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Instruments

MASTER

INDUSTRIAL INTERFEROMETRY

L. G. Whitten

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the **ATOMIC ENERGY COMMISSION** *under* **U. S. GOVERNMENT** **Contract W-7405 eng 26**

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CARBIDE**

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INDUSTRIAL INTERFEROMETRY

L. G. Whitten

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ABSTRACT

After three-hundred years, the science of interferometry is being accepted in industrial environments. Its progress has been slow, but it is now a useful shop tool. It can be used for the measurement of linear distance, straightness, flatness, and surface finish. It is adaptable to use either as the control or the feedback of tape-controlled machine position.

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SUMMARY

Interference, or the meeting of two beams of coherent light, produces bands, or fringes, alternately light and dark. When the path difference in one beam is changed by an amount equal to one-half the wavelength of light, a new band is produced. This physical phenomenon provides the basis for a measuring system of extremely high resolution. For many years the sensitivity of this system has been a problem; however, with the advent of closer tolerances, interferometry is moving from the laboratory to the production shop. Examples are presented in this report to show its use in measuring linear distance, straightness, flatness, and surface finish.

INDUSTRIAL INTERFEROMETRY

INTRODUCTION

The title of this report was chosen to reflect the belief that interferometry (the application of the phenomenon of light interference) does have industrial uses and is no longer solely a laboratory curiosity.

However, like many other useful things today, interferometry did get its start in the laboratory. Some of the laboratory techniques will be reviewed prior to a discussion of some of the current industrial applications of interferometry.

Interferometry is not a new science. In 1665, Grimaldi observed diffraction fringes which were produced from narrow obstacles and slits. In the same year, Cooke attempted to explain the colors of thin films by means of a crude wave theory. In 1678, Huygens announced his principle of wave propagation through subsidiary wavelets. Newton, between the years 1666 and 1704, did considerable work with interferometry and calculated with surprising accuracy the quantity which is now called the wavelength. Young, in 1802, proved by simple experiments that light is subject to interference and is propagated as a wave form. In 1809, Herschel discovered highly sharpened fringes in a thin film when light emerges near the grazing incidence. Brewster reported in 1817 his observation of the interference effect which takes place when light passes through or is reflected by two similar plane parallel plates slightly inclined to each other. Lloyd, in 1837, performed an important interference experiment using a single mirror. In 1849, Haidinger observed and accounted for the rings now known by his name.

All of this work was done and all of these observations were made prior to the American Civil War. With this background, questions which might arise are: What is interference? What did these early investigators see? What were they looking for?

INTERFERENCE

Using Figure 1 as a reference, interference can be defined, at least partially. If two sources produce waves of the same frequency and similar amplitudes, the pattern is formed as shown by the dark lines in this figure. If, for example, the circles represent the point on the wave of maximum amplitude, then the intersection of these points of maximum amplitude form the pattern which is shown by the heavy dark lines. In Figure 1, the zero-order fringe is located along the line which is equidistant from the two sources. Adjacent to each side, the first, second, and subsequent orders of fringes are shown. Figure 1 depicts an ideal situation because in actual practice it is virtually impossible to get two light sources to vibrate at exactly the same frequency at the same time. However, this phenomenon can be demonstrated by attaching sharp points, such as needles, to the prongs of a vibrating tuning fork and dipping

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Figure 1. THE PRINCIPLE OF INTERFERENCE. (Hydrodynamic Analogy)

the points in the water. Each point will create circular waves which spread out over the surface and produce interference. This situation happens because the two disturbing needles are strictly in phase and thus are able to produce standing waves.

A wave is simply a shape like that shown in Figure 2. Two waves of identical frequency which are in phase are shown in Figure 3. The result of adding these waves is shown by the bottom wave. Here, the amplitudes are in phase to produce a reinforced wave. Figure 4 shows the effect of two waves which are exactly out of phase. In this case, the crests and troughs of the waves cancel each other to give a resultant wave of zero amplitude.

