

# QUARTZ WATCHES AND NAVIGATION

by Dick Suiter

The Dava Sobel book *Longitude* as well as the 1990's A&E series of the same name emphasized the greater difficulty of determining a ship's longitude (i.e., how far east or west it is) compared to ship's latitude (or how far north or south). Keep in mind that the events depicted in this book preceded elaborate naval almanacs. Indeed, one of the methods mentioned in *Longitude* was the construction of the first such almanac. In the northern hemisphere, the position of Polaris is only 0.63 degree off the pole, so if you take a careful measurement of its height, correcting for the offset, you can make a fairly accurate estimate of the latitude of a ship (for example, if the two Guardian stars of Ursa Minor are directly over the pole, the offset is a full 0.63 degree negative). You can even use the noon sun as the target, if you correct for the movement along the ecliptic for the year. In the summertime in the northern hemisphere, the sun appears more northward in the sky. Of course, there is the finite aspect of the solar disk, which demands another correction, but these corrections are a few paltry calculations that do not vary from year-to-year. The north-south direction is hence easy.

Longitude is hard. If you are timid, you can crawl along the coast, always keeping landmarks in view, but some destinations do not allow this. Once you have left the sight of land for a significant time, your east-west coordinate degrades. This is why John Harrison pursued the idea of making an accurate clock that can operate at a variety of temperatures and was not sensitive to acceleration variations. You take a local-noon sight and you look at the clock to see what the time is back at Greenwich, and the difference is related to the longitude (you have another correction for the equation of time, but this is simple and widely understood by contemporaries who had to correct mean-time clocks to the "true solar time"). Accurate clockmaking is difficult, as well, but at least the hard part is placed on the maker of the clock and not on the user every time the calculation is made to reduce measurements.

The competitor to Harrison's clock was a computation-intensive way of obtaining time or longitude. It is to perform lunar measurements. The distance from the moon's edge and nearby bright stars distributed along the ecliptic varies with motion of the moon and where you are on the surface of the earth. It varies about 12 degrees per day. By looking up the conditions for the day and doing a mind-numbing set of calculations, interpolations, and corrections to the predictions of a set of tables, you can infer the longitude without knowing the time. If you are carrying a marine chronometer, you can then use the lunar information to calculate the time in Greenwich and therefore *check* the chronometer's time.

To create literary excitement, Ms. Sobel wrote of a controversy between Nevil Maskelyne and John Harrison as to which method was superior. No doubt some of this was real, especially having to do with winning the Longitude Prize, a gigantic fortune at the time, but the technical argument itself had no merit. The methods were mutually complementary, each doing things the other could not do. The chronometer served when the moon was not visible; the lunar method worked during favorable times to verify the chronometer. Dr. Maskelyne liked chronometers just fine after they were simplified enough to make them repeatably manufactured. It seems that he just didn't like John Harrison!

Mechanical marine chronometers are expensive, especially those made in the early days. The price of an early ship's chronometer was 50£ in a day and age where lower middle class yearly incomes were about the same amount. Certification of chronometer fitness can be supplied even today if you want to pay Contrôle Officiel Suisse des Chronometres (COSC) for such certification.

Perhaps a word should be said about measurement of angles. Sky-angle measurement has been done with successively greater and greater accuracy for a long time. Suffice it to say that sextant measurement can be made repeatedly to about 0.1 to 0.5 arcminutes, depending on the operator and the conditions.

I wondered if the common quartz watch was adequate to use in a pinch without certification. Quartz watches are sensitive to ambient temperature, so they are not well controlled over the long haul. However they have an effective operating temperature that is approximately met by the temperature of the wrist. We don't care as long as the operating temperature is about the same throughout the voyage and was the same temperature as the calibration was determined. Off-wrist chronometers would presumably be held deep within the ship.

## DETERMINING THE ERROR RATE

For my test group, I used my own watches at the very bottom end of price: 1) Casio G-Shock (inner works 3232), 2) Timex Expedition, and 3) a plain Casio W800H-1AV (inner works 3240). All three were quartz oscillators, with the Timex an analog display. Respectively they were \$55, \$40, and \$15-20 in price (early June, 2022). The standard was the Atomic Clock and Watch Accuracy Tool in the Google Play App store. I checked this app with the internet clock at the US Naval Observatory and could not tell the difference. There could be a lag in the internet propagation time, but good applications will ping back a signal and correct this lag time.



Figure 1. All three watches used. During the testing time, I wore the Timex.

I first recorded the relative time compared with the standard app. The results appear in Figure 2. This is over about 2.5 months.

