The British Post Office Speaking Clock, Mark II*

A. J. FORTY, B.A., A.M.I.E.E., and
F. A. MILNE, A.M.I.E.E.†

Part 1.—Design and Performance

U.D.C. 621.395.91:529.786

The original B.P.O. speaking clock has proved satisfactory during nearly 20 years of operation in this country, but did not meet the requirements of the Australian Post Office in respect of civil and marine time signals. The clocks for Australia were therefore made to a new design which was being undertaken by the P.O. Research Station and which is described in this article. Equipment to the new design, with quartz-crystal drive, has recently been installed in Australia giving signals accurate to ±5 mS (corrected every 24 hours) which compares with ±100 mS (corrected every hour) for the B.P.O. installation with pendulum drive. Part 2 of the article will deal with the manufacture of the new speaking clock, its testing and packing for export, and with the layout of the installation on site.

Introduction

Telephone subscribers in Melbourne and Sydney can now dial a special code and hear time announcements from a speaking clock. The equipment used for these two installations has been designed by the British Post Office Engineering Department and made in England by the Telephone Manufacturing Company. It is an improved version of the original speaking clock apparatus which has provided a similar service in Great Britain since 1936.[1]

Each speaking clock consists of an announcing machine (which produces the actual speech and time signals) together with auxiliary rack-mounted apparatus for driving the machine at a constant speed, for amplifying its audio signals, and for correcting the time signals to conform with standard time as determined by an observatory. The original design of speaking clock was controlled by a pendulum, and required hourly correction in order to produce time signals accurate to within ±0·1 sec. This order of accuracy is insufficient for the requirements of the Australian Post Office because it is necessary to derive, from each clock, civil and marine time signals not deviating more than ±20 mS from standard time. The requirement has been met by the British Speaking Clock, Mark II, in which a quartz-crystal-controlled oscillator is used for the drive, and which gives signals accurate to within ±5 mS when corrected only once every 24 hours. The use of a daily rather than hourly correction is attractive, especially when the greater distances (and correspondingly higher charges for the correcting circuit) involved in Australia are considered.

Each installation consists of two complete clocks plus common equipment and auxiliary power supply. Either of the two clocks of an installation may be used to supply announcements of time to the telephone subscribers. The second clock runs continuously as a standby (driven by the auxiliary power equipment) and is put into service automatically if a fault should occur in the first. Facilities are provided to enable the signals from the Melbourne installation to be used to maintain service at Sydney (or vice versa) in the event of a total breakdown of the local system. Intermediate centres can be fed with signals as desired.

After the initial setting-up procedure, the operation of an installation (including the daily time check) is entirely automatic, and skilled attention is required only for routine maintenance and for the clearing of faults if they should arise.

General Principles

Basically each clock consists of a synchronous motor which is driven at a constant speed from the amplified output of a crystal oscillator. Upon the motor shaft are mounted discs carrying sound tracks from which the successive announcements are derived.

Fig. 1 shows the block schematic diagram of an installation. Each clock is driven from a 100 kc/s crystal-controlled oscillator, the output of which is fed into a frequency divider which produces the 50 c/s supply required by the announcing machine motor. A third oscillator is also provided for reasons which are discussed later. The 50 c/s supply passes first through a timing corrector circuit, which is used during the daily correction interval, and then via amplifiers to the synchronous motor of the announcing machine.

The announcements and time signals produced by the announcing machine pass through a preamplifier, termed "Line Amplifier and Pilot Tone Alarm," and are then fed into two local power amplifiers. One of these is connected to relay sets feeding the local telephone network, while the other acts as a reserve.

Superimposed upon the speech signals from each announcing machine is a pilot tone of 3,200 c/s, which is used to detect the presence or absence of any portion of the announcements. The detection occurs in the "Line Amplifier and Pilot Tone Alarm" panel, and the tone is removed before passing on the signals to the local network. Announcements with the tone included are sent out over lines to a distant centre, if required, to act as a reserve for the distant installation. Similarly, incoming signals from the distant centre pass through "Line Amplifier and Pilot Tone Alarm" panels for the detection and removal of the pilot tone, and act as a reserve for the local installation.

Four sources of signals are thus available for distribution to the local subscribers. If a fault should occur, switching from one source to the next reserve is controlled by the Pilot Tone Alarm circuits and by other alarm circuits of the installation.

The above is a brief outline of the fundamental units of which a clock installation is composed. In the succeeding paragraphs these units are described in greater detail.

The Stable 50 c/s Supply

Three 100 kc/s bridge-stabilised crystal-controlled oscillators are provided for each installation. Two of these are normally linked to the clocks via a patching panel; the third is supplied to assist in fault detection, since by intercomparison the identification of a faulty oscillator can readily be made. An alarm is given whenever the frequency deviation between oscillators becomes excessive. In addition, meters are provided to show the difference in rate of the oscillators, and a log of the readings of these will provide an indication of long-term drift.

The oscillators are connected to individual frequency dividers which give outputs of 50 c/s for driving the clock motors.

* This article was published in the Telecommunication Journal of Australia (Vol. 10 No. 1, June 1954) and is reproduced by kind permission of the Editors of that Journal.

† The authors are, respectively, Senior Executive Engineer and Experimental Officer, P.O. Research Station.

[1] "The Speaking Clock." L. E. Magnusson, E. A. Speight and O. W. Gill, *P.O.E.E.J.*, Vol. 29, p. 261.

