A Study of the Characteristics of Glow-Discharge Voltage-Regulator Tubes

((Part 1)

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The suitability of glow-discharge tubes for use in precision electronic circuits has been investigated. A large number of tubes of several types have been examined to determine whether they show appreciably different characteristics. The work includes detailed studies of the variations in striking and running voltages for both short and long-term operation, steps and hysteresis, the effects of temperature, current overloads, vibration, stray magnetic fields, and storage. It is found that published tube specifications and characteristics are generally misleading and glow-discharge tubes are unsuitable for precision circuits unless they are specially chosen and used under carefully controlled conditions.

It is well known that a glow-discharge tube forms a very simple and inexpensive method of voltage stabilization. Such a stabilizer makes use of the substantially constant-voltage characteristic of the tube over a certain current range and is generally regarded as suitable and extremely useful for small load-current circuits[1]. Glow-discharge tubes are also extensively used in electronic stabilizers of the degenerative type for providing a reference voltage which is essential for stabilization[1,2].

For both these purposes the ideal tube should have the following properties: —

(1) There should be no drift in running voltage either due to changes of temperature or other causes when operated for any length of time and there should be an absence of spontaneous jumps in voltage.

(2) For a given tube current the running voltage should be the same after any "strike."

(3) The differential resistance should be very small.

Some work has previously been carried out by Lammchen[3], Kirkpatrick[4], Titterton[5], Cain, Clucas and the author[6,7] to determine certain characteristics of glow-discharge voltage-regulator tubes. Lammchen dealt with the variations of the characteristics with time for certain tubes, but the work was limited to periods of about 50 hours. Kirkpatrick has studied short and long-term voltage drifts together with temperature coefficient for the three American-type tubes VR75, VR105, and VR150. Titterton has examined many tubes in common use, namely types CV188, CV216 (VR150), CV1070, (7475), CV110 (S130) (VS110), VR105, 85A1, and the miniature types CV284, CV286, and CV287. His work did not, however, include measurements of long-term stability or of temperature coefficient. Cain, Clucas and the author confined their measurements to two types of tube only, viz. the type CV1070 (7475) and the type 85A1. The author[6] has also studied for several tubes the initial drifts in running voltage, which occur during the first few minutes of operation after striking.

The present article covers a much wider field than the previous ones and gives the results of detailed investigations which have been carried out over a period of more than two years on 135 new tubes of 14 different types obtained from several manufacturers. The tests were made to determine the suitability of glow-discharge tubes for use in stabilized power supplies of high stability or other precision electronic circuits and whether different types show appreciably different characteristics. Many characteristics with which few engineers are acquainted are discussed.

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The tube types examined are: CV45 (6), CV71 (6), CV188 (6), CV284 (2), CV1070 (36), S130 (19), 85A1 (34), KD60 (6), G50/1G (2), G120/1B (2), G180/2M (2), VR105 (2), VR150 (6) and NT2 (6). The figures in the brackets indicate the number of each type tested. The tubes investigated cover a voltage range of 50 to 160 volts and a current range of 0·1 to 75mA. It should also be noted that some special high-stability and miniature tubes are included as well as a few of American manufacture.

Studies of the variations in striking voltages and running voltages, including step and hysteresis effects, have been made. The temperature coefficient of each tube and its initial drift have been recorded. The effects of overloads magnetic and electric fields, vibration, and storage have been noted. Some figures for voltage drifts to be expected during the life of a tube are also included and it has been determined whether improvements can be made by ageing tubes before putting into service. In some cases tubes have been operated continuously for as long as 10,000 hours.

Striking Voltage

The striking voltage of each tube was recorded. The results, showing the upper and lower limits and the average value of striking voltage for each type of tube, are given in Table 1. In the Appendix detailed results are given for the cases where six or more tubes of one type were tested, to show the distribution of the striking voltage values.

Several tubes of each type were struck thirty times at half-minute intervals. The striking voltage of a particular tube is not constant. The maximum variations in striking voltage observed for a single tube are:

CV1070	3·5V
85A1	2·0V
CV45	10·0V with ignition electrode disconnected 4·0V with ignition electrode connected
S130	2·0V
CV71	25·0V
KD60	0·5V
CV188	1·0V
G50/1G	1·0V
G180/2M	5·0V with one anode used only 0·5V with anodes strapped or one used as ignition electrode
G120/1B	0·5V
VR105	5·0V } for tubes influenced by amount of illumination falling on them.
VR150	10.0V }
CV284	10V
NT2	1·5V

Thus, large variations in striking voltage are obtained even for tubes of the same type. It follows that specifications for the tubes would be of greater value if they quoted striking-voltage limits rather than a single average or maximum figure. All the tubes tested met the present striking-voltage specifications.

