U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

TESTING OF TIMEPIECES

CIRCULAR C432

U. S. DEPARTMENT OF COMMERCE
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NATIONAL BUREAU OF STANDARDS
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TESTING OF TIMEPIECES

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I. INTRODUCTION

The functions of the National Bureau of Standards include the testing and comparison with standards, of various kinds of measuring apparatus, and the certification of the accuracy of such instruments. Included in such measuring apparatus are timepieces of various kinds, such as pocket watches, wrist watches, stop watches, chronometers, clocks, and chronographs.

In deciding upon the forms of tests to be given the Bureau has had in mind chiefly the value of the test to the users of timepieces. It is well known that all timepieces vary somewhat from correct time. The most careful adjustment can not entirely eliminate this variation. For example, the isochronism, or the uniformity of rate as the watch runs down, is dependent upon the poise of the balance, and, consequently, a watch carefully adjusted to give a perfect isochronal rate in one position may have a variable rate when changed to another position.

This Circular is confined largely to a description of the methods and procedure followed at the National Bureau of Standards in testing timepieces. The tests and tolerances involved in the certification of pocket watches, stop watches, and chronometers are given in detail.

The regulations under which such tests are conducted and the general instructions covering the submittal of timepieces for test are given.

The data given in the test report may be used to advantage in securing a better pocket performance of the watch, by avoiding those positions and temperatures for which it has the poorest rates. Satisfactory performance under test assures the owner that the watch is free from defects which are likely to effect its value as a timekeeper under reasonable conditions of service.

The tests also furnish information as to the relative performance of various grades of timepieces, and particularly as to the value of any special features or improvements that may be introduced into their manufacture.

No standard has been established for the performance of wrist watches. In ordinary use these watches are subjected to shocks and sudden changes of position which may affect their performance and cause the rate to change from day to day. Also, the wide variety of sizes and shapes makes it impracticable to establish satisfactory performance standards that will be generally applicable. Special tests are usually arranged when information regarding the performance of these watches is desired.

Variations 50 percent greater than the tolerances for the business-precision test should probably not be regarded as excessive for a fairly high-grade wrist watch. Very small or very low priced wrist watches should not be expected to keep accurate time.

A certain amount of general information is included in the Appendix on the subjects of standard time, time signals, time zones, and also on the use and care of a watch.

II. DEFINITIONS

Correction.—In the rating of a timepiece, the "correction" is the amount of time to be added algebraically to the reading of the instrument to give the correct time. As most timepieces in common use

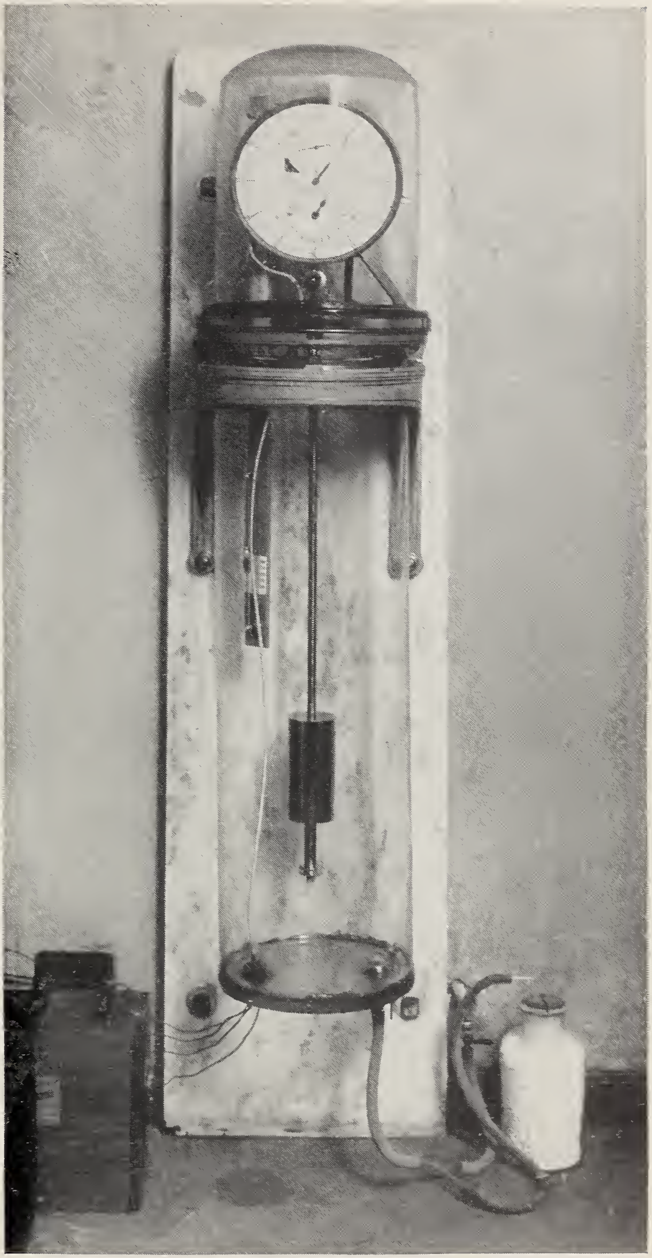

FIGURE 1.—*Precision mean time clock (Riefler type) used as a standard in the testing of timepieces at the National Bureau of Standards.*

[This clock is kept at constant temperature and pressure and will keep time to an accuracy of about 0.02 second a day.]

FIGURE 2.—*A corner of the time laboratory.*

A, Chronograph upon which readings are recorded.
B, Telegraph key.
C, Electrically operated time stamp.
D, Switchboard for distributing the signals from the Riefler clock to other laboratories.
E, Radio set for receiving time signals from the U. S. Naval Observatory.

FIGURE 3.—*One of the cabinets in which timepieces are tested at controlled temperatures.*

This cabinet, with others, makes it possible to conduct tests at controlled temperatures between −40° C and +50° C.

FIGURE 4.—*Special key used in the testing of stop watches.*

The key is pressed against the crown of the watch to start and to stop it. This closes a contact at *C* which operates the pen of the chronograph, automatically recording time of the operation.

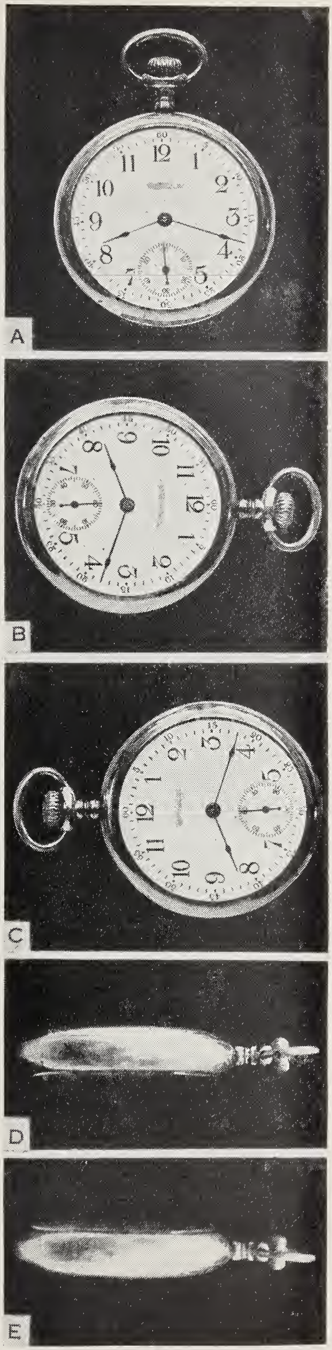

FIGURE 5.—*Five positions in which watches are tested.*

A, Vertical, pendant-up (PU).
B, Vertical, pendant-right (PR).
C, Vertical, pendant-left (PL).
D, Horizontal, dial-down (DD).
E, Horizontal, dial-up (DU).

