The Demonstration of Concaves

For:

ENGR 3030

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Western Michigan University

By:

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Introduction

At the beginning of the semester we were presented a challenge of designing a demonstration kit for Mr. Kevin Koch of Milwood middle school to use in his classroom to show how concave mirrors work. Mr. Koch teaches physical science to grades 6^{th} through 8^{th}. Mr. Koch currently was using an old satellite dish to show what a concave object looked like and how the concave surface helped collect and concentrate the television signal waves. The problem was that Mr. Koch had no means to visibly show how this process works. He wanted a new and creative way to teach his lesson on concave mirrors and how they work, so our task was to design and manufacture a demonstration kit that he can use as and interactive teaching aide. We choose to use lasers to represent the signal waves that the satellite dish collects. We wanted the laser beams path to be visible so the students could see how the concave mirror collects the beams and then reflects them to a point of intersection, called the focal point.

Proof of Concept

We began to collect the necessary background information on the principles of concave mirrors. Concave mirrors have an inner reflective surface of a mirror and a sphere-like inner radius giving it the shape of a shallow bowl. The way concave mirrors work is that the light rays enter towards the mirror which then reflects all the different light rays to a central point of intersection which is called the focal point. The focal point is determined by the size of the inner radius, with larger radiuses producing focal points further away for the mirror and smaller radiuses producing focal point closer to the mirror. This distance from surface of the mirror to the point of intersection is called the effective focal length, or EFL. Our task was to visibly show the light rays being shot towards the concave mirror and then see them being reflected to a central focal point.

Please view appendix A (view of concave mirror)

Constraints & Criteria

Once we had our background information we then had to brainstorm a list of constraints and criteria from which our designs would be evaluated against. We started by meeting with our client, Mr. Koch, to see what types of ideas he was looking for in this demonstration kit. At the meeting we showed him a prototype we had been using for earlier testing and he gave us his thoughts and ideas that he would like incorporated into our design. Some of those ideas included, the use of three laser beams to show the intersection at the focal point better and giving the laser beams path a conical shape. He also requested that we incorporate the use of two concave mirrors side-by-side with different effective focal lengths to demonstrate how the greater the inner radius depth the further away the focal point is. Mr. Koch stressed the need for a push button switch, to insure the apparatus doesn't get carelessly left on and drain the batteries. The fact that Mr. Koch wanted the apparatus to be a demonstration tool, as well as, be used by the students to collect experimental data as part of an in class lab experiment, required an overall solid design with sturdy construction, to protect against the wear and tare of classroom use. With these recommendations we proceeded to establish a list of constraints and criteria. *Please view appendix B* (*constraints and criteria)*

Design Process

Throughout the length of this project we incorporated the steps of the engineering design process. As stated earlier we were first presented our initial problem by Mr. Koch, we then proceeded to collect our background information on the concept of concave mirrors and how they work. Our next step was to meet with Mr. Koch and establish a set of constraints and criteria that our final design needed to meet. With our design specifications established we then moved on to brainstorming ideas to meet these constraints and criteria. We then moved on to using a decision making matrix to calculate which design best met our requirements. Once the design is finalized a budget is established and materials ordered. Fabrication is the next step in the design process with testing and refinement to follow after the initial prototype is built.
Please view appendix C (Gantt chart)

Design Specifications

Mr. Koch gave us some ideas about what he wanted this demonstration kit to contain during our meeting October 6, 2006. From his ideas, we created a list of design constraints and criteria that we referenced during the design phase of our project.

- **Constraints:**
  1. The design should require the use of three laser modules per concave mirror to better visualize the point of intersection.
  2. The design needs fit within a 1 cubic foot space for ease of storage.
  3. The design should incorporate sturdy construction methods and materials to withstand any abuse it may encounter while being used in a classroom setting.
  4. The design needs to be operated by a momentary switch to prevent the apparatus from being accidentally left on.
  5. The laser beams path of travel must be made visible by projecting the laser beam through a median.
  6. The total development budget must not exceed $500 dollars.
  7. The design needs to include the use of two concave mirrors with different effective focal lengths.

