

ON THE IMPORTANCE OF TESTING CHRONOMETERS BEFORE
THEY ARE USED AT SEA, WITH EXAMPLES TO SHOW HOW
THEIR MOST COMMON FAULTS MAY BE DETECTED.

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It is well known by those who have had much experience with chronometers, that some of the most serious defects to which they are liable cannot possibly be detected by an inspection of the works, however carefully they may be examined by the most skilful chronometer maker. It is also well known that the mariner, unaided, has no means whatever of efficiently testing the quality of a chronometer. From the first introduction of marine timekeepers, as an aid to navigation, it has been the practice to test all those employed in the British Navy at the Royal Observatory at Greenwich, previous to their being placed in the hands of the officers appointed to use them at sea. But the merchant captain has never been able to avail himself of this privilege; and until the Corporation of Liverpool made the necessary provision in this port, a few years ago, he had no authority to appeal to for information as to the quality of a chronometer, notwithstanding that this instrument is used, almost exclusively, for so important an object as that of finding the longitude of a ship at sea.

The subject is so novel, that some explanation appears necessary, to show the merchant captain how the chronometer can be tested for him, and what degree of confidence he may place in the tests which are applied, in an establishment provided with the necessary instruments and apparatus for making the experiments, and in which there is a proper guarantee for the records being faithfully kept for his inspection. In giving this explanation, examples will be introduced to which we shall frequently refer, in order to explain the nature of the most common faults which are found to exist in the chronometers now in use in the merchant service. These examples have been taken from the records of the Liverpool Observatory. In the following (Nos. 1 to 4), the daily rate is given in each, for twenty days in succession; and we trust that this period, short as it is, will be seen to be

sufficiently long to prove that the faults in Nos. 1, 2 and 3 rendered them unfit for sea use at that time; but that confidence might have been safely placed in No. 4.

EXAMPLES.

No. 1. New and Gaining on its Rate.		No. 2. Compensation not properly effected.		No. 3. Rate irregular in the same Temp.		No. 4. Rate steady and Compensation good	
Daily Rate. Gaining.	Temp.	Daily Rate. Losing.	Temp.	Daily Rate. Gaining.	Temp.	Daily Rate. Gaining.	Temp.
s.	°	s.	°	s.	°	s.	°
0.1	60	2.2	52	3.2	67	0.3	59
0.3	61	2.0	52	5.9	64	0.3	60
0.4	62	2.3	54	5.8	64	0.4	60
0.4	63	2.4	55	5.7	64	0.2	63
0.5	61	2.7	56	2.3	66	0.2	63
0.6	60	2.8	56	5.0	63	0.2	59
0.9	60	11.6	83	5.1	62	0.4	80
1.1	61	11.5	83	4.7	66	0.4	84
1.5	58	11.8	84	3.8	69	0.4	84
1.4	56	11.9	84	3.6	63	0.3	65
1.4	55	2.6	55	0.6	69	0.7	65
1.5	54	3.0	55	0.8	69	0.7	63
1.6	55	2.7	54	0.2	68	0.6	62
1.7	53	2.8	55	0.3	68	0.8	60
2.0	53	3.1	56	1.0	69	0.8	59
2.0	54	3.2	57	2.2	64	0.7	60
1.9	52	3.2	57	2.1	63	0.7	58
2.0	53	2.9	56	2.6	63	0.6	59
2.1	55	3.0	56	5.4	62	0.5	58
2.4	57	2.2	53	6.1	62	0.6	58

In the choice of a chronometer, the object of the mariner should be to select one which keeps a steady rate in those temperatures to which he will be most frequently exposed at sea; and the uniformity of the daily rate of No. 4, in temperatures ranging from 58° to 84°, would doubtless lead him to select this for a warm climate. Without such records to refer to, he has nothing to guide him in his choice.

The four chronometers here selected, appeared equally good to the eye, although three of them were quite unfit to take to sea at that time. Yet, a few months after the above results were obtained, No. 1 did keep, and Nos. 2 and 3 were made to keep rates nearly as steady as No. 4.

