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The conversion efficiency of a piezoelectric quartz crystal: Relation between input electrical power and frequency

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With 6 figures in the text

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The dependence of the conversion efficiency of a piezoelectric transducer on its frequency and the input electrical power has been examined and it is found that the efficiency is dependent not on the input power but on frequency and the nature of the liquid

1. Introduction

It was shown earlier [1] that when a quartz crystal converts electrical power to thermal power through the mechanism of the production of ultrasound and dielectric heating the efficiency of conversion is different for different liquids at different frequencies. It was found that the greatest total efficiency occurred in liquids of low sound absorption whereas the greatest ultrasonic efficiency occurred in liquids of high sound absorption and vice versa. These efficiencies decreased as the frequency of the crystal increased.

To check whether these efficiencies remained the same irrespective of the voltage applied to the crystal i.e. irrespective of the power delivered into the crystal, the experiment was performed by oscillating the crystal at several discrete voltages and the output from the crystal measured by the thermal method described in our earlier communication (q. v.).

2. Results and Discussion

Before proceeding to check how the efficiencies varied with the input power it was decided to find what the relation is between the current passing through the crystal and the voltage across it when once the electrical matching and the neutralisation of the dead capacity of the crystal by the variable inductance was complete. This was done for almost all the liquids in all the frequency ranges and the results are shown graphically in figures 1. 2 and 3. It is seen that the relation between voltage and current in all the frequencies studied is linear which means that the crystal behaves as a pure resistance.

Table 1. *Efficiency of Quartz Transducer for Several Voltages*
Water equivalent of calorimeter, stirrer etc. 12·3 gm.

Liquid	Mass of liq. gm.	Electrical input			Rise in temp. in 10 min. °C.			Thermal output. Watt		Efficiency %	
		Crystal voltage	Crystal current m.a.	Elec. power watts	Total	Dielec.	Ultrasonic	Total	Ultrasonic	Total	Ultrasonic
1	2	3	4	5	6	7	8	9	10	11	12
1. Frequency 4·916 Mc./sec.											
a) Propyl alcohol(n)	98·8	52	6·3	0·328	0·525	—	—	0·258	—	78·9	—
	97·5	79	9·3	0·730	1·250	—	—	0·573	—	78·5	—
	96·8	115	15·1	1·736	2·90	—	—	1·413	—	81·2	—
	100·9	167·5	20·5	3·433	5·35	—	—	2·675	—	78·7	—
b) Carbon tetrachloride	205·3	50	3·0	0·15	0·30	—	—	0·111	—	74·0	—
	208·6	78	5·0	0·39	0·75	—	—	0·281	—	72·0	—
	204·8	125	8·0	1·00	1·925	0·075	1·850	0·718	0·694	71·8	69·4
	188·5	173	11·8	2·04	4·00	0·125	3·875	1·406	1·361	69·0	66·7
c) Ethylene glycol	137·1	60	6·1	0·366	0·35	—	—	0·225	—	61·5	—
	137·1	122·5	13·3	1·659	1·225	—	—	0·969	—	58·4	—
	137·2	171	17·0	2·91	2·300	0·975	1·325	1·819	0·840	62·0	36·1
2. Frequency 8·7 Mc./sec.											
a) Propyl alcohol(n)	99·5	40	20	0·80	0·85	0·525	0·325	0·417	0·160	52·1	20·0
	94·1	61	37·5	2·287	2·525	1·500	1·025	1·201	0·488	52·5	21·3
b) Carbon tetrachloride	185·9	40	13·5	0·54	0·80	0·30	0·50	0·278	0·174	51·0	31·9
	189·6	60	21·0	1·26	1·70	0·55	1·15	0·605	0·409	48·0	32·4
	189·4	81	29·75	2·41	3·40	1·15	2·25	1·19	0·793	49·3	32·8
c) Ethylene glycol	134·4	40	17·5	0·292	0·50	0·20	0·30	0·292	0·174	42·0	25·2
	134·8	60	28	1·680	1·325	0·575	0·750	0·774	0·438	46·0	26·1
	137·5	80	36·5	2·92	2·275	0·90	1·375	1·335	0·806	46·2	27·9
3. Frequency 14·7 Mc./sec.											
a) Propyl Alcohol(n)	98·5	40	22	0·88	0·25	—	—	0·123	—	14·0	—
	97·3	60	32·5	1·95	0·575	—	—	0·279	—	14·3	—
	98·0	80	44·0	3·52	0·95	—	—	0·463	—	13·1	—
b) Carbon tetrachloride	186·5	40	16·2	0·648	0·20	—	—	0·070	—	10·7	—
	187·9	60	23·0	1·38	0·40	—	—	0·141	—	10·2	—
	190·8	80	28·6	2·28	0·675	—	—	0·240	—	10·5	—
c) Ethylene glycol	134·5	40	21·0	0·84	0·19	—	—	0·108	—	12·6	—
	137·6	60	32	1·92	0·375	—	—	0·223	—	11·6	—
	140·1	80	44	3·60	0·70	—	—	0·420	—	11·9	—

