"DER UHRSTANDSMESSER"

"Chronometer difference meter"

(Auxiliary apparatus for accurate comparisons)

by

DR.-ING. EDGAR MULLER, BERLIN.

INTRODUCTORY REMARKS.

Chronometer comparisons for the purpose of determining the chronometers differences with great accuracy are generally effected by the use of a vernier counter or by chronographic registration. With the employment of the vernier counter it is encumbent upon the observer to note the exact moment of coincidence of the beats of the instrument to be observed and those of the instrument serving as a basis of comparison (counter having a period of oscillation (pendulum) slightly different from the clock or a coincidence spark signal) and to fix this instant by a reading of the time-pieces. It follows from this mode of procedure that the accuracy of the comparison in such cases cannot be very great and, above all, it is not susceptible of being improved at will. The limitations of the capacity of the human organ of perception (the ear) set a bound to the accuracy.

The nicety with which one is able to evaluate the coincidence in time of two phenomena depends upon the nature and the excellence of these phenomena; in this case also, on the frequency of the coincidences produced by the times-pieces. Experience has shown that a trained observer is capable of evaluating the instant of coincidence with an accuracy (inner) of about 1/60 to 1/70 of the coincidence interval (length of time between two coincidence). This corresponds to an accuracy of comparison of the difference of about 0.015^s. A systematic influence opposes any appreciable increase in this accuracy by repeated observations which results from the personal conception of the observer of the instant of coincidence; therefore it is hardly possible to count on a greater accuracy with this procedure than $\pm$ 0.01^s.

Special technical supplementary devices, such as those proposed by Cooke(1), and involving more extensive apparatus, do not, for similar reasons, produce any appreciable increase in accuracy. The observer stands much too much at the central point. The excellence of the comparison depends to a large extent up on his cooperation, while the efforts towards an increase in accuracy must be in the direction of eliminating the observer, as far as possible, by adopting devices which will permit his influence to become really effective at the point where the imperfections of the apparatus employed, the special nature of the procedure, or the conditions of service, tend to limit the accuracy.

This goal is attained in the recording chronograph such that the observer exercises no influence upon the automatic recording of the time interval but cooperates solely in the interpretation of the record. The accuracy of the comparison is essentially dependent upon the rate of feeding of the paper strip. In addition there are the influences of accidental and systematic errors, which, arising from the design of the apparatus and the cooperation of the observer (interpretation) limit the accuracy of the results to the order of thousandths of a second.

The comparison by means of chronographic recording however does not by any means exhaust the possibility of determining the state of the chronometer (clock) with great accuracy. The author, with his apparatus for measuring the chronometer differences, built by himself, has carried out comparisons giving results of remarkable accuracy. This involves a procedure in which, by mechanical measurement, the second fraction of the chronometer difference can be obtained in thousandths of a second. The full seconds are obtained on the other hand by means of an approximate comparison. As compared with the usual present-day methods of chronometer comparison this procedure results in completely eliminating all the disadvantages which were inherent in the method. In this way it is possible to reduce the otherwise considerable expenditure of time required for the measurement, and, with the use of relatively few devices, to obtain such immediate and good results, that a subsequent evaluation becomes unnecessary.

The demands on the observer are slight, because the apparatus for measuring the chronometer difference assumes the problem of sub-dividing the units and the observer has simply to read the scale. In the following we shall give a description of the apparatus for measuring the state of the chronometer and also add some of the special features of the device.

DESCRIPTION OF THE COMPARISON APPARATUS.

Construction. By means of a synchronous motor *M* the disk *Sch* is caused to revolve about a vertical axis *A* (see fig. 1). The speed of rotation of the disk can be varied within narrow limits by a horizontal displacement of the motor by means of the screw (D) and the friction drive. The motor shaft turns at a rate of about 80 r.p.m., while the mean rate of the disk *Sch* is about 60 r.p.m.

