Luxeon K2 Flashlight

ME 409 - Li

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1. Overview

To investigate the implementation of high-power white LEDs in portable applications, a flashlight was chosen for the project. The flashlight utilizes three Philips Luxeon K2 emitters, which are rated at 6W per unit. Due to the lambertain emission a 3° lens will be incorporated to increase range.

The device will be supplied with 4 Duracell Ultra D-Cell batteries, and will require electrical drive circuitry, liquid thermal cooling and protection circuitry. Sufficient area will also be reserved for future incorporation of a moderate-power laser diode, lens and drive circuitry.

The aesthetic design draws inspiration from medieval lighting, namely torches. This design choice both allows for an elegant body design, but also hides the tremendous length associated with the constraining dimensions of the internal components.

The focus of this report shall be the design and construction of the flashlight body and head, with an overview of the remaining components.

2. Methodology

Constraining dimensions were first identified for the different components of the device. While the battery/contacts and LED/heatsink/lens constraints were straightforward, the internal circuitry and cooling constraints were not so straightforward.

Given the timeline of this project, it was necessary to fabricate the housing before the electrical/thermal components had been finalized. Thus several design iterations and tests were performed to estimate a worst-case scenario for these components, including a small safety margin. This included circuit board estimation, heatsink estimation, and control circuitry estimation.

Once the internal dimensions were identified, a minimum wall thickness of .100 inches was established, and a design worked through using Bezier curves. After a sufficient profile was established, the profile was replicated with simple arcs, as the available equipment was constrained to arcs and lines. This then represented the final profile for fabrication.

3. Design

The specifications for the design are as follows:

Table 1: *Design Constraints*

Constraint	Description
Power Supply	4 Duracell Ultra D-Cells
Output	Full Intensity for 1 hr
Thermal	Handle Temperature <95 For 1 hr
Control	Variable Output from 10-100%

Table 2: *Design Constraints*

Constraint	Description
Power Supply	4 Duracell Ultra D-Cells
Output	Full Intensity for 1 hr
Thermal	Handle Temperature <95 For 1 hr
Control	Variable Output from 10-100%

As stated in section 2, from this resulted in the following internal constraints:

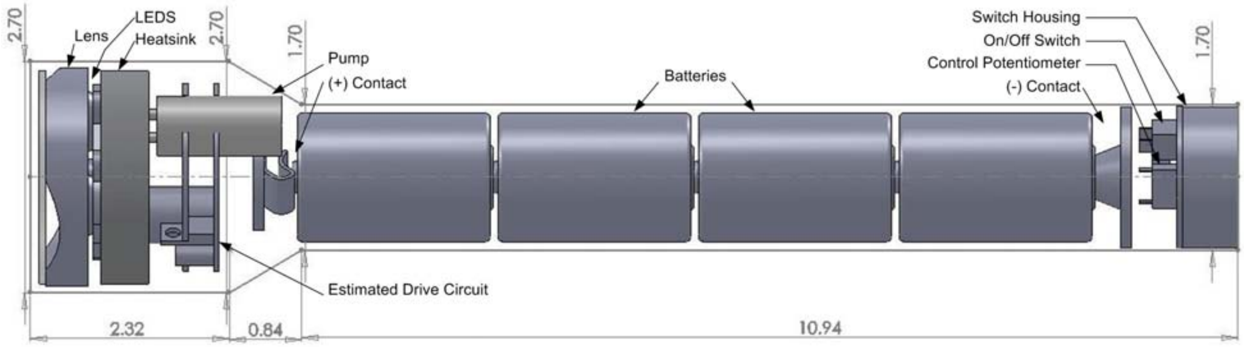


Figure 1: *Least Material Condition (LMC)*

To note the cooling lines and laser components are omitted from the sketch from clarity; appropriate space is still allocated in Figure 1.