For the determination of the conversion efficiency when the applied voltages changed in the same liquid, three different liquids were tried at three different frequencies. The liquids tried were (n) propyl alcohol, ethylene glycol and carbon tetrachloride. They represented a low and a high ultrasound absorbing liquid and a highly viscous liquid.

The results of the experiments are summarised in Table 1 and represented graphically in figures 4, 5 and 6.

In Table 1 column 2 gives the voltages applied to the crystal at the three frequencies studied. The experiments were performed at four different voltages in the lowest frequencies and at three voltages in all the other frequencies, the only criterion being that the amount of heat developed calorimetrically should be sufficient to be measured.

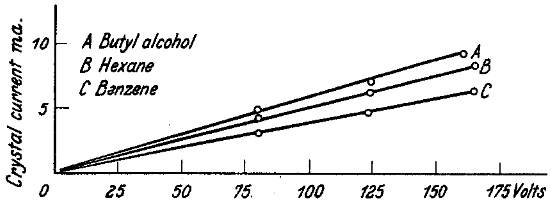

Fig. 1. Voltage across the Crystal (Freq. 2·84 Mc./sec.)

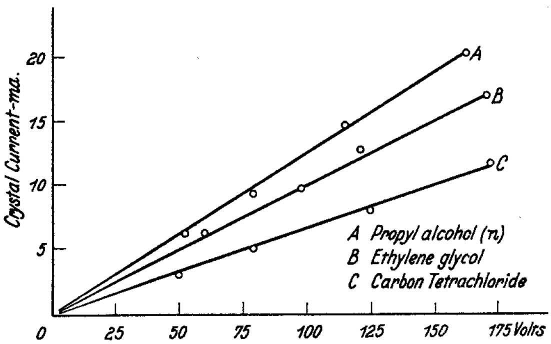

Fig. 2. Voltage across the Crystal (Freq. 4·916 Mc./sec.)

The efficiencies are given in columns 11 and 12. The transfer of energy from quartz to liquid clearly shows that in so far as the ultrasonic energy is concerned, other things remaining the same, the energy is proportional to the square of the applied voltage. In the case of heating of the dielectric it is well known that the dielectric heating power is given by the equation [2]

$$\text{Power} = 1{\cdot}41 \cdot V^2 \cdot \nu \cdot \frac{A}{t} \cdot F_1 \cdot \times 10^{-12}\,\text{watts}$$

where V is the applied RF voltage, ν the frequency, F_1 the loss factor, A area and t thickness of the crystal; the loss factor is defined as the product of the dielectric constant and power factor. It then follows that the dielectric heating is also proportional to the square of the applied voltage. In the case of the oscillating quartz both heating effects take place simultaneously and therefore the total heating should be proportional to the square of the applied voltage.

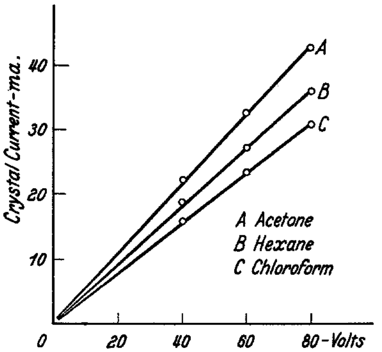

Fig. 3. Voltage across the Crystal (Freq. 14·7 Mc./sec.)