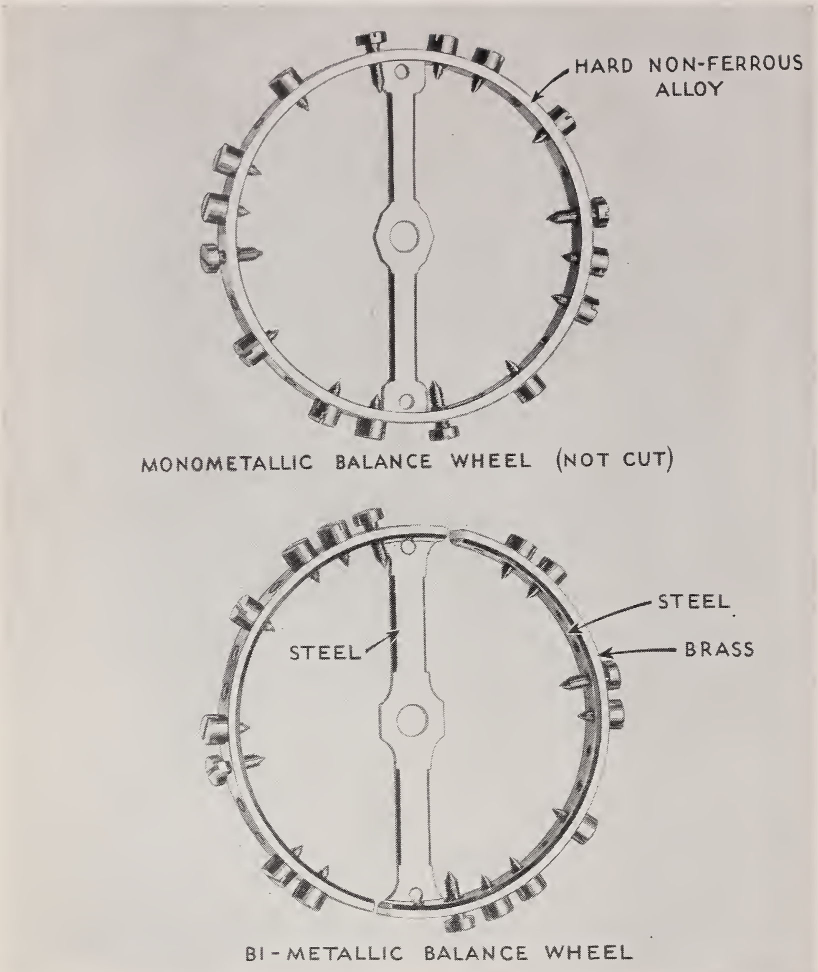

FIGURE 6.—*Two types of balance wheels.*

An elinvar hairspring is used with the uncut wheel and a steel hairspring with the cut wheel.

indicate mean solar time, the corrections are always such as to give the correct mean solar time. If a watch is slow, its correction is plus, and, if fast, its correction is minus.

Daily rate.—The "daily rate," or more simply the "rate," is the amount of time gained or lost in 24 hours. It is found by subtracting the correction at the beginning of the 24-hour period from the correction at the end of that period. If this difference is negative, a gaining rate is indicated, and if positive, a losing rate.

Signs.—In the National Bureau of Standards and other national testing laboratories it is customary to regard a gaining timepiece as having a minus (—) rate, and a losing timepiece as having a plus (+) rate. It is understood, however, that in American factories the opposite practice is generally followed; that is, a gaining timepiece is regarded as having a plus rate, and a losing timepiece as having a minus rate.

Difference in rate per degree change in temperature.—In determining the "difference in rate per degree change in temperature," the rate at the lower temperature is subtracted from that at the higher temperature, and the result is divided by the difference in temperatures. The meaning of the signs obtained is the same as for daily rate.

III. CHARACTER OF TESTS OF TIMEPIECES

The testing of timepieces consists of the determination of their daily rates under the various conditions for which they are adjusted. From the results several criteria are computed to determine whether the performance is such as might reasonably be expected from a properly adjusted timepiece. The daily rates are obtained by comparing the indication of the timepiece under test with that of the standard clock. In making a comparison the daily readings are recorded on a chronograph (fig. 2), which also records time through the electric seconds contact of the Bureau's mean time clock (fig. 1), by tapping a telegraph key when the second hand of the timepiece reaches a given point of the dial. It is easily possible in this way to obtain the correction each day to within 0.1 second. As the readings are made at the same point on the dial each day, the effect of any error in graduation of the dial or eccentricity of the position of the hand is avoided. Furthermore, the comparisons being made at the same time each day, within a few minutes, the daily rate is obtained at once without further correction, other than possible small variations in the standard, which is checked daily. The timepieces are wound each day just before they are read, so that isochronal variations are not introduced into the daily readings.

The signals from the Bureau's standard clock are compared daily by radio with those transmitted from the United States Naval Observatory in Washington, D. C., to ascertain any error in the indication of the standard clock.

1. POSITION TEST

The better grade of watches are usually adjusted for three or five positions, to isochronism, and for temperature variations. While some watches, mostly of foreign make, are adjusted for two, four, or six positions, the three- and five-position watches are much more common. Accordingly, two classes of tests have been adopted, one for the five-position and the other for the three-position watch. The five positions for which watches are generally adjusted are (*a*) vertical, pendant-up; (*b*) vertical, pendant-right; (*c*) vertical, pendant-left; (*d*) horizontal, dial-up; and (*e*) horizontal, dial-down. (See fig. 5.) In the three-position, adjusted watches, the pendant-right and pendant-left positions are usually omitted.

The test for position adjustment consists of running the watch for several days in each of the three or the five positions. The test is conducted under temperature conditions as constant as possible in order to eliminate from this test any irregularities due to temperature variations. The rates are taken for several days in each position to ascertain the degree of uniformity of rate on successive days. In the class A and the class B tests, described later, special emphasis is placed upon this uniformity of rate.

It has been found by tests that most watches have a progressive change in rate, usually a slowing up. It is desirable to eliminate the effect of this progressive change in rate as much as possible in determining the true precision of the position adjustment. This is done in the class A and class B tests by repeating the series of position tests in reverse order. The mean of the two sets of rates for each position is taken as the mean rate for that position. The difference between the mean rates of the two periods in the same position gives the progressive change in rate for the time between the two periods.

The accuracy of the position adjustment is judged primarily by the deviations of each of the mean rates for the various positions from the average of these mean rates. Certain tolerances are allowed for the maximum difference in rate for any two positions, and also for the differences between the mean rates of the more important positions—vertical, pendant-up; horizontal, dial-up; and horizontal, dial-down.

2. TEMPERATURE TEST

In the tests for temperature adjustment the timepieces are usually run for several days at each of three temperatures approximating 5°, 20°, and 35° C (41°, 68°, and 95°). The tests are conducted in cabinets in which the temperature is maintained constant by thermostatic control. In all cases where a timepiece is tested at more than one temperature, an intermediate day is allowed after each temperature change to permit the instrument to adjust itself to the new temperature.

In interpreting the results of the test for temperature compensation, consideration must be given to the type of balance wheel and hairspring used in the watch. With the ordinary bimetallic (brass and steel) cut balance wheel (fig. 6) and steel hairspring, it is practically impossible to reduce the variation of rate with temperature to a linear function, and at the same time keep the change of rate small. The variations that take place usually follow approximately the form of a parabola, and the adjustment of the timepiece is so made as to bring the point of greatest gaining rate as near as possible to the temperature at which the timepiece is ordinarily used and to make the rates at the high and low temperatures approximately equal. Consequently, with a given balance wheel and hairspring, practically all that can be done is to make the rate at the high temperature (35°C) equal to the rate at the low temperature (5°C), and to let the rate at the medium temperature (20° C) be what it may. The adjuster, therefore, is chiefly interested in the difference between the rates at the high and low temperatures, and in the general slope and flatness of the curve, while the user is concerned in knowing what the rate of the watch is at the various temperatures.

The use in recent years of a monometallic uncut balance wheel (fig. 6) with a hairspring made of elinvar or a similar nickel-steel material has had the effect of causing the variations of rate with temperature to follow very nearly a straight line, the slope of which indicates the degree of temperature compensation. (See fig. 7.)

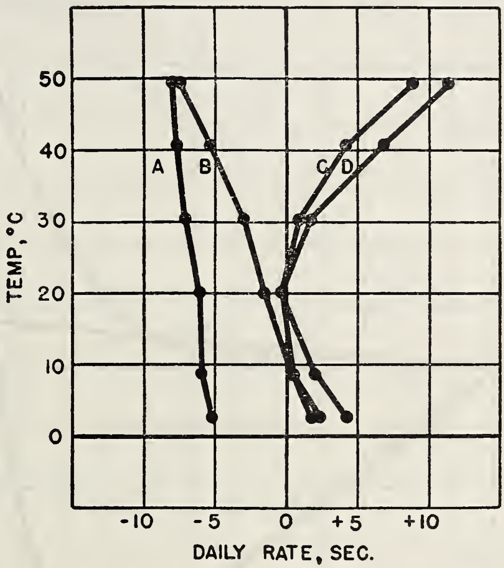

FIGURE 7.—*Temperature-rate curves for watches.*

These curves illustrate how the performance of a watch changes with temperatures. Curves A and B are for watches having uncut, monometallic balance wheels and elinvar hair springs. Curves C and D are for watches having cut, bimetallic balance wheels and steel hairsprings.

