to the human eye and provide illumination; the other ninety percent cannot be seen but are felt as thermal energy, heat (incandescent,…). When a certain color of light is desired, the light must be filtered, a process that blocks all wavelengths other than those desired. Therefore, when colors are needed, much of the light's visible emissions are blocked by the filter, decreasing incandescent efficiency.

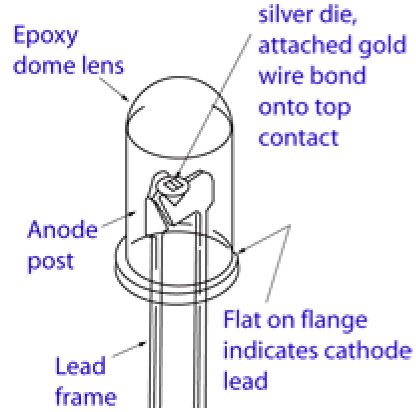
Figure 1



Courtesy Patrick Thrush, UWSP

LEDs also produce light when an electron is excited and then returns to its normal state while releasing a photon, like the incandescent lights, but LEDs excite electrons in a different way. In an LED, impurities are added to two pieces of semiconductor, named P and N, in a process called doping (Fig. 2). When placed very close to each other and current applied, electrons will jump from the P-type semiconductor to electron holes in the N-type semiconductor. A photon is released when the electron and the electron hole meet in the middle of the gap between the

Figure 2



Courtesy Marktech

semiconductors; the size of this bandgap junction determines the wavelength or color (bandgap size is changed by using different materials for the P and N semiconductors) (Light-emitting Diode). Therefore, as compared to incandescent lights, which radiate over most of the electromagnetic spectrum, the wavelength of an LED can be controlled; it will only emit light in the desired wavelength or color. Obviously, because all of the power that is inputted to the LED is emitted in the desired color, LEDs convert more energy into light than an incandescent bulb does and should therefore be more energy efficient. As one would expect, when incandescent light is filtered, as in colored Christmas lights, the efficiency of the LED is much greater than that of a colored incandescent light (The LED FAQ Pages 7). This is due to the incandescent light being filtered, which only allows a certain color of light to pass and blocking all of the rest; LEDs emit all of the light in the desired color, therefore none has to be blocked and the efficiency is greater.

LEDs are a new technology that is still being researched. Blue LEDs are a recent development; their creation has allowed the first white LEDs to be produced. They produce white light by either filtering the output of a blue LED or by combining red, blue, and green LEDs inside the white LED’s casing (Klipstein). They are slightly more efficient than incandescent bulbs, but cost much more, hindering mainstream adoption. The high cost of both blue and white LEDs keeps them from showing up in everyday devices for now, but with further development they will be as ubiquitous as red, green, and yellow are today. The high cost is the main reason that I’ve chosen to produce multicolored strands of red, yellow, and green and not include white or blue LEDs.

Companies have begun to produce LED Christmas lights, producing them in much the same way as incandescent light sets. For instance, Forever Bright Inc. uses LEDs shaped like the mini incandescent Christmas lights and pushes the cost effectiveness, safety, and energy savings of their light strands when selling. Their sets feature all the colors, red, green, yellow, and blue, and even use faceted coatings to direct the light so that the sets look similar to incandescent strands (Forever Bright Lights). Power utilities also recognize the benefits of LEDs and are offering incentives and rebates to their customers that buy LED Christmas lights. These efforts help, but LEDs still cost more than incandescent light strands (The Cost of Operating Christmas Lights?). Due to these incentives and further refinement of LED production methods, LEDs will eventually win over incandescent light sets, but not until they cost the same or less than mini incandescent light sets, despite their energy savings.

