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THERMAL CHARACTERISTICS OF PIEZOELECTRIC OSCILLATING QUARTZ PLATES.

By

Issac KOGA.

Tokyo University of Engineering.

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THERMAL CHARACTERISTICS OF PIEZOELECTRIC OSCILLATING QUARTZ PLATES.

By Issac KOGA.

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(Received June 15, 1934.)

Abstract.—Piezoelectric oscillating quartz plates having very small temperature coefficients are devised and applied to the short-wave radio transmitter under commercial service with very good results. The temperature coefficients of the frequency of quartz plates, such as X-cut and Y-cut plate, are generally somewhat higher than those which are ever reported. It is because the plates used in our experiments are sufficiently thin, so that the values of the temperature coefficients become their asymptotic values. By the way, the procedures of the preparation of test pieces and the measurement of the temperature coefficient of frequency are explained.

1. Introduction.

We have no doubt as to an established fact that a valve-maintained quartz oscillator is the most satisfactory apparatus of producing the high-frequency alternating current of extremely stable frequency. And yet, the existing state of things sometimes requires a quartz oscillator capable of producing a more stable frequency. For this purpose it has become a recent practice to place the quartz plate in a thermostat with a view to eliminating even the minor effect of temperature upon the oscillating frequency of quartz. On the other hand, the use of a thermostat is accompanied by a number of inconveniences; therefore we hope to dispense with it, if there is some good idea to get rid of the thermal effect upon the frequency. From this point of view a few ideas or designs were published[(1)-(4)] to get the quartz plates having such characteristics as that the thermal effect upon the frequencies is practically negligible, but they are not yet extensively used because of the difficulty involved in manufacturing or the inconvenience of manipulation. The chief object of this paper is to introduce some new quartz plates of practical value suitable for use in both short and long wave transmissions without the necessity of placing them in thermostats, and to report the actual results obtained with the plates used in some of the high-power transmitters being actually put under commercial service as well as in other uses.

2. Quartz Plates of Zero Temperature Coefficient for Short-Wave Oscillators.

In short-wave oscillators, a thin crystal plate is generally employed to make use of a period of vibrations proportional to the thickness of the plate. We showed[(5)(6)] that such a kind of vibrations, commonly called "Thickness Vibra-

Table I.

θ	Thickness	Frequency	Temperature Coefficient
Degree	mm	kc	$\times 10^{-5}/°C$
27	0.71	2 715	−10.0
32	0.47	3 978	− 9.0
45	0.63	2 709	− 4.8
52	0.62	2 690	− 1.8
64	0.56	2 981	+ 4.8
73	0.57	2 980	7.6
80	0.65	2 691	9.8
90	0.73	2 688	10.3
100	0.71	2 981	8.7
110	0.84	2 689	6.3
123	0.90	2 700	3.2
128	0.92	2 689	2.0
133	0.93	2 696	+ 0.9
138	0.94	2 690	− 0.2
148	0.95	2 690	− 2.4
153	0.95	2 690	− 3.4
158	0.94	2 690	− 4.5
163	0.93	2 693	− 5.5

Dimensions of principal surfaces : 22mm × 27mm, the shorter sides being parallel to the electrical axis.

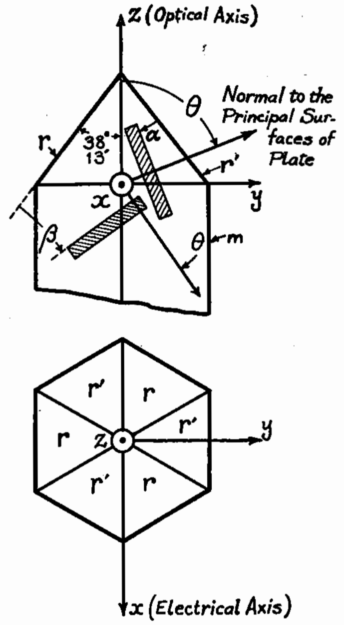

Fig. 1.

tions," is due to the standing wave produced by interference of plane waves incident to and reflected from the principal plane boundary surfaces of the plate, and especially in the case of a quartz plate, if the principal planes are parallel to the electrical axis x (See Fig. 1), the vibrations are always in the pure shear mode and the fundamental frequency is given by the following expressions:

$$f=\frac{1}{2a}\sqrt{\frac{c}{\rho}}, \qquad c=c_{66}\sin^2\theta+c_{44}\cos^2\theta+c_{14}\sin 2\theta, \qquad (1)$$

where a—thickness of the plate,

ρ—density of quartz (2.654 g/cm³),

θ—colatitude of the normal to the principal surfaces,

c_{66}, c_{44}, c_{14}—adiabatic elastic constants of quartz; the numerical values(7) are given below:

$$c_{66}=\frac{1}{2}(c_{11}-c_{12})$$

$$c_{11}=85.45\times10^{10}\ \text{dynes/cm}^2, \qquad c_{44}=57.09\times10^{10}\ \text{dynes/cm}^2,$$

$$c_{12}=7.26\times10^{10}\ \text{dynes/cm}^2, \qquad c_{14}=-16.87\times10^{10}\ \text{dynes/cm}^2.$$

We can see at a glance these expressions show that the influence of temperature upon the vibration frequency is dependent upon the value θ. Moreover, Table I confirms this fact from experimental results.(8) It was especially noticeable from this table that at angles $\theta\simeq55°$ and $\theta\simeq138°$, the temperature coefficients became zero, so that we repeated the experiments several times with great care in the vicinities of these special regions, and obtained the following results: At the angle $\theta \simeq 55°$ the frequencies of vibrations of a sufficiently thin plate increase or decrease always linearly with temperature, and the temperature coefficients of frequencies are as shown in Table II and Fig. 2,[(8)] while at the angle $\theta \simeq 138°$ the frequencies increase at first and then decrease as shown in Fig. 3.[(9)] Numerals given in the figure correspond to those in Table III.