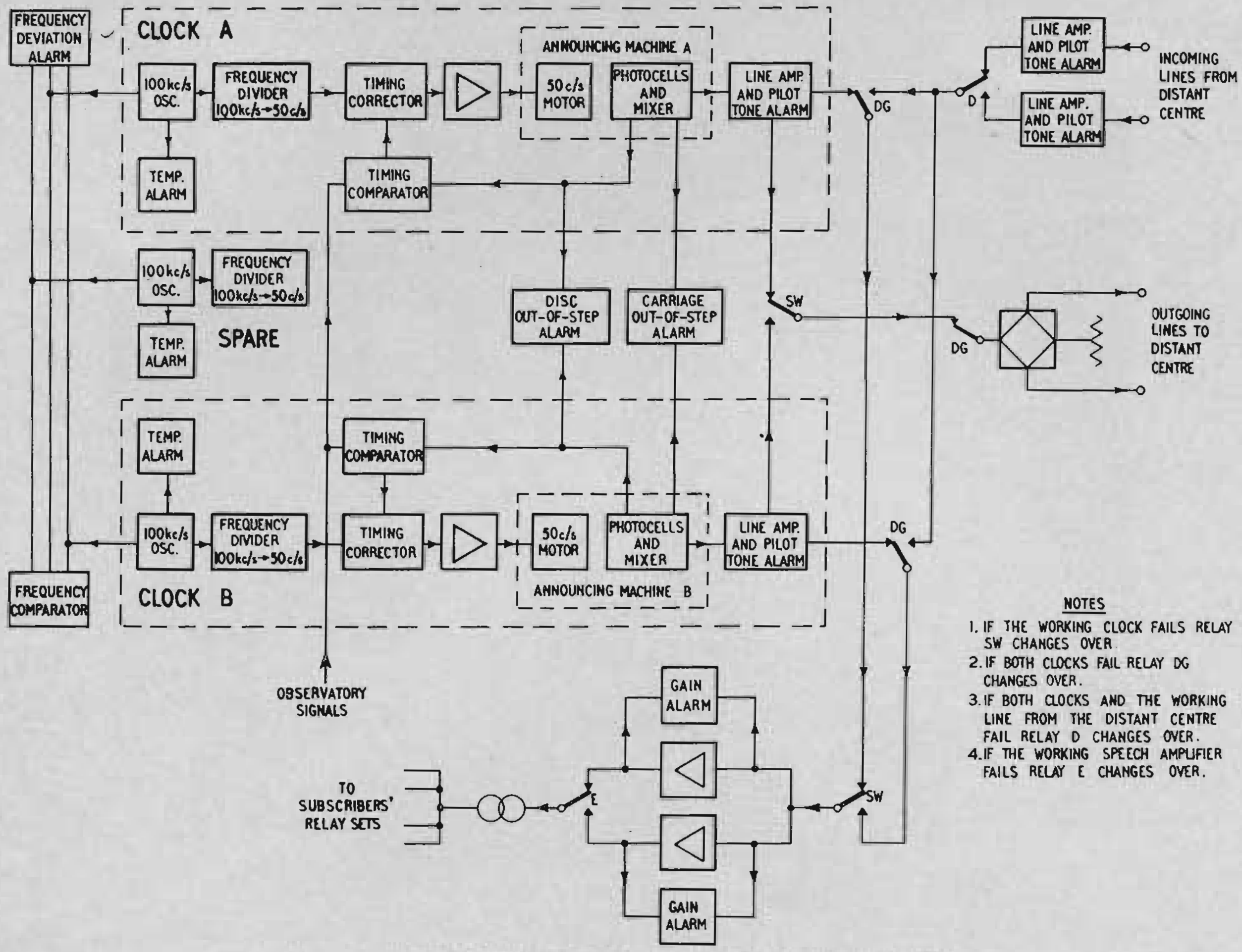


FIG. 1.—BLOCK SCHEMATIC DIAGRAM OF A CLOCK INSTALLATION.

THE ANNOUNCING MACHINE

Fig. **2*** shows the Announcing Machine, the fundamental mechanism of a clock. Its main function is to produce, at 10-second intervals, announcements of the type "At the third stroke it will be ten, twenty-four, and forty seconds," followed by three pulses of 1,000 c/s tone (called "pips") each 100 mS long and spaced at one-second intervals. The commencement of the third pulse of tone marks the time stated in the preceding announcement. Normally the 12-hour system of denoting time is used (e.g. 1 o'clock in the afternoon is called "one" and not "thirteen" hours) but the clock mechanism is so designed that it may easily be adapted for a 24-hour system, if required.

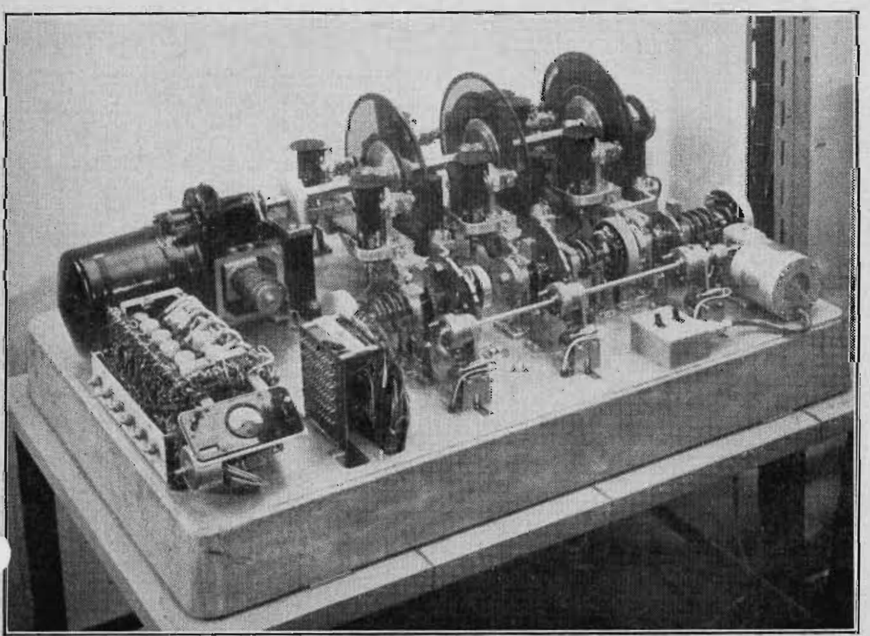


FIG. 2.—THE ANNOUNCING MACHINE.

Referring now to Fig. **3**,* the synchronous motor (4) drives at the constant speed of 30 R.P.M. a shaft upon which are mounted three glass discs (1, 2, 3). The announcements and the time signals are derived from variable-area circular sound tracks which have been recorded photographically[2] upon these discs in the following manner:—

Disc 1: The minute tracks "one" to "59" and "o'clock."

Disc 2: The words "At the third stroke . . . " (called the "Phrase") and the hours tracks "(It will be one . . . ," "It will be two . . . ," etc.).

Disc 3: A synchronising signal, the seconds tracks (" . . . and ten

[2] "A Photographic Technique of Sound Recording on Glass Discs." A. J. Forty, *P.O.E.E.J.*, Vol. 47, p. 19.

* Figs. 2 and 3 show the prototype announcing machine with all covers removed. Illustrations of the machines supplied to the Australian Post Office will appear in Part 2.

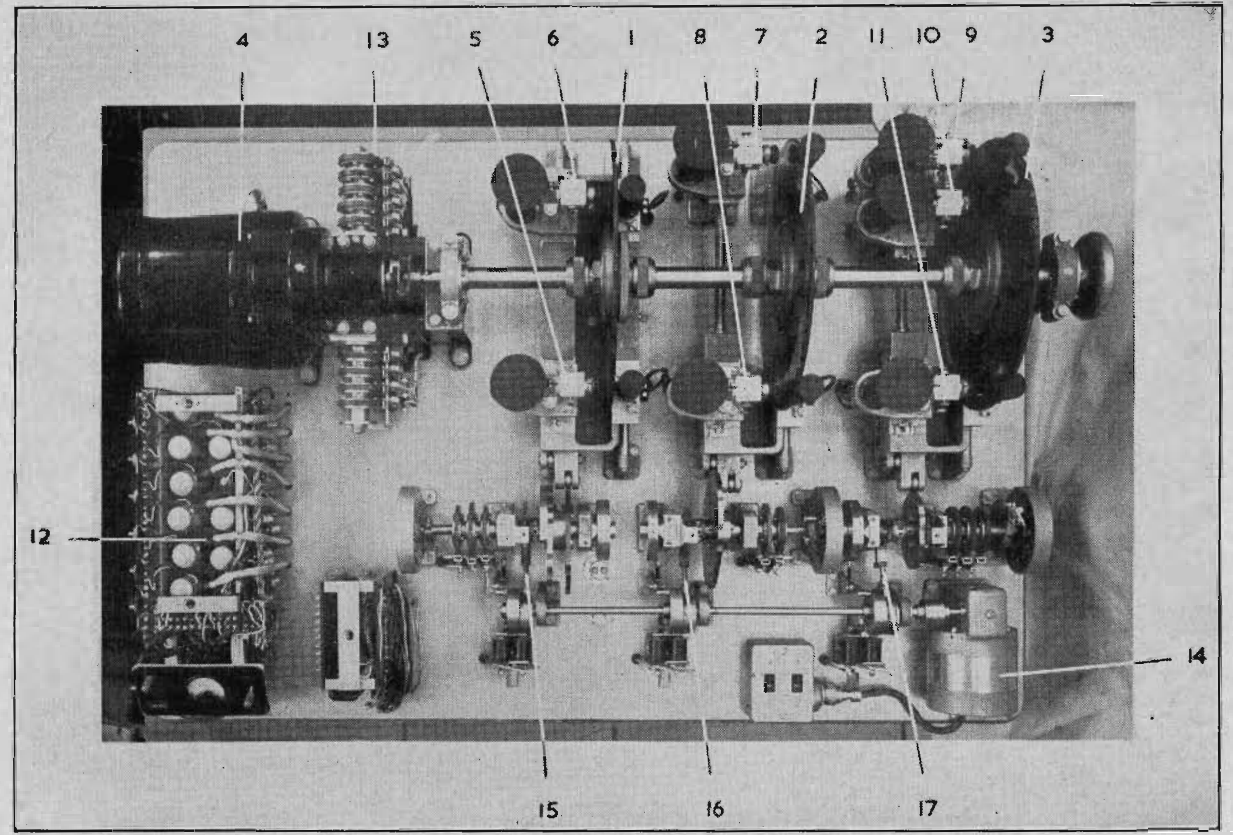


FIG. 3.—PLAN VIEW OF THE ANNOUNCING MACHINE.

seconds," " . . . and twenty seconds," etc., and "precisely"), and a series of 13 "pips" tracks.

