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TABLE IV. STRATOSPHERE CORRECTION, ϵ_3

$\lvert 90° - z \rvert$ \ h (km)	10.0	9.5	9.0	8.5	8.0	7.5	7.0	6.5	6.0	5.5	5.0	4.0	3.0	2.0	1.0	0.0
0°.0	20″	16″	12″	10″	9″	8″	7″	6″	5″	5″	4″	4″	3″	2″	2″	2″
0.5	18	13	11	9	8	7	6	6	5	5	4	4	3	2	2	2
1.0	12	10	8	7	6	6	5	5	4	4	4	3	2	2	1	1
1.5	8	7	6	5	5	5	4	4	3	3	3	2	2	2	1	1
2.0	5	5	4	4	4	3	3	2	2	2	2	2	1	1	1	1
2.5	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1
3.0	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0	0
3.5	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
4.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Acknowledgment. This paper is an abstract of the dissertation presented for the degree of Doctor of Philosophy in Yale University in June, 1943. The author wishes to express his deep appreciation to Dr. DIRK BROUWER, the Director of the Yale Observatory, who had suggested this work and given valuable advice and inspiration throughout.

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Yale University Observatory,
New Haven, Conn.,
1943 *May.*

EXPERIMENTS IN THE DESIGN OF THE TRAVELING-WIRE MICROMETER

BY C. B. WATTS

(Communicated by the Superintendent, U. S. Naval Observatory)

Introduction. The traveling-wire micrometer was developed in practical form by J. REPSOLD between 1889 and 1895.[1] REPSOLD had hoped that the use of the hand-driven micrometer would eliminate the personal errors characteristic of the method of observing with fixed wires, but it was found that appreciable personal errors still affected the observations, although they were greatly reduced in magnitude. However, with the addition in many instances of mechanical or electrical driving mechanisms but with few other changes, the new device eventually became a part of most transit circles and portable field instruments.

The development of a satisfactory driving mechanism, which it was believed would decrease accidental errors and possibly further reduce personal errors, was rendered somewhat difficult by the wide range of speed required (1 to 0.017 from the equator to declination 89°). Speed variation has usually been obtained with the cone-and-disc type of friction drive, interposed at a convenient point between the source of power and the micrometer, and it has been customary to maintain coincidence between the object and the moving wire by the use of differential gears or similar means, sometimes effective only as a retardation. Descriptions of micrometers with driving mechanisms are given by RENAN in *Annales de l'Observatoire de Paris, Mémoires*, Vol. **26**, 1910; by GILL in his *History and Description of the Cape Observatory*, 1913; and by MOREAU and VERBAANDERT in *Bulletin Astronomique de l'Observatoire Royal de Belgique*, Vol. **2**, 1935, to mention a few of many examples.

In 1929, while looking for a more satisfactory method of driving a micrometer, I settled upon the use of a small synchronous motor, which was mounted on the micrometer itself and geared directly to the screw without the interposition of a speed-regulating device.[2] In this arrangement the frequency of the current supplied to the motor is established at a value dependent on the declination, thereby causing the motion of the moving wire to approximate closely that of the object; coincidence is maintained by increasing or decreasing the established frequency momentarily by small amounts. After some tests on a portable instrument it became apparent that this method possesses certain desirable qualities, and it was adopted in 1933 by the late J. C. HAMMOND for use on the six-inch transit circle and in 1936 by H. R. MORGAN for the nine-inch.

An essential feature of the traveling-wire micrometer in its usual form is an electric contact wheel, which is mounted on the micrometer screw. The function of this wheel and its associated mechanism is to record on a chronograph the time of passage of the moving wire through a number of specified positions. The observer's key of the older method is in effect made a part of the micrometer, and the transit of the object over a series of imaginary fixed wires is observed. But the time interval between successive signals initiated by such a method varies as the secant of the declination; accordingly, if the signals at equatorial speed are spaced sufficiently far apart to be mutually independent, those for circumpolar stars succeed one another only after long delay. This

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peculiarity, coupled with the shortcomings of driving mechanisms, has frequently necessitated some modifications of observing methods at high declinations.