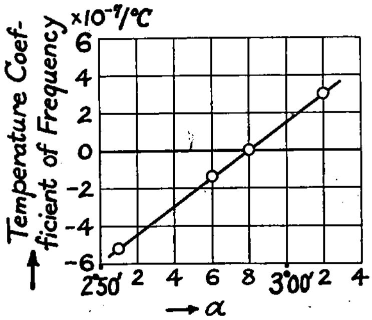

Fig. 2.

Test pieces are all rectangular plates and their principal surfaces are made parallel to the electrical axis within a half minute by means of an X-ray spectrometer.

Table II.

α	θ	Dimensions	Frequency	Temperature Coefficient
		mm³	kc	$\times 10^{-7}$/°C
2° 51′	54° 38′	0.615×23.1×28.3	2 688.9	−5.2
56′	43′	0.618×23.2×28.5	2 689.8	−1.4
58′	45′	0.615×23.2×28.5	2 689.3	0.0
3° 02′	49′	0.618×21.2×24.1	2 691.7	+3.0

Shorter sides of the principal surfaces are parallel to the electrical axis.

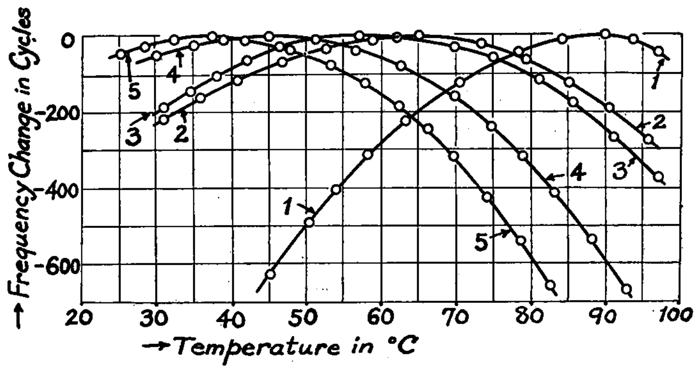

Fig. 3.

Table III.

	θ	β	Dimensions (mm³)	Frequency (kc)
1	136° 06′	7° 53′	0.504×25.9×29.9	5 014.6
2	137° 10′	8° 57′	0.541×25.8×29.6	4 661.9
3	137° 44′	9° 31′	0.542×22.2×28.3	4 654.6
4	138° 13′	10° 0′	0.540×25.0×29.7	4 678.3
5	138° 47′	10° 34′	0.542×25.0×29.2	4 653.6

Shorter sides of the principal surfaces are parallel to the electrical axis.

3. Temperature Coefficients of the Adiabatic Elastic Constants of Quartz.

From those data given above we further determined the temperature coefficients of adiabatic elastic constants.(10) Differentiating the expression (1) with temperature T, we have an expression

$$2\frac{1}{f}\frac{\partial f}{\partial T}=\frac{1}{c}\frac{\partial c}{\partial T}-\frac{1}{\rho}\frac{\partial \rho}{\partial T}-2\frac{1}{a}\frac{\partial a}{\partial T}, \tag{2}$$

where

$$-\frac{1}{\rho}\frac{\partial \rho}{\partial T}=\frac{1}{x}\frac{\partial x}{\partial T}+\frac{1}{y}\frac{\partial y}{\partial T}+\frac{1}{z}\frac{\partial z}{\partial T}, \tag{3}$$

$$\frac{1}{a}\frac{\partial a}{\partial T}=l^2\frac{1}{x}\frac{\partial x}{\partial T}+m^2\frac{1}{y}\frac{\partial y}{\partial T}+n^2\frac{1}{z}\frac{\partial z}{\partial T}, \tag{4}$$

$$\left.\begin{aligned}&\frac{1}{x}\frac{\partial x}{\partial T}=\frac{1}{y}\frac{\partial y}{\partial T}=13.7\times 10^{-6}/{}^\circ\mathrm{C},\\&\frac{1}{z}\frac{\partial z}{\partial T}=7.5\times 10^{-6}/{}^\circ\mathrm{C}.\end{aligned}\right\}^{(11)} \tag{5}$$

Therefore

$$2\frac{1}{f}\frac{\partial f}{\partial T}=\frac{1}{c}\frac{\partial c}{\partial T}+(7.5+12.4\times\cos^2\theta)\times 10^{-6}, \tag{6}$$

where

$$\frac{\partial c}{\partial T}=\sin^2\theta\frac{\partial c_{66}}{\partial T}+\cos^2\theta\frac{\partial c_{44}}{\partial T}+\sin 2\theta\frac{\partial c_{14}}{\partial T}. \tag{7}$$

But, from Table I, Table II and Fig. 3, we get

$$2\times 103\times 10^{-6}=\left(\frac{1}{c}\frac{\partial c}{\partial T}\right)_{\theta=90^\circ}+7.5\times 10^{-6}, \tag{8}$$

$$0=\left(\frac{1}{c}\frac{\partial c}{\partial T}\right)_{\theta=54^\circ 45'}+(7.5+12.4\times\cos^2 54^\circ 45')\times 10^{-6}, \tag{9}$$

$$0=\left(\frac{1}{c}\frac{\partial c}{\partial T}\right)_{\theta=138^\circ}+(7.5+12.4\times\cos^2 138^\circ)\times 10^{-6}. \tag{10}$$

Further from (8) and (1),

and

$$\left.\begin{aligned}&\left(\frac{1}{c}\frac{\partial c}{\partial T}\right)_{\theta=90^\circ}=\frac{1}{c_{66}}\frac{\partial c_{66}}{\partial T}=+199\times 10^{-6},\\&\frac{\partial c_{66}}{\partial T}=+77.8\times 10^{6}.\end{aligned}\right\} \tag{11}$$

From (7), (9), (10), (11) and (1),

$$\frac{\partial c_{44}}{\partial T}=-113.5\times 10^{6},\qquad \frac{1}{c_{44}}\frac{\partial c_{44}}{\partial T}=-199\times 10^{-6}, \tag{12}$$

$$\frac{\partial c_{14}}{\partial T}=-18.5\times 10^{6},\qquad \frac{1}{c_{14}}\frac{\partial c_{14}}{\partial T}=+110\times 10^{-6}. \tag{13}$$

Once the temperature coefficients of the adiabatic elastic constants are obtained, we may be able to obtain the temperature coefficient of frequency for any value of θ. The curves in Fig. 4 are drawn from the calculated values, while the measured values given in Table I are plotted with small circles in the same figure showing how good they are in coincidence.