Limitations of size restrict the number of complete tracks which can be accommodated on a disc to between 30 and 40. This number is adequate for disc 2 (13 tracks) and disc 3 (20 tracks), but not for disc 1 which requires 60 tracks. Fortunately, however, the "minutes" portion of the announcement is the shortest component (there are no additional words like "and . . . seconds" or "it will be" included) and so each minute track may be recorded on a half-sector of the disc. Disc 1, therefore, has recorded upon it two sets of 30 half-length tracks, one half of the disc bearing the "odd" and the other the "even" minute numerals.

For each set of tracks there is provided a lamp and photocell unit, which is fixed for the phrase, the synchronising signal and the pips, and is moved on a carriage for selection of the hours, minutes and seconds.

Disc 1 therefore has two moving photocell units (5, 6), disc 2 has one fixed and one moving (7, 8) and disc 3 has two fixed and one moving (9, 10, 11). The photocell outputs are connected to cathode followers (12) and thence to springsets (13) which are operated by cams on a 6 R.P.M. shaft of the main motor gearbox. This timing shaft rotates once in 10 seconds (the period of an announcement) and at the appropriate moments the successive parts of the announcement are switched in so that the complete sentence is built up. Thus the switching sequence is in the order

Phrase: Disc 2 (fixed photocell)
Hours: Disc 2 (moving photocell)
Minutes: Disc 1 (moving photocell)
Seconds: Disc 3 (moving photocell)
Pips: Disc 3 (fixed photocell).

The announcement must be changed every 10 seconds in order to state the correct time. This is achieved by moving the carriages carrying the photocells across the face of each disc in such a manner that the correct tracks are selected The motive power for this operation (which obviously must take place between announcements) is derived from an auxiliary motor (14) via a subsidiary shaft which runs past the carriages and carries clutch-operated pawls (15, 16, 17) which engage with ratchet wheels on small camshafts associated with each moving carriage.

Once every 10 seconds, the closing of contacts on the 6 R.P.M. timing shaft of the gearbox causes the clutch (17) of the "seconds" carriage to operate. Its pawl is engaged, the ratchet and cam are moved and the carriage advances one step to select the next track required for this portion of the announcement.

As the carriage moves across the disc, alternate tracks are used for successive announcements until the limit of travel is reached. The carriage then returns in steps to its original position, selecting the remaining tracks as it goes. By using this interlaced system of recording of the tracks it is possible to reproduce the announcements in sequence without the discontinuity of a "carriage return" operation.

The seconds camshaft rotates once every two minutes in 12 discrete steps. Six of the positions correspond to "odd" minute announcements and the other six to "even" minutes. Now the "odd" and "even" minutes photocells must be switched after each "and 50 seconds" announcement, but the minute carriage must be moved only once every two minutes—i.e. once per revolution of the seconds camshaft. This is achieved in the following way.

When the seconds carriage moves to the "odd minute—50 seconds" position, contacts associated with the seconds camshaft are closed and a circuit is thus prepared for the operation of the "minutes" carriage shift. When the nex impulse arrives from the timing shaft both the seconds and the minutes carriages move on together. As the seconds carriage thus moves into the "even minute—precisely" position an additional pair of contacts operate a relay which changes over the input to the announcement combining cams from the odd-minute photocell to the even-minute photocell. The six "even" minute announcements then follow. Then when the seconds carriage moves to the "odd minute—precisely" position the changeover relay releases, and the announcements are again taken from the odd-minute photocell until the "odd minute—50 seconds" position whereupon the cycle recommences. After each announcement ending in " . . . fifty-nine and fifty seconds" all three carriages move simultaneously and the hour track is also changed. The time taken for the carriage movements is not critical, provided that the operation is completed during the interval between announcements. It is thus permissible to drive the auxiliary motor (14) from the mains supply.

The final part of each announcement, the "pips," is derived from one of a series of 13 tracks recorded on disc 3. These are so disposed on the disc that the pips on successive tracks are displaced by the angular equivalent of 10 mS. By a suitable selection of the pip track, therefore, the timing of the pip signal can be adjusted in steps of 10 mS. This facility is used for compensating for the delay times of the observatory line and the distribution network: the most suitable pip track is chosen when the equipment is installed, and thereafter the pip optical system remains fixed.

Mounted on the announcing machine bedplate is a small chassis (12). This carries cathode followers and a mixer stage for combining the outputs of the various photocells.

Time Correction

The system so far described would produce announcements of time at 10-second intervals. It is necessary, however, to make these announcements conform with standard time which is determined by the national observatory. The clock oscillator frequency may not be exact or may change with ageing of the crystal. Furthermore, standard time is subject to corrections which are applied by the observatory as a result of astronomical observations. Consequently it is essential to make a periodic comparison of the time declared by the clock with time signals obtained from the observatory, and to apply a correction to the clock if it should be required. A regular check is therefore made for this purpose once per day.

To simplify the error detection and the correcting equipment, the correction is applied in a series of discrete steps. At a prearranged time, therefore, signals derived at one-second intervals from the clock (from the synchronising track on disc 3) are compared with similar signals received over a line from the observatory, and it is determined whether, at the instant of comparison of the first pair of pulses, the clock is fast or slow. If the clock is found to be fast, then it is retarded by an interval of 1 mS, or vice versa. This correction is performed automatically, and is completed before the next pair of pulses arrive for comparison.

The 1 mS corrections continue to be applied in this manner at one-second intervals until it is found that the observatory signal and the clock signal differ by less than $\pm 1{\cdot}5$ mS, when the examination ceases until the next correction check on the following day.

Referring to Fig. 1, it will be seen that the observatory line is connected to a panel called the Timing Comparator which also receives the signals from the synchronising track of the clock. Associated with this panel are three others called Timing Corrector panels. These collectively form a control circuit in the 50 c/s supply from the oscillator to the clock motor, and contain a phase-shifting device which may introduce a phase shift of either sign and of predetermined magnitude.

The sequence of operations which occurs when time correction is applied may now be described in greater detail. Shortly before the observatory transmits its time signals, a series of cam-operated contacts associated with the photocell carriages of the announcing machine prepare the time-correction apparatus for the check. When the first pulse arrives from the observatory, it passes through a circuit where its shape is modified and then into the Timing Comparator. At approximately the same time a similar signal is supplied by the clock. The two are compared, and if the clock is fast (or slow) by more than 1·5 mS the "fast" (or "slow") relay of the Timing Comparator is operated and the information is passed to the phase-shifting device of Timing Corrector No. 1. This device then retards or advances the phase of the 50 c/s supply to the clock motor by an amount which corresponds to a change of 1 mS in the clock time. Towards the end of this phase-shifting operation a reset signal is sent to the Timing Comparator to prepare it for the arrival of the next pair of pulses.

