LASER INTERFEROMETER MEASUREMENT SYSTEM ON THE YALE PDS 2020G

Jin-Fuw Lee, Wean-Shun Tsay and William van Altena
Yale University Observatory

ABSTRACT

We have installed a dual-axis laser interferometer system on the Yale PDS 2020G microdensitometer to replace the linear encoders. Various diagnostic tests show that the laser interferometer is a superior encoder system for the PDS with a positional accuarcy of about 0.3 micron.

I. INTRODUCTION

During the past three years, the positional accuracy of the Yale 2020G PDS has been studied in a number of ways. Based on these studies, we found that the major source of nonrepeatability came from the drunken stage motions which were caused by the irregular shape of the guiding ball bearings. This problem was remedied by monitoring the drunkenness of the stage motions with optical micrometers (see Lee and van Altena 1983). However, the lack of straight and smooth reference lines limited the accuracy of the monitoring system to 0.6 micron. To further improve the accuracy of the PDS, we considered replacing the linear encoder system with a dual-axis laser interferometer system. An early test in February 1982 with a conventional laboratory interferometer showed that the interference fringes were destroyed by vibrations generated by the stage drive shafts. Following successful tests with the Hewlett-Packard two-frequency single-axis laser interferometer in February 1983, we decided to employ the H-P dual-axis laser interferometer system, since the single-axis system was immune to the vibrations and produced an accuracy unsurpassed by the previous systems. Furthermore the annoying problem of glitches (discontinuous zero-point changes) in the previous systems is not present in the interferometer system. We note that the H-P system has also been adopted by Perkin-Elmer for a prototype PDS 1010A and by Kinsey (Kinsey 1983; Kinsey, Deuman, and Evzerov 1984) for use on Space Telescope Science Institute's PDS 2020G microdensitometers.

H. K. Eichhorn and R. J. Leacock (eds.), Astrometric Techniques, 237–242.

II. THE HEWLETT-PACKARD LASER INTERFEROMETER SYSTEM

In what follows, we give a brief description of the system, which consists of the H-P model 5501A laser transducer, plane-mirror interferometers, a beam splitter, beam benders, pulse converters and detectors. The model 5501A is a two-frequency He-Ne laser source. The Ne 6328A laser line is Zeemann-split into two orthogonal, linearly polarized frequency components f1, f2 with a separation of 2MHZ, on passing through an electromagnet, and a quarter-wave plate. The combined beam is directed by beam benders and a beam splitter to the plane mirror interferometers. One frequency, f2, is reflected internally inside the interferometer and returned unchanged to a photo receiver, while the other frequency, f1, is transmitted out to a plane mirror, and reflected back with a Doppler shifted frequency f1+df, where df is proportional to the relative velocity between the mirror and the interferometer. Due to the geometry of the plane mirror interferometer, the frequency f1+df is sent back for the second time to the plane mirror and finally returned back to the receiver with a doubly-shifted frequency f1+2df. The beat frequency of the return beam is then mixed with the 2MHZ reference signal and sent directly from the laser into the pulse converters. The Doppler shift term 2df is extracted and the "up" and "down" signals are generated from the fringe counts to give the relative mirror - interferometer diplacement in the +/- directions. The resolution in the fringe count is, in our case of double Doppler shift, the Ne wavelength divided by 8, or approximately 0.08 micron. The maximum speed of the PDS is limited by the line blending to about 150 mm/sec. which is further limited by the pulse conveters to 90 mm/sec. This is still acceptable, since in our applications, the speed is limited by the acceleration characteristics of the PDS.

III IMPLEMENTATION ON THE YALE PDS

The laser is mounted on the right rear side of the granite base of the PDS. The optical cluster, including one beam splitter, two interferometers(x and y), two beam benders and two receivers, is rigidly fixed to the focussing section of the upper optical assembly of the PDS. To make room for the cluster, the PDS alignment and locking ring, originally on the upper objective, was moved to the objective on the lower optical assembly. Since the upper aperture is slightly smaller than the lower aperture, the upper aperture is the defining aperture of the PDS optical axis, which will be less affected by the drifts in the aligment and locking ring on the lower objective.

Mounting of the interferometer cluster directly on the upper PDS objective has proven to be stable. It also provides us with the ability to raise or lower the interferometers by turning the focus knob of the

PDS. Elevation of the cluster is necessary to provide clearance while changing the platen or the plate. Refocussing after the change will bring both the objective and the interferometers down close to the focal plane.

Two optically flat, 21-inch (520x25x38mm) long plane mirrors, manufactured by Muffaletto Optical Co., were mounted on the right side and the front side of the carriage, and carefully aligned perpendicular to the plane mirror interferometers. The "up" and "down" pulses, arising when either the mirrors or the interferometers move, are sent to DCRS position counters of the PDS. Since the resolution of the interferometer system is about twelve times finer than that of the scale amplifier, the 6-digit DCRS counters will overflow for a full 20-inch travel. A fast divider was made by A. Wandersee of Yale Center for Electronic services, which is capable of dividing these pulses by 1, 2, 4, or 8. Even at scale 8, the resolution, 0.63 micron, is still better than the scale amplifier, and the overflow problem is not present at this scale. For the software part, the same interface and scan program can be used, except for a rescaling of the ramp table, corresponding to a change of resolution.

Environmental changes are normally small for short scans(say 30 min.), in which case compensation for either material expansion in the stages, or the change of the laser wavelength is not necessary. For long scans, a set of check stars have to be prepared and inserted into the scan sequence to determine possible zero-point drifts or scale changes.

We have installed a weather station, made by A. Wandersee, to monitor the temperature, the pressure, and the humidity of the PDS room. In the future, these data will be read into the computer, and the compensation for the environmental effects will be incorporated into the process of data reduction.

