STANDARDISATION OF TIME
AND ACCURATE DETERMINATION OF EXACT TIME (1).

by Commander H. BENCKER, *Technical Assistant I.H.B.*

Unification of time. In the national field, this problem has been exercising the minds of clock makers especially since 1850. In 1867, the astronomer Leverrier planned a system for the synchronization of various Paris public clocks by the Observatory. This scheme was put off until 1879.

In the International field, following the Metre Convention of May 20, 1875, Sir Sandford Fleming proposed that time should be unified in 1879. The International Geodetic Congress of Rome in 1883, suggested the adoption of the same fondamental meridian of origin for all countries. The Washington Meridian Conference, of 1884, advocated the division of the earth into 24 zones or time belts and adopted the Greenwich international fundamental meridian (Prime Meridien) (2).

Local mean time, however, continued to be legal in France until March 14 1891, when Paris mean time was adopted as "legal time" for the whole territory. The first radio-telegraphic time signals broadcast by the Eiffel Tower station, at the instigation of Commander Guyou and Hydrographic engineer Bouquet de la Grye, were transmitted from March 23, 1910 under this regime, which continued for 20 years, until March 9, 1911, the date of the adoption in France of universal time and international system of 24 time zones centred on Greenwich (following the International Conference on time zones, of 1911), although the question had been referred to the Chamber of Deputies ever since the year 1898 and the Senate had expressed a favorable opinion on the subject in December 1910. For France G.M.T. corresponds approximately to Saumur or better to Argentan Mean time.

From the 15th to the 23rd October was held in Paris the "Conférence Internationale de l'Heure" at which it was decided in particular that radiotelegraphic time signals would be transmitted in universal time.

Introduction of Summer time. Parliamentary discussions on the introduction of summer time into civil life started in 1908, when the Daylight saving Bill was brought in.

Astronomically speaking it was a matter of superceding midday (Meridies) on a plea of light saving. But, from a social point of view this matter was of obvious interest, in the sense that a lot was said about it in particular "that meridians were made for man and not man for meridians" (Sir Robert Ball). That "noon, is lunch time which is given by the clock striking, or by a stomach feeling and not by the sextant" (Léon Lecornu) — that the time pointed to by clocks is a fairly arbitrary symbol and that a little lie or a great lie is still a lie and that after all, the sun itself, is fairly dishonest with the public in its erratic movements.

British Summer time — (B.S.T.) following the bill tabled in 1915 by W. Willett. M. P. was adopted on May 22, 1916, during the World-War. Germany adopted summer time on May 1st, 1916. On the 15th of June 1916, a first experiment was made with summer time in France, the matter was brought under regulation by the law of May 24, 1923 ; that of

(1) Paragraphs relating to the working out of the exact time and the role of the International Time Commission are taken from an article by Mr. A. Lambert, at Paris Observatory Astronomer, published in the *Annuaire du Bureau des Longitudes* for the year 1940.

(2) Hipparchus prime meridian was that of the Isle of Rhodes from where he was observing.

Plotemy adopted that of « Insulae Fortunatae » the most westerly known spot, as Marinus of Tyre had done in the beginning of the IInd Century.

In the early days of sea voyages of discovery, the Peak of Teneriffe meridian was used.

In 1630, a Scientific Congress convened by Richelieu in Paris, adopted the Meridian of the « Ile de Fer ». This was recognized on April 25, 1634 by King Louis XIII and supplanted those of Uranieborg and San Miguel (Azores) which were used occasionally.

In 1724, Louis Feuillée determined the longitude difference Paris-Ferro ; which he found equal to 20°01'45", but Guillaume de l'Isle (1675-1726) suggested the adoption of a round value of 20° W. Paris meridian was used for national purposes like that of Greenwich until the time when the Washington Conference of 1884, initiated Greenwich meridian as fundamental meridian for international purposes.

December 19, 1940 refers to the amplitude of alteration of summer time, to the extent of 2 zones hours (Double Summer Time).

Time at sea. Extension of the zone system. — Navigators continued to set their ships-time-pieces at sea by the previous true noon time, so that two ships that met and passed each other did not generally carry the same time.

For example : on May 31st 1916, at the Battle of Jutland, the Naval encounter took place about the time when true time was 23 minutes fast on the British ships time and 1 h. 37 m. slow on that of the German ships. These times were besides quite different from those of the coast signal-stations, which did not make it very easy to check chronologically the developments of the fighting.

