THE SHORTT FREE PENDULUM CLOCKS AT GREENWICH OBSERVATORY

Summary of Five Years' Experience and Degree of Accuracy Achieved

by

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AT the Royal Astronomical Society's recent meeting at Burlington House, Dr. Jackson described the performance of the Synchronome Free Pendulums, known as the "Shortt" clocks, in Greenwich Observatory, for the year 1929. Three have been installed there successively in the years 1925, 1926, and 1927. Dr. Jackson's review of their performance is becoming an annual event much looked forward to by Astronomers.

On a similar occasion in January last year, Dr. Jackson said: "It seems that we are getting to the stage in which we can compare the lengths of two successive years to one second of time." And after an analysis of the performance of the clock for the year 1929, he says: "The conclusion to be drawn from this paper is that hopes of checking the regularity of the earth's rotation from the Free Pendulum have considerably increased."

This hope is based upon a study of the clock and its performance as it is. I have to consider the possibility of its further improvement.

In the first place it cannot be too clearly understood that it has been necessary to put the whole performance of the clock under the microscope in order to discover any error at all.

Anyone with a life-time's experience of the best Astronomical clocks hitherto known would say, as Professor de Sitter, of Leiden, said when he first saw the record of the Free Pendulum at Greenwich Observatory in 1927, "its rate is absolutely invariable."

Yet it is by no means perfect. It is ordained that perfection shall be elusive, and since the joy is in the chase rather than in the achievement, we must not rebel if the golden apple is held just beyond our reach.

The rate of the clock having been ascertained by a long series of transit observations, and its performance forecasted on a chart by a straight line at a certain inclination, then a further long series of transit observations during the next few months will show that changes of rate have occurred, sometimes amounting to as much as 1/100th of a second per day.

In our search for the cause of these variations, we observe that the arc varies and until the causes of these variations are ascertained and cured, the work of the clockmaker is not done.

Circular error has usually been assumed to be negligible in such small arcs as we employ, but where we are dealing with time measurement of the order of accuracy of one part in thirty millions, it must be taken into account.

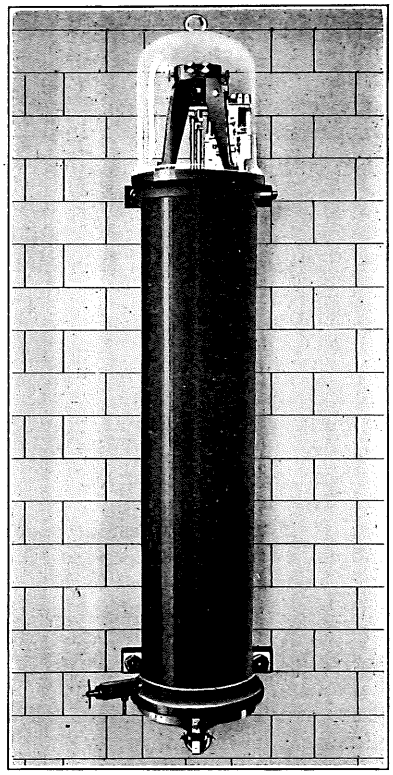
It is difficult to see why there should be any variation of arc when the pressure in the case remains the same, *i.e.*, exhausted to about 1″ of mercury, since the impulse is imparted by the fall of a lever providing a constant weight falling a constant distance and acting upon the pendulum at identically the same phase position every time, yet changes of amplitude do occur, and have amounted occasionally to ·1 mm. in the semi-arc.

In the Synchronome Free Pendulum, the beat plate is fixed face downwards on the extreme bottom end of the pendulum. It is read with a microscope, through the plate glass panel which constitutes the floor of the case. By this means it is possible to read to within two seconds of arc, or a hundredth part of a millimetre in a normal semi-arc of less than 1° or about 50 minutes or 17 mm.

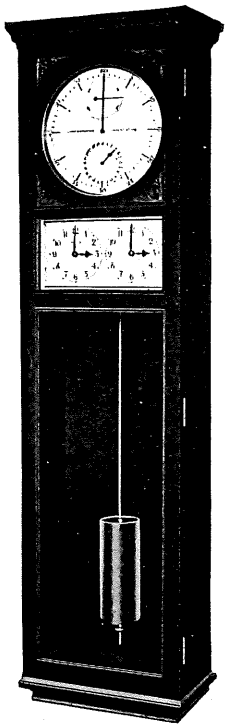
Now a variation of ·01 mm. will, by circular error, alter the rate by ^{S}·00145, or ^{S}·53 in a year, so the necessity for this close observation is obvious.

