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BDX-613-1848 (Rev.)

EQUIPMENT FOR A LASER
SURFACE MEASURING SYSTEM

By R. T. Stagner

Published November 1978

Topical Report
P. E. Klingsporn, Project Leader

Prepared for the United States Department of Energy
Under Contract Number DE-AC04-76-DP00613.

Bendix

**Kansas City
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Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price:	Microfiche	\$3.00
	Paper Copy	\$4.50

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EQUIPMENT FOR A LASER SURFACE MEASURING SYSTEM

BDX-613-1848 (Rev.), Topical Report, Published November 1978

Prepared by R. T. Stagner

An automated device for inspection of highly polished spherical surfaces has been designed and the components substantially integrated into a functional system which has been used to provide experimental data. The computer-controlled opto-electronic system processes laser light reflected from polished surfaces and provides data from which the size of small flaws may be determined. Operating parameters for the system have been characterized and projected inspection times calculated for various sphere sizes.

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A prime contractor with the United States
Department of Energy under Contract Number
DE-AC04-76-DP00613

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SUMMARY

An automated inspection system for highly polished spherical surfaces has been designed to replace the time consuming, highly subjective interference microscope techniques currently in use. Equipment for the system has been procured, tested and substantially integrated into a functional device which was used during this reporting period to provide experimental inspection data from defects on stationary spheres.

Three interactive devices--a minicomputer, a highspeed diffraction pattern sampler, and a two-axis rotary fixture--are the major system components. As a sphere is moved by the computer-controlled, two-axis rotary fixture, light reflected from the surface is sampled by the high speed diffraction pattern sampler.

The light source for the system is the output of a He-Ne laser which is processed through appropriate optics.

Numerous support devices were designed or procured including an electro-mechanical positioning device, an optical tramming system, an optical mounting system, a vibration isolation system, and a system enclosure.

Operating parameters for the system have been characterized and projected inspection times calculated for various sphere sizes.

DISCUSSION

SCOPE AND PURPOSE

Manual inspection of highly polished spheres using interference microscopes is an extremely time consuming process which is heavily dependent upon the judgment of the inspector. To decrease inspection time and improve inspection consistency, an automated surface inspection system has been designed. Equipment for this system has been procured, tested, and for the most part integrated into a functional device which, during this reporting period, was used only experimentally to examine defects on stationary spheres. This work was accomplished between June 1975 and December 1976.

PRIOR WORK

Numerous possible methods of inspecting highly polished surfaces were investigated, and a technique using the diffraction effects caused by defects which were illuminated with laser light was chosen for development. The theoretical aspects of this technique have been thoroughly investigated¹ and an appropriate optical system designed.²

ACTIVITY

The automated surface inspection system (Figure 1) is a mini-computer-based electro-optical device. Its purpose is to identify and measure the depth and width or diameter of pits and scratches on highly polished surfaces. This function will be accomplished through the evaluation of perturbations in reflected laser light caused by the light scattering and diffraction effects of the defects. Efforts during this reporting period made the data-taking system operational and allowed measurement of defect diameters and widths on non-rotating spheres.

A block diagram of the inspection system is shown in Figure 2. The output of a He-Ne laser is passed through the optical system and brought to a virtual focus at the center of the sphere being inspected which is held in a two-axis rotation fixture. The light reflected from the sphere surface is passed back through a portion of the optical system and focused on the face of a 64-element photodetector. The electrical response of the photodetector is sampled and converted to digital format by the high speed diffraction pattern sampler. The digital output of the diffraction pattern sampler is read into the minicomputer, which evaluates and stores the reflected light information. The minicomputer also receives information from the two-axis scanning

Figure 1. Laser Surface Certification System

Figure 2. Block Diagram of Laser Certification System

fixture, which allows computation of defect location and controls the scanning movement of the fixture.

System Minicomputer

The brain of the system is a minicomputer that has 16K bytes of memory and includes two 1.25 mega-word disk storage units. Interface to peripherals such as the high speed diffraction pattern sampler (HSDPS-1) and rotary fixture is accomplished through interface cards. The computer controls data-taking rate, evaluates and stores the incoming data, and controls the vertical axis of the two-axis rotary fixture.

