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Administratie

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A NEW DECADE (GLOW DISCHARGE) INDICATOR TUBE, WHICH CAN BE OPERATED BY A LOW VOLTAGE AND LOW ENERGY

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SUMMARY:

A ten position indicator tube (pixie-type) is described which can be operated by a signal of a few volts and a current of 50 μA, supplied on the triggers. Besides the ten triggers the tube contains one main anode and one cathode, the surface of which is divided into ten parts separated by a thin layer of Al_2O_3 or mica. The tube is filled with Ne-0.1% A at a pressure of about 15 c.m. Hg.
The main discharge is supplied by a rectified a.c. power source. The current of the main discharge is about 2 mA (r.m.s.) and produces a bright glow (brightness 1300 cd/m^2). The trigger on which an extra voltage is supplied reaches the breakdown potential before this occurs at other triggers and the appearing discharge ignites the main glow discharge at that particular position. The resulting decrease in voltage over the tube prevents ignition at other positions. Measurements have been carried out on the statistical and formative time lag of the trigger and main discharge. Some life-tests indicate that for well sputtered tubes an operating voltage of 5 volts is sufficient to operate the indicator tube during life.

1. Introduction

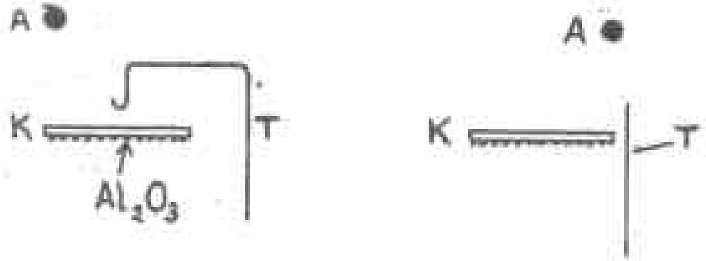
In gas-filled counter tubes, such as the dekatron, both the counting and the read-out function are present in one tube. However, for gas-filled tubes the limit to high frequency is rather low (some $Kc/_{sec.}$) For the last few years still more computers have been built with transistors, because of the advantages of low power-consumption, high counting rates and small volumes. A disadvantage of transistors is that they need a read-out system. Therefore investigations have been carried out to develope a gas-discharge indicator tube which can be applied in transistor-circuits. In this case, the indicator has only the function of indication and then the low limit of frequency of the discharge tube is of no importance. The application of such a tube in transistor-circuits requires the tubes to be operated by a signal of low voltage and power consumption and the voltage of the discharge are too high to be supplied directly by transistors. In the tube, described here, the main discharge is supplied by a seperate power source, whereas the transistor signal is applied on trigger electrodes. The decade indicator tube (based on an idea of M.v.Tol and Botden) has ten positions along a circle. The construction, circuitry and the experimental results will be given in the following sections.

2. Construction and processing of the tube.

An experimental tube is shown in diagram in fig. 1. The molybdenum cathode K has the shape of a ring made of a 0.5 mm thick plate. Its bottom side is covered with a thin layer of alundum (Al_2O_3) in order to prevent a glow discharge on this surface. The top-side of the cathode is divided in ten parts, separated by Al_2O_3 or mica, or partly by notches in the cathode (see fig. 2). The outer diameter was 30 mm.

The main anode consists of a nickel wire, bent in the shape of a circle with an open end, in order to prevent too high temperatures during the high frequency heating of the cathode. The distance between cathode and anode is about 4 mm, but it is not critical.

Ten trigger-anodes of nickel wires (diam.0.5 mm), at equal mutual distances, are mounted in two different models. Most experiments have been carried out with tubes in whigh the ends of the triggers T (see fig. 3a) are bent, in order to obtain better defined ends; the distance between triggers and cathode



a

b

surface is about 1 mm. Also some tubes have been made with straight trigger-wires, and equal distances between triggers and the edge of the cathode (fig. 3b). The mounting leads of the cathode are screened off by thin glass tubes or by a layer of alundum. The alundum is fixed up after etching of the cathode. The hard-glass bulb (G 28) has an inner diameter of about 34 mm.

The tubes are evacuated for about 6 hours at 450°C, then the cathode is outgassed by high frequency heating. After sputtering of the cathode during about ½ to 1 hour in Ne-0.1% A at a pressure of about 5 mm Hg, the tubes are filled with Ne-0.1% A at a pressure of about 15 cm . Hg and sealed off. The final cleaning of the cathode surface is carried out by a pulsed discharge during about 10 minutes.

3. <u>Principle and circuit of the tube.</u>

The circuit-diagram is schematically shown in fig. 4. The main power for the glow discharge was supplied by a variac, connected to 220 V a.c. mains, and rectified by a single wave rectifier. The resistance R_1 limits the current of the glow discharge between cathode and anode. The triggers T_1, T_2, T_3 (only two are drawn in the figure) are connected to the anode via a resistance R_2 of 0.1 to 1 MΩ , and the voltage source X. In the experiments a variable voltage from a dry battery has been used for X, but in transistor circuits the X_1, X_2 etc. represent transistors, which by turns will give a signal on the triggers. In order to keep the transistors at earth-potential the anode is earthed, while the negative potential of the cathode varies with the a.c. mains.

For the moment we will regard only one trigger (T_1). When the voltage between K and A increases, the voltage between and T_1 increases simultaneously also. Since the distance between T_1 and K is shorter than between A and K, the breakdown potential (V_T) for the trigger is reached first (fig. 5). The resulting auxiliary discharge gives rise to ignition of the main discharge between K and A, because the breakdown potential of the anode is decreased by the auxiliary discharge (see section 4). At the same time the voltage over the tube is diminished to the burning voltage (V_b) of the glow discharge. The glow will remain

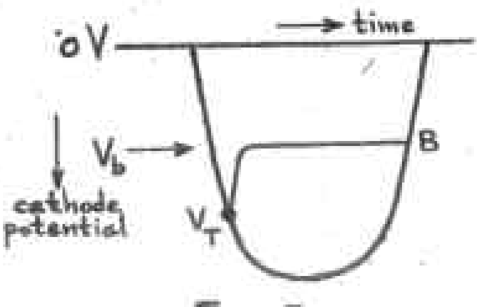


Fig. 5

during the half period until the voltage supplied reaches the value V_b (at point B), where the discharge breaks off. In the next negative half cycle this process is repeated.

Now we will take into account all triggers and assume that they have the same potential as the anode. Then the glow discharge will appear at that particular trigger with the lowest breakdown potential, and this discharge prevents the development of a glow near other triggers, due to the decrease of the voltage.

However, when a sufficient positive voltage (with respect to the anode) is supplied by the source X_n at the trigger T_n, then this T_n will reach the breakdown potential before the other triggers. Thus the glow discharge will appear near trigger T_n. In this way the various positions can be operated by a signal supplied by the sources X.

In the following sections we will discuss the magnitude of the signal necessary for operation.

4. The operating current and voltage of the trigger.

To operate the indicator tube directly by transistor signals, both the current and the voltage of the trigger must preferably be as low as possible.

a) The current of the auxiliary discharge defines the decrease of the ignition voltage of the main anode. This can be seen in fig. 6, where the anode voltage V_a for breakdown is plotted versus the steady current I_t of the auxiliary discharge. This result was obtained for a tube (of the trigger-type of fig. 3b) filled with Ne-0.1% A to a pressure of 14 cm Hg. The measurements were carried out with a d.c. power-source. The figure shows, that for a current I_t = 10 µA the value of V_a is appreciably decreased and is found below the breakdown voltage of the trigger, as will be seen furtheron. Therefore a current I_t of about 30 µA is sufficient for operation.

b) The voltage required by the trigger for operation, depends mainly on differences in breakdown voltages of the various triggers.

The breakdown voltage V_d is given by

$$\gamma(e^{\eta V_d} - 1) = 1 \quad (1),$$ in which η = the ionisation coefficient of the gas, depending on the type fo gas and on p.d (pressure x electrode distance) [1];

γ = secondary ionisation coefficient, i.e. the number of electrons delivered by the cathode per striking ion; γ depends on the type of ions and on the condition of the cathode surface [2].

Since $e^{\eta V_d} \gg 1$ we obtain

$$V_d = \frac{1}{\eta} \ln(1/\gamma) \qquad (2)$$

Thus the variations in η have a much stronger influence on V_d as variations in γ.

From the above it follows that V_d depends on: 1) the type of gas and its pressure (i.e. gas effects); 2) condition of the cathode surface; 3) electrode distance. Then also the operating voltage will depend on differences at these points for the various triggers. We will consider this more in detail.

b1. With regard to gas-effects, it may be remarked that the advantage of the ten positions in one tube is the elimination of influences due to variations in gas-pressure and gas mixture during life. Moreover, these variations which may occur from tube to tube, only result in a change of the breakdown voltage which is the same for all the triggers; this effect also is eliminated in the circuit given in section 3.

Besides this gas effect the warming up of the cathode by the glow discharge, can give rise to an inhomogeneous distribution of the gas density[3] and consequently to differences in breakdown voltage. However, no such effects could be detected in the tubes under normal burning conditions.

b2. The condition of the cathode surface is of importance on the breakdown voltage due to variations of the γ. In the well-known sputtering technique [4] clean molybdenum surfaces can be obtained and also kept clean during life when the glass bulb is sufficiently covered by a sputtered layer. (Therefore the cathode has been sputtered at low pressures.) In that case small variations in γ can be expected.

b3. According to the Paschen-law, the breakdown voltage V_d is a function of pd. In our case p is the same for all triggers, so V_d is a function of d. Consequently deviations of the distance of various triggers to the cathode give rise to differences in V_d. For the gas mixture Ne-0.1% A the Paschen curve is rather flat 1,5, i.e. V_d is nearly independent of pd in a certain pd range. For this reason Ne-0.1% A is used in the tubes; since the gas pressure is high (about 15 cm Hg) the clean up of Argon is not important.