With the purpose of eliminating the deficiencies of the contact method of registration and of gaining some new advantages, I began in 1938 the use of a device which records the position of the moving wire at specified times without regard to its rate of motion. The recording is

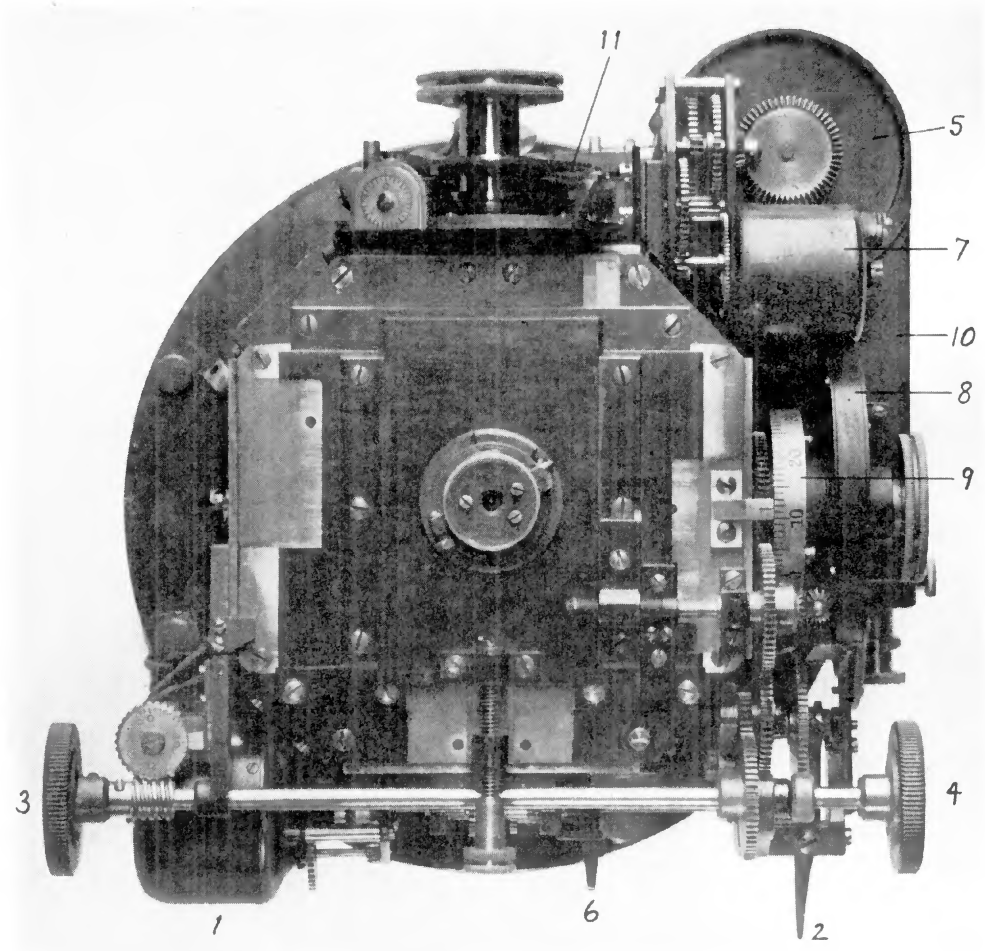


Figure 1. Micrometer of the Six-inch Transit Circle, U. S. Naval Observatory. (Scale 1 : 1.7).

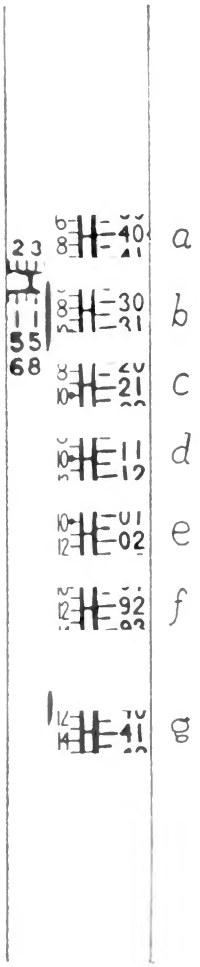


Figure 2. Photographic Record. (Scale 1.6 : 1).

accomplished by photographing the divided head of the micrometer screw periodically while the transit is in progress, the exposures being initiated by the standard clock.