High Speed Diffraction Pattern Sampler

The HSDPS-1 acts much like a high-speed camera. On command from the computer, it freezes the output from all 64 photodetector elements and serially converts the electrical impulses to digital format. These 64 data points give a comprehensive picture of the light intensity levels at various locations on the photodetector face.

The HSDPS-1 (Figure 3) consists of three main elements: the photodetector, the amplifier unit, and the main frame digital unit. The photodetector (Figure 4) consists of 64 silicon photodiodes formed on a single substrate. Thirty-one of the photodiode elements are semi-annular in shape and increase in width with increasing radius. The center, or "DC" element, is circular with a diameter of 178 μm . These elements are useful in measuring radial intensity variations in circular diffraction patterns. The remaining 32 elements are wedge shaped and are useful in measuring angular energy distribution. Space between elements for both rings and wedges is 25 μm . The amplifier unit contains 64 preamplifier and sample-and-hold circuits, channel multiplexing units, and the output line driver. The main frame digital unit contains an autoranging amplifier, the analog-to-digital converter, and the necessary digital-logic control devices.

The HSDPS-1 has both manual and remote control capability. Under the manual mode, channel selection and readout are accomplished through the control panel and timing is completely controlled by an internal clock.

With the HSDPS-1 under computer control, the data-taking sequence is initiated with a hold command from the computer. The hold command freezes the voltage level on all 64 samples-and-hold circuits. The computer next outputs the octal address of the channel to be selected and initiates the analog to digital (A/D) conversion process. The A/D conversion process is a two-step sequence. During the

Figure 3. Block Diagram of High Speed Diffraction Pattern Sampler

Figure 4. Sixty-Four Element Photodetector

first A/D conversion, the autoranging amplifier is at the lowest gain state. At the end of the first conversion, the output of the A/D converter is fed to an eight-input priority encoder which establishes the proper gain state for the autoranging amplifier. The encoder outputs are the inputs to a programmable read-only memory, which causes selection of the proper feedback resistor in the auto ranging amplifier circuit. With the autoranging amplifier now in an optimal gain state, the second A/D conversion takes place and an "end of conversion" (EOC) signal is transmitted to the computer. Upon receipt of the EOC signal, the computer reads the 11 data lines. Eight of the output data lines form the octal mantissa of the data and the three remaining lines are a binary characteristic.

Having read the data from one channel, the computer then selects a second channel and the data taking process is repeated. The sample-and-hold amplifiers are not returned to the sample mode until all 64 channels have been read. The entire process of reading 64 channels under computer control takes less than 5 ms. The ratio of largest to smallest light intensity that can be handled by any one channel is 65,500 to 1. The resolution is 1 part in 256.

For experimental work, a more useable output results when the basic octal data is converted to intensity in $\mu\text{W}/\text{cm}^2$. This is accomplished by converting the octal output to decimal and multiplying by a factor which accounts for the area of given detector elements and responsivity of the detector material. To develop the responsivity factor, a light beam of known intensity is projected onto the detector and the corresponding output from the largest photodetector element is determined. This allows units of output to be correlated to intensity. Since detector output is proportional to both intensity and area, the output of other detector elements is multiplied by the intensity factor and the ratio of the largest detector element area to the area of the element being read. For example, a light intensity which produces a 5 V output through the circuitry of ring number 32 would cause an output of only 19.3 mV from ring number 10 because of the difference in area.

Each of the 64 data channels has a characteristic output when the photodetector face is covered. While this output is referred to as the "dark current," it is actually a result of amplifier drift and preset bias. The true dark current from the photodetector elements is offset by biasing the first stage amplifiers to zero output during setup. Dark current levels are determined and stored prior to data-taking operations. Dark current values are then subtracted from detector outputs prior to conversion to intensity values so that all data is referenced to a "zero" base.

