California Polytechnic State University
Mechanical Engineering Department
ME 428 – Senior Project

TEAM F101 – HEADLAMP/BIKE LIGHT DAMPING SYSTEM

Final Design Report

by
Ethan Clark eclark16@calpoly.edu
Alec Stonehouse stonehou@calpoly.edu
Omeed Ostry oostry@calpoly.edu
Mitch Anderson mande123@calpoly.edu

Advisor:
Eltahry Elghandour
eelghand@calpoly.edu

Sponsor:
Tony Emanuel
tony65ss@aol.com

June 7, 2023

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Table Of Contents

Abstract

The task for this project is to design a headlamp and/or bike light that absorbs the impact shocks from the user's actions. The user that the system is being designed for may be riding a bike or running on a trail in the evening or early in the morning where the light needs to be stabilized and their path must be illuminated. This report presents the final design chosen after months of prototyping and design iteration. It encompasses the system design, design verification through testing, implementation, future recommendations, and lessons learned throughout the process. The chosen design utilizes a fully passive, magnetic damping system to counteract disturbances in the vertical direction. Through vibration tests, drop tests, and field tests, the design is refined and validated to ensure it fulfills its intended functions. The main test was the vibration test which used accelerometers to help find the optimal height between the magnets that will induce the most damping. The vertical axis was the most important that saw the most instability so that was where the stabilizing system was implemented. The ideal distance was found to be 1.22 inches which means the distance to the middle magnets is 0.61 inches. When the magnets move closer than this 0.61 inches it causes a rapid increase in the magnetic force and causes the system to rapidly stabilize. This distance will provide the best damping for when the headlamp is worn for casual use and up to light jogging. When going through the design process many different types of damping systems were considered and magnets ended up being the most efficient due to their ability to self-stabilize, decrease the manufacturing difficulty, and keep the system completely mechanical.

Introduction

The team has been entrusted with the task of creating a solution to an issue many campers, hikers, runners, bikers, and outdoor enthusiasts are facing. This issue is regarding lack of stability of a light for outdoor use. The average headlamp/bike light is typically worn or mounted in such a way that rigidly connects the light source to the user. This may not seem like a problem to most people, but for frequent headlamp/bike light users, the problem arises with the stability of the light. This lack of stability arises from any movement that the light is attached to as the light will mimic every movement, impact, and vibration that the user or bike experiences. Hence, the light from the headlamp or bike light will be very shaky and vibratory, making it a less effective light source.

The task is to develop a mechanism that can stabilize this light source throughout several types of movements and impacts that an outdoorsman would experience. The team, Stable Light, is comprised of four intelligent mechanical engineering students that are motivated to create an original, fully mechanical system to solve this issue at hand. The following final design report (FDR) is presented with the intention of explaining the final chosen design after several months of prototyping and narrowing down the possible design paths. This report illustrates the system design, design verification (testing), implementation of the design, future recommendations, and things that were learned along the way.

The final design consists of a fully passive, magnetic damping system that will dampen all disturbances to the system in the vertical direction. Through various shake table vibration tests, drop tests, and field tests, the design will be fine-tuned and validated to ensure it accomplishes the basic functions it was designed to complete. The product will consist of 3D printed and machined parts for the first fully designed prototype but if it becomes a successful product, it would be made from mostly injection molded pieces to reduce production costs and increase quality. To date, a structural prototype focused on the damping system was designed and manufactured through rapid design and prototyping.

Design Overview

The "Stable Light" is made up of two main subsystems: mechanical and power. The mechanical subsystem includes the headlamp mounting and the damping system. The headlamp mounting consists of elastic straps to mount the light around your head, and hold the enclosed damping and power system. Shown in **figure 1** is the CAD model for the damping system, where the cover was made transparent for the purpose of exposing the damping design. Currently, the damping is done with a block sliding on a linear shaft with a nylon bearing, and opposing magnets provide the nonlinear forces to dampen the movement of the block holding the LED. See **figure 2** for visual representation of the dynamics of the damping system.