As a result of occasional experimentation these variations of the original design have been developed to a state which I regard as quite satisfactory. Their practical application may be seen in the view of the micrometer of the six-inch transit circle shown in Figure 1.

The motor drive. A two-phase synchronous motor, which drives the micrometer during an observation, is visible at 1. When in use it is connected through reduction gears, engaged with the lever 2, to the train of the hand drive 3 and 4; the latter, being permanently geared to the micrometer screw and to the screw which controls the eyepiece slide, serves to return the wire after an observation to its starting point. The motor is readily reversible and will start and run synchronously at frequencies ranging from 10 to 175 cycles per second. As this is not a sufficient range, additional speed-reducing gears, engaged with the lever 6, are used for declinations between 75° and 89°. The frequencies required range from 123 to 32 c.p.s. for declinations 0° to 75° and from 149 to 10 c.p.s. in the interval 75° to 89°. The rotor is of light construction and responds with negligible delay to the corrective changes of frequency made by the observer.

Power for the motor was originally supplied by a small A. C. generator, which was driven at a speed proportional to the frequency desired. In 1940 the generator was replaced by an electronic beat-frequency oscillator, the scale of which is graduated in terms of declination. The

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oscillator, located on the observer's desk, supplies the necessary two phases; the amplifiers, with other electronic apparatus, are well separated from the instrument to avoid detrimental heating effects. Increments are added to, or subtracted from, the frequency corresponding to a particular declination by switching capacities into or out of the tuning circuit with two sensitive relays.

The observer starts the motor and corrects its operation by means of keys or push buttons on a control block small enough to be held comfortably in the hand. The correcting keys, three in number, are arranged in a row and are connected with the relays in the oscillator; the first and third can be used interchangeably to decrease the frequency, while the second increases it by the same amount. It is unnecessary and undesirable for the observer to keep in mind the functions of the keys with respect to accelerating and retarding the speed of the moving wire. The adopted procedure is to correct with the first and second keys during the first half of the transit and to shift to the second and third upon reversing the eyepiece prism. The observer thus regards his corrections as causing displacements of the object with respect to the traveling wire, which appears to be stationary, and not as removing a condition of leading or lagging. The frequency increment found most satisfactory is about 12 c.p.s.; this corresponds to a displacement of 1".5 in a second of time, or of 0".3 if the low-speed gears are engaged. The correcting effect is graduated by a simple and obvious manipulation of the control keys.

The photographic register. The part of the micrometer devoted to photographic registration is shown in the upper right-hand portion of Figure 1. The records are made on a tape of bromide paper one-half inch in width and about 25 feet in length. The paper is wound on a reel within the magazine 5, which can be conveniently replaced by another when the supply of paper is exhausted. When an observation is in progress the motor 7 causes the paper tape to advance at a uniform speed down the shielded channel 10 and back to a second reel alongside the first. In doing this the sensitized surface of the paper passes near a circular glass scale corresponding to that of the visual divided head 9, so that shadow pictures of the index and of a portion of the scale may be made. Part of a short linear scale of whole revolutions is also included. The circular scale is within the enclosure 8 and is similar to the scale 11 of the zenith distance screw, from which the covering has been removed. The light source is a quarter-watt argon glow lamp and the exposures, initiated by the clock for a transit and by the observer for other purposes, are of $0^s.002$ duration. The length of the exposure is determined by auxiliary electronic apparatus.