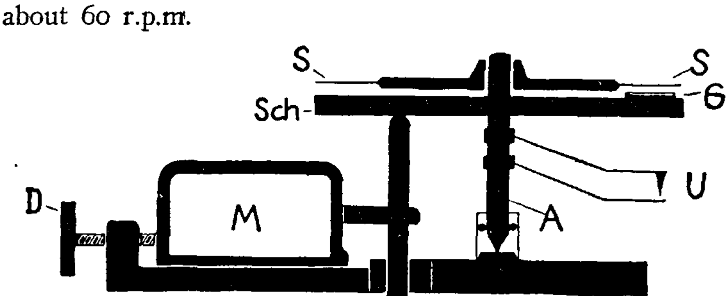

FIG. 1. — *The comparison apparatus* (construction diagram).

The disk *Sch* carries on its circumference a small neon tube *G*, which is connected externally to the electrical circuit by means of slip-rings. Above the neon tube is a glass disk *S* which has one hundred equal graduations radially engraved on its surface. The glass disk does not turn with the neon tube. With the lighting up of the neon tube through a small opening in the longitudinal screen, it is possible to read off its position on the graduated scale. Since the average time of revolution of the disk *Sch* with neon tube is about one second, it is possible to read of the position of the tube when it flashes on the scale to exactly one hundredth of a second. One thousandth of a second can be estimated. The scale *S* can be turned to any desired initial position, as it is held by frictional contact.

Stipulations. One stipulation for the procedure of watch comparison with this device is an electric contact in the clocks (chronometers) to be compared, or, a device for transmitting the time signal to the circuit containing neon tube *G*. If a chronometer contact or time signal is introduced into the circuit of G, then the small lamp will be illuminated for the period of the contact. If the disk is then in rotation it is possible to read off the length of this interval of the glass scale, since the times of making and breaking the contact are distinctly indicated.

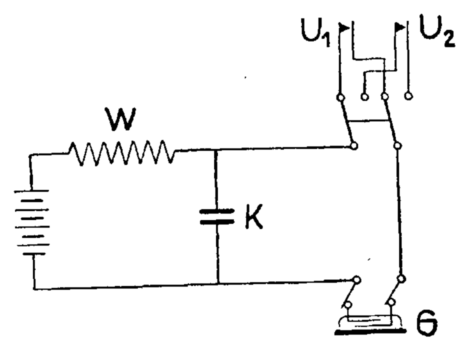

FIG. 4. — *Connection Diagram.*

Reading of the Light Signal. For our purpose the comparison depends upon the reading of the position on the scale of the beginning of the contact (or when otherwise arranged-with the opening of the circuit). Since the making of the contact is manifested by a sudden flashing of the neon tube, and since the eye suddenly perceives the entire scale lighted up (by the small neon lamp), the reading is found by experience to be less sharp than in the case where, for instance, a sudden flash occurs on a darkened scale.

In order to eliminate such a systematic error in estimating the position and to facilitate the observation, a device was arranged (the contact button to the right in fig. 3) to provide for the flashing of the neon tube with a short duration of about 0.001^s, as shown in fig. 4. By means of a suitable resistance *W* a slow charging of the condenserblock K is achieved. The closing of the contact, then brought about by the chronometer contact (time signal) *U* causes a sudden discharge of the condenser through the neon tube

G, which manifests as a very quick flash. There is sufficient time for recharging the condenser in the interval between the breaking of the circuit and the next subsequent closing of the contact. Through the action of a double throw switch (left in fig. 3) it is possible to throw into circuit in quick succession the two contacts U and U_1 of the neon tube circuit.

