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GERMAN QUARTZ CLOCKS

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

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GERMAN QUARTZ CLOCKS

Reported by

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B.I.O.S. Trip No. 2889.

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See Table of Contents.

British Intelligence Objectives Sub-Committee,
32, Bryanston Square,
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(A) ...

(A) Visit to Deutsche Hydrographische Institut

Interviewer: L.Essen

1. Introduction

The increasing application of quartz clocks to time-keeping adds special weight to certain of their properties. When the quartz oscillators were used mainly as frequency standards which were checked by means of time signals, constancy of frequency and reliability of operation for long intervals of time were not essential, but now that they are used by the Observatories to control the time signals themselves these factors become most important. Relative experimental data can be obtained only from observations extended over a number of years and full use must therefore be made of all the experience gained in the past.

Particular interest was attached to the Deutsche Hydrographische Institut because it was known that they had used quartz clocks as time-keepers since about 1933 and that they had found the clocks made commercially by Rohde and Schwarz to be more satisfactory than the P.T.R. clocks, some account of the present position of which has already been given by the writer[1].

The Institut, which had formerly been known as the Deutsche Seewarte, had been damaged in Hamburg and evacuated to Saxony. When this region was taken over by the U.S.S.R. they were evacuated again and housed temporarily at the Observatory, Hamburg-Bergedorf. Most of the papers had, however, been lost and the eight quartz clocks had been taken by the American authorities. These general historical details were given by the assistant director of the Observatory, the director, Prof.Heckmann, being away at the time.

2. The Quartz Clock Equipment, 1933-1945

Discussions were held with Dr.Lange and Mr.Voss who were now in charge of the time-keeping activities of D.H.I. It appeared that they had been engaged in this work only for the last few years and this may account for the vagueness of some of their replies.

The equipment had consisted of four clocks made

by ...

by themselves from details supplied by P.T.R. in about 1933 and four clocks bought from Rohde and Schwarz in 1942. The P.T.R. clocks were of the type described by Scheibe and Adelsberger. The Rohde and Schwarz clocks were of the type CFQ, a description of which is already available at the N.P.L. The essential features were, however, confirmed as far as the limited technical knowledge of Lange and Voss permitted. The quartz oscillators in the latter clocks were bars similar to those used by P.T.R., except that their frequency of oscillation was probably 100 kc/s instead of 60 kc/s. The division of frequency to a value suitable for driving a synchronous motor was effected by means of a tuning fork the frequency of which was controlled by the quartz oscillations.

None of the clocks had been mounted on especially constructed foundations because extensive work carried out by Rohde and Schwarz had shown that the frequency was not affected by shock vibrations. (This is not supported by a report by Rohde and Schwarz. It is not known which is the later view, but it is likely that the oscillators are affected to some extent by severe ground vibrations.)

The synchronous motors used to divide the frequency from 1 000 c/s or 500 c/s to 1 c/s were made by Kienzle, Schwarzwald.

3. Performance of the Clocks

Lange and Voss not having been associated with the early part of the work and all papers having been lost it was not easy to obtain details or even a very clear general picture of the performance of the clocks. It was stated that a detailed study of their performance had been made by H.Dobberstein[2] and Lange undertook to send a copy of the report of this work through the appropriate channels in Hamburg.

Lange was convinced that the Rohde and Schwarz clocks had given the better performance particularly from the point of view of reliability. One uninterrupted period of operation of over two years had been obtained and the average was perhaps four months. At one time frequent stoppages had been obtained with the P.T.R. clocks but a much better performance had been obtained after the replacement of the valves by a special long-life type R.E.134 made by Telefunken and a reduction of the operating

voltages ...

voltages. As regards the rates of the clocks they were all reliable to 0.001 second per day and some of the clocks had maintained time accurate to 0.01 second in a month.

Lange and Voss were emphatically of the opinion that quartz clocks were far better time-keepers than any pendulum so far constructed. When asked about the Schuler they said that in their view this was completely unreliable and they would prefer to use a Riefler.

The quartz clocks at Deutsche Seewarte had been used to control the Nauen time signals from 1942. Prior to that the signals had been controlled (presumably indirectly) by the clocks maintained at P.T.R.

4. Conclusions

(a) The fact that in their 1942 equipment Rohde and Schwarz used the P.T.R. bar supports the view held by P.T.R.[1] that in spite of the various experiments that had been made with other types of oscillator and other systems of mounting the bars no substantial improvements had been made. The use of the 100 kc/s bar in place of the 60 kc/s bar had not however resulted in a worse performance.

(b) Since the oscillators in the P.T.R. and Rohde and Schwarz equipments are substantially the same and are made by the same firm, much weight should not be placed, in the writer's view, on the stated greater variations in rate of the P.T.R. clocks. They could easily be explained by imperfections in the circuit conditions due to the building of the equipment by people not familiar with quartz clock technique.