The appearance of the photographic record is shown in Figure 2. The right-hand two-thirds of the tape receives the records of the traveling wire; the numbered divisions at the right are hundredths of a revolution, and those at the left are the even whole revolutions, of the micrometer screw. Frames *a* to *f* were exposed at four-second intervals. This is the usual number of frames recorded for a transit, whatever the declination of the object. Fifteen accurately timed exposures per minute, at 2^s, 6^s, 10^s, $\cdots$ 58^s, are available to the observer, who starts and stops the registration at will. Exposures made at 10^s, 30^s and 50^s are identified by code markings introduced by the clock at the left of these frames, as at *b*. From this marking it is ascertained that the middle frames *c* and *d* were exposed at 34^s and 38^s, hence the mean of all is 36^s. This instant corresponds to the mean of the six scale readings, which is 9.660 revolutions; the adopted reference point being 10.000 revolutions, the difference between these two quantities must be applied with the proper sign to the collimation constant. Except for these details the computation does not differ from older practice.

A convenient method of recording the bisections made with the zenith distance screw is afforded by the presence of the registration device. In taking advantage of this possibility a projected image is used, which is formed by a simple optical system not clearly shown in Figure 1. The left margin of the tape receives the projected images, the exposures in this case being initiated by the observer. The vertical frame at *h* in Figure 2 is such a record, the horizontal frame *g*, exposed at the same moment, indicating the point in the field at which the bisection was made.

An exposed tape contains the records of about 60 observations, comprising six frames each, as well as the usual settings on the collimators, meridian marks and reflected nadir images. The chronograph is no longer needed. Little practice is required to enable an observer to start a transit at a time that will cause it to be approximately symmetrical about the meridian. Exact symmetry is, of course, neither possible nor necessary. No change in procedure is required for the stars of high declination.

With a simple accessory the photographic register lends itself to the detection and evaluation of a possible systematic displacement of the traveling wire from its indicated position while in motion. This condition, which can be a source of appreciable error, was reported by SPENCER JONES to exist for a time in one micrometer.[3] The accessory consists of a glow lamp connected in series with that in the register and mounted temporarily inside the telescope tube; a condensing lens concentrates its light on the reticle. In a trial of this device a photographic film holder containing about five feet of one-half inch film was substituted for the eyepiece, and successive shadow pictures of the reticle were made simultaneously with those of the micrometer head with the wire at rest and in motion. These photographs were sufficiently sharp to admit of precise measurement; the measured distances being very small, the use of a film base was not objectionable. The position of the moving wire could be determined within about one-half micron (in this case $0^s.004 \sec \delta$).

Discussion. The combination of a satisfactory motor drive with the technique of observing described above has had a beneficial effect on personal errors and on the quality of the observations in general. There is at present

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no machine for the determination of absolute personal equation that is adapted to the form of registration used on the six-inch. However, with the nine-inch, which is equipped with the same type of motor drive without photographic registration, absolute determinations have been made by Dr. MORGAN and his associates as follows. In the clock star zone the results for six observers range from $-0^s.004$ to $+0^s.001$, the probable error of each determination being $0^s.002$ and the average magnitude of the personal equation for all six being $0^s.0015$. For declinations 65° and 85° the averages are $0^s.004 \sec \delta$ and $0^s.003 \sec \delta$ respectively. The observers using the hand-driven micrometer formerly attached to the six-inch had personal equations ranging from $0^s.000$ to $0^s.015$, the mean of six observers being $0^s.009$.[4]

The probable error of the clock correction derived from a single observation made with the six-inch is now found to be $0^s.011$. This is based on the accordance of the clock star observations on individual nights over a period of nearly three years and it includes the effect of errors in the star places and in the instrumental constants. The corresponding quantity for the hand-driven micrometer is $0^s.018$; that for the photographic zenith tube is given by P. SOLLENBERGER as $0^s.0095$.[5]

While the characteristics of the motor drive have contributed greater accuracy, the photographic register has brought about the desired uniformity in the details of observing which led to its introduction. There is a marked saving in the time required at the instrument, and the records are free from the clerical errors that can so easily arise as the result of haste and fatigue.