High Speed Diffraction Pattern Sampler Upgrade

Following receipt of the HSDPS-1, the device was given an operational check in accordance with the manufacturer's recommendations. This check consisted of manually reading the 64 channels while the photodetector array was under uniform illumination. The relationship of these outputs was found to follow closely the area relationship of the photodetector elements. This provided an initial indication that all photodetector-amplifier channels were functioning properly.

The HSDPS-1 was interconnected with the minicomputer, which allowed fully computer-controlled, high-speed operation. With the increased ability to take data samples of statistically significant proportions, serious questions arose concerning the accuracy of data produced by the HSDPS-1. Repeated sampling of reflected light taken

under relatively stable conditions gave deviations from the means which were much greater than those which could be explained by light intensity variations. A detailed evaluation of the equipment indicated that while the basic design concept of the equipment was adequate, the execution of the design was substandard in many respects. To accomplish the needed improvements in the equipment, all active components (i.e., circuit boards, LEDs, switches) were remounted in a new chassis and the entire mainframe unit was rewired. In conjunction with the rewiring, an improved grounding system was implemented, all 120 Vac lines were shielded, analog and digital lines were physically separated and bypass capacitors were installed.

In addition to the general electrical noise, which was reduced from 800 mV to 20 mV during the mainframe rework, an analog signal problem was found which was related to the channel switching logic. A reduction of the analog signal level into the auto-ranging amplifier was found to occur when multiplexer logic lines were switched during the multiplexing operation. The worst case occurred when the autoranger input was switched from the last channel on one amplifier unit board (111) to the first channel on the next board (000). During this switching operation, three logic lines were changing state at once in the same direction. Two opposite state changes, such as (001) to (010), had no effect on the analog signal level. It was found that the switching noise was being propagated onto the photodetector cable shield leads, thus directly affecting analog voltages through the high-gain first stage amplifiers. By increasing the logic switching device load resistors to reduce the relative change in current drain during switching and by changing the detector lead shielding arrangement from a capacitively coupled to a directly coupled ground arrangement, the effect of logic switching was reduced to acceptable levels.

Two-Axis Rotary Scanning Fixture

If the entire surface of a sphere is to be examined, either the laser beam or the surface must be moved. Movement of the laser beam was judged impractical; therefore, a fixture was purchased with the capability of rotating a sphere so that the entire part could be inspected in two hemispherical sections.

The fixture, consists of a small air-bearing spindle mounted horizontally on a precision rotary table (Figure 5). The position of the horizontal spindle can be adjusted along a radial line through the center of the rotary table to accomodate varying sphere sizes. A fine adjustment is also available to bring the vertical and

Figure 5. Precision Two-Axis Rotation Fixture

horizontal spindle axis into coincidence. To avoid movement of reflected light patterns relative to the photodetector, the geometric center of the sphere being inspected must remain in a relatively fixed location as the sphere surface is moved. This required vertical and horizontal spindle accuracies of better than $0.25 \mu\text{m}$ TIR.

The horizontal spindle is driven by a variable speed, feedback controlled, dc motor. The horizontal spindle rotation rate is set manually and accurate to within 3 percent, up to 20 rad/s. In addition to the motor-tach system, an optical encoder outputs ten pulses per revolution to be used in computer verification of spindle speed and indicating the completion of one revolution. The vertical axis is driven by a stepper motor which is programmable to 99.99° in 0.01° increments. Incremental angular rotation of the table is set manually in response to computer instructions; the initiation of the indexing sequence is under computer control.

Acceptance tests of the rotary fixture were conducted by the Bendix Metrology Department. Results of these tests are included as Appendix A. Axial and radial runout of the horizontal spindle were found to be less than 0.08 and $0.18 \mu\text{m}$, respectively. Axial runout of the rotary table was found to be $0.18 \mu\text{m}$ and radial runout was found to be $0.48 \mu\text{m}$ over 120° of travel. The radial runout figure on the rotary table was found to be partially due to bending stress, which resulted from the off-center load of the horizontal spindle. The addition of a counterweight opposite the horizontal spindle is expected to improve the radial runout of the rotary table.

