A Study of Vibrating Objects using Time-Average Holographic Interferometry

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Time-Average holographic interferometry was used to capture interference fringes of a vibrating soda can's wall on a photosensitive glass plate. Although interference fringes were observed and measured, no conclusive information was obtained from the results. Attempts at imaging a Chladni plate, organ pipe and hand bell were also made. However, of these objects, only a faint image of the organ pipe was captured. This experiment has been the first step in refining this holographic technique at The College of Wooster and much has been learned that will improve the experiment in the future.

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INTRODUCTION

A hologram is a record of microscopic interference fringes that are recorded on photosensitive material. The interference fringes are produced by coherent laser light that is split into two beams, one reflecting off of an object and onto photosensitive material (object beam) and one that is directly incident on the photosensitive material and does not reflect off the object (reference beam). Because of the constructive and destructive interference of these two beams, interference fringes are produced on the photosensitive material.[1] When the developed photosensitive material is viewed in the same type of light, a three dimensional object appears as a real image, one that is in front of the plane of the hologram. The hologram can be viewed by looking through the glass with diffuse laser light incident from behind the glass, or the hologram can be projected in two dimensions on a flat surface by placing the holographic plate in the laser beam.

Since holograms record interference fringes, any change in the interference pattern is also recorded. Changes in the position of the object appear as alternating dark and light bands, superimposed on the object's holographic image. Hologram's are highly sensitive to "out of plane" motion, the motion of an object in the direction perpendicular to the objects surface. Very small displacements cause fringes to occur because of the small wavelength of the laser light, 633nm. This is the case because the interference pattern created on the photographic medium is dependent on the path difference between the object beam and the reference beam. Out of plane motion changes the path difference and as a result, the interference pattern. A resonating object, like a bell is going to have out of plane motion in certain areas depending on the frequency of the excitation. Motion during the exposure results in light and dark bands, superimposed on the images of the object. The light and dark bands are a result of constructive and destructive interference of two interference patterns. [6] Because the interference patterns are representative of the sinusoidal peak-to-peak displacement of the object, a path difference of one-quarter wavelength results in destructive interference between the two records. I mention the interference of two interference patterns because in using the time-average imaging technique, what appears on the hologram is equivalent to a double exposure of the object at the positive and negative amplitudes of its sinusoidal motion. The nodes on the object appear bright because there is no motion at those points. The anti-nodes appear either bright or dark depending on the amplitude of the oscillation and whether it is an integer or half-integer multiple of the laser light wavelength, respectively. Also dependent on the amplitude, a certain number of fringes appear in the space between the centers of the node and anti-node. The fringes are the result of two holographic images interfering upon reconstruction; the image of the object with the anti-nodes displaced farthest away and closest to the film plate.[6]

Because of this result, there are many applications for time-average interferometry. It can be used in industry for testing of structural components, airfoils or other objects. The most important part about this type of imaging is that it does not require a large amplitude of oscillation for an image. In fact, this is the hardest part of producing a good image, having very small amplitudes of vibration; stray vibration on the optics table can ruin images.[7] One advantage of using this type of acoustical testing is that one not need touch the object in any way to measure it. The vibration detection is independent of the physical system under measurement.[2] Other methods of visualizing the vibration of an object use accelerometers to record the amplitude of vibration at an array of points. An image of the object can be approximated on computer by plotting the amplitudes with respect to position on the object.

APPARATUS

Theoretically, the setup for transmission holography is fairly simple. Specific distances between optical elements are not required because the interference is due to the change in path difference caused by the object's surface and vibration, not the original path difference. As long as the laser beam travels straight through each optical element, each beam is centered on the photographic plate, and there are no stray vibrations of the equipment or the table the hologram will likely work. Still holography is simple, but once you add vibration it can ruin the images if done incorrectly. Too much vibration of the object when it is resonating will cause the image to appear as a shadow. As shown in Figure 1, the setup allows for two beams to strike the photographic plate, one reflecting off the object (object beam) and a reference beam that does not interact with the object. It is ideal to check each beam's alignment before exposure. For example, this can be accomplished by blocking the path of the object beam, and making sure that the reference beam is centered, with the highest intensity in the middle of the plate area. It is best to align the optical elements in straight lines and 90-degree angles. This will ensure that there is a "clean" beam striking the plate; one without diffraction fringes from the beam's interaction with lenses. Sometimes angles need to be used to accommodate different object and photo plate positions.

It is also important to consider the stray light that is released from the laser housing. The laser housing needs to be covered so that the light from inside will not leak into the room during exposure. This may cause poor quality images. In addition, as part of the setup, understand that the room will be completely dark during exposure and developing except for a dim, green safelight. It is therefore important to keep track of where objects in the room are located. The holographic image quality is best when a light colored, reflective object is used.