In optics, the phenomenon just described is produced by using a real image and a virtual or reflected image of the same source to give the effect of two waves from a single source. The basic method of doing this is shown in Figure 5. Here, light is supplied from an extended source, such as that which comes from a skylight or a fluorescent lamp. The beam divider divides the light into two components, one component goes to the fixed reference mirror and the other to the moving mirror. Notice that the path lengths are not equal when the mirrors are equidistant from the divider since the light to the movable mirror goes through the glass only once, while the light to the fixed mirror goes through three times. Since the paths must be equal in order to obtain white-light interference fringes, Michelson added a compensator plate

Figure 2. A SINGLE LIGHT WAVE.

Figure 3. WAVES COMBINING. (Addition - In Phase)

Figure 4. WAVES CANCELLING. (Addition - Out of Phase)

Figure 5. PRINCIPLE OF THE MICHELSON INTERFEROMETER.

(Figure 6) which equalizes the path lengths and permits each beam to go through glass three times. This plate is simply a piece of glass which has the same optical properties as the beamsplitter plate.

Figure 6. MICHELSON INTERFEROMETER WITH A COMPENSATOR PLATE.

INTERFEROMETRIC DEVELOPMENTS

The first significant dimensional measurement made by using interferometry was Michelson's measurement of the meter bar at the International Bureau of Weights and Measures in 1892.

Figure 7 shows a view of the International Bureau which is located in Sevres, France. Michelson's original interferometer is still being used in a room almost directly across the hall from the spot where the white car is located in this photograph.

Work on interferometry is historically slow. Four years later, in 1896, Michelson chose the red line of cadmium as the best primary standard and measured its wavelength in terms of the meter. It was not until 1906 that Benoit, Fabry, and Perot confirmed Michelson's measurement of the wavelength of the red line of cadmium.

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Figure 7. INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES.

In 1916, Twyman-Green modified the basic Michelson interferometer (Figure 8) by adding a collimator lens so that a point source of light could be used instead of the extended light source previously used. Figure 9 presents a view of the fringes which would be seen by an observer if monochromatic light were used as the light source. A fringe is formed at each point where the change in light path in either of the two legs of the interferometer is equal to one-half the wavelength. Therefore, each fringe represents a change in distance of about eleven microinches for this particular light source. In this case, each fringe is essentially the same as its neighbor; therefore, no single fringe can be assigned a unique value. If a compensator plate is added and white light is substituted, the field of view changes to that shown in Figure 10. Here, the easily identifiable black, "zero-order" fringe represents a line along which each leg of the interferometer is exactly equal. Unfortunately, the fringes fade away quite rapidly, as seen along the edges of the figure.

Proceeding historically to 1922, the International Astronomical Union defined the unit of wavelength, the angstrom, in terms of the wavelength of the red cadmium line. The angstrom is the unit of length for all electromagnetic waves perceptible by optical means.

Figure 8. MICHELSON INTERFEROMETER AS MODIFIED BY TWYMAN-GREEN.

Figure 9. FRINGES FROM MONOCHROMATIC LIGHT.

Figure 10. FRINGES FROM WHITE LIGHT.

In 1927, the Seventh General Conference on Weights and Measures gave provisional sanction to the standard measurement of length in terms of the wavelength of the red cadmium line instead of by direct reference to the meter. The Conference did not substitute the red cadmium line for the meter as a standard of measurement at this time but did give provisional sanction to the use of the red cadmium line.

In 1933, the International Institute of Weights and Measures appointed a subcommittee to make detailed suggestions for the use of some wavelength of light as a fundamental standard.

In 1939, Sears and Barrell completed a precision measurement of the refractive index of air.

The subcommittee established by the International Institute of Weights and Measures continued their work and, in 1960, the wavelength of light was adopted as a new international standard of length measurements. The standard of length is now defined as the wavelength of the orange-red line of krypton-86 operating at the temperature

of the triple point of liquid nitrogen. This temperature, 63°K , is maintained by operating both the lamp and liquid nitrogen under vacuum conditions of about 95 torr. Under these conditions, the krypton is frozen. Therefore, both the temperature and vapor pressure are well established.