Piezoelectric Wobble Plate

To obtain the full advantage of the rotational accuracy of the air bearing spindle, a suitable method of aligning a sphere along the horizontal axis was required. Analysis of numerous approaches indicated that a wobble plate design such as that shown in Figure 6 would be most practical. A purely mechanical version of this device has been used to align parts during inspection by interference microscope for some time. Experience with the existing device indicated several deficiencies for use in a high volume inspection system.

Movements in the low micrometer range (i.e., $0.25 \mu\text{m}$) were unpredictable and not sufficiently fine.

The device required "hands on" adjustment by the operator which would necessitate thermal settling.

The device can be adjusted only with the spindle at rest.

To overcome these deficiencies, a wobble plate, using piezoelectric pushers, was designed.

Figure 6. Piezoelectric Wobble Plate

The new design incorporates two PZ-30 piezoelectric pushers mounted orthogonally behind the wobble plate. These pushers respond to applied voltage by changing length at the rate of $5.5 \mu\text{m}/1000 \text{ V}$. As the PZT transducers are almost purely capacitive there is no heat dissipation, and the positioning resolution is almost infinite, limited only by the smallest incremental voltage step which can be applied and the noise and ripple associated with the power supply. The effective range of positioning is enhanced by mounting the pushers closer to the center of rotation of the wobble plate than to the center of the sphere being aligned. Coarse adjustment of the wobble plate is accomplished by moving the screws against which the PZT pushers bear. Return force is provided by disc springs which bear against the wobble plate. The selection of these springs proved critical during prototype development. Calculations indicated that springs with too great a spring constant could damage the PZT pushers, but that too low a spring constant would allow displacement of the ball because of gravity.

The PZT pushers are controlled by PZ-62 variable dc power supply. This supply has three output channels which are variable from 1 to 1000 vdc. Coupling of the supply to the PZT pushers is

accomplished through gold-plated copper slip rings and dual rhodium brushes. The high voltage and almost nonexistent current requirement of the pushers tends to minimize any possible effects of brush noise, so that the dimensional stability of the PZT pushers is almost entirely a function of the power supply stability.

The range of sphere travel provided by the PZT pushers is about $2.5\text{ }\mu\text{m}$ in $0.03\text{ }\mu\text{m}$ steps. Tests have shown that manual coarse adjustment to within $1.27\text{ }\mu\text{m}$ can be easily accomplished and that runout of less than $0.25\text{ }\mu\text{m}$ can be attained with minimal difficulty using the PZT pushers.

Optical Trammig Device

As has been stated, the geometric center of the sphere being inspected must be accurately positioned on the vertical and horizontal axis of the scanning fixture to ensure correct interpretation of reflected light patterns falling on the photodetector. Mechanical or electronic contact probes are unsuitable for trammig of the sphere because stylus contact would degrade the highly polished surfaces. An optical sensing device has been developed that allows accurate positioning of a sphere while avoiding actual contact.

Movement of the geometric center of the sphere being inspected relative to a light beam focused approximately to the center of the sphere will cause a movement of the reflected light beam. The movement of the reflected light can be sensed by a change of output from a position sensing photodetector. By minimizing this change in output variation, a sphere can be aligned on the axis of rotation.

A schematic of the position sensing detector circuit is shown in Figure 7. A change in the position or intensity of the light beam incident on the SC-10 photodetector results in a change in the inputs to the sum and difference amplifier. The outputs of the amplifier are the difference in input currents which is responsive to both position and intensity and the sum of input currents which is responsive to intensity only. By dividing the difference output by the sum output, a signal is generated which is responsive only to position of the light beam. This output is displayed on a differential voltmeter to provide an analog readout.

The SC-10 is responsive to both vertical and horizontal displacement of the light beam through two sets of outputs. A switch is incorporated so that either vertical light beam displacement, which corresponds to movement of the sphere center in the vertical plane, or horizontal light beam displacement, which corresponds to movement in the horizontal plane, may be measured.