The way in which these improvements were brought about, we will endeavour to explain, beginning with No. 1. When new, chronometers have a tendency to gain on their rates, for periods varying from two or three, to six or eight months. This tendency to gain, appears to be caused by a change which gradually takes place in a new balance spring; the spring must be made hard to insure good performance, and the harder the spring the longer the chronometer appears to gain. Old chronometers, with new balance springs, gain as much as new chronometers. The effect of this tendency to gain is shown in No. 1. On the first day of the twenty, the daily rate was one-tenth of a second; on the last day, it was two seconds and four tenths. In this case, the chronometer continued to gain for upwards of four months, and the rate increased from one-tenth of a second to upwards of ten seconds a day. Five months subsequent to the period at which these results were obtained, the rate became steady, and the chronometer might then have been taken to sea, with every probability of good performance. A chronometer having this fault, might increase its gaining rate ten or fifteen seconds a day, in a voyage of three or four months; and the mariner not knowing the cause, would become dissatisfied, and possibly part with it at a great sacrifice, just at the time when good performance might be expected from it. It is quite a common thing for captains to bring their new chronometers to the Observatory *after*, instead of *before*, the first voyage, for the purpose of having them tested; in consequence of bad performance during the voyage. In such cases, we frequently find the fault to be this tendency to gain, from being new, and notwithstanding the great increase of rate which has taken place, it often happens that the tendency to gain has then nearly or quite ceased; and without anything being done to the chronometers, they are generally found to give satisfaction the next voyage.

We will now proceed to an explanation of the cause of the irregularity in the daily rate exhibited in No. 2. This is a case of imperfect compensation for change of temperature. The chronometer loses nine seconds a day more in 84° than it does in 55° . The shipmaster in possession of a timekeeper with this imperfection might be subjected to the most serious inconvenience, and possibly, after giving it a trial for a voyage or two, he would come to the conclusion that it was worthless, and part with it for a fault which could be removed for a few shillings. A chronometer maker who understands his business, on being shown the

tabulated results here given, would instantly know how to make the necessary alteration; the weights on the compensation balance, in this case, should be shifted a little towards the ends of the curved arms. In No. 4, it will be seen that no sensible alteration of rate took place on changing the temperature from below 60° to above 80° , and there is nothing whatever indicated in the performance of No. 2, to lead us to suppose that it might not be made to perform equally well. The defect is one of very common occurrence, as may be seen by our records; hundreds of similar cases have been detected during the past ten years at the Liverpool Observatory. It sometimes happens that chronometers are sold with both the faults shown in Nos. 1 and 2, and the increase of gaining rate during the first voyage is on some occasions so nearly equal to the loss from defective compensation, that the ship's longitude by chronometer is found to be sensibly accurate. On the next voyage, the tendency to gain having ceased, defective compensation acts alone, and the result is great disappointment. We have known captains in such cases to say that the performance of the chronometer was satisfactory during the first voyage, but that it had never gone well since.

In No. 3 the irregularities cannot be attributed to either of the faults exhibited in Nos. 1 and 2. The change of rate is not so gradual, continuous, and in the same direction as in No. 1; nor is it dependent on temperature, as in No. 2. The irregularity is quite as decided as in either of the preceding cases, but the cause is not so apparent; precisely similar irregularities are found to arise from a great variety of causes. The oil may be glutinous, or it may have escaped from one or more of the jewelled holes; a jewel may be loose or defective; the escapement may be imperfectly adjusted, or some other imperfection may exist, which the skilful workman will probably detect on taking the chronometer to pieces. Another and similar trial will prove whether he has detected and removed the fault. Sometimes the chronometer may pass through the hands of the most experienced chronometer maker several times, before he detects the fault, for it requires, on some occasions, no ordinary amount of skill; but the test, subsequent to the last examination by the maker, will show if the desired improvement is effected.

Supposing, therefore, that the mariner has access to an establishment in which experiments, similar to those exhibited in the preceding examples,

are made for him, he can himself, with the greatest ease, detect those faults which chronometers are so frequently found to have, and which are to him of so much importance. He has only to look down the column of daily rates, and to see that the temperature, shown in the side column, has been changed 20° or 30° . The difference between the results given from day to day will indicate at once if the chronometer has a steady rate. He must, however, bear in mind, that absolute perfection is impossible, variations of a few tenths of a second will take place. Chronometers which will bear a change of temperature of 20° or 30° , and in which the extreme difference between any two days for thirty or forty days in succession, does not amount to more than one second, or one second and a half, may be safely taken as first-rate marine timekeepers. If it were possible to make chronometers perfect in all other respects, the defect of the ordinary compensation balance would alone produce a change in the daily rate, as large as that above named. This may be seen in the following examples, in which we have selected three chronometers which were found to have nearly the same rates in 50° and 80° . By examining the rates about half way intermediate between 50° and 80° , it will be seen that each of them gained from one second to one second and a half more, than they did in either the high or low temperatures. The daily rates here given are all *gaining*, and the averages have been taken instead of the rate for each day, as in the preceding examples, the errors to be detected being very small.