Following a recommandation made by the Paris " Bureau des Longitudes " by Ingénieur Hydrographe Général G. Renaud France decided to apply at sea the universal time system of time zones, including summer time, as from March 25, 1917. A Conference held in London from June 21st to July 3rd 1917 adopted this system, numbering the 24 zones from 0 to + 12 and — 12 to West and East. The same Conference recommended the use of the same origin for the civil day and the astronomical day. French Nautical Ephemerides were compiled in accordance with this rule from the year 1920.

In 1912 the " Bureau International de l'Heure " (International Time Commission) was set up in Paris. It works out the most exact time in co-operation with observatories covering the whole world and broadcasts radiotelegraphic time signals for the benefit of astronomers and navigators. It is also responsible for the publication of data resulting from international longitude measuring operations.

In 1926, measurements covering the whole world gave the exact longitude of 32 observatories ; those made for 1933 resulted in the longitude determination of 71 stations.

Setting up an international radio telegraphic time signal transmission service.

In 1908, following some decisive wireless time signal transmission experiments, made in France as well as in other countries, the " Bureau des Longitudes ", of Paris, requested that a time signal service be set up, tentatively, on the Eiffel Tower, for the determination of longitudes.

General Ferrié and Mr. M. Baillaud, Director of the Paris Observatory suggested the transmission of two sorts of signals : some daily, at a fixed hour, with 1/2 second precision, for naval requirements, others, occasional, for the determination of differences in longitude, aiming at a 1/100 second precision.

On May 23rd 1910, was inaugurated the transmission by the Eiffel Tower, of regular time signals, which has continued ever since, without cessation, at various times and according to various schedules. Originally, the daily signal transmission took place at midnight, but soon after this, a second transmission took place at 11 a.m.; then there were four per day and in 1940, fourteen daily series of signals were controlled from the Paris Observatory and transmitted by the wireless station of the Eiffel Tower, Bordeaux (Croix d'Hins) and Pontoise.

About the same time other stations also undertook a regular transmission of time signals ; such as the Norddeich station in liaison with the Wilhemshafen and that of Arlington in liaison with the Washington Observatory.

According to statements made by navigators, these various signals were frequently in disagreement, sometimes by as much as one second. So the need for a central time unifying body was felt and Général Ferrié, in a *Memorandum* drafted towards the end of 1911, proposed the setting up of a Time Office, located near an astronomical Observatory and a powerful broadcasting wireless station, whose duty would be to fix international time.

On the proposal of the " Bureau des Longitudes ", the French Government convened an International Conference that met in Paris from October 15, to October 23, 1912, for the practical unification of time and working out a scheme to organize an international time service.

In 1913, a second Conference including 32 States (1) drafted an International Convention in Paris for the creation of an "International Time Association" (Association Internationale de l'Heure) whose constitutional reputations were also determined. The Association comprised : a Committee, a Permanent Council and "The International Time Commission" (Bureau International de l'Heure).

During the World War (1914-1918), the Time Commission functioned as an independent body with the assistance of the Paris Observatory an auxiliary station was set up in 1918 at Lyons close to the La Doua wireless station.

After the World War (1914-1918) former scientific associations were reconstituted on new bases : The International Research Council (Conseil International des Recherches) included various international Unions set up for definite purposes.

The Astronomical Union, in particular, includes a Time Commission.

The International Time Commission Regulation were drafted on July 26, 1919, during a session held at Brussels by the International Research Council.

« 1. As regards ordinary signals, the International Commission shall centralize the results « of universal time determinations expressed in Greenwich time, transmitted to it by national « time centres, who shall be responsible for the most accurate computation of mean time « deduced from determinations made by their National Observatories. These results shall be « communicated as early as possible to transmitting stations and National Centres.

« 2. As regards scientific signals, it shall centralize time determinations made in Asso- « ciated Observatories and shall deduce the most exact time therefrom. »

The International Time Commission publishes the results of these comparisons. Those of these results which are not published promptly, are communicated in details and on the request of official scientific Associations and Institutions.

Transmission of International Time Commission Time Signals.

Time signals controlled and checked by the B. I. H. (Bureau International de l'Heure — International Time Commission) of the Paris Observatory which is its head office, are transmitted in Universal time at a *fixed hour* as *exact as possible,* in accordance with two different schedules : first, *automatic signals of international type,* to meet the requirements of clockmakers, sailors, airmen and whose transmission precision exceeds to a great extent the users' requirements. They consist of a grouping of dots and more or less long dashes whose arrangement permits an every minute identification of the signal. They are tarnsmitted by mecanical apparatuses with contact cams controlled by wheels whose section corresponds to the various signals. Simple listening-in permits to estimate a signal time, in local clock time, with an accuracy of less than 1/2 second.