Until the causes of these minute variations in arc are ascertained and cured they must be carefully observed and recorded, and their effect in circular error allowed for. That is what Dr. Jackson and Mr. Bowyer have been doing at Greenwich, and they have recounted their observations in this article, which appears in the January issue of the Monthly Notices of the Royal Astronomical Society.

Dr. Jackson has found that by applying the appropriate correction for circular error to the past performance of the clock, its variations



FREE PENDULUM



SLAVE (Type B)

Have been installed in the following Observatories :

0	Edinburgh	1922	19	Adelaide	1928
1	Helwan	1924	20	Loomis, Tuxedo, N.Y. ..	1928
2	Tokio	1924	21	„ „	1928
3	Greenwich	1924	22	„ „	1928
4	Edinburgh	1925	23	Lick	1928
5	Melbourne	1925	24	Copenhagen	1928
6	Adml. C.A. Fountaine, C.B.	1925	25	Lourenco Marques ..	1929
7	W. H. Shortt, M.Inst., C.E.	1925	26	„ „	1929
8	Sydney	1925	27	Cape of Good Hope (2nd)	1929
9	Batavia	1926	28	Kyoto	1929
10	Cape of Good Hope ..	1926	29	Dominion, Ottawa ..	1930
11	Greenwich (2nd) ..	1926	30	Cracow	1929
12	Tokio (2nd)	1926	31	Canberra	1929
13	National Physical Lab.r..	1926	32	Washington	1929
14	Warsaw	1927	33	Manila	1929
15	St. Louis	1927	34	Dehra Dun	1930
16	Greenwich (3rd) ..	1927	35	Nikolaevskaja	1930
17	American Geogphcl., N.Y.	1927	36	Rio de Janeiro	1930
18	Mount Faber, Singapore	1928	37	„ „	1930

are smoothed out almost into a straight line. Incidentally he has measured the changes of arc and rate which result from a change in pressure. Obviously a reduction in pressure, in itself a cause of acceleration, will result in an increase of arc, which, by circular error, retards. These opposite effects are found to compensate one another exactly at a pressure of ·74″ of mercury.

This ability to isolate the circular error and to apply its theoretical calculated effect as a correction to the rate of the clock implies the elimination of practically all other sources of variation, or at any rate the identification and measurement of whatever residual causes of irregularity may remain, such as the secular growth of the rod and its temperature error.

It is only by means of this prolonged and critical study of the performance of the clock that it has been possible to analyse these residuals and allow for them, but having done so, variations of arc give direct readings for correction of rate.

This is a notable advance, not so much in the going of the clock as in the understanding of its performance.

None of these small residual causes of irregularity could be diagnosed in an ordinary clock; they would be completely masked by escapement errors. This success of the analysis at Greenwich is born of faith in the Free Pendulum and its freedom from all the ills that clocks are heirs to, and this faith is growing.

But until we can find the cause of these minute variations of arc, we cannot rest content. A song of triumph would be inappropriate; let us rather face the fact that all we have done so far is insufficient.

It is not enough that we have removed all interference with the pendulum excepting only that involved in giving impulse to it, because we have to admit that owing to human imperfections the impulse is not absolutely invariable, (although the most invariable thing we can conceive of, viz., a constant weight falling a constant distance).

It is not enough that we have reduced the period during which interference takes place to one part in 100 of the time measured by giving a concentrated impulse every half-minute instead of a prolonged one every second, although this enormously reduces the proportion of the one variable element, pivot friction.

It is not enough to divide this force (and with it this vice of its variability) by *five*, which we do by putting the pendulum in vacuum, incidentally removing every kind of barometric error.

It is not enough that we perform the self-winding, switching and time-counting operations with a certainty and precision which is unassailable and will build up unbroken records for years.

It is not enough to apply the impulse to the pendulum at such a point in its path that its variations will not affect its time-keeping, the clock being innocent of anything in the nature of escapement error, because variations of arc will occur (albeit discoverable only by a microscope) and variations of arc bring in the circular error.

Mr. Shortt showed us in 1910 how to introduce an escapement error with opposite sign to circular error by means of his inertia escapement, but we must not be content with palliative measures; it is for us to find the causes that eliminate them.

In the meantime, Dr. Jackson and Mr. Bowyer come to the rescue. They say, in effect, "all other errors having been eliminated or evaluated, we can watch the arc microscopically and apply a correction for the circular error."

That is the position to-day after five years' experience of the Free Pendulum at Greenwich, and it indicates that the clock can keep time to within a second in a year on its own dead reckoning.

It also gives ground for hope that when two or more, set going in the same group, are closely compared and their performances studied with the same care, they will throw light upon hitherto unsolved problems, such as the discrepancies between the period of rotation of the earth, and the motions of the moon and other members of the solar system.