THE PROJECT

I set out to design and build a machine that would produce a strand of LED lights and then test them for efficiency versus a like strand of incandescent lights. Prior to this project, I had a moderate, hobbyist-level knowledge of the mechanical principles involved with my pursuit. This project forced me to design and build something on a larger scale than what I had done previously and mandated that I meet certain deadlines in order to succeed. I was able to draw on my own knowledge and resources while consulting my mentor, Jeff Blume, and my dad, Joe Conrad. Through our collective reasoning, I was able to overcome the design and construction problems that I ran into, construct the machine, and test the LED strings.

DESIGNING AND CONSTRUCTING THE MACHINE

My central idea was to attach the LEDs by pushing them through paired, two-conductor wire; eliminating any type of socket and making it a more simple and reliable design (Appendix 2, Fig. 4c). As I was beginning to design the machine, I thought about how a sewing machine operates and envisioned adapting one to poke two holes through the wire and then inserting the

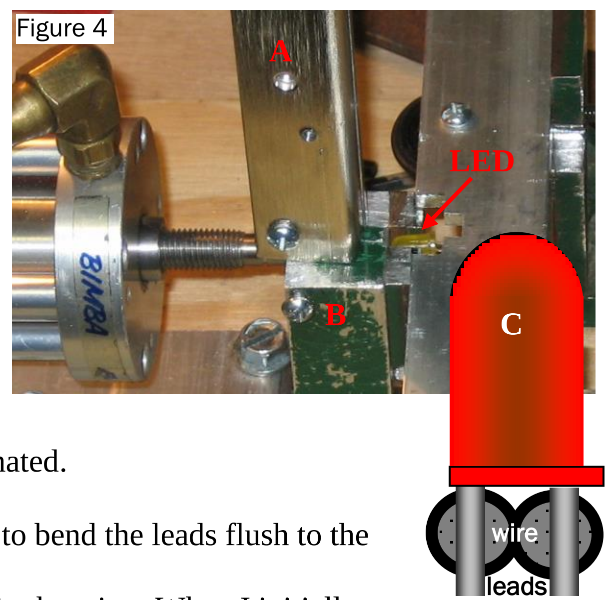
LEDs into the holes later. After some initial sketches and designs (Appendix 3) it occurred to me that I might be able to drive the LED leads through the wire, eliminating the need for the sewing machine step. I ran this idea past my dad who suggested using Pneumatic Cylinders because of their simple operation and wide variety of applications.

The materials that I used to construct the machine were either salvaged from other machines and equipment or bought at places like Fleet Farm or through online suppliers. I was fortunate in that during my dad's previous occupation as a furniture maker, he built many specialty machines and had a stockpile of parts that I could use. This lowered the cost of my project significantly and increased the quality of the components that I could use. This is especially true with the pneumatic cylinder I use to insert the LEDs into the wire. Such a cylinder would have cost me around thirty dollars, and I would have been unable to test it before I bought it.

I have quite a collection of the metals, plastics, motors, and other componentry necessary to build the machine from disassembling printers, videocassette recorders, and the like. I will never use all that I have, but it was good to have a selection of components available as I built the machine. Having such a selection is essential for brainstorming on a budget; being able to manipulate the pieces and envision how they will work together was very useful in avoiding problems with my design. As I built the machine, I made use of the materials that I had instead of buying them. Thus, when one looks at the machine, metals are different colors, there are seemingly random holes, and pieces reminiscent of their former applications, but it all works together to produce the strands.

The production begins with twenty four awg paired wire on the spool (the conductors are approximately .02010 inches in diameter) (Mims). As seen in appendix note 3, this wire is small; the wire is only about an eighth of an inch wide. This wire is drawn through the feed rollers that align it for the rest of the processes by the power feeder (Appendix 4). After the feeder, it proceeds to the insertion stage. The LEDs, meanwhile, have been sorted and sequenced into the color order and their leads have been cut closer to their base. The leads are made of a soft alloy and bend fairly easily; by cutting them closer to the base of the LED, they are less likely to bend when driven through the wire (Appendix 5). Lastly the LEDs are transferred to the hopper for the insertion stage.