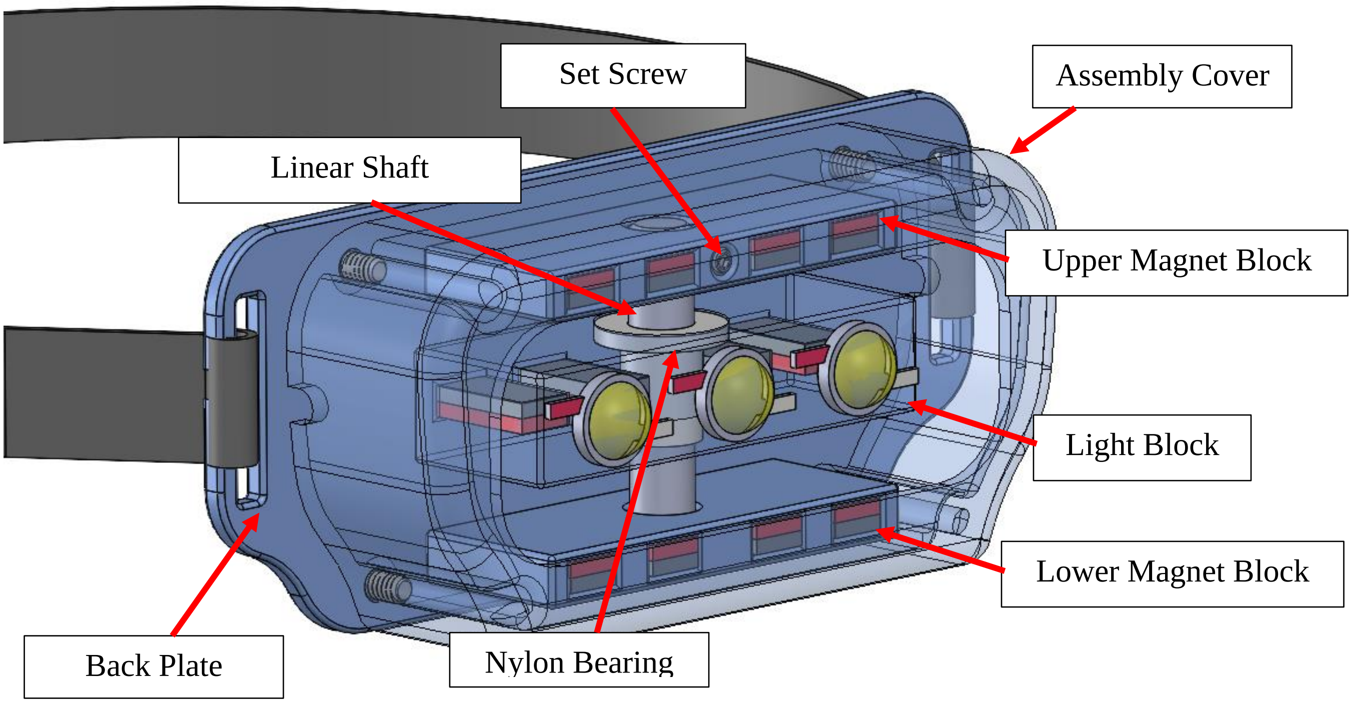


Figure 1: Overview of damping system assembly with labeled components.

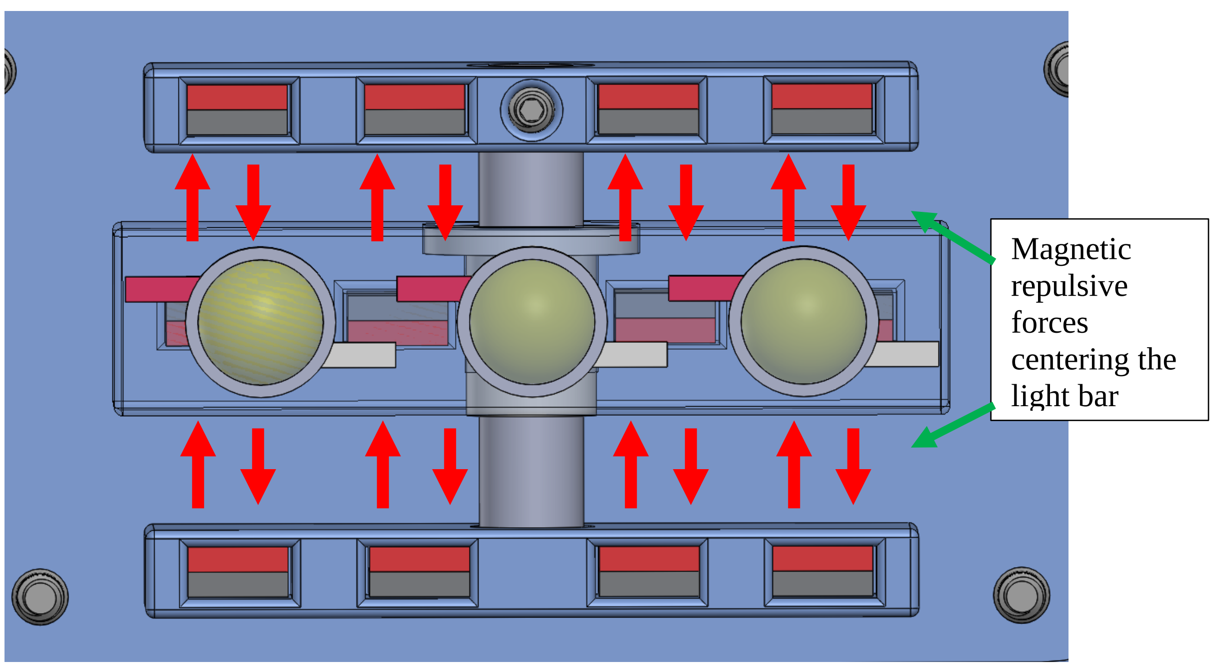


Figure 2: Visual representation of the repulsive magnetic forces that act on the light bar to passively re-center the light after impact.

This product was designed to be cheaply manufactured since one of the requirements was for the light to be a marketable solution to the shaky light problem. The headlamp is easy to use and does not require any setup or user manipulation to work as it was designed to. The user manual is

appendix A describes some of the safety hazards that may present themselves but the wires will be shrink wrapped and the batteries will have a protective case as well to mitigate the risks.

Figure 3: Assembled prototype containing power system and damping system.

The power system consists of a rechargeable battery pack that just requires a USB-C cable to charge which are readily available cables. The battery pack is connected to a light switch board and then to a step-up converter board which will all be contained in a 3D printed power box. See **fig.4** for a picture of the assembled power system. The power wires will run along the side of the headband and through the side of the assembly cover and soldered to the LED bulbs on the center light block. Most of these parts will be commercial-off-the-shelf (COTS) in order to reduce the production costs if this were to ever be mass produced.

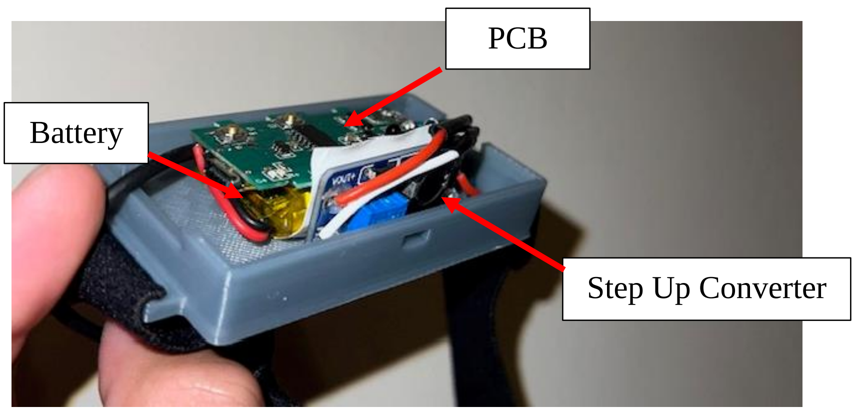


Figure 4: Power system assembly for headlamp consisting of rechargeable battery, light controller PCB, and the step up converter.