3. ISOCHRONISM TEST

Isochronism, or the uniformity of rate as the watch runs down, is determined from readings taken every hour or two during the first 36 hours after winding, the timepiece being wound only at the beginning of the test.

Watches are tested for isochronism in the horizontal, dial-up position because in this position the poise of the balance wheel and side friction on the pivots have practically no effect, and a close approach to true isochronism may be obtained. The isochronism test for chronometers is also conducted with the instrument in the horizontal position, which is the normal operating position for this type of timepiece.

Although a fair isochronism adjustment can be expected only for the first 24 hours, the test is continued for the longer period to show more clearly the changes in rate that may occur after 24 hours. Any attempt to secure isochronism for more than 24 hours usually results in the sacrificing of isochronism for the first part of the run.

The character of the variations after the first 24 hours depends largely upon the methods used to secure isochronism. For some timepieces the rate continues in the same direction as during the

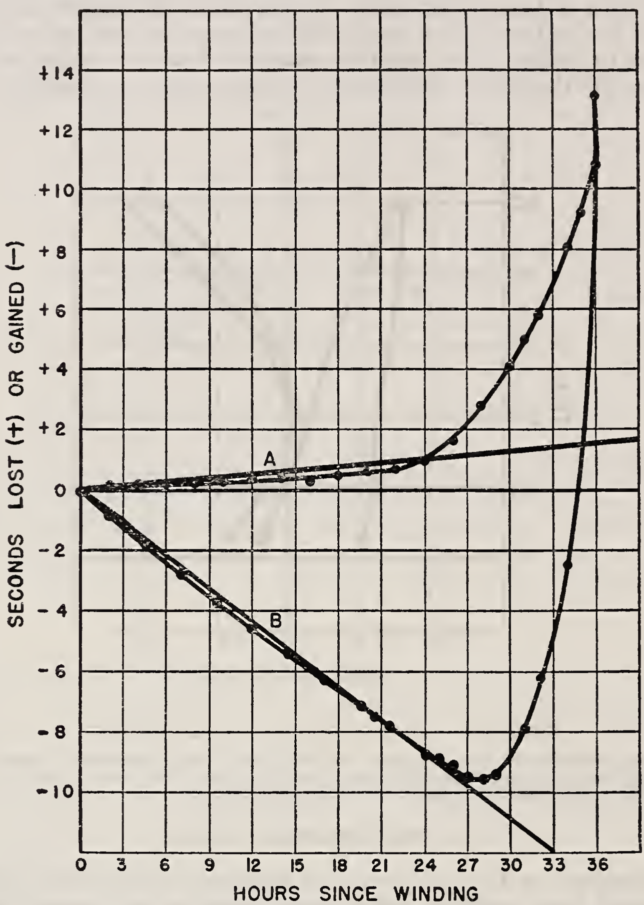

FIGURE 8.—*Isochronism curves for well-adjusted watches.*

These curves are for watches well adjusted for isochronism for the first 24 hours after winding, but showing marked changes in rate soon after 24 hours.

first part of the test but increases rapidly, whereas for other timepieces there is a sharp reversal of rate within a few hours after the twenty-fourth. The rate as the spring runs down often increases to several times the earlier rates.

Figure 8 shows typical examples of isochronism curves of watches well adjusted for isochronism during the first 24 hours after winding, but showing marked changes in rate shortly after that time. Figure 9 shows poor adjustment during the first 24 hours, and a steady increase of rate after that time. The correction—that is, the number of seconds gained or lost since winding—is shown by the vertical ordinates of the curves, while the elapsed time is plotted horizontally. A straight line drawn from the zero point through the 24-hour point of the curve is taken to represent true isochronism for the observed 24-hour rate. The vertical difference between this straight line and the curve may

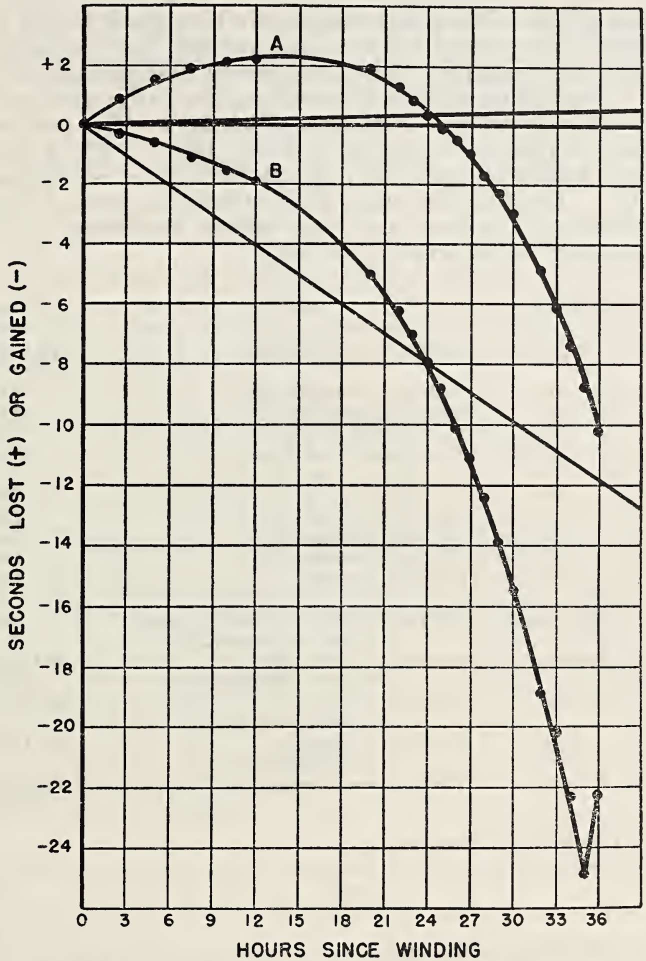

FIGURE 9.—*Isochronism curves of poorly-adjusted watches.*

These curves are for watches poorly adjusted for isochronism during the first 24 hours after winding and showing a steady increase in rate after 24 hours. Curve *A* shows a small error for 24 hours but a much larger error for 12 hours. Curve *B* shows a reversal of rate after 35 hours.

be taken to indicate the isochronal error at any time during the test. In the standard tests the isochronal error is taken as twice the error at the 12-hour point subtracted from the error at the 24-hour point.

These curves indicate the importance of regular daily windings and the variations that may be expected when the intervals between windings are irregular.

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IV. DESCRIPTION OF TESTS

Detailed descriptions of the various standard tests adopted by the National Bureau of Standards for the testing of timepieces are given in the following paragraphs.

1. CLASS A TEST FOR WATCHES

Program of test.—This test is designed for high-grade pocket watches adjusted for five positions, three temperatures, and for isochronism, and is the most complete scheduled watch test conducted by the Bureau. The test consists in determining the daily rates in a series of 15 periods occupying a total time of 54 days. The positions and approximate temperatures are as indicated below. The watches are wound and read once each day, except during the isochronism test (period 11). During this period the watch is not wound, except at the beginning of the test, and observations are made at frequent intervals during the 36 hours of the test.

Period	Duration	Position	Temperature
1	3 days	Vertical, pendant-up	Approx. 25° C (77° F).
2	do	Vertical, pendant-right	Do.
3	do	Vertical, pendant-left	Do.
4	do	Horizontal, dial-up	Do.
5	do	Horizontal, dial-down	Do.
6	do	do	Do.
7	do	Horizontal, dial-up	Do.
8	do	Vertical, pendant-left	Do.
9	do	Vertical, pendant-right	Do.
10	do	Vertical, pendant-up	Do.
11	36 hours	Horizontal, dial-up (isochronism)	Do.
		(Intermediate day)	
12	5 days	Horizontal, dial-up	5° C (41° F).
		(Intermediate day)	
13	do	Horizontal, dial-up	20° C (68° F).
		(Intermediate day)	
14	do	Horizontal, dial-up	35° C (95° F).
		(Intermediate day)	
15	3 days	Vertical, pendant-up	Approx. 25° C (77° F).