I built the insertion stage first because it was central to the rest of the machine's processes, its operation would determine how the rest of the machine would function. The LED drops down from the hopper (Fig. 4a) into the bit and is then pushed by the air cylinder (b) into the wire. The metal stop forces the leads to be pushed through the wire, making contact with the conductor inside the wire as they do so (c). By having the leads of the LEDs directly connecting to the wire, any type of socket is eliminated.



With the LEDs in the wire, the next task is to bend the leads flush to the wire to act as a mechanical stop to hold the LEDs in the wire. When I initially designed the machine, I thought to coat the wires in a rubber or plastic compound to prevent the connection from shorting out, starting fires, or other mishaps. As I thought more about it, I realized the difficulty of making this stage work, developing the necessary molds and injection system, and decided that this stage was beyond the scope of my project; I can develop this element later.

The final stage of production is to cut the strands into sections, ranging from 25 to 100 LEDs per strand, and attach the power connector. Each strand is run by nine-volt dc transformer that plugs into a regular wall outlet. With some more development, I could make a custom transformer that would flash the LEDs, dim them, and be able to drive multiple strands; however that also is beyond the scope of my project. At this stage of development, the machine is a prototype. The ideas that I have built into it can definitely be refined and improved upon in later versions; the overall design is sound.

Testing the LEDs

To test my hypothesis, I researched the specifications of the incandescent light and the LED lights and then tested the individual lights to see if they matched their predicted performance. I also compared the power usage of the two strands by measuring the amount of power each would consume operating one hour. Lastly, I tallied the defect rate of the LED production to see if the machine was ninety percent effective in the production of the strands.

Information about the LEDs was plentiful while the vague term “miniature light” used to describe the most common style of Christmas light led to fewer results (Klipstein). I found that miniature incandescent lights use approximately 300 milliamps (mA) per bulb when operated at their suggested 2.5 volts direct current (The Cost of Operating Christmas Lights?). This translates into 0.75 watts of electrical energy used per bulb. The LEDs were rated for 20 mA of current at 2.8 VDC, using only .056 watts per LED (34825.pdf). Therefore, based on the specifications each device, LEDs should use much less power than their incandescent brethren.

For the hands-on test, I constructed a light meter to measure the light output and measured the power consumption of each strand. Using a photoresistor connected to a digital multimeter, I tested the light output of each color light. I then tested the power consumption of each strand by measuring the voltage consumed by each (Blume). Taking these measurements together, the ratio of resistance as measured by the photoresistor to the voltage consumed will tell which strand is more energy efficient.

Results

I produced one, thirty LED strand and found that my production process needed much more refinement as none of the LEDs on the strand would even light up. Therefore, the second part of my hypothesis failed; I did not achieve a ninety percent production success rate. I believe that, after having built this machine, that a new one, built to higher tolerances and using better components, would be able to produce the LEDs as I had intended. I still think that my original idea of inserting the LEDs is sound, just in need of refinement. Specifically, the LEDs did not always drop into the bit successfully which led to the leads not hitting the conductors or even the wire itself, they were therefore improperly positioned or laying on the bench after the stage was complete (Fig. 5).

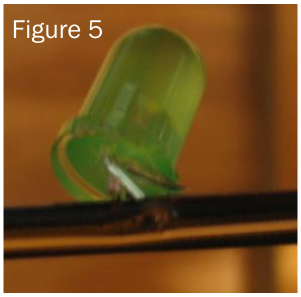


Figure 5

Given the failure in producing the LED strand as I had originally intended, I built a second strand of ten LEDs by hand so that I could test the first part of my hypothesis. These measurements, found in Table 2, compare the input voltage and output voltage to determine how much voltage each strand is using. I found that the incandescent strand used 4.2 volts while the LED strand consumed 3.4 volts. More voltage used translates into more power consumed, but does not tell how much of that voltage is being converted into light. When taken together, in Table 3, it is seen that the LEDs use less power but emit less light than the incandescents, negating my hypothesis.