Where an ignition electrode is fitted this lowers the striking voltage considerably and for the CV45 and G180/2M tubes tested also reduces the variations a good deal. In both VR105 and VR150 types of tube a starting probe is connected from the cathode and extends to within a short distance of the anode to lower the striking voltage. The starting probe is a permanent fixture, however, so tests could not be made without it. One tube of each of the VR105 and VR150 tubes tested showed a photo-electric effect. Placing such a tube in the dark caused an increase of striking voltage of about 12 per cent over that recorded in normal daylight. It will be observed that, in some cases a single new tube may show a considerable variation in striking voltage from strike to strike. This appears to be an ageing effect, possibly caused by changes at the cathode surface, the striking voltage starting at a high value and being reduced a good deal during the first few strikes.

TABLE 1.—VARIATIONS IN STRIKING VOLTAGES.

TUBE TYPE	LIMITS OF STRIKING VOLTAGE (V)	AVERAGE VALUE OF STRIKING VOLTAGE (V)
CV1070* ..	111–134	120.7
85A1* ..	110.5–116.5	113.2
CV45 ..	115–125†	120.6†
	145–158‡	153.2‡
S130 ..	141.5–175	158.2
CV71 ..	140–170§	151.2§
KD60 ..	74–80	76.7
CV188 ..	106.5–118	112.3
G50/1G ..	72.5– 80	76.3
G180/2M ..	161–181‖	171.0‖
	159–161¶	160.0¶
G120/1B ..	94.5–102	98.3
VR105 ..	111 –125**	113.5‡‡
VR150 ..	131–172††	154.0‡‡
CV184 ..	87– 97	92.0
NT2	61– 72	64.7

KEY FOR TABLE 1

* *The tubes were not all obtained at the same time but in batches over a period of two years.*
† *Ignition electrode connected to 220V* D.C. *positive through a 54k Ω resistor.*
‡ *Ignition electrode not connected.*
§ *Independent of whether glass bulb is rendered opaque, as required by specification, or not.*
‖ *With one anode used only, other disconnected.*
¶ *With two anodes strapped or one connected to 220V* D.C. *positive through a 100k Ω resistor.*
‡‡ *For the tube influenced by amount of illumination falling on it, the figure obtained in ordinary daylight is used in calculating the average value.*
** *Includes one tube which was influenced by amount of illumination falling on it. This tube struck at 116 volts in ordinary daylight and 125 volts in the dark.*
†† *Includes one tube which was influenced by amount of illumination falling on it. This tube struck at 131 volts in ordinary daylight and 147 volts in the dark.*

Running Voltage

VARIATIONS IN CHARACTERISTICS

The current-voltage characteristic of each tube was obtained as the current was varied from its maximum to minimum value. Figs. 1, 2 and 3 show the wide variations obtained when a fairly large number of tubes are examined. The running-voltage variations from tube to tube of the same type and for a single tube are given in Table 2.

The characteristics of several tubes of each type were taken 30 times, the tubes being extinguished and restruck each time. Such characteristics differ slightly, but in general the voltage at a given value of current is reproducible to within less than 0·5V. The CV71 tube is an exception. In this case, for a given value of current variations of up to 5V are common after two successive strikes, and the large regulation associated with this tube seems

TABLE 2.—VARIATIONS IN RUNNING VOLTAGE

TUBE TYPE	VARIATION FROM TUBE TO TUBE (V)	VARIATIONS FOR SINGLE TUBE (V)	
		Maximum	Mean
CV1070	87.5–109.5	3.4	1.9
85A1	82.0– 87.0	2.9	1.3
CV45*	115.0–121.5	3.0	2.5
S130	114.0–131.5	11.3	3.3
CV71	124.5–163.0	32.5	30.0
KD60	58.5 61.5	0.8	0.6
CV188	83.5 – 92.0	6.9	3.9
G50/1G	52.0–57.0	0.6	0.5
G180/2M	151.5–160.5†	7.2†	6.7†
	151.0–160.0‡	9.1‡	7.0
G120/1B	53.0– 58.5	3.0	2.9
VR105	105 –106.5	1.5	1.0
VR150	149.0–159.5	8.5	4.5
CV284	67– 73.5	5.0	4.8
NT2	48.5– 60.5	4	3.4

KEY FOR TABLE 2

* *Ignition electrode connected to 220V* D.C. *positive through a 54kΩ resistor.*
† *One anode connected only.*
‡ *Both anodes connected in parallel or one used as ignition electrode.*

