QUARTZ CHRONOMETERS IN PRACTICAL ASTRONOMY

By

J. FORRAI

Department of Surveying, Institute of Geodesy, Technical University, Budapest

Received: November 20, 1978

Presented by Dr. F. SÁRKÖZY, Director

Among partial operations of practical astronomy, timing of path across the wire is perhaps the most delicate one. To keep for instance the accuracy limits prescribed for the Hungarian geodetic surveying, the time has to be fixed at a hundredth part of a second accuracy, requiring, in addition to the chronometer, both an impersonal micrometer and some type of chronograph.

Topographic, military or expedition purposes need not exacter timing than by tenths or even integer seconds. Some methods — mostly related to observing the Polaris or the Sun — are best made with a stop-watch with two second hands as timepiece. Before and after observation, however, radio time keeping is required.

This problem is much facilitated by the advent and extension of rather inexpensive quartz chronometers. To be adequate, a quartz chronometer has to know at least as much as a mechanical watch with double second hands, that is, one "hand" has to run continuously, while the other can be stopped at any time instant at will and — after recording the stop-watch time — it can be sent after the other hand.

As an example, the Japanese quartz watch SEIKO-0634 will be presented as one adequately solving the problem, remarking, however, that several other quartz stop-watches may be just as convenient.

Description of the watch

The watch can be operated in two, quite independent operation modes termed:

a) clock operation to indicate "clock time";

b) stop-watch operation to run "stop-watch time".

Change from one operation to the other is by pushing the keyless button (Fig. 1).

In clock operation, dial indicates the following (Fig. 1/a):

— time of the day (morning or afternoon);

— date (without month);

— hour and minute according to "clock time".

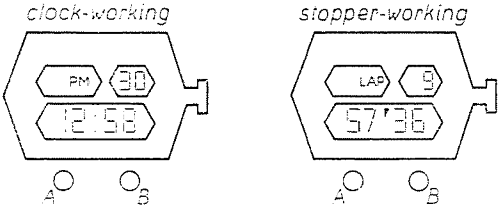

Fig. 1.

In clock operation, button "A" actuates a small lamp to illuminate the dial (an operation possibly avoided because of rather high energy consumption). Button "B" serves to adjust the clock when the keyless button is pulled out, not to be described here.

In stop-watch operation, the following are indicated (Fig. 1/b):

— minute and second ("stop-watch time");
— tenth second ("stop-watch time");
— LAP-indication with indication stopped, indicating part time after a starting time.

Without particulars of operation, stop-watch uses include:

a) duration timing;
b) summing of durations;
c) storage of duration sums;
d) fixing times within the running time (understood here as stop-watch time between a single starting and stopping of stop-watch);
e) simultaneous storage of an intermediate time within the running time and of the time of stopping.

Among them, function d) is of importance for us, it being that of the stop-watch with two second hands. Namely, stop-watch indication is push-button stopped but the real motion continues as seen by the rhythmic flash of a mark (minute). After having recorded the "stopped" time, the display can be push-buttoned to the real "stop-watch time".

It should be stressed that the modes of operation as a watch and as a stop-watch are perfectly independent. As a matter of fact, two watches have been accommodated in one watch case: one wrist watch without second hand, and a stop-watch without hour hand, likely to be controlled by the same oscillator with different gears. (It seems to be confirmed by encountering different chronometer-rate values between watch times and stop-watch times.)

Common control buttons act differently, depending on the mode of operation. There is no inner but only an outer possibility of synchronization, — e.g. time keeping from radio time signals.

Examination of the chronometer-rate

Examination of the chronometer-rate requires two fundamental problems to be cleared:

1. the reference time;
2. time accuracy of time keeping.

Time signals emitted by the Hungarian Radio have been used as reference, produced at a frequency stability of at least 10^{-8}, corresponding to a chronometer-rate of yearly ± 0.3 sec.

At the same time the accuracy of watch display is not better than a tenth of a second. With these proportions, the reference time may be considered as "absolute good" for a period of two or three months.