Since the critical design review (CDR) a few changes have been made, mainly the overall appearance of the headlamp but also the implementation of the testing outcomes. The damping assembly was made wider to accommodate more LED bulbs as well as more magnets on all three magnet rows. This helped hold the light in the center of top and bottom magnet rows since it increased the magnetic field. Also from testing, it was determined that the magnets needed to be closer together in order to provide a larger magnetic force on the center block at equilibrium to increase the damping ratio.

Implementation

All materials acquired were either purchased online, found in scraps from lab (with permission to take), or printed off-campus. As an entrepreneurial endeavor, the project was given a very low budget which also came along with the nature of the product desired. **Appendix C** reflects the wide variety of items purchased online, which correlates to a long brainstorming process for a non-existing product.

The process of manufacturing and assembly of the Verification Prototype consisted of mainly 3D printing and assembly. The design of the prototype was very simple, which corresponded with the goal of keeping the product low-cost and small, and once the housing and other designed components were printed the assembly could be done. There was no outsourcing for this process because of the nature of the product and its simplicity. The assembly comprised of the passive damping system and the power system. The damping system had a 3D-printed housing and sliding block (**Figures 5 and 6**), on which the LEDs were attached. The power system consisted of a 3D-printed housing with the power assembly inside and the LEDs wires running along the headband to the damping assembly.

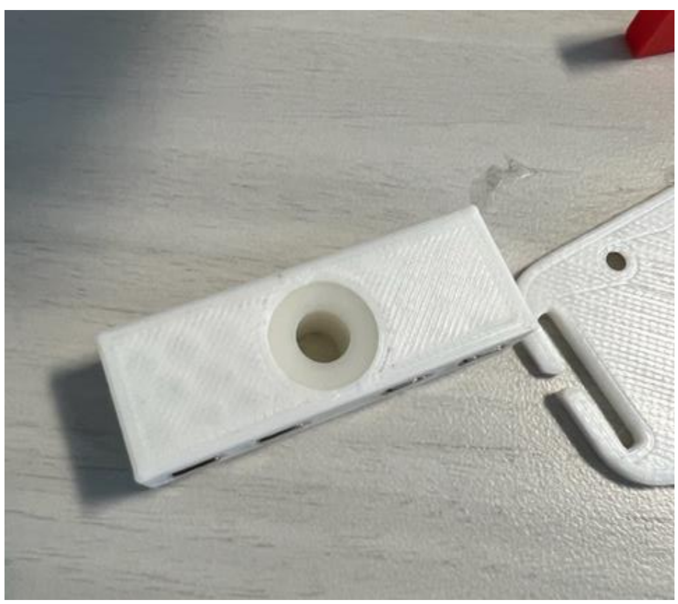


Figure 5: Sliding block for passive damping system that holds LEDs.

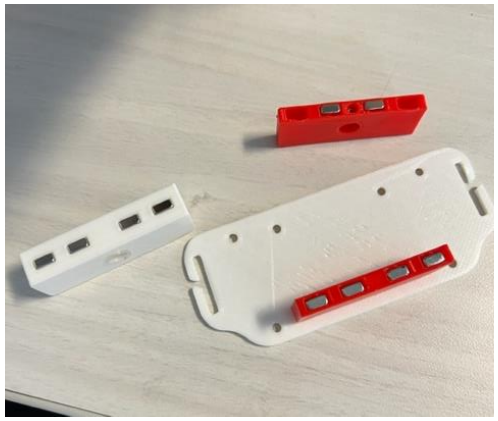


Figure 6: Passive damping system housing and assembly done with counter-sunk screws.

The most difficult part of the implementation process was connecting the wires to the LEDs in a way that would not affect the motion of the block sliding along the vertical shaft. Nonetheless, with enough investigation and attempts, suitable electrical wire was found. This wire that connects power from the power assembly to the LEDs is a very low-gauge and flexible one that did not significantly affect the block sliding motion. This assembly allows for the sliding block holding the LEDs to move freely without obstruction from the wire.

Design Verification

Meeting Design Specifications

There were moments where the design characteristics became such a long list with incredibly complex problems. Thus, the solution was to create a structural prototype that would make it much simpler to test and improve the vibration damping system specifically. Almost the entirety of the focus was concentrated on the vibration damping system because this was the most complex and required the largest amount of creative design. This process of creative design was completed through rapid prototyping where multiple preliminary prototypes were manufactured to see if testing was even feasible. This was the repeated design process up to now, and the listed specifications below are the design characteristics that were prioritized in our design process.

- Vibration resistance
- Light weight
- Water resistant
- Inexpensive
- Robust
- Shock resistant
- Strong direct light
- Sufficient battery life

This list helped organize and continue to drive the design process. Our rapid prototyping is what advanced the structural prototype most significantly. Shown in **figure 7** is an image of the several prototypes made, and the progress is evident. Creating from scratch a product that is not on the market is difficult, but the structural prototype in **Figure 8** will provide the foundation for the next testing and design phases. This will involve reducing the limitations of our latest damping system and further developing the power system. The following figure shows small images of the rapid prototyping process with Appendix C containing larger images. Many different types of damping systems were tried, and the most significant challenge was designing a system for such a small mass. Creating an effective and intuitive vibration damping system while still holding true to our listed design characteristics was difficult, but the current prototype is an incredible foundation.