Rhythmical signals, comprising 61 beats (ticks) in 60 seconds of mean time, are transmitted one minute after the end of automatic signals ; and, for five minutes, a longer dash marks the beginning of every round minute. They are intended for scientific objects, such as : measuring differences of longitudes, determination of local time, when knowing longitude, study of the rate of all kinds of time-keepers and of their periodical variations, standardization of frequencies, investigations into radioelectric wave propagation,. etc... When it is simply a matter of locating these signals within one or two hundredths of a second in relation to the time-keeper beats (clock or chronometer), the observer may employ the method of acoustic coincidences by using a contrivance enabling him to hear rhythmical signals and time keeper beats simultaneously, a mean time second beating clock gives a coincidence every 60 seconds, a sidereal time second beating clock gives a coincidence every 72 seconds. From the position of the signal in coincidence with the second beat, one can easily deduces the time of any beat, in terms of the clock time. If greater precision is desired (a few thousandths of a second) the observer should have at his disposal receiving apparatuses for recording signals and time keeper seconds on a chronograph, so as to place them in relation to one another.

---

(1) Germany, Argentina, Austria, Belgium, Brazil, Chile, Belgium Congo, Cuba, Denmark, Egypt; Ecuador, Spain, United States of America, France, Great Britain, Greece, Guatemala, India, Italy, Kiaochau, Mexico, Monaco, Nicaragua, Netherlands, Portugal, Russia, Serbia, Siberia, Sweden, Switzerland, Turkey; Uruguay.

In order to take into account the inertia relating to the various recording parts special measurements, are made in respect of signals of 10 seconds duration which follow each transmission. Rhythmic signals are transmitted by oscillator whose period is adapted to the signals : small contact clock, free pendulum connected to a photoelectric cell, clock under bell glass maintained at constant pressure and temperature and whose error and rate are adjusted at every moment by a remote controlled electromagnetic rectifier.

Various transmitters of automatic signals and rhythmic signals (with the exception of under bell clocks are synchronized by a clock set by mean time, whose error is reduced to zero at the moment of signal transmission : in fact, this synchronizing clock is given a slight gain equal to all the losses introduced by interposed relays between the small transmitting clock and the sending out aerial.

Precision of time signal time.

The seven fundamental weight clocks available in the Paris Observatory are heated in a cellar 28 meters under ground whose temperature remains practically constant.—Their parts are maintained under a pressure variation proof bell. Being thus carefully isolated from any promiscuity, their precision remains of the order of 1/100 second per day.

It is known that a pendulum period $T = \pi \sqrt{\frac{l}{g}}$ is likely to be altered on account of three causes.

1. Variation of the pendulum length ;
2. Variation of atmospheric pressure, which increases or decreases air resistance ;
3. Variation of terrestrial attraction, that is to say, gravity.

The first cause is reduced to a minimum by using an invar steel pendulum with a very low dilatation coefficient and also by maintaining time-keeper at a uniform temperature.

As for the second cause, time keepers are enclosed in a cylindrical constant pressure bell, their beats being listened to from a distance by means of a telephone and electric connections.

In respect of the third cause, gravity may be fictituously made to vary by fastening on the pendulum a bar magnet oscillating over a fixed electro-magnet through which the flow of current is regulated : a 1/10 milliampere current gives rise to a gain or a loss of 3/10 second per day.

It is in this way that the time keeper used for the radio-phonic broadcasting of time is regulated.

Fundamental time keepers, however, are not regulated ; it is sufficient to note by how many seconds each one is fast or slow, this quantity varies only by a few units per year. A small electric motor winds up the clock driving weight every 35 seconds.

Every 18 months, the vault is visited for purposes of lubrication and every three years each time keeper is taken to pieces and overhauled.

The indication average of the 7 time keepers kept in the Observatory basement is obtained by means of a graphic record of their indications on a chronograph cylinder driven at a constant speed by synchronization with two tuning fork clocks.

A specialist compiles this average by using a micrometric frame and a sliding microscope for analysing graphic records : Tuning fork clocks of which the Observatory possesses two specimens are also located in a vault.

