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## PERSONAL ERRORS IN THE USE OF A SELF-REGISTERING MICROMETER,

By J. C. HAMMOND.

[Communicated by Rear Admiral J. A. HOOGWERFF, U. S. Navy, Superintendent, U. S. Naval Observatory.]

The following results are derived from investigations and observations made with the 6-inch transit circle of the U. S. Naval Observatory during the years 1911 to 1918, in the course of the determination of the positions of the standard stars contained in the *American Ephemeris* and in the lists of BOSS, BACKLUND and HOUGH. The instrument is equipped with a hand-driven self-registering micrometer of the Repsold type made by the Warner and Swasey Company of Cleveland. A close pair of threads is used to follow the star and a reversing prism is attached in front of the eye-piece, all observations being made with the prism in two positions to eliminate errors due to bisection and the direction of motion of the star.

## ABSOLUTE PERSONAL EQUATION

The absolute personal equations of five different observers were determined with a personal equation machine made by the instrument maker of the Naval Observatory. This machine was described by Professor F. B. Littell in a paper read before the Astronomical and Astrophysical Society of America during its meeting at Washington, D. C., in 1911. The essential feature is a carriage which carries an artificial star alternately east and west across the line of sight of the telescope and which causes an automatic record to be registered on the chronograph. The speed of the artificial star can be varied to correspond to that of any star and it is observed in the same manner as a real star. By comparing the record with the automatic one made by the carriage, the observer's absolute personal equation can be determined.

The following table gives the absolute personal equations of the five observers for stars of different declinations. The signs are such as to make them applicable to observed transits.

## CORRECTIONS FOR ABSOLUTE PERSONAL EQUATION

| Decl. | Hammond | Frederickson | Rines | Wylie | Aston |
|-------|---------|--------------|-------|-------|-------|
| °     | s       | s            | s     | s     | s     |
| 0     | -.018   | -.026        | -.012 | -.011 | -.021 |
| 40    | -.012   | -.023        | -.011 | -.006 | -.013 |
| 60    | -.011   | -.021        | -.008 | -.001 | -.007 |
| 80    | -.02    | -.01         | .00   | +.02  | +.02  |
| 85    | -.02    | +.01         | +.02  | +.05  | +.06  |

An inspection of this table shows that each one observes the transit of a star too late, with the possible exception of stars near the pole, and that the amounts do not vary much for the different observers. There is some evidence that for slow moving stars near the pole there is a tendency, at least on the part of some observers, to get ahead of the star. The evidence is not conclusive on this point however as the personal equations for stars of declination 80° or more are not as well determined as the others.

The absolute personal equation in observing the *Sun*, as determined for four observers by attaching a brightly illuminated disk representing the *Sun* to the carriage of the personal equation machine, are as follows:

ABSOLUTE PERSONAL EQUATIONS IN OBSERVING THE *Sun*

| Hammond | Frederickson | Wylie | Aston |
|---------|--------------|-------|-------|
| s       | s            | s     | s     |
| -.016   | -.037        | -.031 | -.023 |

It will be seen that, for each observer, these personal equations are nearly the same as for stars of the same declination.

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## RELATIVE PERSONAL EQUATION

The relative personal equations of the various observers were derived from the observations of the clock stars by taking the clock correction of one and carrying it forward by means of the clock rate to the clock correction as determined by some other observer. In no case was this done when the interval exceeded 24 hours, so that any error in the result introduced by the clock will be negligible. Weight 2 was given when observers worked on the same night and weight 1 when the interval was approximately one day.

The corrections to be applied to observed transits of clock stars for the different observers to reduce to the system of HAMMOND are as follows:

| Frederickson          | Rines                 | Wylie                 | Aston                 |
|-----------------------|-----------------------|-----------------------|-----------------------|
| <sup>s</sup><br>-.007 | <sup>s</sup><br>-.021 | <sup>s</sup><br>+.005 | <sup>s</sup><br>+.005 |

These values of the relative personal equations are small and moreover there was no evidence of change in the different years.

