Holography

Tim Sir Louis

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

April 26, 1999

This experiment used double exposure holography to find the strain on an aluminum can by an outside force. The strain on the can is related to the stress by Young's modulus. The strain on the can when a rubber band was wrapped around it was found to be $(1.84\pm0.03)x10^{-7}$. The stress on the can by the rubber band was found to be 48 ± 13 N/m^2. These two values were related by the constant $(2.7 \pm 0.7)x10^6$ N/m^2. When a mass of about 4.5 kg was applied to the top of the can, no strain was observed. This is because the mass was not heavy enough. In order for the strain to be measurable, a mass of about 6.6kg would be required.

INTRODUCTION

Holography was developed in 1948 by the British scientist Dennis Gabor.[1] Holography was developed more than ten years before the laser, but it now relies heavily on the use of the laser. A conventional photograph is a two-dimensional version of a three-dimensional scene. The hologram allows the scene to be viewed in 3D. Instead of waves of light coming just from the object, as in a two-dimensional photograph, waves of light also come from a reference source. The object waves and the reference waves are made to meet on a holographic plate, which is a high-resolution photographic emulsion on a glass plate. Since the object waves and the reference waves come from the same laser source, they have a high degree of mutual coherence and produce an interference pattern on the plate.[2] The interference pattern is complex interference pattern of microscopically spaced fringes.[1] After the holographic plate is developed, it can be illuminated with the same laser light to see the hologram.

In this experiment the strain on an aluminum can will be compared to the stress on the can. To determine the strain on the can, a double exposure of the holographic plate will be made. The first exposure will be taken with a force applied to the can, and the second exposure will be taken without the force being applied. If enough force is applied, a pattern of dark interference fringes will be apparent in the hologram due to the movement of the can between the two exposures.

The slightest movements in the aluminum can between exposures can be detected in the hologram. The movements cause dark fringes to occur as a result of the interference of the light waves from the first exposure to the second exposure. Every time the can is compressed or expanded a half a wavelength a dark fringe will be created. Knowing this makes it easy to find the change in the circumference of the can. By counting the number of fringes present in the hologram and multiplying by two gives the total number of half wavelengths the can changed by. The reason for multiplying by two is because only half of the can is visible in the hologram. To get the total change in circumference of the can, one simply needs to multiply the number of half wavelengths by a half a wavelength. This equation can be written as $\Delta P=2n(\lambda/2)$. The wavelength (λ) of a helium-neon laser is 633nm.

The strain on the can is a unit measure of the deformation of an object. It is represented by the ratio of the change in the object to the normal size of the object. When the rubber band is applying a force on the can, the circumference of the can will change. The strain in this case will be represented by the equation $\Delta P/P$. When a force is applied to the top of the can, the height of the can will be affected. This will cause the strain equation to be $\Delta h/h$. Another measure of the deformation an object undergoes is stress. Stress is the deforming force per unit area (F/A). The force (F) that a rubber band is used can be measured once the spring constant (k) is measured. The force is found using Hooke's law ($F=k\Delta x$).

The two deformation equations, stress and strain are related by Young's modulus (Y). Young's modulus is different for different materials. It is a measure of the compressibility of a material. In the case for this experiment, Young's modulus for aluminum[3] is $70x10^9$ N/m^2. The two deformation equations can be related as follows:

$$\frac{F}{A} = Y\frac{\Delta P}{P} \qquad (1)$$

EXPERIMENT

In order to create a hologram it is necessary to have light waves coming from the object and light waves coming a reference source. It is also important that the two waves come from the same source. In this experiment, the source is a 60mW helium-neon laser model 127-25. To split the laser beam, a beam splitter with a 5%-reflecting insert is used. The reflected light is passed through a diverging lens and reflected by a flat mirror onto the plate holder. The light waves that passed through the beam splitter are reflected by a flat mirror through a diverging lens. The light travels from this diverging lens to the object (aluminum can) and is reflected onto the plate holder. A diagram of this can be seen in the following figure.

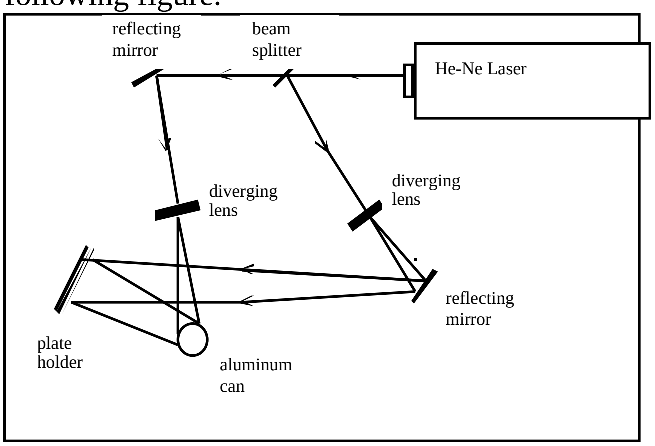

Figure 1: The beam from the laser is split into two beams, each directed through a diverging lens. Light waves from one lens fall on the object and are reflected onto the plate holder. Light waves from the other lens are reflected onto the plate holder by a reflecting mirror.