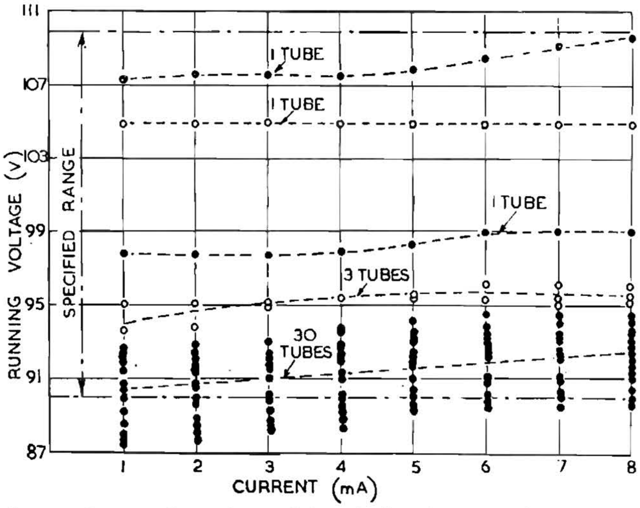
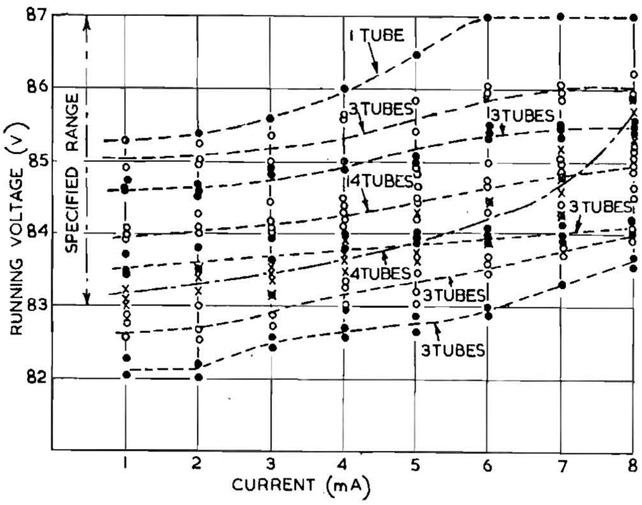


Fig. 1. Current-voltage characteristics of glow-discharge voltage-regulator tubes, type CV1070

The tubes are grouped into comparable characteristics; the dotted lines show the mean curves and the points indicate the spread about them. The specified range is also indicated.

Fig. 2 Current-voltage characteristics of glow-discharge voltage-regulator tubes, type 85A1



to suggest that the glow is abnormal. Further, for this type of tube, and this only, the running voltage is greater than the striking voltage over a large part of the current range. This is presumably due to the small electrode spacing for the gas pressure employed.

For the 85A1 type the current-voltage characteristic of a given tube is reproducible, within the range 3·5 to 8mA to better than 0·1V.

In any tube, apart from certain discontinuities to be described later, there is a rise of voltage with increase of current which is sometimes attributed to voltage-drop variations outside the cathode dark space.

Many of the tubes tested had running voltages well outside the limits quoted in specifications as can be seen from a glance at Figs. 1, 2 and 3, and Table 2.

To keep the variations in the characteristics of tubes of the same design and of an individual tube over a long operating period small, certain high-stability tubes have been produced. Jurriaanse[8] has demonstrated that the glow discharge itself can liberate contaminations from the glass walls which contaminate the cathode and vary the working voltage. In the 85A1 high-stability tube there is a sputtered layer of molybdenum on the walls which serves as a shield between the glow discharge and the

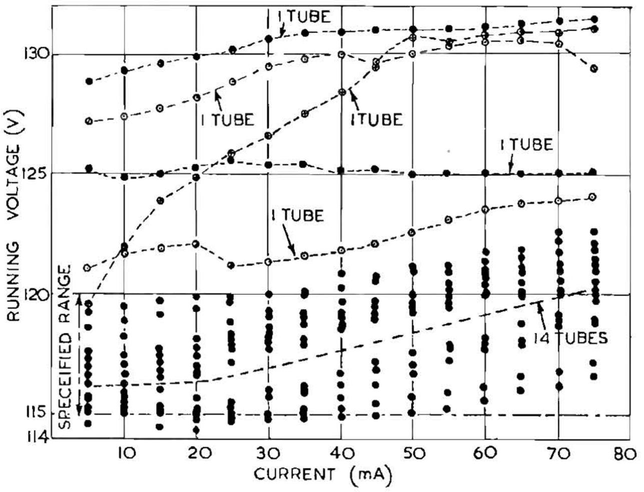


Fig. 3. Current-voltage characteristics of glow-discharge voltage-regulator tubes, type S130

envelope and also acts as a getter[9]. High-stability tubes can also be produced by using potassium-activated cathodes of the type described by Chilcot and Heymann.[10] Such cathodes are obtained by coating a non-reacting metal base, which is usually nickel or nickel-iron alloy with potassium. The coating is produced by distillation in vacuo during the final pumping of the tube. The KD60 type is of this class.