Elinvar metal tuning forks are enclosed in a series of concentric hot air chambers between which two heating circuits maintain a temperature constant within 1/100° C. They function at a musical frequency of 1000 periods per second and duplicate the 7 mechanical time keepers by the synchronized clocks coupled with them. The three rotary recording cylinders or chronographs are located in the eastern cupola state circular hall of the Observatory. Two of them record foreign time signal radiotelegraphic broadcasts transmitted by

NOTE : The loud speaking clock. BRILLIÉ system. has been established at Paris Observatory on 14th March 1932. In 1937 transmission was given by wireless.

other associated Observatories whose duty is to cooperate in the working out of "standard time". Their recording cylinder is driven at a rigorously constant speed by a synchronous motor fed by the musical current supplied by the tuning fork clocks. The stylus worked by a "pick up" coil leaves a red line on the oil-paper used for recording the transmissions of the seven time keepers, of the two tuning fork clocks and various rhythmic signal transmissions broadcast by associated stations (Bordeaux, Nauen, Rugby, Arlington, etc.).

Apart from the seven weight time-keepers and two tuning fork clocks with the synchronized clocks coupled with them, the B.I.H. equipment includes transit telescopes for astronomical observations, serving for the determination of sideral time by the meridian transit of stars at night whenever weather conditions are favourable.

These telescopes are fitted with an "impersonal reticle" to eliminate the observer's individual error ; the frame bearing this reticle is driven by a small electric motor ; the astronomer's part consists merely in regulating the motor speed by means of a rheostat, so as to keep the cross-wire in coincidence with the star image : an automatic release takes place at the moment when the cross wire passes over the contact mark, the resulting error not exceeding a few hundredths of a second.

Secondary clocks contained in basement glass-cases which are read off at a distance by means of a telescope, are used as a "reserve" for recording the exact time by causing them to gain or lose by means of the magnet pendulum regulator mentioned and described above.

The knowledge of the error of the clocks controlling the B.I.H. signals, results from a comparison with the directing sidereal clock of the Paris Observatory. As regards the latter clock, corrections are based on the Observatory meridian observations. Moreover, its rate is checked with due regard to the reception in Paris of time signals transmitted by other stations such as Annapolis, Rugby, Nauen, on the provisional assumption that these signals are transmitted at the exact universal time.

By this procedure, the moment of transmission of signals controlled by the B. I. H. is not erroneous, on an average, by more than 0 s. 03. The difference with theoretical time is subsequently calculated and published in the *Bulletin Horaire*, issued every two months under the auspices of the International Time Commission (B. I. H.), by the publishing firm Gauthier-Villars, Paris.

First approximation of the exact time [1].

It is obtained through the meridian sidereal observations of the Paris Observatory time service and the B.I.H. recording of radiotelegraphic time signals controlled by some foreign observatories.

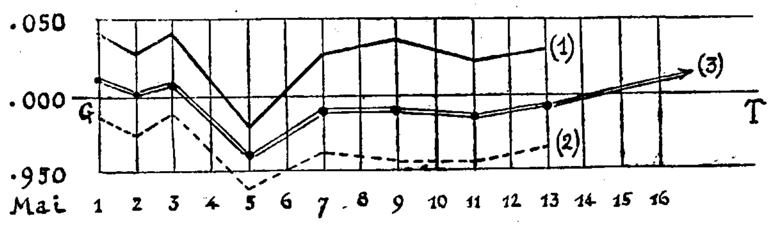

FIG. 1

1. Paris meridian sidereal observations are referred to one of the Observatory fundamental sidereal clocks, which furnishes this clock correction in relation to local sidereal time or else to Greenwich sidereal time by attributing the Conventional value — 9 m. 20 s. 935 to the longitude Paris-Greenwich. A daily chart is kept of clock (1) corrections fig. 1.

2. The coming in moments of time signals from associated Observatories recorded at the B. I. H. also indicate other values of the Paris clock correction, for this purpose it is

(1) The description of devices and method for working out exact time is borrowed from the article entitled: « Le Bureau International de l'Heure — son rôle, son fonctionnement », by Mr. Armand Lambert, Astronomer to the Paris Observatory, published in the *Annuaire du Bureau des Longitudes*, for the year 1940.

assumed provisionally that the transmission of these signals was effected at the exact theoretical mean time of Universal time assigned to them.

This mean theoretical time is converted into sidereal time by means of tables for the conversion of mean time into sidereal time, supplied by Ephemerides such as the "Connaissance des Temps" (Nautical Almanac); hence, by comparison, the fundamental clock correction which furnishes the elements of the drawing of curve (2) fig. 1.