PROBLEMS ASSOCIATED WITH INTERFEROMETRY

Suitable Light Source

The three-hundred-year delay between the first observation of interference fringes and their acceptance as a primary standard of measurement was not because of a lack of interest or study. One of the biggest drawbacks was that of obtaining a satisfactory light source. Up until a very short time before he made the measurements on the meter bar, Michelson was proposing sodium as a light source because of its extremely bright yellow-colored radiation. However, there are two yellow spectral lines of sodium which are separated by only a few angstrom units and this causes problems with long measurements. (An angstrom is equivalent to approximately 0.004 micro-inch.) It was for this reason that Michelson switched to the red cadmium line for his investigation. The problem is one of getting a lamp which has an easily identifiable sharp spectral line or lines. A lamp which radiates many colors is not acceptable because each color has a different wavelength. The spectrum from some lamps can be isolated and sharpened with filtering which produces a longer theoretical range of interference for a particular lamp; but, unfortunately, the filtering effect cuts the intensity to such an extent that the range is reduced because of a lack of intensity rather than the spectral problem.

The nucleus affects the wavelength of a spectral line to a small extent. However, it was not until the 1940's that significant work was accomplished with respect to purifying the lamp sources used for interferometry. At this time, the investigation and use of the isotopes of elements in a lamp instead of the natural elements was begun. One of the first breakthroughs was that of using mercury-198 as the lamp element. This isotope of mercury was obtained by bombarding gold, which has an atomic weight of 197, with neutrons in one of the atomic piles at the Oak Ridge National Laboratory. Others throughout the world were working on this same problem. A strong contender with mercury-198 was krypton-86.

During the 1950's, the various light sources which had been recommended as a new international standard of length were evaluated at the International Bureau of Weights and Measures in Sevres. The basic interferometer system which Michelson had used in the 1890's was used for this work.

As mentioned previously, the International Committee on Standards finally adopted the orange-red line of the krypton-86 isotope as a new international standard of measurement.

Measurement

There have been problems in utilizing interferometry to measure length, straightness, flatness, and surface finish. A discussion of some of these problems may help in understanding the difficulties that interferometry encountered in gaining acceptance as a standard of measurement.

Concerning length measurements, the problems associated with the use of interferometry have been very real for lengths of one inch or longer.

One of the problems is illustrated in Figure 11. When a length is measured by comparison with wavelengths in air, it is necessary to know the index of refraction of the air because the wavelength changes as the index of refraction of the air changes. In turn, the index of refraction of the air changes as the barometric pressure changes. Therefore, when making interferometric measurements in air, it is necessary to know the barometric pressure and apply a correction if the barometric height differs from the standard pressure of 760 millimeters of mercury. An error of 1/4 millimeter in the measurement of the height of the mercury column of a barometer will result in an error of 0.1 microinch per inch in the length of the final measurement (Figure 11).

Figure 11, EFFECT OF INACCURATE BAROMETRIC PRESSURE MEASUREMENT ON INTERFEROMETRIC MEASURING ACCURACY.

Similarly, the index of refraction of air changes and hence the wavelength of a standard radiation is also affected by the temperature of the ambient air. As indicated in Figure 12, an error of 0.1°C in the temperature of the air will introduce an error of 0.1 microinch per inch of measured length.

Figure 12. EFFECT OF AIR-TEMPERATURE MEASUREMENT ON INTERFEROMETRIC MEASURING ACCURACY.

Other environmental conditions which affect the index of refraction and, consequently, the wavelength of the light being used are humidity and the gas content of the air. However, all of these conditions (that is, barometric pressure, humidity, temperature, and gas content) can be determined quite accurately.

Characteristics of Light Waves

One of the greatest drawbacks to accurate interferometric measurement, as mentioned earlier, is that of obtaining satisfactory light sources especially that which pertains to spectral sharpness and coherence.

So far, light waves have been discussed as though they were individual waves; but, actually, this is not the case. The light emerges from the source as a bundle of waves, and the range over which they can be used for length-measuring interferometry is limited by the range or the distance in which the light rays remain coherent. A

squad of marching men can be used to illustrate what is meant by coherence. As the squad marches and cadence is counted, the squad remains in step, and even after a hundred paces, all left feet come down together and all the right feet come down together. So this squad, this "bundle of light rays", is coherent. Now, on the other hand, a drill master might prepare the same squad of men for the march by saying, "All right you guys. On your mark, get set, go". It is easy to see that without counting cadence this squad would quickly be incoherent and probably step all over each other instead of being in step. When this happens in optics, the orderly interference of light is impossible.