EXAMPLES.

No. 5.			No. 6.			No. 7.		
Mean Daily Rate.	Gaining.	Temp.	Mean Daily Rate.	Gaining.	Temp.	Mean Daily Rate.	Gaining.	Temp.
s.		°	s.		°	s.		°
0.2		50	0.2		50	0.0		50
1.9		65	1.9		65	1.7		65
0.8		80	0.3		80	0.8		80

These rates were obtained from chronometers having the ordinary compensation balance. This balance is in use in the merchant service almost without exception. It does not perfectly compensate for the change of elasticity in the balance spring. With it the chronometer can be made to go the same in any *two* temperatures, but it cannot be made to go precisely the same in any *three* temperatures. All chronometers with this description of balance go faster in some particular temperature than they do in any other temperature, and the chronometer maker has the power of fixing

this maximum gaining rate, either in a high, low, or medium temperature, at pleasure ; by so adjusting the weights, on the compensation balance, as to give the chronometer the same rate in two temperatures at equal distances from that in which the maximum gaining rate is required. In example No. 6, the maximum gaining rate is fixed at 65° , as near as possible, and the loss at 50° is one second and seven tenths, and at 80° one second and six tenths. The temperature at which the maximum gaining rate is fixed, is a matter of the highest importance in chronometers with this description of balance ; because we find, that the further this point is departed from, the greater will be the variation of rate for a given change of temperature. At the distance of 15° , as we have seen, the change of rate is about one second and a half, but at 30° distance it is found to be much more than twice that amount. Ships at sea are for the most part exposed to temperatures ranging from 50° to 80° , and captains should therefore take care that their chronometers have as nearly as possible the same rate in these two temperatures.* Suppose a chronometer with the ordinary compensation balance to go *mean time* in 50° and 80° , then, as we have seen, it may be expected to gain about one second and a half in 65° ; in 90° it would probably lose about two seconds, and in 40° it would probably lose from two to four seconds a day. In temperatures below 40° there is less certainty ; the thickening of the oil and the consequent decrease in the arc of vibration, appear to be the cause of this. By winding up or letting down the main spring, and thereby increasing or diminishing its power, the maker can cause the chronometer balance to vibrate in a large or a small arc ; and there is a certain length of the balance spring, at which the daily rate of the chronometer is found to be the same, whether the arc of vibration be large or small. Now it is very probable that some makers so adjust the balance spring as to cause the chronometer to have the same rate in the large as in the small arcs ; and that others so adjust it as to make the chronometer gain more or less in the small arcs. In the former case, the loss from additional friction, caused by the thickening of the oil, together with that from the defect of the balance, might be excessive ; while, in the latter case, it would be more or less compensated for by the gain consequent on the diminished arc of vibration. Mariners who have chronometers compensated for high tem-

* This circumstance is either not known by chronometer makers, or it is not sufficiently attended to : the records of the Liverpool Observatory clearly prove this.

peratures, should, if possible, when in high latitudes, keep their time-keepers in a room with the temperature not much lower than 50° ; as it is by no means unusual for us to meet with chronometers having rates nearly as steady as can be desired between 60° and 85° , but which will, nevertheless, in temperatures between 30° and 40° , change their rates ten, and even twenty seconds a day. Chronometers intended for constant use in low temperatures, should be compensated exclusively for low temperatures; for with the balance in common use, they cannot be made to go with any degree of satisfaction, through so long a range of temperature as 60° or 80° .

There cannot be a doubt as to the practicability of removing this defect in the ordinary balance, but two things above all others are necessary for its accomplishment. Our means of testing must be such as to satisfy the makers that we can detect at once and without delay any improvement which they may make; and mariners, who are generally the customers of the makers, must make themselves so far acquainted with the defects of chronometers as to show that they can understand and appreciate improvements. The Corporation of Liverpool made the necessary provision for testing chronometers in this port some years ago, and arrangements are now being made in London, under the direction of the Board of Trade, for testing chronometers in a manner precisely similar to that which we have practised for the past ten years. The testing apparatus for London has been made in this town under our immediate superintendence; and an officer has, by permission of the Corporation, been taught our method, in order that the same plan may be adopted in London. No chronometer maker, therefore, either in Liverpool or London, need now be in doubt for more than a few days, as to the efficiency of any improvement which he may attempt in the compensation balance of a chronometer; for the result of our experience is, that extreme cold is not necessary for the detection of this fault, and the higher temperatures are always under our control. Temperatures below 40° are not favourable for this experiment, unless the fluidity of the oil can be depended on, as a large change in the arc of vibration may render the result uncertain. In testing chronometers for this particular fault, it is however, desirable to elevate the temperature to 100° and upwards, and the oil by being subjected to very high temperatures, even for a few days, may become deteriorated. In the method which we are about to describe, it must therefore be understood that it is only practised at the special request of the maker, who supposes that he has