The failure of the LEDs to output more light than the incandescents is most likely due to the LEDs being of the standard variety while the incandescent bulbs are tailor-made for light output. If I had bought super- or ultra-bright LEDs, they may have outshone the incandescent bulbs but would have cost much more to buy. Another source of error may be the transformer used to lower the voltage to twelve volts. I do not know how efficient the transformer is, but it certainly impacted the results, as seen in Table 3.

Most consumers will buy LEDs depending on their cost. If an LED Christmas light set would cost less than a brighter incandescent version, people will buy it despite it emitting less light. Similarly, LED Christmas light sets will consume less power and save money in the long run, but consumers sacrifice these benefits for lower initial price. For instance, the fifty bulb incandescent strand that I used in my project was very cheap, only $1.19 at Mills Fleet Farm. For comparison, the materials to produce my thirty LED strand cost $14.98, without adding in the cost of manufacture or any profit. Much of this cost could be lowered by buying mass quantities of the parts needed, but the LED strands would still be more than the incandescent ones.

Conclusions

The strand that I produced by hand works perfectly. Some companies, maybe all, assemble their strands by hand overseas, in countries where there is no minimum wage. Were I able to do the same, the labor and production costs would be less and I would enjoy a lower defect rate. I think that given time and a larger commitment to developing the LED strands and bring them to the market that I could turn the LED strands into a viable business venture. There are some problems that still need to be addressed, however I have tested my hypothesis and do not have the required time to refine them for my Senior Project. For the near term, I am done with the project; eventually, I could fix the problems that I encountered and try selling a couple sets online.

The main problem of this project was my ambition and the over scheduling of my time, not leaving enough to work on the project. Going into it, I knew that this project would be difficult, but I had nowhere near an idea of how much work I was committing myself to. I began working on my project three weeks before summer ended. I accomplished very little during soccer and resumed work on it the first week of November. Three weeks of almost daily work on it were not enough, in the past five days, I have spent 55.5 hours on the project to get it done. Obviously, the project took much more time than I anticipated and took too long to complete.

I also was hindered by the precision of the tools that I was using to construct the machine. I have a decent assortment of tools at my disposal, but to increase the machine's precision would require an equal increase in the precision of my work and the tools that I am using. The quality of the parts that I used was also the cause of headaches. In fact, I did not use any new parts on the machine; every piece is from something else. By scavenging the parts, I did not have to spend any money, but had to make use of odd components. The exception to this is that I was able to use some preexisting systems in the machine, eliminating design and construction work that would have otherwise been required.

The work itself was enjoyable, if at times exasperating, and I found that I already knew how to do the many required actions to construct the machine and test the strands. My background definitely helped and my enjoyment further confirms my career plans as an engineer.

I would think that if I had set deadlines over the summer and the first part of the school year for my project, that I would have made more progress and completed the project sooner. My recommendation, then, would be to require deadlines to be submitted to the student's advisor before summer vacation. These deadlines could be part of the final grade, an aspect that would force some to get their projects on track. By the same token, part of the benefit of the senior project is to let students direct their project, letting them establish their own timetable and enduring the consequences of falling behind it. My other suggestion would be to post a listing of what everyone else is doing shortly after the projects are approved, so that some students do not get stuck committing themselves to too much work.