For this experiment it is also important to have a developing station set up in the same darkroom. This should be prepared before exposure and includes a source of running water, chemical trays, and chemicals. The chemical trays should be arranged in order of use, developer, bleach, and photoflo. Chemicals and red-sensitive plates were purchased from Integraf. The developing chemical is an equal mix of two diluted solutions. JD-2A consists of water, catechol, ascorbic acid, sodium sulfite, and urea. JD-2B contains water and sodium carbonate. The bleach solution contains water, potassium dichromate, and sodium bisulfate. For developing, there should be enough solution in each tray to cover the hologram plate. The developer, once poured, is good for one day and the bleach and photoflo are usable for much longer.

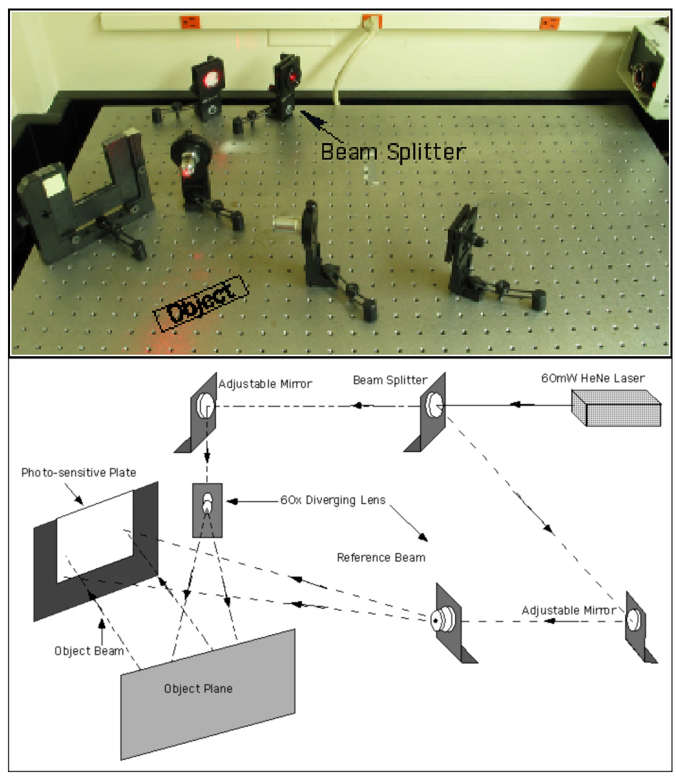

Figure 1: Diagram and photograph of the transmission hologram optical setup in The College of Wooster darkroom. Shiny surfaces, such as the optics bench and the light colored wall were covered with black cloth to cut down on fogging of the film plate during exposure.

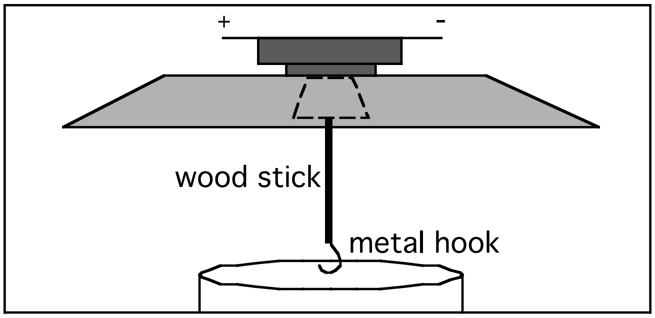

Figure 2: Modified speaker with a wooden probe cemented in the center cone. The metal hook touches the center of the can's top.

In order to couple the speaker (vibrator) to the can, the speaker is suspended above the can with the attached stick touching the top of the can with a gentle pressure. The speaker apparatus is mounted on several mounting rods that are clamped to the table, not the optics bench. This helps keep vibration from propagating to the optics bench. A digital function generator is connected to the speaker and allows one to select specific frequencies and amplitudes of oscillation. The modified speaker is illustrated in Figure 2. It is also important to note that the pop can is attached to a wooden mounting board that is then gently clamped, on top of foam insulations, to the optics bench. The foam helps to dampen the vibrations.

PROCEDURE

Choosing the frequencies for the can vibration was challenging because I was hoping to find a normal mode of the can. At first I used lower frequencies such as 65Hz or 130Hz because those seemed to produce greater resonance in the can as detected aurally and by touch. After holograms at those frequencies produced no image at all, I decided to increase the frequencies above 400Hz because the table seemed to dampen higher frequencies better than at lower. I chose to oscillate the can at 555Hz and at 480Hz because those frequencies seemed to produce audible resonance of the can.

For a continuation of this experiment I attempted to take holograms of three more objects. First, I setup the optics bench to accommodate the Chladni plate. The plate was mounted in the object area with a white painted surface facing the plate holder. The plate was suspended by a support pole that was clamped to the counter edge, not to the optics bench. The mechanical vibrator from Pasco is made to hold the central mounting post of the Chladni plate and the vibrator was secured to the steel mounting arm and connected to the frequency generator. Although the mounting arm was strong, it was not completely rigid so the plate could move if bumped. Care was taken to wait for any vibrations to dampen before the hologram was exposed. Two holograms were taken of the plate while still; a 25 second and 30 second exposure. Both holograms showed little detail of the plate, although the central screw was visible.