Before turning off the lights, slip the rubber band over the aluminum can and place it in the center. Working under a dark light only, remove a holographic plate from its storage container and place it in the plate holder. Turn on the laser and expose the plate to the laser light for about three seconds. After turning off the laser remove the rubber band using a knife making sure not to bump any of the equipment. Once the rubber band has been removed, expose the plate for another three seconds. The plate is now ready to be developed.

To ensure high quality of the image, the plate should be developed as soon after exposure as possible. The procedure for developing the plate should be included with the developing solutions. When the plate is dry, the three-dimensional holographic image should be able to be seen with the diverging laser light. To project a two-dimensional image of the can onto a screen, remove the diverging lens and pass the laser beam through the plate. If there was enough strain on the can during the first exposure, an image should be seen similar to the one in figure 2.

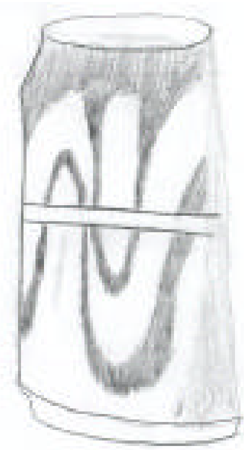

Figure 2: Interference fringes can be seen on an aluminum can when a double exposure hologram is made. The first exposure is taken with a rubber band around the center of the can, while the second exposure is taken once the rubber band is removed.

This experiment could in principle be done using a mass to create a force pushing down on the top of the can using the same procedure. The first exposure is taken with a mass on top of the can and the second exposure is taken once the mass has been removed. When this was tried, however, no effect was observed. It is estimated that more than 6.6 kg would have to be applied to see an effect.

In order to determine the stress, the force the rubber band exerts on the can must be found. This cannot be calculated until the spring constant is measured. The spring constant k can be found by suspending the rubber band by one end and attaching a mass to the other end. As more mass is added, the rubber band stretches a distance Δx which gives the needed value for k to be 230±18N/m.

ANALYSIS AND INTERPRETATION

From figure 2, it can be seen that there are five dark fringes across the can along the rubber band line. Before jumping to the conclusion that n is equal to five, it is necessary to continue the pattern for the other half of the can to make sure that none of the fringes were lost on the edge of the can. After analyzing figure 2, it was determined that n is actually six. This is because a fringe had to be added in order to continue the pattern. The value of n found enabled the change in the perimeter of the can to be determined. The change in the perimeter (ΔP) was found to be 6λ=3800nm. The perimeter (P) of the can was measured to be 20.7±0.3 cm. Using these values in the appropriate strain formula gave the strain to be $(1.84\pm0.03)\times10^{-7}$. To find the stress on the can, the force exerted by the rubber band had to calculated. This was done using Hooke's law. The measured value for the length the rubber band stretched was found by subtracting the length of the rubber band from the perimeter of the can. Before the stress was calculated, the area that the rubber band covered on the can had to be determined. This was done by finding the surface area of the un-stretched rubber band. The change in the area of the stretched rubber band can be neglected. The stress on the can was found to be $48.3\pm13\text{N/m}^2$. Relating the stress on the can with the strain on the can was done using equation (1). The modulus Y was found by dividing the value found for stress by the value found for the strain on the can. From this calculation the value for Y was found to be $(2.7\pm 0.7)\times10^6\text{N/m}^2$

CONCLUSION

Creating a hologram allows very small distances to be measured. In this experiment , distances as small as a half a wavelength (320nm) can be measured. The hologram created a very nice image as can be seen in figure 2. The value found for Young's modulus Y was different from the known value by a factor of 10^4. Young's modulus is a measure of the compressibility of a certain material. The reason the value found in this experiment was so far off from the known value is because the rubber band did not actually compress the metal. Instead the can crinkled under the force of the rubber band.

To actually compress the metal, it would be necessary to apply the force to the top of the can. This was attempted twice. The first time a double exposure hologram was made with a mass of about 2kg. No fringes occurred so a heavier mass (4.5kg) was placed on the top of the can. Again after the hologram was made no fringes were seen. Using equation (1), it is easy to see why no fringes occurred. Substituting into equation (1), the height h, along with the area A that the mass rests on and using $\lambda/2$ (the minimum distance the can would have to be compressed in order to see one fringe) for ΔP, meant that the force required to see one fringe would be 65N. This means that the mass required to see one fringe would be about 6.6kg.

ACKNOWLEDGMENTS

[1]Pedrotti, Frank L. and Pedrotti, Leno S. Introduction to Optics, Prentice-Hall Inc., Englewood Cliffs, New Jersey 1993.

[2] Callen, Russell W.; O'Shea, Donald C.; Rhodes, William T. Introduction to Lasers and Their applications Addison-Wesley Publishing Company, Reading, Massachusetts 1978.

[3]Taylor and Zafiratos. Modern Physics for Scientists and Engineers, Prentice-Hall Inc., New Jersey 1991.