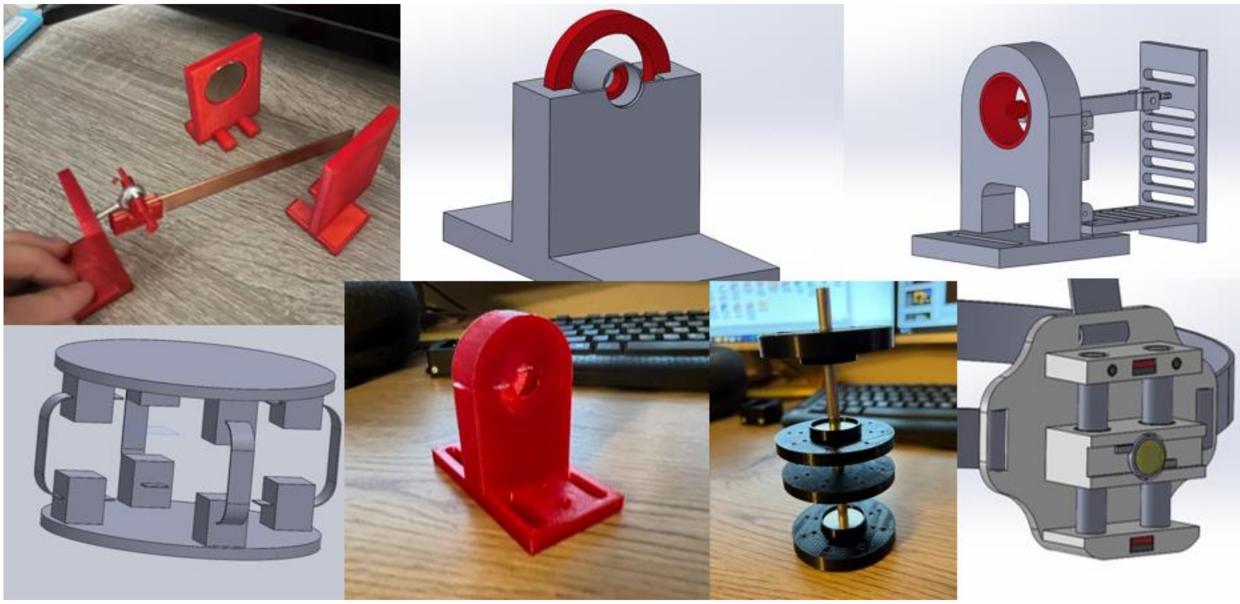


Figure 7: Compilation of rapid prototypes that were manufactured.

Safety, Maintenance, & Repair

The design that the team is going forward with does not have many hazards, but every possible situation must be considered. The only "high accelerations" that can possibly occur would be because of the mass (lights) recentering itself from the magnets. This would be because of whatever frequency the light undergoes while on a person's head or a person's bike. This is not something to be concerned about because it will not produce enough force to hurt anyone. There will be batteries in the system that will be used to power the LED lights. The batteries are not large. They are going to be around the size of two double A batteries and will produce a voltage of about 6 volts. Another factor that is a slight issue of concern is the use of the step-up converter. This could lead to the part of the headlamp getting a bit hot, which is concerning because the mounting would be on the person's head. If the converter gets hot, it could have negative health effects on a person since it will be directly contacting their skin.

Testing

The tests started with a basic function test where a user will wear the headlamp system and visually evaluate the effectiveness of the light. This will debug the system and bring out large adjustments that need to be made. Another test will be the vibration tests which will consist of a control test (no damping), and a damped test using the complete assembly. There will be two accelerometers attached to the system; the input (headlamp base), and the output (location of light mount). The amplitude ratios for several setups (stiffness variation) will be determined through an oscilloscope. Refer to **Figure 9** for the oscilloscope data and the **DVP&R** in **appendix D** for the summary of the testing. The results showed that a medium stiffness value will provide the best amplitude ratio for our purposes. This corresponded to a gap of .75in between the upper and lower magnet rows. The resting distance between the center and lower/upper magnet rows is approximately .3 in which according to the force vs distance chart in **Figure 10** will provide a decent amount of force to hold the light but when the center mass deviates from equilibrium, that force will sharply increase, allowing the magnet to recenter itself. **Figure 10** shows the approximate force vs distance curve for the bar magnets used in the assembly. Curve is based on the general relationship $F \propto \frac{1}{d^2}$ where the coefficient over d^2 is based on the magnet strength. Since our magnets hold .3lbs at a distance of zero, this curve best predicts the behavior. The optimal distance should be in the middle of the large slope and low slope sections since we want a high force to act quickly when the magnets are moved slightly closer to each other in order to quickly center the light block.

Figure 8 : Vibration Testing setup. Accelerometers attached to input and output locations of interest.