Figure 7. Schematic of Optical Trammig System

During preliminary tests, the device was found to have an output change of $1.41 \text{ mV}/\mu\text{m}$ at the detector. For the existing optical system, movement of the sphere center is magnified 12 times at the photodetector. Therefore, a $1 \mu\text{m}$ change in position of the sphere center will result in a 16.9 mV change in detector output. Because of system noise, the limit of readability of the voltmeter is 10 mV ; thus, the prototype system is capable of allowing alignment of a sphere within $0.6 \mu\text{m}$. During a use test, a sphere with a roundness of $1.0 \mu\text{m}$ was centered to within $1.5 \mu\text{m}$ TIR as verified with a conventional electronic indicator. This seems satisfactory, as tests have shown that runout of the sphere surface of up to $2 \mu\text{m}$ can be tolerated by the diffraction pattern analysis system.

Optical System

The optical system (Figure 8) provides appropriate illumination of the sphere being inspected and directs light reflected from the surface onto the diffraction pattern sampler photodetector.

The light source for the system is a Model 120, 5 mV He-Ne laser. This laser was chosen for its relatively low output power variation (ripple). After passing through a $1/2$ -wave plate, the laser output is directed into the spatial filter by two beam steering mirrors. The spatial filter removes off-axis perturbations in the raw laser spatial filter removes off-axis perturbations in the raw laser output and expands the beam. The expanding laser beam is collimated by an anti-gaussian lens assembly. The collimated laser beam, which has a diameter of 12.7 mm , passes through the beam-splitting cube and the $1/4$ -wave plate and is brought to a virtual focus at the center of the sphere being inspected by the lens. Light reflected from the surface is recollimated by the same lens, passes through the $1/4$ -wave plate, and is reflected by the beam splitting cube and mirror to the focusing lens, which focuses the light onto the photodetector.

The anti-gaussian lens has been designed to serve two functions. Aside from collimating the expanding beam from the spatial filter, it also flattens the gaussian intensity profile of the laser beam so that a nearly uniform intensity profile is projected onto the part being inspected. A uniform beam profile is necessary because the measurement of defect depth is dependent upon variations in the amount and distribution of light reflected by defects. Reflected light variations which could arise from defect location within a non-uniformly illuminated area would give rise to erroneous defect depth determination.

The anti-gaussian lens, is designed to absorb proportionately more of the incident light near its center than at the edges. When the input beam has a gaussian intensity profile, the output beam will

Figure 8. Block Diagram of Laser Optical System

be uniform in intensity to within 5 percent out to the $1/e$ point of the gaussian input. Schematically, this would appear as in Figure 9. The intensity of the output beam of the anti-gaussian lens is approximately 35 percent of the peak intensity of the input gaussian beam.

To make use of the light reflected from the part surface, it must be redirected out of the original optical path. This is accomplished through the use of a beam splitter. The beam splitter must pass light through to the part surface and then reflect the light returning from the surface so that it can be directed onto the photodetector.

Initially, three types of beam splitters were investigated: the cube, the parallel plate, and the pellicle. All these types depend on partially reflecting surfaces which pass 50 percent of incident light and reflect 50 percent. The cube and plate beam splitters proved unsuitable because of multiple reflections. The pellicle beam splitter virtually eliminates multiple reflections, but is sensitive to acoustic vibrations. All three types of beam splitters involve total loss of more than 75 percent of the input light during the two interactions with the beam splitter.

A polarizing cube beam splitter has been ordered, which should minimize the undesirable characteristics of the other types. This beam splitter reflects light which is polarized in one direction while passing light, which is polarized at 90° to the original polarization. In the optical system, the $1/2$ -wave plate is used to align the highly polarized laser output so that nearly 100 percent of the laser energy striking the beam splitter is passed. The light passing the beam splitter is then transformed to circular polarization by a $1/4$ -wave plate. After reflection from the part surface, the light again passes through the $1/4$ -wave plate and is returned to linear polarization, but at 90° to the original plane of polarization. This light is then reflected rather than passed by the polarizing beam splitter and is directed to the photodetector.