Derived results and tolerances.—

No.	Criteria	Tolerance allowed
		Seconds
1	Mean deviation of daily rate	0.75
2	Mean deviation of rate for change of position	3.00
3	Largest difference in rates for any two positions	10.0
4	Rate in horizontal, dial-up position minus rate in vertical, pendant-up position	5.0
5	Rate in horizontal, dial-down position minus rate in horizontal, dial-up position	4.0
6	Progressive change in rate in periods 1 to 10	3.00
7	Recovery of rate	6.0
8	Isochronism error	3.0
9	Difference in rate per degree from 5° to 35° C	.20
10	Difference in rate per degree from 5° to 20° C minus difference in rate per degree from 5° to 35° C	.30
11	Largest mean daily rate for any period	10.0

Computation of derived results.—The derived results are computed in accordance with the following rules:

1. The "mean deviation of daily rate" is the mean, regardless of sign, of the 48 differences obtained by subtracting each of the 48 daily rates of the 14 periods of the test (period 11 being omitted) from the mean rate of the period in which the daily rate occurs.
2. The "mean deviation of rate for change of position" is the mean, without regard to sign, of the differences between each of the "mean rates" for the five positions and the algebraic mean of the five. The "mean rate" for each position is the average of the mean daily rates for the two periods in the same position.
3. The "largest difference of rate between any two positions" is the largest difference between any two of the "mean rates" for the five positions. (Periods 1 to 10.)
4. The "rate in horizontal, dial-up minus the rate in vertical, pendant-up position" is the difference between the "mean rates" for these two positions taken as indicated.
5. The "rate in horizontal, dial-down minus the rate in horizontal, dial-up position" is the difference between the "mean rates" for these two positions, taken as indicated.
6. The "progressive change in rate in periods 1 to 10" is the algebraic mean of the differences between the mean rate for the first period of the test in each position and the mean rate for the second period in the same position. It indicates the progressive change in rate which has taken place during the position tests.
7. The "recovery of rate" is the difference between the mean rate in period 15 and the mean rate in period 1.
8. The "isochronism error" is the difference between the amount gained or lost in the isochronism test, period 11, in the first 24 hours after winding, and twice the amount gained or lost in the first 12 hours after winding.
9. The "difference in rate per degree from 5° to 35° C" is the difference between the mean rate in period 14 and the mean rate in period 12 divided by the difference in temperature in ° C for the same two periods.
10. The "difference in rate per degree from 5° to 20° C minus the difference in rate per degree from 5° to 35° C" is the difference between the two rates taken as indicated. The difference in rate per degree from 5° to 20° C is the difference between the mean rate in period 13 and the mean rate in period 12 divided by the difference in temperature in degrees centigrade for the same two periods.
This criterion shows the uniformity of the change in the daily rate with temperature. This quantity, when averaged without regard to sign, with the result obtained in criterion 9 serves as a joint measure of the temperature compensation, and is used as the term *c* in the formula for calculating relative performance.
11. The "largest mean daily rate for any period" is the largest mean rate for any of the 15 periods, omitting the isochronism test, period 11.

Relative performance.—For watches which do not exceed any of the tolerances of this test, a "relative performance" is computed in accordance with the formula:

$$\text{Relative performance} = 30\left(1-\frac{a}{0.75}\right)+30\left(1-\frac{b}{3.00}\right)+30\left(1-\frac{c}{0.25}\right)+10\left(1-\frac{d}{6.0}\right),$$

in which

a = the mean deviation of daily rate as computed in criterion 1.
b = the mean deviation of rate for change of position as computed in criterion 2.
c = the arithmetical mean of the difference in rate per degree from 5° to 35° C, as computed in criterion 9, and the amount by which the difference in rate per degree from 5° to 20° C differs from the difference in rate per degree from 5° to 35° C. (Mean of criteria 9 and 10.)
d = the recovery of rate, as computed in criterion 7.

It will be noted that the quantities 0.75, 3.00, 0.25, and 6.0 in the formula are the tolerances allowed for criteria 1, 2, 7, and 9, and that, consequently, the sum of the allotted weights, 30, 30, 30, and 10, represent the total number of points which it would be possible for a watch, which was perfect in these respects, to obtain, while a watch which just passed all of the tolerances for these particular criteria would receive zero points. If a, b, c, and d each equal zero, the watch would have a relative performance of 100. If $a=0.375$, $b=1.50$, $c=0.125$, and $d=3$; that is, if each is one-half the tolerance, the relative performance will be 50.

It will be seen from the above that the relative performance rating is based only on the criteria 1, 2, 7, and 9 and that the computed relative performance of a watch which meets all of these requirements—that is, for which the error in each of these four cases does not exceed the tolerance for that criterion—will lie between 0 and 100. The relative performance rating may, therefore, be taken as an indication of the amount by which the errors in performance fall within the errors permitted in these four criteria. Only a high-grade watch, well adjusted and in good condition, will give errors in performance within these limits. It is therefore apparent that a watch that attains a relative performance rating of 50 or more may be regarded as of very high quality, while one that attains a rating of 75 or more is exceptional.

Certificates and reports.—A certificate is issued for each watch which does not exceed any of the tolerances of this test. A report is issued for each watch which fails to meet one or more of the tolerances. The certificate or report is accompanied by an "abstract of results" showing the mean daily rate and the mean temperature for each period of the test and the values computed for the 11 criteria described above. Curves showing the results of the isochronism test and of the temperature test also accompany each certificate or report. All certificates show the "relative performance" computed for the watch. No "relative performance" is computed for watches failing to meet any of the tolerances.

2. CLASS B TEST FOR WATCHES

Program of test.—This test is designed for pocket watches which are adjusted for three positions and three temperatures, and is less exacting than the class A test. The test consists in determining the daily rates in a series of 10 periods occupying a total time of 40 days. The positions and approximate temperatures are as indicated below The watches are wound and read once each day throughout the test.

Period	Duration	Position	Temperature
1	3 days	Vertical, pendant-up	Approx. 25° C. (77° F).
2	do	Horizontal, dial-up	Do.
3	do	Horizontal, dial-down	Do.
4	do	do	Do.
5	do	Horizontal, dial-up	Do.
6	do	Vertical, pendant-up	Do.
		(Intermediate day)	
7	5 days	Horizontal, dial-up	5° C (41° F).
		(Intermediate day)	
8	do	Horizontal, dial-up	20° C (68° F).
		(Intermediate day)	
9	do	Horizontal, dial-up	35° C (95° F).
		(Intermediate day)	
10	3 days	Vertical, pendant-up	Approx. 25° C. (77° F).

Derived results and tolerances.—

No.	Criteria	Tolerance allowed
		Seconds
1	Mean deviation of daily rate	1. 00
2	Rate in horizontal, dial-up position minus rate in vertical, pendant-up position	6. 0
3	Rate in horizontal, dial-down position minus rate in horizontal, dial-up position	5. 0
4	Recovery of rate	8. 0
5	Difference in rate per degree from 5° to 35° C	0. 30
6	Difference in rate per degree from 5° to 20° C. minus difference in rate per degree from 5° to 35° C	. 40
7	Largest mean daily rate for any period	10. 0

Computation of derived results.—The derived results above are computed in accordance with the following rules:

1. The "mean deviation of daily rate" is the mean, without regard to sign, of the 36 differences obtained by subtracting each of the 36 daily rates of the 10 periods of the test from the mean rate of the period in which the daily rate occurs.

2. The "rate in horizontal, dial-up position minus the rate in vertical, pendant-up position" is the difference between the "mean rates" of these two positions, taken as indicated. The "mean rate" for each position is the average of the mean daily rates for the two periods in the same position.

3. The "rate in the horizontal, dial-down position minus the rate in the horizontal, dial-up position" is the difference between the "mean rates" for these two positions, taken as indicated.

4. The "recovery of rate" is the difference between the mean rate in period 10 and the mean rate in period 1.

5. The "difference in rate per degree from 5° to 35° C" is the difference between the mean rate in period 9 and the mean rate in period 7 divided by the difference in temperature in degrees centigrade for the same two periods.

6. The "difference in rate per degree from 5° to 20° C minus the difference in rate per degree from 5° to 35° C" is the difference between the two rates, taken as indicated. The difference in rate per degree from 5° to 20° C is the difference between the mean rate in period 8 and the mean rate in period 7 divided by the difference in temperature in degrees centigrade for the same two periods.

The change in rate with increase of temperature in a well-compensated watch is seldom linear, but, instead, the rate at middle temperature is generally faster than at either low or high temperatures. This criterion shows the uniformity of the change of rate with temperature.

7. The "largest mean daily rate for any period" is the largest mean rate for any of the 10 periods of the test.

Certificates and reports.—A certificate is issued for each watch which does not exceed any of the tolerances of this test. A report is issued for each watch which fails to meet one or more of the tolerances. The certificate or report shows the mean rate for each period of the test and the computed values of the above criteria.

