

# CAMPAIGN FOR DETERMINING THE LONGITUDE OF THE FUNDAMENTAL POINT OF THE ASTRONOMIC OBSERVATORY IN NAPLES

## II. . PRELIMINARY STUDY OF AN IMPERSONAL MICROMETER

by E. FICHERA, S. MANCUSO and A. PUGLIANO  
with the cooperation of the technicians  
V. CASELLA, P.G. COLOGNA and L. IEVOLELLA

---

### INTRODUCTION

In a meridian observation the most complex and delicate operation is that of determining the time  $T$  of the star's transit at the meridian of observation. The errors which are committed during this determination arise from very many causes; some are due exclusively to the technical defects in the instrument and others to a combination of these defects and the observer's reactions, i.e. the *personal equation*. Moreover to a large extent these errors *cannot be expressed* accurately by analytical relations, and consequently the relation allowing the corresponding correction for the final reductions cannot be found.

In every case it can be said that the largest error affecting a longitude determination is the observer's error in his measurement of  $T$ .

The correction to be made to the observation in order to take this error into account is called the personal equation — giving to this word equation the classical sense of correction that it has in Greek. In order to make this equation's effect *minimum* and *constant* two basic principles must be followed, and these are that *a*) special technical precautions must be taken concerning the optical-micrometric system and *b*) the determination must be carried out by an observer having much practical experience of this type of observation so that he has a good knowledge of the operations to be made and, even better, that he knows what not to do in order to avoid introducing into the determinations errors which are only identifiable in the reductions with difficulty.

Otherwise the effects of unforeseeable accidental errors will completely mask the systematic error of the personal equation, and consequently the final value obtained will contain large uncertainties.

It is difficult to list the causes which produce a variation of the personal equation in their order of importance.

These causes generally depend on the following factors :

- (a) The observer's reflexes;
- (b) The chromatic reactions and visual sensitivity of the observer's eye;
- (c) The optical system;
- (d) Imperfections in the eyepiece mounting;
- (e) Mechanical constants of the micrometer screw;
- (f) Electro-mechanic constants of the impersonal micrometer drum.

Not knowing quite where to start this study, we decided to follow the order given by TARDI [1] on page 169 of his work on geodetic astronomy and to specify the precautions taken by the present author, after consultation with the research group, in order to reduce the effect of these causes to the minimum.

### 1. THE OBSERVER'S PHYSIOLOGICAL STATE

Under this heading will come the effects due to temporary fatigue, to depression and above all to the observer's nervous excitement caused by his fear of not having sufficient time to complete the various operations which he must carry out during the observation.

This can be considered as the cause producing the largest error in the determination of time  $T$  of a star's meridian transit.

Studying the effects carefully to find the precautions to be taken to minimize them, let us first of all consider the case of a calm and well disciplined observer who has no preoccupations or anxieties.

Every observer instinctively tends to place the impersonal micrometer's movable thread either above or below the centre of the star image without taking into account the direction in which the star is moving in the field of the eyepiece.

This effect is known as the *equation of motion* [2]. If it were possible to eliminate the feeling of the star's motion in the eyepiece field we should do away with the equation of motion. In order to eliminate this effect the observer must from the very beginning of the motion impart a very uniform rotation to the micrometer screw controlling the movable thread so that this thread moves at the same speed as the star's apparent motion. It will be noted that this speed varies with each star as a function of  $\sec \delta$ , where  $\delta$  is the star's declination.

In actual fact the observer confines himself to following the star by imparting a speed to the thread that is on the average equal to the star's apparent motion. This is to say that if he sees that he is slightly late he speeds up the revolution of the screw, and for the opposite case he slows it down. The mean of numerous automatic contacts supplies the most likely value for the star's meridian transit time  $T$ ; and this is the advantage of using an impersonal micrometer — indeed this reduces considerably the observer's equation of motion.

However it must not be thought that this error will be decreased by increasing the number of contacts (and consequently of readings) for each revolution of the micrometer drum.

In actual fact, from the recent investigations carried out on the personal reactions of near-perfect individuals — such as astronauts — who have continued rest, it has been discovered that the lag for visual stimulation is of the order of half a tenth of a second of time ( $-0.05$  s). This is for astronauts: for mortals like us this interval is between one and two tenths of a second.