Because the geometry of the electrodes in our case is different from parallel plates, as used by Penning and Frouws to determine the Paschen curves (loc. cit.) the breakdown voltage has been measured for the trigger opposite to a plane cathode or a cathode wire, as a function of the distance d (see fig. 7). As can be seen, the distance is not critical at values below about 0.3 mm. In the case of a plane cathode V_d changes 0.8 Volt when d varies 0.1 mm at a distance d = 1 mm. Similar results were obtained in a tube with a plane cathode, one fixed trigger (with d about 1 mm) and one movable trigger. In this tube the voltage difference V_x (or operating voltage) between the two triggers, to displace the glow from the first to the second trigger, has been measured at increasing distances of the second trigger. The results, given in fig. 8, are in good agreement with the upper curve of fig.7: the slope of both curves is the same.

b4. The trigger voltage required for operation in the experimental tubes.

For a number of tubes in table I the operating voltage is given for each of the ten triggers separately. The measurements have been carried out with the circuit given in fig. 4, the operating voltage V_x was supplied by a dry battery via a potentiometer. The resistance R_2 = 1M Ω (fig. 4), R_1 about 10 kΩ; the peak current of the trigger was about 50 μA.

It turned out that the value of V_x for displacement from one position to the next one in most cases was lower than for displacement to a position at larger distances. (We will come back to this in section 5). In the table the values of V_x are given by starting again and again at the most favourable position for ignition, which is identified by the value $V_x = 0$. From the table it follows that the experimental tubes can be operated with a voltage on the triggers of less than 4 volts.

In a few tubes (not given in the table) the V_x of one or two positions was much higher, even up to 30 volts. This was caused by an electric contact between some electrodes via the sputtered layer. The behaviour under various circumstances will be described in section 7.

5. The operating voltage as function of the frequency of the main discharge; statistical and formative time lag.

As shown in fig. 4 the a.c. mains can be used as power supply for the main discharge. The frequency of 50 c/sec for the glow discharge is high enough to give the human eye the impression of a constant light intensity. To find the upper limit of the frequency, the operating voltage V_x has been measured as a function of the frequency.

Fig. 9 shows that V_x is nearly constant up to about 300 c/s, then increases slowly and finally shows a steep rise near 2000 c/s. This means that above 2000 Hz the glow cannot be displaced from one to another position. This effect can be explained by the de-ionisation time of the plasma. The charge carriers disappear too slow by diffusion and recombination[6] with the result that re-ignition sets in as soon as the burning voltage is reached. This can be seen in fig. 10, in which the depression of the ignition voltage ΔV is plotted versus the time t between the quenching of the discharge (at voltage = 0V) and the re-ignition. For t = 1 msec the ignition voltage is decreased by 13 Volts. This is in fairly good agreement with the results of fig. 9; the t = 1 msec must be compared with a frequency of 2000 Hz because of the single wave rectification.

To find out whether the de-ionisation time or a statistical and formative time lag has some influence on the operation of the tube, the following experiments have been carried out. With the method, diagrammatically shown in fig. 11, the current of the trigger and of the main discharge are applied to the oscilloscope, either separately or simultaneously. The time base of the oscilloscope was chosen so that the full width of the screen corresponded to about 30 µsec. This method could be used without a special triggering because the statistical time lag proved to be only a few microseconds. This can be seen in fig. 12, which gives a number of successive discharges. (The curves with the upper zero level belong to main discharges, the other series to trigger + main discharges; the two series were photographed at separate times.) The "jitter", which must be ascribed to statistical time lag, is about 10 µsec. It may be remarked that the very first discharge may have a much longer statistical time lag, but even a time lag of 1 sec would be unimportant; by the first discharge the time lag is decreased to some µsec. The increase of the a.c. voltage in

From $V = A. \sin \omega t$ it follows

$$\frac{dV}{dt} = A\omega \cdot \cos \omega t.$$

For $A = 300$ V, $\omega = 50.2\pi$, time interval $\Delta t = 10^{-5}$ sec and taking $\cos \omega t = 1$ (since the breakdown voltage of about 130 V is reached at small values of ωt), we find the change in voltage ΔV in 10 μsec:

$$\Delta V = 10^{-5}.300.100.\pi = 1 \text{ Volt.}$$

For lower values of A also $\cos \omega t$ becomes < 1, and consequently ΔV decreases.

So, one may expect a small rise of the operating voltage with increasing voltage of the a.c. power supply. This effect indeed could be detected. At a peak voltage of 150 V the operating voltage was about 1 volt lower as in the case of 320 V peak. Also the effect, mentioned in section 4, that the displacement of the glow to a particular position from a subsequent one occurs with a lower voltage as from a position at greater distance, can be explained by the statistical delay. The number of charge carriers diffusing from a burning position to one at a larger distance, is small compared with the number reaching a neighbouring position. Then the statistical delay time will be shorter in the latter case, resulting in a smaller operating voltage. With regard to the formative time lag some conclusions can be drawn from fig. 13. Curve a gives the build up of the trigger discharge. Although the starting point is difficult to determine, the occurring overvoltage will prevent a slow rise in current found by Kluckow[7], so the peak of the current will be reached after about 10 μsec.

Ignition of the main discharge sets in immediately after this maximum of the trigger current. This is shown in curves b and c, where the main current is superposed on the trigger-current; the ratio of both signals is made different in b and c, while the signal of the main current is reduced by a large factor (see fig. 11). This result proves that the voltage over the tube decreases rapidly about 10 μsec from the moment that the trigger reaches the breakdown voltage. So it is clear that another trigger (not having an additional operating voltage), which would reach the breakdown voltage only about 30 μsec. later, cannot give rise to breakdown and to ignition of the glow discharge.

. The brightness of the glow discharge.

It is well-known that the brightness of the glow increases with the current density and that the glow in neon is the brightest one of the inert gases. Addition of argon diminishes the current density[8]. Since a mixture of Ne-A must be used, to obtain a rather flat Pashen curve (section 4), the Ne-0.1% A mixture has the advantage of giving a higher current density than mixtures with higher argon content.

The current density is approximately proportional to p^2 (p = pressure)[9]. In this respect it is pleasant that a pressure

Finally, the current can be increased by burning the discharge in the abnormal glow, which is possible through the separation of the cathode positions by Al_2O_3 or mica. However, the current is limited, since the glow jumps to neighbouring positions at too high currents. The limit of current density was found to be about 10 mA/cm² (r.m.s.) with single wave rectification and a pressure of about 15 cm Hg. In the experimental tubes the current limit is 2-3 mA.

The brightness of the glow was measured (by Mr. Vliegen of the Nat.Lab.) at a current density of about 10 mA/cm² and was found to be 1300 cd/m². For comparison we may mention the surface brightness of the fluorescent lamps, being on the average 8000 cd/m². Because the orange-red colour of the neon glow also gives a good contrast, the glow is well visible even in rooms in normal daylight.

When numbers are fixed around the tube, in a way similar to that usual with the dekatron, the position of the glow can easily be identified.

7. Preliminary life-tests on the experimental tubes.

From the preceding sections it will be clear, that the value of the operating voltage V_x depends only on the condition of the cathode surface. Even when the condition (and also the γ) is changed the same for the ten positions, then the value of V_x remains constant. However, continuously burning at one position may result in a difference in γ at this position, giving rise to an increase of V_x.

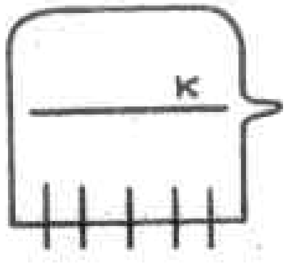
Therefore the following measurements have been carried out:

a) determination of V_x after 0 hours burning.
b) after burning for 200-300 hours in one position.
c) after a shelf-life test in a bath at 100° C for 12-20 hours.
d) the shelf-life test followed by burning in one position.
e) determination of V_x after shelf-life of about 4 months (partly after preceding tests).

The results of 12 tubes are given in figs. 14, 15 and 16, which give the values of V_x (measured similarly to table I.) for the various positions.

The influence of test b could hardly be detected with a measurement accuracy of 0.2 volts.

Test c gives rise to some alterations in V_x, but up to 20 hours at 100° C, the maximum values of V_x are still below 5 Volts in figs. 14 and 15. However, the tubes of fig. 16, show a larger increase of V_x at the positions near the arrows. The arrows indicate the position of the cathode near the tip in the glass bulb where



the pumping-tube is sealed off (fig. 17). Since no sputtered material can diffuse to this point, gas impurities from this uncovered part of the tube will reach the cathode and disturb the surface condition. The other tubes were sealed off at the bottom of the tube. These results indicate that a well sputtered glass bulb is necessary, but in that case the operating voltage can be kept below 5 volts. It may be remarked that the top of the bulb, through which the glow is observed, was covered with a very thin sputtered layer which could hardly be observed.

Burning on one place for 300 hours after the shelf-life test at 100°C (test d), seems to have a small influence. The same holds good for a normal shelf-life of 4 months at roomtemperature (see fig. 15). It might be, that at the high pressures used, a life test at roomtemperature over a long time shows smaller variations of V_x as found at a temperature of 100°C in 20 hours.