It will be observed from Table 2 that even the high-stability tubes show considerable running-voltage variations, especially from tube to tube.

Hysteresis Effects

The current-voltage characteristics of tubes are not the same for increasing and decreasing currents, but may vary considerably, giving a "hysteresis" effect which has previously been reported by Titterton[4]. For the majority of tubes the voltage is higher at a given value of current when the current is decreasing than when it is increasing. Some tubes, however, show the reverse effect while several of the S130 type give characteristics of the complicated nature shown in Fig. 4. The hysteresis effects in the CV71 and 85A1 tubes are of particular interest. In the CV71 types the characteristics for increasing and decreasing currents are usually identical below about 2mA (Fig. 5). In the 85A1 types, hysteresis is absent above a current of about 3·6mA (Fig. 6) and even below this the effect is small. The hysteresis effect is reported to be dependent on the frequency at which the current is varied[11], but detailed work on these lines has not been undertaken in the present investigation.

Tube specifications make no mention of these hysteresis effects.

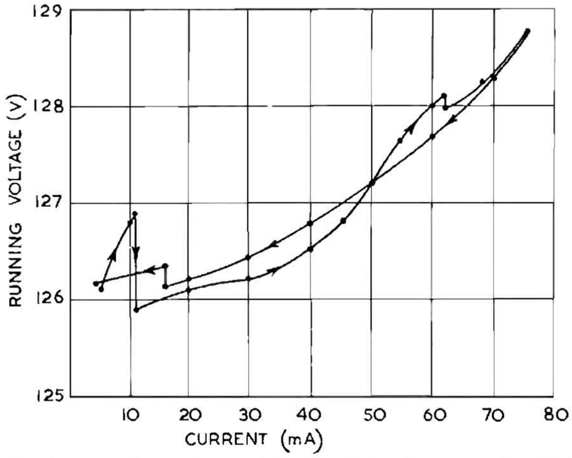


Fig. 4. Current-voltage characteristics, typical of several glow-discharge voltage-regulator tubes type S130, for increasing and decreasing currents

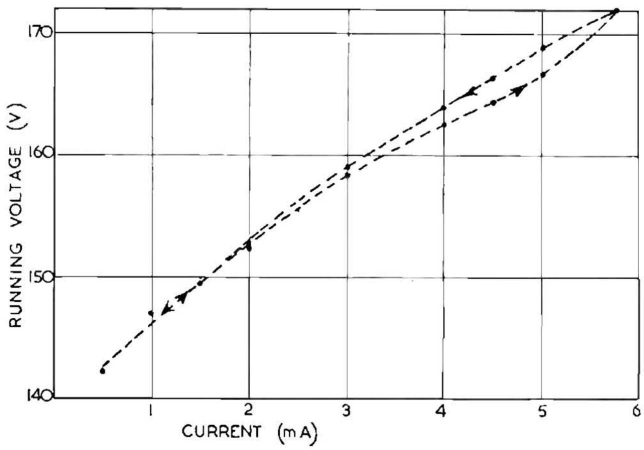
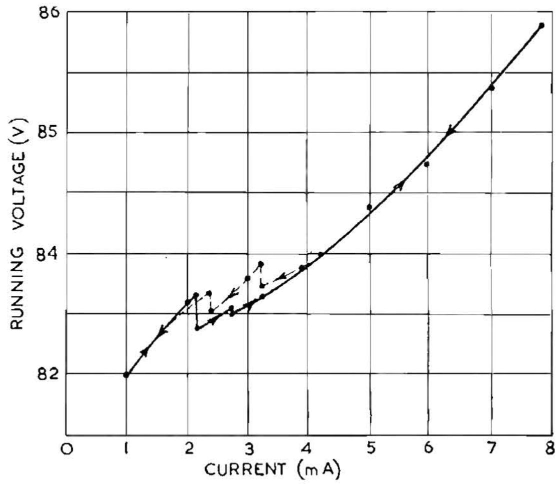


Fig. 5. Typical current-voltage characteristics of glow-discharge voltage-regulator tube type CV71 for increasing and decreasing currents

Fig. 6. Typical current-voltage characteristics of glow-discharge voltage-regulator tube type 85A1 for increasing and decreasing currents



Step Effects

As the current through a tube is varied slowly from one limit to the other, it is usual to observe sudden changes in voltage called steps, jumps, or negative-resistance discontinuities which generally occur simultaneously with pronounced changes in the area of the cathode covered by the glow. They can be explained by the fact that the cathode surface is generally not homogeneous. Thus, as the current is increased, the glow at certain points on the surface will be abnormal although it is normal for the major part.