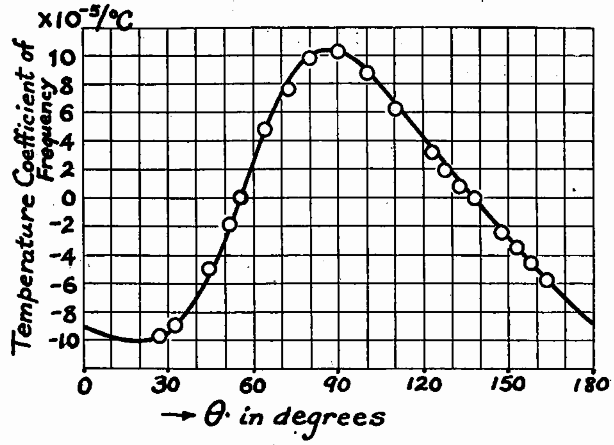

Fig. 4.

We can further determine the second differential coefficients of the adiabatic elastic constants.(9) Differentiating once more the expression (2), we get at angles $\theta \simeq 55°$ and $\theta \simeq 138°$

$$2\frac{1}{f}\frac{\partial^2 f}{\partial T^2}=\frac{1}{c}\frac{\partial^2 c}{\partial T^2} \tag{14}$$

remembering that the first differential coefficient of frequency with respect to temperature is nearly zero at angles $\theta \simeq 55°$ and $\theta \simeq 138°$. On the other hand, as has already been referred to, the frequency varies always linearly with temperature at or near an angle $\theta=55°$, the second differential coefficient of the frequency with respect to temperature is zero and is independent of θ at an angle $\theta \simeq 55°$, while the second differential coefficient of the frequency with respect to temperature at or near an angle $\theta=138°$ is $-0.6\times10^{-6}/°C^2$ and is independent of θ at an angle $\theta \simeq 138°$ from Fig. 3, that is

$$\text{when} \quad \theta \simeq 55°, \quad 2\frac{1}{f}\frac{\partial^2 f}{\partial T^2}=\frac{1}{c}\frac{\partial^2 c}{\partial T^2}=0 \quad \text{and} \quad \frac{\partial}{\partial\theta}\frac{\partial^2 c}{\partial T^2}=0 \tag{15}$$

$$\text{and when} \quad \theta \simeq 138°, \quad 2\frac{1}{f}\frac{\partial^2 f}{\partial T^2}=\frac{1}{c}\frac{\partial^2 c}{\partial T^2}=-1.2\times10^{-6} \text{ and } \frac{\partial}{\partial\theta}\frac{\partial^2 c}{\partial T^2}=0 \tag{16}$$

or introducing the numerical values of the adiabatic elastic constants and θ,

$$\frac{\partial^2 c_{66}}{\partial T^2}\sin^2\theta_2+\frac{\partial^2 c_{44}}{\partial T^2}\cos^2\theta_2+\frac{\partial^2 c_{14}}{\partial T^2}\sin 2\theta_2=-79\times10^4, \tag{17}$$

$$\frac{\partial^2 c_{66}}{\partial T^2}\sin^2\theta_1+\frac{\partial^2 c_{44}}{\partial T^2}\cos^2\theta_1+\frac{\partial^2 c_{14}}{\partial T^2}\sin 2\theta_1=0, \tag{18}$$

$$\left(\frac{\partial^2 c_{66}}{\partial T^2}-\frac{\partial^2 c_{44}}{\partial T^2}\right)\sin 2\theta_1+2\frac{\partial^2 c_{14}}{\partial T^2}\cos 2\theta_1=0. \tag{19}$$

$$(\theta_1=54°45', \quad \theta_2=138°).$$

Solving these equations,

$$\frac{\partial^2 c_{66}}{\partial T^2}=-2.4\times10^4, \qquad \frac{1}{c_{66}}\frac{\partial^2 c_{66}}{\partial T^2}=-6.1\times10^{-8}, \tag{20}$$

$$\frac{\partial^2 c_{44}}{\partial T^2}=-7.8\times10^5, \qquad \frac{1}{c_{44}}\frac{\partial^2 c_{44}}{\partial T^2}=-1.3\times10^{-6}, \tag{21}$$

$$\frac{\partial^2 c_{14}}{\partial T^2}=+1.3\times10^5, \qquad \frac{1}{c_{14}}\frac{\partial^2 c_{14}}{\partial T^2}=-7.7\times10^{-7} \tag{22}$$

By the way the measurement of the temperature coefficient of frequency of a sufficiently thin X-cut plate gives us $-26.8\times10^{-6}/°C$. As the frequency of the X-cut plate is given[(5)(6)] by

$$f=\frac{1}{2a}\sqrt{\frac{c_{11}}{\rho}}, \tag{23}$$

the temperature coefficient of the adiabatic elastic constant c_{11} is determined in the same manner as has been explained above. The calculated values[(12)] are as follows:

$$\frac{1}{c_{11}}\frac{\partial c_{11}}{\partial T}=-61.1\times10^{-6}, \qquad \frac{\partial c_{11}}{\partial T}=-52.2\times10^{6}. \tag{24}$$

Combining (11) and (15),

$$\frac{1}{c_{12}}\frac{\partial c_{12}}{\partial T}=-286\times10^{-5}, \qquad \frac{\partial c_{12}}{\partial T}=-207.8\times10^{6}. \tag{25}$$

4. Thickness Versus Frequency and Its Temperature Coefficient of the Vibrations of Quartz Plates.[(12)]

Several results obtained in the last two chapters are true only when the thickness of plate is sufficiently thin compared with the dimensions of principal surfaces. Many authors[(13)(14)] have reported the values of the temperature coefficients of frequencies that are always somewhat less than that we have given, this suggesting us that their test pieces were not sufficiently thin. We believe, therefore, it is very important to see the relation between the thickness and the frequency with its temperature coefficient of the vibrations of quartz plates for certain

Table IV.