Acknowledgments. The work was undertaken with the approval and encouragement of the Superintendent, Captain HELLWEG. As it was desired not to interfere unduly with the regular observing program of the instrument, progress was necessarily slow. The new construction was skillfully performed by the Observatory instrument maker, A. G. ILSE, who also contributed some details of design. The micrometer to which the new parts were added is an excellent one furnished with the transit circle by its makers, the Warner and Swasey Company. I am indebted to CHESTER B. WATTS, Jr., an electrical engineer, for supplying the circuits used in the electronic apparatus and for much helpful advice in this part of the work. A. N. ADAMS supervised the installation of the electrical circuits; all of the observers assigned to the instrument cooperated effectively.

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U. S. Naval Observatory,
Washington, D. C.,
1943 *October.*

OBSERVATIONS OF *PLUTO* WITH THE 24-INCH REFLECTOR OF THE YERKES OBSERVATORY

BY G. VAN BIESBROECK

U. T.	α	δ	Comparison Stars
1939 Nov. 11.42406	$8^h24^m23^s.75$	+23° 6′ 57″.6	Par. ph. +24°, 8^h24^m, 137, 144, 148.
Nov. 13.40885	24 22.25	7 22.5	ibid.
1940 Feb. 11.10131	18 2.43	38 14.5	+24°, 8^h16^m, 85, 90, 97.
1941 Nov. 18.24065	37 20.41	15 29.6	+23°, 8^h36^m, 40, 49, 52.
Nov. 19.28396	37 19.18	15 46.6	ibid.
Nov. 27.25431	37 6.16	18 5.4	+23°, 8^h36^m, 40, 45, 48.
Dec. 14.20280	36 16.64	23 59.4	+23°, 8^h36^m, 29, 32, 37.
Dec. 21.28392	35 48.32	26 49.8	+23°, 8^h36^m, 19, 24, 32.
1942 Jan. 13.16575	33 58.07	36 17.4	+24°, 8^h32^m, 136, 149, 150.
Jan. 15.14200	33 47.07	37 8.5	ibid.
Jan. 16.17631	33 41.34	37 34.5	ibid.
Jan. 17.15817	33 35.92	37 59.3	ibid.
Jan. 22.21241	33 7.31	40 6.9	+24°, 8^h32^m, 127, 136, 150.
Feb. 12.13650	31 9.69	48 6.9	+24°, 8^h32^m, 101, 104, 112.
Feb. 14.12633	30 59.10	48 47.5	ibid.
Feb. 18.06998	30 38.47	50 3.8	+24°, 8^h24^m, 85; 8^h32^m, 101, 104.
Feb. 20.14745	30 27.81	50 41.6	ibid.
Mar. 10.28510	29 6.71	55 16.4	+24°, 8^h24^m, 70, 187, 77.
Mar. 19.17847	28 36.34	56 45.3	+24°, 8^h24^m, 57, 70, 187.
Mar. 22.20299	28 27.63	57 8.2	ibid.
Apr. 4.13335	28 0.88	58 4.9	+24°, 8^h24^m, 53, 57, 70.
Apr. 11.13953	27 53.84	58 6.4	ibid.
Apr. 13.10509	27 52.86	58 2.8	ibid.
Apr. 15.11545	27 52.24	57 58.5	ibid.
May 8.13896	28 17.23	55 15.5	+24°, 8^h24^m, 57, 70, 187.
May 9.11962	28 19.60	55 4.6	ibid.
May 19.10108	28 49.14	52 55.2	ibid.
1943 Feb. 7.07477	38 26.36	49 20.1	+24°, 8^h32^m, 81, 198, 97.
Feb. 8.09282	38 20.59	49 42.5	ibid.
Mar. 5.12412	36 13.52	57 35.4	+24°, 8^h32^m, 63, 69, 179.
May 22.11021	35 31.90	55 39.9	+24°, 8^h32^m, 57, 63, 167.
May 25.12507	35 43.18	54 52.9	+24°, 8^h32^m, 57, 63, 173.
May 28.12083	35 55.20	54 2.0	+24°, 8^h32^m, 63, 69, 173.

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