Although the number of tubes tested is small, it may be concluded that it is possible to make such indicator tubes, which can be operated with voltages of 5 volts during life.

Eindhoven, 10 Juli 1959

Natuurkundig Laboratorium der
N.V. Philips' Gloeilampenfabrieken

GL

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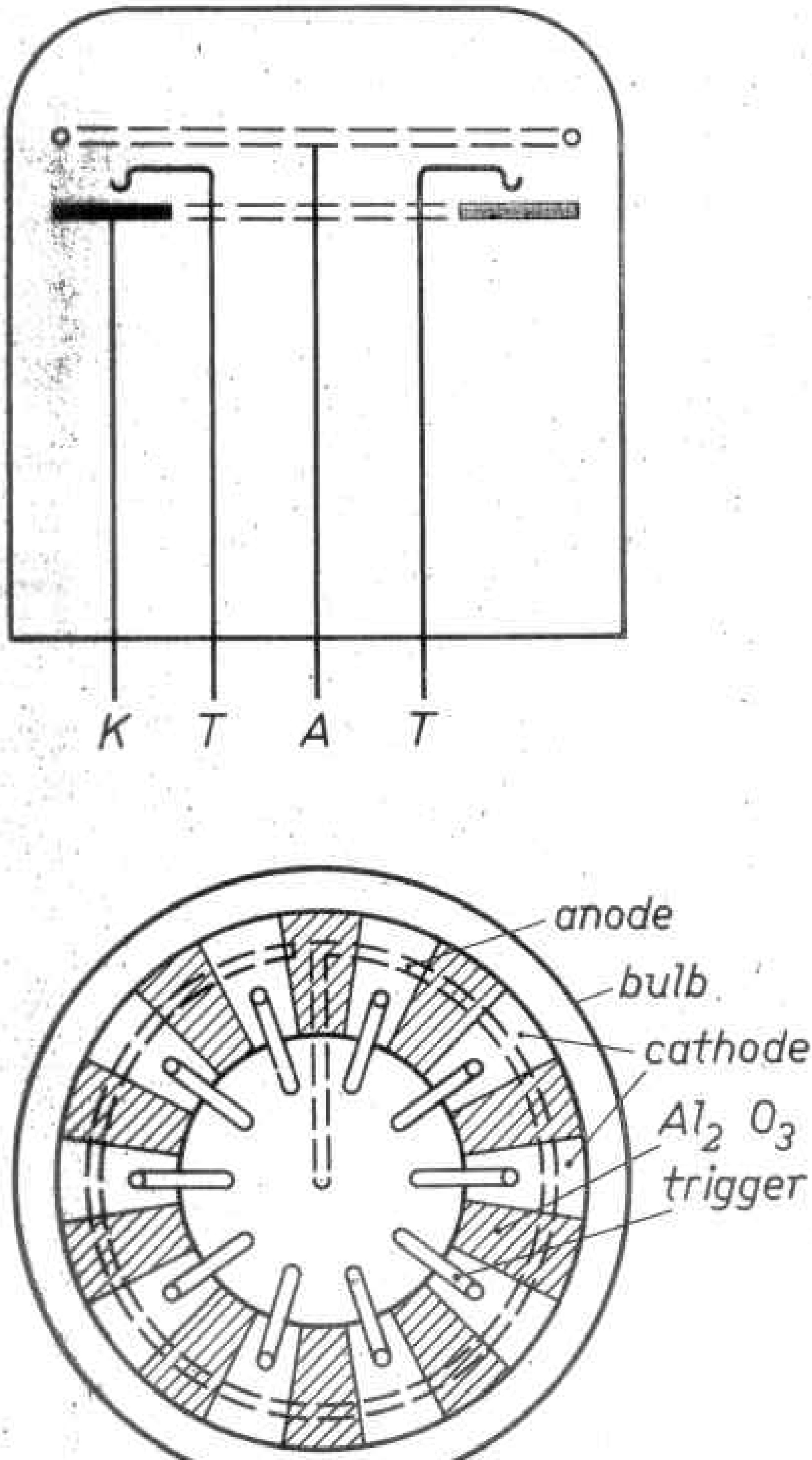
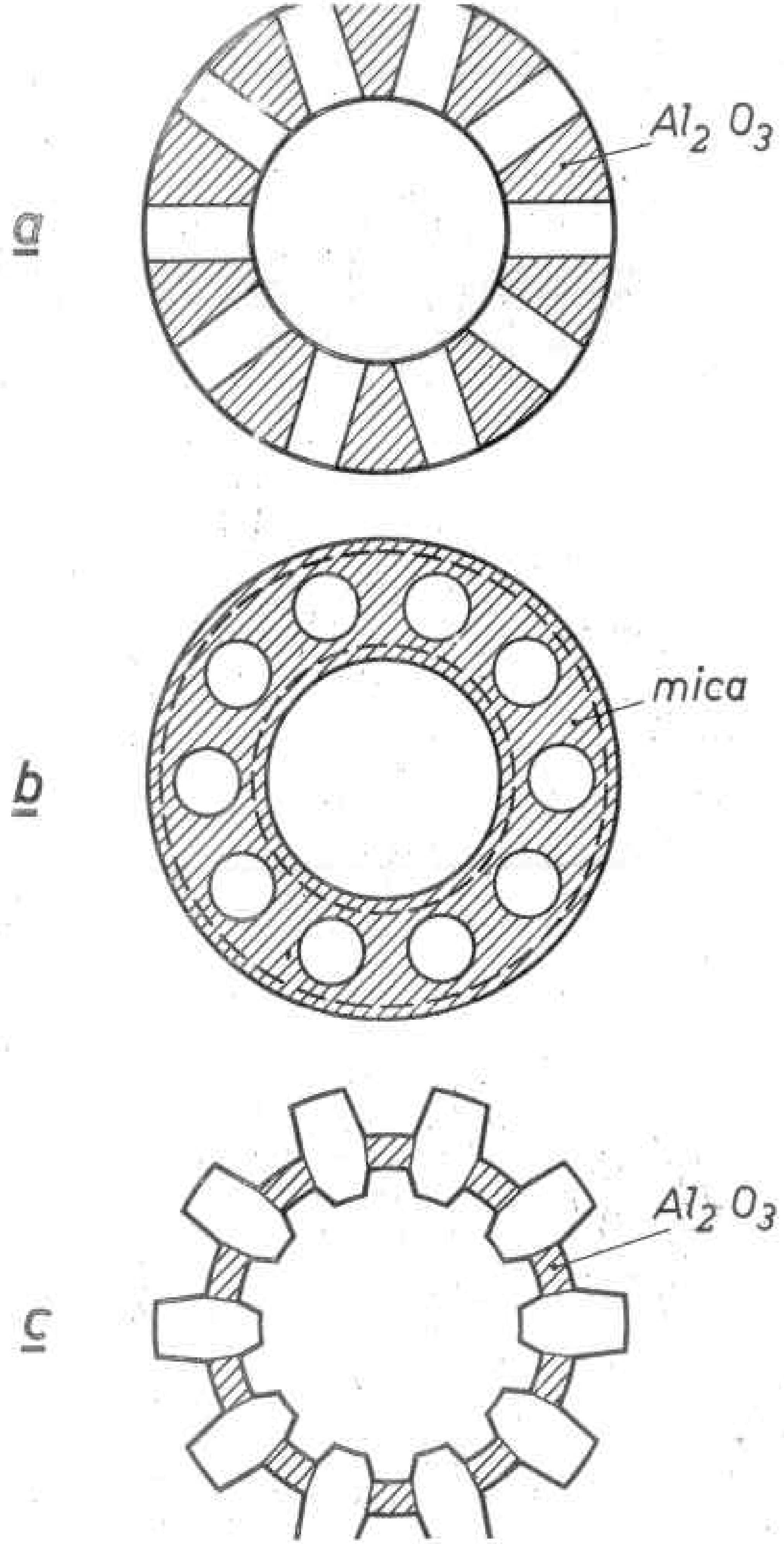
TABLE I

tube nr.	I 5	I 6	I 7	I 8	I 11	I 12	I 13	I 14	I 18	I 22	I 23	I 24	I 28	I 29	I 30	I 33	I 35	I 37
	operating voltage V_x (in volts) at 0 hour life																	
trigger nr.																		
1	1.5	1.0	2.3	3.2	2.3	2.2	2.3	3.6	1.5	1.7	0	1.4	0	1.3	2.4	2.1	1.4	0
2	2.2	0.5	2.6	2.4	2.0	2.0	1.9	2.0	1.2	1.6	1.1	1.5	0.8	2.8	2.0	0	1.1	2.0
3	2.5	0	2.0	2.8	1.5	2.8	3.1	3.1	1.3	0.8	2.2	2.3	3.2	3.7	2.6	2.8	0.8	3.1
4	1.7	2.7	1.7	2.4	0.6	2.5	2.7	3.9	0.9	0.4	3.1	2.0	3.2	4.2	2.7	3.4	0	2.6
5	1.8	3.0	1.6	2.3	0	2.8	2.9	2.9	0.3	0	2.7	1.7	3.2	2.9	1.6	2.9	--	2.7
6	1.1	2.1	0	2.2	0.8	1.8	3.1	1.6	0	0.7	2.3	0.9	3.6	3.5	0.5	2.6	1.0	2.1
7	2.3	2.7	0.6	1.5	1.2	1.8	2.7	1.1	1.0	1.3	1.9	0.9	2.6	1.7	1.5	1.9	0.8	4.1
8	0	3.6	1.8	0	1.8	1.5	2.5	0	1.4	1.5	2.1	0	3.2	1.2	0	1.8	1.1	4.1
9	1.0	4.1	1.5	1.3	2.1	0	0	0.9	1.1	1.7	3.1	1.9	2.2	0	1.2	0.9	1.7	4.1
0	2.0	4.2	2.7	1.9	3.0	0.9	0.7	2.3	1.6	1.9	1.0	2.2	2.1	0.8	2.8	2.8	1.5	2.6