	Thickness	Frequency	Frequency × Thickness	Temperature Coefficient
	mm	kc		$\times10^{-5}/°C$
X—cut	6.28	455.3	2 860	−1.74
	3.65	782.9	2 858	−2.31
	2.40	1 192.9	2 857	−2.54
	1.37	2 087.2	2 855	−2.63
	0.95	2 999.7	2 850	−2.68
	0.72	3 940.9	2 845	−2.68
	0.51	5 554.2	2 844	−2.68
Y—cut	4.41	471.4	2 081	−1.42
	2.53	786.6	1 992	+1.99
	1.92	1 024.0	1 963	+4.06
	0.95	2 052.2	1 943	+9.42
	0.63	3 069.1	1 940	+10.3
R—cut	3.75	671.8	2 521	−0.69
	1.90	1 305.3	2 477	+1.19
	1.24	1 991.4	2 471	+1.89
	0.70	3 521.2	2 458	+2.56
	0.55	4 510.0	2 458	+2.56

dimensions of the principal planes. The principal results of our experiments with the rectangular plate measuring 25 mm × 30 mm in principal surfaces are given in Table IV and Fig. 5. The principal surfaces of the X-cut plate are made perpendicular to the electrical axis always within an accuracy of half a minute, and those of other plates are made parallel to the electrical axis within the same accuracy. It is a very interesting matter to note that a plate cut parallel to the electrical axis and having a positive temperature coefficient of frequency decreases its temperature coefficient with increase in the thickness, and turns over to the negative temperature coefficient passing through zero. Precise measurements with such a plate show that with the increase of temperature the frequency increases at first and then decreases gradually as shown in the example of Fig. 3, so that the temperature coefficients given in Table IV and Fig. 5 must be the values at a certain temperature in a rigorous sense, but as the curvature of the frequency-temperature curves are very small, we may take these results to hold generally in a region of the ordinary room temperature. Marrison[3] once reported on his special ring-shape plate that the smaller the net area of the principal surfaces to face the electrodes compared with the thickness, the smaller the temperature coefficient. Now we see this is not the special property for the ring-shape plate, but this is common for all the plates having a sufficient thickness compared with the dimensions of principal surfaces.

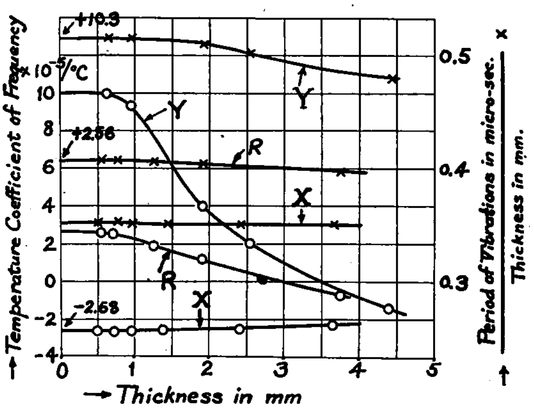

Fig. 5.

Suppose our desire is such as to get only the low temperature coefficient of frequency, it will be sufficient to use the Y-cut plate or its equivalent, but this kind of plate is not easy to be manufactured as the special dimensional ratios must be kept throughout even in the case of the adjustment of the thickness to meet requirements in obtaining the assigned frequency, and the plate must be of sufficient thickness to realize the low temperature coefficient, so that it is not suitable to employ it in the crystal oscillator circuit of short-wave radio transmitters.

5. Quartz Plates of Zero Temperature Coefficient for Long-Wave Oscillators.[15]

Quartz plates used hitherto in low-frequency oscillators are limited to the X-cut plates. This is explained as follows:—the strains along the principal surfaces can be produced by the electric field normal to the surfaces or parallel to the electrical axis; but the fact that the similar strains are also able to be

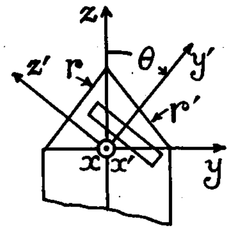

Fig. 6.

produced in the plate cut parallel to the electrical axis, and therefore vibrations of relatively low natural frequency may be realized, did not arouse much interest. In fact, if we choose the new coordinate axes x', y', z' in the crystal as shown in Fig. 6, x' being coincident with x, the strains referred to the new axes due to the electric field along the axis y' are as follows:

$$\left.\begin{aligned} e_{z'x'} &= -\sin\theta\,(d_{14}\sin\theta - 2d_{11}\cos\theta)\,E_{y'}, \\ e_{x'y'} &= -\sin\theta\,(d_{14}\cos\theta + 2d_{11}\sin\theta)\,E_{y'}. \end{aligned}\right\} \qquad (26)$$

Therefore in the plate cut perpendicular to y' axis, provided that the angle θ is not too near 0° or 90°, the strain $e_{z'x'}$ along the principal surfaces is not small. By way of experiment such a plate was employed in the Pierce's oscillator and it was observed to start oscillations very easily. Next we observed the relations between θ and the vibration frequency with its temperature coefficient of a rectangular plate of 14.5 mm × 29.0 mm in the principal surfaces, short side being always parallel to the electrical axis, and of 2 mm in thickness. Fig. 7 shows the result. Figs. 8 and 9

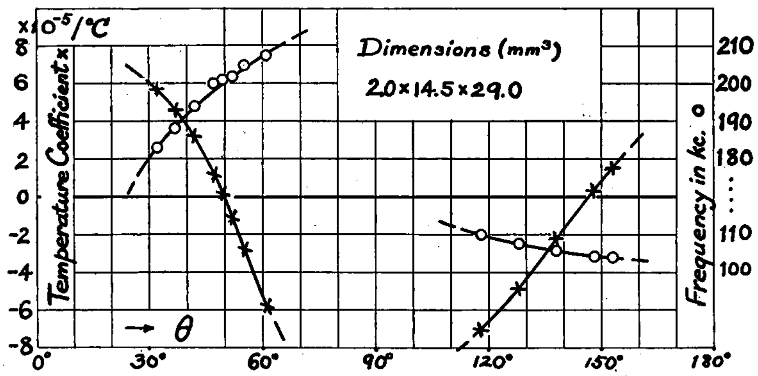

Fig. 7.