The whole of this detecting, correcting and resetting operation takes less than one second to complete. The process is repeated at one-second intervals until the clock time is within $\pm 1{\cdot}5$ mS of standard time. When this condition occurs both the "fast" and the "slow" relays of the Timing Comparator are operated, no phase shift takes place in Timing Corrector No. 1 and no reset signal is returned. The correction circuit is thus shut down until the next check is initiated. The amount of correction applied to the clock is displayed on the Timing Corrector No. 2 panel, and an alarm is given if a correction of more than 6 mS has been required.

Alarm Circuits and Standby Facilities

As described above, there may be four sources of signals available for distribution to local telephone subscribers, i.e., two local clocks and two incoming lines from a distant installation. One of the local clocks is chosen as the working source: the other and the distant clocks are used as reserves. All four sources are linked by changeover contacts which will switch in a reserve source if the working source fails. This operation is controlled by the alarm circuits of the installation, and in particular by the pilot tone alarm system, which will now be described.

During the recording of the announcing machine discs, a constant level tone of 3·2 kc/s has been superimposed on all the speech and "pip" tracks. Consequently if the machine is working correctly this tone should be present continuously in the output signals. A "line amplifier and pilot tone alarm" panel is inserted in the line from each source. On this panel a low-pass filter suppresses the tone and transmits the speech signals to the local distribution amplifiers while a band-pass filter rejects the speech frequencies and passes the tone to a detection alarm circuit. This system gives a complete safeguard against any fault which would cause the omission of part or all of an announcement (such as photocell, lamp, contact, or amplifier faults).

There remains the possibility that a clock may be making announcements which are complete but incorrect. This may happen if, through a fault condition, the motor drive frequency changes, or if a photocell carriage is not stepped forward at the correct moment.

It is unlikely that such faults would occur simultaneously on both the clocks of an installation and so a reliable detection of this type of fault may be made by comparison of the two.

The "disc out of step" alarm compares the timing of the synchronising tracks of disc 3 of the machines and so determines differences of drive frequency, while the "carriage out of step" alarm gives an indication of differences of carriage position. Other alarm circuits are provided to give warning of failure or excessive frequency drift of the oscillators.

Distribution of Announcements

The speech and time signals of the working clock are fed into the two power amplifiers, one of which supplies the public network and the other acts as a reserve. An alarm circuit, which detects change of gain, controls the change-over of the amplifiers if a fault should occur on the one connected for service. Since the amplifiers can be interchanged independently of the rest of the system, service can continue provided that any one amplifier and any one clock or distant source are functioning.

It is expected that a clock installation will be accommodated in an exchange building, but its location may be remote from the telephone apparatus room. To avoid loss of level in the junction, therefore, the designed load impedance of the power amplifier is 400 ohms, and a transformer is provided to be installed in the apparatus room to step down to a 4-ohm load resistor across which the subscribers' relay sets are connected in parallel (the low value of 4 ohms for the load being employed to avoid level changes with varying load and to prevent crosstalk).

Time-Signal Generators

Provided with each installation are two mechanisms (manufactured by Muirhead & Co., Ltd.) for producing civil and marine time signals. Each machine consists of a small synchronous motor which drives a series of cams through suitable gearing. Contacts are closed by the cams at the correct intervals to control the signals transmitted. The machines are mounted on a single table between the clock announcing machines and are driven from the controlled 50 c/s supplies which feed the clocks. Consequently each time-signal generator will continue to function in step with observatory time as long as its parent clock is in operation.

Auxiliary Power Supply

An auxiliary 200/250V, 50 c/s power supply is provided to ensure that service is maintained in the event of a mains failure. The equipment comprises two generators, driven by 50 V D.C. motors, and a switchboard. The working clock is normally run from the mains supply and the standby clock from the first generator. The second generator is normally idle. If the mains should fail the standby clock is automatically brought into service and an alarm is given. The second generator may then be started up and used to supply the first clock (which now becomes the standby and which will, of course, require to be synchronised with the second clock before it can be used). It is important that the supply to the 100 kc/s oscillators should not be interrupted since this would cause a sudden and unpredictable change in the rating of the crystals. Consequently arrangements are made to switch the oscillator supplies automatically from the mains to generator and vice versa if one of these supplies should be interrupted.

Accuracy

The ultimate accuracy of the time signals received by a telephone subscriber depends upon the following factors:—

(*a*) The precision of correction of the clock to conform with observatory time.

(*b*) The short-term stability of the synchronous motor.

(*c*) The stability of the drive oscillator.

(*d*) The time delays in the distribution network and in the observatory line.

Each clock is normally corrected once per day, and immediately after the correction interval the time announced should be within $\pm 1{\cdot}5$ mS of standard observatory time as received at the clock installation. However, the synchronous motor driving the clock mechanism is subject to random angular variations arising from compliance in both the electrical and the mechanical couplings. These variations give rise to an error which varies from instant to instant but does not exceed ± 1 mS. Furthermore, the drive oscillator frequency is likely to drift by an amount not exceeding 2 mS per day. Consequently the accuracy of the clock signals is within about $\pm 2{\cdot}5$ mS immediately after correction or $\pm 4{\cdot}5$ mS just before correction is applied.

Added to these errors is that due to the time delay in the distribution network. This may amount to several milliseconds per 100 miles, and is, of course, always tending to make the signals slow with respect to standard time. Delay in the line from the observatory to the clock has a similar effect. If the distribution network is considered as a whole, it may be desirable to minimise the average error in time signals by sending them from the clock in advance of true time. If, for instance, the delay to the furthest point of the network is 20 mS and the signals are sent 10 mS fast, then the error due to line delay at any point in the system will not exceed ± 10 mS. To make this compromise possible a series of "pip" tracks is provided on the "seconds" disc as previously described.

(*To be continued*)

Book Review

"Magnetic Materials in the Electrical Industry." P. R. Bardell, B.Sc., M.I.E.E., F.Inst.P. Macdonald. 288 pp. 157 ill. 32s. 6d.

The author, according to his preface, has set out to write a book intended to be helpful to students of physics and electrical engineering and to bridge the gap between an academic study of the properties of magnetic materials and the limited treatment of the subject possible in most textbooks for engineers. In this task he has succeeded. The bias is perhaps more to engineering than to physics and it represents a very commonsense approach.

Following two commendably brief (for this type of book) chapters on Terminology and Theoretical Considerations the book divides naturally into two parts, materials and measurement, and applications. The information is fully up-to-date and presented in a business-like way and we are reminded from time to time that the author has not forgotten his potential readers by sentences such as "A generous safety-factor must be allowed to cover the losses in the magnetising circuit. Experience shows that three is a reasonable factor" (page 54) and "To express the torque in gram-centimetres the above value must be divided by 981" (page 58).

As usual in this type of book it has been difficult to decide just what of the published data should be passed on, but what is less usual is that Mr. Bardell has made a not unsuccessful attempt to discriminate between data on the attainable properties of materials and those which may be reached in commercial practice. This is a valuable point.

One small point in table 4.3 needs correction; the reviewer believes that both Permalloy C and Mumetal (British made) contain both copper and molybdenum. This explains the resistivity (60) which is higher than that for 4-79 Permalloy (about 55) and for copper-mumetal (about 25).

Among the applications dealt with are magnetic recording magnetic amplifiers and transducers; the chapters are brief but give an adequate introduction to the subjects.

The book is well produced and well worth the price.

C. E. R.

The British Post Office Speaking Clock, Mark II*

R. L. SMITH†

Part 2.—Layout, Manufacture and Testing of Equipment, and Packing for Export

U.D.C. 621.395.91

Part 1 of this article dealt with the design and performance of the Speaking Clock, Mark II. This, the second and final part, deals with the general layout of the installation, its manufacture, testing and packing for export.