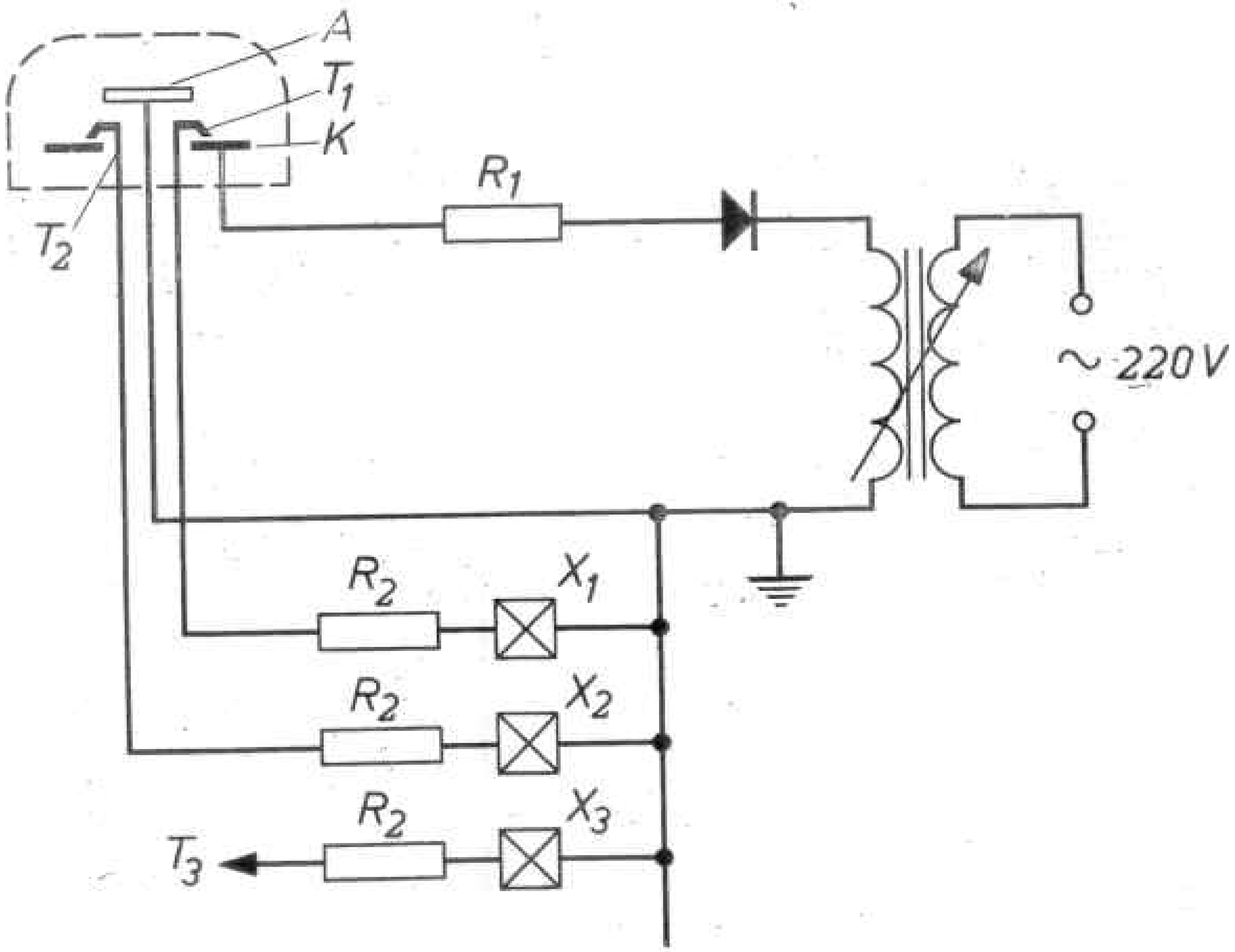
tubes I 33, 35 and 37 with triggers as shown in fig. 3b; other tubes as in fig. 3a.



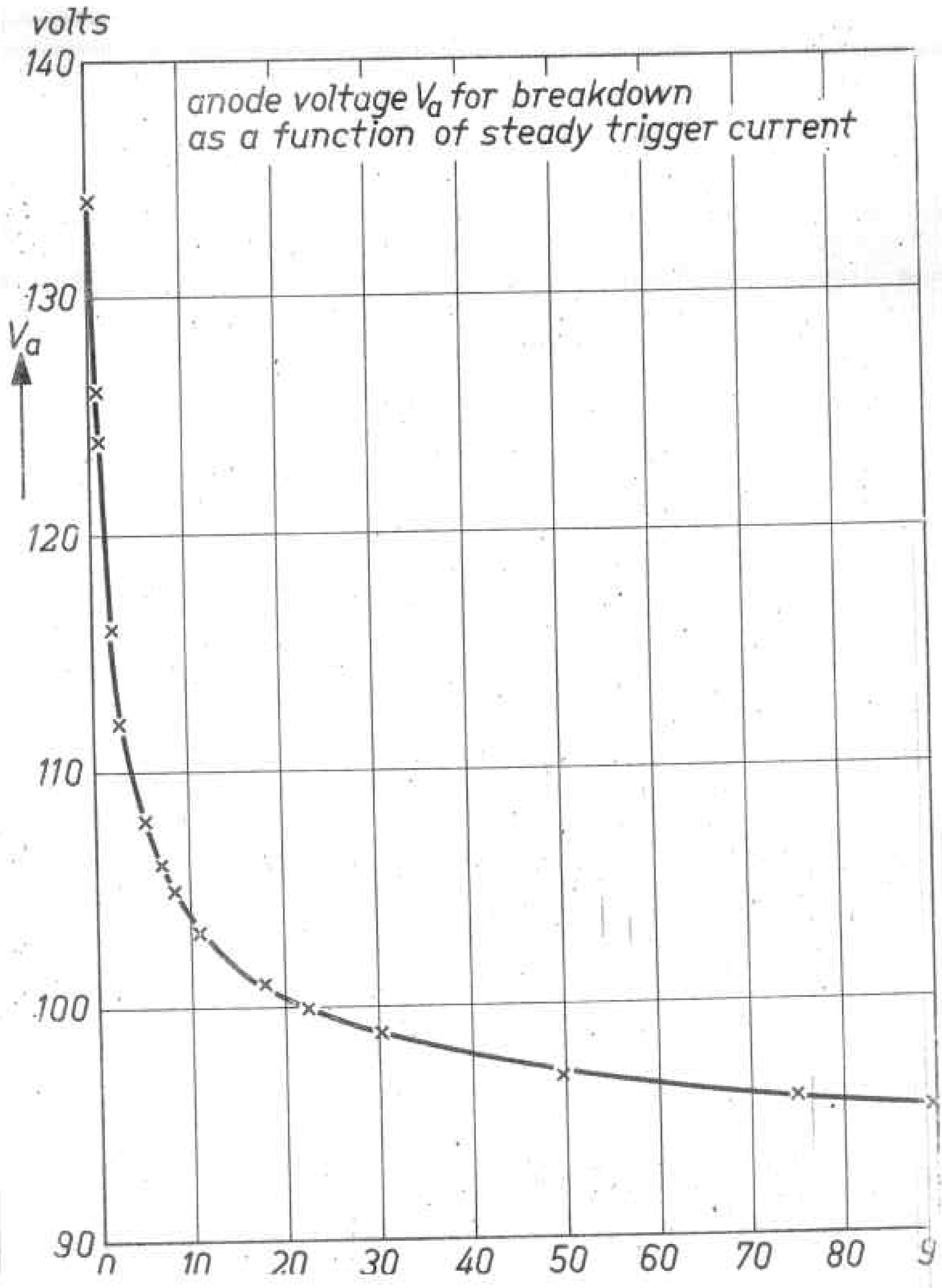
I.