In most cases these negative-resistance regions are mainly to be found at the lower end of the current-voltage characteristic. All tubes do not exhibit the steps, many show one only but several have up to 10 in the current range. The steps rarely occur at the same currents for increasing and decreasing paths, and there is frequently a different number in both directions. They are not always reproducible at the same current values in the characteristics.

The steps occur in tubes of all types tested except the CV71 which has a very large regulation. It sometimes happens in tubes of the S130 type that the voltage at maximum current is less than at minimum current due to the large steps. A typical example is illustrated in Fig. 7 where a step of about 2·4 volts is observed. In

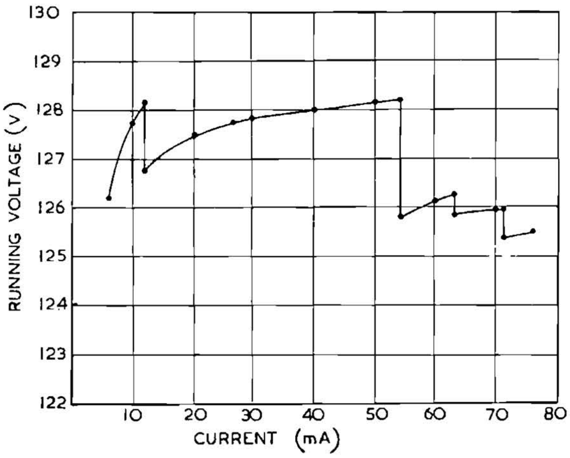


Fig. 7. Typical current-voltage characteristic of glow-discharge voltage-regulator tube type S130

the 85A1 tubes all steps occur below 3·5mA and are small. For these tubes the glow seems to expand uniformly over the cathode surface probably due to careful preparation and cleaning of the molybdenum.

Relaxation-oscillation troubles have been experienced when large capacitors are placed in parallel with glow-discharge tubes. Such oscillations are, presumably, associated with the negative-resistance portions of the current-voltage characteristic curves of the tubes.

As in the case of hysteresis effects it appears that steps are never shown on curves published by manufacturers or in valve manuals. Some care must be taken, however, when deciding on the value of current through a tube to avoid locating it near a step.

Analysis of Stabilizer Performance from a Knowledge of the Current-Voltage Characteristic

An analysis of a simple glow-discharge tube voltage-stabilizer circuit is readily possible and has often been made by assuming the current-voltage characteristic of the tube is linear[12,13].

If the equation of the characteristic is represented by the expression:—

$$V = xI + v \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where V is the voltage, I is the current, x the slope of the curve and v the intercept of the characteristic on the V axis, then it is easily shown that for the circuit of Fig. 8

$$dV/dVi = x/\{x + R + Rx/R_l\} \quad \ldots\ldots \quad (2)$$

if R_l is constant

and

$$dV/dI_l = -Rx/(R + x) \quad \ldots\ldots\ldots\ldots \quad (3)$$

if Vi is constant.

In general the characteristic is very much more complicated than that represented by Equation (1). It is seen from Figs. 1, 2 and 3 that the values of both x and v vary over a wide range from tube to tube and x is also a func-

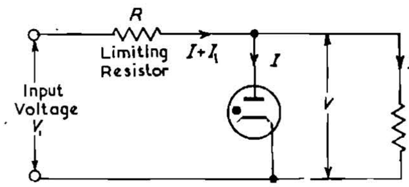


Fig. 8. Simple glow-discharge tube voltage-stabilizer circuit

tion of current. It is pointed out later that x is also a function of life. Thus, a value of x can only be ascribed to a specific tube and a given operating point at a given time.

Temperature Effects

Variation of Running Voltage with Temperature

The tubes were each run at a constant current through a variation of ambient temperature from 20°C to 100°C by placing them in either a water-bath or a small electrically-heated oven. The maximum and average temperature coefficients of running voltage are given in Table 3.