General Layout of the Equipment

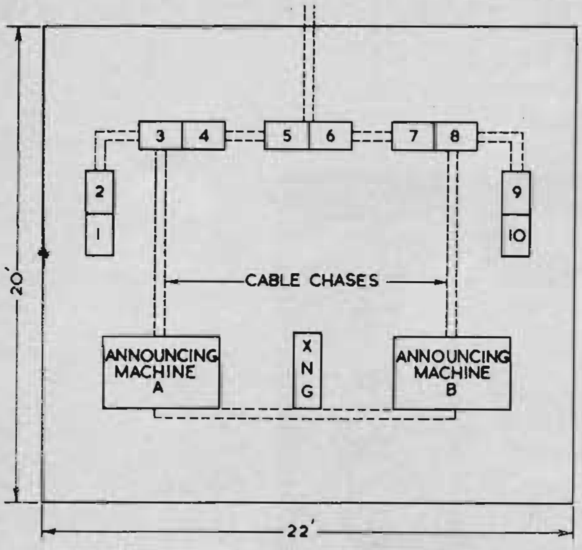
As stated previously, each installation comprises two complete clocks, together with common equipment and auxiliary power supply. Each clock consists of an Announcing Machine, which is mainly mechanical, together with drive oscillators, amplifiers and correcting apparatus which are almost entirely electronic. This electronic equipment, plus the common equipment (which is also electronic), is mounted on ten 7-ft. high racks. Because of association of function, these racks were bolted together in pairs and electrically interconnected to form five units before leaving the factory. The various items comprising the complete installation at Melbourne (with a similar installation at Sydney) are therefore:—

(*a*) Two announcing machines.
(*b*) Five pairs of 7-ft. racks carrying electronic equipment.
(*c*) Two Time-Signal Generators (mounted, with a control panel, on one table).
(*d*) Auxiliary power supply and control panel.

Fig. **4** shows how the first three of these items are arranged in the Clock Room. Item (*d*) is not shown because it is housed in a separate room. The five pairs of racks of electronic equipment are arranged in a U-formation with the Announcing Machines and Time-Signal Generators closing the open end of the "U." The racks are equipped with panels on the front only (except for some of the power supply units) and the fronts face inwards, as also do those of the Announcing Machines and Time-Signal Generators. Thus a maintenance engineer standing in the middle of this square formation can observe with ease the various meters, switches, indicator lamps, etc., on the racks, and also the operation of the mechanical equipment, without moving from his central position.

It will be seen from Fig. **4** that Oscillators A and B are mounted on Racks Nos. 1 and 10 and that these are at the ends of the "U." Normally Oscillator A drives Clock A (carried on Racks 3 and 4) while Oscillator B drives Clock B (carried on Racks 7 and 8). Oscillator C (Rack 2) is normally spare and may be used to drive either clock if Oscillators A or B should fail. The changeover is accomplished by plugs and sockets on Rack No. 9, which also carries the Monitor and Alarm equipment for all three oscillators. The two racks of Common Equipment (Nos. 5 and 6) are conveniently placed between Clocks A and B. It will also be seen that Announcing Machine A is placed opposite the electronic equipment of Clock A, while Announcing Machine B is opposite that of Clock B, the Time-Signal Generators being between the two Announcing Machines. An engineer starting up or making adjustments to either Announcing Machine is therefore able, merely by turning his head, to observe the results on the indicating instruments on the appropriate racks. He may also listen to the announcement on loudspeakers which are mounted at the top of racks Nos. 1 and 10 and which can be switched independently to monitor various points in the system. The whole makes a pleasingly symmetrical arrangement of the two clocks about the common equipment.

It will be noticed that spaces have been left between the pairs of racks and also that there is what may appear to be waste space between the racks and the machines. The reasons for this are threefold. Firstly, it adds to ease of maintenance; secondly, it minimises fire risk; and thirdly, it allows a reasonable number of people to see the installation at one time. The last reason is important since the equipment obviously has exhibition value, because these are probably the most accurate Speaking Clock Installations in the world.



RACK No.	UNIT
1	OSCILLATOR A
2	OSCILLATOR C
3, 4	CLOCK A
5, 6	COMMON EQMT.
7, 8	CLOCK B
9	COMMON OSCILLATOR EQMT.
10	OSCILLATOR B
XNG	TIME SIGNAL GENERATORS

Fig. 4.—Layout of Clock Installation.

Arrangement of the Panels on the Racks.

Certain general principles have been adopted in arranging the panels on the racks. These are:—

(*a*) No panels carrying controls or indicating instruments are mounted on the rear of the racks. In fact, only power supply panels are thus mounted, and this has been done only on racks where the front is already fully occupied.

* This article was published in the Telecommunication Journal of Australia (Vol. 10, No. 2, Oct. 1954) and is reproduced by kind permission of the Editor of that Journal.

† Formerly Line Transmission Department, Telephone Manufacturing Co., Ltd., St. Mary Cray, Kent, England, now with E.M.I. Engineering Development, Ltd., Wells, Somerset, England.

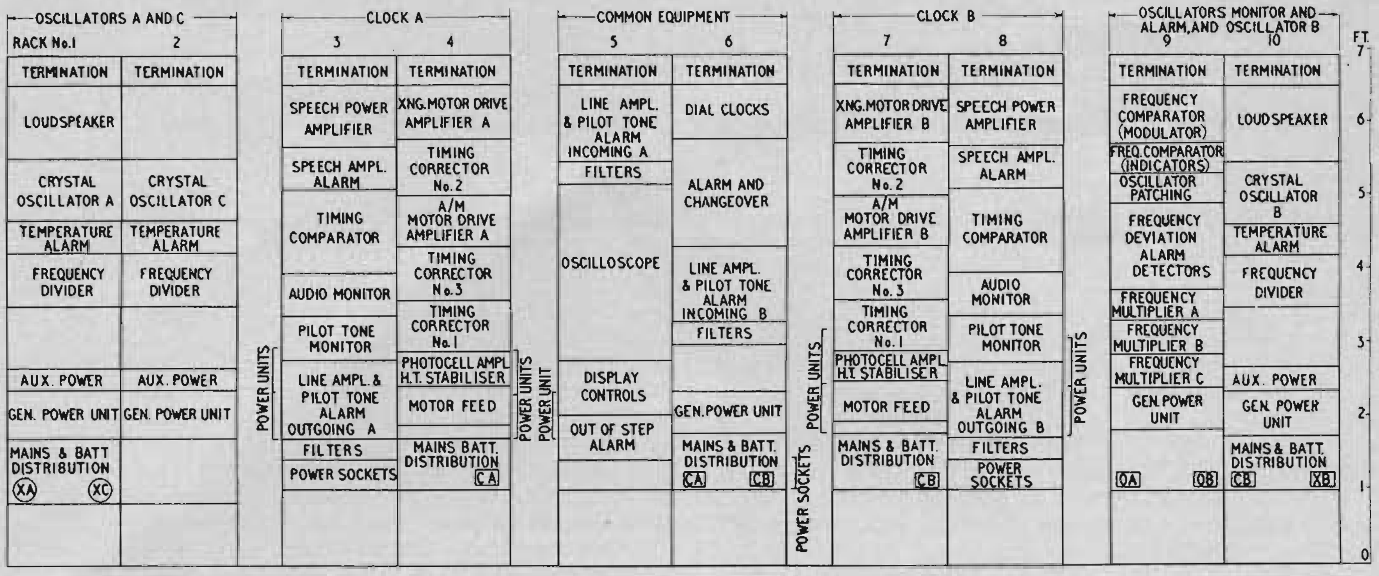


Fig. 5.—Arrangement of the Panels on the Racks.