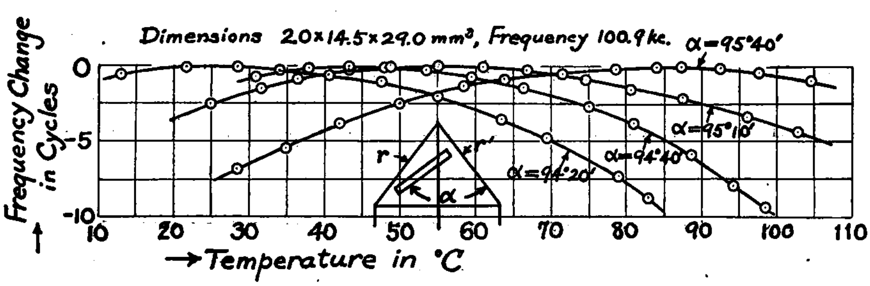

Fig. 8.

are the details for $\theta \simeq 50°$ and $\theta \simeq 147°$, showing again that frequency does not vary linearly with temperature. If the proportion of these dimensions or the orientation of long sides referred to the electrical axis is different, the curvature of these

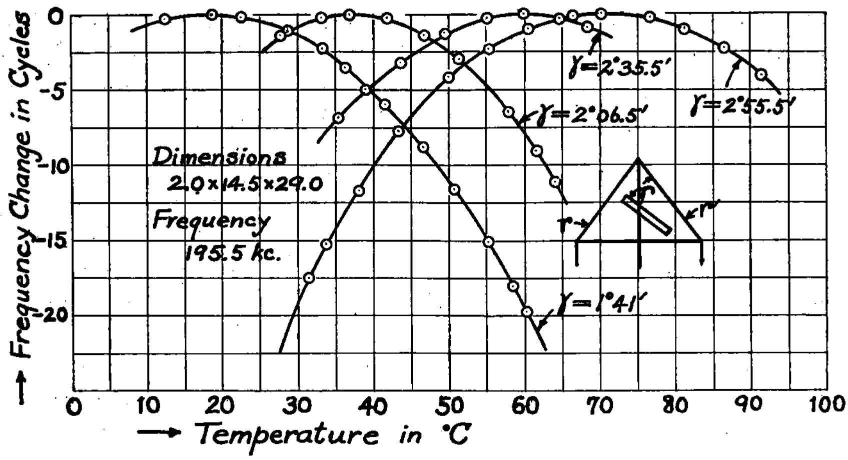

Fig. 9.

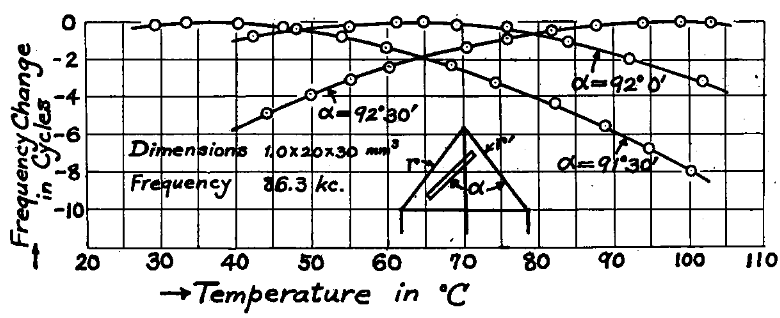

Fig. 10.

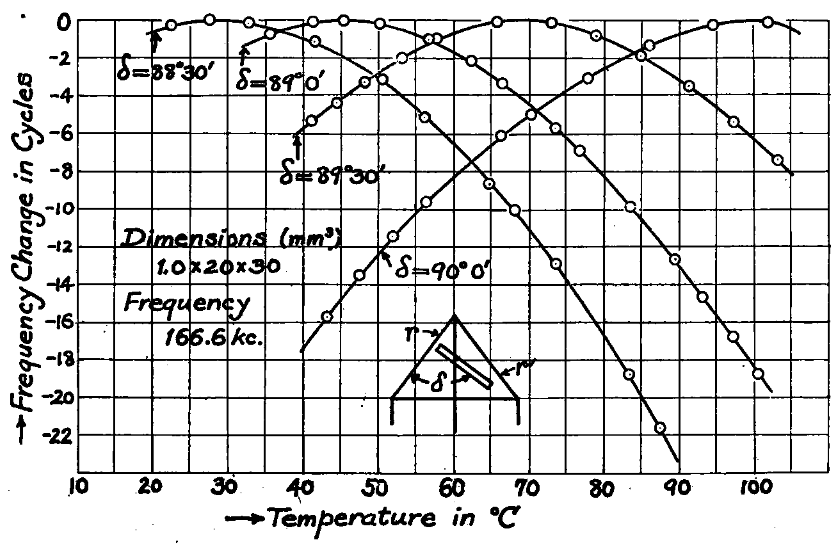

Fig. 11.

curves varies though in the same rectangular plate. Figs. 10 and 11 are the results for plates of 20 mm × 30 mm in principal planes and 1 mm in thickness, other things being the same with the case of Figs. 8 and 9. It goes without saying that such plates are very suitable to crystal clocks and others.

6. Determination of the Orientation of Principal Surfaces of the Oscillating Plates.

At this occasion it seems to be suitable for adding a few articles concerning some special problems relating directly or indirectly to the above results. The first is the determination of the orientations of the principal surfaces. Test pieces are always prepared in the following manners so as to be sure of obtaining at will the accuracy of experiments and feasibility of reproduction of the plates of certain characteristics. Mineral quartz is first cut with two parallel planes (say x-planes for the sake of brevity) sufficiently apart each other and perpendicular to the electrical axis, both planes being finished with great care to be precise planes and checked with an X-ray spectrometer within an accuracy of half a minute, and then prepare the principal surfaces with reference to r or r' face of the crystal by means of a bevel protractor to meet the desired value of θ in Fig. 1, keeping the principal surfaces always perpendicular to the x-planes. Especially the orientation of the principal surfaces of the test pieces referred to in Tables II and III are able to be measured by an X-ray spectrometer. α and β are the values thus determined.