The polarizing beam splitter is mechanically stable and suffers a relatively low inherent light loss. In prototype setups, some multiple reflection problems were encountered between the beam splitter and the $1/4$ -wave plate. These will be eliminated in the device, by physically contacting the $1/4$ -wave plate to the beam splitter.

Optical Mount

The optical mount provides a stable base for the lens system and allows alignment of optical components relative to each other and relative to the rotary fixture (Figure 10).

Figure 9. Profile of Laser Beam Before and After Apodizing

The movable undercarriage was designed and manufactured at Bendix. Both vertical and horizontal movement is provided, so that the optical system can be aligned with the center of rotation of the sphere being inspected. The optical bench structure is composed of components from, Macro Optical construction system. Use of this construction system allowed the flexibility required during early design stages while providing a structure that will be directly usable in the production system.

Vibration-Isolated Support

During the early stages of evaluation, vibration was identified as a major source of possible system error. Vibrational motion of the photodetector relative to the ball being inspected could

Figure 10. Laser Optics Mount

lead to erroneous interpretation of reflected light information. To establish the characteristics of the vibration isolation system required, a vibration survey of the area in which the system is located was performed. From the information generated, it was decided that a pneumatically isolated table of honeycomb construction would best meet the requirement. The laminated honeycomb construction was chosen for its superior acoustical damping characteristics. Horizontal and vertical vibration isolation requirements are presented in Figure 11. A 3.66 by 1.22 m vibration-isolated table was purchased. Some difficulty was initially experienced with the automatic leveling system, but replacement of the servo-valve mechanisms and improved adjustment procedures corrected the problems. Vibration isolation was determined to meet or exceed the requirements.

Optical System Enclosure

To provide safety for the operator and eliminate the effect of overhead illumination on the photodetector, an enclosure for the optics system was required. Because the optical path of the system is fairly long, it was decided to enclose the entire optical table.

The enclosure has interlocks on all doors which will cause reduction of the laser output to below safe levels when opened. Overhead lighting is provided to illuminate the interior during setup operations. It was originally planned that the operator would be able to view the operation of the system's mechanical components through blue Plexiglas doors. A He-Ne line filter in front of the photodetector was to filter out the blue exterior light which would enter the system through the doors. Unfortunately, difficulties were encountered with the He-Ne line filters, and the doors were ultimately painted black on the inside.

System Operating Parameters

The time required to scan a hemisphere is primarily dependent on three variables: sphere diameter, sample acquisition and processing time, and the area of the sphere which can be included in each sampling.

At present, the largest area which can be included in a given sample is considered to be 0.114 mm^2 . This is due to the existence of a minimum intensity at the part surface which will sufficiently illuminate a defect to cause usable reflected light information. It is possible that an increase in laser energy supplied to the part surface could allow larger sample areas. Laser energy requirements, however, go up in direct proportion to increased illuminated area.

Figure 11. Isolation System Requirements

Tests and calculations have shown that the sample acquisition and processing time can be expected to fall between 5.0×10^{-3} and 1.0×10^{-2} s. For a specific sphere diameter and illuminated spot size, the sample acquisition and processing time (SAPT) will determine the rotation rate of the horizontal spindle. The centers of adjacent samples are spaced at 1.414 times the radius of the illuminated spot (R_S) rather than at $2R_S$. This permits overlapping of sample areas so that complete surface coverage is accomplished. The rate of sphere rotation is thus:

$$\text{Rev/s} = \frac{1.414 R_s}{\pi D(\text{SAPT})} \quad (1)$$

where SAPT is the sample acquisition and processing time, D is the diameter of the sphere being inspected, and R_s is the radius of the illuminated area.