3. RAILROAD PRECISION TEST FOR WATCHES

Program of test.—This test is designed for pocket watches of high grade, generally designated as five-position adjusted railroad watches, and is somewhat less exacting than the class A test, but more exacting than the class B test. In general, it is more satisfactory than the class B test and has largely superseded that test. The test consists in determining the daily rates in a series of eight periods, occupying a total time of 19 days. The positions and approximate temperatures are as indicated below. The watch is wound and read once each day during the test.

Period	Duration	Position	Temperature
1	2 days	Vertical, pendant-up	20° C (68° F).
2	do	Vertical, pendant-right	Do.
3	do	Vertical, pendant-left	Do.
4	do	Horizontal, dial-down	Do.
5	do	Horizontal, dial-up	Do.
		(Intermediate day)	
6	do	Horizontal, dial-up	5° C (41° F).
		(Intermediate day)	
7	do	Horizontal, dial-up	35° C (95° F).
		(Intermediate day)	
8	do	Vertical, pendant-up	20° C (68° F).

Derived results and tolerances.—

No.	Criteria	Tolerance allowed
		Seconds
1	Maximum difference in daily rate for any two positions	12. 0
2	Difference in daily rate between dial-down and dial-up positions	5. 0
3	Maximum difference in daily rates for any two temperatures	8. 0
4	Recovery of rate	4. 0
5	Regulation	7. 0

Computation of derived results.—The derived results are computed in accordance with the following rules:

1. The "maximum difference in daily rate for any two positions" is the maximum difference in the mean daily rates of any two of the first five periods.
2. The "difference in daily rates between dial-down and dial-up positions" is the difference in the mean daily rates for periods 4 and 5.
3. The "maximum difference in daily rates for any two temperatures" is the maximum difference in the mean daily rates of periods 5, 6, and 7.
4. The "recovery of rate" is the difference in the mean daily rates for periods 8 and 1.
5. "Regulation" is the mean daily rate in the vertical, pendant-up position, period 1.

Certificates and reports.—A certificate is issued for each watch which does not exceed any of the tolerances in this test. A report is issued for each watch which exceeds one or more of the tolerances. The certificate or report shows the mean daily rates for each of the eight periods of the test and the computed values of the above criteria.

4. BUSINESS PRECISION TEST FOR WATCHES

Program of test.—This test is designed for ordinary commercial pocket watches, designated as three-position watches, and is less exacting than any of the tests previously described. The test consists in determining the daily rates in a series of six periods occupying a total time of 15 days. The positions and approximate temperatures are as indicated below. The watch is wound and read once each day during the test.

Period	Duration	Position	Temperature
1	2 days	Vertical, pendant-up	20° C (68° F).
2	do	Horizontal, dial-down	Do.
3	do	Horizontal, dial-up	Do.
		(Intermediate day)	
4	do	Horizontal, dial-up	5° C (41° F).
		(Intermediate day)	
5	do	Horizontal, dial-up	35° C (95° F).
		(Intermediate day)	
6	do	Vertical, pendant-up	20° C (68° F).

Derived results and tolerances.—

No.	Criteria	Tolerance allowed
		Seconds
1	Initial rate in vertical, pendant-up position	10
2	Maximum difference in daily rate for the three positions	12
3	Maximum difference in daily rate for the three temperatures	12
4	Recovery of rate	6

Computation of derived results.—The derived results are computed in accordance with the following rules:

1. The "initial rate in vertical, pendant-up position" is the mean daily rate for period 1.
2. The "maximum difference in daily rate for any two positions" is the maximum difference in mean daily rates for periods 1, 2, and 3.
3. The "maximum difference in daily rate for any two temperatures" is the maximum difference in mean daily rates for periods 3, 4, and 5.
4. The "recovery of rate" is the difference in the mean daily rates for periods 6 and 1, both of which are with the watch in the vertical, pendant-up position

Certificates and reports.—A certificate is issued for each watch which does not exceed any of the tolerances in this test. A report is issued for each watch which fails to meet one or more of the tolerances. The certificate or report shows values of the derived results computed for the above criteria.

5. TEST FOR STOP WATCHES

Program of test.—For testing purposes stop watches are divided into two classes; namely timers and combination watches (watch and stop watch). The test for both classes consists in a preliminary examination to determine how well the sweep hand returns to zero at the "flyback" and a series of timing runs with the watch in the horizontal, dial-up position, and at ordinary room temperature of approximately 25° C (77° F). The watch is wound at the beginning of each period of the test, which covers the following intervals:

Period 1.—One run of 6 hours.
Period 2.—Three runs of 1 hour each.
Period 3.—Five runs of 30 seconds each.

In addition to this test, combination watches are submitted to a test of their performance as watches in two positions; namely, vertical, pendant-up and horizontal, dial-up. The watches are run two days in each position at a temperature of approximately 25° C (77° F).

Derived results and tolerances.—

For stop watches having from 0 to 7 jewels, inclusive:

No.	Criteria	Tolerance allowed
		Seconds
1	Correction for the 6-hour run	6. 0
2	Mean correction for the three 1-hour runs	1. 5
3	Mean correction for the five 30-second runs	0. 30
4	Maximum difference in corrections in each period	. 5

For stop watches having from 8 to 14 jewels, inclusive:

No.	Criteria	Tolerance allowed
		Seconds
1	Correction for the 6-hour run	4. 0
2	Mean correction for the three 1-hour runs	1. 0
3	Mean correction for the five 30-second runs	0. 30
4	Maximum difference in corrections in each period	. 5

For stop watches having 15 jewels or more:

No.	Criteria	Tolerance allowed
		Seconds
1	Correction for the 6-hour run	3. 0
2	Mean correction for the three 1-hour runs	1. 0
3	Mean correction for the five 30-second runs	0. 30
4	Maximum difference in corrections in each period	. 5

For combination watches, in addition to the above:

5. Difference between the mean daily rates in vertical, pendant-up and horizontal, dial-up positions. Tolerance, 10.0 seconds.

Computation of derived results.—The derived results are computed in accordance with the following rules:

1. The "correction for the 6-hour run" is found by subtracting the interval indicated on the watch from the true interval, shown on the chronograph sheet.
2. The "mean correction for the three 1-hour runs" is the algebraic mean of the three corrections obtained in this period of the test.
3. The "mean correction for the five 30-second runs" is the algebraic mean of the five corrections obtained in this period of the test.
4. The "maximum difference in correction," periods 2 and 3, is the greatest algebraic difference between any two of the corrections for the period.
5. The "difference between the mean daily rates in vertical, pendant-up and horizontal, dial-up positions" is found by taking the algebraic difference of the mean rates of two position periods. (This applies only to combination watches.)

Certificates and reports.—A certificate is issued for each stop watch which does not exceed any of the tolerances set for a watch of its type. A report is issued for each watch which fails to meet one or more of the tolerances. The certificate or report shows the mean correction for each period and the maximum differences for periods

2 and 3. In the case of combination watches, it also shows the mean daily rate for each position, and the difference in daily rates for the two positions.

6. TEST FOR CHRONOMETERS

Program of test.—This test is designed for the ordinary ship's chronometer, but may also be applied to other types. The test consists in determining the daily rate in a series of nine periods, occupying a total time of 30 days, with the chronometer in horizontal, dial-up position and at approximately the temperatures indicated below. The chronometer is wound and read once each day except during the isochronism test, period 7.

Period	Duration		Temperature
1	3 days		20° C (68° F).
		(One intermediate day)	
2	do		35° C (95° F).
		(One intermediate day)	
3	do		20° C (68° F).
		(One intermediate day)	
4	do		5° C (41° F).
5	do		Do.
		(One intermediate day)	
6	do		20° C (68° F).
7	36 hours	Isochronism test	Do.
		(One intermeidate day)	
8	3 days		35° C (95° F).
		(One intermediate day)	
9	do		20° C (68° F).

Derived results and tolerances.—

No.	Criteria	Tolerance allowed
		Seconds
1	Mean deviation of daily rate	0. 50
2	Difference between daily rates at 5° and 35° C	2. 5
3	Difference between daily rate at 20° and the algebraic mean of the daily rates at 5° and 35° C	1. 5
4	Isochronism error	1. 0
5	Largest recovery difference	2. 0
6	Recovery of daily rate for the five recovery differences	1. 25
7	Largest mean daily rate of any period	6. 0

Computation of derived results.—The derived results are computed in accordance with the following rules:

1. The "mean deviation of daily rate" is found by computing the arithmetical mean of the 24 differences obtained by subtracting each of the 24 daily rates of the

eight periods of the test (period 7 being omitted) from the mean rate of the period in which the daily rate occurs.