PROCEDURE FOR OBSERVATIONS

1). *Comparison of two chronometers which have the same rate of oscillation.*

Order of Observations. The ends of the leads of the chronometer contact U_1 (observation clock) and U_2 (comparison clock) are then connected to the contacts of the "Uhrstandmesser" which have the same designation. The double-throw switch is turned to U_1 and the apparatus is set in rotation. The spark produced by U_1 in the neon tube will then appear at some place on the glass scale S, and, owing to the speed with which the neon tube rotates, it will appear from second to second to progress over the scale, to retrogress or to remain stationary. If a "movement" of the light along the scale occurs then this an indication that the speed of rotation does not correspond exactly to that of the second rate of the chronometer. By turning the screw D (fig. 1) it is possible to adjust the speed so that the neon tube flash appears to remain stationary on the scale; for instance at A in fig 5.

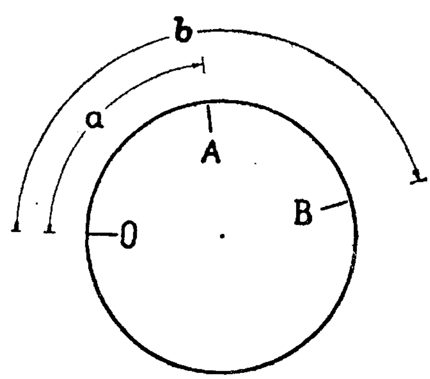

FIG. 5. — *Example of observation.*

Calculation. Suppose the readings on the scale are *a* and *b;* then we have b — a = z in which z is the fraction of the second of the chronometer reading, given in units of hundredths of a second (graduations of the glass scale); the reading to thousandths of a second is estimated.

In order to read off the value of z directly, it is possible, for instance, after having adjusted the speed of the neon tube to the correct velocity, to bring the zero mark of the scale over "A". This then makes a = O and the reading at "B" will then equal z (or, what is the same thing, 100 — z).

The comparison ΔU then results from the following, if we take the nearest full second of the comparison designated as $\Delta U'$.

$$\Delta U = \Delta U' - z.$$

Example

Comparsion of two watches running on mean time

1940; 12 January, Friday.

U_1 observation chronometer U_2 comparison chronometer

Approximate comparison	*Comparison with apparatus*	*Chronometer difference*
$U'_1 = 12^h\ 16^m\ 17^s$ $U'_2 = 12^h\ 16^m\ 21.3^s$	a = 50.2 b = 18.4	$\Delta U' = + 4$ sec. $z = - 0.318$ sec.
ΔU appr. = + 4.3 sec.	b — a = — 31.8	$\Delta U = + 4.318$ sec.

II). *Comparison of two chronometers having different rates of oscillation.*

Taking into account the displacement of the light signal. The procedure when comparing two chronometers having different rates of oscillation is the same as that described under heading 1. Since however the velocity of rotation of the neon lamp can correspond to only one of the chronometers, the observer perceives a progressive movement of the light signal along the scale as soon as the second chronometer is connected in circuit. This procedure however necessitates further the counting of the second beats (at least that of the chronometer whose beats are not synchronized with the measuring apparatus) and to note this time in order that in evaluating the observation both values may be referred to the same identical instant of time.

We assume further that U_1 represents the observation chronometer and U_2 that which serves for the comparison; that U_1 is keeping sidereal time while U_2 is regulated to mean time. The chronometer-difference meter is then exactly synchronized with U_2 for the second beats. From the approximate comparison we obtain the data from U'_1 and U'_2, both referred to the same instant of time. Then for the two observations we have:—

for U_1 ...... a ; for U_2 ...... b

and, from equation (1) $z = b - a$ in "mean time"

the difference ΔU (of the observation chronometer) U_1 at the time of the reading U_2 (as comparison chronometer) may then be determined as follows:

$$\Delta U = U_2 - U_{12} = U_2 - (U_1 + z) \qquad (3)$$

in which U_{12} represents the reading of the chronometer U_1 at the time of the observation of U_2. Equation (3) is identical with equation (2) except that $U_2 - U_1$, (referred to the same unit of time) is designated as $\Delta U'$. If we seek as usual to find ΔU in units of sidereal time, then U_2 and z must first be converted into sidereal time intervals.

Example

Comparison of two chronometers with different rates of oscillation.

Observations.

