

Double Exposure Holography

Sarah Suddendorf

Physics Department, The College of Wooster, Wooster, Ohio 44691

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This experiment uses holography to look at the physical effects a rubber band can have on an empty aluminum pop-top can. A double exposed hologram was made of a soda can. Throughout the first exposure, a rubber band was stretched around the center of the can, compressing the can, so the laser beam reflecting off the can towards the hologram plate had to travel a longer distance than it would for a non compressed can. The distance depends on how much the can was compressed. Before the second exposure, the rubber band was cut, so the aluminum can was exposed without anything compressing it. For each full wavelength further the beam had to travel, the hologram reveals a dark interference fringe. By counting these fringes for each compression on the can the depth of each compression can be found. From the hologram, four compressions were able to be analyzed, giving four depths of 950 ± 320 nm, 2210 ± 160 nm, 1270 ± 160 nm, and another 1270 ± 160 nm, as a result of a tension in the rubber band of 3.07 ± 0.39 N.

INTRODUCTION

A hologram is a three dimensional image created by capturing the interference patterns, found by light reflecting off the object, on an emulsion plate. When looking at a three dimensional object, what is seen is the light waves reflecting off the object and hitting your two eyes. Without two eyes, there would be no depth to the object, and without light, no object would be seen at all.¹ A hologram simply replicates these two ideas, by using two beams of light, and catching the light waves reflected off an object. The first beam, called the reference beam, puts a wash of light over the plate. The second beam, the object beam, illuminates the object, allowing the light to reflect off the object and onto the plate, interfering with the light from the reference beam. This interference creates the hologram, replicating the idea that objects are viewed with two eyes. By capturing the exact interference pattern of the two beams, the hologram image produced is a three

dimensional image that can even be maneuvered so the hologram allows the object appear to rotate.

The distance this beam travels depends on the placement of the object. Compressing the soda can with a rubber band, it causes the object beam to travel further to reach the object, and the reflected light has to travel further to reach the hologram plate for one exposure than another. Now the interference between the two exposures is important. For each wavelength extra the light has to travel in reaching the object, a dark interference fringe is seen on the hologram, when double exposed with and without the rubber band on the soda can. Although each dark fringe represents a full wavelength increase in distance, half of that distance is the beam approaching the object, and the other half of the distance increase is the reflected light traveling further to the hologram plate, and therefore each dark fringe represents a compression depth of half a wavelength. By counting how many dark fringes are seen at each depression, the the depth of each

depression on the soda can caused by the rubber band can be measured.

EXPERIMENT

This experiment requires a precise optical set up. All the optics are mounted on a reduced vibration optical bench. The optics begin with a powerful Helium Neon laser with a wavelength of 632.8 nm, rated about 50mW of power. Next the beam travels through a beam splitter, breaking the beam in two directions, the one that goes straight is the object beam, and the beam to the right is the reference beam, which is shown in figure 1, a diagram of the optics. The object beam bounces off a mirror with a 90° angle and goes through a diverging lens to spread out the beam. The reference beam also travels through a similar lens to expand the beam, and then reflects off a mirror to send the beam in the direction of the hologram plate.

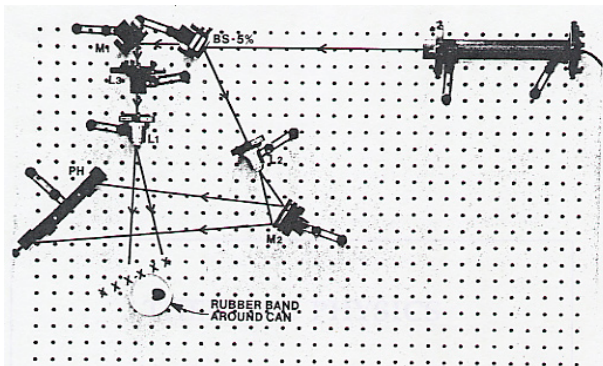


Figure 1: A diagram of the optics used. M_1 and M_2 are the two mirrors, and L_1 and L_2 are the two diverging lenses. (revised from reference 2)

After the optics are in place, and the developing solutions have been prepared, the procedure for making the hologram is easy. The object needs to be in line with the object beam, so that the majority of light hitting the object reflects onto the hologram plate. The object also needs to be placed so that it does not block the reference beam. To start a new plate is slid into the plate

holder with the emulsion side towards the object. With a beam blocker in front of the laser, the laser can be turned on. The beam blocker should now be raised off the air table, but should continue to block the beam. This is done to allow the vibrations, caused by lifting the blocker off the table, to die down before the plate is exposed. After about 10 seconds, the beam blocker is removed the plate is exposed for about 20 seconds. At this time the beam blocker is placed in front of the beam again. Now the rubber band on the can is cut with a utility knife, and removed. The beam blocker is removed again, and the plate is exposed for another 20 seconds. At this point the plate has been exposed twice, and can be developed.

RESULTS AND ANALYSIS

In this experiment a double exposed hologram of a soda can compressed by a rubber band. Figure 2 shows the real image of the double exposed hologram.