Taking this investigation into account we devised our impersonal micrometer so that the time interval between one automatic contact and the next is at least 0.3 s for an equatorial star — twice the interval of time accepted as constant for visual reaction in an ordinary person.

A larger number of contacts with the micrometer drum does not increase accuracy in any way: in the case of numerous contacts instead of having one wrong reading there will be at least two consecutive readings in error.

The diagram (fig. 1) of the drum proposed by the author has been excellently put into actual effect by the technician V. CASTELLA, as can be seen from the data shown in the table given below which were obtained

TABLE 1

T sec.	<i>d</i> sec.	T sec.	<i>d</i> sec.	T sec.	<i>d</i> sec.	T sec.	<i>d</i> sec.
11.846	0.200	6.942	0.378	16.500	0.440	11.846	0.200
12.046	0.368	7.320	0.222	16.940	0.269	12.046	0.368
12.414	0.280	7.542	0.268	17.209	0.307	12.414	0.280
12.694	0.228	7.810	0.274	17.516	0.234	12.694	0.228
12.922	0.310	8.084	0.356	17.750	0.376	12.922	0.310
13.232	0.282	8.440	0.352	18.186	0.370	13.232	0.282
13.514	0.316	8.792	0.228	18.496	0.190	13.514	0.316
13.830	0.416	9.020	0.311	18.686	0.340	13.830	0.416
14.246	0.270	9.331	0.487	19.026	0.384	14.246	0.270
14.516	0.286	9.818	0.366	19.410	0.348	14.516	0.286
14.802	0.388	10.184	0.321	19.758	0.222	14.802	0.388
15.190	0.263	10.505	0.359	19.980	0.290	15.190	0.263
15.453		10.864		20.270		15.453	

MEAN VALUE = 0.287

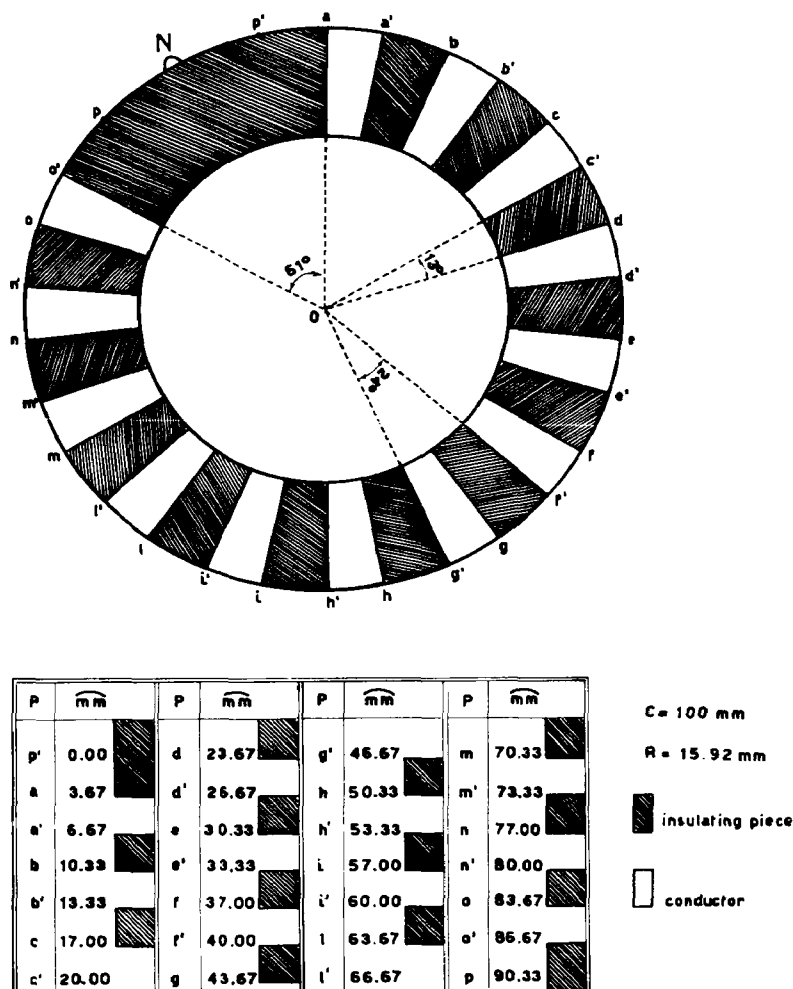


FIG. 1. — Projected Impersonal Micrometer.

from a series of observations of an equatorial star (n. 756 FK 4) tracked with the above-mentioned impersonal micrometer.

