The Measurement of the Maximum Deformed Depth of a Can Using Double-Exposure Holographic Techniques

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A double-exposure hologram of a can deformed by a rubber band was created to measure the deformed depth. To create a hologram of an object, an image of the object was recorded with a HeNe laser in an unexposed film, and the film was encoded with a chemical process. The image in the hologram was seen when shone by the HeNe laser. To make a double-exposure hologram, both an image of the deformed can stressed with the rubber band and an image of the same can without the rubber band were recorded together in a single film. As a result, the constructive and destructive fringes were observed from the film due to the interference of two images. According to the thin-film theory, the maximum deformed depth caused by the stress of the rubber band was proportional to the number of fringes. The number of both constructive and destructive fringes were counted to measure the maximum deformed depth. The counted number was 20 ± 2, and the maximum deformed depth was (3.2 ± 0.3) μm.

I. INTRODUCTION

The hologram is a reconstruction of the three-dimensional image recorded on a film by lasers. It was first introduced by Dennis Gabor in 1948 and made practical by the invention of the laser in 1960. The hologram is regarded as a true three-dimensional image because the objects change the relative position in the image when it is viewed from the different angles. To give a similar example, Facebook of Instagram users might have the experience to see or create a three-dimensional picture. The hologram image is almost identical to those examples although it is monochromatic.

Nowadays, the hologram is used for various purposes. It is used for not only the expression of the three-dimensional image in art but also the commercial usage of security. Since the hologram is possible to record any kind of wave including the electric wave, it is also used for the creation of electric holography on credit cards or driver licenses. Furthermore, the hologram is utilized for military mapping, information storage, and medical instrument, etc.

To learn how to create a hologram, a hologram of a swan miniature was created with the single exposure method. Then a double-exposure hologram of a can stressed by a rubber band was created. The deformed depth of the can is difficult to measure by hand because the depth is infinitesimally small. However, the depth can be calculated by analyzing the double-exposure hologram of the can. Since the image of the can without the rubber band and the image with the rubber band were overlapped in a single hologram, an interference pattern occurred in the hologram. The number of the fringes in the image was counted, and the deformed depth of the can was determined by applying the thin film theory.

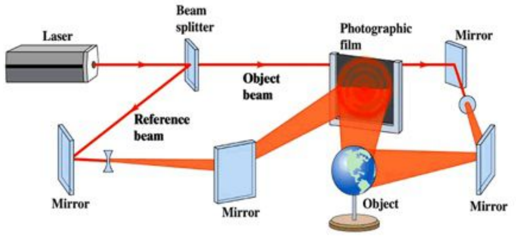

FIG. 1: A setting for making a hologram, cited from [1]. The hologram was made by recording both a reference beam and an object beam simultaneously on a film.

II. THEORY

The method of making the hologram follows two major steps: recording the image of the object on the unexposed film with laser light, and encoding the recorded image in the film with a chemical process. After those steps, the recorded image is shown when the light is exposed to the film.

The recording process of an object is shown in Fig 1. The laser light is split into an object beam and a reference beam by the splitter. An object beam reflects off the object onto the film, while the reference beam illuminates the film directly. Although both lights consist of the same wavelength, the phase change in the light wave occurs in the object beam. Due to the phase change, a three-dimensional image is recorded on the film when both lights shine on the film simultaneously.

After recording the image on the film, the film was encoded with the chemical process. The specific steps of the chemical process are shown in the procedure section. The hologram is created when the two major steps were done. The image in the hologram can be seen when the laser light passes the hologram as shown in Fig 2. An observer can see the virtual image when the observer watches the opposite side of the film on which the light is exposed.