TABLE 3—TEMPERATURE COEFFICIENTS OF RUNNING VOLTAGE

TUBE TYPE	TEMPERATURE COEFFICIENT OF RUNNING VOLTAGE mV/V/°C.	
	Maximum	Average
CV1070	−0.30	−0.07
85A1	−0.08	−0.03
CV45	−0.17	−0.11
S150	−0.35	−0.18
CV71	+1.89	+1.23
KD60	−0.28	−0.25
CV188	−0.36	−0.21
G50/1G	−0.86	−0.52
G180/2M	−0.05	−0.02
G120/1B	−0.26	−0.22
VE105	+0.14	+0.10
VR150	*	*
CV284	−0.37	−0.29
NT2	−0.28	−0.20

KEY FOR TABLE 3

** This type shows either positive or negative temperature coefficients. For the tubes tested the limits are −0·09 and +0·10.*

Variation of Striking Voltage with Temperature

Attempts to measure the variation of striking voltage with temperature were unsuccessful because the variations obtained are of the same order of magnitude as those already discussed for the case of successive strikes of a tube at constant temperature.

Discussion of Results

Most tubes exhibit a negative temperature coefficient, i.e. the running voltage drops as temperature increases, although three types of tube tested show positive ones. Tubes, even of the same type, give widely different results, in fact, some tubes have a practically constant running voltage throughout the whole temperature range.

Jurriaanse[14] has ascribed the negative temperature coefficient to a small variation in the gas density in the region of the cathode. Considering the discharge tube divided into two parts (1) the cathode region with temperature T_c, volume V_c and gas density ρ_0 and (2) the rest of the tube with temperature T, volume V and gas density ρ then the density near the cathode is given by the expression:

$$\rho_c = \rho_0 / \left\{ V_c/V_t + VT_c/V_tT \right\} \ldots (4)$$

where $V_t = V_c + V$

and $\rho_0 = (\rho V + \rho_c V_c)/V_t$.

If the temperature T rises, ρ_c is seen to increase. It is found that an increase of ρ_0 produces a drop in tube running voltage.

It is thought that the few positive temperature coefficients observed may be caused by cathode-surface conditions in these tubes changing with temperature producing an increase of running voltage greater than the drop produced by gas-density variations.

Tubes operate normally at ambient temperatures of 0°C and 100° C for short periods. Life tests with such conditions have not been undertaken.

Temperature coefficient of running voltage decreases, in general, with life. The reduction amounts to about 25 per cent during the first 8000 hours of continuous operation in the case of 85A1 tubes.

TABLE 4—MAGNITUDES AND DURATIONS OF INITIAL DRIFTS

TUBE TYPE	MAXIMUM DRIFT (percentage of running voltage)		AVERAGE DRIFT (percentage of running voltage)		TIME FOR RUNNING VOLTAGE TO BECOME APPROX. STEADY (MIN.)		TUBE CURRENT
	+	−	+	−	Max.	Average	(mA)
CV188 ..	0·61	0	0·25	0	17	10	10
CV1070 ..	0.05	0.23	0·03	0·17	12	11	8
S130 ..	3·39§	1·35§	1·55§	0·61	*	*	75
85A1 ..	0·21	0·06	0·16	0·01	2·5	2·0	8
KD60 ..	0·02	0·23	0·01	0·14	16	10	2·5
CV71 ..	2·65	0·58	1·68	0·33	8	5	6
G50/1G ..	0	2·20	0	1·73	19	15	0·5
G180/2M† ..	0·98	1·75	0·84	1·56	23	21	40
G120/1B ..	0	2·12	0	1·75	14	9	30
CV45‡ ..	2·78§	0·66§	1·88§	0·26§	*	*	75
VR105 ..	1·10	0	0·74	0	15	11	40
VR150 ..	0·48§	0·44§	0·32§	0·35§	¶	¶	40
CV284 ..	3·29	0	3·07	0	25	22	20
NT2	2·21‖	3·29‖	1·78‖	1·66‖	**	**	1

KEY FOR TABLE 4

§ *After* 15 *minutes operation.*

* *Still drifting at random after* 30 *minutes operation. The variations are accompanied by abrupt changes in the area of cathode covered by the glow.*

† *One anode only connected.*

‡ *Ignition electrode connected to* 220V D.C. *positive through a* 54kΩ *resistor.*

¶ *Some tubes still drifting at random after* 20 *minutes operation, in others the running voltage becomes approximately steady after* 10-15 *minutes.*