(c) A point of considerable interest is the comparative freedom from stoppages of the Rohde and Schwarz equipment. This probably constitutes the only evidence so far available concerning the long time reliability of the type of dividing circuit used and the results suggest that this and the other time discrimination methods of division described recently by F.C.Williams and T. Kilburn should be considered for possible application to quartz clock equipments. In the United Kingdom the frequency division is usually effected by the multivibrator type of circuit and this has on the whole been found satisfactory, unbroken periods of operation of over a year having been obtained. The Rohde and Schwarz method using a tuning fork as an intermediate oscillator has one considerable

advantage ...

advantage however. Owing to the inertia of the system, control of the tuning fork by the quartz oscillator can be maintained in spite of transient impulses which might be induced in the circuit by, for example, a momentary breaking of the circuit; whereas with electronic division such transients would almost certainly disturb the phase relationship between the quartz oscillator and the dividing circuits. On the other hand there is some "hunting" of the tuning fork frequency and consequently some loss in the precision of the time impulses. This can be overcome by the use of special circuit arrangements by which the tuning fork impulse serves only as a "gate" for the appropriate impulses from the standard itself.

(d) It is noteworthy that all the quartz oscillators used as time standards in Germany were made by a commercial firm. In the United Kingdom, on the other hand, oscillators of the necessary precision have so far been made only in Government laboratories.

(B) Visit to Rohde and Schwarz, Munich

Interviewer: W.T.Blackband

Dr.Bannemann and Herr Leonhardt were interviewed. They confirmed that the type C.F.Q. was the only type of oscillator they had made although it had been mounted in various assemblies with different multiplier units. They maintained three clocks in continuous operation and undertook to supply a copy of their records, which included unbroken runs of several years. The interviewer was given a copy of Dr.Rohde's book which gives a full description of the clock.

(C) Summary of an interview (in England) with Dr.L.Rohde, 24th February, 1947

Interviewer: L.Essen

The opportunity was taken of Dr.Rohde's presence in England to obtain confirmation of indirect information concerning the Rohde and Schwarz quartz clocks and to question him on some details of their construction and performance.

The quartz bars were made in their own crystal

factory ...

factory and tied with silk thread (now artifical silk) in the manner of the P.T.R. bars. The final mounting and adjustment was a highly skilled job and only one in ten of the finished bars was found suitable for a standard. They all showed considerable frequency drift at first but this gradually decreased and the drift of the three clocks which had been in operation at Rohde and Schwarz for eight years was now of the order of 1 in 10^{10} per day. The frequency of 100 kc/s instead of 60 kc/s was chosen as it was more convenient for a decade frequency scale and also enabled smaller pieces of quartz to be used. There had been very close collaboration between Rohde and Schwarz and P.T.R. and he could say that there was nothing much to choose between the performances of their respective clocks.

The main reasons for using the tuning fork dividing circuit were those of compactness and cheapness. (In the interviewer's opinion these reasons are not sound but there is the advantage of extra reliability as explained in (A)4c.)

Before deciding on the present form of standard, experiments had been made with plated crystals and soldered wire supports but the performance of such bars was in all cases inferior to that of the bars tied with silk thread between metal electrodes. A point of interest was the extremely low operating current of the valve driving the crystal. This was of the order of 0.1 m.a. and the long life of the valve - there had been no failure yet although some had been in operation for eight years - was attributed to their low anode dissipation. (In this respect, however, it should be noted that Dobberstein reported failures of two driving valves in the clocks at the Deutsche Seewarte, attributing the failure to excessive filament current.)

Dr. Rohde called attention to the time signals transmitted from Munich, details of which are given in the Appendix. These signals are not derived from stellar observations but from their own clocks rated in terms of a large number of other signals, including those from Rugby, Paris, Moscow, America (WWV). He had observed over the course of a number of years that there appeared to be periodic variations (October and May) in stellar time as compared with his quartz clocks; and he undertook to supply the full details of the results supporting this theory.

(D) ...

(D) References

1. Report from N.P.L. dated 20th October, 1945.

2. H.Dobberstein, Uber die Gangleistungen zweier technische Quarzuhren. Zschr.f.Instrumentenk.61, 1941, p.188.

3. F.C.Williams and T.Kilburn, I.E.E.Convention Paper, March 1946.

(E) Documents received

1. Normalfrequenz und Frequenzmessung, book by L.Rohde.

2. The Time Signal of Rohde and Schwarz, Munich (in English).

3. Quarzuhr und Normalfrequenz - Generator, L.Rohde and R.Leonhardt. Reprint from E.N.T.1940, Bd.17, Vol.6.

4. Uber die Gangleistungen zweier technische Quarzuhren, H.Dobberstein, reprint from Zeitschr.fur Instrumentenkunde, 61, June 1941.

5. Kleinquarzuhren, H.Dobberstein, reprint from Zeitschr. fur Instrumentenkunde, 62, September 1942.

APPENDIX

Abstracts of documents received

1. Normalfrequenz und Frequenzmessung, by L.Rohde (in German), Ref.BIOS/DOCS/2889/1926/Quartz Clocks 1.

Printed in 1943 for Rohde and Schwarz from "Fortschritte d. H.F.Technik II" Akadenische Verlaggesellschaft Becker and Erler Kom.Ges.Leipzig.