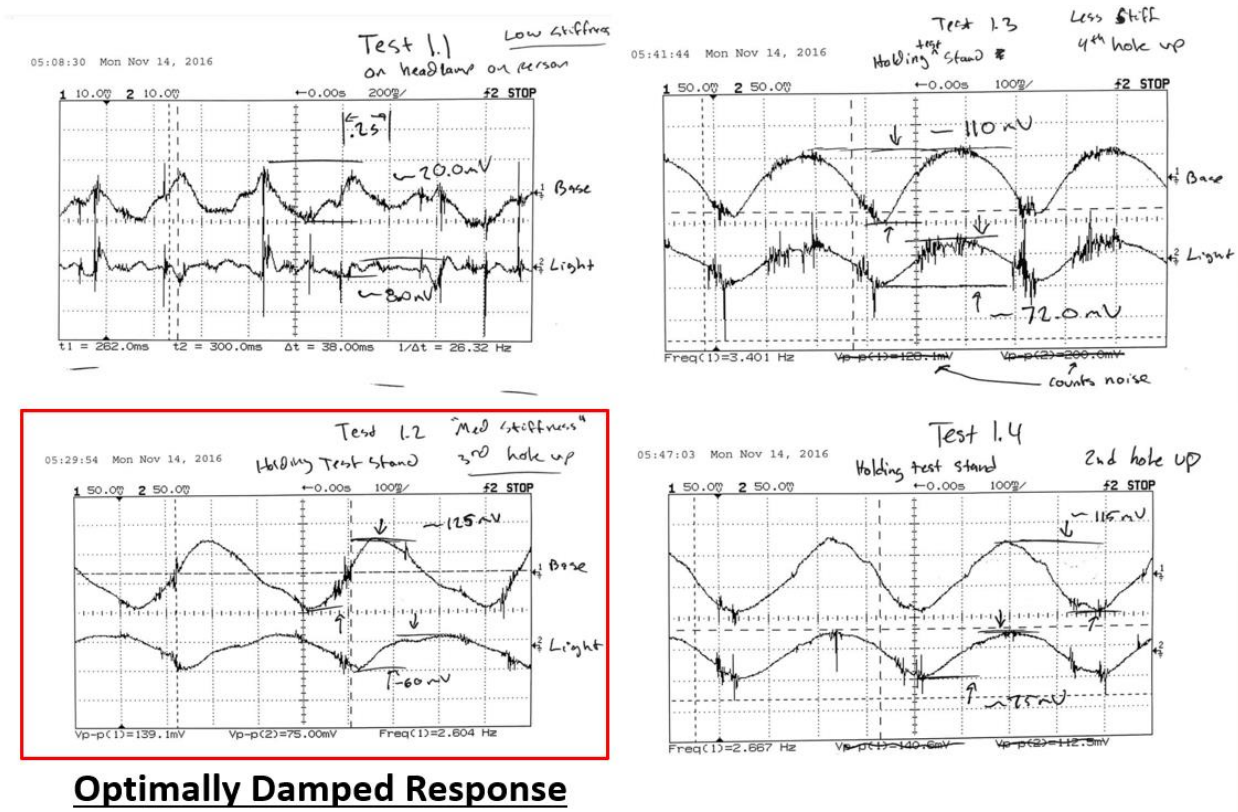


Figure 9 : Vibration Testing results. Plots of accelerometer data for a jogging frequency of about 3 Hz. Input amplitudes are the top curves and output amplitudes are the lower curves on each plot.

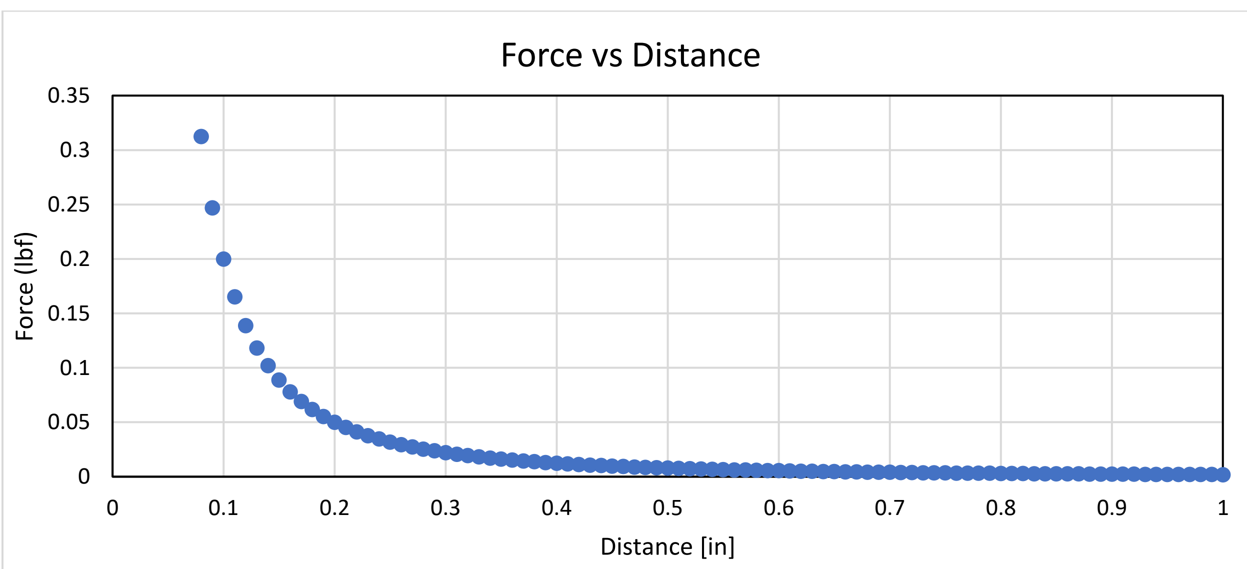


Figure 10 : Plot of force vs distance for the bar magnets used in the Stable Light damping system.

Structural Prototype

The structural prototype has been built several times and the CAD has been modified every time since 3D printing parts is not always predictable. Also, the bushing was first a bronze self lubricating bushing but it provided too much friction after it had dried up and reduced the effectiveness of the system. To solve this issue, a nylon bearing was put in place of it which made a significant improvement to the functionality of the of the prototype. Also the system originally had two linear shafts but this configuration constrained the motion of the center piece too much and lead to binding and inability to freely slide up and down. The number of magnets was also increased since the three magnet design provided too little repulsive force and did not hold the center piece up as well as it should. After testing, the location of the upper magnet row was lowered in relation to the lower magnet row in order to provide larger repulsive forces to help stabilize the center mass. See **figure 11** for an overview of the physical damping system structural prototype.

Lessons Learned

The testing process was difficult since the technology that was available was fairly outdated but the team managed to make it work. The team had to use the resources available and create tests that provided informative data that could be used to make effective changes in the design. A big lesson that was learned was that a design should be as simple as possible for several reasons including cost, manufacturability, and overall ease of use. This would have been good to know in the beginning of the process since many of our original prototypes were very complicated and had too many complex mechanisms.

Figure 11: Photos of the structural prototype that will act as final prototype for the project since the sponsor decided to focus on the damping system rather than the entire light system.