- **Criteria:**
  1. The design should be enclosed in a type of shadow box to prevent outside light from limiting the visibility of the laser beams.

2. The design should be of minimal weight to make it portable enough to move for classroom to classroom with little effort.
3. The design should be relatively easy to manufacture.
4. The design should be easy to set up and maintain so the use doesn't have to spend large amounts of time setting up and maintaining the apparatus
5. The design should be aesthetically appealing to interest the students and make them interested in the experiment.

Decision Matrix

The established constraints and criteria were also used to rank our design sketches using a decision making matrix. In the matrix the constraints are judged on a "YES" or "NO" bases that either the design meets the requirement or it does not meet the requirement. The criteria however was different in the fact the each criteria was given a certain weight or importance. This number was then multiplied by the ranking of how well the design fit the criteria. By adding up all the scores you had a mathematical answer to which design best fit the constraints and criteria.
Please view appendix D (decision making matrix)

Initial Designs

The first design we sketched was a free standing dual tube design. This design incorporate two clear acrylic hollow tubes filled with the median anchored to a solid base. The two concave mirrors would be place at the bottom of each hollow tube On top of the tubes a laser holder would be place containing the three laser modules. A momentary switch would be placed off to the side of the base connected to the two laser holders. The problem with this design is that excess light could compromise the visibility of the laser beams. Also the wiring from the switch to the laser holders would be exposed risking the integrity of the wiring.
The second design was the enclosed tank design. This design was similar to a fish tank with three of the four sides blacked out to prevent outside light from entering. Two concave mirrors would be secured to the bottom of the tank and the entire tank would be filled with the median. The laser modules, batteries, and wiring would all be contained within a housing that fit onto the top of the tank. The momentary switch would be located on top of the housing. The problem with this design was that the amount of median contained within the tank would cause the apparatus to be extremely heavy.
With neither of the first two designs best fitting the constraints and criteria we took the good things from the first two designs to create a type of hybrid version for our final design.

Final Design

The final design took the hollow clear acrylic tubes from the first design and placed them in the shadow box structure of the second design. The hollow clear acrylic tubes held less median then the tank design cutting down the overall weight of the apparatus. The concave mirrors were placed at the bottom of the tubes held within an end cap for the

tube. The top laser module holders were placed within the housing structure on top of the enclosed shadow box. This housing securely held all the laser modules, batteries, and wiring components, with the momentary switch place on top of the housing. This design met all of our constraints and criteria and was clearly best design.
Please view appendix E (Design sketches)

Materials

As we drew closer to starting construction of the kit we had to first do vendor research and establish a list of material that would be needed. The main problem we faced was the fact that we had to use salt water as a median for our laser beams to travel through because the salt water helped make the laser beam visible, but the salt water reacted with several of our test mirrors causing corrosion on the surface of the mirror. Through our research we found if we used gold plated, or dielectric coated mirrors they were less likely to react with the salt water. The dielectric mirrors were very expensive, so we choose to go with the gold plated mirrors because gold is inert and less likely to react with the salt. The gold mirrors were definitely not cheap because they are gold plated, but they were less than the dielectric coated mirror, which would have taken up our entire $500 budget with just two mirrors. With the mirror problem solved and most of the other parts ordered, we then moved into the manufacturing phase of our project.
Please view appendix F (Bill of materials)

Construction

The manufacturing stage is where we our currently with the fabrication being down in three steps. The first step is the construction of a shadow box to hold the clear acrylic cylinder. The second is to fabricate the two cylinders which have two end caps one that holds the concave mirror and the other that holds the three laser modules. The third step is to construct the top cover which holds the batteries, all the wiring components and the top end cap for the cylinders which house the laser modules.

Manufacturing process

After the final design was selected using the decision making matrix it was time to construct the apparatus. The best of the three designs turned out to be the hybrid design, even though it will prove to be one of the more difficult designs to manufacture.