Four iterations were processed to establish an appropriate profile. Each balanced weight, length and aesthetic quality. The four iterations were as follows:

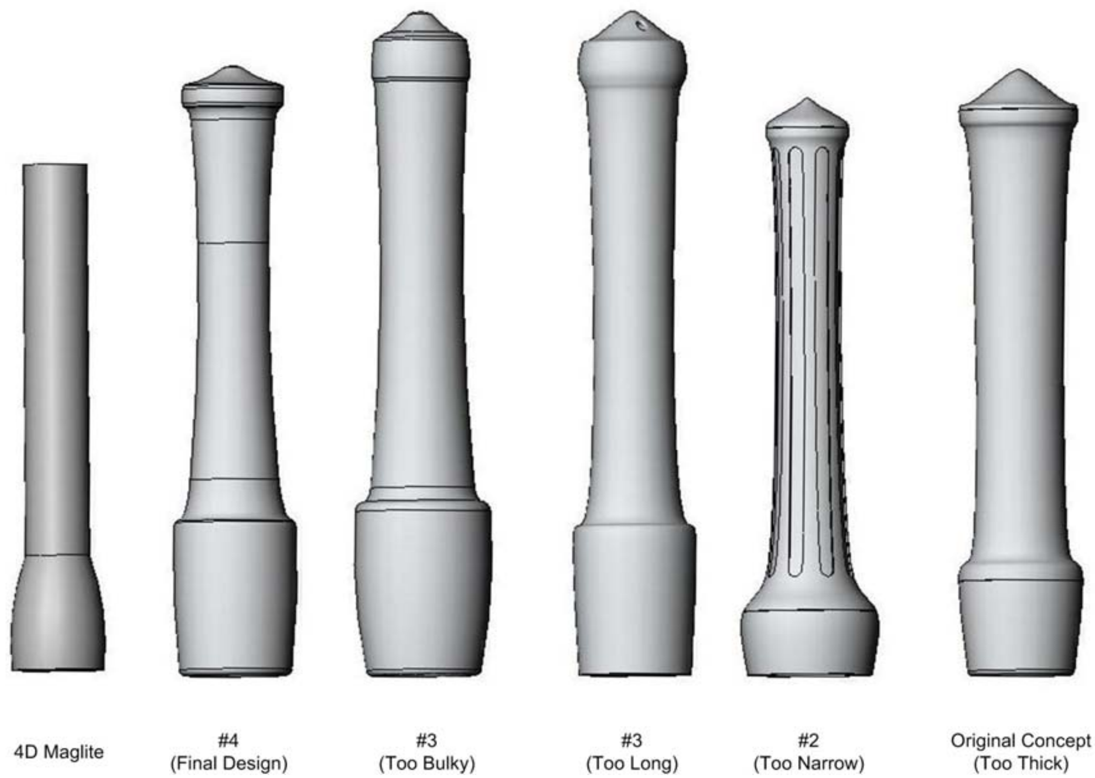


Figure 2: *Design Iterations*

The final profile is as follows:

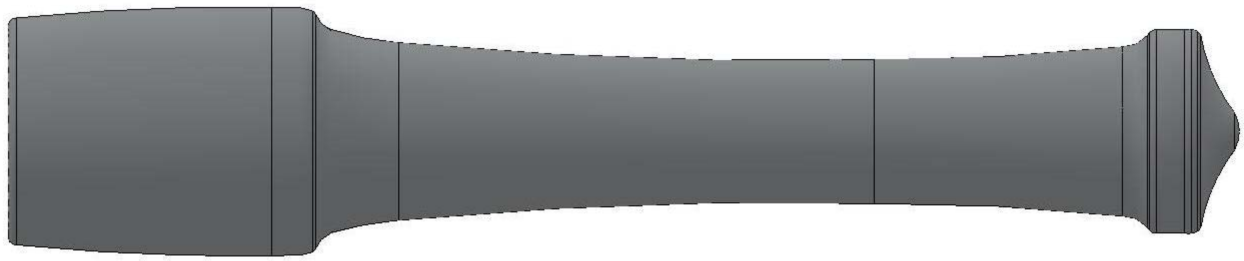


Figure 3: *Final Profile*

An exploded view of the profile is as follows:

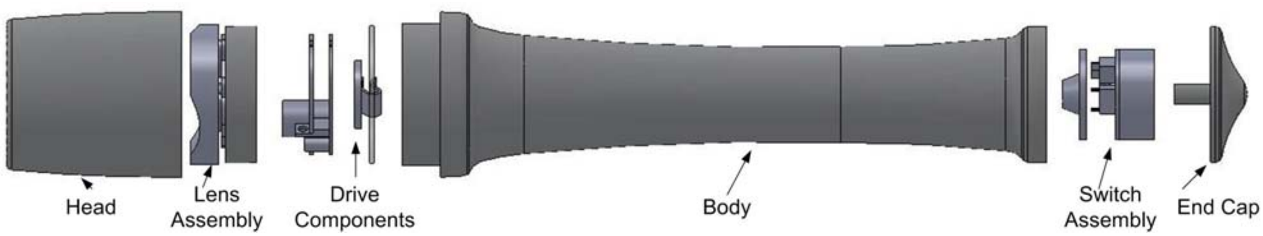


Figure 4: *Exploded View of Internals*

4. Part Summary

The project consisted of three sets component sets. The housing, internals and electronics as follows:

Housing:

- Body
- Cap
- End Plug
- End Cap
- Lens Cover
- *Lantern Body

Internals:

- Heat Sink
- Lens Restraint
- *Electrical Carriage
- *Cap Plate
- *Negative Terminal
- *Positive Terminal

Electronics:

- LEDS (3)
- Lenses (3)
- *Laser Diode, Housing
- *Lantern Lens
- *DC Step Up Circuit
- Low-Voltage/High-Temp Protection Circuit
- *Laser Regulator Circuit
- *End Plug Switching Circuit

*Not Yet Fabricated

5. Machine Summary

The following machinery was used in the fabrication of the flashlight.

5.1. CNC Lathe

The CNC lathe was used for the majority of the profiles, boring, thread cycles and separations.

Figure 5: *CNC Lathe*

5.2. CNC Mill

The two-axis CNC mill was used for fabrication

Figure 6: *2-Axis CNC Mill*

5.3. Rotary Table

The rotary table was used in combination with the mill to create the end plug slots necessary for restraining the end piece. It utilized a three-jaw chuck, and a simple locking mechanism

The table did not have a rotational handle however; which made the radial slots exceptionally difficult. This required inserting the chuck tool into its slot and slowly turning the table.

The design called for ±2° tolerance on the slots. It was found after fabrication that this table provided the necessary resolution.

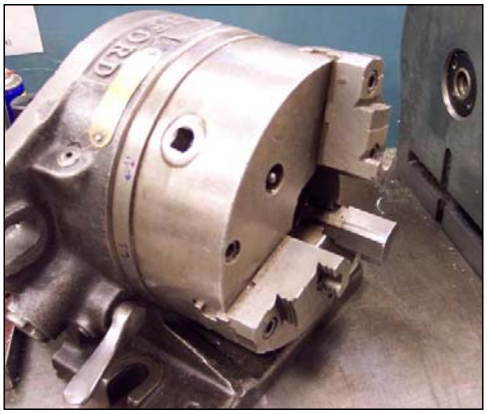


Figure 7: *Rotary Table*

5.4. Waterjet

The Waterjet was used for fabrication of the lens restraints.

5.5. Industrial Lathe

The industrial lathe was used for the initial boring of the stock. It is a remnant from WWII, but is still in exceptional working condition.

6. Tooling Summary

The following tools were used:

6.1. Right Hand Tool (RH)

A steel-carbide cutter was used with a .010” TNR. Cuts for this tool were restricted to .020”.

The RH Tool was used in turning operations. It was also used for the inside lip profile on the head.

6.2. Left Hand Tool (LH)

A steel-carbide cutter was used with a .010” TNR. Cuts for this tool were restricted to .020”.

The LH Tool was used for facing.

6.3. Large Boring Bar

The large boring bore was a solid-piece bar. The tool radius was unknown, but approximately .040”. Cuts were restricted to .100”.

The large boring bar was used for boring the head cavity.

6.4. Small Boring Bar

The small boring bar utilized a steel-carbide cutter with a TNR of .020”. Cuts for this tool were restricted to .015”.

The small boring bar was utilized for any boring operations utilizing the expanding mandrel. Its sharp cutter resulted in less chatter during these operations.

6.5. Internal Thread

A steel-carbide internal thread cutter was used for the head’s threading.

6.6. External Thread

A steel-carbide external thread cutter was used for the bodies threading.

6.7. Slot Cutter

A .046” slot cutter was used for separation of miscellaneous features, for the external thread relief, and for retaining clip slots.

7. Component Processes

There were several components of significant complexity in this project. This report shall cover in detail then only the two primary components in detail, the body and the head.

