Holographic Interferometry

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0.1 Outline of the Lab

0.1.1 Part 1: Understanding the Interferometer

The first part of this lab is the construction and understanding of the *Michaelson Interferometer* (MI). The MI is an incredibly sensitive technique that measures path differentials. Using this technique we can easily detect movement on the sub-micron level. Bob will spend some time introducing the optics to be used along with showing procedures for cleaning and aligning them. *Remember to use safety goggles!*

> **Question:** What is temporal and spatial coherence? What is the coherence of our laser (roughly)?
>
> **Question:** Assume the light source for the MI is a *perfect* plane wave. Sketch the intensity at the screen as a function of increasing path differential. Make a new sketch that shows the effect of a limited temporal coherence on the source.
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> **Question:** Sketch the intensity viewed on the screen of the interferometer as both legs of the MI are increased. Assume the same setup as the previous question and that the path differential between the legs is zero. What happens if the source has limited temporal and spatial coherence?
>
> **Exercise:** Measure the index of refraction of a thin glass slide using the MI. Do this by inserting the glass slide in the beam, rotating the slide and counting the fringes. Justify each step. This exercise should be completed by the end of the first day or at the beginning of the second.

Things to keep in mind: Always be looking for practical effects that limit the usefulness of measuring path differences.

0.1.2 Part 2: Making Regular Holograms

Bob will start with building a holographic *camera* and developing the resulting holograms. The design of such cameras is both a science and art. We have found that the transmission geometry is well suited for the technique of HI.

> **Questions:** Answer the questions in the lab manual that deals with imaging a point source. The derivation of Holography in the lab manual should give enough information to answer this question.
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> **Question:** What happens if an object moves during an exposure? To what degree will it disappear? What is actually recorded on the hologram in this case?
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> **Question:** What practical factors limit our ability to make holograms? What happens if we try to make a very large hologram – one significantly larger than the coherence length of our source?

0.1.3 Part 3: Holographic Interferometry

Here we use holography as a tool to create an MI at every point on the image. Again, the goal is to prove HI is a quantitative technique of measuring small displacements. We start by taking our system in stressed (unstressed) position and expose the hologram for half the normal time. We then stop the laser, remove (apply) the stress and turn the laser back on for the rest of the exposure time. The total intensity remains constant but we actually have two holograms that have been superimposed. If the system is mechanically stable, these holograms interfere and produce the desired interferometric effect at each point on the image. From the fringe patterns produced and emphcareful experimental design, we can deduce the displacement of the object.

You should be able to answer the following before you start trying to implement HI.

> **Question:** An intuitive way of understanding this behavior is illustrated by making a small cube on a translator stage. Instead of stressing the cube, we simply move it from the first half of the exposure to the second half my a known amount.
>
> Translating the cube in the plane of the hologram a small amount will only produce a hologram with fuzzy edges but no interference fringes. Why?
>
> What will we see if we move the cube by $\lambda/4$, $\lambda/2$, λ, 2λ, and $9\lambda/4$ in the direction perpendicular to the plane of the hologram (i.e. looking straight at the cube)?
>
> What would we see if we were looking at an angle θ and the cube was moved by $\lambda/4$, $\lambda/2$, and λ? At what angle do we have the most sensitivity to the movement of the cube?
>
> What does the fringe pattern look like if we twist the cube? What is the spacing of these fringes? If we originally twisted the cube by some angle κ, can we resolve the difference between this hologram and one where the cube rotated by $-\kappa$?

> **Question:** What are the smallest displacements you can detect with this technique?

> **Question:** If an object is moved very far from its original location from the first part of the exposure to the second[1]. This will (in general) produce a very high density of fringe patterns. The density is so high that we do not see any fringes. Why? How does this limit the technique?

[1] To clarify, I am assuming that the object remains completely stationary during exposure. Movement only occurs between the exposures

The Experiment

The system we want to study is a bending beam. Specifically, what is the displacement of the beam as a function of position with an applied stress. The main difficulty is proving the fringes produced on the hologram are only from the applied stress and not from some other effect. We will hang small, known masses to apply the stress. To prove HI as a quantitative technique, we have to verify the stability of the apparatus experimentally and reduce as many static and dynamic errors as possible. Think about what surfaces you want to measure on the beam and what each surface would give.

Here are a few ideas for experiments:

1. Find the bending of a thin beam fixed on both endpoints as a function of position.
2. Do the same for a beam fixed only at one end.
3. Do the bending of a flat plate/circle with well defined boundary conditions.

Once you have proven your technique as an accurate way of finding displacement, you can take data very quickly. For whatever experiment you are doing, try finding a scaling relationship between mass and overall displacement. These are fairly simply mechanical systems which have well developed theories. Compare your scaling relation to the theoretical one if possible.

You should also be able to determine a range of masses where this technique is practical for a given system. This is basically set by our limited ability[2] to count fringes and the minimum measurable displacement.

[2] i.e. patience