1940 January 16, Tuesday; Berlin.

U_1 = Observation chronometer (Sidereal time).

U_2 = Comparison chronometer (Central European mean time).

The meter for measuring chronometer differences was exactly synchronized with the second beats of U_2.

Approximate comparison	*Comparison with Difference meter*	
$U'_1 = 17^h\ 40^m\ 44^s$	$U_1 = 17^h\ 36^m\ 52^s$	a = 7.9
$U'_2 = 10\quad 8\quad 40$	$U_2 = 10\quad 4\quad 49$	b = 48.2
	z = b — a = 40.3 = + 0.403 sec Mean T.	
	transformation (sidereal) = + 0.001 sec S.T.	
	z = + 0.404 sec S.T.	

Calculation.

Time interval in sidereal time	$U_1 - U'_2$ =	— $0^h\ 3^m\ 52^s$
Conversion to mean time	=	+ 0.6
Time interval in mean time	$U_1 - U'_1$ =	— $3^m\ 51.4^s$
Chronometer reading	U'_2 =	10 8 40
Approximate chronometer reading of U_2 at instant of comparison with U_1	U'_{21} =	10 4 48.6
Rounded off to full seconds	U'_2 =	10 4 49
Conversion to sidereal time for observation datum ...	U'_2 =	— 17 36 46.830
$U_{12} = U_1 + z$	=	17 36 52.404
Chronometer difference, therefore	ΔU =	+ 5.574^s S.T.

Note: The first five lines of this calculation serve only to determine the reading of U_1 to the nearest full second of U_2.

It is also possible, in the manner described, to make the comparisons by using time signals. If apparatus is available, arranged so that the circuit of the neon tube can be closed by the time signal, then the individual time signals are, for a technical standpoint, equivalent to the second beats of the comparison chronometer.

As a result of the friction disk transmission, which does not permit the exact adjustment of the speed of the light indicator with sufficient rapidity, some appreciable time must elapse in practice before the "difference-meter" can be exactly synchronized with the second beats of the chronometer. It has therefore been found expedient to synchronize the apparatus only approximately with the second beats of the chronometer and to take into consideration the slight "wandering" of the light signal over the scale. As opposed to the previously described procedure there is the additional requirement of once more having to read the chronometer, with which the apparatus is (approximately) synchronized after the second chronometer or time signal has been connected to the apparatus.

ACCURACY OF COMPARISONS WITH THE APPARATUS FOR MEASURING DIFFERENCES.

The accuracy of the results is preponderately influenced by the instrumental errors and by the readings of the scale. The transmission of the chronometer contact to the neon tube is practically without loss of time (instantaneous); the inertia of the tubes is given by the manufactures by the small figure of 10^{-5} sec. Even should this not be quite exact, the error would still lie far below the limits of error in chronometer comparisions and we can regard it as non-existent for all practical purposes.

The one great source of error in the chronometer comparisons with the apparatus is the possibility of variation in the speed of rotation of the neon tube. Attention has been previously directed to this point. This represents one of the "bugs" in the chronometer difference meter; and every conceivable attempt at improvement in accuracy must begin with this problem. The variation may be caused both by fluctuations in the electric circuit and by inaccuracies in the mechanical construction of the apparatus.

The fluctuations in the electrical circuit vary in time and place and can only be determined empirically as they cannot be calculated. The Berlin Electric Company "BEWAG" gives the figure of 10^{-4} of the frequency as the mean accuracy of its alternating current (50 cycles). As a result of the extremely brief duration of the time of observation the depreciation in accuracy as a result of the fluctations in the electrical circuit is not great. Efforts must be made, however, to effect the readings as quickly as possible in rapid succession and to switch back to the chronometer first observed in order to determine the amount of any possible shift of the light signal. A comparison of the observations with each other will make it clear at once if any appreciable variation has occured during the time of the observation.