The resulting values of relative personality from the personal equation machine for stars of 10° declination, corresponding to the mean declination of the clock stars, as derived from the first table are as follows:

| Frederickson          | Rines                 | Wylie                 | Aston                 |
|-----------------------|-----------------------|-----------------------|-----------------------|
| <sup>s</sup><br>-.009 | <sup>s</sup><br>+.004 | <sup>s</sup><br>+.006 | <sup>s</sup><br>-.003 |

The agreement is good except in the case of RINES, whose absolute personal equation is not based on many determinations. It should be noted also that the relative personal equations as derived from clock corrections are affected by peculiarities in the determination of the instrumental constants.

## MAGNITUDE EQUATION

The instrument is equipped with two screens by means of which the magnitude of all the standard stars observed were reduced to some magnitude between 5.0 and 8.0. It was only necessary therefore to determine the magnitude equation for a range of 3 magnitudes between these limits. This was done with considerable accuracy for 3 observers and the following results obtained:

## MAGNITUDE EQUATION FOR A RANGE OF 3 MAGNITUDES BETWEEN 5.0 AND 8.0 IN SENSE BRIGHT MINUS FAINT

| Hammond              | Frederickson         | Wylie                 |
|----------------------|----------------------|-----------------------|
| <sup>s</sup><br>.000 | <sup>s</sup><br>.000 | <sup>s</sup><br>-.001 |

The magnitude equation with the self-registering micrometer for stars between the 5th and 8th magnitude is negligible.

## CORRECTIONS TO OBSERVATIONS OF STANDARD STARS TO REDUCE TO SYSTEM HAMMOND

| $\delta$ | Frederickson |              | Rines        |              | Wylie        |              | Aston        |              |
|----------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|          | Clamp East   | Clamp West   | Clamp East   | Clamp West   | Clamp East   | Clamp West   | Clamp East   | Clamp West   |
| °        | <sup>s</sup> | <sup>s</sup> | <sup>s</sup> | <sup>s</sup> | <sup>s</sup> | <sup>s</sup> | <sup>s</sup> | <sup>s</sup> |
| - 25     | .000         | -.003        | -.010        | +.008        | +.020        | -.018        | +.015        | -.015        |
| - 15     | +.001        | -.002        | -.007        | +.005        | +.015        | -.014        | +.009        | -.010        |
| - 5      | +.001        | -.001        | -.004        | +.002        | +.009        | -.010        | +.005        | -.007        |
| + 5      | +.001        | .000         | -.002        | -.001        | +.003        | -.004        | +.001        | -.002        |
| 15       | -.001        | +.001        | -.002        | -.002        | -.003        | +.003        | -.001        | +.003        |
| 25       | -.002        | +.002        | -.002        | +.001        | -.008        | +.008        | -.003        | +.007        |
| 35       | -.004        | +.004        | .000         | +.005        | -.007        | +.014        | -.004        | +.011        |
| 45       | -.004        | +.004        | +.003        | +.001        | .000         | +.021        | -.001        | +.013        |
| 55       | -.002        | +.007        | .000         | -.003        | +.010        | +.033        | +.005        | +.016        |
| 65       | .00          | +.01         | +.01         | .00          | +.03         | +.04         | +.02         | +.02         |
| 75       | +.01         | +.02         | -.02         | +.01         | +.04         | +.04         | +.05         | +.04         |
| 85       | +.02         | +.08         | -.05         | +.01         | .00          | .00          | +.15         | +.18         |
| 95       | +.02         | +.10         | -.01         | -.03         | -.16         | +.07         | .....        | .....        |
| +105     | +.01         | +.04         | +.02         | -.03         | -.12         | +.07         | .....        | .....        |

## COMPARISON OF OBSERVATIONS OF STANDARD STARS

All the observations of the standard stars made by any observer were in general reduced with clock corrections and constants determined by himself. From these observations, the differences between the various observers were deduced. In doing this, the two positions of the clamp were kept separate and the comparisons were made in zones  $10^\circ$  wide in declination. These differences, which are small, must be due to peculiarities in the determination of the instrumental constants, combined perhaps with a variation in absolute personal equation with the declination.

The preceding table gives corrections for each observer to reduce to the system HAMMOND.