This book of 80 pages describes the Rohde and Schwarz clocks in general terms and outlines the processes of rating the clocks in terms of time signals and of using them for frequency measurement in great detail. Although the general principles of measurement and particular

methods ...

methods are described in detail, the apparatus used is represented only schematically. Only one or two of the smaller items of equipment described appear to be novel. A list of headings is given below to indicate the scope of the book.

Frequency Standards

Primary standards - P.T.R. clocks, General Radio Clock - Rohde and Schwarz clocks - A.E.G. standard - Audio frequency (1 000 c/s quartz) standard.

Secondary standards - transmitting stations, e.g. Munich 740 kc/s within a few parts in 10^6 of its nominal value - frequency measuring equipment - heterodyne wavemeter 30-3 000 Mc/s accuracy stated to be 2 in 10^5.

Control of standards - time signals - clocks corrected for rate and acceleration - control by P.T.R. standard transmissions - comparison of standards by beats.

Standard Frequency Equipments

Requirements. Construction and Layout. A simple arrangement for the measurement of the time interval ($<$ 10 ms) between two signals and for the automatic correction of a clock by the time signals. Distribution of standard frequencies by line and radio. Amplifiers and multipliers. Frequency standards higher than 1 Mc/s.

Application of Frequency Standards

Control of transmitters - A scheme for obtaining frequencies up to 12 200 kc/s in steps of 1 kc/s. Synchronisation. Frequency measurement. Measurement of audio frequencies. Frequency meters. Frequency bridges.

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2. The Time Signal of Rohde and Schwarz (in English), Ref. BIOS/DOCS/2889/1926/Quartz Clocks 2.

At the works of Rohde and Schwarz three quartz clocks are maintained in continuous operation and rated in terms of a number of time signals. The mean errors and rates are determined and from these results time

signals ...

signals are transmitted in two forms.

(a) Minor Time Signal

Six dots at the 55th to 60th seconds of the 60th minute before each hour from 6.00 to 2.00

Station A.F.N.	1 249 kc/s	100 kW
some delay errors due to land line	1 204 kc/s	10 kW
	1 411 kc/s	10 kW
	6 080 kc/s	50 kW

(b) Major Time Signal

21 dots at the 30th to the 50th seconds and 6 dots at the 55th to the 60th seconds of the 60th minute before 1 200 and 2 400 E.C.T.

Absolute accuracy ± 30 milliseconds. Day to day uniformity 1 millisecond.

Station Munich	740 kc/s	100 kW

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3. Quarzuhr und Normalfrequenz - Generator (in German), Ref.BIOS/DOCS/2889/1926/Quartz Clocks 3.

A complete circuit diagram of the Rohde and Schwarz quartz clock is given. The frequency division from 100 kc/s to 1 kc/s by means of a controlled tuning fork is described in some detail. The paper also contains results showing the variation of frequency with voltages and capacitances. These are summarised in the following table.

Variable	Frequency change in parts in 10^7
Anode volts 45-80	0.4
Fil. volts 3 - 4	0.05
Anode capacitance ± 20 pF	4
Grid capacitance 60 pF	400

The acceleration of 5 oscillators during their first eight weeks of operation is given. At the end of this period the accelerations per day were

$$2 \times 10^{-8}$$
$$1 \times 10^{-8}$$
$$4 \times 10^{-9}$$
$$3 \times 10^{-9}$$
$$2 \times 10^{-9}$$

Of 40 oscillators tested, all showed an initial positive acceleration, i.e. increase of frequency. The time given by one clock is shown for a period of 26 months and of two additional clocks for a period of 7 months. When the times are corrected according to the formula

$$T = T_o - (ad + bd^2 + cd^3)$$

d being the number of days and the constants being determined for each period of 4 months, the times all lie within about $\pm$ 10 milliseconds of correct time.

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4. Uber die Gangleistungen zweier technische Quarzuhren (in German), Ref. BIOS/DOCS/2889/1926/Quartz Clocks 4.

The performances are given of two Rohde and Schwarz clocks maintained at the Deutsche Seewarte and of two P.T.R. clocks, from October 1939 to October 1940. A failure in the mains supply for one half day caused a permanent change of rate of about 20 ms per day. The rates of three of the clocks are expressed in terms of that of one of the P.T.R. clocks. The rate of the worst of the clocks appears to change by 40 ms/day during the year.

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5. Kleinquarzuhren (in German), Ref. BIOS/DOCS/2889/1926/ Quartz Clocks 5.

The quartz oscillator used is a bar 13 cm long vibrating

in ...

in a flexural mode. Its temperature coefficient of frequency is -7 in 10^6 per 1°C. Tests made with two such clocks give deviations of daily rate amounting to 0.3 sec.

Note:- The documents referred to herein, with the exception of BIOS/DOCS/2889/1926/Quartz Clocks/1, have been lodged with:- Board of Trade, German Division (Documents Unit), Lansdowne House, Berkeley Square, London, W.1. Tel: Grosvenor 4060. Ext. 2923.
BIOS/DOCS/2889/1926/Quartz Clocks/1 is in the possession of Dr. Essen at:- The National Physical Laboratory, Teddington, Tel: Molesey 1380.

All applications for permission to inspect these documents should quote the relevant BIOS. reference number.