The U.S. Naval Observatory Automatic Measuring Machines, Present and Future

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The automatic measuring machine acquired by the U.S. Naval Observatory in 1966 was built by Nuclear Research Instruments (NRI) in Berkeley, California, based upon design specifications by the Naval Observatory and upon a considerable amount of innovative engineering by NRI. The performance of the machine and the results obtained over the past four years clearly show that a reliable high speed measuring system has been achieved. Hence, when requirements developed for a second machine it was decided to copy the earlier machine, incorporating modifications which the present state of the art permit and which were not available when the machine was designed in 1963.

The primary purpose of the machine is to save manpower in measuring the extensive plate material which is obtained in the trigonometric parallax program with the 61-inch Astrometric Reflector, thus avoiding accumulating a backlog of unmeasured plates, a situation that normally has been the case in such programs in the past.

The machine incorporates the following characteristic features:

1. Automatic centering of images, with an opto-mechanical scanner.
2. Moiré fringe measuring system of x, y coordinates with recording of data on punched cards.
3. Automatic prepositioning on selected images with input from punched cards.
4. Image projection with $40\times$ and $3\times$ magnification on viewing screen in front of the control console.
5. Easy access to the machine with features for rapid changeover from plate to plate.

The measuring system consists of:

1. The opto-mechanical assembly called "the machine".
2. A three rack electronic cabinet.
3. A two rack air supply and vacuum control system.
4. Two IBM-526 Card Punches.

Only a few salient features of the machine will be described here. The main structural members of the machine, and the two carriages which move the plate over a 25×25 cm area, are made of massive, dimensionally stable granite components. This permits the operator to be near the machine, rather than in a separate location. Motion and guidance system of the carriages employ airbearings riding against granite flats and granite guideways.

Both carriages are moved by means of ball screw assemblies driven by synchro motors, with opto-electrical transducers employing moiré fringe gratings monitoring carriage movement along the two axes for measurement to a least count of ±1 micron.

The detecting head for the automatic centering of the star images is an optical mechanical assembly which includes a 12.5 cm scanning disk with 24 slits rotating at 3600 r.p.m.

The image beam entering the detecting head is split into two orthogonal beams which intersect the edge of the rotating disk. With each image beam a narrow beam of light, representing the measuring axis, passes alongside.

Two photomultipliers are used for each coordinate, one for the image and one for the reference beam. Pulses from these photomultipliers go to the time discriminator circuitry which converts the time displacement into servo control signals to drive the x and y carriages until the pulses are coincident.

Two oscilloscopes below the viewing screen monitor the detecting operation which enables the operator to view the interpretation of the image by the scanner.

Within the past year the machine has been completely overhauled, and the Ferranti moiré fringe system replaced with a Heidenhain system, resulting in a substantial increase in the long term stability of the machine.

Over the past four years the machine has been used to measure plates taken with telescopes with focal lengths from 2.3 m to 19.4 m. In addition to the Naval Observatory, five other observatories have

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used the machine and realized a considerable saving in measuring time and a substantial increase in accuracy, as compared with the conventional manual method.

In the case of the parallax program with the 61-inch Astrometric Reflector, the measuring time has been reduced by a factor of five and the mean error of measurement by 30 per cent. Image sizes that can be measured automatically range from a maximum of 200 μm to a minimum of 50 μm.

The new machine, currently under construction by Optronics International at Chelmsford, Massachttsuse, is intended primarily for the measurement of some 4000 plates to be taken with a 20 cm double astrograph of a focal length of 2 m, of the positions of approximately 200 000 southern hemisphere stars.

In order to complete a project of this magnitude within a period of five years, it is most essential that the measuring phase be made as automatic as feasible.

For this purpose, the approximate positions of the stars to be included will be selected from existing catalogs and punched on cards for input to the machine for the speedy acquisition of the star images.

We still contemplate examining each image before the automatic centering and in this way will operate the machine in a semi-automatic mode.