The first step in constructing the apparatus is building the outer shell. The woodworking was all accomplished in Eddie Brabandt’s garage using a miter saw, table saw, pneumatic tools, and a drill. It consists of two 8ft x ¾ in., furniture grade, pine planks. They are mitered on all sides for visually aesthetic edges. The completed wooden shell measures 10” x 10” x 8”, well within our one cubic foot constraint. After filling all the nail holes, painting inner areas black, three coats of stain, and three coats of polyurethane the box was complete and we had an excellent start on the project.

The next stage in the manufacturing process was to machine all of the necessary parts. The laser holders are machined out of 3” delrin material (plastic). The three laser are place on a 1.75” bolt hole circle evenly spaces around a center ¾ in. hole. They are made to pass through the top portion and lower portion of the box and finally seal in each of the lower clear tubes. The lower clear tubes are made from acrylic and consist of a sealed black delrin cap on the bottom that also holds its respected mirror. The top of the tube is seal with an acrylic clear disc that also has a “median” (substance to visualize lasers) filling hole. The filling hole is plugged with a delrin plug constructed using a lathe and thread cutting tool. On the top of the box we desided to go with a ¼ in. delrin cover. This way we are able to construct a door that allows access to the two D cell batteries.

Once all of the machining was complete, we did our final wiring. Throughout the construction, we wired the circuit to test various aspects of the machined pieces. The final wiring required fixing the wires permanently to each other using solder. The wires are soldered to prevent lack of contact to any one laser resulting in a weaker beam. Also soldered wires will withstand a certain amount of misuse where as twisted together wires will not sustain as much abuse. Once we had our laser beams aligned properly the top was assembled and the lower two tubes were filled with water. The top and bottom sections are attached using four button head machine screws.

Manufacturing these on a production scale would be done more easily in a machine shop designed for production. In a proper machine shop numerous products could be manufactured in the time it took us to build just one. This is something that will be taken into consideration if we decide there is a market for the mass production of the apparatus.

Evaluation / Presentation

The last step in the engineering design process is to test and evaluate. Now that we have a working prototype we needed to go into the classroom and see how effective our design was at helping Mr. Koch teach his lesson on concave mirrors and light reflection. The problem we ran into is that Mr. Koch doesn’t teach his lesson on light till the spring semester so testing in the classroom will have to be postponed till this spring. We will proceeded to meet with Mr. Koch and have him personal evaluate our project and how well it meets his expectations. After reviewing his evaluation we will make the necessary changes and revisions to the apparatus and/or lesson plans. We hope to arrange an in class test this spring with his students and have the students evaluate the apparatus. After these tests we will make final revisions and then present our project to Mr. Koch for him to keep in his classroom and use in the future.

Please view appendix G (Evaluation sheet)

Recommendations

When we initially did our visibility testing we used laser pointers to see how visible the laser beam was through our various test medians. Towards the end of the manufacturing phase we did a mock up test and found that regular tap water worked just perfect as a median for our laser beams. In our final project we used laser modules which our more powerful than laser pointer. The more powerful laser module along with the minerals found in regular tap water proved to be very effective at visual representing the path that the laser beam followed. By using tap water instead of salt water this eliminated the need for gold plated mirror reducing the cost overall cost of the project. It also greatly reduced the set up time and maintenance requirements since the operate now didn't have to mix up the salt water solution prior to use and more importantly the tubes do not need to emptied and cleaned after each use.

Conclusion

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At the beginning of the fall 2006 semester we were presented the challenge of designing and manufacturing a device that visually demonstrated the concept of how concave mirrors focus light rays to a common point of intersection, or focal point. We meet with our client Mr. Koch and laid down the foundation of what the device needed to accomplish. From this information we used to engineering design process to take the project from concept to completion of a working prototype. Throughout the process we worked to follow the series of tasks that needed to be complete one after another to produce a successful design project. Through evaluations we concluded that the hybrid design of dual hollow acrylic tubes mounted in a shadow box would be the best design to fit our needs. We used laser modules to simulate the light rays collected by a concave mirror and passed the laser beams through a liquid median to make there path of travel visible. In the machine shop the project went for sketches on paper to an actually working prototype with which we hope to test soon. After testing we will present Mr. Koch with the device for him to use in his classroom as a tool to help enhance his lessons on light and mirror.