2. The "difference between the daily rates at 5° and 35° C" is found by subtracting the mean of the daily rates observed in periods 4 and 5 from the mean of the daily rates observed in periods 2 and 8.

3. The "difference between the daily rate at 20° C and the algebraic mean of the daily rates at 5° and 35° C" is found by subtracting from the mean of the rates observed in periods 1, 3, 6, and 9 the algebraic mean of rates at 5° C (periods 4 and 5) and at 35° C (periods 2 and 8).

4. The "isochronism error" for the first 24 hours after winding is obtained by subtracting twice the amount gained or lost in the first 12 hours from that gained or lost in the first 24 hours. A curve shows the results of the isochronism test, and from this curve the correction at any hour of the day can be obtained.

5. The "largest recovery difference" is found by computing the differences in mean daily rates of periods at the same temperatures as follows: Period 8 minus period 2, period 3 minus period 1, period 6 minus period 3, period 9 minus period 6, and period 5 minus period 4. The largest of these five differences is the largest recovery difference.

6. The "recovery of daily rate for the five recovery differences" is the arithmetical mean of the five recovery differences found in computing criterion 5 above.

7. The "largest mean daily rate of any period" is the largest mean daily rate obtained in any period except period 7.

Certificates and reports.—A certificate is issued for each chronometer which does not exceed any of the tolerances in this test. A report is issued for each chronometer which fails to meet one or more of the tolerances. The certificate or report is accompanied by curves showing the effects of temperature changes upon the daily rate and the results of the isochronism test. The mean daily rate for each period of the test and the derived results explained above are also given.

V. GENERAL INSTRUCTIONS TO APPLICANTS FOR TESTS

1. APPLICATION FOR TEST

All timepieces submitted for test should be accompanied by a written request stating the particular standard test desired, and listing the timepieces submitted. Timepieces may be submitted by one person with the request that the certificate or report be made out in the name of another person; or the purchaser of a timepiece, in placing an order, may direct that the timepiece be sent to this Bureau for test before being forwarded to the purchaser. In such instances, the request for the test should state whether the timepiece, in case of failure to pass the test and receive a certificate, should be returned to the person from whom it was purchased or be forwarded to the purchaser.

2. SPECIAL TESTS

The Bureau will gladly cooperate with investigators, manufacturers, and others who have particular problems to solve. When no standard test provides the information desired, special tests may be arranged if the work is important and the facilities and time of the bureau permit. Such tests should be arranged by consultation or correspondence before shipment is made.

3. CERTIFICATES AND REPORTS

Certificates are granted for all timepieces found to meet all the requirements of any of the standard tests described in this Circular, and reports are issued for those that fail to meet one or more of the requirements. No certificates are granted for special tests, a detailed report of the test being rendered to the applicant.

4. FEES AND REMITTANCES

Fees have been established for the six standard tests described in this Circular, and are given in Test-Fee Schedule 231, which may be obtained from the National Bureau of Standards upon request. The fees for special tests depend chiefly upon the time consumed and the amount of alteration required in the regular testing equipment. An estimate of fees for special tests will be furnished upon request. Fees should be remitted by money order or check drawn to the order of the "National Bureau of Standards," and should be sent with the request for test whenever practicable.

5. IDENTIFICATION MARKS

Each timepiece submitted for test should bear the name of the manufacturer and an identification number. This marking will be used as identification in rendering reports of the test.

6. SHIPPING DIRECTIONS

When timepieces are not delivered at the Bureau personally they should be securely packed in cases or packages which will not be broken in transportation and which may be used in returning them to the owner. The shipment in both directions is at the applicant's risk. It is recommended that shipment be made by registered mail or express. Great care should be taken in packing. Each instrument should be wrapped in strong paper or other covering to prevent dust from getting into it. The tops of large boxes should be put on with screws, as the jar due to nailing and the subsequent opening is liable to cause damage. All packages should be plainly marked with the shipper's name and address. The tops of the shipping boxes should have the return or forwarding address on the underside. Transportation charges are payable by the person requesting the test. The charges for shipment to the Bureau must be prepaid, and, unless otherwise arranged, articles will be returned or forwarded by express "collect."

When timepieces are submitted by one person with instructions to test and forward to another, directions should be given for the disposition of such as may be rejected by the Bureau. If such instructions are not given at the time the test is requested, much unnecessary delay may result.

7. BREAKAGE

No risk of breakage will be assumed by the Bureau. All possible care will be taken in handling the apparatus submitted for test, but breakage is sometimes unavoidable.

8. ADDRESS

All communications concerning the testing of timepieces and all material for test should be addressed "National Bureau of Standards, Attention Division II-3, Washington, D. C."

VI. APPENDIX

1. USE AND CARE OF A WATCH

The importance of the careful handling of a fine watch, of regularity in winding it, and of frequently checking its correction with some source of correct time, in order to obtain an accurate indication of time, is so well known as scarcely to need emphasis. However, with the thought of calling the reader's attention to some important details included under the above general head, the following suggestions on the handling, winding, and carrying of a watch are included here.

(a) HANDLING OF A WATCH

It is well known that a fall or severe jar is liable to result in injury to the mechanism, especially in the bending of a pivot or the breaking of a jewel. It is, perhaps, not so well known that the mere fall of a watch to the end of its chain, or the jar it may receive when the article of clothing containing the watch is thrown down or dropped may cause injury to some part of the movement. Therefore, all sudden motions of the watch even when in the hand, should be avoided.

Likewise, care should be taken to keep the parts of the watch from becoming magnetized by proximity to electrical apparatus having strong magnetic fields, such as exist in the neighborhood of large motors and generators.

Unless the watch has a thoroughly dustproof case care should be taken to keep the pocket free from dirt and lint, and it is desirable to have a watch pocket of a material that gives off a minimum amount of lint. The watchcase should be opened only when necessary and only in places where there is little chance of dust gathering on the movement while it is exposed. A broken watch crystal should be replaced promptly to prevent dirt getting into the mechanism.

(b) WINDING OF A WATCH

The importance of the regular winding of a watch will be quickly realized when one sees the isochronism curve of a given watch. Even the delay of an hour in the time of winding may cause considerable variation in the rate in some instances. Sometimes a watch will have a more uniform rate for 24 hours if it is wound twice a day, but it is not a desirable plan to follow unless it is carried out every day, as a watch having comparatively poor adjustment for isochronism may exhibit larger varations of rate when semidaily windings are occasionally omitted than if it were wound only once a day. The practice of winding the watch a little at a time, often absent-mindedly, whenever it is taken from the pocket, is not productive of uniformity of rate. The winding should be done steadily and not too rapidly, and its conclusion should be approached carefully to avoid injury to the spring or winding mechanism.

(c) CARRYING OF A WATCH

The pocket in which one carries his watch, the size of the pocket, and the kind of watch chain or fob used have a more important effect on the uniformity of the rate of a watch than is generally realized. The temperature of the watch in different pockets varies considerably, and the amount of motion and jar to which the watch is subject also varies. For instance, a watch carried in the upper coat pocket generally is at a lower temperature and is more frequently disturbed, as well as being held in various positions more irregularly, than in other pockets. In a large pocket the watch is apt to turn to the right or left by various amounts, giving irregular rates unless one adopts some method to hold it upright. Perhaps the best method to prevent a watch turning in this way (other than actually pinning it in place) is to keep the watch in a chamois or kid watch bag, such as may be obtained from jewelers in correct size to fit one's watch, as the friction of the bag in the pocket prevents its turning. The bag also protects the watch and keeps it clean. Most watch chains and many watch fobs are not effective in holding the watch upright. A fob of the type that hangs over the top of the pocket sometimes holds the watch upright fairly well, but with such a fob there is danger that the watch may be accidentally dropped out of the pocket unless the watch is held by some kind of safety device.

In case a watch is well regulated for one position and one temperature but not well adjusted for other positions and temperatures, it is obviously advantageous to keep the watch in that position and at that temperature for which it is best adjusted and regulated for as large a proportion of each 24 hours as is practicable. Also it is often possible by proper selection of position at night to compensate for errors accrued during the day. This compensation of errors by change of position, of course, requires accurate knowledge of the performance of the watch in various positions.

(d) COMPARISONS WITH SOME RELIABLE SOURCE OF STANDARD TIME

The regular daily comparison of one's watch with a reliable regulator, chronometer, or time signals received from some authoritative source will be found very valuable in determining the regularity of the watch's rate.