The new machine will depart in certain aspects from the present machine. In place of a moiré fringe coordinate measuring system, a helium-neon interferometer will be employed with a digital readout of image position. An additional feature of this machine will be an opacity measurement of the image with a four digit readout.

The card punches operated with the present machine will be replaced in the new machine with a high speed card reader for the input data and with a magnetic tape unit and a digital recorder for the readout of the data. The magnetic tape output will be compatible with the IBM-360 computer for speedy data reduction and analysis.

The present manufacturer also intends to employ a commercially available computer for the controls and operation of the machine rather than building an electronic unit specifically designed for the machine.

It is expected that the features just described will improve the performance of the new machine over the present one—in particular with respect to maintenance. At the same time it should be emphasized that the present machine in performance, speed and accuracy has exceeded by far our expectations at the time it was conceived.

DISCUSSION

E. Høg: Do you think that the slit scanning method is acceptable also for plates with higher star densities?

K. Aa. Strand: It would be difficult to measure adjacent images within say 200 μm of each other. You cannot change the slit-length. Of course you can in such cases operate the machine manually.

E. Høg: What method of centring are you contemplating for the new machine?

K. Aa. Strand: It has not been decided; we are thinking of a rotating prism.

C. N. W. Reece: What is the effective linear bit size, what type of servo damping do you use, and what is the effective settling time of the table?

K. Aa. Strand: The readout is to 1 μm, but repeatability is of the order of 0.8 μm.

J. F. Wanner: Damping is entirely in the servo, by tachometer feedback; there is no viscous damping.

A. P. Linnell: Is there any potential difficulty from heat absorption in the emulsion, from the high-intensity beam?

K. Aa. Strand: No, we do not use the full wattage, only about 250 watts, and of course we have an infra-red filter.

P. J. Treanor: Does the rather coarse readout to 1 μm introduce a kind of rounding-off error?

K. Aa. Strand: In relation to photographic noise, it is fully satisfactory.

L. Gratton: Is there any significant magnitude error in automatic setting?

K. Aa. Strand: On parallax plates, our comparison stars are chosen within a range of 0.5 magnitude at most; this is possible because we obtain parallaxes only of faint stars. The present machine has a bias, which we circumvent by reversing the plate and measuring twice. There is so much economy in the measuring process that we can afford to do this.

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G. S. WALKER: Do you expect stability problems with the helium-neon laser, and why has this system of measurement replaced the moiré system?

K. AA. STRAND: When the laser system was specified, nickel-in-glass moiré gratings were not available. We had had considerable difficulties with the system using photographic gratings, because their separation was so close that they were easily damaged by a change in pressure to the air-bearings.

E. HØG: What is the absolute accuracy and linearity of your machine, and how good is the orthogonality of the axes?

J. F. WANNER: The orthogonality of the axes is good to a few arcsec, and the grating accuracy is of the order of 1 μm over 25 cm.

R. PARKS: Has the orientational error of the carriage motion been measured? Since the grating is considerably offset to the side of the carriage, errors of orientation will give rise to significant positional errors at the working point on the plate.

K. AA. STRAND: I don't think so. The ways are quite wide, and the carriage moves against them on air bearings.

R. B. DUNN: Are you going to use a Hewlett-Packard helium-neon laser system for measurement?

K. AA. STRAND: No, it will be the Perkin-Elmer system.

C. N. W. REECE: Were the moiré gratings you originally used 100 lp/mm with divide-by-ten input circuitry, or 250 lp/mm with divide-by-four?

K. AA. STRAND: They were 250 lp/mm.

C. N. W. REECE: With the finer gratings, one does indeed have problems with maintaining the separation to very close tolerance. For linear one-micron systems we no longer use a grating of 250 lp/mm with a divide-by-four electronic circuit. The setting tolerance was far too tight for most applications, and as the grating was prismatic, the signal was not very satisfactory. We now use 100 lp/mm photographic gratings with divide-by-ten circuits, and this has been found to be eminently satisfactory.

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