

Using double-exposure holographic techniques to evaluate the deformation of an aluminum can under stress

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Holographic methods have historically been used to record three dimensional images as well as to investigate the structure and the deformities in materials under stress. In this experiment, multiple holograms were developed of objects under stress, and thin film interference theory was used to determine the amount and patterns of deformation due to three different configurations of rubber bands around an aluminum can. In general, the deformation was along the length of the can, and ranged from (1896 ± 300) nm to (3164 ± 300) nm depending on the configuration and the type of rubber band.

I. INTRODUCTION

Holography is a method of recording the phase of light. This method, developed by Dennis Gabor, uses the difference in phase between two beams to record information about an object, much like a photograph records the color and intensity of light to give a picture. In this lab, multiple holograms were developed, including recording the image of a dolphin and using a double exposure technique to record the deformation of an aluminum can by a rubber band.

II. THEORY

Holograms record the phase of the light that has reflected off an object. Holograms recorded using lasers are exposed to a reference beam and an object beam split from the same source. The reference beam shines directly on the holographic plate, and the object beam is shone onto the object so that it bounces off the object and then onto the holographic plate, as shown in Fig. 1. Since the two beams were split from the same source using a beam splitter, the main difference in the light will be the distance that it has traveled, meaning that the interference that happens on the holographic plate will only be due to the difference in phase of the two beams.

The phase of light is something that can only be measured with respect to something else. This is very similar to the idea of electric potential which is the work done to move a charge from one position to another in an electric field. This value is then the difference between two quantities and is not something that has innate value by itself. Much like the concept of electric potential, the phase of light must be measured with respect to something else. It is the phase difference between the reference beam and the object beam that we record on the holographic plate.

The phase difference of the light that is recorded by the holographic plate to make the image is due to the concavity of the object, and the minute difference in optical path length, which results in the light hitting the plate with many different phases. The reference beam is then used analogously to “ground” when referencing electric

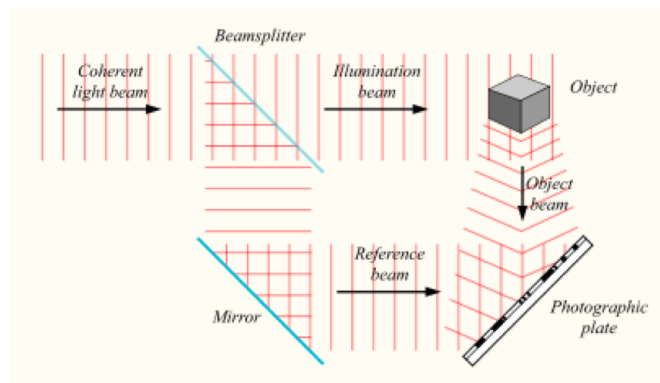


FIG. 1: A schematic of the path of the laser where the red lines are the wavefronts of the laser light. This figure is reproduced from [1].

potential. The reference beam is a reference so that we can talk about the phase between the reference beam and the object beam at any point on the holographic plate.

When the hologram is developed and the plate is exposed to light identical to the light that used to originally expose the plate, the interference patterns formed by the phase difference reconstruct a three-dimensional virtual image of the original object, as in Fig. 2.

In the double exposure holograms that were made, the interference fringes that appear can be analyzed using the theory of thin film interference. In this case the difference between the path length of the light in the first and second exposure creates an interference pattern based on the deformation of the aluminum can.

A diagram in Fig. 3 details the path of the light for the first exposure with the rubber band and the second exposure without the rubber band. This gives the relationship between d , the deformation distance, and ℓ , half the total optical path length difference to be

$$\cos \theta = \frac{d}{\ell}. \quad (1)$$

For simplification purposes, we will assume normal incidence. This then means that $d = \ell$ and consequently, the total path length difference of the light is $2d$.