7.1. Body

a. Cut To Length
    i. Large Bandsaw – 19”
    ii. Length Included Head, Body, stock grip, spacing, body grip
    iii. Time <5min
b. Bored Through (7/32”, 1.5”)
    i. Big Blue - Used Tripod
    ii. Center Tap
    iii. Drilled 7/32” full Length of Bit (~9”)
    iv. Drilled 1.5” full Length of Bit (9.875”)
    v. Time - ~1 Hr
c. Cut Outside Profile on CNC Lathe
    i. CNC Lathe
    ii. Supported using stock grip in 3-Jaw, body grip in Active Center
    iii. Ran 1st cycle to turn to 3.1” Diameter (Started at 3.5”) – Simple Turning Cycle
        1. .025R per pass, 8in/min, 600RPM
        2. RH Tool
        3. Time-~.75Hr
    iv. Ran CNC Profile
        1. Same Tool
        2. .20R per pass, .05 finish pass (600/800 RPM), (8/3 in/min)
        3. Time -~3Hr
    v. Hand Smoothed Imperfections in Arc Profile

d. Separated Head
    i. Large Bandsaw
    ii. Approximated
    iii. Time <5min
e. Faced Top End (Base)
    i. Reset the Body into the CNC Lathe
    ii. Body Grip in the Chuck, active center at top end
    iii. Enough Room to face the majority of the Top End
    iv. Faced to Length
f. Cut Thread (CNC Cycle)
    i. Turned Thread Section To Correct Diameter
    ii. Placed Relief Cut For External Threads
    iii. Used CNC Thread Cycle to Perform Threads
    iv. Chamfered Thread Ends
g. Bored Both Ends
    i. Standard Lathe
    ii. Using Expanding Mandrel, no end support
    iii. Bored with small passes (lots of spring)
    iv. Lots of chatter in final surfaces (acceptable)
h. Drilled End-Peg Holes
    i. CNC Mill
    ii. Secured body grip in vice
    iii. Tapped
    iv. Drilled small diameter through (.100)
    v. Drilled final diameter (.180) through
i. Turned Pegs
    i. Standard Lathe
    ii. Took Many Attempts (~8)
    iii. Aluminum tolerances very narrow at this diameter (too big would deform)
        1. final tolerance was exact dimension with heating the base for press
j. Pressed Pegs
    i. Pressed with Large Press
    ii. Heated base for ease of fit
    iii. Pressed until .18” depth in chamber
k. Turned Pegs Smooth
    i. Standard Lathe
    ii. Expanding Mandrel
    iii. 320 grit sandpaper
l. Faced End
    i. Standard Lathe
    ii. Removed Body Grip
    iii. Faced End to the correct final length
m. *Cut Top O-Ring Slot
    i. Adequate Design has not yet been achieved
    ii. May omit if can’t establish a secure enough fixture.

7.2. Head

a. Removed Excess Material/Faced
    iii. CNC Lathe
    iv. Faced To Correct Length
b. Bored Through
    v. Bored Primary Hole (2.35")
    vi. Bored Secondary Hole (2.55")
    vii. Accidently Bored to Pitch Diameter (2.575")
c. Cut Thread (CNC Cycle)
    viii. Started with small pitch diameter
    ix. Worked Slowly larger (.005"+) and checked fit until snug
    x. Was surprised at significant amount of spring in thread cycle
d. Separated from Grip
    xi. Used separating Tool
e. Flipped, Cut Inside Profile (CNC)
    xii. CNC Turn Program
    xiii. Had to Align on Lathe manually
    xiv. Lot s of Chatter; Made excellent Surface Finish However
f. Chamfered Outer Edge
    xv. Sanded outer Edge to desired radius

7.3. Lens Cover

a. Cut Round Stock To Size
b. Separated
c. Milled To Thickness
d. Drilled Bolt Holes, Lens Holes
e. Flipped
f. Chamfered Lens Holes

7.4. Heatsink

a. Turned To Size
b. Bored Center Hole
c. Pocketed
d. Separated
e. Faced
f. Pocketed
g. Holes (CNC Cycle)

7.5. Base Plug

a. Turned to Size
b. Drilled Through
c. Separated
d. Notched Slots(0,20,10)

7.6 End Cap

a. Turned To Size (Both Sections)

b. Cut Retaining Clip Slot
c. Cut O-Ring Groove
d. Turned End Profile

7.7. Lens Restraint

a. Cut On Waterjet
b. Tapped Holes
c. Chamfered Lens Edges

7.8. Lens

a. Cut Rough Outline
b. Press Hold – Pieces
c. Turn To Circle
d. Chamfer Edge

*7.9. *Coolant Heat Sink*

7.10. Electronics Carriage

The current design uses Waterjet fabrication. It will be finalized upon final circuit design.