The results shown in table 1 can be obtained by an observer working calmly and having all the time necessary to bring the whole of his attention to the series of contacts made during the course of a star transit observation. Every factor likely to disturb this state of calm and attention immediately produces a considerable irregularity in the succession of readings and consequently compromises the whole observation when this is solely based on readings.

The anxiety and the fear arising from his preoccupation with not having time to observe the next star in the established programme transforms even the best of astronomic observers into an incapable amateur.

This is why the star programme for highly accurate observations must

be sufficiently studied and prepared in advance. Reasonable intervals of time must be left between the star transits and consequently reasonable differences in right ascension of these stars. Moreover these differences must be functions of  $\sec \delta$ , a quantity from which must be deducted the time taken by the star to traverse the entire eyepiece field. It must also be remembered that for each star observation a whole series of striding level readings [4] must be taken, and that time must be left to finish all these operations which cannot be eliminated by instrumental automatization.

Furthermore during an hour of observation it is necessary at least once to leave an interval of time longer than the average between two consecutive stars so that the observer may have a longer period of time available in order to eliminate the effects of any momentary fatigue.

In drawing up our programme — an operation entrusted to Dr. A. PUGLIANO — we were much preoccupied with this factor. The interval between one transit and the next is 4 — 6 minutes on the average, whereas in the middle of the observation hour there is at least one interval of 8 — 10 minutes.

TARDI, in the afore-mentioned work, cites the length of the observation as a secondary cause of variation in the personal equation. We prefer not to consider this as a cause in itself, and to rank this factor with the observer's physiological state because a long observation actually gives rise to observer fatigue.

The author has had much experience of this observer fatigue, first as director of the Carloforte International Astronomic Latitude Station from 1952-1955, and then when in charge, together with M. NICOLINI, of the computing of final reductions for the International Service's publication for the period 1941-1948.

At the International Service's latitude stations each observer is in actual fact required to carry out a series of determinations for each night over a period of six hours (three groups of six Horrebow-Talcott couples per group). The keeping of such a programme is the limit of human possibilities. During the six hours of night the observer must carry out a total of 512 very delicate instrumental operations, and at the same time transcribe onto the observation log 440 sets of three figures each.

To all this must be added the fact that the observer must work almost in the open so as to eliminate the refraction effects ascribable to the observation cabin, and we must remember also the monotony of work carried out in exactly the same way each evening over a minimum period of three years (in some cases observers have been working uninterruptedly at the stations for 16 years). It can then be said in this case that the individual is subjected to a psychic depression even when he is not observing.

At the time when the final reductions are made at the Central Office — as we are now actually doing for the period 1941 - 1948 — it is seen that accidental errors increase considerably during the last hours of the observation, and this makes all final discussion problematical and renders quite useless the sacrifices of these observers whom we ought rather to consider as having served science well.

It should be noted that we are in the process of reducing the observations carried out according to a programme of four hours per night as was in operation before the programme of six hours was put into effect.

To return to our longitude determinations : in order to avoid useless sacrifices — from the scientific point of view — on the part of the observer the author organized observational sessions in groups of an hour each, so that the observers could replace each other, resting for at least one hour and on alternate days.

## 2. AUTOMATIZATION OF THE OBSERVATION

Under this heading we have put all the causes of variation of the personal equation that TARDI mentions in his *observation method*.

We have turned our attention to giving our instrument the greatest possible automation, on the principle that the observer must carry out with *efficiency* only the minimum of operations required for an observation, without however reducing the number of data necessary for a good numerical reduction later on.

By the term *automatization* we mean the operations which the instrument must carry out automatically at a given time without any assistance from the observer.

The realization of this kind of automatization is the fruit of months of study, analysis and practical tests carried out by the whole research group, combining the author's experience of this type of observation with the immense technico-scientific abilities of all his collaborators.

The basic equipment chosen by us for the campaign is as follows :

- (a) Bamberg (Askania 100) transit instrument;
- (b) Repsold type impersonal micrometer;
- (c) Omega type Time Recorder — a chronograph printing to the thousandth of a second, stabilized by a quartz crystal plate, and transistorized;
- (d) Isatome crystal clock;
- (e) Philips short-wave radio receiver with wide band;
- (f) Philips 2-channel oscillograph, coupled to a camera for the reception of international time signals.