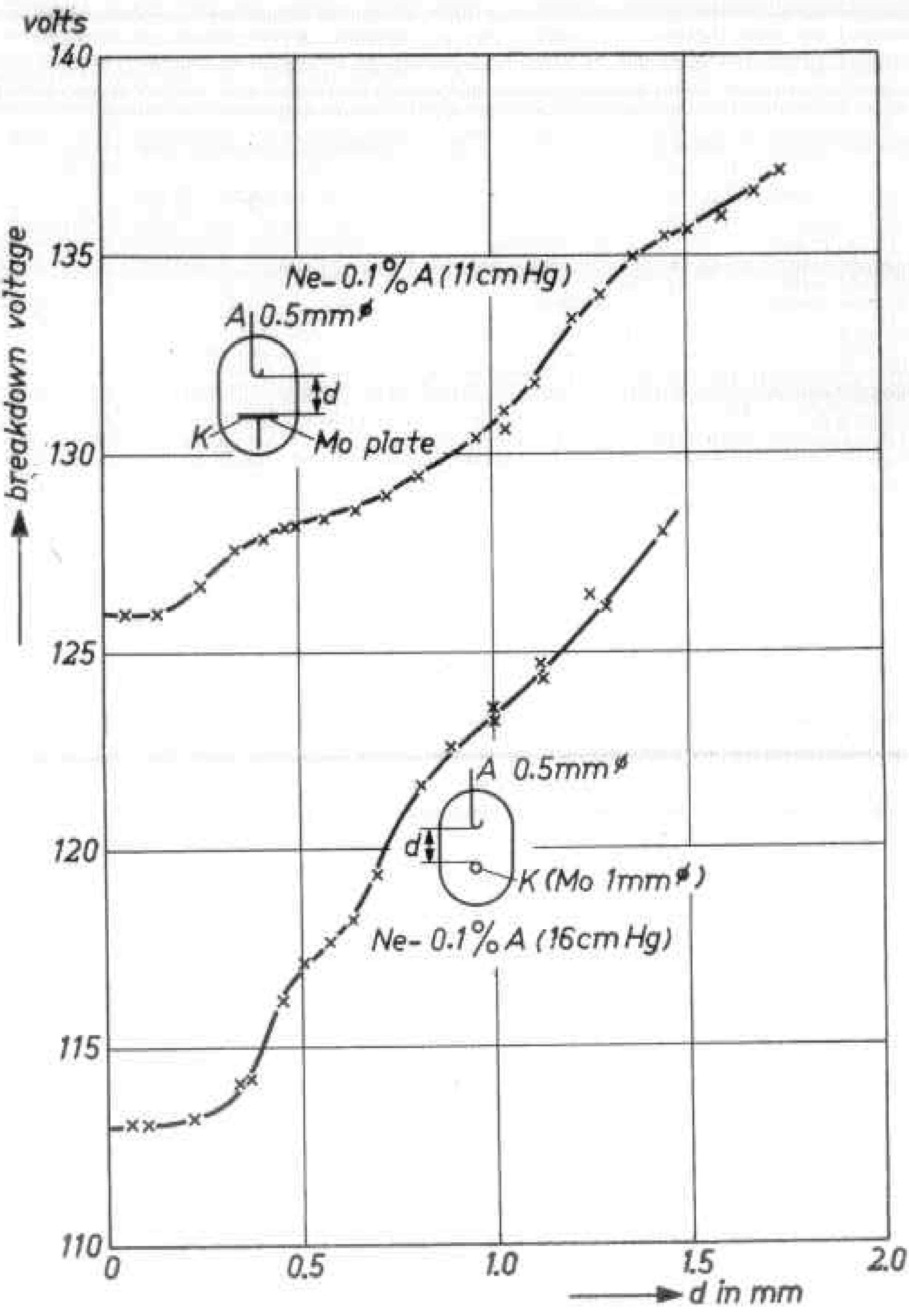


2.

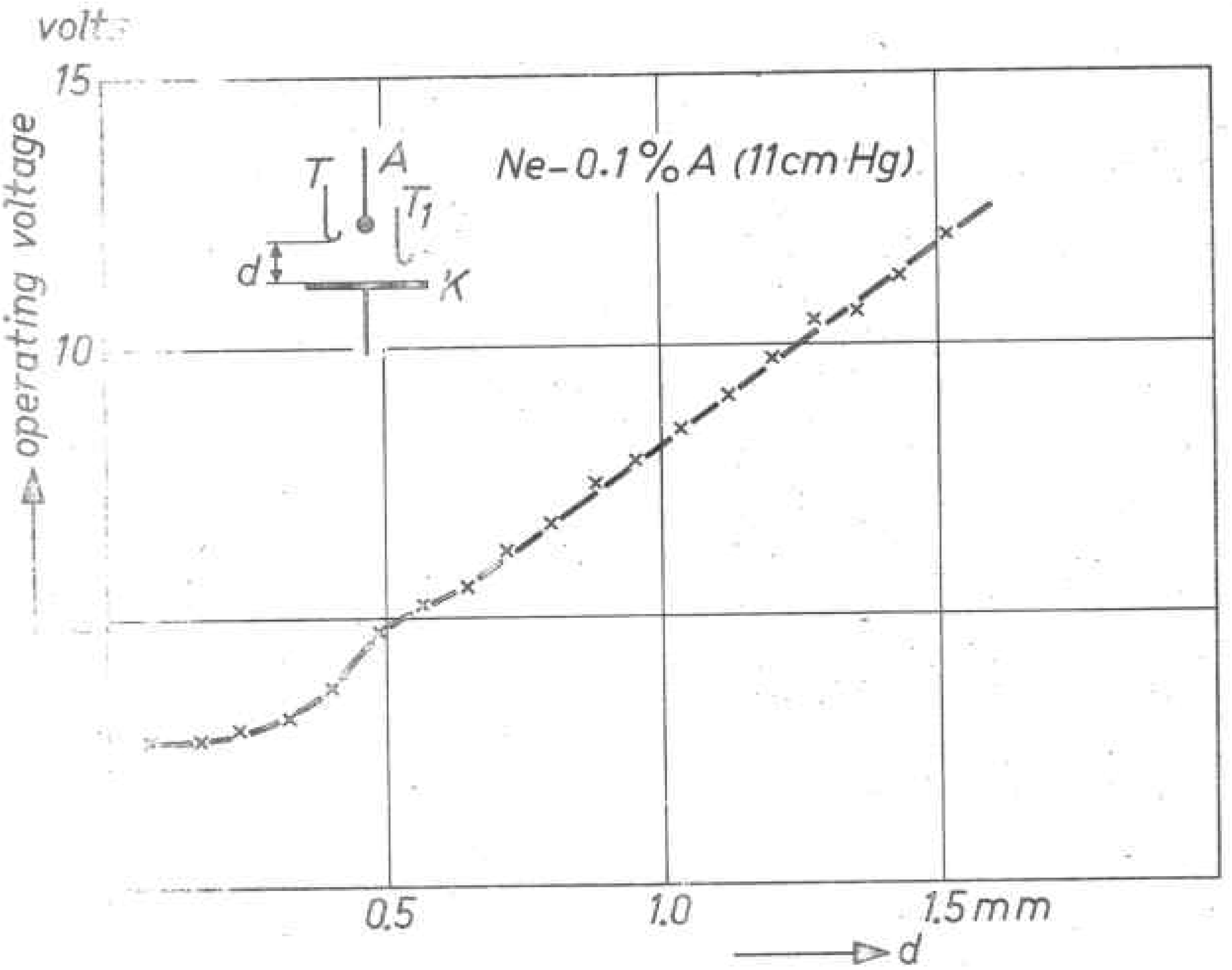


4.

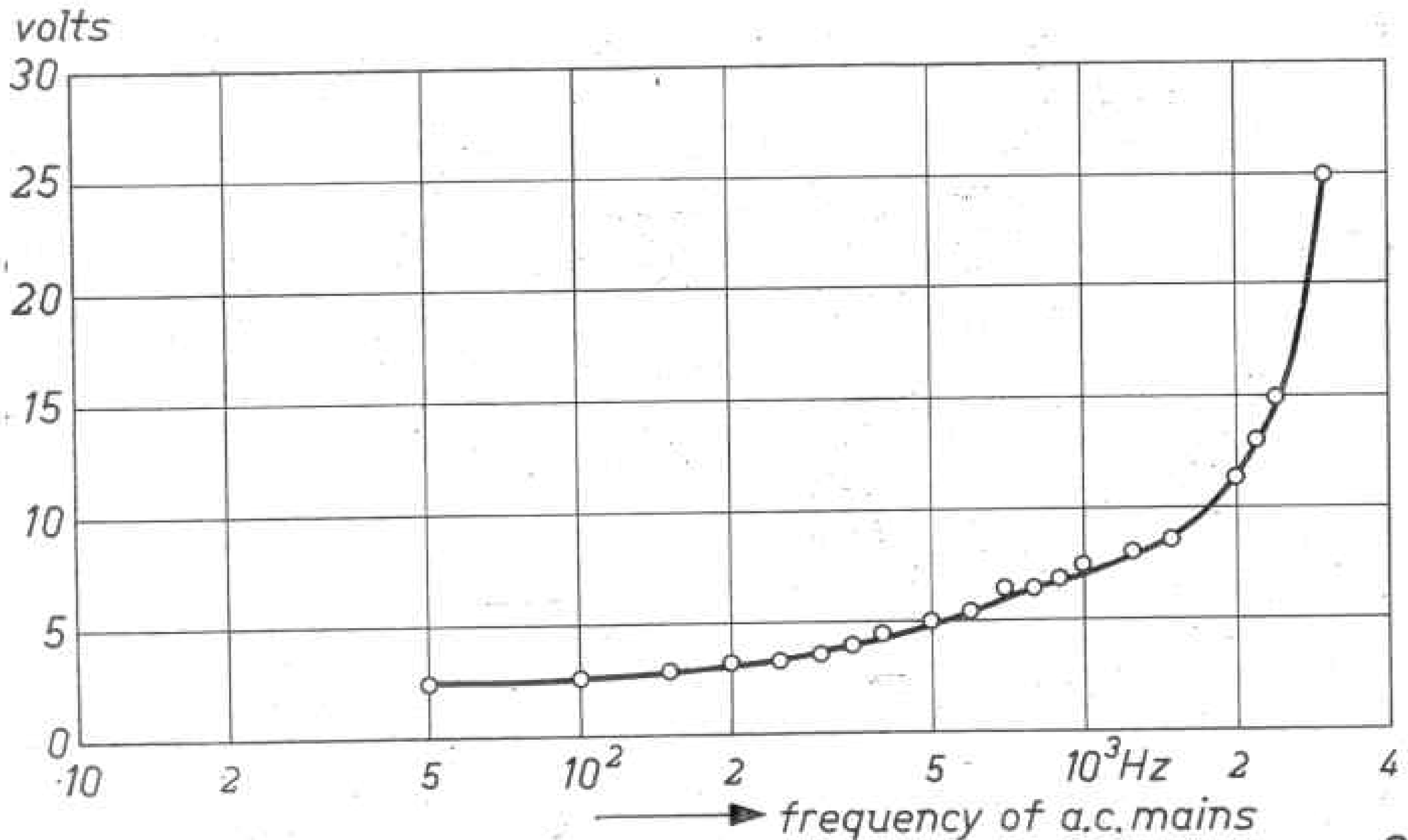

volts
140
130
120
110
100
90
V_a
anode voltage V_a for breakdown
as a function of steady trigger current
0
10
20
30
40
50
60
70
80
9