By taking these two charts into account, the second of which is especially useful to define the rate of the time keeper, it will be possible to plot, by producing the curve (3), the figurative points of the sidereal clock correction for the 24 following hours. This is the procedure to determine inferred sidereal time called "first approximation time".

The mean difference between the inferred time and time called *semi-standard* time resulting from a second approximation which will be dealt with further on, showed lately decreasing values from 0 s. 016 to 0 s. 013, which shows the advantage of the confrontation adopted in connection with the various data supplied by different observatories for drawing the diagram.

Technique of International Time signal transmission.

The B. I. H. possesses three models of automatic transmitters of the Belin, Brillie-Leroy and Lepaute systems.

The apparatus of the latter model which is now in regular use includes a source of electric energy constituted by a battery of Cadmium-nickel accumulators, a small clock with a time meter, a pilot receiver and a key receiver.

The small clock pendulum swings every half second, it is kept up electrically and synchronized every second, the small clock wheel drives two cams ; the first effects one revolution in 24 hours and bears gabs towards 7 h. 53 m., 9 h. 23 m., 19 h. 53 m. and 22 h. 23 m. that is 3 minutes before the B. I. H. starts transmitting signals. The other cam effects one revolution in 5 minutes and makes contact every revolution at 0 m. 0 s., 5 m. 0 s., 10 m. 0 s., etc.

At 9 h. 23 m., for instance, the small clock breaks contact with the 24 h. cam, and at 9 h. 25 m. 0 s. with the 5 minutes one. The pilot-receiver, at the stop until then, starts being driven and controlled by the small clock, every half-second ; it bears a train of wheels whose last movable one revolves in 12 minutes and whose axis bears eleven mercury tilting phials, each of which is to cause at the desired moment the closing or opening of the different circuits connected with the cam sections.

The key receiver is a half second receiver, it is set in motion by the action of a pilot-receiver cam at 9 h. 25 m. 25 s. its last movable wheel revolves in 60 seconds and its axis bears 5 cams connected with 5 day contacts which insure the closing or breaking of the signalling key circuit according to the cam section.

The combined action of the pilot receiver cams and key receiver cams performs the following duties :—

Manipulation of the call-sign B. I. H. ;
Manipulation of the 0 s. (2 letters O, a dash, 2 letters O) in morse code ;
Manipulation of the X's (10 letters X, followed by 6 dots) ;
Manipulation of the N's (5 letters N, 6 dots) ;
Manipulation of the G's (5 letters G, 6 dots).

The 6th of each set of 6 dots, falling on round minutes 58 m., 59 m. and 60 m.

Stopping of the key receiver whose work is now at an end.

Closing and breaking of the rhythmic test signal circuit.

Restoring and breaking the final rhythmic signal circuit.

We may reckon that, on an average the 6 final dots of the last three minutes are not in-error by more than 5 to 6 hundredths of a second.

The small clock of the transmitting set is synchronized every second by a Leroy clock fitted with an electro-magnetic rectifier used for re-setting at the exact time shortly before transmitting.

Time-setting device.

For this purpose, the Leroy clock pendulum is fitted with a straight permanent magnet which when passing through the vertical, lies in a solenoid axis. A weak electric current is sent through the solenoid just long enough to correct the error of the clock, fast or slow according to the direction of the current. This magnetic brake acts in proportion to time ; its application for 3 minutes alters the error to the extent of 0 sec. 1. For this time re-setting, one takes into account the duration of inertia of the relays and the position in time of the small clock contact so that the radiotelegraphic transmission may take place at its theoretical time.

As regards the Lepaute apparatus, this shows a loss of 0 s. 015 which is estimated by reading off on the recording chronograph the moment when clock contact is made and that when the corresponding wireless signal is recorded.

Rhythmic signal transmission device.

The rhythmic signal transmission lay-out includes at the beginning of each 5 minutes emission a long beat of about 1/2 second followed by 60 short beats ; the beginnings of these 61 beats must be rigorously equidistant and transmitted at the, as exact as possible, theoretical time.

This necessitates a knowledge of the inevitably inferred clock correction, the estimation of the total lag due to the inertia of the relays interposed between the clock and the radiotelegraphic transmitter, including shifting in process of time, which depends on the pendulum position at the moment when the signal controlling contact is made and finally the re-setting of the controlling gear at the exact time.