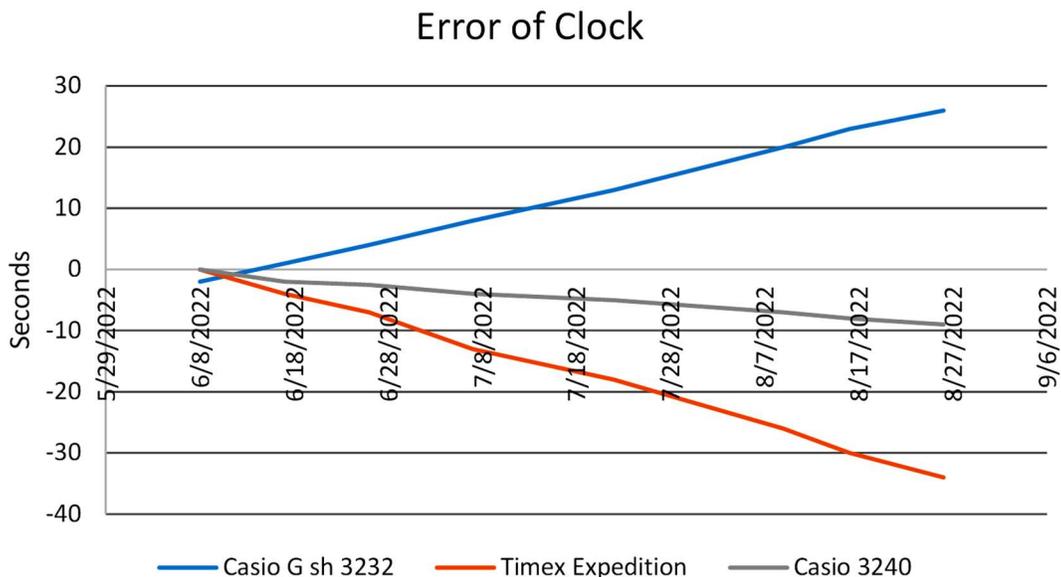


Figure 2. Errors of clocks over 2 3/4 months

Important in each of these three traces is that they are *linear*. The slope of these lines is called the "rate." Establishing the difference between the absolute time and the chronometer has been done since day one. Even Harrison, clock nerd that he was, could not be expected to disassemble his clock many times to fine tune a rate of 0 second/day. What he did, and what the government chronometer departments around the world performed when the chronometer became standard equipment for seagoing ships, is have a calibration service that cleaned and lubricated them. Finally, they measured their rates and wrote it on the certificate of calibration. No doubt the calibration expired after the service no longer trusted the lubrication, and the whole process started again.

By using the Solver in Excel, I got the statistics in Table 1. The "error minus rate" is depicted in Figure 3. Note the G-shock started with an error of -2 seconds (it was difficult to hit the sunken buttons). Much of the random errors are caused by my failure to read the two clocks simultaneously. The residual random errors are smaller than a second. The Casio 3240 (the cheapest watch) is near at the COSC level for quartz chronometer certification already ( $\pm 0.07$  sec/day), and all three exceed the mechanical limits.

Table 1. Accuracy statistics of three quartz watches.

Quartz Timepiece	Rate [sec/day]	Standard Deviation [error - rate]
Casio G-shock 3232	0.36	$\pm 0.29$
Timex Expedition	-0.43	$\pm 0.50$
Casio 3240 W800H-1AV	-0.11	$\pm 0.31$

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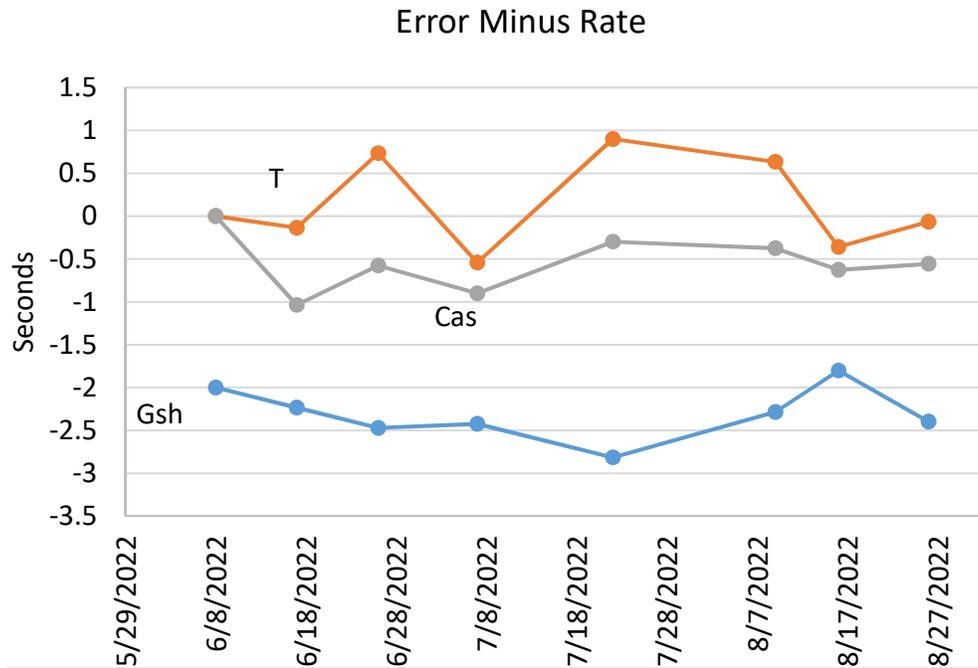


Figure 3. Random error after the systematic error is stripped away.