The actual comparison of a watch with any source of standard time can readily be made to within a half or a quarter of a second, with a little practice. If the comparison is made with a signal beating seconds or with a clock ticking seconds where one can hear the beats, the best method is to count the seconds one hears and note with the eye the second and fraction of a second on the watch when the signal to which one is listening reaches the sixtieth second, or some integral 10-second point, or else, keeping the count of the second beats, note the number of the second and fraction thereof when the second hand of the watch reaches the sixtieth second or some integral 10-second point. If the beat of the comparison clock can not be heard on account of other noises, it will be necessary to get the count of the seconds on the regulator or chronometer by watching the beats of the pendulum or the unlocking of the second hand, and when this is secured read the watch by either process outlined above and then without stopping the count of the seconds look back at the clock to check the count. If in looking at the watch the count has been slightly accelerated or retarded, it may be necessary to repeat the trial to obtain accurate results.

Whether the watch is fast or slow must be determined by a separate rough comparison or, when time signals are being used, by waiting until the end of the signal, if the approximate correction of the watch is unknown. If the daily comparisons of a watch are not made at the same time each day, it is, of course, necessary to interpolate between them to determine the 24-hour rate of the watch.

Any marked departure from such a regular rate usually indicates that the watch needs cleaning or oiling or that some accident has happened to the mechanism. It is always desirable that repairs be made promptly before further damage or wear takes place from the friction of any bent or broken parts. When a watch of high grade and good condition is running well, differences of successive daily rates of not more than two to four seconds may be expected, if the precautions suggested are observed, especially those in regard to the constancy of position and temperature of the watch day and night; otherwise, much larger variations of rate may result.

When the variations of daily rate gradually become larger and the progressive change in rate becomes more pronounced, it is a very reliable indication that the watch should be cleaned. The frequency with which a watch should be cleaned varies greatly and depends largely upon the usage it has received, such as the exposure to air, to contamination of dirt, fumes, and moisture, and to temperature changes. A watch which under one man's usage may require cleaning every year may, under the care of another man, give as accurate or better results for five years without being serviced. When a watch does require cleaning or repairing it is always important that the work be done by an experienced and reliable watchmaker.

2. WATCH-TESTING MACHINES

There are now on the market several machines for quickly determining the instantaneous rate of a watch. The basic elements of these machines are : (1) A vibrating crystal or tuning fork for providing an alternating electric current of controlled frequency, (2) a microphone for picking up the sounds of the ticks of the watch, and (3) a printing mechanism for recording the ticks on a moving sheet of paper. The rate of the watch over a period of ½ minute or more is read directly on an indicator on the instrument or is determined by the slope of the line, plotted by the ticks of the watch, in relation to the graduations on the paper.

Most of these instruments are also provided with earphones and amplifiers for listening to the sounds within the watch while it is running. This feature is very useful to the research worker and to the watchmaker in diagnosing what is happening within the watch and where to make adjustments. It must be remembered, however, that the rates indicated are instantaneous values of the daily rates and not the true daily rates because of changes of rate that take place as the watch runs down. By testing the watch at frequent intervals after winding, the changes in rate throughout the day may be determined.

3. WATCH SIZES

The size of a watch is the diameter of its pillar plate. When the watch is elliptical the size is the smaller of the two diameters.

There are in general use two systems for designating watch sizes;

namely, the French or Swiss system based on the Paris inch and the American system based on the United States inch.

The Paris inch is 1/12 of a Paris foot, which is 1/6 of the French toise. This inch is subdivided into 12 lignes, which are used in designating the size of most foreign-made watches.

The American system, originated by Aaron L. Dennison, uses a series of numbers with zero (0) size equal to 35/30 of a United States inch, and successive sizes differing by 1/30 of an inch. Size 1 is, therefore, 1/30 inch more than size 0, or 36/30 inch, while size 00 or 2/0 is 1/30 inch less than size 0, or 34/30 inch, etc.

The following table compares the two systems and gives the corresponding measurements in the English and the metric systems.

One ligne equals 0.088814 of the U. S. inch, or 2.25589 millimeters.

Watch Sizes

American watch sizes	Diameter of pillar plate			
	Lignes	*mm*	*Inches*	*30ths of an inch*
19	----	45.72	1.800	54
------	20	45.12	1.776	----
18	----	44.87	1.767	53
17	----	44.03	1.733	52
16	----	43.18	1.700	51
------	19	42.86	1.687	----
15	----	42.33	1.667	50
14	----	41.49	1.633	49
13	----	40.64	1.600	48
------	18	40.61	1.599	----
12	----	39.79	1.567	47
11	----	38.95	1.533	46
------	17	38.35	1.510	----
10	----	38.10	1.500	45
9	----	37.25	1.467	44
8	----	36.41	1.433	43
------	16	36.09	1.421	----
7	----	35.56	1.400	42
6	----	34.71	1.367	41
5	----	33.87	1.333	40
------	15	33.84	1.332	----
4	----	33.02	1.300	39
3	----	32.17	1.267	38
------	14	31.58	1.243	----
2	----	31.33	1.233	37
1	----	30.48	1.200	36
0	----	29.63	1.167	35
------	13	29.33	1.155	----
2/0	----	28.79	1.133	34
3/0	----	27.94	1.100	33
4/0	----	27.09	1.067	32
------	12	27.07	1.066	----
5/0	----	26.25	1.033	31
------	11½	25.94	1.021	----
6/0	----	25.40	1.000	30

Watch sizes—Continued

American watch sizes	Diameter of pillar plate			
	Lignes	*mm*	*Inches*	*30ths of an inch*
------	11	24. 81	0. 977	----
7/0	----	24. 55	. 967	29
8/0	----	23. 71	. 933	28
------	10½	23. 69	. 933	----
9/0	----	22. 86	. 900	27
------	10	22. 56	. 888	----
10/0	----	22. 01	. 867	26
------	9½	21. 43	. 844	----
11/0	----	21. 17	. 833	25
12/0	----	20. 32	. 800	24
------	9	20. 30	. 799	----
13/0	----	19. 47	. 767	23
------	8½	19. 18	. 755	----
14/0	----	18. 63	. 733	22
------	8	18. 05	. 711	----
15/0	----	17. 78	. 700	21
16/0	----	16. 93	. 667	20
------	7½	16. 92	. 666	----
17/0	----	16. 09	. 633	19
------	7	15. 79	. 622	----
18/0	----	15. 24	. 600	18
------	6½	14. 66	. 577	----
19/0	----	14. 39	. 567	17
20/0	----	13. 55	. 533	16
------	6	13. 54	. 533	----
21/0	----	12. 70	. 500	15
------	5½	12. 41	. 488	----
22/0	----	11. 85	. 467	14
------	5	11. 28	. 444	----
23/0	----	11. 01	. 433	13
24/0	----	10. 16	. 400	12
25/0	----	9. 31	. 367	11
------	4	9. 02	. 355	----

4. WATCH JEWELS

Jewels are used as bearings in watches to reduce friction and thus improve the performance of the watch. Hole jewels are bearing jewels through which the staffs of the wheels pass. End or cap jewels are thrust jewels at the ends of the staffs beyond the hole jewels.

The most common materials used for making watch jewels are diamond, sapphire, ruby and garnet. Diamond is the hardest but is seldom used except for cap jewels. Sapphire is the next in hardness and is most commonly used. Ruby is a red variety of sapphire but is not quite as hard. The color of the ruby does not indicate its quality but adds to the appearance of the watch. Garnets are much softer and are used in some of the cheaper grade of watches. Rock crystal (quartz) is sometimes used instead of garnet.

Watches generally have 7, 11, 15, 17, 19, 21, or 23 jewels. Some foreign-made watches have an even number of jewels, generally omitting one of the lower cap jewels. The location of the jewels in a watch may vary somewhat in the different makes and grades, but the general practice is as follows:

7 jewels:

A hole jewel at each end of the balance staff.
An end jewel at each end of the balance staff.
2 pallet jewels.
1 roller jewel.

11 jewels:

The 7 jewels listed above, and in addition—
A hole jewel at each end of escape wheel staff.
A hole jewel at each end of pallet lever staff.

15 jewels:

The 11 jewels listed above, and in addition—
A hole jewel on each end of the fourth wheel staff.
A hole jewel on each end of the third wheel staff.

17 jewels:

The 15 jewels listed above, and in addition—
A hole jewel on each end of the center wheel staff.