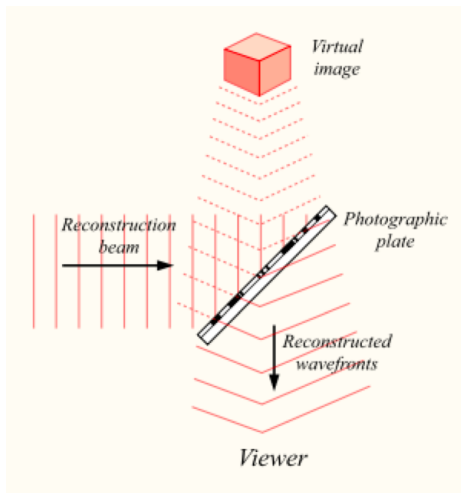


FIG. 2: A schematic of the set-up needed to view the hologram. The reconstruction beam must be identical to the beam used to make the hologram. This figure is reproduced from [2].

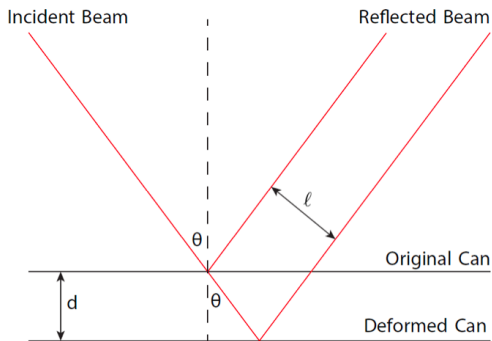


FIG. 3: A diagram of the path lengths of the light from the first and second exposures.

For constructive interference to occur, the total path length difference would need to be some integer multiple of the wavelength of the light which means that

$$2d = m\lambda, \quad (2)$$

where m is some integer and λ is the wavelength of the laser, which in this experiment is 632.8 nm. This means that by counting the number of bright fringes from the edge of the can to the position of the rubber band and using Eqn. 2, we can solve for the distance the can has been deformed by the rubber band.

III. PROCEDURE

To produce a reference and object beam from the same source beam, a beam-splitter was used to split the intensity of the single coherent beam into two equal parts, as in Fig. 4. It was important to use a beam splitter instead

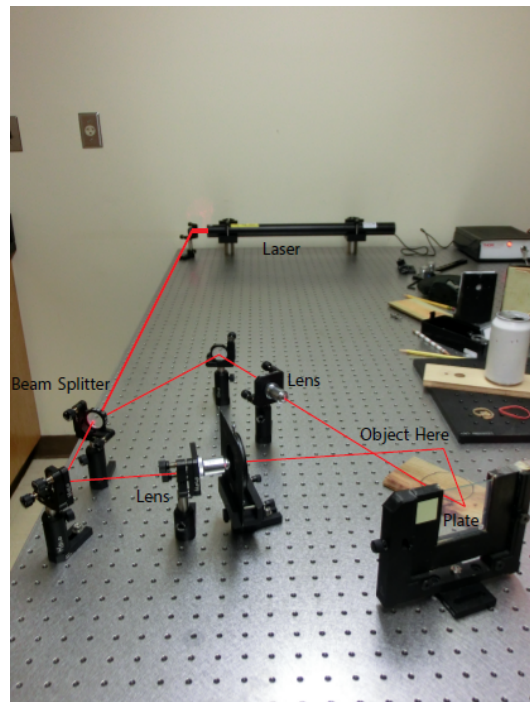


FIG. 4: An image of the set-up taken directly from the lab. There is no object set in the beam path, however the piece of wood with the circle indicates the place that the object would sit.

of using two lasers because each laser has its own phase, coherence and polarization, so these three attributes of the two different lasers would not be identical. To get the best interference, the laser beam must be split so that the light interferes with itself. The split beams will have the same polarization instead of the two lasers interfering with each other because of the differences in phase and polarization.

Two mirrors and two lenses were then used in order to have the reference and object beam oriented in the same direction with a similar intensity. The recording of the holograms is most effective when the intensity of the reference and object beams are similar. This then gives the best interference between the two beams.

After the optical elements were put in such a place that both the reference and object beams hit the holographic plate with similar intensity, as in Fig. 4, the plates were exposed in the dark room for about 20 seconds.

The holographic plates were then developed in the dark room before being exposed to white light. After the development process, the virtual image recorded by the holographic plate could only be viewed using a laser. The image can be viewed using multiple wavelengths of laser, however the image cannot be viewed in white light.