In the beginning, the B. I. H. employed for the transmission of rhythmic signals a small contact clock giving 61 double vibrations in 60 seconds of mean time, synchronized every minute by a good quality clock : sometimes, however, the re-timing of the clock did not result rapidly and truly enough, in that of the small clock. Consequently, the B. I. H. uses a more reliable contrivance :

A Leroy time keeper of great precision, quite up to the best astronomical clocks (stabilized invar Guillaume clock), kept under constant pressure bell, is located in a stable temperature basement room in the Observatory. Its pendulum gives 61 vibrations per minute, electric winding up is effected automatically about every 32 seconds. The switch worked directly by the pendulum is a double one : a first circuit produces a short closing at every vibration ; so does the other, with the exception of the 51st beat which is suppressed by means of an extra switch to allow the fixing of the minute at the time of recording or listening-in with a head-phone.

The lengthening of dashes marking the beginning of minutes is secured by an auxiliary small clock with 61 beats per seconds, permanently synchronized by the time-keeper : it includes a switch in parallel with that of the time keeper and fitted so as to lengthen the signals 1, 62, 123, 184, etc., the beginning of the lengthened dash being always controlled by the time keeper.

Action is exerted on the inner pressure so as to render the rate obviously nil : a pressure increase of 1 mm. of mercury produces a daily lag of about 0 s. 018. The low daily rate being a known quantity, the error of the time keeper is corrected, if necessary so that it points to the exact time at transmission time, the correction being effected by means of low current switched on through a solenoid acting on a straight magnet borne by the pendulum rod.

The beats controlled in this way are rigorously equidistant and the instrument cadences provide a regular time vernier of extreme precision, for purposes of comparison with 60 beats clocks set by mean time as well as with clocks set by sidereal time.

The control transmitter of the Edouard Belin works is based on a different principle :— An electrically maintained tuning fork being one of the fundamental clocks in the Observatory vibrates at a frequency of 1000 periods per second of sidereal time, it is followed by a mechanical transformer converting 1000 periods per second of sidereal time into 1000 periods per second of mean time, whose current drives a 100 pole synchronous motor with a rotor and two stators shifted by one half polar pitch (1°13'). On one side of the motor is a mean time synchronous clock fitted with a contrivance for transmitting the first signal at the required time ; on the other side is a metal disc driven at a rate of 61/60 revolutions per second, producing the cadence of rhythmic signals. An opening in the disc, whose edges make an angle of 36°36' allows the transmission of 1/10 second short rhythmic signals, in the following manner : by means of a condenser a lamp lights up a slit whose image, reproduced through a lens is formed in the disk plane. This image lights up a photo-electric cell each time the disc opening passes in front of the slit.

The photo-electric cell acts on a circuit allowing either the direct modulation of the broadcasting station or its control by means of a relay. A phase shifter makes it possible to correct the error of the synchronous clock and re-set it at the exact time, without stopping the movement. This is done by shifting the stator which bears a ring divided into one hundred parts, — each division corresponds to 1/1000 second since a complete revolution of the stator shifts the disc by 1/10 second.

Reception of time signals by Observatories.

They are recorded on chronographs of great precision called " frequency meters ", which is also used for clocking time keepers second by second.

The chronograph is synchronized by an elinvar tuning fork of 1000 periods of sidereal time, placed in the centre of a series of hot-air cabinets with alternately insulating and conducting partition-walls between which a thermostatically heating rheostat regulates temperature within 1/100 degree C. : the tuning fork has a low thermic coefficient, a water-tight tank immersed in an oil bath preserves it from outside pressure variations. The tuning fork is electrically maintained at a steady voltage of supply, its frequency is ensured within 5.10^{-7}, the variations of this frequency not exceeding this figure either. At the exit, may be connected a sidereal time synchronous clock including a 1000 period phonic wheel which goes round ten times per second and drives a time switch on mechanical transformer of sidereal time into mean time.

The chronograph proper includes a motor alternator set which may be synchronized at will either by the 1000 per second current, tuning fork sidereal time or by the 1000 per second current, transformer mean time. This motor set, after being mechanically geared down, drives a rotating cylinder, 50 centimeters in circumference and 50 centimeters long, on which records are made. It rotates at will either 1 rotation per second (sidereal or mean time) or 61/60 of sidereal time. A carriage is driven at a uniform pace in a parallel direction to the generatrices of the cylinder, it bears 3 sensative relays whose movable armature is provided with a needle, when the relay is being worked the needle scratches a trace into a tinted oil paper sheet round the cylinder.

The recording relay carriage may be driven at 3 translation speeds : either 1 mm., 1/10th of millimeter or 1/100 of millimeter per cylinder rotation.