Logically the first operation to be carried out was to connect the instrument's impersonal micrometer to the Omega Time Recorder.

Let us now analyse only the technical questions, taking into account the complex needs of our type of observation.

To carry out a star transit observation the following procedure is used. The observation is made by following the star with the movable thread of the impersonal micrometer for a part of its path before it reaches the central thread. Then the instrument is revolved (and consequently there is a change in the direction of the star's movement in the eyepiece

field) and we wait for the star to arrive in the position in which the movable thread was left, and we then follow the star to the end of the observation.

Let us now see what technical measures must be taken to avoid most of the errors.

First of all the intrinsic error of the optical system must be eliminated; i.e. in practice we must determine the part of the eyepiece that is free from this error.

This error is called the *image displacement due to distortion*, and is a phenomenon well known to specialists in optics. It suffices to point it out, and to refer the reader who wishes to study the question more closely to the work on optics by DANJON [5] from which we have taken figure 2a.

Let M be a point on the object plane situated on this plane at a distance  $d$  from the optical axis; M' being its image produced by an optical system S placed on the image plane at distance  $d'$  from the optical axis. According to elementary optical laws we must obtain :

$$\frac{d}{d'} = \text{constant}$$

and this relation is called the *linear magnification* of the S system. When the foregoing relation has been checked for the finite values of  $d$  and  $d'$  we say that the system is *orthoscopic*. But in practice this does not happen. The M image instead of being produced at M' is produced at another point M'' which is at distance  $d''$  (differing from  $d'$ ); i.e. there is a *distortion* which is given by the relation :

$$d'' = d' + E d'^3$$

where E is the *coefficient of distortion* for the lens.

For a telescopic system the relation observed is given by the following relation :

$$\tan \theta_2 = G \tan \theta (1 + E \tan^2 \theta)$$

where G is the magnification of the system, and  $\theta$  and  $\theta_2$  the angles shown in figure 2a.

In reality the lens distortion is always negligible; the coefficient E is so small that we can consider it as nil. The distortion then varies with  $\theta^3$ , and the angle  $\theta$  is very small in astronomic lenses.

But it is quite otherwise for the eyepiece, which is our particular concern, for the principal radius of the oblique beam no longer passes through the optical centre but through the rear focus of the lens.

If the magnification G is high, and the field consequently reduced, as in our instrument, angle  $\theta_1$  (figure 2a) will be very small and it can therefore be confused with the height  $y_2$  of incidence of the principal radius (figure 2b) of an elementary beam with  $d_2$  as ordinate in the focal plane F.

The condition for orthoscopy will then become :

$$\frac{d_2}{\tan \theta_2} = \frac{y_2}{\tan \theta_2} = \text{constant} = \overline{\text{OP}}_2$$