This is fully borne out by the experiments at all the voltages and in all the liquids. This is seen from figures 4, 5 and 6 where the total thermal output is plotted against the square of the voltage applied to the crystal, in the three liquids propyl alcohol (n), ethylene glycol and carbon tetrachloride. The slopes of these straight lines are different in

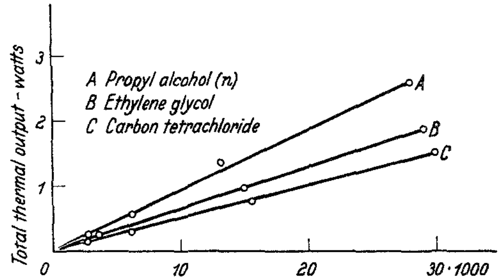

Fig. 4. Square of the voltage applied to the Crystal (4·916 Mc./sec.)

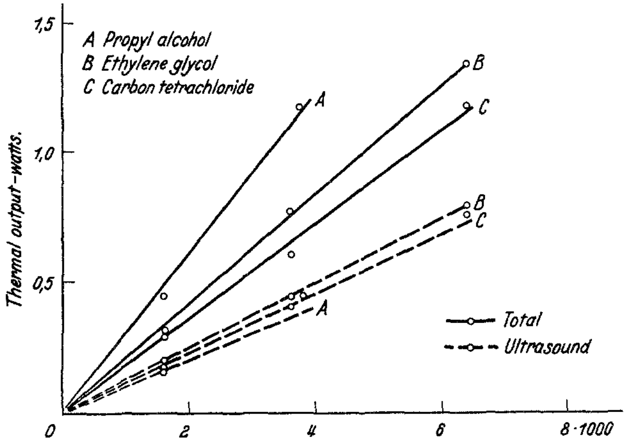

Fig. 5. Square of the voltage applied to the Crystal (8·7 Mc./sec.)

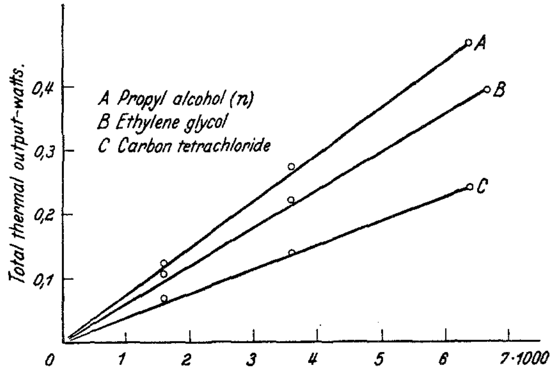

Fig. 6. Square of the voltage applied to the Crystal (14·7 Mc./sec.)

the three liquids which only means that the efficiency of conversion is different in them, greater slope indicative of greater efficiency. From

Table 1, column 11 it is seen that for a given liquid the total conversion efficiency at a given frequency is nearly constant irrespective of the applied voltage and within the limits of accuracy claimed in these experiments.

In some cases where the dielectric heating experiment was performed, as for example in all the three liquids at frequency 8·7 Mc./sec., the ultrasonic efficiency also remains constant irrespective of the voltage applied to the crystal but depends purely on the nature of the liquid and the frequency at which the measurements were made.

The study of the ultrasonic efficiency was not performed at 14·7 Mc. in view of the very small rise in temperature even in total heating.

3. Conclusion

The significant points that these experiments lead to are that within the voltage range studied here

1. The total heat output per second from a quartz crystal oscillating in a liquid varies directly as the square of the voltage and depends only on its frequency and on the nature of the liquid in which it oscillates.

2. Greater total output comes out of the transducer at lower frequencies and in low absorbing liquids.

3. The efficiency of conversion total as well as ultrasonic is independent of the applied voltage but is dependent on the nature of the liquid.

4. When the dead capacity of the crystal is compensated for by a suitable inductance the crystal with its liquid load behaves a pure resistance at all voltages applied to the crystal.

References

[1] PARTHASARATHY, S., and V. NARASIMHAN: The performance of a quartz oscillator in liquids, Parts I and II. Z. Physik **143**, 300, 623 (1955/56). — [2] WESLEY CABLE, J.: Induction and Dielectric heating, p. 331. New York: Reinhold 1954.