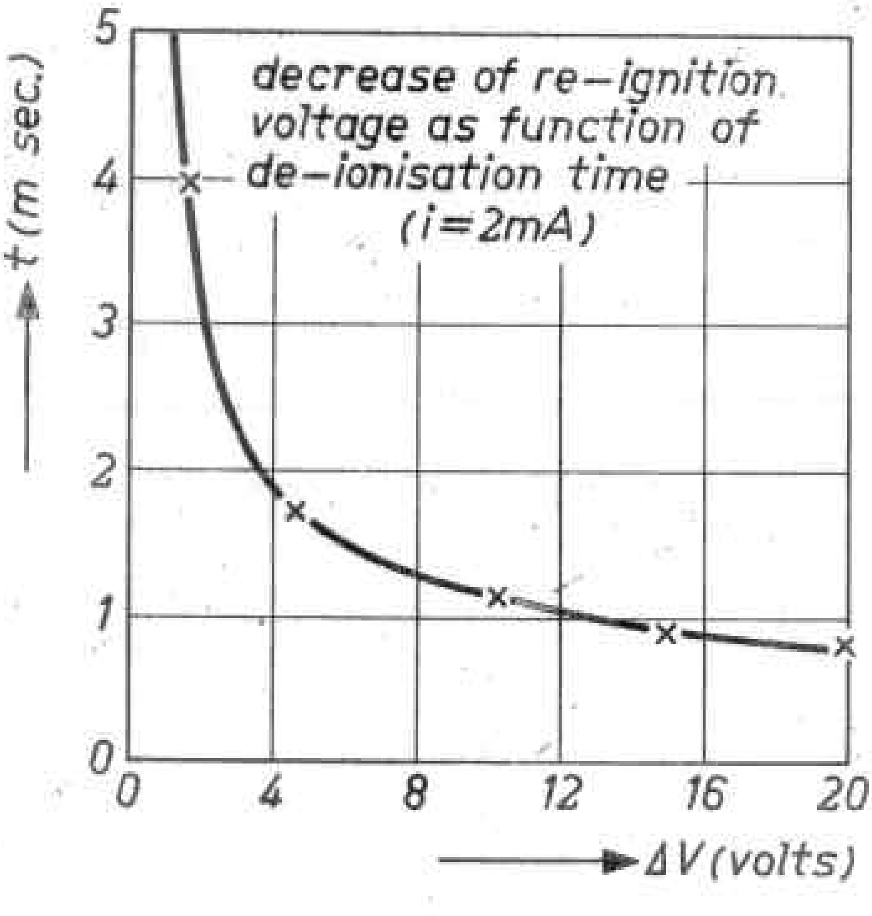
volts
140
135
130
125
120
115
110
breakdown voltage
Ne-0.1% A (11cm Hg)
A 0.5mm ∅
d
K
Mo plate
A 0.5mm ∅
d
K (Mo 1mm ∅)
Ne- 0.1% A (16cm Hg)
0
0.5
1.0
1.5
2.0
d in mm