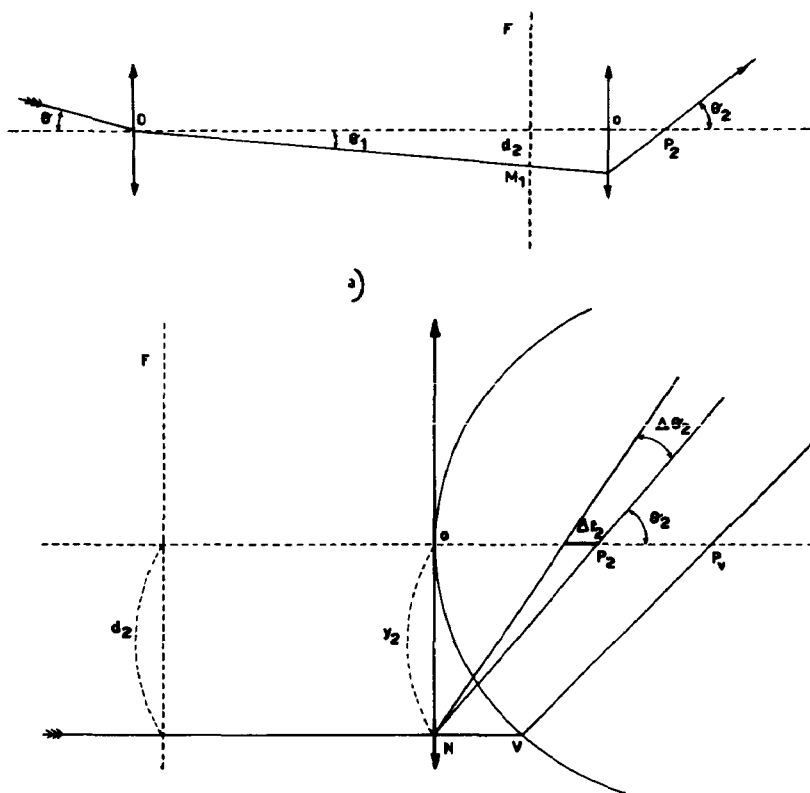


FIG. 2

but since  $oP_2$  is constant for all values of  $y_2$  this only happens when the eyepiece is free from spherical aberration relative to the rear focus.

The most usual eyepieces are far from being thin systems without any curvature, the radius of incidence and the radius of refraction meet not on the front plane but usually on a surface  $oV$ . The condition for orthoscopy is then :

$$\frac{y_2}{\tan(o\widehat{P}_vV)} = \text{constant}$$

and the distortion is dependent on the values of the segments  $NV$  and  $P_2P_v$ .

It is obvious that this distortion is detrimental to the automatic contact made during the star transit observation, but it is only discernible at the edges of the eyepiece field. In order to avoid this error in the star's motion two threads  $aa'$  and  $bb'$ , symmetrical in relation to the central thread, have been placed in the eyepiece field, so as to limit the field and to warn the observer never to let the movable thread pass outside this part of the field (figure 3).

In the second category of errors to be eliminated are those produced by a defect in the mounting of the micrometric graticule of the eyepiece.



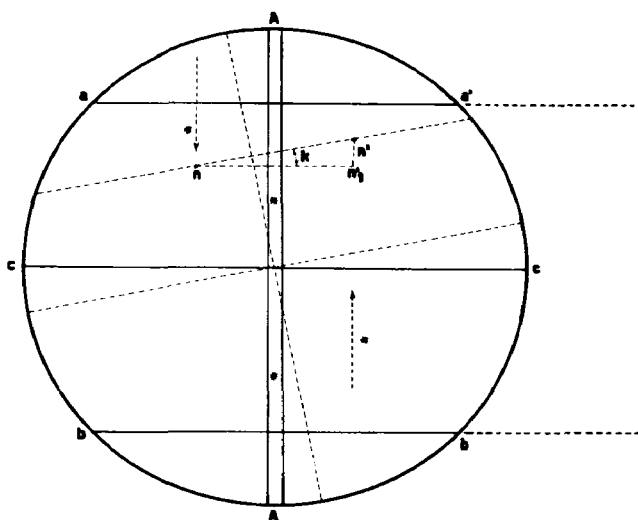


FIG. 3

If the micrometric thread is inclined at a certain angle in relation to the N-S direction any automatic contact made — for example in position  $n$  — will differ by the quantity  $j = \bar{n} \bar{n}' \sin k$  (fig. 3) expressed in seconds of arc in relation to the symmetrical position of the corresponding  $n'$  contact made in the second part of the observation (i.e. after changing round the instrument face). Thus, if we designate the times of transit at points  $n$  and  $n'$  by  $T$  and  $T'$ , and the transit of the star across the thread without collimation by  $T_m$ , we shall have :

$$T_m = \frac{T + T' + j \sec \delta}{2}$$

i.e. the true time  $(T_m)_v$  of the transit of a star of declination  $\delta$  will differ from the observed time by the quantity :

$$|(T_m)_v - T_m| = \frac{j \sec \delta}{2}$$

To eliminate this error a series of preliminary rectifying measurements is then carried out and then a pair of threads AA is inserted in the graticule so that the observer only takes a sight on the star after having set it within these threads by means of the screw regulating these small movements in height.

The last instrument error which is present in impersonal micrometer star measurements is the one arising from the combined effect of the *semi-contact* and the *play* of the screw. But this is a characteristic of the impersonal micrometer used and can be determined once and for all.

The determination of the width of the contact was made using the same method, i.e. by connecting the impersonal micrometer to the Time Recorder through an electronic relay. Making the micrometric screw revolve

very slowly we carried out a reading on the graduated drum of this screw each time that the circuit was opened and closed.

The determination was carried out by making the micrometric drum revolve first of all in one direction for 30 complete revolutions and then in the other direction for another thirty revolutions. In this way the measurement also included the effect due to the width of the brush contact.