Discussion and Recommendations

Throughout the course of this design challenge, the team learned about the many damping systems that could be used to accomplish the task at hand. Deciding on the exact damping system took some time, but a clear system was chosen through testing. On the electrical side of this design, the team learned about LEDs, lenses, and power systems. The team honed in on soldering skills during the construction of the light sources to the headlamp. If the team were to continue the design, the team would continue to fine tune the damping system to see if the product could be applicable to other uses as well. Additionally, the power system could be modified in order to give a battery life rating for when the product would be put on the market. These would be changes that would help satisfy customer needs if the product were to be sold to the public. If this project were to be done again, the team would try and expedite the process of choosing a specific damping system and then deciding on the strength and distance of the magnets. This would give the team more time to design the light for other uses such as on a bicycle handlebar. Since a lot of the time spent on the project was finding the right strength of magnet for the damping system, high volume production of the product would be easier since it would go off the already existing damping system. Additionally, the team would create a more rounded shape to the front of the light and the back where the battery pack is to allow for maximum comfort to the user. These would be easy changes and would create a much better product where not much additional design would be required. This product is intended for those who are outdoor people and do many activities during the night. The team believes this product will be extremely beneficial and would please the target audience.

Conclusion

When the team started the design process many types of damping systems were purposed such as active, passive, and hydraulic. When thinking of the manufacturing process the team had to make sure the product would not be too difficult to create in order to keep the manufacturing costs low. After weeks of brainstorming and considering numerous designs, passive magnetic damping was chosen because of its simplicity and affordability. The overall goal was to create this damping system in a way that is not currently on the market and can compete cost wise. This magnetic system has done so and has a max manufacturing cost of about $30. A large portion of this cost came from not buying items in bulk such as the $10 headband strap. When the COTS parts are bought in bulk this manufacturing cost will be able to drastically reduce and can be sold at a reasonable price. The team believes this is a unique product that is not currently on the market and has the possibility to expand beyond headbands. What was not done was implement the passive damping system into a bike light mount. With head lamps being bright, cheap, and easily accessible, applying the product into a bike light can thrive on its own. The next steps to do so would be to remove the head straps and attach it to a mount that can clip onto bike handlebars. Overall, this project achieves a new and marketable product that utilizes magnetic forces to create a passively damped system. By adjusting the distance between the magnetic components, a different damping ratio can be achieved which can be applied to various speeds of running or walking.

Appendices

Appendix A – User Manual

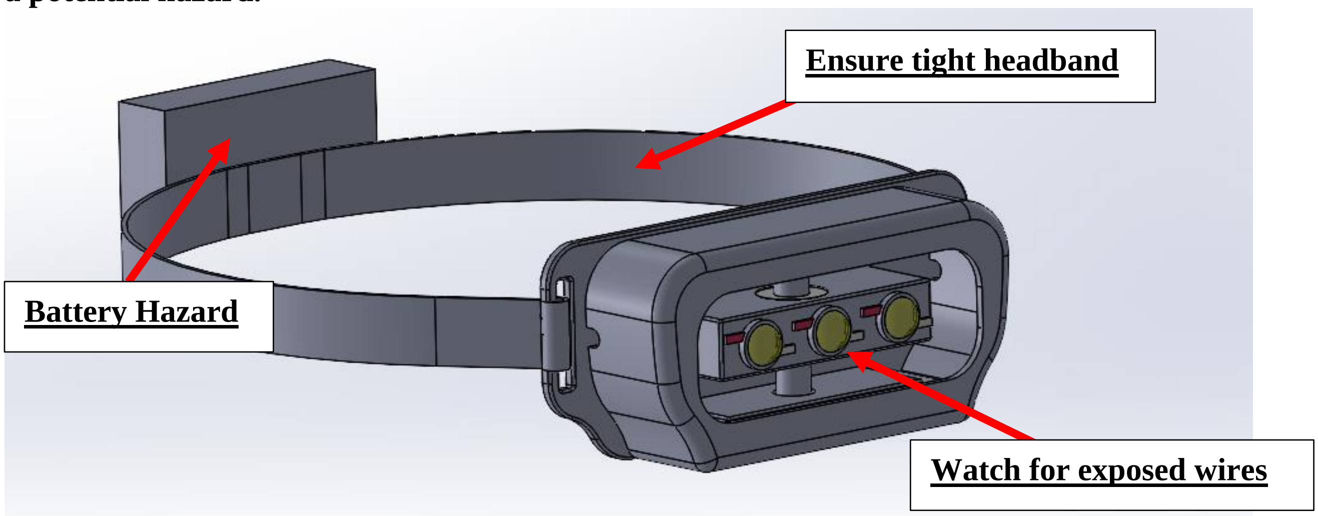
Stable Light User Manual

Safety

If you see exposed wires, do not power on or attempt to operate.
Do not shine light directly into others' eyes, can cause damage to sight

Operational Steps

Always properly tighten the headband strap when using product.
Adjust light to desired settings for the surrounding conditions.
Be sure to fully close battery pack when changing/charging batteries. Exposed batteries are a potential hazard.



No user assembly will be required
If parts are broken or missing, please contact Team Stable Light