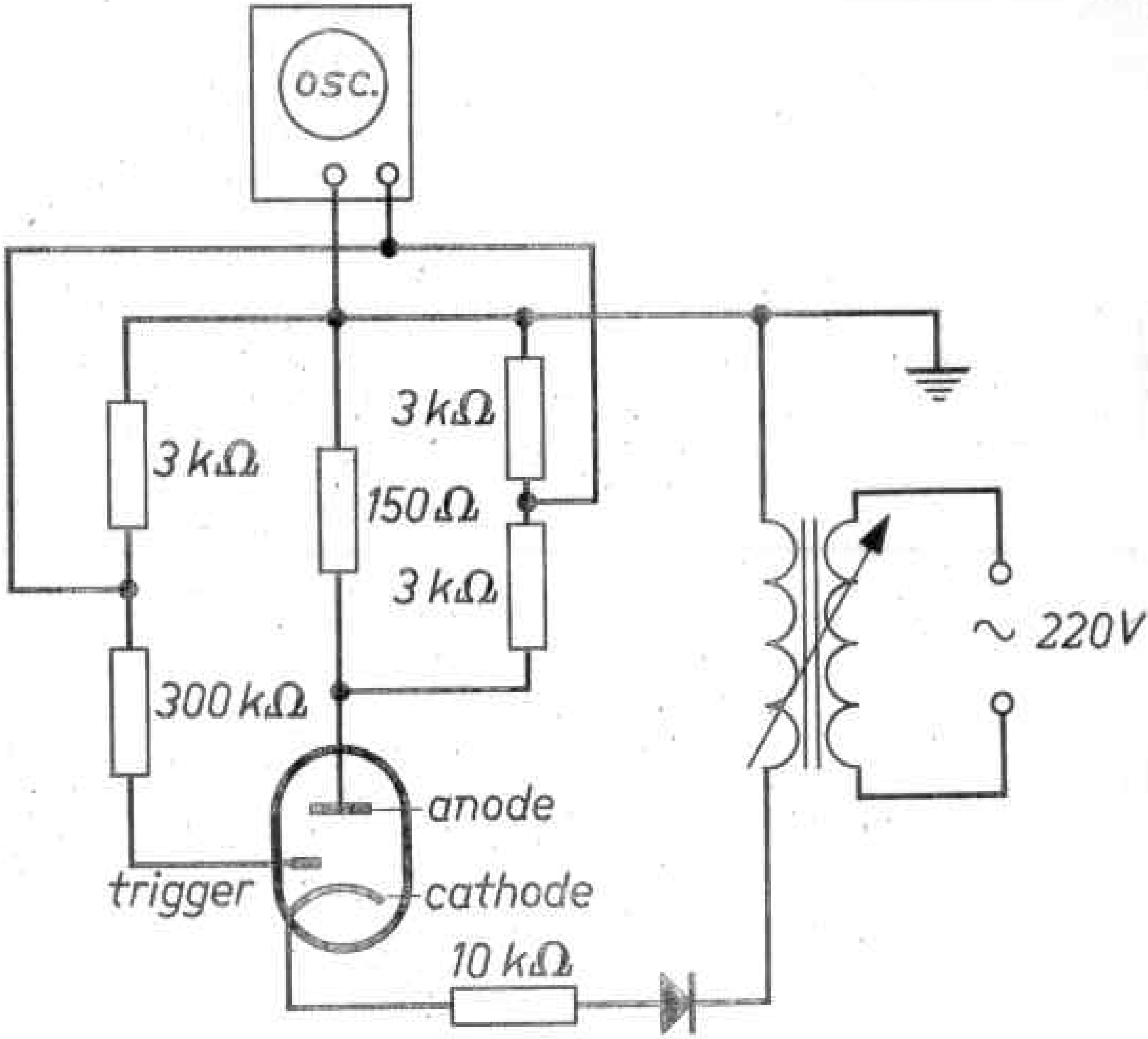

volt
15
10
operating voltage
Ne-0.1% A (11cm Hg)
T
A
T_1
d
K
0.5
1.0
1.5 mm
d

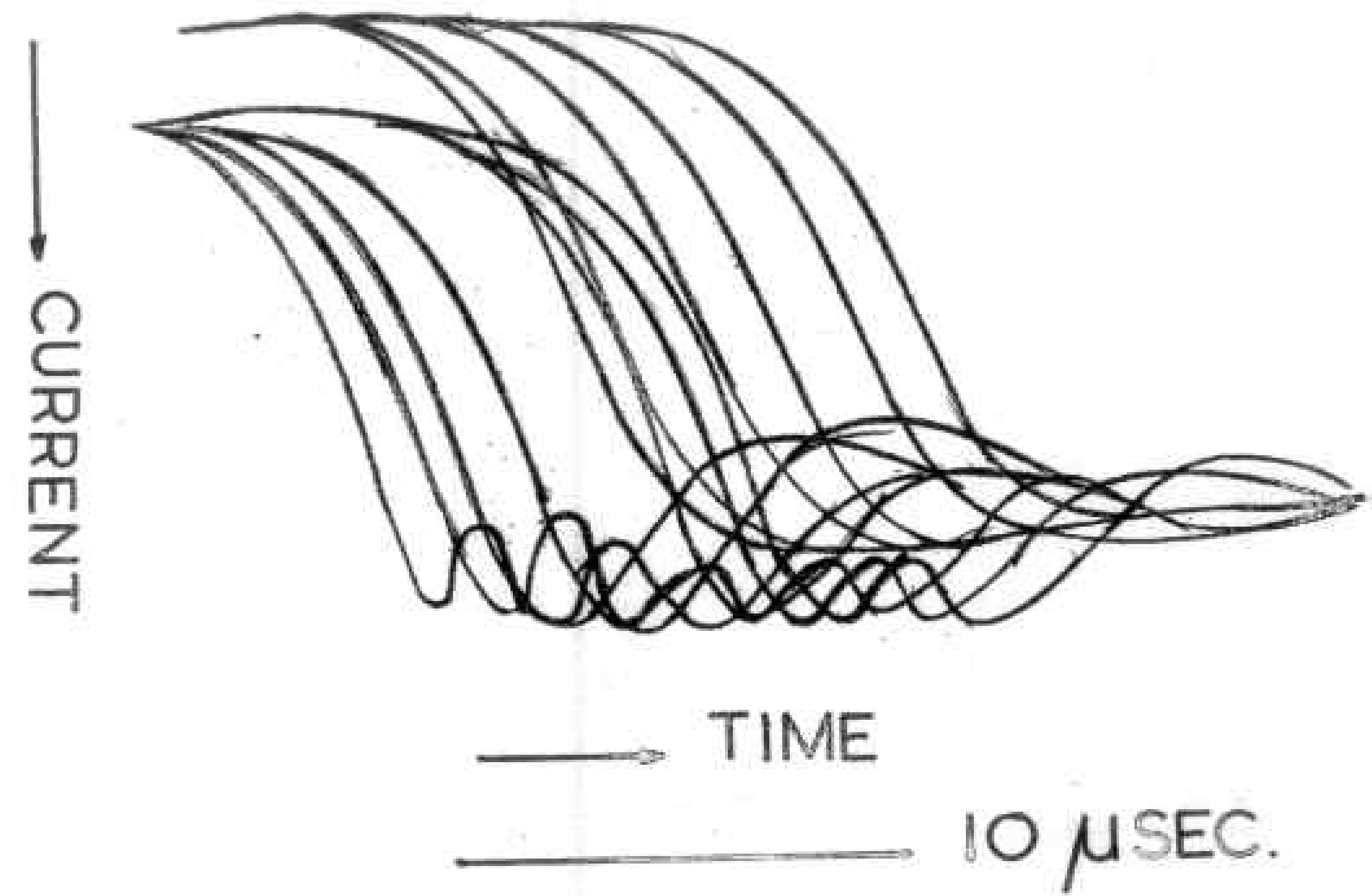
8.


volts
30
25
20
15
10
5
0
10
2
5
10^2
2
5
10^3 Hz
2
4
frequency of a.c. mains

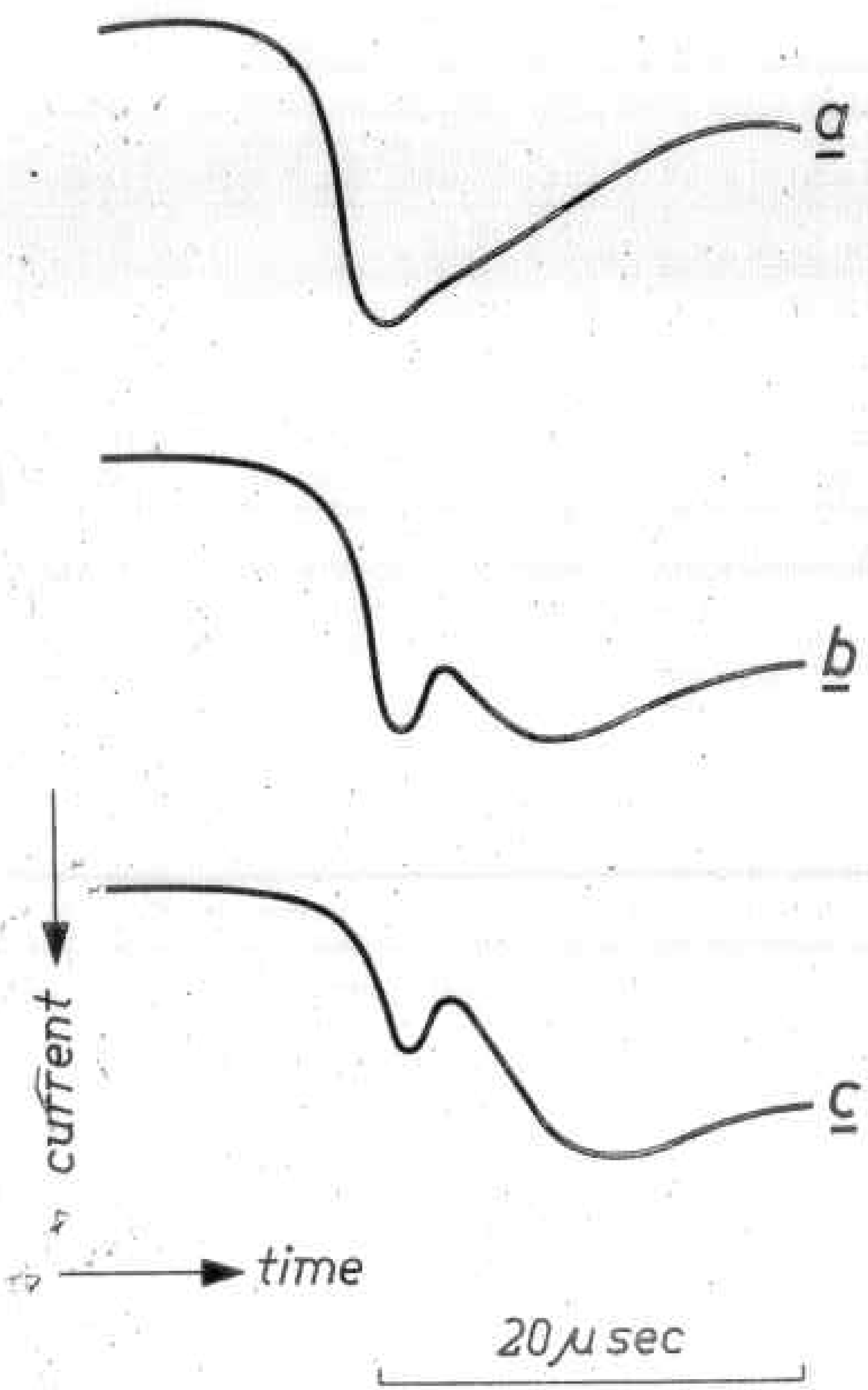
9.


decrease of re-ignition
voltage as function of
de-ionisation time
(i=2mA)
t (m sec.)
5
4
3
2
1
0
0
4
8
12
16
20
ΔV (volts)