The 1 mm. per second speed is used for checking the quality of the successive time signals of one transmission or that of the successive second contacts of a clock, for checking their equidistance, for instance. The shifting of 1/10 millimeter per rotation is normally used for signal reception.

Recording of signals.

The chronograph cylinder rotating at 61/60 sidereal time, the successive odd seconds of the Observatory fundamental clock are recorded according to a discontinuous helix whose traces are easily figured, as second 59 is done away with in all the Observatory time keepers (*Fig. 2*). A radiotelegraphic signal being recorded on the same stylus, it will be easy to refer it to the fundamental clock indications and then to know the sidereal time of its arrival, the correction of the clock being once determined and having regard to the lag introduced by the set of amplifying and selecting apparatuses.

This lag, which is about 3/1000 of a second, is determined at the moment of transmission of the 10 sec. long dash broadcast for this purpose by some stations following on their time signals.

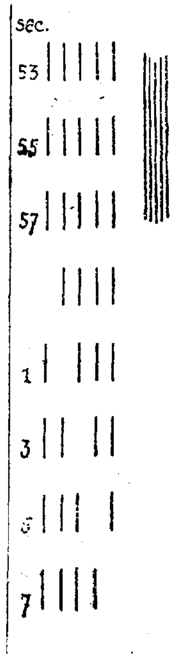

Fig. 2

Exact time by second approximation :
Time called semi-definitive time of time signals.

Inferred time is revised through a second approximation by means of all Observatory fundamental clocks found in good working order.

The various sidereal clocks of the Observatory are permanently compared with one another by recording their second contacts on a chronograph quite similar to the frequency meter described above, whose cylinder is lead by a sidereal time synchronous clock coupled with the 1000 periods per second tuning fork (sidereal time). The sensitive relay bearing the recording stylus is driven, in the course of each second, by every one of the clocks to be compared : a difference of 1 mm. between the traces recorded by two clocks means a difference of error of 4/1000 of a second. The sizes of the cylinder permit continuous recording for a week.

Let D'1 be the *semi-definitive* correction of the directing clock (1) at a given moment and D'2, D'3 .... the corrections, at the same moment, of the clocks (2) (3), etc... Let us likewise designate by the notation (1), (2), (3), the times pointed to by the clocks, we have :

$$(1) + D'1 = (2) + D'2 = 3 + D'3 = \ldots\ (m) + D'm$$

(m) is the clock's mean indication, D'm the correction of a mean fictitious clock.

Chronographic recording of the various clocks gives the comparisons (1)-(2), (1)-(3), (1)-(4).... and if p be the number of clocks employed, we have :

$$M = \frac{(1) - (2) + (1) - (3) + (1) - (4) + \ldots}{p} = (1) - (m) \text{ hence :}$$

$$D'm = M + D'1$$

The correction of the directing clock furnished by meridian observations is referred to the sidereal time, it is reduced to what is *called mean-sidereal* time, neglecting the nutation and obliquity of the ecliptic.

We have thus : Dm = M + D1 which is calculated every day of astronomical observation : the Dm diagram is drawn and the broken line smoothed out.

The Dm's are plotted on the curve so obtained.

D1 is obtained by Dm — M and by adding — 9 m. 20 s. 935, Paris conventional longitude in relation to Greenwich, we obtain the *semi-definitive* correction deduced only from Paris meridian observations and referring to Greenwich mean sidereal time. This inferred correction in connection with the time of arrival of signals added to the plotting of their chronograph record furnishes the *semi-definitive time of arrival* of time signals picked up by the B. I. H.

There are 37 every day. The *Bulletin Horaire* which is issued every other month publishes their divergences from transmission theoretical time in Universal Time. For instance, on the 1st of October, the indication 973 means that the signal time instead of falling on the round second of noon, actually occured at 11 h. 59 m. 59 s. 973.

In 1938, the divergences between semi-definitive time and definitive (standard) time did not exceed a maximum of 0 s. 022 and their mean value amounted to 0 s. 0075.

Such is the precision which may be obtained by a time connection of an observed phenomenon with one of these time signals.

International co-operation for standard time.

Associated Observatories numbering about twenty, all well equipped for meridian astronomic observations, for radiotelegraphic signal reception and for good time keeping on account of their precision clocks, are co-operating in a third and last approximation of time, by transmitting periodically to Paris, the hours in Greenwich mean time which they assign to time signals recorded by them.