effected some improvement in the balance, and who intends to clean the chronometer again after the experiment. Unless this special request be made, 85° or 90° is the extreme heat to which we expose chronometers. This temperature is not greater than chronometers must occasionally be exposed to at sea, and we have found from long experience that no injury whatever is done to the oil by such exposure.

The following is the method of testing for improvements in the compensation balance, which we have always found both expeditious and successful. The maker is first requested to adjust the chronometer with the supposed improvement, to go the same in 50° and 80°. The experiment should be repeated several times to insure this being successfully done, and when it is found that changes from 80° to 50°, and from 50° to 80° can be made without altering the rate more than a few tenths of a second, the temperature is increased from 80° to 90°, from 90° to 100°, and from 100° to 110° in succession, and the change through these temperatures repeated two or three times. In chronometers with the ordinary balance the losing rate increases from 80° upwards, till at 110° it is found to amount to several seconds a day; but if the chronometer which is being tested cannot be made to lose more in 90°, 100°, and 110° than it does in 50° and 80°, the balance will be found to be, for all practical purposes, sensibly perfect.* Several chronometers which stood this test at the Liverpool Observatory, were afterwards tested by Professor Bond at the Cambridge Observatory in North America, during a very severe winter. The result was such as to show that when the oil did not become hard or glutinous, the rates of the chronometers remained as steady at several degrees below zero of Fahrenheit as they did in the higher temperatures, scarcely altering more than one second a day in a range of temperature exceeding 100 degrees; but that, if the oil became glutinous or hard, the chronometers, even with this balance, would lose considerably in temperatures below 30°.

Until chronometers used in the merchant service are more generally subjected to a test previous to their being purchased than they now are,

* We do not here allude to auxiliary compensations, the adjustments of which depend on the skill of the maker in each individual chronometer. If ever the balance now in use be superseded, it will be by an improvement of such a nature that if the balance compensates at all, the defect which we have attempted to describe will be removed without any additional trouble to the *springer*.

the makers will for the most part confine their improvements to the chronometers which are sent to the Royal Observatory at Greenwich for trial previous to purchase by the Admiralty. A chronometer sold to the Admiralty gives the maker a name, and this name has till recently been the only guarantee afforded to the merchant captain; hence we often find him in possession of a chronometer, the rate of which is quite as irregular as either of those exhibited in the first three examples.

The makers will exert themselves to the utmost, to supply the astronomer with a good chronometer, because they know that he can test its qualities, and appreciate its value; and that he will not be unreasonable in his expectations. Not that the astronomer is often perfectly satisfied with the performance of his instruments, but he generally makes himself too well acquainted with the failings to which they are liable, to allow himself to be deceived by such imperfections. Now, this is precisely what we wish to see in the mariner. He is called upon almost daily to exercise his judgment as to the degree of confidence which he is justified in placing in his instruments; and a knowledge of the imperfections to which they are liable is the only thing that can guide him to correct conclusions in these, to him, very important matters.

Since the preceding has been in type, I have received a letter from the Chairman of a Committee of Merchants, recently formed in New York, for the purpose of establishing an Observatory in that city, in all respects similar to the Liverpool Observatory, with the exception of the large and elaborately mounted equatorial. Agreeably to the request of the Chairman of this Committee, I have obtained estimates of the probable expense of a Transit Instrument, Sidereal and Solar Clocks, Testing Apparatus for Chronometers, Osler's Anemometer and Rain Gauge, &c., &c., which will be forwarded to New York as soon as possible. We may expect, therefore,

in a short time, to have in full operation a first-rate Nautical Observatory, on the other side of the Atlantic.

The present intention is to confine the business of this Observatory to such objects of practical utility as are more immediately connected with navigation. One or more time balls will be dropped daily, and especial attention will be paid to the rating and testing of Chronometers, for which it is intended to make ample accommodation. Now that the importance of the subject is beginning to be more clearly understood, other sea ports will doubtless soon follow the examples set by Liverpool, London and New York ; and there will be no excuse for Chronometers being sent to sea without previously having them properly tested.