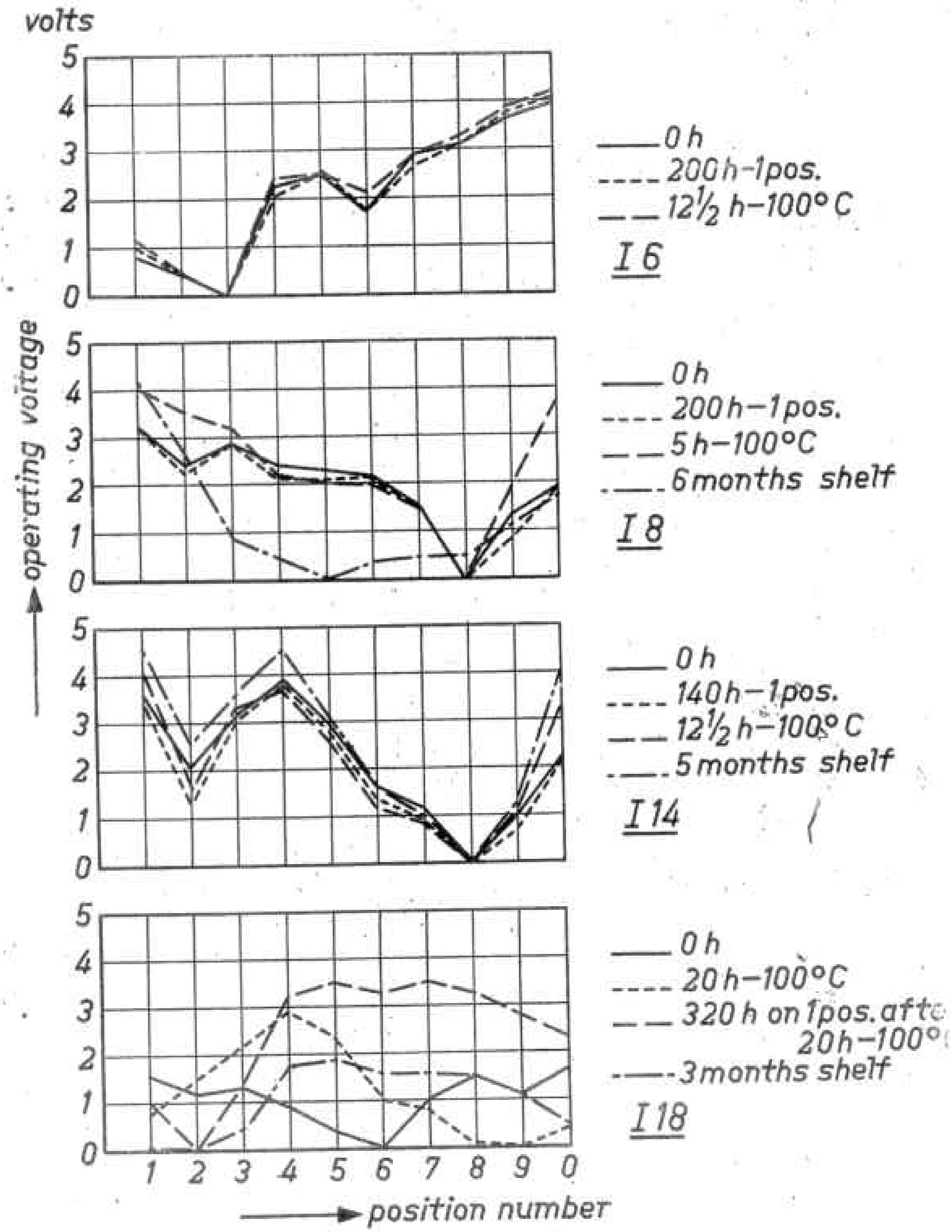

OSC.
3 kΩ
3 kΩ
150 Ω
3 kΩ
300 kΩ
~ 220V
anode
trigger
cathode
10 kΩ



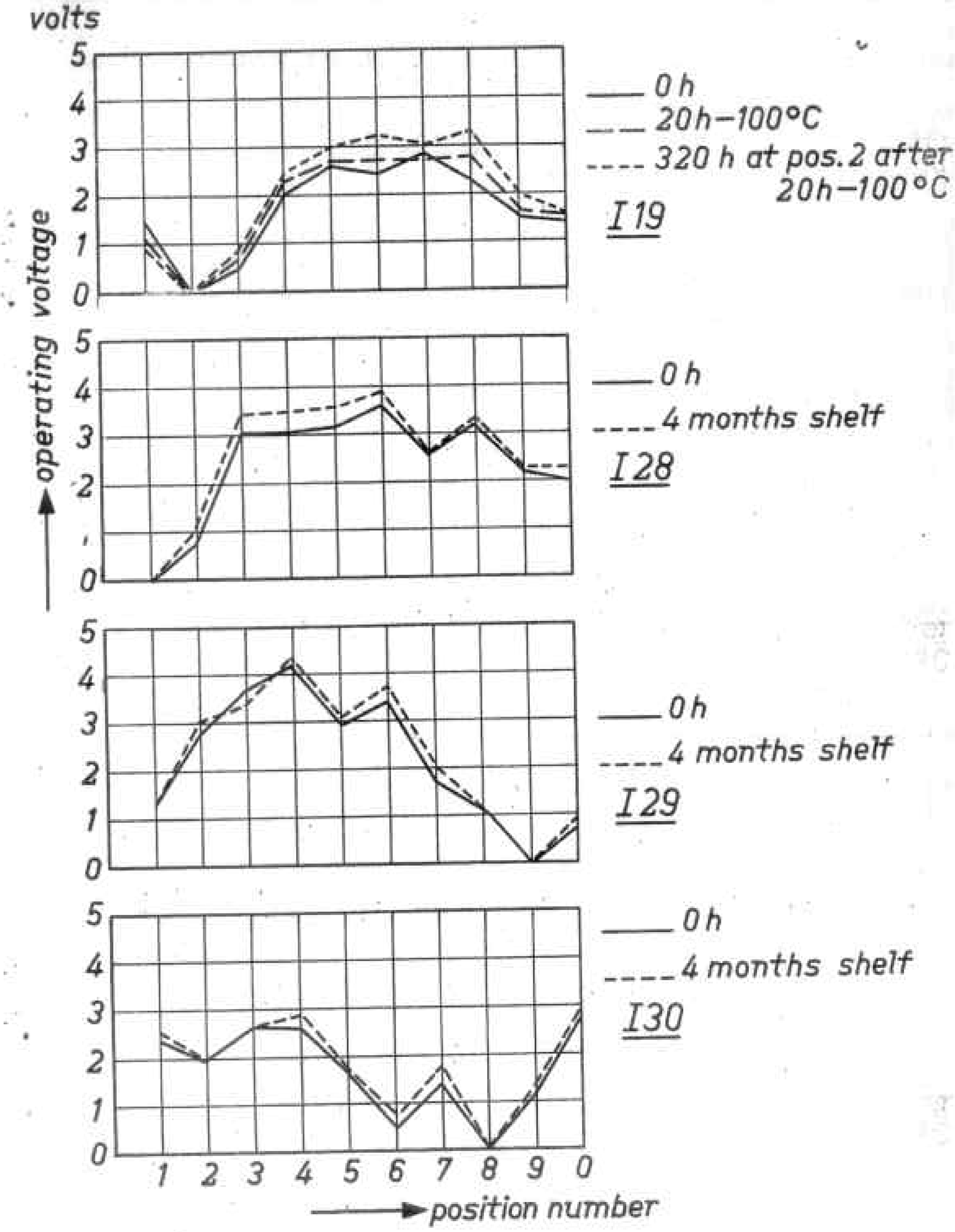
12.

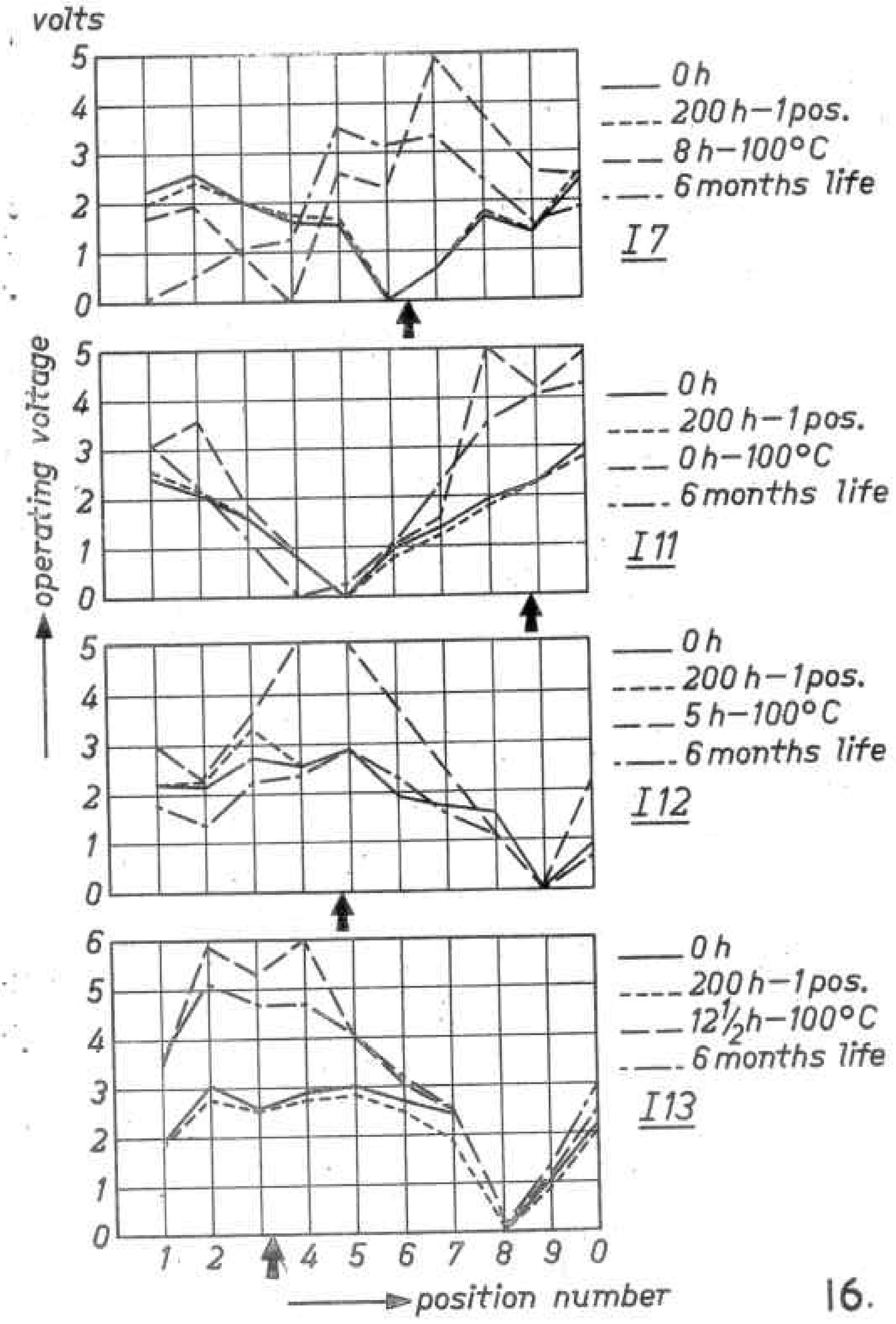


13.



volts
operating voltage
0 h
200 h-1pos.
12½ h-100° C
I 6
0 h
200 h-1pos.
5 h-100°C
6 months shelf
I 8
0 h
140 h-1pos.
12½ h-100° C
5 months shelf
I 14
0 h
20 h-100°C
320 h on 1pos. aft
20 h-100°
3 months shelf
I 18
1 2 3 4 5 6 7 8 9 0
position number


volts
operating voltage
0 h
20h–100°C
320 h at pos.2 after 20h–100°C
I 19
0 h
4 months shelf
I 28
0 h
4 months shelf
I 29
0 h
4 months shelf
I 30
1 2 3 4 5 6 7 8 9 0
position number


volts
operating voltage
0 h
200 h–1 pos.
8 h–100°C
6 months life
I 7
0 h
200 h–1 pos.
0 h–100°C
6 months life
I 11
0 h
200 h–1 pos.
5 h–100°C
6 months life
I 12
0 h
200 h–1 pos.
12½ h–100°C
6 months life
I 13
position number