The part is scanned from equator to pole in concentric rings with a spacing of $1.414R_s$. The number of rings scanned is:

$$N = \frac{0.25\pi D}{1.414 R_s} \quad (2)$$

For each ring scanned, the part must rotate one additional revolution to allow for indexing of the fixture about the vertical axis and initiation of data-taking along the same meridian on every pass. The total time required to scan a hemisphere is, therefore, twice the time required to rotate N times. By substituting Equation 2 into Equation 1, this can be stated as

$$\text{Total inspection time/hemisphere} = \frac{0.25\pi^2 D^2 (\text{SAPT})}{R_s^2} \quad (3)$$

As can be seen from Equation 3, the total time required to inspect a hemisphere increases as the square of the diameter of the sphere being inspected if other parameters are constant. Figure 12 represents the time required to inspect hemispheres of parts up to 52.8 mm diameter with $\text{SAPT} = 0.010$ s and $R_s = 0.0075$. Under these expected conditions it can be seen that a sphere of 17.8 mm diameter would require an inspection time of about 3.6 minutes per hemisphere.

ACCOMPLISHMENTS

The basic equipment required for a working automated inspection system has been procured, tested, and assembled to form the basis of an operating device. Analog noise levels in the High Speed Diffraction Pattern Sampler have been reduced by a factor of 40 through extensive analysis of the system and appropriate equipment modifications. An electromechanical method for tramming spheres has been developed, along with a non-contacting optical displacement measurement system. It has been shown that spheres can easily be centered to within $0.25 \mu\text{m}$ TIR on the horizontal axis of the rotary fixture using the electromechanical wobble plate. Tests have shown that a stable, low-light-loss beam splitter can be constructed by taking advantage of the highly

Figure 12. Time Required to Scan Hemispherical Sections

polarized nature of laser light. Basic operating parameters for the system have been determined, and projected inspection times for hemispheres have been calculated.

FUTURE WORK

During this reporting period, the automated surface inspection system was used only to analyze defect width data from prealigned, stationary defects. Future efforts will center on development of the necessary computer software to allow continuous data taking and analysis over complete hemispherical sections and on measurement of defect depths.

Refinement of the optical system will continue with receipt of the polarizing beam splitter and the anti-gaussian lens assembly.

Methods of chucking the sphere during inspection will be evaluated, and a fixture will be designed to accurately rotate the sphere 180° after completion of the inspection of one hemisphere.

Under the present rotation scheme, the HSDPS-1 can operate at its maximum data-taking rate only at the equator. As the ball is indexed toward the pole, the data-taking rate must be slowed to maintain constant data spacing relative to the surface. The application of computer control to the horizontal spindle rotation rate will be considered so that the maximum data-taking rate can be sustained throughout the scan of a hemisphere by using a steadily increasing rotation rate.

Equipment to measure the waviness and surface profile of highly polished spheres has been procured and tested. Development of a computer-based system to characterize the geometry of parts will proceed as the primary goals of surface defect recognition are accomplished.

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¹P. E. Klingsporn, *Reflected Light Intensity Distributions From Defects on Highly Reflective Spheres* (Topical Report). Bendix Kansas City: BDX-613-1174 (Rev.), March 1977 (Available From NTIS).

²P. E. Klingsporn, *Optical System for Automated Inspection of Highly Reflective Spherical Surfaces* (Topical Report). Bendix Kansas City: BDX-613-1497, September 1976 (Available From NTIS).

Appendix

EVALUATION DATA FOR THREE-AXIS SCANNING FIXTURE

Appendix

EVALUATION DATA FOR THREE-AXIS SCANNING FIXTURE

HORIZONTAL AXIS TRUENESS OF ROTATION

Axial Runout of the horizontal spindle was found to be less than 76.2 nm (3 microinches). Radial Runout of the horizontal spindle was found to be less than 177.8 nm (7 microinches). It should be noted that radial runout may be less than the value shown above when the improved wobble plate is completed.

TABLE LOADING TEST

Probe 1 was located at a fixed point on the base below the 90° point, and Probe 2 was located on top of a centered sphere, as shown in Figure A-1. The table was rotated through an angle of 180°, and readings were taken with both probes at 30° intervals. One run was made with no load added to the table, and a second run was made with a 20.43 kg weight located over the 90° point in the above sketch. The data in Table A-3 shows a decrease in vertical table movement when counterweight is added.