The communicated data (time of reception) are first converted into transmission time by taking off the duration of wave propagation between the radiotelegraphic transmitting station and the receiving Observatory. The wave propagation speed adopted for long waves lengths is 252.000 km. per second and 270.000 km./sec. for short wave lengths.

Let us assume that the same signal has been received by participating Observatories, *i* being the signal transmission time in Greenwich time as resulting for data furnished by Observatory I in Conventional longitude *l* ; *pa* being transmission time as regards Paris.

A graph is drawn of the slight difference *i-pa* whose curve is smoothed. A similar curve is drawn for each of the Observatories and an average is taken of the values *i-pa* plotted at one and the same time (20 h. Universal Time, or instance) on the smoothed curves.

The starting values (*i-pa*) are tainted with the difference of accidental errors effecting the original reception in Observatory I and in Paris. This difference is represented on the diagram by the ordinate divergence between the figurative point and the smoothed curve. Assuming a balance of the various accidental errors affecting the observed *i, s,* the average of the divergences relating to the same signal for all the observatories will furnish the reception error *dpa* in Paris.

So that the *standard time* adopted for the signal $H = pa + \frac{\Sigma\,(i\text{-}pa)}{n} + dpa.$

This *standard time* refers to the system called : " Mean Observatory ". It is the time of a meridian practically very close to Greenwich whose precise definition would place at a Greenwich longitude distance equal to the average of systematic errors affecting universal time determinations by each one of the participating observatories and resulting chiefly from adopted longitudes.

Conventional longitude correction

If greater precision than 1/100 second be desired for standard time, it will be necessary to take into account the influence of the pole displacement on the longitude of the observatories co-operating in the measurement of time.

The "Bureau International des Latitudes" of Capodimonte, furnishes every 1/10 year the x and y co-ordinates of the instantaneous pole in relation to the mean pole.

Let φ_i and λ_i be the latitude and conventional longitude selected for Observatory I. The influence of the pole displacement on longitude is expressed by :

$$\Delta \lambda_i = \frac{1}{15} (x \sin \lambda_i - y \cos \lambda_i) \text{ tang } \varphi_i$$

Let $\Delta \lambda$ be the mean of $\Delta \lambda_i$; standard time will become $Hd = H + \Delta \lambda$.

The *Bulletin Horaire* issued every two months notifies the *semi-standard time* of arrival of signals recorded by the B. I. H. with a delay of 2 months.

It issues with a delay of 6 months, the signal *standard time* referred to the "Mean Observatory" and once a year notifies the influence of pole displacement on standard time with the annual correction to be made to the conventional longitudes of participating Observatories.

The International Time Bureau as a scientific research body.

Apart from improving our knowledge of time, data collected by the B. I. H. permitted the study of various scientific problems connected with geophysics.

By comparing daily signals coming from Associated Observatories distributed all over the world, one obtains a permanent determination of the said observatories longitude, which permits the immediate disclosure of continuous or discontinuous deformation which might occur on the continental surface from the point of view of longitude variation. It has thus been ascertained that the yearly 60 centimeter broadening of the Atlantic to which the German Geologist Wegener's theory of "Continents drift" was leading, did not presumably exceed 2 or 3 centimeters as testified by the Constancy of American longitudes.

Many observations made on the Paris-Washington and Paris-Tokio distances have shown, that as regards radiotelegraphic wave propagation, there is a change of speed amounting to a day-time additional 7.000 km. per second when passing from the earth's lighted portion into the dark zone, this is due to the fact that the ionosphere reflecting layers are lower in lighted regions.

Data collected from longitude international operations in 1933 have revealed a daily variation of propagation with a maximum at about 16 hours for long wave lengths and a minimum 12 hours later. These hours are reversed for short wave lengths. The difference would be of 60.000 km. per second for long waves and 30.000 km. per second for short wave lengths.

As most likely value of the apparent mean speed, 250.000 km. per second, has been adopted for long wave propagation and 274.000 km. per second, for short wave propagation.

It has been possible to determine the precise expression of the short period irregularities of our planet rotation by comparing the astronomical time furnished by sighting stars with that supplied by weight, tuning fork or quartz precision clocks : they do not exceed 4/1000 second per day, that is about 2 meters on the distance of 40.000 km. run daily by a point on our Equator.

Local variations of gravity may also be disclosed when comparing at the same place the rates of weight clocks in Observatories with those of tuning fork time keepers : a variation of 1/10 milligal, in the value of G, alters a weight clock rate by about 0 s. 005, which is the extent of precision that may be obtained at present.