After these holograms were taken, the plate was tested for its mode frequencies. I used sand on the flat surface of the plate to check for the modes by looking for the patterns as shown in a node-line diagram in reference 4. Figure 3 shows the black side of Chladni plate I used in several of these modes. It was difficult to get the fundamental (2,0) mode to stabilize enough so that the sand would stay on the surface. The frequencies listed in Figure 3 are difficult to compare to the relative frequencies listed in reference 4 because I was unable to get an accurate reading on the fundamental mode (2,0). However, using the ratios of the relative frequencies to the predicted fundamental mode, the modal frequencies in Figure 3 indicate that the fundamental for the plate is roughly 62Hz; this is an average for the four plate modes pictured.

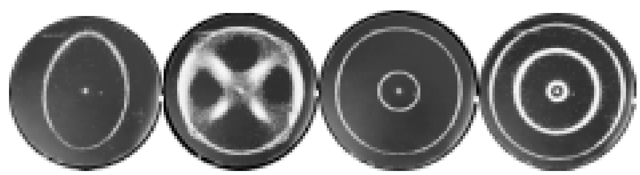

Figure 3: Chladni plate modes using sand to illustrate the node lines. These images were captured with a digital camera. The modes are, (left to right), [0,1] [2,1] [0,2] [0,3]. The actual frequencies of these modes are 107Hz, 360Hz, 460Hz 863Hz, respectively. These frequencies are accurate to within +/- 2 Hz.

One could check for modes at higher frequencies using holography and taking a series of images. The mode will be marked by the greatest number fringes between node and anti-node indicating the largest displacement.[8] After checking for the modes, I used each mode in several hologram exposures at a variety of different amplitudes. None of the holograms showed any fringes or even the plate at all. A small, ceramic, white elephant was placed near the plate in several holograms because it is an object that has reliably showed up in previous exposures.

After having no success making holograms of the Chladni plate, I began trying to take an image of the organ pipe. Several exposures of the pipe's rear showed only faint images. I polished the rear face of the pipe, which is made of a lead-tin material and then attempted more images. Figure 4 shows the pipe used in this experiment.

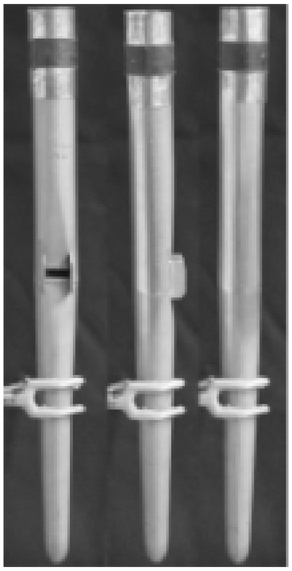

Figure 4: G4 principal diapason organ pipe, front, side and rear view. Notice the shiny surface on the rear of the pipe, a result of polishing the surface with crocus cloth.

With no success imaging the still pipe, I tried the exposures with the pipe sounding. In order to make the pipe speak, the air supply was attached to the pipe foot (bottom end). The air was turned on slowly until just enough was passing through the pipe to make it sound a G4 pitch. Images were also taken with acoustical excitation of the pipe by mounting a small speaker above the pipe's top opening and tuning the speaker frequency until a maximum sound intensity was reached at 813Hz. Neither configuration could be captured on a hologram.

RESULTS & CONCLUSIONS

No useable images were obtained from any of the holograms I exposed and developed. The plate, pipe or bell did not show up in the hologram whether exposed still or vibrating. I am fairly certain that the images did not appear because there was too much vibration of the objects in their mounted configurations. The mounting pole was not attached to the optics bench, so it was not insulated from resident vibrations in the room. The optics bench sits on four rubber bladders, which dampen out vibrations from the counter top and the room. In the soda can experiment, the object was secured to the optics bench and the vibrating mechanism was mounted above the object. This meant that the object was only being excited by vibrations from the mechanism. The soda can was imaged with fringes as shown in Figure 6.

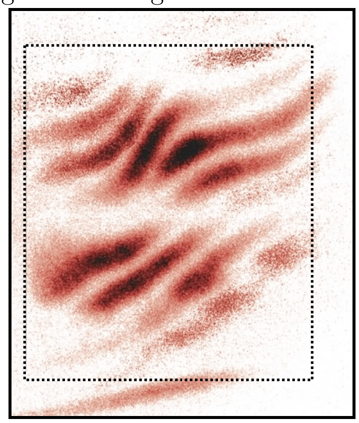

Figure 6: Image of the soda can with fringe pattern. The height of the pictured area of the can is approximately 6.5 cm. The visible can area is outlined with a dashed box.

There is a great deal of further research that could go into this project, considering that there are few if any studies of organ pipes that uses time-average interferometry to shed light of the oscillatory behavior of the pipe wall. I believe that there were two factors that prevented any decent images from being taken. One, the objects were all mounted independently of the optics bench instead of coupled to the bench. Two, when vibrating the objects the amplitudes were too large for proper holographic imaging to work. For future work, I would begin by fixing the object or the object mount to the optics bench and try to get quality still images first. It is important to get decent still images before bringing added vibration into the picture.

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