The time keeping reliability based on continuous time signals of the Czechoslovak radio emitter OLB-5 has been examined in the *Cosmic Geodesic Observatory* in Penc (Hungary), as follows: continuously emitted radio time signals sounded every second. At the instant of a time signal at random, the stop watch had been started, involving, of course, a non-zero chronometer correction, referred to the radio time signal system. Though, time keeping reliability for the stop-watch does not depend on the chronometer correction but on the reliability of determination. Therefore series of so-called elementary time keepings, single trials of determining the watch position upon pushing the part-time button at the sound of a time signal at random have been performed. It is righteous to assume with [3] an absolute error of "hand to ear" time keeping below 0.2 sec, hence an absolute chronometer correction value below 0.2 sec. The stop watch cipher for tenths of a second simply indicates the chronometer correction at an accuracy of 0.1 sec.

The first time keeping series consisted of pushing the stop button after 76 elementary time keepings. Series 2 and 3 were made in an analogous manner.

It should be stressed that every elementary time keeping entered the Gaussian mean square error calculation, whether the observer subjectively felt it to be poorer than the rest or not. Weighting for this subjective feeling still could improve the reliability [3].

Results of consecutive time keepings were:

	Series 1	Series 2	Series 3
Number of elementary time keepings	76	57	63
Gaussian mean error of one elementary time keeping	± 0.05 sec	± 0.05 sec	± 0.04 sec

Reliability values of the elementary time keepings are in perfect agreement with earlier findings published in [3].

Chronometer-rate findings were the following:

Chronometer-rate has been tested vs. temperature. Test results at three different temperatures were:

	Period 1	Period 2	Period 3
Test period	4.3 days	8.3 days	97.5 days
Number of time keepings during the period	9	16	18
Mean temperature during the period	10 ± 2 °C	19 ± 2 °C	23 ± 2 °C
Chronometer-rate direction tangent to the regression line	0.06 sec/day	0.25 sec/day	0.32 sec/day
Regression coefficient r^2	0.87	0.99	1.00

A and B values in the regression line formula ($y = A + Bx$) have been calculated as:

$$A = \frac{\Sigma y \Sigma x^2 - \Sigma x \Sigma xy}{n\Sigma x^2 - (\Sigma x)^2} \qquad B = \frac{n \cdot \Sigma xy - \Sigma x \Sigma y}{n \cdot \Sigma x^2 - (\Sigma x)^2}$$

and the fitting coefficient of the regression line by:

$$r^2 = \frac{[(x - \bar{x})\ (y - \bar{y})]^2}{[\Sigma(x - \bar{x})^2][\Sigma(y - \bar{y})^2]}$$

overdash indicating arithmetic mean of x and y values.

Test results and regression lines are seen in Figs 2, 3, 4.

Dash line in Fig. 3 indicates directions corresponding to the chronometer-rate at three different temperatures.

Fig. 5 shows the stop watch motion to linearly vary vs. temperature, at least between +10 °C and +23 °C. According to the plotted regression line, the stop watch rate would be zero at +6.9 °C. (Remark that no tests have been made at other temperatures, partly in lack of an adequate thermostat, and partly, because the manufacturer dissuades from using the watch even at 0 °C else than on the wrist, hence contacting body heat.)

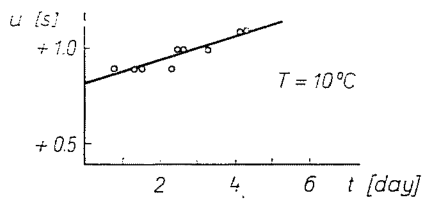

Fig. 2.

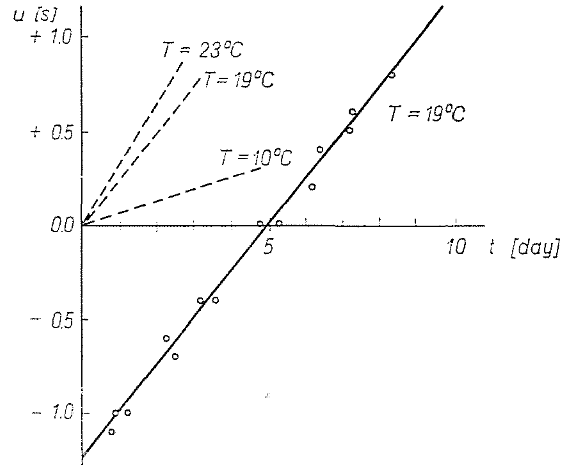

Fig. 3.