7. Observation of Frequency Change with Temperature.

One of the most important features of our work is the precise measurement of frequency change with temperature. In Fig. 12 plate A is a test piece on which

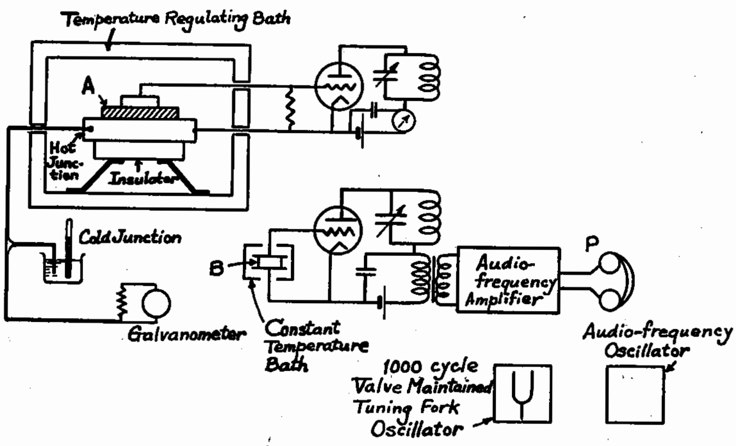

Fig. 12.

the upper electrode rests lightly; B is another plate of nearly the same frequency and of the smallest temperature coefficient ever manufactured up to the time of that measurement. The upper electrode of this plate is adjusted and fixed over the plate to give a certain air gap to get readily a suitable difference in audio-frequency between the two oscillators A and B. Near the telephone receiver P to hear this difference of frequency, there is an audio-frequency oscillator, the frequency of which is previously calibrated and checked from time to time by a 1000 cycle valve-maintained tuning fork oscillator at frequencies, such as $\frac{1}{5}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{1}{2}$, $\frac{3}{5}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{4}{5}$, 1, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, 2, $\frac{5}{2}$, 3 kilocycles. Now in order to observe the frequency change due to the ambient temperature rise or fall of the plate A, the frequency of the audio-frequency oscillator is always so adjusted to coincide with the frequency heard in the telephone receiver P, and plot the frequency of the audio-frequency oscillator referred to the temperature, which is observed by a thermojunction of copper-constantan and a galvanometer. Especially, if the change of frequency is very small, the frequency difference between the two oscillators A and B is adjusted carefully to 1000 cycles plus or minus a few cycles, whereupon we can hear the note of about 1000 cycles with beats of a few times per second. From this number of beats counted in a certain lapse of time measured by a stop watch, we can easily measure even the change of a few parts in 10^{8}, provided that the freqency of the plates A and B is sufficiently high. If we are to manipulate the plate of relatively low fundamental frequency, the frequency of B may be selected several (sometimes up to 12) times as high as that of A.

8. Practical Applications and Actual Results.

For use in the quartz oscillator of a short-wave radio transmitter for commercial service, X-cut quartz plates are generally used in our country, because their temperature coefficient of frequency is smaller than that of any other kind of plates practically suitable for a transmitter. However, X-cut plates do not function satisfactorily at very high frequency, so the frequencies of the plates are always

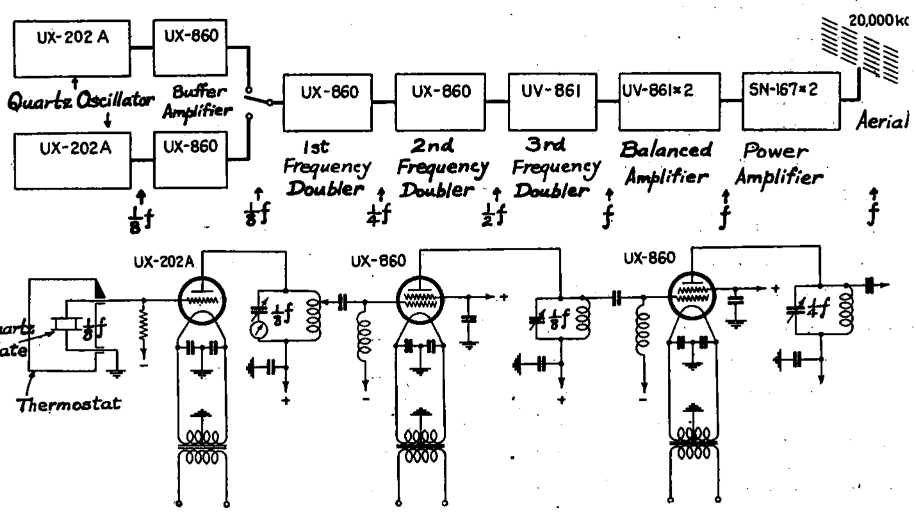

Fig. 13.

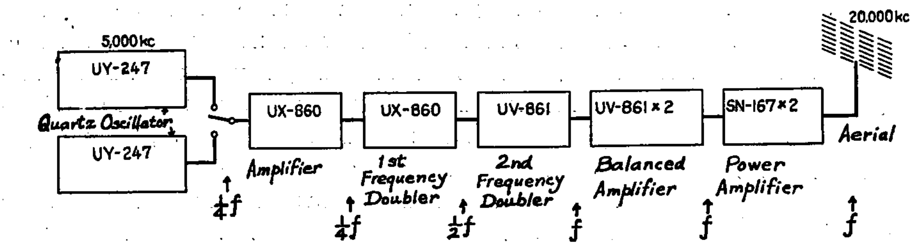

Fig. 14.

