Physics 325 Experiment 11: Holographic Interferometry of a Cantilever Using Instant Holographic Film

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Abstract

This experiment used holographic film to measure the deflection of a cantilever by analyzing the interference patterns of the cantilever and its hologram. A small mass produced data which deviated extremely from the theoretical values—the data were 0% consistent. A large mass produced data which deviated moderately from the the theoretical values—the data were 38% consistent.

Theory

Holographic interferometry is based on the interference between similar wavefronts coming from an object and its hologram. The hologram is made by letting a laser source reflect off an undisturbed object and letting the holographic film develop. Then if the object is disturbed a tiny distance, it creates new wavefronts which will interfere with the previously developed holographic image, creating a fringe pattern.

In this experiment, we used a cantilever as our object, and small and large masses to create the fringe pattern. When a mass was placed at the free end of the cantilever, the number of bright fringes could be counted. Each of these fringes corresponded to an integer number of wavelengths, N, which started from 0 at the mounted end of the cantilever. The deflection of the beam was then given by

$$\Delta y = -\frac{N\lambda}{\cos\alpha + \cos\beta}, \tag{1}$$

where λ is the wavelength of the laser, and the angles α and β can be derived based on the apparatus (see Appendix). This equation gives us a measure of the displacement at a given part of the cantilever.

The theoretical counterpart to equation (1), was given in the lab manual [1]:

$$\Delta y = \frac{12F}{\mathcal{E}wt^3}\left(\frac{L^3}{6} - \frac{(L-x)^3}{6} - \frac{L^2x}{2}\right). \tag{2}$$

In this equation, F is the weight of the mass used and x is the position along the cantilever. All other values can be found in Table 1 (see Appendix).

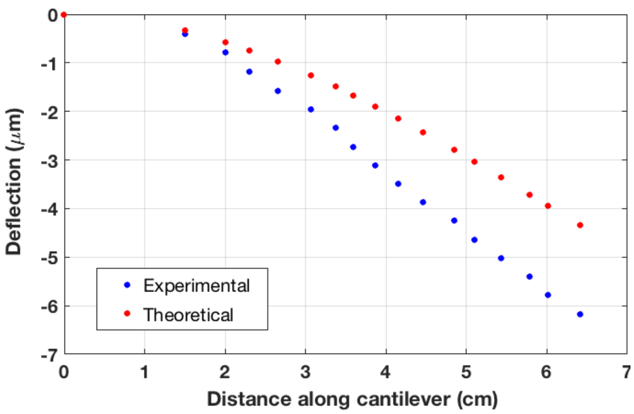

Figure 1: Results from part I of the experiment using the small mass of 2.22 grams.

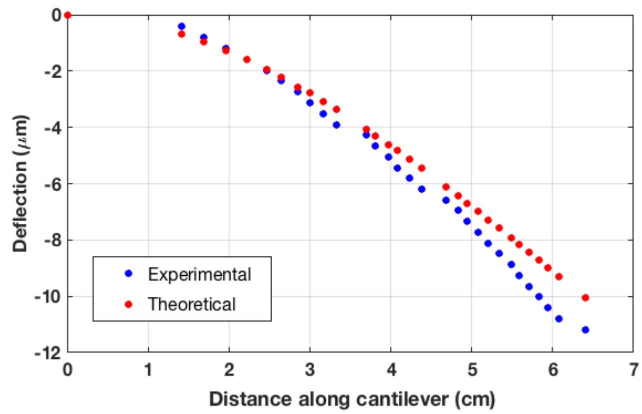

Figure 2: Results from part II of the experiment using the large mass of 5.26 grams.

Experimental Procedure

For this experiment, the apparatus was comprised of a laser source, holographic film, a camera, two masses (between 2 to 6 grams each), support structure with sand-bed, and a computer with *Logger Pro* software.

Many preliminary steps were taken to ensure the experiment was successful. The laser source was turned on fifteen minutes prior to attempting the experiment to ensure that the laser had reached a stable temperature and that the wavelength of the light would not vary during the experiment. A support structure was mounted in a bed of sand in order to damp out any high frequency vibrations that could destroy the interference pattern. The film was stored in a light-tight package so that it would not prematurely develop.

To begin, the laser source was covered, the lights were shut off, and the computer monitor was covered with a black cloth. Then, in the dark, the film was retrieved from its packaging and placed on the apparatus above the cantilever. After the film was screwed tight into place, the camera began recording and the laser source was uncovered. This began the film's exposure, and after thirty seconds the small mass was placed on the free end of the cantilever. After five seconds it was replaced with the large mass, and after another five seconds the large mass was removed and the recording was stopped.

Discussion of Results

As designed, the experiment worked well and provided a good learning experience; however, it did not yield consistent results. The recording of the experiment was uploaded to the computer and screenshots of each instance of interference were captured and imported into *Logger Pro* (see Figures 3 and 4). There, they were analyzed and the appropriate data were gathered. Using equations (1) and (2), a set of experimental and theoretical values were obtained for each mass and were plotted in Figures 1 and 2.

Part I

The image of the cantilever supporting the small mass was digitized and the necessary data were collected and manipulated. This produced the image in Figure 3. These experimental data were compared with their theoretical counterparts and plotted in Figure 1. As seen in the plot, there was great deviation from the theoretical values. In fact, 0% of the points were deemed consistent when compared to their theoretical values (Figure 5). Potential sources of error do not appear obvious; however, a symptom of a more fundamental problem appears to be that the non-uniformly spaced fringes in Fig-

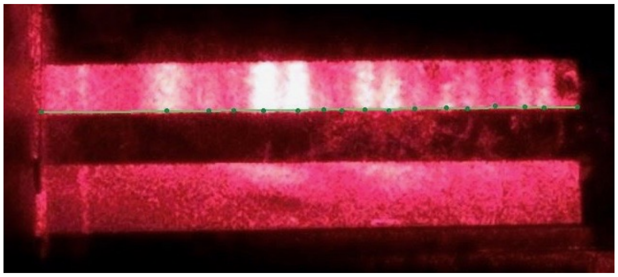

Figure 3: Interference pattern from part I using the small mass.