19 jewels:

The 17 jewels listed above, and in addition—
An end jewel on each end of the escape-wheel staff.

21 jewels:

The 19 jewels listed above, and in addition—
An end jewel on each end of the pallet lever staff.

23 jewels:

The 21 jewels listed above, and in addition—
A hole jewel on each end of the barrel arbor.

5. MAGNETISM

A watch sometimes shows very erratic performance, gaining or losing irregularly or even stopping without any apparent reason. In such cases, it may be that the watch has been in close proximity to some electric machine or apparatus which is surrounded by a strong magnetic field. Screwdrivers, tweezers, and other small tools used by watchmakers often become magnetized and in turn magnetize the small steel parts of the watch.

The presence of magnetism in a watch may be detected by laying the watch on its face and passing over it a small exploring compass about ½ inch long. The magnetized parts will be indicated by deflection of the compass needle. The only remedy is demagnetizing. This may be accomplished by placing the watch for a few seconds inside a solenoid through which an alternating current of high tensity is flowing, and then gradually withdrawing the watch.

To those wishing to make their own demagnetizing solenoids or other demagnetizing equipment, the following books are recommended: F. J. Britten, Watch and Clock Makers Handbook; H. G. Abbott, American Watchmaker and Jeweler.

6. STANDARD TIME SIGNALS

The best generally available source of accurate time is the time signal as transmitted by telegraph from the United States Naval Observatory and broadcast by radio from Annapolis, Md., and certain other naval stations as listed in the table below.

All naval time signals are made in a standard manner, which is as follows:

The signals begin 5 minutes before the hour and consist of a dash on each second, except that no dashes are sent on the seconds listed below:

55 minutes; 29, 51, and 56 to 59 seconds.
56 minutes; 29, 52, and 56 to 59 seconds.
57 minutes; 29, 53, and 56 to 59 seconds.
58 minutes; 29, 54, and 56 to 59 seconds.
59 minutes; 29, and 51 to 59 seconds.

Beginning exactly on the hour a much longer dash is sent. In all cases the exact second is denoted by the beginning of the dash, the end being without significance. It will be noted that the number of seconds sounded immediately following the single second omission and preceding the long omission at the end of each minute indicates the number of minutes of the signal yet to be sent. For instance, the signal for 56 minutes and 52 seconds is omitted and then 3 seconds are sounded, indicating that 3 minutes of the signal remain to be transmitted.

These time signals, if received directly and automatically are seldom in error by as much as 0.10 second. The average error is generally less than 0.02 second.

The stations now used for the transmission of the official time signals are: NSS, Annapolis, Md.; NPG, Mare Island, Calif.; NPM, Pearl Harbor, Hawaii; NBA, Balboa, Canal Zone.

Station NAA, Arlington, Va., long used as the principal station for the transmission of the official time signals, has been abandoned and the equipment transferred to NSS, Annapolis, Md.

Station NSS automatically transmits the signal as received from the Naval Observatory at Washington, with errors averaging only 0.02 second. The other stations reradiate, and the error may be somewhat larger. The signal, however, is sufficiently exact for commercial use.

(a) U. S. NAVAL OBSERVATORY TIME SIGNALS

The following schedule as of April 1941, gives the hours of the ending of the U. S. Naval Observatory time signal rtansmissions. The first column gives Greenwich Mean Time (GMT). The second column gives the corresponding Eastern Standard Time (EST). Under the call letters of the radio stations are listed the frequencies in kilocycles used in transmitting via those stations.

Hour		NSS	NSS	NSS	NSS	NSS	NPG	NPM	NPM	NBA
GMT	EST									
0	7 p. m.	113		9425			42. 8			
1	8 p. m.	113								
2	9 p. m.	113	4390	9425	12630					
3	10 p. m.	113	4390	9425	12630		42. 8 113 9090 12540			
4	11 p. m.			9425				115 9090	12540	
5	12 p. m.	113		9425						115 4390 9250
6	1 a. m.	113		9425						
7	2 a. m.	113		9425						
8	3 a. m.	113	4390	9425	12630		42. 8			
9	4 a. m.	113	4390	9425	12630					
10	5 a. m.	113	4390	9425	12630					
11	6 a. m.	113								
12	7 a. m.	113								
13	8 a. m.	113		9425						
14	9 a. m.	113		9425	12630	17370				
15	10 a. m.	113		9425	12630	17370	42. 8 113 9090 12540			
16	11 a. m.			9425				115 9090	12540	
17	12 m.	113		9425			42. 8			115 4390 9250
18	1 p. m.	113								
19	2 p. m.	113		9425						
20	3 p. m.	113		9425	12630	17370	42. 8 113	115 9090		
21	4 p. m.	113		9425	12630	17370				
22	5 p. m.	113		9425	12630	17370				
23	6 p. m.	113		9425						

The telegraph office in many of the larger cities is provided with a master clock which is set daily, usually at noon, to agree with the signal from the U. S. Naval Observatory, and a service is furnished to subscribers of synchronization of other clocks in the city hourly by means of this master clock. If the master clock receives proper attention and is regulated so that its daily rate is small—only a few seconds a day—and, if the subsidiary clocks are in good condition so that they are regularly synchronized, this system furnishes a very satisfactory means of establishing the correct time. The subsidiary clocks, or jewelers' regulators corrected by them, may, therefore, serve as suitable standards for determining the rate of a watch.

It is desirable, however, on account of the possible large rate of the master clock in the telegraph office, to make watch comparisons with such clocks within an hour or two after the time of the Naval Observatory or other signal from which the master clock is set has been received, as thus the effect of the daily rate of the master clock is minimized. Many jewelers, however, have regulators or chronometers which have a very small rate, and, if such timepieces are frequently set correctly by comparison either with a telegraphic time signal or with a synchronized clock immediately after the receipt of the time signal, they will generally serve as accurate sources of time at any period of the day.

7. STANDARD TIME ZONES

The use of standard time in sections differing by integral hour differences of longitude from Greenwich instead of local mean time is nearly universal throughout the civilized world. Practically all the nations of the world have abandoned their local meridian time in favor of time as reckoned from the meridian passing through Greenwich, England.

The United States is divided into four standard time zones, each approximately 15° of longitude in width. All places in a given zone use, instead of their own local time, the time counted from the transit of the "mean sun"[1] across the meridian which passes through the approximate center of that zone.

These time zones are designated as Eastern, Central, Mountain, and Pacific, and the time in these zones is reckoned from the seventy-fifth, ninetieth, one hundred and fifth, and one hundred and twentieth meridians west of Greenwich, respectively. The time in the various zones is slower than Greenwich time by 5, 6, 7, and 8 hours, respectively.

Hence, when it is noon in the eastern time zone it is 11 a. m. in the central time zone, 10 a. m. in the mountain time zone, and 9 a. m. in the Pacific time zone. In traveling from one time zone to another, one must set his watch one hour ahead if traveling eastward and one hour back if traveling westward whenever he crosses a zone boundary.

The question of changing from the time of one time zone to that of an adjacent zone arises in practice largely in the operation of railroads, and in transcontinental flying. Because of the inconvenience of changing the time by the necessary amount of one hour at every point where a railroad crosses one of these boundary lines, the more convenient practice has usually been followed of making the change at some terminal or division point on the road, at some junction point, State boundary line, or at the boundary line between the United States and Canada. The result is that practically the boundaries of the time zones are defined by the lines connecting these points of railroad time change. Because of the location of these railroad junctions or terminals the resulting lines are rather irregular. The boundaries of these time zones in the United States are established by the Interstate Commerce Commission in accordance with an act of

[1] The interval between successive passages of the sun across the meridian is somewhat variable, and for this reason apparent solar days are of unequal length. Therefore, mean time has been adopted, which is kept by a fictitious or "mean sun" moving uniformly in the plane of the Equator at the same average speed as that of the real sun, thus making days of equal length. It is "mean noon" when this "mean sun" crosses the meridian.

Congress dated March 19, 1918. They have been changed from time to time as circumstances have shown such changes to be advisable. A detailed description of the time zone boundaries in the United States giving a complete list of the railroads and towns affected is issued by the Interstate Commerce Commission.

A map showing the Standard Time Zones in the United States and Adjacent Parts of Canada and Mexico, known as National Bureau of Standards Miscellaneous Publication M155 may be obtained from the Superintendent of Documents for 10 cents. Circular C406, Standard Time Throughout the World, published by the National Bureau of Standards and available from the Superintendent of Documents, Government Printing Office, for 5 cents, gives a list of the times used in various countries of the world.

WASHINGTON, April 29, 1941.