Figure A-1. Probe Locations

Table A-1. Vertical Axis Trueness of Rotation

Table Position (Degrees)	Displacement of Centered Sphere*			
	Vertical		Horizontal	
	nm	microinches	nm	microinches
0	0	0	0	0
10	+25.4	+1	+25.4	+1
20	-76.2	-3	+25.4	+1
30	-25.4	-1	+127.0	+5
40	-101.6	-4	+203.2	+8
50	-101.6	-4	+254.0	+10
60	-76.2	-3	+127.0	+5
70	-25.4	-1	-203.2	-8
80	-50.8	-2	-254.0	-10
90	+25.4	+1	-228.6	-9
100	-25.4	-1	-127.0	-5
110	+76.2	+3	+76.2	+3
120	+76.2	+3	0	0

*Values were obtained using a height gage stand located on the surface plate which supports the Scanning Fixture.

Table A-2. Vertical Axis Indexing Accuracy Test

Angle Setting (Degrees)	Deviation* From Nominal Setting (Arc seconds)			
	Clockwise Runs		Counterclockwise Runs	
	1	2	1	2
-5	-52	-51	-51	-51
-4	+20	+20	+18	+18
-3	+29	+29	+29	+30
-2	-3	-3	+1	+2
-1	-8	-7	-8	-8
0	Ref	Ref	Ref	Ref
1	+63	+61	+62	+62
2	+24	+23	+24	+24
3	-5	-5	-2	-2
4	-10	-10	-11	-11
5	+5	+5	+3	+4
55	-247	-248	-260	-259
56	-238	-238	-252	-251
57	-220	-219	-250	-250
58	-219	-218	-248	-248
59	-212	-212	-239	-240
60	-241	-240	-265	-267
61	-226	-226	-252	-252
62	-199	-198	-223	-224
63	-187	-189	-200	-200
64	-180	-179	-176	-175
65	-247	-248	-244	-246
115	-210	-209	-217	-219
116	-253	-251	-256	-259
117	-252	-250	-257	-259
118	-259	-257	-263	-266
119	-212	-211	-217	-219

Table A-2 Continued. Vertical Axis Indexing Accuracy Test

Angle Setting (Degrees)	Deviation* From Nominal Setting (Arc seconds)			
	Clockwise Runs		Counterclockwise Runs	
	1	2	1	2
120	-210	-208	-214	-216
121	-216	-214	-225	-227
122	-263	-261	-274	-276
123	-248	-246	-262	-263
124	-167	-165	-181	-182
125	-166	-165	-176	-176

*Data adjusted to 0 deviation at 0°. Data was obtained by following a specific pattern of rotation prior to each run, including pre-travel of at least 30° in the run direction.

Table A-3. Table Loading Test Data

Table Position (Degrees)	Readings			
	Probe 1		Probe 2	
	nm	microinch	nm	microinch
No Load				
0	0	0	0	0
30	+736.6	+29	-177.8	-7
60	+990.6	+39	-254.0	-10
90	+1143.0	+45	-152.4	-6
120	+1066.8	+42	-127.0	-5
150	+812.8	+32	-50.8	-2
180	+330.2	+13	+152.4	+6
20.43 kg Load				
0	0	0	0	0
30	+381.0	+15	-50.8	-2
60	+381.0	+15	-50.8	-2
90	+381.0	+15	0	0
120	+355.6	+14	-76.2	-3
150	+304.8	+12	-152.4	-6
180	+127.0	+5	-76.2	-3

Table A-4. Horizontal
Axis
Tachometer
Tests

True Rotation Rate (rad/s)	Tachometer Reading (rad/s)
0	0.01*
2	1.99
4	3.98
6	5.97
8	7.94
10	9.92
12	11.91
14	13.89
16	15.86
18	17.84
20	19.80

*Rotation of horizontal axis is not 0 when speed control is turned to 0. It is very difficult to set the control for 0 rotation rate.

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