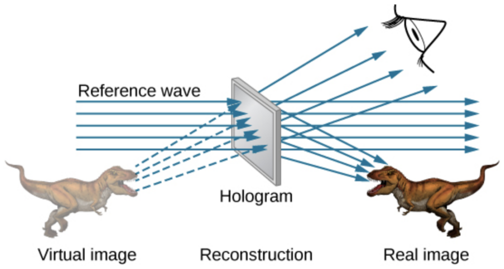

FIG. 2: A process of viewing the image recorded in a hologram, cited from [2]. The virtual image is seen to an observer when the reference wave passes through the film.

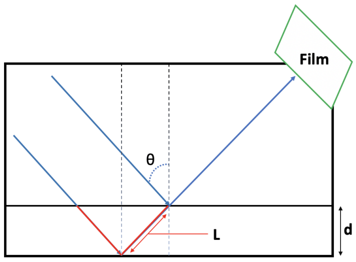

FIG. 3: A diagram of the interference of the light reflected from the can stressed with a rubber band and the light reflected from the can without the rubber band.

By recording both the image of a can stressed with the rubber band and the image of a can without the rubber band on the same film, a hologram with an interference image can be created. The detailed diagram of how the lights of each image interfere is shown in Fig 3. The first layer represents the can without the rubber band, and the second layer represents the can stressed with the rubber band. Additionally, d represents the deformed depth, the red-colored two lines, $2L$, represent the path difference between two lights, and θ represents the incident angle. Using the trigonometric identity,

$$\frac{d}{L} = \cos\theta. \tag{1}$$

The constructive interference occurs when the path difference is equal to the wavelength, while the destructive interference occurs when half of the path difference is equal to the wavelength. The relation can be expressed as

$$2L = \frac{n\lambda}{2}. \tag{2}$$

where the constructive interference occurs when n is even, the destructive interference occurs when n is odd. From the interference image, the number of constructive fringes and destructive fringes between the center of the can stressed with the rubber band and the top or end of it can be counted. The maximum depth, d_{max}, occurs at the counted number. By combining two equations, the maximum depth can be expressed as

$$d_{max} = \frac{n\lambda\cos\theta}{4}. \tag{3}$$

Since the angle is difficult to be measured precisely, the light is assumed to be a normal incidence. Then, the above equation can be simplified as

$$d_{max} = \frac{n\lambda}{4}. \tag{4}$$

III. PROCEDURE

As shown in Fig 1, a HeNe laser, a beam splitter, mirrors, diverging lenses, and a film holder were fixed at the location. To create a single-exposure hologram, a swan miniature was placed in front of the film holder and a used film was also equipped in the film holder. In the darkroom, the HeNe laser was turned on to check whether both reference light and the object light passed the used film. The object beam was blocked first to check the alignment of the reference beam, then the reference beam was blocked to check the alignment of the object beam. An observer could watch the image of the swan miniature when the observer viewed the opposite side of the used film where the beams came in. If a part of the image was not seen or not aligned at the center, the direction of the mirror was slightly adjusted with an attached knob. After checking the alignment of the lights, the used film was removed.

Before starting to record a hologram, the setup for a chemical treatment was prepared because the encoding process with the chemical treatment should be done quickly. A mixture of 50ml of A and 50 ml of B solution, 100ml of bleach solution, and 100ml of formaflo solution were prepared in each tray. Also, a stop bath was filled with water. The mixture was used for developing the hologram image, the bleach solution for fixing the image, the formalflo solution for rinsing the water, and the water in the stop bath for rinsing the chemicals.

The process of both recording and encoding a hologram should be conducted in the darkroom because the light disturbs the formation of the hologram. Since it is dangerous to conduct the whole process in the darkroom, the green safelight which does not affect the formation of the hologram was turned on. The HeNe laser was blocked, and an unexposed film stored in the cabinet was equipped on the film holder. Since the unexposed film could be harmed by the light easily, the other unexposed films were stored inside the cabinet. The unexposed film was exposed by the HeNe laser for 15-20 seconds, and the laser was blocked again. The film was removed from the holder for the encoding process with the prepared chemical solutions. During the encoding process, the film was carried with latex gloves for safety.