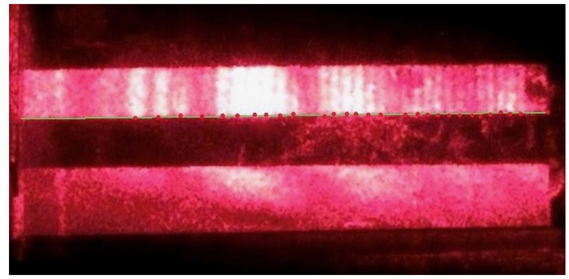

Figure 4: Interference pattern from part II using the large mass.

ure 3. The fringes were hard to distinguish as there were prominent bright spots along the cantilever.

Part II

The image of the cantilever supporting the large mass was digitized and the data were collected. This produced the image in Figure 4. These data were compared with their theoretical counterparts and were plotted in Figure 2, which indicates that the deviation was much less than that of part I. This set of data were 38% consistent when compared to their corresponding theoretical values (Figure 6). Similar to part I, the sources of error do not appear obvious. Although the results of part II are better than those of part I, the majority of the data were inconsistent with the theoretical values. As seen in Figure 4, part II suffered similar problems as in part I: very bright areas made it hard to discern between fringes.

Summary

In part I of the experiment, the image of the cantilever supporting the small mass was digitized and a plot of the experimental deflection versus theoretical deflection was produced (Figures 3 and 1). These experimental deflection data were 0% consistent when compared to their theoretical counterparts.

In part II of the experiment, the image of the cantilever supporting the large mass was digitized and a plot of the experimental deflection versus theoretical deflection was produced (Figures 4 and 2). These experimental deflection data were 38% consistent when compared to their theoretical counterparts.

Literature Cited

[1] *Physics 325 Laboratory Manual: Optics.* Department of Physics and Astronomy, University of Victoria. Exp. 11, Ver 2.1, August 20, 2017

Appendix

Table 1: Important experimental values.

Small mass	2.22 g $\pm$ 0.01 g
Large mass	5.26 g $\pm$ 0.01 g
Height of laser from cantilever (h_1)	14.5 cm $\pm$ 0.1 cm
Height of camera from cantilever (h_2)	16.5 cm $\pm$ 0.1 cm
Horizontal projection of the distance between the cantilever and the camera (d)	17.5 cm $\pm$ 0.1 cm
Cantilever length (L)	6.4 cm $\pm$ 0.05 cm
Width (w)	0.63 cm $\pm$ 0.005 cm
Thickness (t)	0.16 cm $\pm$ 0.005 cm
Wavelength of laser (λ)	650 nm
Young's Modulus of cantilever material ($\mathcal{E}$)	2.08 $\times 10^{12}$ dyn/cm^2

Consistency checks for data from part I and II:

Difference	Uncertainty	Consistent?
0.033121524	0.001656076	No
68.81051532	36.35489047	No
220.5192693	68.09911844	No
443.1282354	96.14851375	No
606.6285971	126.8407581	No
701.3192937	160.647055	No
849.9369303	191.7446304	No
1060.462383	219.793069	No
1213.329859	250.5046282	No
1345.399762	282.1446997	No
1446.132045	315.242343	No
1470.604639	351.9945161	No
1609.62747	383.2609307	No
1664.085906	418.6511499	No
1690.78902	455.4910844	No
1843.386594	486.2465622	No
1820.89285	525.8000581	No

Figure 5: Consistency check for part I as seen in Figure 1. These points showed 0% consistency. The error per datum was 5% each.

Difference	Uncertainty	Consistent?
0.076880864	0.003844043	No
284.2360167	54.04880802	No
168.8050177	87.84757332	No
85.6217731	123.0243737	Yes
27.91506438	159.2710732	Yes
10.43543941	196.310068	Yes
129.5394302	229.2990607	Yes
184.1303372	265.3166839	Yes
340.4130208	296.3199161	No
435.0549972	330.2306679	No
536.5320129	363.7422073	No
203.9508291	418.1677549	Yes
375.4544509	448.1683725	Yes
441.0947251	483.2483774	Yes
603.1721902	513.6276899	No
677.3548989	548.2254768	No
745.6186641	583.0843779	No
479.0795085	634.1667122	Yes
532.5819793	669.7287562	Yes
649.7297723	702.1882173	Yes
741.6481321	735.8718777	No
830.9999994	769.6824871	No
918.0899294	803.610322	No
956.7836427	839.9216959	No
1110.016796	870.6341195	No
1215.62763	903.6975119	No
1296.844295	937.9850075	No
1424.27251	970.0192774	No
1504.27481	1004.428547	No
1113.965548	1062.332565	No

Figure 6: Consistency check for part II as seen in Figure 2. These points showed 38% consistency. The error per datum was 5% each.

Derivation of the angles α and β:

In the diagram on the left it is easy to see that

$$\alpha = \arctan\left(\frac{L - x}{h_1}\right).$$

And in the diagram on the right it is also easy to see that

$$\beta = \arctan\left(\frac{d}{h_2}\right) = 46.7^\circ.$$