Please note what Figure 3 implies. Using a corrected, rated, quartz clock you can read the time within a second. This error alone translates to 15 arcseconds or about a quarter nautical mile, so the clock error is not yet the dominant factor. Now as you continue on your possibly year-long voyage around the world, either radically differing temperatures or extrapolation error on the rate might drive your error minus predetermined rate as much as 60 seconds (a guess). Suppose you can interpolate a noon sight within a minute or a little less by following the sun as it peaks. Sixty seconds of clock error is no bigger than noon-sight error. Even so, total error is still less than 20 or 25 nautical miles, enough to win the original Longitude Prize.

## CONCLUSIONS

Calibrated quartz watches can work fine as marine chronometers, but they still have that nagging problem of slight temperature dependence. One obvious solution is to place them in a warm box with an electric thermocouple sensor and a resistor that can heat up this small cavity (the rate is measured in the box too). But this may be overkill. I'm going to keep measuring my watches through the year — maybe even with some refrigerator time — and see how they do. My truck clock keeps good time even at temperatures characteristic of a parked vehicle acting as a greenhouse in the summer!

If you're racing away on a world circling *Vendée Globe* (about 90 days) and an inconvenient Kessler's Phenomenon knocks out the GPS constellation (that was a sped-up Kessler's event in the movie *Gravity*), you can fall back on your trusty rated wristwatch, sextant, and this single graph of the equation of time (see Figure 4) to win the event.

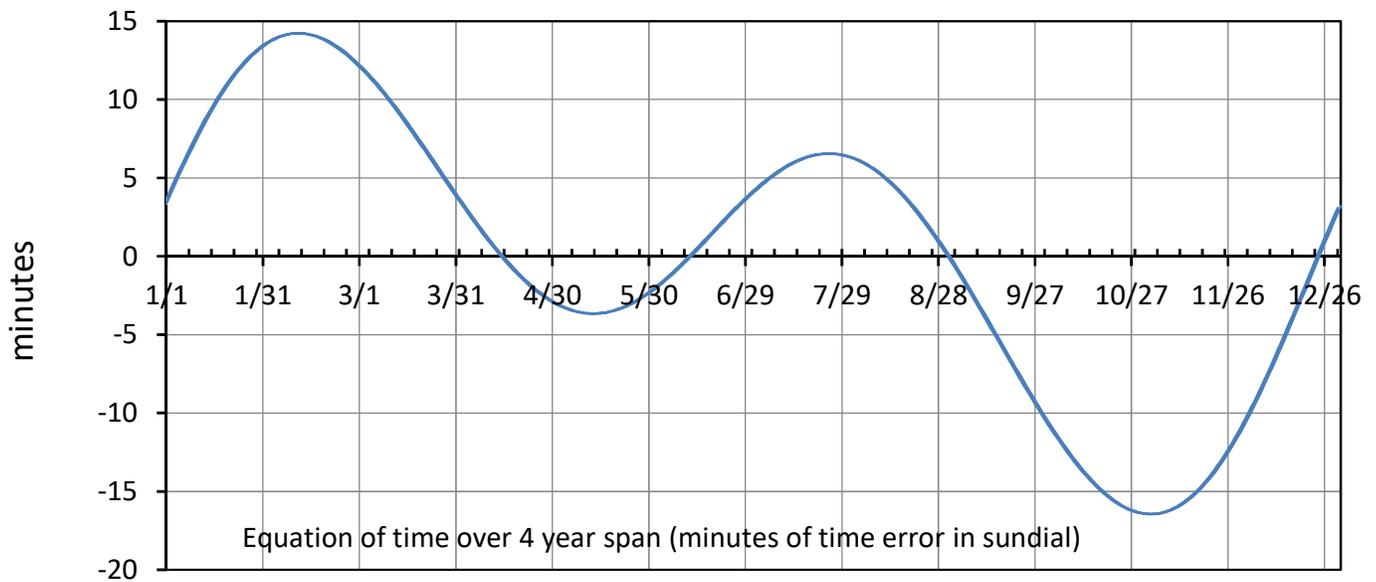


Figure 4. The Equation of Time.