There are two ways to use interferometry in the measurement of length: (1) the fringe-fraction technique, and (2) the fringe-counting technique. In the fringe-fraction technique, the colors of a given source such as krypton are spectrographically separated into the appropriate spectral lines such as orange-red, yellow, yellow-green, green, blue, and violet. This separation, in effect, gives six different scales with which to measure a given length. By knowing the wavelength of each scale (in this case each color) and by observing the fringe fraction which is left over from some integral number of fringes for each color, it is possible to calculate back and determine the exact size if the nominal length is known with sufficient accuracy.

The fringe-fraction technique is complicated and involves many observations for each measurement. For this reason, the fringe-counting technique has preference as a measuring method. However, even this technique is not perfect. Since a fringe is generated with every half wavelength of light, approximately 80,000 to 90,000 fringes will be generated over a distance of one inch, depending on the exact color. In counting these fringes, it is obvious that the count must not lose or gain, and if vibration is present, it must be compensated for by adding and subtracting counts.

It is necessary either to count fringes or to stop, observe, and calculate from the fringe fractions. Corrections must be made for air temperature, barometric pressure, humidity, and the gas content of the air; and, in addition to all of this, the measuring range must be limited to only a few inches.

Lasers

With the advent of the isotopic lamp sources, the useful range of the interferometer was extended considerably. A mercury-198 interferometer is shown schematically in Figure 13. Using this isotope, the range was extended to about eight inches. However, concurrent with the work toward developing electronic counting gear and optical components for this interferometer, the laser was being developed, but for other reasons—principally for a communication channel. One of the additional products of its development has been to provide an extremely coherent monochromatic light source of high stability.

At the present time continuous-wave, helium-neon gas lasers are available, similar to the ones which have been manufactured and evaluated at the National Bureau of

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Figure 13. A MERCURY-198 INTERFEROMETER.

Standards. The Bureau presently reports that the meter bar can be measured using this type of laser as a light source and counting fringes with electronic counters to an accuracy of seven parts in one hundred million. Or, saying it another way, if one hundred inches were measured, the measurement would be off seven microinches.

Even with the laser, the light is not strictly coherent and monochromatic. All spectral lines exhibit a broadening effect similar to that shown in Figure 14. However, the single-frequency laser has a dip at the peak of the curve, as indicated, which is named after its discoverer and known as the Lamb dip. By adjusting the cavity length of the laser, it can be made to operate at the center of this dip and, therefore, at a known frequency, because frequency is proportional to the cavity length. This adjustment is something that is easily observable on either a meter or an oscilloscope.

Figure 15 shows a cross section of a typical single-mode laser tube. The laser consists of a Fabry-Perot interferometer with a plasma discharge tube containing helium and neon between the two reflecting mirrors. The plasma tube acts as an amplifier and the Fabry-Perot cavity provides positive feedback to form an oscillator. The plasma tube has end windows oriented at an angle known as Brewster's angle. At this angle,

Figure 14. CURVE TO ILLUSTRATE THE BROADENING EFFECT.

the transmission loss through the windows is extremely small for one linear polarization orientation. Therefore, the light output from a gas laser with Brewster's angles will be linearly polarized.

Inside the plasma tube, a glow discharge takes place in the helium-neon gas between the cathode and the anode. The glow discharge excites the helium-neon atoms to all states which are energetically and quantum-mechanically possible.

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Figure 15. CONTINUOUS-WAVE HELIUM-NEON GAS LASER.

The theory behind the laser action is not covered in this report; however, it has been found that the plasma tube gain is a function of the inside diameter of the plasma tube. The gain varies inversely with the tube's inside diameter; therefore, a small bore is required for a large gain. This means the helium-neon gas lasers characteristically emit beams of small diameter which can be considered advantageous in interferometric work.

Since a light source which can be used over a long range is now available, what remains to be accomplished is that of counting the fringes at a high rate in both a forward and reverse direction. The Y-12 Plant has had in operation for the past several years a project to attain this goal. The present status of this project is discussed in the sections that follow.