7.11. Plug Assembly

The plug assembly will be finalized after final electronics review.

8. Results

The following is the final flashlight assembly:

Figure 8: *Final Assembly*

The final result closely matched the initial model. Comparisons are as follows:

Figure 9: ***Longwise Comparison***

Figure 10: *Oblique Comparison*

It was found that overall the final result appeared significantly more slender than the model. Also, it was observed that increasing the reflection of the surface of the model would have increased its similarity. Overall, the design matched the model.

The following is a comparison of the lens.

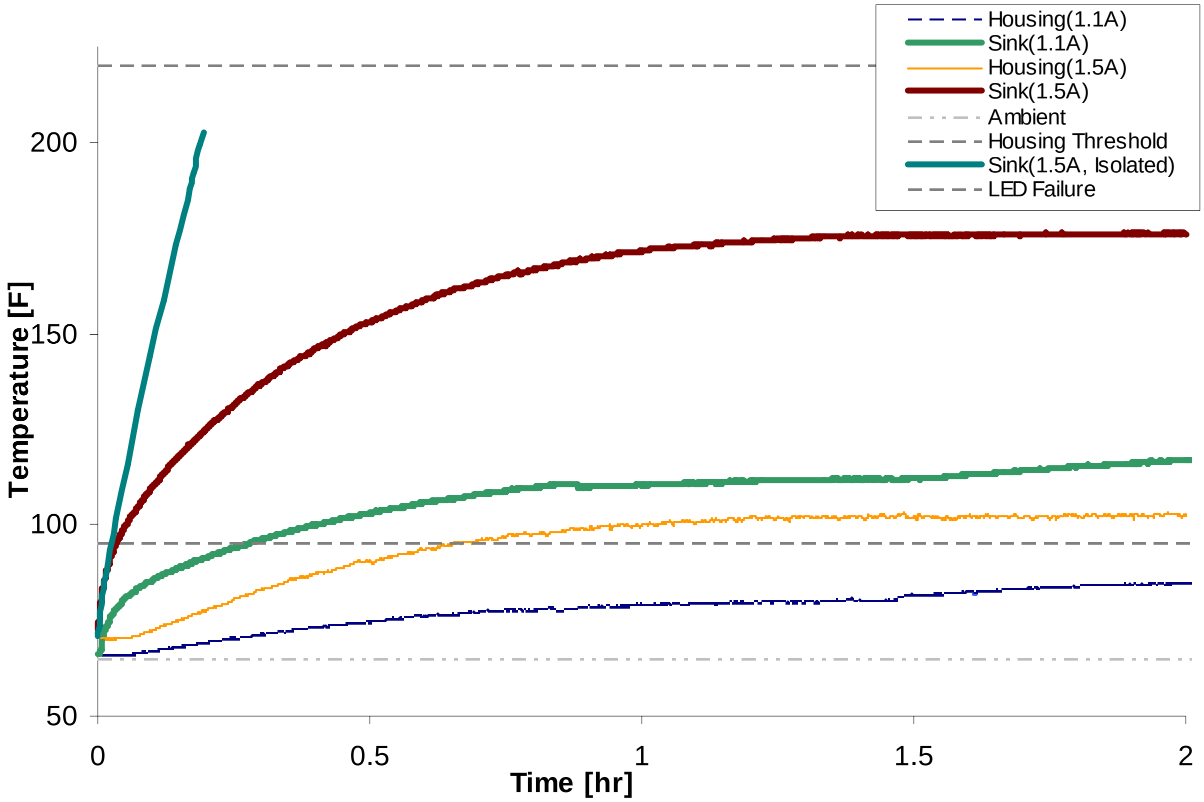
Figure 11: *Lens Comparison*

9. Conclusion

Overall the project was a success. Through this project, CNC operations and principles were not only learned, but also extensively employed. The ability to think of these considerations at all points of the design phase has also been identified as a valuable result of this project and course.

At this point in the design, the electronics are slowly developing. Currently, the heat dissipation is still a limiting factor. Initial tests show that the handle exceeds 95°F in less than 30 minutes, significantly less than the design target of one hour. The results are as follows, at medium current (1.1 A) and full current (1.5A):

Figure 12: *Temperature Results*



As seen in Figure 12, the current design does not keep the handle cool enough for the one hour test cycle. It is close however and the proposed liquid cooling system should extend the temperature threshold to approximately one hour. It currently is at 20 minutes.