Another source of errors may come from the nonlinear motion of the measurement axis, which consists of three components: roll, pitch, and yaw. The effect of yaw is negligible, if we carefully align the beam path with the measurement axis of the PDS. Because of geometrical limitations, the beam path measured by the interferometers is actually 28 mm higher than the focal plane of the PDS. A roll or pitch of the interferometer about the measurement axis will then give an error between the measured path length and the real path length in the focal plane. The heavy and long y yoke is especially susceptible to the disturbance caused by the irregular motions of the guiding bearings. In what follows, we shall consider y yoke. Assume that all ball bearings are made of the same material and have the same elastic property. If the mean pertubation on each bearing is D microns, the angle of roll or pitch introduced is then calculated from the laws of mechanical equilibrium to be approximately

$$A = D\,L^{-1}\,n^{-1/2} ,$$

where n is the number of bearings participating in the roll, and L is the effective lever arm length of these bearings. The roll causes an error in the x path length, given by dx=H*A, where H is the height of the measurement path above the focal plane. In our case, H=28 mm, L=100mm, n=10 and D is less than 2 microns (estimated from our repeat measurements of straight edges). This gives an upper limit of 0.2 micron for dx. The lever arm length for the pitch is about L=200mm, which produces an error of the y path length on the order of 0.1 micron. These errors are quite small, so no effort has been made to correct for them.

IV TESTING PROCEDURE AND RESULTS

Some simple tests(see van Altena and Lee 1983) were performed to isolate electro-mechanical problems. For the first test, we monitored the position of a dust speck on the platen with the carriage moving back and forth repeatedly. A loss of zero-point was found to be associated with crosstalk inside the divider. After making appropriate corrections, we found that the PDS maintained its zero-point , even when the stage is moving at the current maximum speed of 50 mm/sec, and at the finest resolution, 0.08 micron. This correpsonds to a pulse counting rate of 600 KHZ.

Next, a sharp razor blade was taped on the platen. Short 40-line scans across the blade edge showed that the dispersion of the edge determinations is only 0.05 micron. This dispersion does not depend on either the scale of the divider or the time delay forced between two consecutive scan lines. This is contrary to the situation for the scale amplifier, where the dipersion deteriorated to 0.25 micron when the timing delay was eliminated. Futher tests included 4000-line 15-minute scans of the blade edge. Initially, we found peculiar drifts which were nearly periodic, even though the room temperature did not show any significant change. The source of this error was later identified to be the resonant motion of the long reflecting mirrors induced by the high-speed stage motions. Strengthening the mirror mounting seemed to eliminate the resonance. Finally , we used long scans, ranging from one to twelve hours. The results showed that the edge position drifted continuously even after a 12 hour warmup. Most drifts occurred during the first hour of the scan, which is probably associated with the temperature change when the plate was set up by the operator. After that, the drift decreased to below 1 micron per hour. Also, we did not observe any glitch, a discontinuous drift, in these knife edge tests.

The drunkenness of the PDS stage motion caused by the irregular motions of the guiding bearings will not directly affect the accuracy of the laser system, since a dual-axis system with long plane-mirrors is used. However, the roll and the pitch may contribute secondary errors. To check this effect, we scanned an 18-inch long smooth wire twice. The rms difference between two mearsurements of the shape of the way is less than 0.1 micron, which is definitely an improvement over our previous results.

According to the manufacturer's specification, the plane mirrors are straight to one eighth of a wavelength per inch. An indirect test of this can be made by placing a fine-grained emulsion plate on several different parts of the PDS platen and measuring the positions of a set of well formed images. Comparison are then made between different sets of measurements using a linear least squares fit. The unit weight error is less than 0.2 micron for measurements repeated immediatedly, while is about 0.3 to 0.4 micron in the general case.

V CONCLUSION

The H-P dual-axis laser interferometer proves to be the best encoder system ever employed on the Yale PDS. The resolution is about twelve times finer than the linear encoder. The maximum speed of scan is slightly reduced to 90 mm/sec, which is not a real limitation for our applications. The improvements on the PDS measuring accuracy include (1)the elimination of the electronic glitch; (2)a new set of measurement axes which are less sensitive to the drunken stage motions; and (3)a twelve fold increase in resolution.

VI ACKNOWLEDGEMENTS

We would like to thank Dr. James Rodman for setting up the laboratory interferometer tests and helping to solve various problems that we have had with the PDS. We are also pleased to acknowledge several useful conversations with Dr. James Kinsey, and Dr. Anthony Hull about the use of the H-P interferometer on the PDS. In particular, we would like to thank Dr. Kinsey for suggesting that we utilize the output from the pulse converters followed by a fast divider to drive the DCRS display and other PDS registers, and for making it possible for us to order our long reference mirrors in conjunction with those for the Space Telescope Science Institute's PDSs. This research was supported in part by the National Science Foundation and the National Aeronautics and Space Administration.

REFERENCES

Lee, J.-F. and van Altena, W.: 1983. in Astronomical Microdensitometry, edited by D.A. Klinglesmith, III., p. 151.

Kinsey, J. H.: 1983. in Astronomical Microdensitometry, edited by D. A. Klinglesmith, III., p. 135.
Kinsey, J. H., Denman, R. J., and Evzerov, A.: 1984. in Review of Scientific Instruments, vol. 55, p. 1960.
van Altena and Lee, J.-F.: 1983. in Astronomical Microdensitometry p. 3.

Discussion:

de VEGT: What are the flatness requirements for the mirrors?

LEE: The tolerance on plane-mirrors is one eighth of a wavelength per inch.

RUSSELL: With recent modifications for the HP laser system, the maximum speed can be increased to 190 mm/sec instead of 90 mm/sec.

LEE: It is good to know that.