PRESENT STATUS OF SOME INTERFEROMETRIC MEASURING SYSTEMS

Length

In Figure 16, the interferometric measuring system with its associated components is shown mounted on a 66-inch vertical boring mill. By mounting such a measuring

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Figure 16. INTERFEROMETER INSTALLED ON A 66-INCH VERTICAL BORING MILL.

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Figure 17. DETECTOR UNIT FOR AN INTERFEROMETER.

system on each of the two axes, the machine is converted from a manufacturing machine to a measuring machine. The laser, detectors, and associated electrical components can be seen in this figure.

Figure 17 shows a close-up view of the detector which has been made very small. This instrument contains the beam divider, the two photodetectors for forward and reverse counting, the fixed mirror, and a preamplifier. By combining this device with the laser tube, a bidirectional counter, and a moving reflector, the measuring system is complete and ready to operate.

Another installation is shown in Figure 18. Here, the laser tube is mounted on a hydrostatic measuring machine which is being converted to tape-control continuous-path operation. The difference here is that on the 66-inch vertical boring mill, the amount which the ram moves in either a horizontal or vertical direction is monitored and measured by the measuring system. In this case, the measuring system is being used to control each axis with the fringes acting as pulses in the control circuit computer.

To obtain actual measurements, both of these systems display fringes that must be converted to inches and corrected for changes due to the environmental conditions.

Concurrent with Y-12 developments, industry has been asked for an interferometric measuring system. This system is shown schematically in Figure 19. As shown, the light path is reflected via a corner-cube prism. Such a system (Figure 20) has been built and delivered. Here, the system is mounted on a tape-controlled lathe and is

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Figure 18. INTERFEROMETER INSTALLED ON A HYDROSTATIC MEASURING MACHINE.

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Figure 19. PRINCIPLE OF A COMMERCIAL INTERFEROMETRIC MEASURING SYSTEM.

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Figure 20. COMMERCIAL INTERFEROMETRIC MEASURING SYSTEM MOUNTED ON A TAPE-CONTROLLED LATHE.

being used to calibrate the lathe for accuracy along one axis. A sensor unit contains the laser tube and photodetectors as well as the other optical components for splitting the beam. The reflector is a corner-cube prism which is mounted on the moving member. The control console has the controls to select either forward or reverse counting, the zero setting, and a meter showing the operation of the laser at its null point. The amount moved is displayed directly in inches to the closest ten microinches.

Y-12's specifications required that this system be accurate to 100 microinches and have a range of six feet. Its accuracy far exceeds the minimum requirements and indications are that it will be accurate to approximately 17 microinches. Its counting range is 99 inches (8.25 ft) instead of the six feet of displayed travel. In actual operation, this unit has been used with a separation of over twelve feet between the sensor and the reflector.

Its portability is demonstrated in Figure 21 where it has been removed from the tape-controlled lathe as a calibration device and set up on a measuring machine as a measuring device. In this mode of operation, the slide is traversed a distance as indicated on the control console. When the distance is obtained, the slide is stopped and the gage head is brought into place on the part or piece being inspected; a measurement is then taken and recorded as a deviation from the true value.

Work is continuing toward making interferometry even more useful in length measurements. Commercial units are now being made with a range of 400 inches (33.3 ft), a least count of 10 microinches, a counting rate of 240 inches (20 ft) per minute, and

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Figure 21. INTERFEROMETRIC MEASURING SYSTEM (AIL) MOUNTED ON A MOORE MEASURING MACHINE.

a switch-selected display of units in either the English or metric system. These units, easily adaptable to existing machines, provide increased accuracy. However, it must be realized that errors due to Abbe offset are still present and must be taken into consideration unless the measuring axis and the workpiece axis are coincident.

The use of interferometry for short-distance measurement has not been neglected at the Y-12 Plant. In the early 1960's it was believed that the white-light interferometer could be used as a measuring device by observing the zero-order black fringe as a fixed fiducial mark. Figure 22 shows two white-light interferometers set up to measure a four-inch-diameter gaging ball. The light source and viewing microscope are built directly into the interferometer body. For use, the instruments are each adjusted on a known standard such as gage blocks, and then the part to be measured is substituted. The change in position of the zero-order fringe is an indication of the part size with respect to the standards which were used.