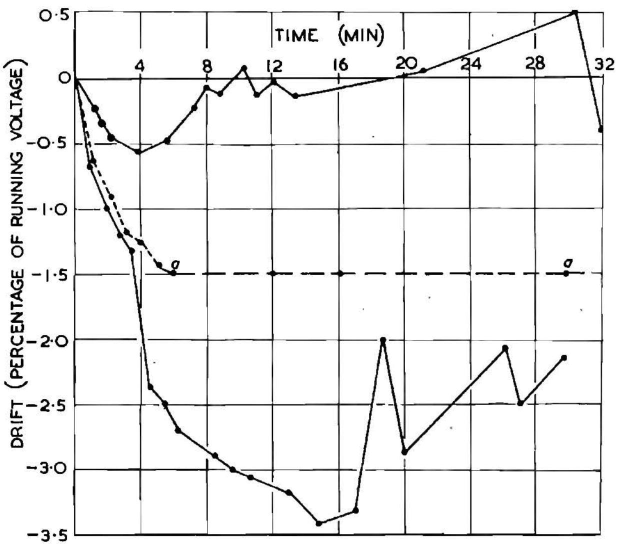
** *Still drifting at random after* 30 *minutes operation.*

‖ *After* 30 *minutes operation.*

Initial Drift

Measurements have been made of the high rates of drift in running voltage which occur in all glow-discharge tubes in the first few minutes of operation after striking. It is frequently desired to know what time elapses after striking a tube before this initial drift ceases or becomes negligible, particularly in the case of electronic voltage stabilizers where glow-discharge tubes are commonly used as reference elements. The magnitude, duration and direction of the drifts to be expected in the various types of tube have been determined. The dependence of the drift on tube current and tube age have also been noted.

Fig. 9. Curves showing typical initial drifts of S130 glow-discharge tubes
Over the region aa of the dotted curve the voltage was varying rapidly at random about the mean value indicated.



Measurement of Drift

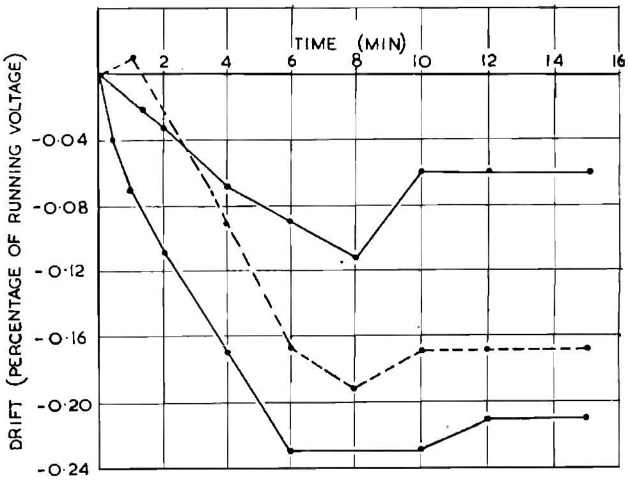
The drifts of running voltage in the first few minutes of operation of the tubes were recorded several times. Tubes were allowed to cool down to ambient temperature each time before restriking. In each case a known fraction of the tube voltage was compared with the voltage of a standard cell using a potentiometer.

Results and Discussion

Table 4 shows the magnitudes and durations of the drifts observed for the various types of tube when they were operated at maximum current. In each case this current was held constant to within ± 0·1 per cent throughout the test. Typical curves which give some idea of the manner in which the drifts vary with time are shown in Figs. 9-12.

Large variations in the magnitude of the drifts occur from tube to tube even of the same type and also from operation to operation for the same tube. The smallest drifts are obtained in the cases of the 85A1, KD60, and CV1070 types, but the 85A1 type has the advantage that its running voltage becomes steady in a very short time.

Fig. 10. Curves showing typical initial drifts of CV1070 glow-discharge tubes



In fact, there is very little drift in most tubes of this type after 1 minute's operation. No negative drifts are observed in the CV188, CV284 and VR105 tubes and no positive drifts in the G50/1G and G120/1B tubes, but for the other types both positive and negative drifts are obtained.