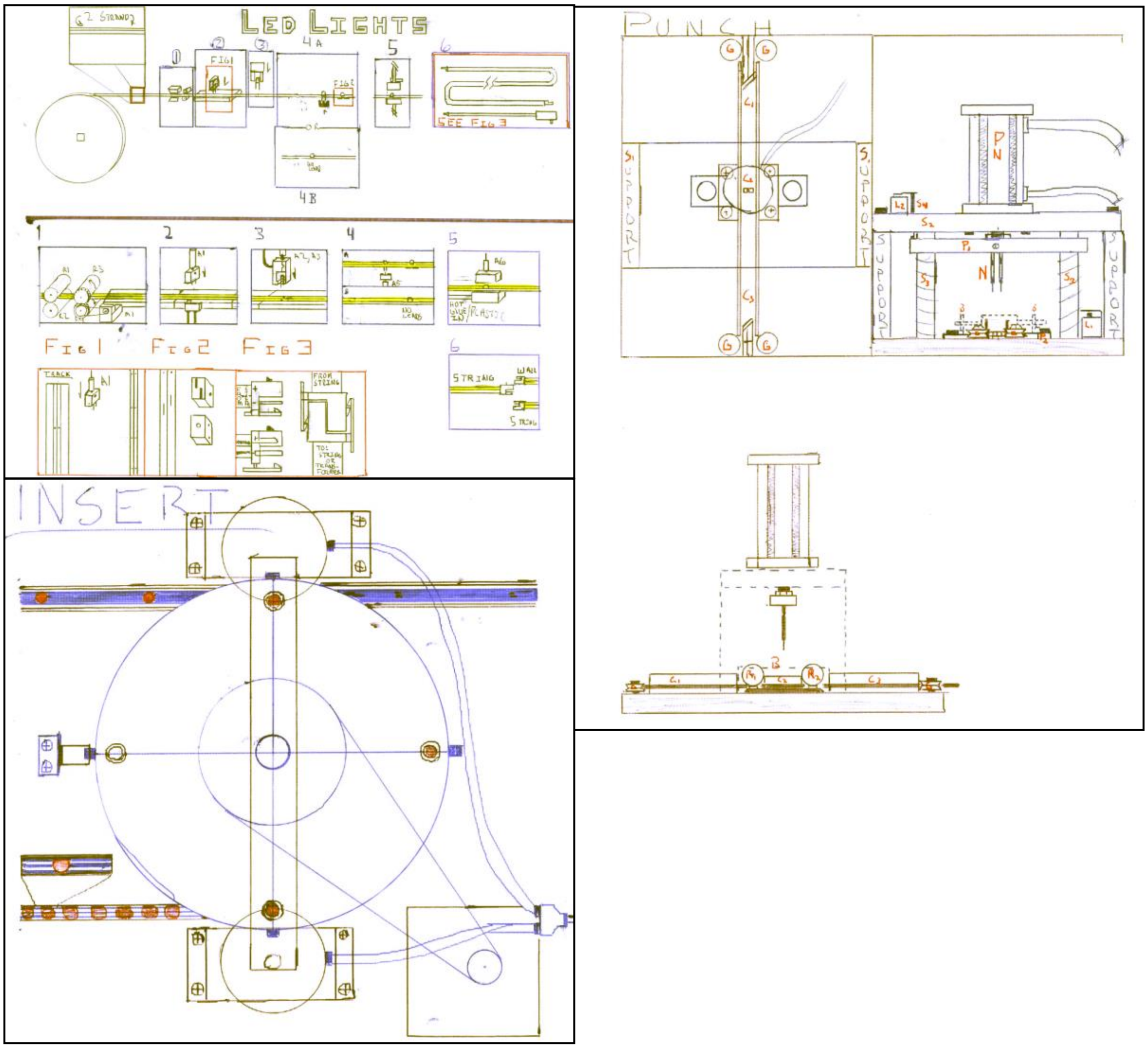
Overall, I am very relieved to have almost all of the work behind me and look forward to presenting my project to others and seeing how they did theirs. It would be good if my project inspired someone else to pursue engineering, and I hope that I can use what I have learned in this project in future endeavours and to further my career.