Figure 23 shows a similar arrangement in that the light comes through a hole in the top of the instrument to a right-angle-prism beamsplitter, hits the moving mirror which is connected to the parallel reed assembly, and then is reflected back to the observer. This device is an extremely small package which is usable in the production shop. It has been used to detect spindle translation with respect to a machine base over long periods of time while the machine was being used routinely in the shop.

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Figure 22. WHITE-LIGHT INTERFEROMETER PAIR.

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Figure 23. WHITE-LIGHT, PARALLEL-REED INTERFEROMETER.

As mentioned earlier, one of the disadvantages of the white-light interferometer is that its range is extremely short—a few fringes or 30 to 50 microinches.

Figure 24 shows an extended-range white-light interferometer. In this arrangement, the fixed mirror is no longer fixed, but attached to the nonrotating spindle of a precise micrometer. By focusing on a part, and then moving the reference mirror and noting how far it has been moved, the range of this interferometer is extended to approximately one inch.

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Figure 24. EXTENDED-RANGE, WHITE-LIGHT INTERFEROMETER.

Straightness

Straightness of motion on the slides of machine tools or gages is important because of Abbe offset, shown in Figure 25. Here, where the measuring axis is offset from the measured axis, there is an error in position which is proportional to the angle. In addition to this offset, there is an error due to the translation of the slide; that is, movement in the direction perpendicular to the travel.

In a copying lathe, the translational movements are of little or no consequence. However, with the advent of tape-controlled machines and gages, translation becomes increasingly important.

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Figure 25. POSITIONAL ERROR DUE TO THE ABBE OFFSET AND SLIDE CURVATURE.

The autocollimator shown in Figure 26 is an excellent instrument for machining small angular errors. However, this instrument will not pick up the translation of a slide, or deviation from straightness. As a result of this shortcoming, the Y-12 Plant developed an alignment interferometer, shown in Figure 27. The light path is made to purposely enter the Kesters prism at a slight angle and diverge as it leaves the faces of the prism. The reference mirror is a right-angle prism and the sensitivity is controlled by the thickness of the rotatable glass plate. Using this instrument, errors in straightness of ten microinches can be detected over a distance of twelve feet. This instrument, installed on the ways of a hydrostatic gage, is shown in Figure 28.

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Figure 26. AN AUTOCOLLIMATOR.

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Figure 27. ALIGNMENT INTERFEROMETER. (Model II)

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Figure 28. ALIGNMENT INTERFEROMETER INSTALLED ON A HYDROSTATIC GAGE.

A typical slideway plot, which shows the relationship between the autocollimator reading in seconds and the actual translation in microinches, is presented in Figure 29. One of the biggest advantages of the alignment interferometer is that the trans-

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Figure 29. A TYPICAL SLIDEWAY PLOT.

lation is measured directly without regard to the distance traveled longitudinally. Because of this, it is possible to analyze errors, as shown in Figure 30. Here, the carriage is moved continuously over several inches while the interferometer output is recorded on a strip-chart recorder. The charts show quite graphically the influence of the five-pitch screw that was used to position the carriage. Obviously, the screw is either bent or the pitch diameter of the screw is not coincident with the axis of rotation.

Figure 30. A METHOD OF ERROR ANALYSIS.

Surface Finish and Flatness

The last major category is that of surface finish, including flatness, which is shown being measured with an optical flat in Figure 31. There is not a clearly defined line

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Figure 31. MEASURING FLATNESS USING AN OPTICAL FLAT.

between flatness and surface finish, especially when the closer surface finishes are involved. The optical flat shown in this figure gives a three-dimensional picture of a part under inspection. It has length, width, and, by interpretation of the interference fringes, a precise reading of depth. It acts just like a contour map; each contour line represents a change in height of eleven microinches. Facilities are available for checking flatness with optical flats in sizes up to twelve inches in diameter. Figure 32 illustrates the principle of operation of the optical flat.

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Figure 32. PRINCIPLE OF OPERATION OF THE OPTICAL FLAT.

