Abstract

The camera system was developed to image samples inside the resistive split magnet. The main focus was to extend the image, created by looking at the object inside the magnet, several meters backwards to a camera with good magnification. The image on the sensor needed to be large enough to be able to see a 300-micron hole with relative ease. This was so that the sample in the magnet could be seen and the laser that would reflect off of it could be aimed accurately onto it. There were no lens systems on the market that were appropriate for the field of view and resolutions desired for the magnet (within a reasonable price range), so one had to be developed using a camera sensor and singlet lenses. After experimentation with the different properties of plano-convex lenses, we came across two viable options.

Background on Plano-Convex Lenses

The properties of lenses we were interested in for this project were the focal lengths, the distance of the object, the distance of the image, and the magnification of the image. What we refer to as the object in the apparatus will end up being the sample inside of the magnet, the image is where it ends up on the camera sensor. These two distances are a function of one another according to the equation below (Fig. 1), dependent on the focal length. In a one lens system (Fig. 4), the object creates an image onto the camera sensor, the distances must all follow the equation in order for the image to be in focus. When adding a second lens, we can recapture the image, not on the camera sensor, but instead with a second lens, further extending the distance between the camera and the object. This became our first option of implementing two lenses (Fig. 3). The problems with tuning the lenses in option one led us to keep experimenting. Rather than having two lenses which each focused the object into a converging point for the image, the first lens could focus the object into a set of parallel rays over any distance to the second lens which would collimate the parallel rays and converge it onto the image. This still had two focal lengths but was much closer to the simplicity of the single lens system because there was only one object and image, making it our second option (Fig. 4).

\[ \frac{1}{d_0} + \frac{1}{d_i} = \frac{1}{f} \]

Figure 1: Thin Lens Equation

Option One: “The Image Relay”

This is the lens system we ended up using because of the fewer possible points of error. Rather than having to refocus an image between the two lenses like we had to in option one, there was only two distances that had to be considered, the focal length of each lens. The collimating lens had to be its focal distance away from the camera sensor and the second lens had to be its focal length away from the object. Once the collimating lens was the appropriate distance away from the sensor, the only distance that ever needed to be adjusted was the second lens’ distance from the object. This meant there was only one point of error, much more reliable and efficient for the experiment.

Figure 2: Two Lens System with Two Objects and Images

In addition to the chance of error and ease of use, we also had to strongly consider the magnification of each system. While option one was significantly more difficult to implement, if it offered better magnification it would still be a contender. Each system had their own equation to calculate the magnification. For option one, the equation we were interested in was the distance of the image divided by the distance of the object. Therefore, in order to have high magnification, the object would have to be closer to the lens than the image. There was a limitation as the closest the second lens could get to the sample in the magnet was around 750 mm, which meant that the image would have to be at least 750 mm away, which would require a lens with a minimum focal length of 375 mm. This was easy to achieve and the second lens could further magnify the image by being very close to the “relay image”. Overall, option one had very good applications for magnification.

For option two, the magnification was equal to the focal length of the collimating lens divided by the focal length of the focusing lens. The same limitation of the object distance applied, the closest we could get the second lens was 750 mm away from the sample in the magnet. This meant that in order to get a magnification of just one, we would need a collimating lens with a focal length of at least 750 mm. This is the upper end of the available singlets so the magnification in option two was limited.

While option two had less ability for magnification, we could still achieve a one times magnification which was sufficient for imaging the 300-micron pin hole. This, in combination with its drastic improvement in usability, made it the best option for imaging the experiment.

Option Two: “Collimating Lens System”

Figure 3: Two Lens System with Collimating Lens

Figure 4: Example of a Single Lens System

Magnification