(*b*) All power supplies (230V A.C. and 50V D.C.) enter the racks via Mains and Battery Distribution Panels which are located at the bottom of the racks, there being one such panel for each pair of racks. These panels carry switches, fuses and neon indicator lamps for the mains input to the individual power units together with rack-isolating switches. They also carry fuses for the 50V D.C. supplies to the various panels and to the announcing machines.

(*c*) All 230V A.C. wiring has been run in conduit to reduce fire risk.

(*d*) All other electrical connections to the racks are made via Termination Panels, which are located at the tops of the racks. These panels carry tag blocks for the D.C. and audio frequencies and coaxial connectors where radio frequencies are involved. One Termination Panel is provided per rack.

(*e*) As far as possible, panels carrying indicating instruments have been grouped at eye level. No panel is closer to floor level than one foot.

Fig. **5** shows the layout of the panels on all ten racks.

The Oscilloscope Panel is perhaps worthy of special mention since it is basically different from the other panels. It consists only of a metal hood, sprayed matt black inside and fitted with doors at the front. There is an aperture at the rear of the hood through which the front of a standard double-beam oscilloscope projects. For normal use the oscilloscope, which is mounted on a trolley, is connected to the clock installation by a plug and socket. By means of controls on the panel situated immediately below the Oscilloscope Panel, simultaneous displays of two waveforms at various points in the system, or the progress of a timing correction, may be followed. If the oscilloscope is required for fault tracing in other parts of the equipment, it may be easily unplugged from the rack, wheeled out of its hood and brought round to the front of the equipment for use in the normal manner.

Fig. **6** shows the two racks of Common Equipment with the Oscilloscope in position, but with the doors removed, and the covers of the other panels also removed. Fig. **7** shows the two racks of Clock B with the covers in position.

Panel Design.

The principle of ease of maintenance has also been dominant in the design of the individual panels. To this end, care has been taken that no component is obscured by another component and all soldering tags have been made easily accessible for the measurement of voltages, resistances, etc. It became obvious, when designing some of the panels, that a meter and its associated wafer switch made compliance with this principle extremely difficult without considerable waste of panel space. The difficulty was solved by hinging the switch and meter sub-panel so that it could be swung out of the way for maintenance purposes. Fig. **8** illustrates this in the case of the Timing Comparator Panel.

In general, electrical connections to panels have been made via soldering tags carried on blocks at each end of the panel, the left-hand block being

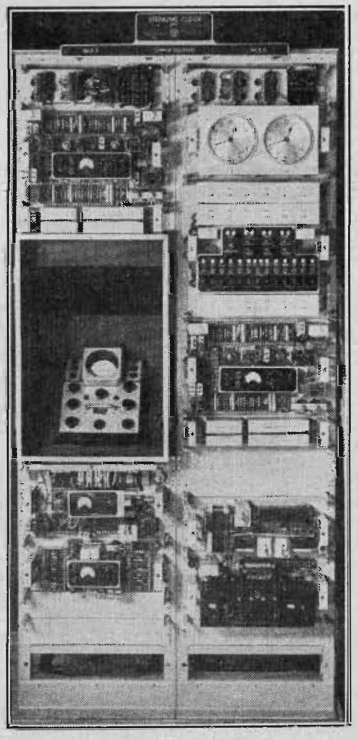


Fig. **6**.—Common-Equipment Racks, with Covers removed.

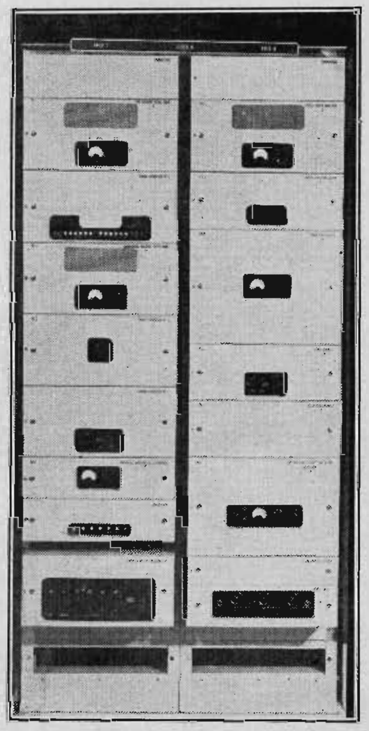


Fig. **7**.—Clock B.

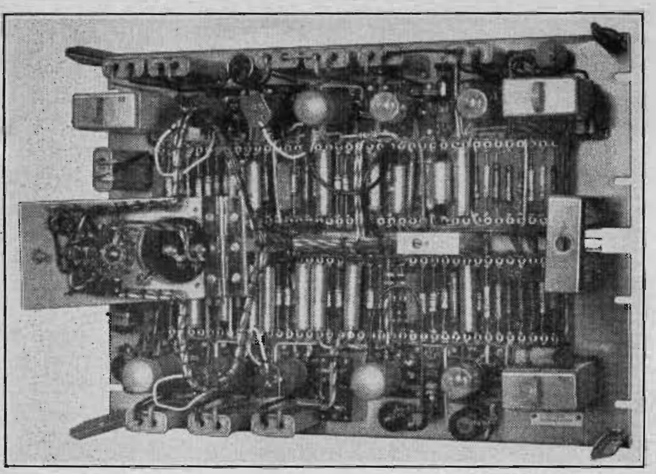


FIG. 8.—TIMING COMPARATOR PANEL, SHOWING METER SUB-PANEL.

used for signal wiring and the right-hand block for power wiring. A standard arrangement was used so that on any panel the same supplies would always be found on the same tags. Thus, H.T. always appears on tag 1 with the negative on tag 3; 6·3V A.C. for valve heaters always appears on tags 4 and 6; 50V negative on tag 11 and so on. For the wiring of the panels, 22 S.W.G. tinned copper wire covered with insulating sleeving has been used almost throughout. By using both striped and plain coloured sleeving a total of 17 different colours was available and these were used to designate the functions of the various leads. For example, input leads are green, grid leads white, anode leads yellow, H.T. red, earth black and so on. The use of this colour coding was of considerable assistance during the testing of the panels and it is believed that it will be very helpful during maintenance and fault finding.

All components were chosen to withstand the tropical conditions likely to be encountered on the sea voyage to Australia, even though, as described later, precautions to minimise the effects of these were taken in the packing.

FEATURES OF MANUFACTURE AND TESTING

When manufacture of the Melbourne installation was begun by the Telephone Manufacturing Co., the design of the whole equipment (which was the responsibility of the British Post Office) was not complete. As a consequence, it was necessary to alter or remake certain parts that had already been manufactured in order that they would work satisfactorily with parts subsequently designed. It also became obvious, as the system was built up, that additional facilities were desirable and this, of course, demanded the design and manufacture of extra parts. All this involved close co-operation between the British Post Office and the Telephone Manufacturing Co., and to this end two of the company's engineers and two of its draughtsmen spent several months at the British Post Office Research Station before and during the early stages of manufacture, while two Post Office engineers spent some months on the company's premises during the testing stage. The situation was complicated by the fact that the mechanical part of the installation was made in one Telephone Manufacturing Co. factory, while the electronic part was made in another. The auxiliary power supply was made by an entirely separate contractor and the Time-Signal Generators by yet a third contractor.

For testing purposes it was essential to bring all these items together in one place and to interconnect them electrically.

The equipment, although rather elaborate in conception, is straightforward in design and based on well-established principles. It did, however, call for a few manufacturing and testing techniques and facilities not normally available in a company manufacturing the more conventional items of telecommunications equipment, and some of these will now be mentioned.