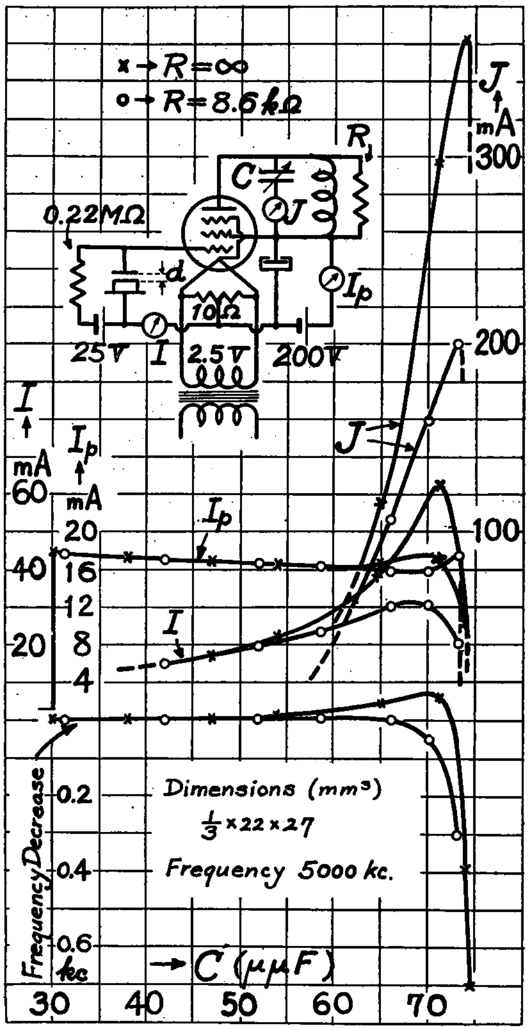

Fig. 15.

chosen under about 2.5 megacycles (120 m) and by means of several stages of frequency doublers and power amplifiers, necessary frequency and power are attained. Moreover, as the X-cut quartz plates have temperature coefficient of about $20 \sim 30 \times 10^{-6}/^{\circ}C$, they are placed in the thermostat, while the thermostat is generally lined completely with thick metal, so that the stray capacity to the electrodes and lead wires to quartz plates increases the equivalent capacity between grid and cathode of the oscillator valve and causes the function of oscillator unstable. Besides, it is much troublesome that the thermostat is to be constantly well kept with great care. Therefore, to find some means to dispense with the thermostat will be of value and the results will be quite beneficial in practical works. Early in July of 1933 we set our hands to test the short wave plates(16) of very small temperature coefficients, referred to in the second chapter, in a high-power radio transmitter at the Yosami (near Nagoya) Sending Station of the Japan Wireless Telegraph Company. Figs. 13 and 14 show the schematic diagrams before and after the improvement. The frequencies of plates are 4490 kc (one-half of 8980 kc—JNA, and one-quarter of 17960 kc—JNC) and 3470 kc (one-quarter of 13880 kc—JNB), their temperature coefficients being both under 10^{-6}/°C. As the ambient temperature of the quartz in the Yosami Station does not exceed the region 15°C∼45°C throughout the year, the frequency variation of the transmitter by the temperature only may be reduced under ± 15 parts in 10^6 from the assigned frequency, and also by the adoption of the valve of Model UY-247, we can reduce the dynamical load of the quartz plate and increase the electrical output, thus one stage of valve (Model UX-860) as a frequency doubler as wel as a power amplifier can be eliminated without any reduction of output power of the transmitter. The characteristics of the oscillators by valves of Model UY-247 and UX-202-A with the quartz plate of 5000 kc are shown in Figs. 15 and 16. In UY-247 oscillator the frequency variation due to about 10% fluctuation

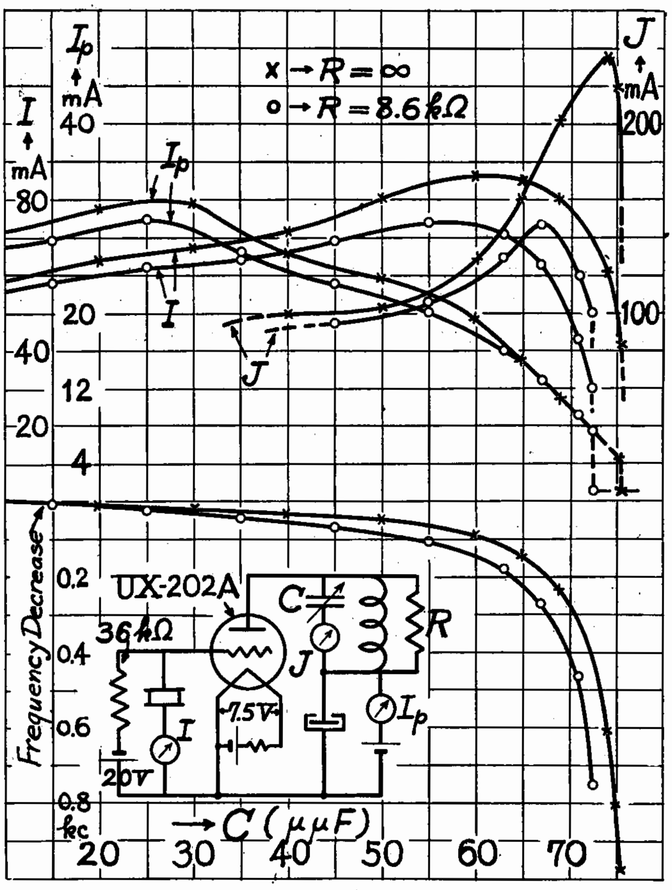

Fig. 16.

of the plate voltage, grid bias voltage, resistance of grid leak, filament terminal voltage is respectively much less than one part in 10^5. In case the quartz plate is transferred from a transmitter to another one of the same type, the frequency change of the oscillator is also less than one part in 10^5, so that if we wish to interchange the frequency under the charge of each transmitter, we may only interchange the oscillating quartz as far as the quartz oscillator is concerned. The quartz plate is held in a container equipped with electrodes, one of which can be adjusted and fixed to keep a certain air gap against the quartz plate. The details are shown in Fig. 17. This container is used in an aslant