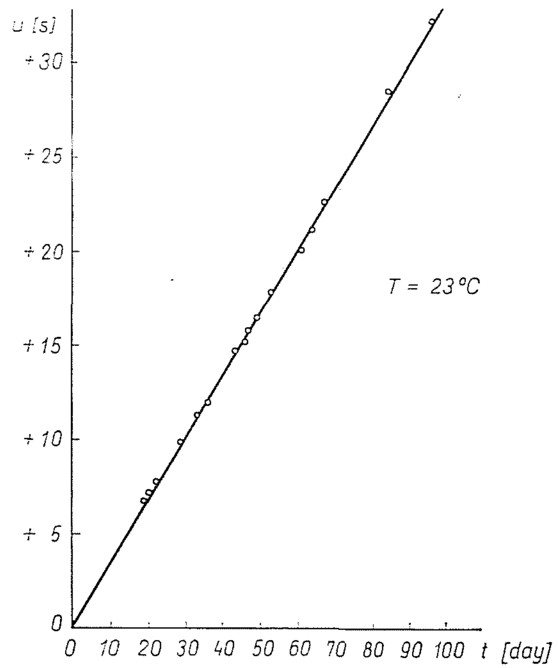

Fig. 4.

From the aspect of use, temperature dependence of the watch motion is only disturbing in case of abrupt, random temperature changes during timing. Namely, about knowing time and rate of change, its effect is easy to reckon with.

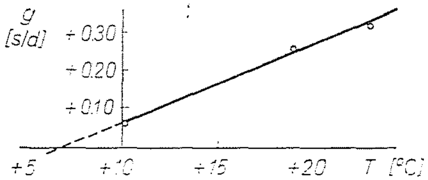

Fig. 5.

Let us consider a somewhat extreme case, where the temperature abruptly changes at once by 20 °C during six hours of timing.

Temperature change by 20 °C can be read off Fig. 5 to alter the chronometer-rate by about 0.4 sec/day = 0.017 sec/h, changing the chronometer correction during 6 h by 0.102 sec compared to that before thermal change. Thus, if time and course of the temperature change are unknown and only arithmetic mean temperatures between start and end are taken, it will result in max. 0.051 sec of error in determining the chronometer correction, comparable to the time keeping accuracy [3]. If, however, start and end of the abrupt temperature change can be assessed at an accuracy as poor as one hour, effect of the chronometer-rate change can be reckoned with at a sufficient accuracy.

Remind that no sensible variation of the watch motion has been observed with exhausting energy source (special knob battery). The first knob battery has been driving SEIKO-0634 since one and a half year, as a matter of fact, without ever using the tiny lamp illuminating the display

Conclusions

A quartz watch can be stated to be rather safe and convenient for procedures or methods of moderate accuracy requirement (such as azimuth determination from hour angles of Polaris or Sun, latitude determinant from the zenith distance of Polaris or Sun). Protecting the quartz watch from abrupt temperature changes and hourly reading off temperature changes during timing permit not to take radio time signals directly before and after timing but only e.g. in the evening and in the morning, utilizing time signals of some local emitter (of course, knowing their relation to other time systems). Thereby no special radio time signal receivers are needed daily, at an important convenience and economy.

Summary

Chronometer-rate of the recent quartz watches is much more stable than that of mechanical watches, recommending them for field astronomy. Under certain conditions, these are rather convenient and adequate for field astronomy methods based on moderately reliable timing.

References

1. LUKÁCS—SÁRDY, A.: Practical Astronomy. Notebook.* Tankönyvkiadó, Budapest, 1975.
2. MUELLER, I. I.: Spherical and Practical Astronomy. Frederick Ungar Publishing Co. New York, 1969.
3. Форраи, Й.: Применение микро-ЭВМ НР-55 для вычислений результатов приближенных астрономических наблюдений. Per. Pol. C. E. Vol. 21. (1977) No. 1—2. Budapest.

József FORRAI, H-1521 Bp.

* In Hungarian.