The Drive Oscillators.

These were expected to have, and in fact did have, a stability of 1 part in 10^8 per day once the crystals had settled down. In order to check this it was necessary to have a 100 kc/s reference frequency which had a day-to-day stability of at least one part in 10^9 and whose daily drift was constant and predictable. No such stable frequency was available when manufacture was begun and the first job was to provide one. This was achieved by building an oscillator identical with the clock oscillators but using a clamped GT-cut crystal and installing this in a vibration-free room, the temperature of which was thermostatically controlled at 30°±1°C. Standby power supplies were provided for this oscillator and these came into action immediately and automatically if the mains failed. The oscillator was thus run continuously; after six months its drift rate had dropped to a few parts in 10^9 per day and after one year's running to 1 part in 10^9. It is of interest to note that after two years' continuous running the daily drift rate was 8 parts in 10^{10}. This sub-standard oscillator was checked daily against standard frequency transmissions received by radio from Rugby, and provided by the National Physical Laboratory. By this means not only could the day-to-day stability of the clock drive oscillators be checked under ordinary room conditions but their performance at extremes of temperature and supply voltage could also be assessed.

The Frequency Comparator Panels.

As stated in Part 1 of this article, three oscillators are provided, the frequencies of which are continuously compared with each other, and the total differences displayed on a scale-of-ten indicator similar to a kilowatt-hour meter. This meter is driven by a small three-phase motor operating at the beat frequency of a pair of oscillators. It was necessary to test these motors (which were a purchased item) before a pair of oscillators was available. This was accomplished by using one oscillator and a delay line giving known amounts of delay in multiples of 30°. The direct 100 kc/s signal and the delayed signal were then fed to a modulator and the output of this fed to the motor via a phase-splitting network. By changing the taps on the delay line, rotations in 30° steps could be obtained.

The Announcing Machines.

The manufacture of the units comprising the announcing machines presented a number of individual machining problems involving extreme limits of accuracy. The bedplate upon which the various units are mounted consists of a very stable aluminium alloy casting of thick section, strongly webbed on the underside and weighing nearly 2 cwt. The top surface measures 46 in. by 30 in. and has been machined so precisely that a feeler gauge 0·002 in. thick will not pass under a straight-edge placed anywhere upon it. The four cams which control the positions of the photocell/lens systems in relation to the sound tracks on the speech discs are made of Nitralloy steel and these, like the feed ratchets on the camshafts, are hardened to a degree approaching that of sapphire. The essential steps cut round the edges, upon which the follower rollers bear for operating the carriage-shift mechanisms, are highly burnished and finished within ±0·001 in. of the theoretical radius. Fig. 9 shows two of these cams together with the pawl and ratchet mechanisms and the electro-magnet for operating the clutch.

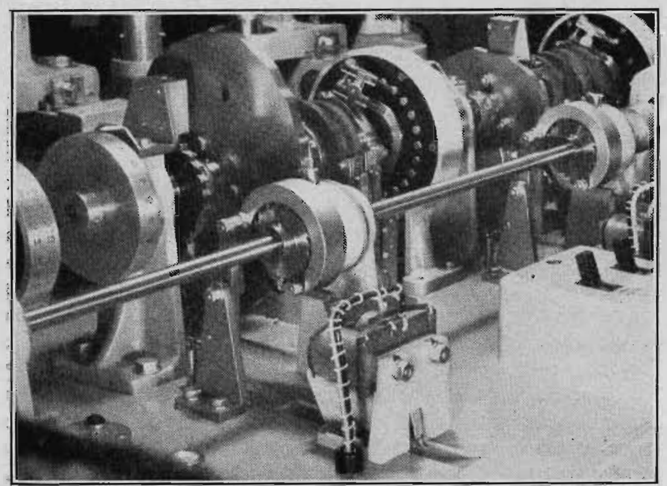


FIG. 9.—HOURS AND SECONDS CARRIAGE-SHIFT MECHANISM.

The 1-in. diameter shaft carrying the speech discs is made of nickel-chromium steel and finish-ground within ±0·0001 in. of nominal size. The motor shaft turns at a speed of 166⅔ revolutions per minute and a two-stage reduction gear produces the final output speed of 30 R.P.M. at the speech disc shaft. Precision-cut helical gears with finely-lapped teeth are employed for this purpose. The accuracy of these gears is of a high order, as shown by the following figures:—

Backlash between any intermeshing pair: 0·0008 in. to 0·0014 in.

Pitch circle concentricity: variation ±0·0003 in. to ±0·0012 in.

Pitch error: Maximum deviation on 36-tooth pinion, 0·0001 in.; on 60-tooth gear, 0·0002 in.; and on 120-tooth gear, 0·0004 in.

Two devices are incorporated to ensure the smoothest possible transmission of power from the main motor shaft to the speech disc shaft. The first of these is a torsion bar which links these two shafts and which, by virtue of its mechanical compliances, smooths out the 50 c/s component of the motor torque. The second is a fluid flywheel, which is mounted on the motor shaft. This prevents motor hunting and also effectively damps any mechanical resonance there may be in the torsion-bar/disc-shaft combination which might be excited by remanent gear irregularities. Frictional losses are minimised by the use of specially-selected ball races throughout the motor and gearbox unit, the fluid flywheel and the disc shaft pedestals. The highest degree of precision on spindle diameters and bored holes for housing the bearings was demanded. Machining limits of the order of 0·0003 in. had to be specified in these instances, calling for very careful selection and fitting in the assembly stages.

The method of checking the rotational stability of the system is interesting. One of the speech discs was replaced by a disc carrying a 1 kc/s sound track and the output obtained from this, when scanned by the optical system, was displayed on one beam of an oscilloscope. On the other beam was displayed a 1 kc/s trace obtained from the frequency divider driving the motor. Any rotational irregularities were thus shown up and could be measured easily. With careful attention to the points mentioned above these were reduced to less than ±1 millisecond.

The satin-chrome finish used on all external brass and steel components (except the shafts) presents a pleasing appearance in contrast with the grey stoved-enamel surface of the various cast parts. Both processes required careful preliminary treatment of the machined items to ensure the results achieved on the finished job.

A steel cover with four glass windows keeps dust from the equipment whilst giving an adequate view of the whole machine. Ventilation is provided by four openings in the lower part of the cover and a louvre at the top; the lower ventilating holes also providing a means of gripping the cover when removing it. The four glass panels are individually removable and are secured normally by a lock.

The base of the announcing machine also mounts an amplifier panel containing seven cathode followers (one for each photocell) and a mixer. This ensures that the signals obtained from the glass discs are fed to the main amplifiers on the racks at a reasonably high level and a low impedance. As a result of this, the announcing machines may, if required, be placed at a considerable distance from the racks. A door in the left-hand end of the main cover gives access to the controls of this panel. Fig. **10** shows a complete announcing machine with its cover in position, and the cathode follower panel may be seen at the left of the illustration.

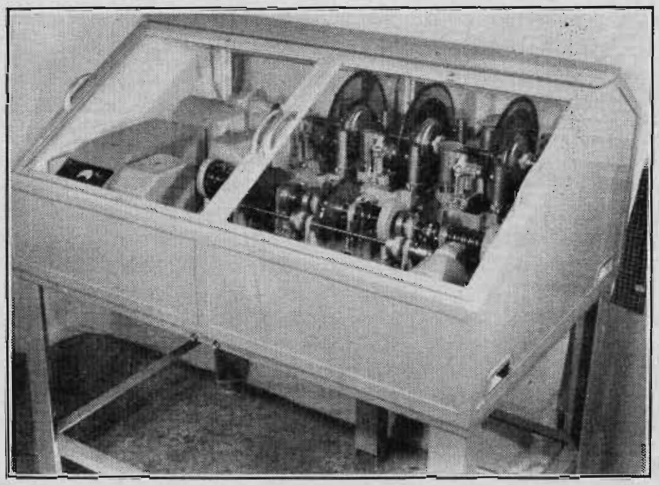


FIG. 10.—ANNOUNCING MACHINE.