Acknowledgements

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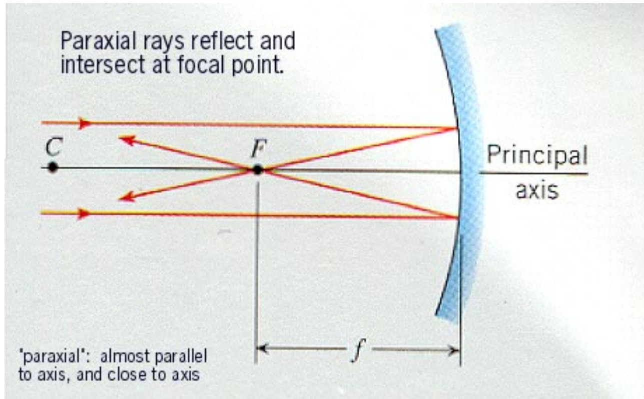
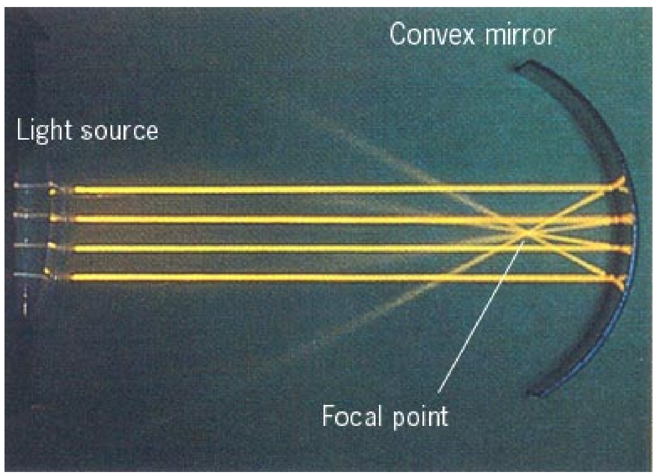
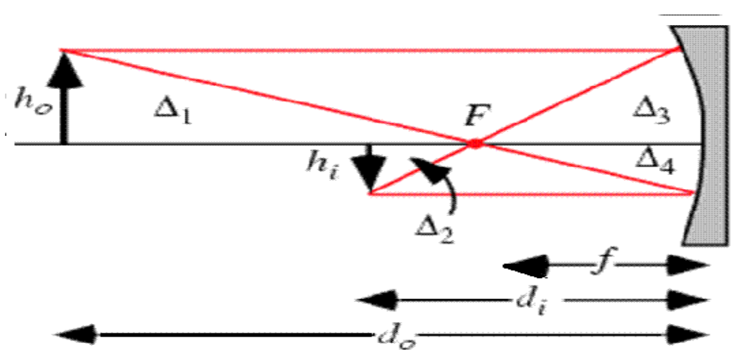
Appendix A:







$$f = \frac{d_i d_o}{d_i + d_o}$$

Appendix B:

Constraints:

- Three lasers per mirror
- Storage (size)
- Kid proof -- Push button switch (hold down)
- Visible laser beam
- Cost (under 500)
- Two different focal lengths

Criteria:

- Enclosed platform
- Scale for measuring focal length
- Weight
- Easy to manufacture
- Easy to maintain [drainage (if needed); replacing battery

	Design 1 (tubes)	Design 2 (tank)	Design 3 (hybrid)
Constraints:			
3 laser per mirror	YES	YES	YES
Storage	YES	YES	YES
Kid proof	YES	YES	YES
Visible laser beam	YES	YES	YES
Cost (under $500)	YES	YES	YES
Criteria:			
2 different focal lengths (5)	5	5	5
Enclosed platform (3)	3	3	3
Push button switch (4)	3	4	4
Scale for measuring (2)	2	2	2
Weight (3)	3	1	3
Easy to manufacture (3)	1	3	3
Easy to maintain (4)	3	4	3
Total:	**20**	**22**	**23**