General Interferometers

① Basics of Interferometry and Interferometers

The dictionary definition goes something like:
"INTERFEROMETER: An instrument designed to produce optical interference fringes for measuring wavelengths, testing flat surfaces, measuring small distances, etc."
As an example of an interferometer for making precise physical measurements, split a beam of monochromatic coherent light from a laser into two parts, bounce the beams around a bit and then recombine them at a screen, optical viewer, or sensor array. The beams will constructively or destructively interfere with each-other on a point-by-point basis depending on the net path-length difference between them. This will result in a pattern of light and dark fringes. If one of the beams is reflected from a mirror or corner reflector mounted on something whose position you need to monitor extremely precisely (like a multi-axis machine tool), then as it moves, the pattern will change. Counting the passage of the fringes can provide measurements accurate to a few nanometers!

Basic Michelson Interferometer shows a simple implementation that's the underpinning of a wide variety of applications:

1. The laser produces a coherent monochromatic beam which is expanded and collimated by a pair of lenses (not shown).
2. Part of the laser beam is reflected up by the Beam-Splitter (partially reflecting mirror), bounces off of Mirror 1 and back down. A portion of this passes through the Beam-Splitter to the Detector.
3. The remainder of the laser beam passes through the Beam-Splitter and bounces off of Mirror 2. Part of this is reflected down by the Beam-Splitter to the Detector.
4. The two beams combine at the Detector resulting in an interference pattern of light and dark fringes or a full field varying between light and dark as the path length is changed. A screen, magnifier, microscope, or other optical imaging system for a human observer or electronic sensor may be provided to view or analyze the fringe pattern in more detail or provide input to an electronic measurement system.

In a perfectly symmetric Michelson interferometer, the fringe pattern should uniformly vary between bright and dark (rather than stripes or concentric circles of light) depending on the phase difference between the two beams that return from the two arms. A circular pattern is expected if the two curvatures of the wavefront are not identical due to a difference in arm-lengths or differently curved optics. Stripes (straight or curved) in any direction would be an indication of a misalignment of some part of the interferometer (i.e. the beams do not perfectly overlap or one is tilted with respect to the other).

In the basic Michelson interferometer, about 50 percent of the light gets reflected back toward the laser and is wasted. When perfectly aligned, the return path will take exactly the same path as the outgoing laser beam, and may destabilize laser action. HeNe lasers are particularly susceptible. Both of these problems can be easily dealt with by, for example, changing the mirrors to retro-reflectors (cube-corners) or roof prisms so that the outgoing and return beams are offset and follow different paths.

A microscopic shift in position or orientation of either mirror will result in a change to the pattern. Thus, for example, Mirror 1 may be mounted on some equipment like a disk drive head actuator that is being tested or calibrated. Its position can then be determined or controlled down to nanometer precision. For these "metrology" applications, the interferometer is set up to produce a fringe pattern with at least two sensors to determine direction and velocity in a sophisticated version of the A-B quadrature decoder used in your typical computer mouse. :) Much more on this topic may be found in the sections starting with Interferometers for Precision Measurement in Metrology Applications.

A long coherence length laser producing a TEM00 beam is generally used for this application. HeNe lasers have excellent beam characteristics especially when frequency stabilized to operate in a single longitudinal mode. However, some types of diode lasers (which are normally not thought of as having respectable coherence lengths or stability) may also work. See the section: Interferometers Using Inexpensive Laser Diodes. Even conventional light sources (e.g., gas discharge lamps producing distinct emission lines with narrow band optical filters) have acceptable performance for some types of interferometry.

Such a setup is exceedingly sensitive to EVERYTHING since positional shifts of a small fraction of a wavelength of the laser light (10s of nm - that's nanometers!) will result in a noticeable change in the fringe pattern. This can be used to advantage in making extremely precise position or speed measurements. However, it also means that setting up such an instrument in a stable manner requires great care and isolated mountings. Walking across the room or a bus going by down the street will show up as a fringe shift!

Interferometry techniques can be used to measure vibrational modes of solid bodies, the quality (shape, flattness, etc.) of optical surfaces, shifts in ground position or tilt which may signal the precursor to an earthquake, long term continental drift, shift in position of large suspended masses in the search for gravitational waves, and much much more. Very long base-line interferometry can even be applied at cosmic distances (with radio telescopes a continent or even an earth orbit diameter apart, and using radio emitting stars or galaxies instead of lasers). And, holography is just a variation on this technique where the interference pattern (the hologram) stores complex 3-D information.

NASA has some information on interferometry oriented toward cosmic measurements at the NASA Interferometry Page. And you can try your hands at aligning a Michelson interferometer at the NASA Interactive Interferometer Page.

This isn't something that can be explained in a couple of paragraphs. You need to find a good book on optics or lasers. Here are some suggestions for further study:

- • Gordon McComb's: "The Laser Cookbook" [1} and the Scientific American collection: "Light and its Uses [5]" include various type of interferometers which can be built with (relatively) readily available parts.

- Keysight Technologies (formerly HP, then Agilent, among others) manufacture 'Laser Interferometry Measurement Systems' based on these techniques. Information and application notes are available by searching for the key words: "Laser" or "Dimensional Measurement". For Agilent in particular, searching for "5501" or "5517" will find information on their specific systems.
- The Astroweb Internet Resources for Astronomy Web site (and others). There are links to people interested in designing, building, and operating various types of laser interferometers. Much of the information relates directly to the testing of optical components for astronomical telescopes but there should be much of general interest as well.