Since our relay, which was constructed by the surveyor COLOGNA, can function equally well at the closing of the circuit linked to the impersonal micrometer as at its opening, for each contact we were able to carry out readings on the micrometer drum for both the closing and the opening.

TABLE 2  
*Width of the contact*

No	Closing	Opening	Width
1	90.33	93.30	2.97 p
2	97.00	100.00	3.00
3	3.67	6.65	2.98
4	10.33	13.34	3.01
5	17.00	20.00	3.00
6	23.68	26.67	2.99
7	30.32	33.31	2.99
8	37.00	40.00	3.00
9	43.67	46.68	3.01
10	50.33	53.35	3.02
11	57.00	60.00	3.00
12	63.68	66.68	3.00
13	70.34	73.33	2.99

Width of the contact = 2.9969 p

Half-width of the contact = 1.4984 p

The data given in table 2 are the means of 60 revolutions. It should be noted that the initial plan shown in figure 1 was for a 3 mm width of contact, with contacts at intervals of 3.66 mm. The excellent realization of the design by the technician V. CASELLA is reflected in the results.

As we have said, our relay can function for a series of automatic contacts at the closing of the micrometric circuit and then for the next series at the opening. This permitted the carrying out of the following absolutely automatic operation. If, for example, the observer has taken sights on the first series of star transits with the contacts at the closure position, then when he changes round the instrument face for the second series of observations the micrometer's contacts at the opening position will cause the relay to react automatically on the chronograph. In this way the contact's half-width error is automatically eliminated, and moreover a clear selection of electric signals in the electronic circuit is obtained.

However the width *sp* of the *brush contact* remains to be considered, a factor which cannot be eliminated because this contact can never be realised in punctual form, and which must be taken into account in the numerical reductions of the observations.

Table 3 gives the measurements carried out inserting the automatic system for reversing contacts into the relay in order to determine the brush

width. These measurements express the mean values from 64 revolutions carried out with the contacts at the closure position and 64 with the contacts at the opening position after reversing the direction in which the screw turns.

TABLE 3  
*Width of the brush contact*

No	Closing	Opening	Width
1	90.33	90.22	0.11 p
2	97.00	96.88	0.12
3	3.66	3.55	0.11
4	10.33	10.24	0.09
5	17.00	16.90	0.10
6	23.67	23.55	0.12
7	30.33	30.24	0.09
8	37.00	36.91	0.09
9	43.65	43.54	0.11
10	50.33	50.24	0.09
11	57.00	56.91	0.09
12	63.67	63.57	0.10
13	70.34	70.25	0.09

Width of the brush contact = 0.101 p

Half-width of the brush contact = 0.050 p

Finally the value of the play of the micrometer screw remained to be measured. This factor, which was measured by S. MANCUSO, is dependent on the following mechanical conditions.

The micrometer's graduated drum and the electrical contact cylinder are axially linked at one end of the micrometric screw which, as it turns inside the leading screw, imparts a rectilinear translation movement to the thread carriage.

On account of play between the screw and the leading screw which can never be entirely eliminated by the manufacturer, the thread-carriage travels with a certain delay, called backlash, at the time when the direction of revolution is changed.

The value of this backlash was determined by sighting the central fixed thread of the eyepiece graticule with the pair of movable threads (\*) for a series of 36 pairs of readings taken at a fixed mark in both directions of drum rotation.

Table 4 gives the observations. The value obtained is :

$$E = 0^p.37 \pm 0^p.05$$

Observing ten stars FICHERA, MANCUSO and PUGLIANO determined the micrometer rate value :

$$1^R = 4.7516 \text{ s} \pm 0.0009 \text{ s}$$

and thus the following data have been obtained.

(\*) The carriage of our micrometer has three threads, one apart and the other two very close to each other. For star observations the detached movable thread is used, whereas for observations of the right ascensions of planets the movable pair is used.