The mechanical construction of the "difference-meter" must be carried out with scrupulous care. The rotating parts must be tested for dynamic balance on a turning-lathe to avoid the possibility of pounding or uneven rotation of the parts. Ball bearings contribute greatly to the smooth running of the apparatus. The vertical axis should bear on a point pivot in order that periodic unevenness in the rotation may be eliminated as far as possible. In spite of this, however, there will still remain certain faults of construction in the apparatus which will be detrimental to the results when making comparisons. Such errors, expressed in fractions of the revolution of the neon tube, effect the results of the comparison in the same ratio in fractions of a second, since the mean period of one revolution of the neon tube is one second.

In order to obtain a measure of the constancy of the revolutions of the neon tube, during a long series of observations, the pendulum contact of a good astronomical clock was connected in circuit with the apparatus. Readings of the light signal were taken at intervals of every ten seconds. The differences in the readings showed only very small and irregular variations. From this test the mean error in the measured differences was found to be about m = 0.0017^s. The greatest individual error shown between two differences during the entire test amounted to m = 0.0028^s, while the smallest error was m = 0.0002^s. The results of the test showed that within an interval of a few minutes no large jumps ever occured. In spite of this however, it is recommended that the readings be taken in as rapid succession as possible. In about 70 seconds it is possible, with one reading, to effect a satisfactory comparison with any clock.

The relation between the instrumental error (variation in the circuit and mechanical inflluences) and the purely personal error with respect to the total accuracy, cannot be determined on the basis of the above described measurements. Experience has shown however that *m* does not derive from purely observational errors, even though the greater part of the error may be ascribed to this source.

The mean error of the resultant chronometer difference has been calculated on the basis of further measurements and theoretical considerations, as follows: —

PROBABLE ACCURACY

of the chronometer difference when the following observations are carried out with the apparatus which has been approximately synchronized: —

N° of measurements with the chronometer U_1	*N° of measurements with U_2*					
	1	2	3	4	5	6
2	± 0.0024^s	± 0.0020^s	± 0.0018^s	± 0.0017^s	± 0.0017^s	± 0.0016^s
4	± 0.0022^s	± 0.0017^s	± 0.0016^s	± 0.0014^s	± 0.0014^s	± 0.0013^s

It follows from the tests made with the apparatus for measuring chronometer differences that the results are accurate to within one or two units of the thousandths of a second. These errors can be regarded as a certain measure of the limits of accuracy of the comparisons to be undertaken with the apparatus, since larger systematic alterations as a result of instrumental errors or personal errors are not possible.

SUMMARY

Description is given of a new procedure of chronometer comparison in which an auxiliary apparatus, the "chronometer-difference-meter", is employed. It is based on the simple principle of a mechanical subdivision of the

second. Many such apparatus are constructed and employed in scientific work based on this principle; but for chronometer comparisons it has not as yet been used in this form. The reason for this may lie in the generally expressed disinclination to use rotating light signals because too much confidence could not be placed in the constancy of the revolution. The experiments have shown that this prejudice is not well founded; it is only necessary to test the apparatus beforehand to determine the possible limits of accuracy attainable so that there may be no subsequent disappointment or false conclusions.

In order to eliminate the irregularities in the speed of revolution which might arise from disturbances in the light circuit, it is possible to conceive an arrangement with the apparatus connected to some purely mechanical rotating device, which has the greatest possible accuracy of movement. To what extent such a driving mechanism is capable of exceeding the regular rotation obtainable with the synchro-electric motor drive depends upon local conditions and must be specially investigated.

The attainable accuracy in the measurement of chronometer differences of a few thousandsths of a second gives this procedure an intermediate position between the purely auditory methods and the chronographic recording. The simplicity of execution, the slight expenditure of time required for the measurement, the possibility of obtaining direct results, as well as the particular far-reaching facilitation of the observations characterize above all the great superiority o fthe chronometer difference meter with respect to the auditory methods. The excellence of the results is especially noteworthy, as it lies within the range of accuracy of the chronographic registration, a fact which could hardly have been foreseen from the start.