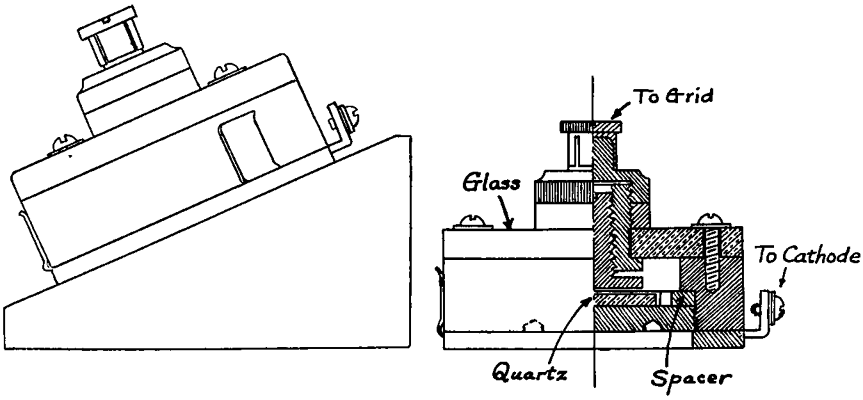

Fig. 17.

position so that the quartz plate rests on a corner of the spacer, which is used not only to fix the lower electrode but also to keep the quartz plate easily in a certain relative position with respect to the electrodes. Fig. 18 shows the dependency of

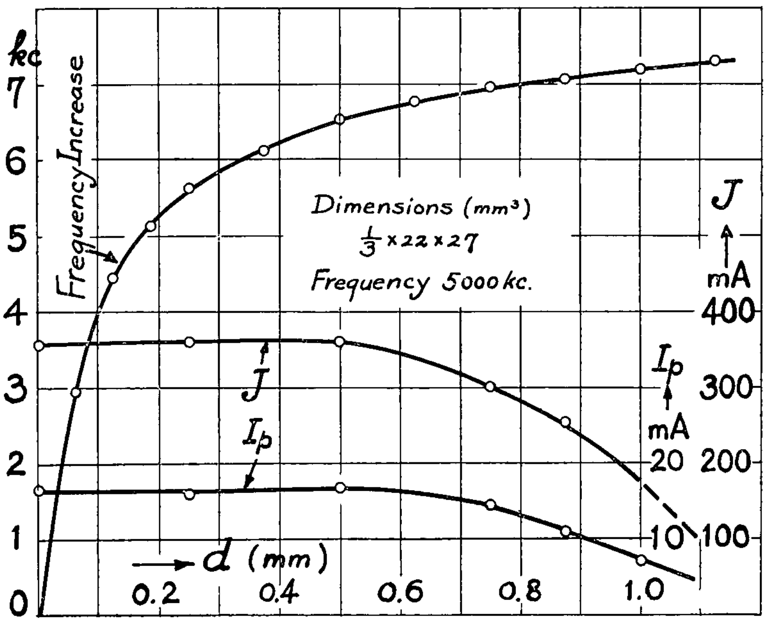

Fig. 18.

frequency upon air gap *d* between quartz plate and upper electrode. It is worthy of note that the amplitude of the current of the plate tank circuit is not changed until the frequency of oscillator is changed over to one part in 10^3, whereupon we may adjust easily the frequency to coincide with the assigned value using the quartz plate of roughly adjusted frequency.

Since the beginning of the test in July 1933, the actual results were quite satisfactory, and the Japan Wireless Telegraph Company decided in March 1934 to replace all the quartz oscillator in the transmitting station with the new systems and a part of the work in connection with the impovement of the transmitters has already been completed. Fig. 19 shows an actual arrangement of the quartz

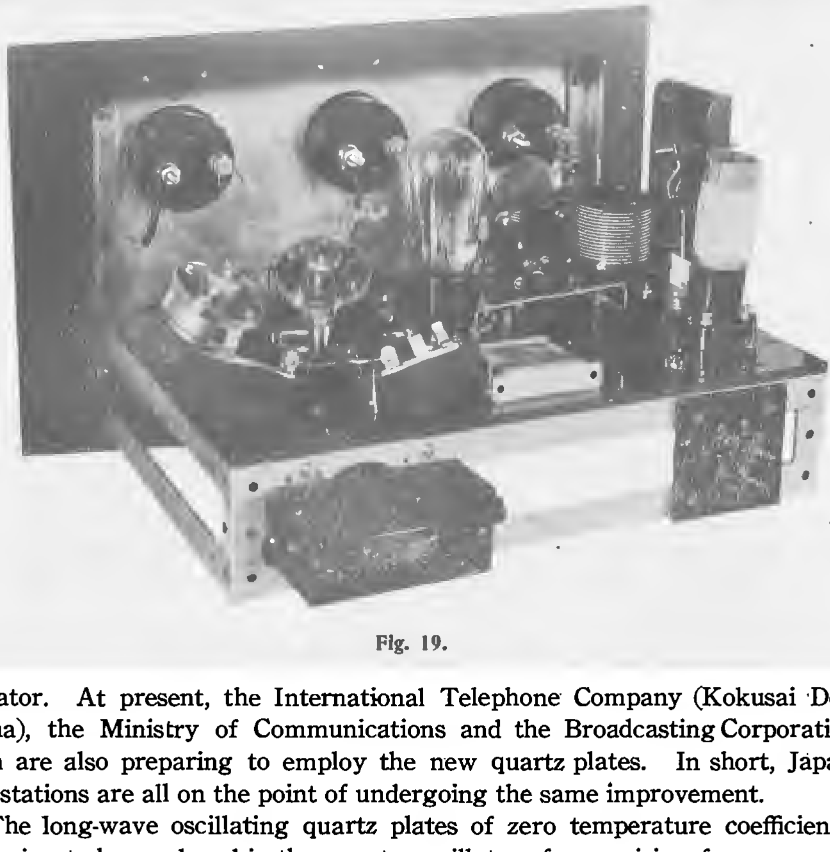

Fig. 19.

oscillator. At present, the International Telephone Company (Kokusai Denwa Kaisha), the Ministry of Communications and the Broadcasting Corporation of Japan are also preparing to employ the new quartz plates. In short, Japanese fixed stations are all on the point of undergoing the same improvement.

The long-wave oscillating quartz plates of zero temperature coefficient are now going to be employed in the quartz oscillator of a precision frequency meter equipped in the Fukuoka Receiving Station of the Japan Wireless Telegraph Company. In addition we wish to prepare a crystal clock of extremely stable frequency in the near future and introduce their actual results in due course.

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