FIG. 4: A single-exposure hologram of a swan miniature.

The film was placed in the mixture of A and B and shaken for one to two minutes to develop the hologram. The transparent film became black, and it was soaked in the stop bath for about two minutes. The film was moved to the bleach solution and soaked for about two minutes to fix the hologram. The film became transparent again during the process. The film was taken out and rinsed with flowing water for about three minutes. After rinsing it with water, the film was rinsed again with formaflo solution for about one minute. The rinsing process with formaflo solution prevented the film from creating the watermark on the image. The film was dried for 5-10 minutes, and it was equipped in the holder to check the hologram image.

To create the double-exposure hologram, the swan miniature was removed and a can was placed in front of the film holder. After checking the alignment of the lights, the position of the can was fixed strongly because the slight movement the can during the recording process of two images could critically ruin the formation of the hologram. A rubber band which slightly stressed the can was selected and slipped to the middle of the can. The HeNe laser was blocked, and a new unexposed film was equipped on the holder in the darkroom. The film was exposed by the HeNe laser for 10 seconds, and the light was blocked again. The rubber band was delicately removed from the can, and the film was exposed by the laser for 10 seconds. The light was blocked again, and the double-exposure hologram was encoded with the same method.

IV. DATA AND ANALYSIS

The first try of making a single-exposure hologram was not successful with an unclear image. During the encoding process, I mistakenly dropped the film to the water while I was drying the film. The watermark seemed to remain in the image so that the image was harmed. In the next try, the encoding process was carefully conducted without exposure to water while the film was dried. As a result, a decent single-exposure hologram of a swan miniature was created as shown in Fig 4. The three-dimensional image was seen when the HeNe laser was shone on the film as described in Fig 2. The swan miniature in the three-dimensional image changed its relative position when it was viewed from different angles.

FIG. 5: A double-exposure hologram of a deformed can with a rubber band. The number of both the bright and dark fringes was used to calculate the deformed depth.

A double-exposure hologram of a deformed can with a rubber band was made as shown in Fig 5. Since the light reflected from the can wrapped with the rubber band and the light reflected from the can without the rubber band overlapped in the single image, the interference pattern with the dark and bright fringes occurred.

To calculate the maximum deformed depth, the number of both bright and dark fringes between the middle of the can and the top of the can was counted. Since Fig 5 was captured with a phone camera, the HeNe laser coming directly into the camera blurred several parts of the image. However, the clear image of the double-exposure hologram was observed with an eye. Thus, the number of bright and dark fringes were counted by looking directly to the film. The counted number was 20 ± 2, and the wavelength of the HeNe laser was 632.8 nm. The uncertainty was generated because the fringes at the center were too tiny to be identified. The maximum deformed depth, d_{max}, was calculated by using the equation 4, and it was (3.2 ± 0.3) μm.

V. CONCLUSION

A single-exposure hologram of a swan miniature was made to learn how to make a hologram image in a film, and a double-exposure hologram of a deformed can was made to measure the maximum deformed depth. A three-dimensional image of the swan miniature was shown when the single-exposure hologram film was shone by HeNe laser. The swan miniature in the three-dimensional image changed its relative position when it was viewed from different angles.

To create the double-exposure hologram, both an image of a deformed can stressed with a rubber band and an image of the same can without the rubber band were recorded together in a single film. Due to the interference between two images, constructive and destructive fringes were seen when the image of the double-exposure hologram was viewed. Since the maximum deformed depth caused by the stress of the rubber band was proportional to the number of fringes according to the thin-film theory, the number of both constructive and destructive fringes were counted to measure the maximum deformed depth. The counted number was 20 ± 2, and the maximum deformed depth was (3.2 ± 0.3) μm.

[1] *https://www.assignmentpoint.com/science/physics/describe-about-holography.html* .

[2] *https://openstax.org/books/university-physics-volume-3/pages/4-7-holography* .