The data in Figure 12 is analyzed in combination with the following steady-state temperature results, for the LEDS and heatsink:

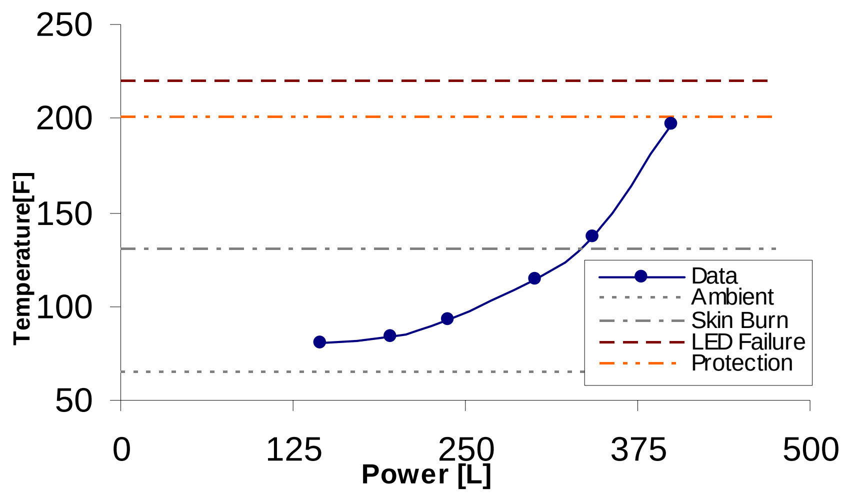
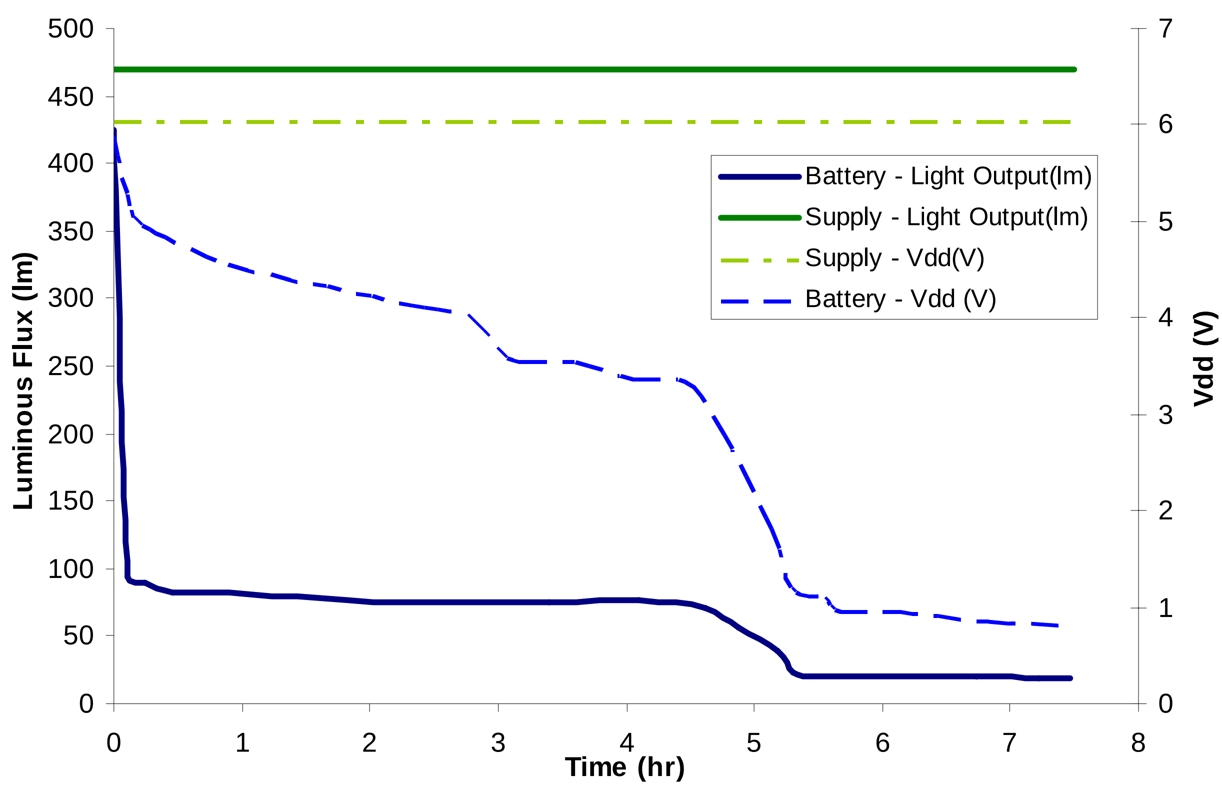