To practice the process and to develop an initial hologram, a single-exposure hologram was developed. Another interesting process was taking a double exposure shot of an aluminum can. The idea of the double exposure is that the first time the holographic plate is ex-

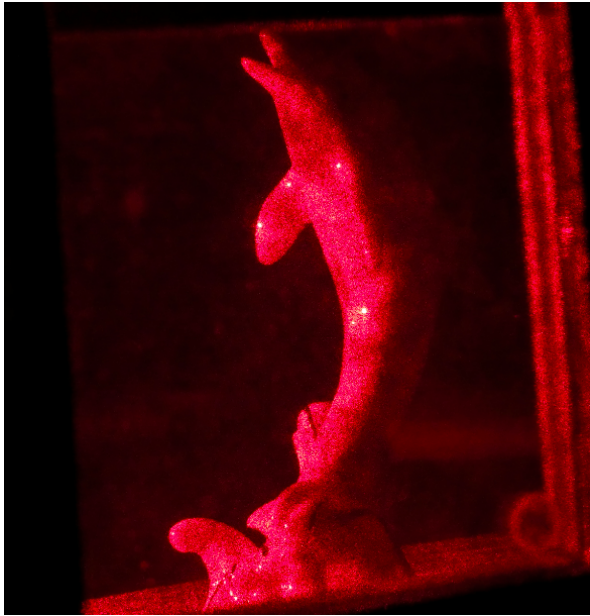


FIG. 5: A photograph of a hologram of a dolphin taken using the single exposure method.

posed, there is a rubber band slightly deforming the can. For the second exposure before development, the rubber band was removed so that the light from the first and second exposure would interfere with each other on the holographic plate. The interference fringes could then be analyzed using thin film interference theory to determine the amount the can was deformed by the rubber band.

Another type of double-exposure experiment was to have one rubber band around the can for the first exposure, and for the second exposure simply move the rubber band to a new location instead of removing it fully.

A third type of double-exposure hologram that was made was to have the aluminum can deformed originally by two rubber bands at difference places and for the second exposure, remove both rubber bands. This forms another type of interference pattern in between the two rubber bands due to the way which the double rubber band deforms the can.

IV. DATA AND ANALYSIS

A photograph taken through the holographic plate with the single exposure method is shown in Fig. 5. The figurine of which the hologram was taken was a dolphin. When I was exploring what would happen as I turned and flipped the holographic plate while trying to view the image, I found that the image is flipped upside-down with a 180° rotation in conjunction with a forward to backward flip of the plate. I also found that solely rotating the plate 180° or flipping the plate will give an enlarged, somewhat distorted version of the image.

The first type of double-exposure hologram that I tried

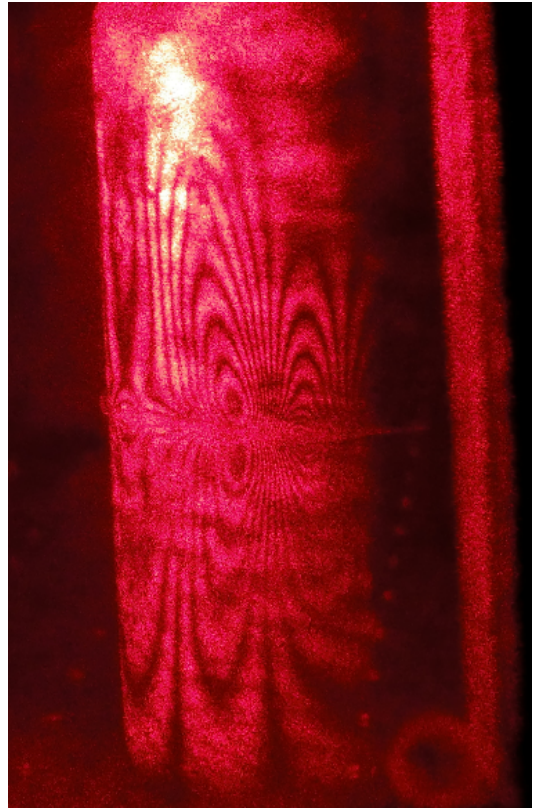


FIG. 6: A photograph of a double-exposure hologram taken of an aluminum can deformed by a rubber band.

was meant to investigate the interference patterns due to one rubber band around an aluminum can. A photograph taken of this hologram is shown in Fig. 6. Focusing on the centermost interference fringe pattern, I counted seven bright fringes between the top of the can and the placement of the rubber band. Using Eqn. 2, seven fringes indicates that the deformation of the can at that point was (2215 ± 300) nm. The relatively large uncertainty comes from the resolution of the hologram and the ability to correctly see the number of fringes.