TABLE 4  
*Play of the screw*

No	Rotation +	Rotation -	No	Rotation +	Rotation -
1	7.07 p	7.13 p	19	7.08 p	7.14 p
2	7.08	7.16	20	7.09	7.10
3	7.04	7.10	21	7.08	7.11
4	7.05	7.12	22	7.05	7.16
5	7.09	7.08	23	7.02	7.08
6	7.09	7.11	24	7.11	7.11
7	7.11	7.13	25	7.12	7.05
8	7.04	7.13	26	7.09	7.09
9	7.13	7.16	27	7.08	7.10
10	7.12	7.11	28	7.06	7.05
11	7.09	7.14	29	7.10	7.13
12	7.11	7.10	30	7.07	7.13
13	7.08	7.09	31	7.12	7.16
14	7.01	7.10	32	7.04	7.11
15	7.11	7.11	33	7.11	7.18
16	7.12	7.12	34	7.07	7.10
17	7.08	7.07	35	7.08	7.09
18	7.12	7.15	36	7.09	7.10

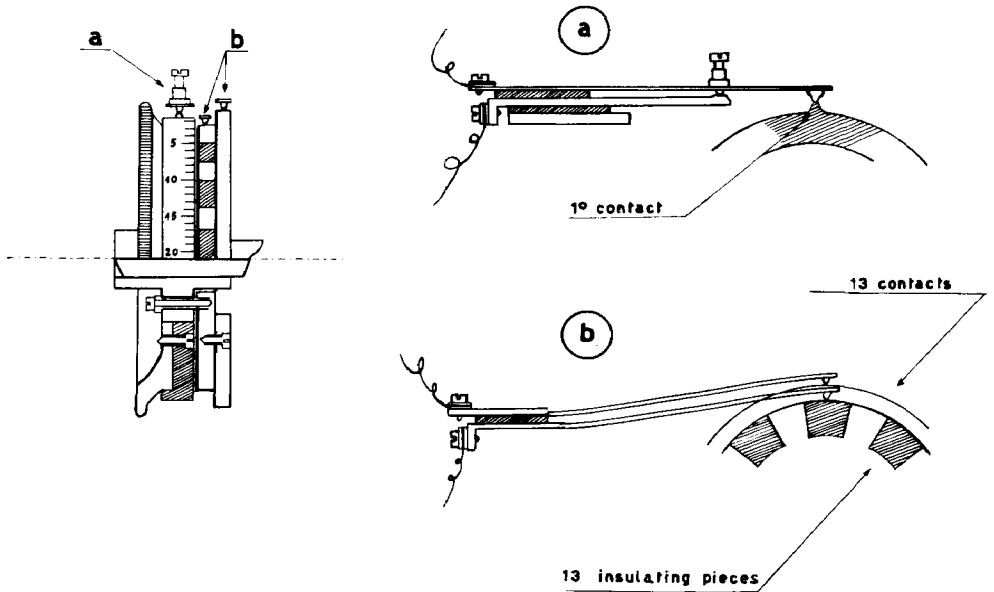


FIG. 4. — Details of Impersonal Micrometer.

Corrections to be made to the star transit time T :

- a) For the half-width of the contact . . . . . = 0<sup>m</sup>.071 sec  $\delta$
- b) For the half-width of the brush contact .. = 0<sup>m</sup>.002 sec  $\delta$
- c) For the delay due to play of the screw . . . . . = 0<sup>m</sup>.009 sec  $\delta$

Consequently the correction to be made to a transit observation on our instrument, with the relay functioning with the automatic contact reversed, is the following :

$$c = 0^s.011 \text{ sec } \delta$$

where  $\delta$  is the declination of the observed star.

Finally, our micrometer drum was constructed in such a way (fig. 4) that the first contact in the  $360^\circ$  circle (indicated by N on the plan shown in figure 1) induces a movement of the chronographic tape without however registering the time.

Thus for each revolution a blank will be registered on the printed chronograph tape, and the same thing will happen again after the instrument face has been changed round.

The observer can therefore finally identify with ease the symmetric contacts for a given observed star. At the end of each complete star transit observation all the blank intervals desired on the chronograph printing tape of the Omega Time Recorder are obtained through the use of a knob.

#### Bibliography

- [1] P. TARDI, G. LACLAVÈRE : *Traité de Géodésie*, Tome II, Paris, 1955.
- [2] N. STOYKO : *Sur la mesure du temps et les problèmes qui s'y rattachent*, Paris, 1931.
- [3] N.A.S.A. Reports on Man-in-Space flights (Medical Section).
- [4] E. FICHERA, A. PUGLIANO : The Chauvenet Problem and the determination of longitude by meridian observations : *International Hydrographic Review*, Vol. XLIV, No. 2, July 1967.
- [5] A. DANJON, A. COUDER : *Lunettes et télescopes*, Paris, 1935.