Figure 13: *Steady-State Temperature Results*

Also, at this point the electronics are not optimized for the high-drain, highly non-linear LED load. The circuit implemented for first trial estimation, while working correctly using a regulated power supply, did not perform the same using the battery supply. The first-attempt results are as follows, using standard Duracell D-Cell batteries:



Further high-drain testing will be conducted for both standard and Ultra Duracell batteries. Several different currents will be explored, with both DC and Saw-Tooth loads applied. The results from these tests are necessary before proceeding further with the electronics.

On a final note, it was observed that the LED restraints bear a striking resemblance to a monkey. It is left to the reader to pursue this observation:

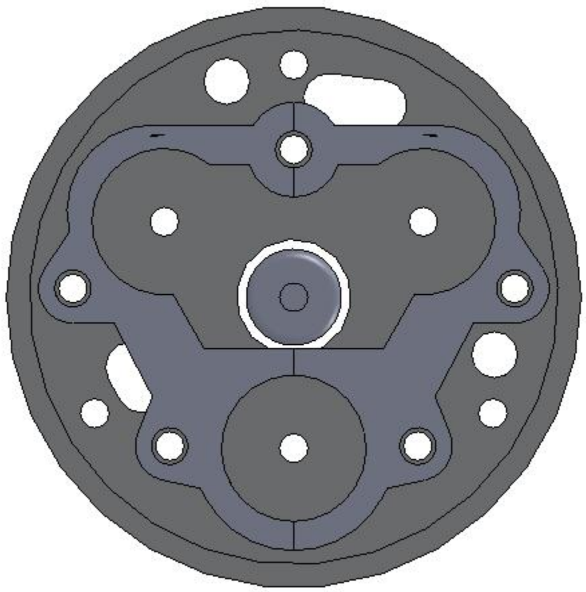


Figure 14: *LED Restraint*

Appendix A: NC File for Main Profile

The following is the nc code used to generate the main body profile. It was used in the Virtua CNC Preadtor Environment to confirm toolpaths before proceeding.

```
(BEGIN PREDATOR NC HEADER)
(MCH_FILE=LATHE.MCH)
(LTOOL T0101 M0100 S1 O30 I0.375 C0.031 A55 N1)
(END PREDATOR NC HEADER)
%
O0000
(IMTSL1)
G90 G20
T0101
M42
G96 S200 M03
G0 X5      Z16.080
G1 X2.272  F4
G1         Z15.831
G1 X2.472  Z15.731
G3         Z15.387 R1.29
G3 X2.392  Z15.301 R.115
G2 X2.322  Z15.277 R.106
G2 X2.066  Z14.975 R.4
G2 X1.750  Z11.965 R25.091
G2 X2.170  Z06.205 R50.346
G2 X2.480  Z05.384 R3.077
G2 X2.856  Z05.199 R.29
G3 X2.928  Z05.161 R.073
G3 X3.000  Z05.010 R.375
G3 X3.014  Z04.675 R27.792
G1 X2.814  Z04.575
G1         Z03.200
G1 X3.014  Z03.100
G3 X2.750  Z00.000 R27.792
G1         Z-.5
M30
%
```