The main disadvantage to the use of optical flats in this manner is that the surfaces are in contact at one point. However, this disadvantage can be overcome by using the instrument shown in Figure 33. Here, the light from a mercury source is filtered, collimated, and projected through a five-inch-diameter reference flat. Upon reflection, the beam is diverted to the eyepiece. The use of filtered monochromatic light which has been collimated allows fringes to be observed when the reference flat and the piece are separated by a distance of several inches.

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Figure 33. THE DAVIDSON INTERFEROMETER.

For longer lengths, the grazing incidence interferometer, shown in Figure 34, is used. Here, the light is divided into two components with a Kosters prism. One component strikes the surface being investigated at the grazing incidence. Upon reflection, this component recombines with the reference component to produce the interference

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Figure 34. GRAZING-INCIDENCE INTERFEROMETER.

fringes shown in Figure 35. Because of the grazing angle, the distance between each fringe represents a change in height of 75 microinches rather than the usual 11 microinches. One of the advantages of this instrument is that interference patterns can be obtained from normally nonreflective surfaces such as black granite. In Figure 34, the instrument is shown on a nonreflective black-granite parallel to check the straightness of one of the surfaces.

The interference microscope is used for the examination of surface finishes. Typical views of such surface examination are presented in Figure 36. The top right-hand and both left-hand views show the surface defects under ordinary, phase contrast, and oblique illumination. The lower right-hand view is the same surface with interference fringes. Disadvantages of this method are: (1) the finish must be reflective; (2) it must have a peak-to-valley height of less than 40 to 60 microinches; (3) the area under observation is generally small, such as 80 mils or smaller; (4) the interferometer is in close proximity to the part; and (5) the results are subject to individual interpretation.

These disadvantages can be overcome in several ways. The reflectivity of any part can be improved with the application of aluminized coatings, the peak-to-valley height can be extended with oil-immersion and replica techniques, the close proximity can be overcome with extension optics, the small-area disadvantage can be overcome

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Figure 35. INTERFERENCE FRINGES FROM THE GRAZING-INCIDENCE INTERFEROMETER.

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Figure 36. SURFACE EXAMINATIONS USING THE INTERFERENCE MICROSCOPE.

by scanning, and individual interpretations can be overcome by making permanent film recordings.

The principle of extension optics, presented in Figure 37, can be applied to interference microscopes as well as to surface-finish comparators. For use with the interference microscope, however, two extension-optic tubes are used. One tube is for the specimen beam and one is for the reference beam. As shown in the figure, the working distance is extended from about 1/8 to 2 inches.

Scanning is accomplished by traversing the specimen over the field of view until all of the area is covered. Alternately, the specimen can be held stationary and the interference microscope can be moved. The most highly successful method is to mount the specimen in a special holder attached to the spindle of a measuring machine. The interference microscope and recording 16-mm movie camera are then placed on

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Figure 37. PRINCIPLE OF EXTENSION OPTICS.

the horizontal table which can move under motor control in either an X or Y direction. The spindle positioning mechanism is used for coarse focusing and regular microscope controls are used for fine focusing.

Film clips of such an arrangement are shown in the following sequence of figures: Figure 38 shows gage block surfaces with and without extension optics; Figure 39 shows successive 16-mm movie frames of a scratch; and Figure 40 shows a peen mark in the scanning sequence.

(a) With Extension Optics

(b) Without Extension Optics

Figure 38. GAGE BLOCK SURFACES.

(a)

(b)

(c)

(d)

Figure 39. SUCCESSIVE 16-MM MOVIE FRAMES OF A SCRATCH.

(a)

(b)

(c)

(d)

Figure 40. SUCCESSIVE 16-MM MOVIE FRAMES OF A PEEN MARK.

CONCLUSIONS

The intent of this report has been to show some of the more unusual applications of interferometry to industrial measurement. Surely, the number of applications of interferometry in the fields of length, straightness, flatness, and surface-finish measurement are unparalleled by any other method. These applications have been brought about by a better understanding of what is happening and by more useful hardware. As time and techniques progress, interferometry will become more of a necessary industrial tool and less of a laboratory curiosity.

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