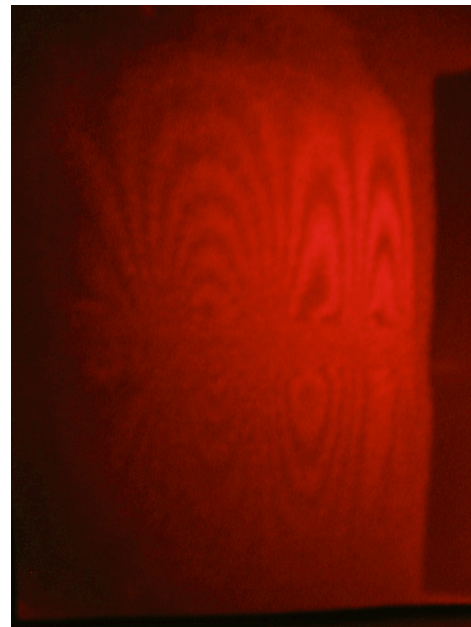


Figure 2: A double exposed hologram of a soda can compressed by a rubber band.

Finding the spring constant, k , of the rubber band is needed to calculate the force the rubber band exerts on the can. To find the spring constant, equation 1 is used,

$$F = k(\Delta x), \quad [1]$$

where F is a force exerted on the rubber band, and Δx is the change in the rubber band's length. To find k , four different weights were hung from the rubber band, and the change in length of the rubber band was measured. The results are shown in figure 3.

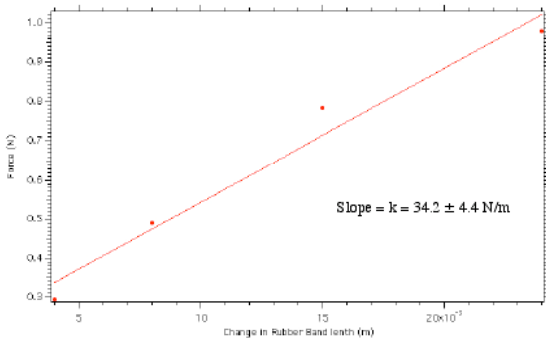


Figure 3: A graph of Force vs. Rubber band length change.

The slope is equal to the spring constant, $k = 34.2 \pm 4.4 \text{ N/m}$.

Using the spring constant, equation 1, the circumference of the can ($0.207 \pm 0.006 \text{ cm}$) and the length of the outstretched rubber band ($0.117 \pm 0.001 \text{ cm}$), the force the rubber band exerts on the can be calculated. To find the force, Δx is the difference between the circumference of the can, and the natural length of the rubber band, which is simply how far the rubber band is stretched, and equals $0.090 \pm 0.007 \text{ m}$. The force the rubber band exerted on the can was $3.07 \pm 0.39 \text{ N}$. Finally the depressions on the soda can are addressed. When the soda can has the rubber band around the middle, the can is compressed. For each half of a wavelength extra the beam has to travel to reach the can, the hologram reveals a

dark interference fringe. By counting these fringes, and using equation 2

$$d = \frac{\lambda}{2} (\# \text{ of dark fringes}), \quad [2]$$

which multiplies the number of fringes by half a wavelength, the depth of the depression, d can be found. Using the hologram made in this experiment, four distinct depressions can be seen on the can. Figure 4 shows a diagram of the soda can from the top, exaggerating each depression, and labeling each. Table I displays the number of dark fringes for each depression, and uses equation 2 to calculate the depth of each depression.

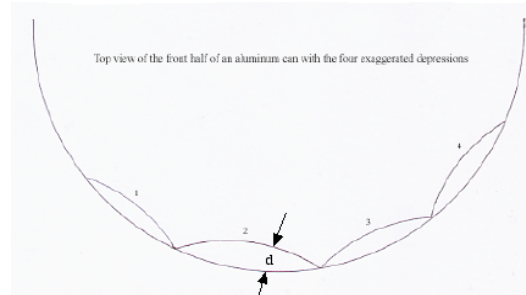


Figure 4: A Top view of the soda can with each depression exaggerated.

Table I: The values for each depression.

	Number of Dark Fringes	Depth of Depression
1	3.0 ± 1.0	$950 \pm 320 \text{ nm}$
2	7.0 ± 0.5	$2210 \pm 160 \text{ nm}$
3	4.0 ± 0.5	$1270 \pm 160 \text{ nm}$
4	4.0 ± 0.5	$1270 \pm 160 \text{ nm}$

CONCLUSION

Holograms can be very useful to examine objects with precision. The light waves are captured on the emulsion with enough accuracy to find a

difference in 160 nm. The double exposed hologram of a soda can with/without a rubber band showed this. From one single hologram, it was shown that the rubber band exerted a 3.07 ± 0.39 N force on the soda can, causing four visible depressions. Two of the depressions were 950 ± 320 nm, 2210 ± 160 nm deep, and the other two were 1270 ± 160 nm deep.

REFERENCES

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3. Kasper, Joseph E., Feller, Steven A. The Complete book of Holograms, Mineola, NY: Dover Publications, Inc. (2001).