Appendix B: Data Points and Features for the Main Profile

Table 3: *Main Profile Psuedo Code*

Type	Xend(Dia)	Zend	R	Dir	Start	Finish	Descrip
Rapid	5	0	X	X	X	X	To Home
Line	2.272	0	X	X	H	19	H-19
Line	2.272	-0.669	X	X	19	18	19-18
Line	2.472	-0.769	X	X	18	19	18-17
Arc	2.472	-1.113	1.29	**CCW**	17	16	17-16
Arc	2.392	-1.199	0.115	**CCW**	16	15	16-15
Arc	2.322	-1.223	0.106	CW	15	14	15-14
Arc	2.066	-1.525	0.4	CW	14	13	14-13
Arc	1.75	-4.535	25.091	CW	13	12	13-12
Arc	2.17	-10.295	50.346	CW	12	11	12-11
Arc	2.48	-11.116	3.077	CW	11	10	11-10
Arc	2.856	-11.301	0.29	CW	10	9	10-9
Arc	2.928	-11.339	0.073	CCW	9	8	9-8
Arc	3	-11.49	0.375	CCW	8	7	8-7
Arc	3.014	-11.825	27.792	CCW	7	6	7-6
Line	2.814	-11.925	X	X	6	5	6-5
Line	2.814	-13.3	X	X	5	4	5-4
Line	3.014	-13.4	X	X	4	3	4-3
Arc	2.75	-16.5	27.792	CCW	3	2	3-2
Line	2.75	-16.75	X	X	2	1	2-1
Retract	2.5	-16.75	X	X	1	Out	1-Out
Retract	2.5	0	X	X	Out	H	Out-H

The following is a list of all data points on the main profile:

Table 4: *Data Points*

Points	X	Z	X_Dia
1	2.750	**-16.750**	**5.500**
2	2.750	**-16.500**	**5.500**
3	3.014	**-13.400**	**6.028**
4	2.814	**-13.300**	**5.628**
5	2.814	**-11.925**	**5.628**
6	3.014	**-11.825**	**6.028**
7	3.000	**-11.490**	**6.000**
8	2.928	**-11.339**	**5.856**
9	2.856	**-11.301**	**5.712**
10	2.480	**-11.116**	**4.960**
11	2.170	**-10.295**	**4.340**
12	1.750	**-4.535**	**3.500**
13	2.066	**-1.525**	**4.132**
14	2.322	**-1.223**	**4.644**
15	2.392	**-1.199**	**4.784**
16	2.472	**-1.113**	**4.944**
17	2.472	**-0.769**	**4.944**
18	2.272	**-0.669**	**4.544**
19	2.272	**0.000**	**4.544**
H	5.000	**0.000**	**10.000**

Visual Confirmation of the data points before proceeding:

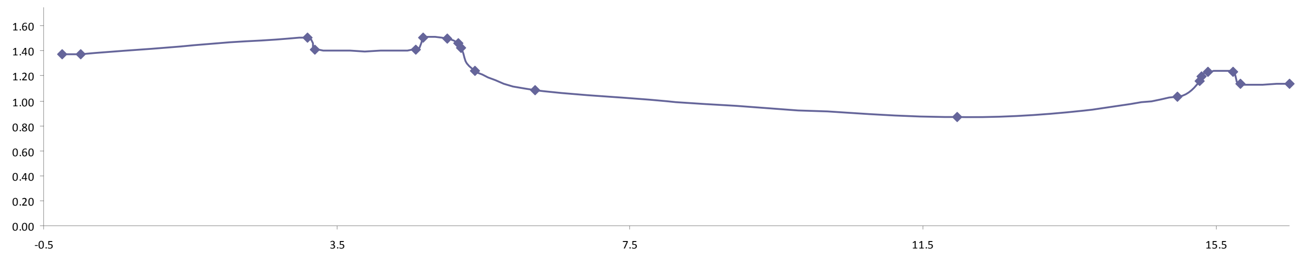


Figure 15: *Verification Graph*

The following is a sequential presentation of turning the main profile. To note, 62 19" passes at 6 in/min takes an exceptional amount of time.

Figure 16: *Initial Stock*

Figure 17: *15 Passes into Cycle*

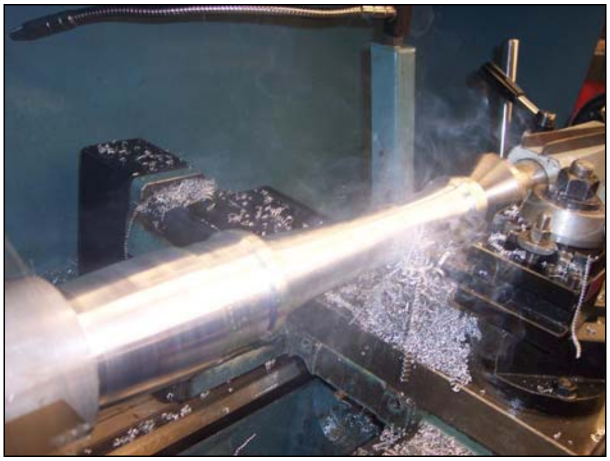


Figure 18: *Approximately 55 Passes into Cycle*

Figure 19: *Final result*