Glass Disc Records.

The manufacture of these, which was undertaken by the British Post Office, will not be described here as an account of the process has already been given.[1]

Fig. **11** shows the hours and seconds discs mounted on the shaft, together with the exciter lamps and photocells.

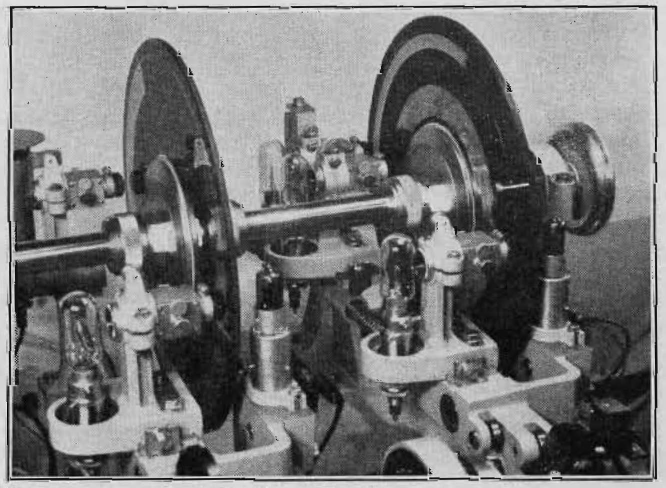


FIG. 11.—TWO OF THE GLASS DISC RECORDS.

Performance Testing.

To assess the performance of the clock, and to make sure that the correcting equipment operated satisfactorily over

[1] Forty, A. J. A Photographic Technique of Sound Recording on Glass Discs. *P.O.E.E.J.*, Vol. 47, p. 19. Apr. 1954.

a period of weeks, time signals were received over a telephone line from the Royal Observatory at Abinger, Surrey, England, and these were used for the daily correction of the clock during its trial run. Tests of the correcting mechanism when operated by signals received over a 400-mile carrier line were also made.

Packing for Export

Packing depended upon three main considerations:—

(i) The delicacy of certain parts of the equipment.
(ii) The deleterious effects of moisture.
(iii) The effects of vibration on adjusted components.

An additional reason for extra care in packing was that most of the components had been individually manufactured, and that spares would not be immediately available but were to be shipped later. It was also important to preserve the fine finish of the equipment. It was therefore decided to adopt the following principles in packing:—

(*a*) The case or crate should securely grip the article to be packed. This case would then be "floated" on a suitable resilient material, such as rubber or wood wool, within an outer container or containers, dependent upon the fragility of the item.
(*b*) A moisture barrier should be introduced between the article and the inner case.
(*c*) The outer case should be protected from weather and sea-water by a moisture-proof lining. This is important since water entering the outer case could damage the resilient packing material.

The packing of the Time-Signal Generators illustrates the above considerations and is typical of the 42 packages which made up the complete shipment.

Fig. **12** illustrates the Time-Signal Generators in their close-fitting case, which was lined throughout with the moisture-insulating material. This material was crêped kraft interleaved with bitumen, having all joints sealed with "Bostik"; crêped kraft is elastic and does not split if the case becomes distorted under stress. The machines were held firmly in position by felt-faced wood blocks. Before sealing this box, a suitable quantity of silica gel in bags was put in to absorb moisture from the air in the box.

After fixing the lid, the box was wrapped in metal foil sandwiched between two kraft sheets, one of which was coated with polythene. The sheets were then sealed by fusing the polythene with a hot iron.

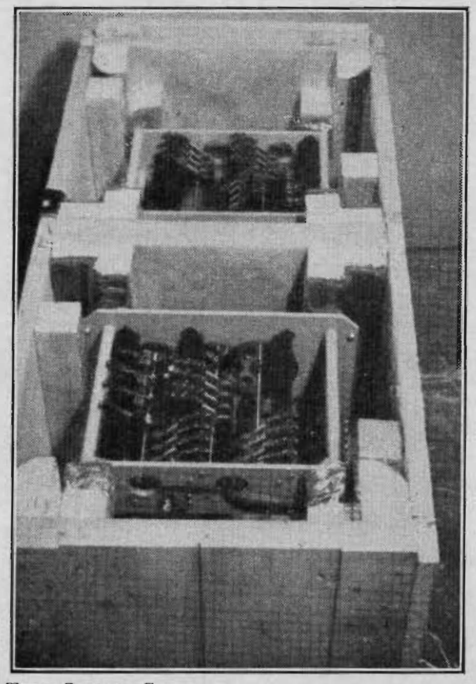


Fig. **12**.—Time-Signal Generators in their close-fitting Case.

The second case, the overall dimensions of which were 3 in. greater than those of the first, was also lined with the moisture-insulating material and sealed with "Bostik." It was then "floated" within the outer case by means of blocks composed of a mixture of rubber and fibre.

The third and final packing case was 6 in. larger than the second in all dimensions. This was lined and sealed as the others and case No. 2 "floated" inside it, this time by means of wood wool, as shown in Fig. **13**.

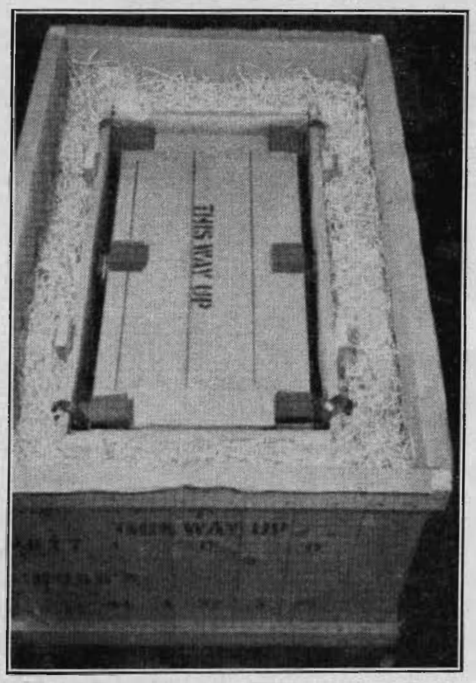


Fig. **13**.—Inner Case "floating" within Two Outer Cases.

The lids of all cases were lined with crêped-kraft moisture-insulating material with sufficient overlap for them to be sealed to the main case lining when closed.

The Quartz Crystals.

Owing to the extreme susceptibility of the quartz crystals to mechanical shock, they were flown to Australia.

The crystals were mounted in the double-walled ovens in which they are housed in the oscillators and these ovens were carried in a special container lined with thick sponge rubber, two ovens being accommodated in one carrying box. In spite of these precautions, of the 10 crystals thus sent, one was damaged in transit.

Spare Parts.

All spare parts were individually packed in such a way that they would remain in good condition over a long period. Bearings were oiled before wrapping and other items were protected by corrugated cardboard. Each part was then closely wrapped in waxed paper and placed in a transparent polythene bag. An identification label placed therein was clearly visible through the polythene. Air was extracted from the bags, which were then heat-sealed to eliminate the danger of sealing the item in a moist atmosphere. The bags were then packed in wooden cases.

This method of packing enables a store-keeper to identify each component by its appearance and by its label without opening the protective wrapping.

Conclusions

It is as yet too early to say whether the method of packing the spare parts has achieved its objects but both installations arrived in Australia in excellent condition and are now operating satisfactorily.