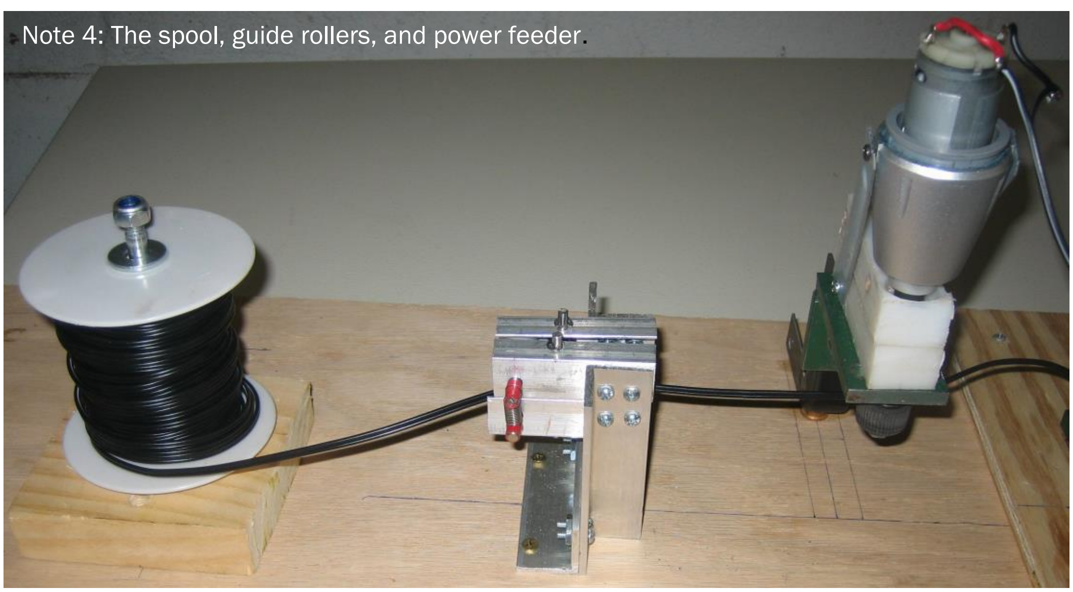
APPENDIX

Note 1: The miniature incandescent Christmas lights that I used in my comparison test.

Note 2: Simplicity of insertion versus the socket.

Note 3: Initial idea sketches of the machine





Note 4: The spool, guide rollers, and power feeder.

Note 5: LED leads cut for insertion, powered spool, hopper, and inserter.

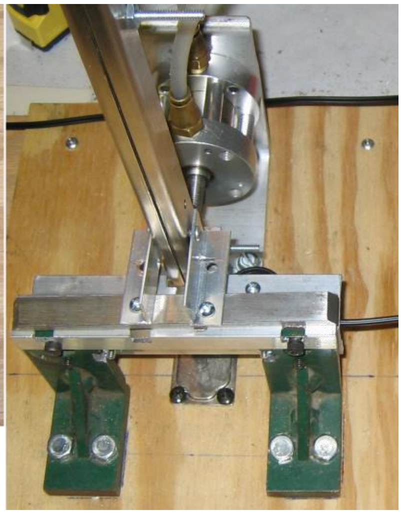


Table 1	Comparison of Incandescent and Light Emitting Diode Outputs	
	Color	**Resistance Measured in kilo Ohms (kΩ)**
Incandescent Christmas Light Strand		
	No Light	404.0
	Pink	0.719
	Orange	2.167
	Green	1.355
	Blue	2.778
	Red	1.621
LED Christmas Light Strand		
	No Light	250.3
	Red	4.3
	Green	1.8
	Yellow	1.5
60 Watt Light Bulb-Reported for comparison		
	Soft White	0.1449
Less resistance equals more output		

Table 2	Comparison the Power Consumption of Incandescent and LED Strands	
	Volts Consumed	**Voltage Drop**
Input Voltage	118.8	-
Incandescent	114.6	4.2
LED	115.4	3.4
The less voltage that is consumed, the more energy is saved		

Table 3	Comparison of Power Consumption and Light Output.		
	Average Resistance	Voltage Drop	Ratio of resistance to voltage; less being more efficient
Incandescent	1.7	4.2	0.40
LED	2.5	3.4	0.74
LED without the transformer	2.5	12	0.21

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Figure 1:

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