The corrections for FREDERICKSON and RINES are small enough to be attributed to accidental errors. In the case of WYLIE and ASTON, however, the corrections appear to be real but it has not been attempted

to represent them by an empirical formula. There was not enough data to determine the corrections in the case of ASTON for stars at lower culmination.

There is considerable difference in opinion as to the relative advantages of the hand-driven and motor-driven micrometers. It is quite possible that certain systematic errors may be introduced by the latter which are lacking in the case of the former. It is my opinion that an observer, after a little practice, can follow a star with as little accidental error with a hand-driven micrometer as with a motor-driven one. For an experienced observer, under good conditions of seeing, the probable error of a single contact or registration with the micrometer of the 6-inch transit circle is,  $p = \pm 0''.022 \sec \delta$ .

This micrometer has never given any trouble and the simplicity of its construction and operation recommends it for use in fundamental work.

## ON DIFFERENTIAL HORIZONTAL REFRACTION,

By WILLIAM B. VARNUM.

On examining the clock corrections for the Albany observations made 1907-18, a well marked term, depending upon the time of day at which the observation was made, developed. It is not the same for all stretches during which the observations were continuous but is very consistent throughout any one stretch. Twenty-one stretches extending from 1915 to 1917 were chosen. These are well distributed as to clamps, observers and months of the year. The means by groups are shown in the following table:—

| (1)                       | (2) | (3)          | (4)          | (5)          |
|---------------------------|-----|--------------|--------------|--------------|
| <sup>h</sup> <sup>m</sup> |     | <sup>s</sup> | <sup>s</sup> | <sup>s</sup> |
| 23 44                     | 4   | +0.040       | +0.017       | +0.023       |
| 1 22                      | 6   | + .036       | + .025       | + .011       |
| 2 2                       | 14  | + .030       | + .013       | + .016       |
| 3 2                       | 27  | — .007       | — .001       | — .006       |
| 4 1                       | 101 | + .029       | + .015       | + .014       |
| 5 0                       | 45  | + .028       | + .027       | + .001       |
| 6 2                       | 53  | + .009       | + .006       | + .003       |
| 7 5                       | 91  | + .009       | + .007       | + .002       |
| 7 59                      | 103 | + .004       | + .002       | + .003       |
| 8 58                      | 132 | + .012       | + .012       | — .001       |
| 10 0                      | 143 | + .014       | + .006       | + .008       |
| 10 57                     | 106 | + .017       | + .012       | + .005       |
| 11 56                     | 63  | + .008       | + .006       | + .003       |
| 12 55                     | 42  | + .011       | + .005       | + .006       |
| 14 0                      | 21  | + .009       | — .004       | + .013       |

| (1)                       | (2) | (3)          | (4)          | (5)          |
|---------------------------|-----|--------------|--------------|--------------|
| <sup>h</sup> <sup>m</sup> |     | <sup>s</sup> | <sup>s</sup> | <sup>s</sup> |
| 14 58                     | 24  | +0.018       | +0.004       | +0.014       |
| 15 54                     | 8   | + .013       | + .005       | + .008       |
| 16 48                     | 10  | — .004       | + .008       | — .012       |
| 18 12                     | 14  | — .009       | + .002       | — .011       |
| 19 4                      | 27  | — .011       | — .007       | — .005       |
| 20 0                      | 53  | — .039       | — .029       | — .010       |
| 20 57                     | 63  | — .005       | — .007       | + .002       |
| 22 4                      | 41  | — .014       | — .007       | — .008       |
| 22 52                     | 18  | — .021       | — .010       | — .011       |
| 1209                      |     |              |              |              |

Column (1) = Albany mean time

Column (2) = No. of observations

Column (3) =  $\Delta T$  — Computed clock correction

Column (4) = Computed value of (3)

Column (5) =  $(O - C) = (3) - (4)$

Believing this phenomenon was due to differential horizontal refraction ( $dr$ ), (4) was computed from (3) by the formula  $\sec \delta \sec (\phi - \delta) M + \sec \delta \sec (\phi - \delta) \times MR$ , where  $M$  = Mass of the air,  $R$  = Rate of change of mass. The lateral refraction will cause a correction to the computed azimuths of the form

$$\Delta a = \sec (\phi - \delta) \operatorname{cosec} (\phi - \delta) dr.$$