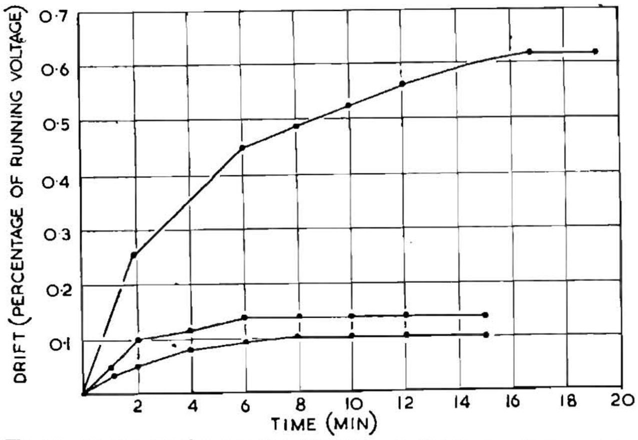


Fig. 11. Curves showing typical initial drifts of CV188 glow-discharge tubes

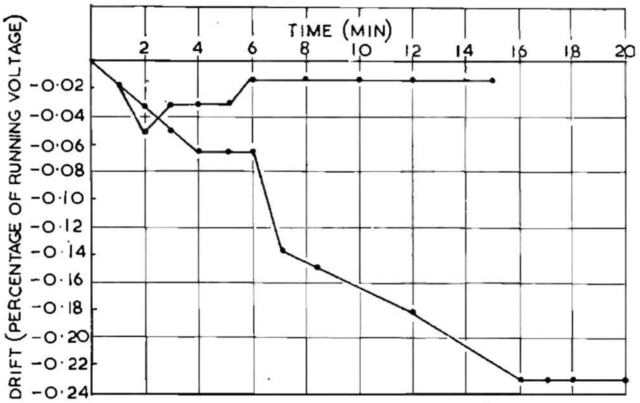


Fig. 12. Curves showing typical initial drifts of KD60 glow-discharge tubes

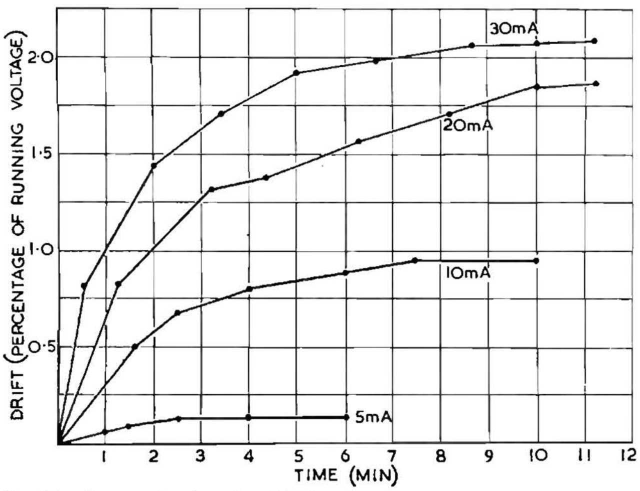


Fig. 13. Curves showing the initial drifts of a typical G120/1B glow-discharge tube at various currents

The largest drifts occur in the case of the S130 type tubes and may be as great as 3·39 per cent of the running voltage in the first 15 minutes.

One interesting fact arises from the tests in that it appears for a given type of tube that the duration of the drift can be predicted fairly accurately.

It is also of interest to note that the maximum drift for the 85A1 type tubes quoted in Table 4 is greater than the figure quoted by the manufacturers for the stability over a period of 1000 hours[15]. Presumably, therefore, the manufacturers ignore this rapid initial voltage-variation when quoting the characteristics of tubes.

The initial drift is markedly dependent on tube current and increases with tube age. From Fig. 13, it can be seen that both the magnitude and durations of the drifts increase with current. The curves illustrated are typical of the G120/1B tubes, but other types behave in a similar way. For example at 5mA, the drift in CV188 tubes ceases, in general, after 3 or 4 minutes' operation, while at 2mA there is practically no drift at all and what little there is ceases in a time less than 1 minute.

Accurate measurements to ascertain how tube age affects the initial drift were confined to the 85A1 type of tube. Several such tubes were tested after running continuously for 200, 500, 1500 and 7000 hours respectively. After both 200 and 500 hours operation there is little change in drift from when the tubes are new but noticeable increases in the magnitude of the drift may be detected after 1500 and 7000 hours respectively. Typical results are given in Fig. 14. There appears to be no change in the duration of drift with life.

It seems that while some of the initial drift observed may be due to changes of gas density in the region of the cathode caused by variation of temperature, much of it is produced by the surface conditions at the cathode changing slightly and hence varying the cathode drop during the warming-up period of the electrodes and envelope of the tube.

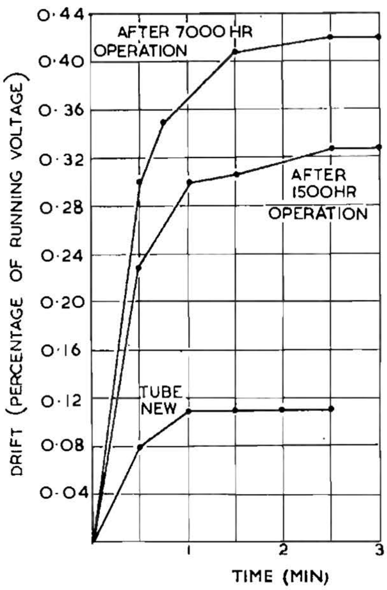


Fig. 14. Curves showing the initial drifts of a typical 85A1 glow-discharge tube at various stages throughout its life

(*To be continued*)

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