Appendix B - Risk Assessment

	Item Id	User	Task	Alt Method	Hazard Category	Hazard	Cause/Failure	Photos	Severity	Probability	Risk Level	Risk Reduction Measures
1	1-1-1	operator	normal operation	No	electrical / electronic	shorts / arcing / sparking			Moderate	Unlikely	Low	Shrink wrap around electrical connections
2	1-1-2	operator	normal operation	No	electrical / electronic	water / wet locations			Moderate	Likely	Medium	Shrink wrap around electrical connections/seal battery case
3	1-2-1	operator	basic trouble shooting / problem solving	No	electrical / electronic	shorts / arcing / sparking			Moderate	Unlikely	Low	Shrink wrap around electrical connections
4	1-2-2	operator	basic trouble shooting / problem solving	No	noise / vibration	equipment damage			Minor	Likely	Low	Design for impact endurance
5	2-1-1	maintenance technician (Us)	parts replacement	No	electrical / electronic	shorts / arcing / sparking			Moderate	Unlikely	Low	Shrink wrap around electrical connections
6	2-1-2	maintenance technician (Us)	parts replacement	No	electrical / electronic	water / wet locations			Minor	Likely	Low	Shrink wrap around electrical connections/seal battery case
7	2-1-3	maintenance technician (Us)	parts replacement	No	heat / temperature	severe heat			Moderate	Unlikely	Low	Insulate battery case
8	2-1-4	maintenance technician (Us)	parts replacement	No	chemical	skin exposed to toxic chemical			Moderate	Unlikely	Low	Seal battery case with o-ring
9	2-2-1	maintenance technician (Us)	adjust controls / settings / alignment	No	mechanical	pinch point			Minor	Unlikely	Negligible	User training
10	2-3-1	maintenance technician (Us)	trouble-shooting / problem solving	No	electrical / electronic	shorts / arcing / sparking			Moderate	Unlikely	Low	Shrink wrap around electrical connections
11	3-1-1	passer by / non-user	Walking near operator	No	electrical / electronic	Bright Light			Minor	Likely	Low	User training - do not point at other people

Appendix C – Project Expenses

ORDER #1	Initial Magnet Function Test Models			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
60645K611	Ball Joint Rod End, 6-32 Thread	MCMASTER	9.7	1
8964K21	Multipurpose 110 Copper Bar, 1/16" Thick, 1/2" Wide	MCMASTER	2.56	1
1844N16	Linear Wave Spring, 0.0200" Thick, 0.25" Wide x 7.5" Long	MCMASTER	3.37	2
		SHIPPING	8.59	
		SALES TAX	1.38	
		TOTAL	28.97	

ORDER #2	Ring Magnets			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
RR0090N	0.409" (10.40mm) OD x 0.252" (6.40mm) ID x 0.142" (3.60mm) thick. NORTH pole on the OD / SOUTH pole on the I	SUPERMAGNETMAN	25	1
RR3500S	1.378" (35mm) OD x 0.984" (25mm) ID x 0.197" (5mm) thick, NORTH pole on the OD / SOUTH pole on the ID	SUPERMAGNETMAN	32.5	1
		SHIPPING	13	
		TOTAL	70.5	

ORDER #3	Arc Magnets			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
NA008-42SHIN	N42SH ARC Neodymium Magnet OD1.5"xID1.25"x0.75"Lx90 Degree ID N Pole	CMS MAGNETICS	4.29	4
		SHIPPING	6.28	
		TOTAL	23.44	

ORDER #4	RC shocks for dampers			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
	Aluminum Oil Filled RC shock absorbers TAMIYA TT01 TT02	AMAZON	21	1
		TOTAL	21	

ORDER #5	Magnetic Strips			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
3651K835	Conformable Magnet for Irregular Surfaces, Holding Power on 2 Faces, 1/16" Thick, 1/2" Wide, 6" Long	MCMASTER	8.48	1
8651K884	Conformable Magnet for Irregular Surfaces, Adhesive Back, Holds on 2 Faces, 1/16" Thick, 1" Wide, 6" Long	MCMASTER	16.01	1
9273K11	Hook and Loop with Adhesive Backing, 1/2" Wide x 5 Feet Long, Black	MCMASTER	6.73	1
3651K827	Conformable Magnet for Irregular Surfaces, Holding Power on 2 Faces, 1/32" Thick, 1/2" Wide, 6" Long	MCMASTER	4.72	1
		SALES TAX	2.61	
		SHIPPING	8.59	
		TOTAL	47.14	

ORDER #6	Acrylic and sealant			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
1221T13	Clear Scratch- and UV-Resistant Cast Acrylic Disc, 1/8" Long, 2" Diameter	MCMASTER	7.09	2
7770A27	Noncorrosive Silicone Sealant, Loctite Model Si 5011 CL, 2.7 FL. oz. Tube	MCMASTER	18.88	1
		SALES TAX	2.4	
		SHIPPING	9.05	
		TOTAL	44.51	

ORDER #7	3D Print Filament			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
	Flashforge PLA Filament 1.75mm 1KG Spool	FLASHFORGE	21.99	
		TOTAL	21.99	

ORDER #8	Magnet and Hardware			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
3651K891	Conformable Magnet for Irregular Surfaces, Adhesive Back, Holds on 2 Faces, 1/8" Thick, 1/2" Wide, 6" Long	MCMASTER	16.64	2
90128A113	Zinc-Plated Alloy Steel Socket Head Screw, 4-40 Thread Size, 3/4" Long, Packs of 10	MCMASTER	5.6	
		SALES TAX	2.82	
		SHIPPING	8.59	
		TOTAL	50.29	

ORDER #9	Magnets and Hardware			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
3360K854	Neodymium Magnet with Straight Unthreaded Hole Thickness Magnetized, 1/8" Thick, 1" OD, 13 lbs. Maxin	MCMASTER	10.5	4
8974K22	Multipurpose 6061 Aluminum 1/4" Diameter, 1/2 Feet Long	MCMASTER	1.95	1
		SALES TAX	3.85	
		SHIPPING	9.36	
		TOTAL	57.16	

ORDER #10	Hardware			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
6061K412	Linear Motion Shaft 1566 Carbon Steel, 1/4" Diameter, 4" Long	MCMASTER	6.11	1
91375A717	Alloy Steel Cup-Point Set Screw Zinc-Plated, 4-40 Thread, 1/8" Long	MCMASTER	9.4	1
2901A124	Black-Oxide High-Speed Steel Drill Bit 1/4" Size, 4" Overall Length		3.84	1
2901A212	Black-Oxide High-Speed Steel Drill Bit Wire Gauge 38, 2-1/2" Overall Length		2.16	1
2901A133	Black-Oxide High-Speed Steel Drill Bit 3/8" Size, 5" Overall Length		8.47	1
		SALES TAX	2.17	
		SHIPPING	8.88	
		TOTAL	41.03	