It is interesting to notice that the number of fringes decreases as you look toward the left side of the can. While the deformation of the can due to the rubber band was mostly likely relatively constant around the circumference of the can, the deformation was in the radial direction. This means that the change in the distance that the light travels from the edges of the can could be slightly different than the change in the distance that the light travels toward the center of the can. This means that even if the rubber band creates a uniform deformation around the circumference of the can, the fringe pattern may not be uniform around the surface.

Another reason why the interference pattern may not be uniform around the surface of the can is that the can most likely has deformities such as small dents or puckers that would effect the way that the can moves under stress.

Another thing to note about the interference fringes

is that they are spaced differently throughout the can. The fringes are more finely spaced close to the region where the rubber band was placed. The fine spacing of the fringes indicates that the deformation is more drastic in the area of the rubber band than at the edges of the can. The fringe density can be thought of as a measure of how deformed the can was in a specified region. This is consistent with intuition that the can would be the most deformed in the place where the stress was being applied.

Another attribute of the fringes that is important to pay attention to is the direction of which they are oriented. These fringes mostly appear to be in the horizontal direction. This indicates that the deformation is in the vertical direction.

The second type of double-exposure hologram where a single rubber band was moved along the position of the aluminum can is shown in Fig. 7. The same rubber band was used in this case as in Fig. 6. Again, looking at the center bottom fringe pattern, there are again seven fringes from the bottom to where the rubber band was placed. This gives identical can deformation as in Fig. 6, which would be expected due to the use of the same rubber band and can.

Though the bottom deformation due to the rubber band is very similar to the deformation in Fig. 6, the top interference pattern is very different. I counted three bright fringes from the top of the can to the placement of the top rubber band, which would give a deformation of (1896 ± 300) nm. I suspect that the significant difference in the fringe pattern between the top and the bottom rubber band spots is due to the fact that the bottom and top parts of the can are not identical. The way that the can is made results in a different contour at the top than at the bottom. This could drastically change the amount of deformation that would occur in a given area due to the same stressors.

The last double-exposure hologram that I investigated was a double exposure where there was initially two rubber bands around the can. The two rubber bands created a unique fringe pattern as shown in Fig. 8. The bottom rubber band was the rubber band that was used in the past two double exposure holograms, and consequently, it gave the same fringe pattern with the same number of fringes. This means that the deformation in the can due to this rubber band was again (2215 ± 300) nm. The top rubber band, however, was slightly tighter. I counted 10 bright fringes from the top to the top rubber band position, which using Eqn. 2 give the deformation distance to be (3164 ± 300) nm.

The space above and below the rubber bands exhibit the horizontal fringe patterns that were seen in the other cans and indicate can deformation in the vertical direction. However, the space in between the two rubber bands has many vertical fringe patterns, with vertical fringes running completely from the bottom to the top rubber bands. The vertical fringes indicate that the deformation of the can in this region was actually in the horizontal direction. This may in part be due to the dif-

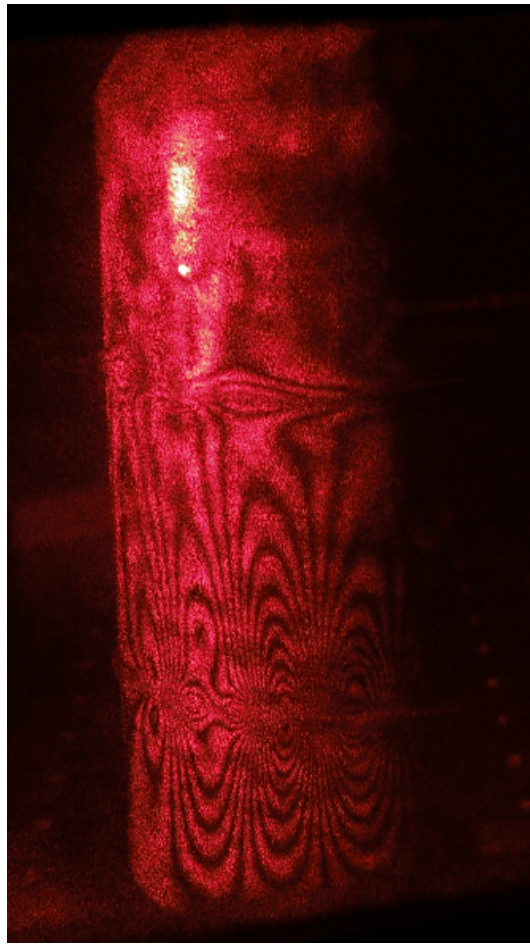


FIG. 7: A photograph of a double-exposure hologram taken of an aluminum can deformed by a rubber band that was moved from one place to another.

ference in the amount of stress on the can due to the upper and lower rubber bands. Since the upper rubber band was exerting more force on the can than the lower, there will be a slight deformation in the horizontal direction.

Investigating the extreme right portion of the can in Fig. 8, there are three distinct vertical fringes, indicating that the horizontal deformation in across that area is (1896 ± 300) nm.

V. CONCLUSION

In conclusion, I used the phase difference of the reference beam and the object beam to record information about the object onto a holographic plate. I then shone the identical laser light onto the developed plate to see the virtual three dimensional image of the object, and I found that a 180° rotation in conjunction with a flip of the plate will result in viewing the hologram upside down. I used a double exposure technique to investigate the deformation of an aluminum can due to the stress

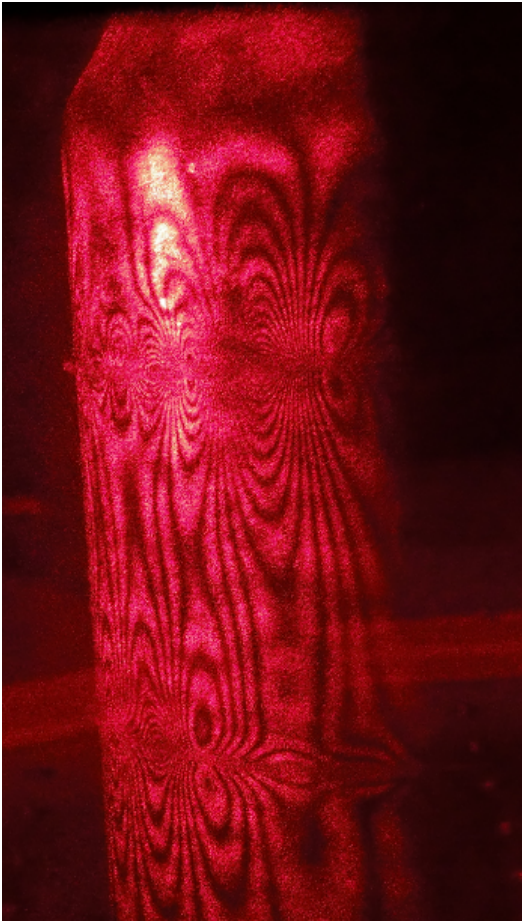


FIG. 8: A photograph of a double-exposure hologram taken with two rubber bands around an aluminum can.

applied by a rubber band in different positions and configurations. Using thin film interference theory the deformation of the can ranged from (1896 ± 300) nm to (3164 ± 300) nm depending on the configuration and the type of rubber band, and finally, based on the orientation of the interference fringes, I could see that the direction of the deformation due to two rubber bands changed from vertical to horizontal in between the two rubber bands.

[1] Mellish, Bob. Holography-record. 2007. Holography, Wikipedia. Web. 03 Oct. 2014.
[2] Mellish, Bob. Holography-reconstruct. 2007. Holography,

Wikipedia. Web. 03 Oct. 2014.