ORDER #11	Magnet and Hardware			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
2901A128	Black-Oxide High-Speed Steel Drill Bit, 5/16" Size, 4-1/2" Overall Length	MCMASTER	5.87	1
91263A376	Zinc-Plated Alloy Steel Hex Drive Flat Head Screw, 4-40 Thread Size, 1/4" Long, Packs of 100	MCMASTER	11.96	1
7122A39	Hex L-Key with Standard Tip, 1/16" Size, 3-1/16" Overall Length	MCMASTER	0.28	2
		SALES TAX	1.33	
		SHIPPING	8.88	
		TOTAL	28.6	

ORDER #12	Nylon Bearing			
PN	DESCRIPTION	SUPPLIER	PRICE	QTY
58068	The Hillman Group 58068 0.312 O.D. Nylon Flanged Bushing, Numer- 1/4, 30-Pack,White	MCMASTER	9.9	1
		SALES TAX	1.39	
		SHIPPING	5.99	
		TOTAL	17.28	

ORDER #	TOTAL		Total Funding	
1	28.97		#1	$500
2	70.5			
3	23.44			
4	21			
5	47.14			
6	44.51			
7	21.99			
8	50.29			
9	57.16			
10	41.03			
11	28.6			
12	17.28			
$ SPENT	451.91		Left Over	$48

Stable Light

Indented Bill of Material (iBOM)

Assy Level	Part Number	Descriptive Part Name			Qty	Part Cost	Source	URL	More Info
		Lvl0	*Lvl1*	*Lvl2*					
0	120000	Final Assy			------	------	------		
1	100000		Light Assy		------	------	------		
2	100006			Bar Magnet	10	$ 2.70	Amazon	https://www.	Comes in 60pc
2	91375A717			4-40 Set Screw	1	$ 0.19	McMaster		Comes in 50pc
2	100007			LED Bulb	1	$ 0.10	Amazon		
2	6061K412			Linear Shaft	1	$ 6.11	McMaster		Must be cut to length
2	91263A376			Countersunk 4-40 screw	8	$ 0.96	McMaster		Comes in 100pc
2	100001			Assembly cover	1	$ 0.10	3D Print		3DP PLA
2	100002			Back Plate	1	$ 0.10	3D Print		3DP PLA
2	100003			Bottom Support	1	$ 0.10	3D Print		3DP PLA
2	100004			Center Bulb Housing	1	$ 0.10	3D Print		3DP PLA
2	100005			Upper Support	1	$ 0.10	3D Print		3DP PLA
2	58068			Nylon Bearing	1	$ 0.10	Amazon	https://www.	Comes in 30pc
1			Headband Assy		------	------	------		
2	100008			Headband	1	$ 10.99	Amazon	https://www.	-
1	110000		Power Module Assy		------	------	------		
2	100009			Power module	1	$ 10.00	Amazon	https://www.	Price adjusted for power system use only
2	100010			18 gauge wire	1	$ -	Amazon	https://www.	Negligible cost
	Total Parts				**30**	**$ 31.64**			

Appendix D – DVP&R

DVP&R - Design Verification Plan (& Report)											
Project:	Stable Light		Sponsor:	Tony Emanuel					Edit Date:	2/10/2023	
TEST PLAN									TEST RESULTS		
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
1	Vibrational damping	use shake table and accelerameters to find how well the system damps the vibrations	damping ratio	works or not	shake table	accelerameter and fixture tooling	whole team	2/14/2023	5/1/2023	Amplitude Ratios: Med Stiffness (3rd Holes Up) - .48: Lower Stiffness (4th Holes up) - .65 : High Stiffness (2nd Holes Up) - .65	Med Stiffness was optimal, provided best amplitude ratio. Highest Damping
2	Distance Illuminated	Use product at night and measure distance to furthest object the user can see using the light.	Distance	>80ft	Outdoors	Light module assy	Whole team	2/14/2023	5/3/2023	Distance Illuminated: 100ft with three LED bulbs	More bulbs didn't necessary increase distance, increased intensity instead
3	Total Weight	make sure system is not too heavy	weight	less 1.5 lbs	scale	none	whole team	tbd	5/3/2023	.7lbs	Pass
4	Ease of Use	make sure system is easy for anyone to use	acceptance	pass/ fail	volunteer	person	whole team	tbd	5/10/2023	N/A	System is easy to use, similar to most headlamps, fairly comfortable with foam attachment. Fits tightly.
5											

Appendix E - Test Procedures

Amplitude ratio testing using accelerometers and oscilloscope

1. Attach two accelerometers to their own cylindrical amplifier and then connect those amplifiers to the main amplifier (red box).
    a. Ensure each cable is transmitting signal by checking the status of each signal on the amplifier.
2. Attach the corresponding BNC-BNC cables from the amplifier to the oscilloscope.
3. Attach one accelerometer to the back plate of the headlamp
4. Attach the other accelerometer to the floating center light bar of the headlamp.
5. Attach the headlamp assembly to the user's head using the headband.
6. Have the user walk, jog, and run in place, effectively simulating the real frequencies of impulse that the headlamp would experience.
7. Obtain a long section of data from the oscilloscope in order to find the average amplitude ratios for each set of frequencies.
8. Adjust the height of the top support piece on the headlamp to a few different heights and repeat steps 5-7 for each height.

Goals: Find top support height that provides the smallest output/input amplitude ratio.

Illumination distance test

1. Attach the fully built headlamp assembly to the user's head using the headband.
2. Switch on the light
3. Measure the distance to the furthest object visible to the user.

User Friendliness Test

1. Give the headlamp assembly to several different users and record their qualitative responses to obtain a list of things that work well and things that need to be improved upon.
2. Address potential changes and make appropriate revisions to the design.