# Corona Discharge Tubes for Voltage Stabilization

By E. E. Shelton* and F. Wade†

CORONA stabilizer tubes are low current, constant voltage devices. Before dealing with their characteristics and manufacture it will be useful first to look briefly at the general current versus voltage characteristic curve observed during the conduction of electricity through a gas at a pressure of the order of a few millimetres of mercury. Fig. 1 shows such a curve, with the current scale expanded towards zero as a convenient way of showing the very small currents in the region OABCD. In a tube with two electrodes, say parallel planes or concentric cylinders, situated in a low intensity of weakly ionizing radiation (as is always the case with the natural background of radioactivity and cosmic radiation) then as the potential difference between the electrodes is slowly increased from zero, we find that more and more of the ions generated between the electrodes are collected (OA) until saturation is reached. Further increase of voltage produces no new effects (B) until gas multiplication starts (C). With increasing voltage, ionization by collision increases (CD), until a point (E) is reached where the discharge is unstable. If the voltage is increased beyond this point a continuous discharge commences. This is called a corona discharge. The current is of the order of a few microamperes, and in the dark a faint glow can be seen near the anode. This voltage is usually referred to as the " sparking " voltage or " striking " voltage, but it will be referred to here as the stabilizing voltage ($V_s$) since this is the region in which corona stabilizers operate.

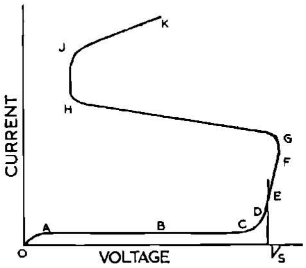



**Fig. 1. General current/voltage characteristic for conduction of electricity through a gas**

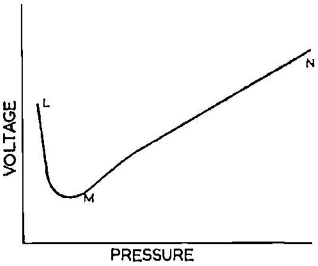



**Fig. 2. General voltage/pressure characteristic**

If the two-electrode tube is now operated with a series resistor of adequately high value, and the current through the tube is increased, it will be found that there is a region (EF) over which the voltage across the tube increases only slightly although the current is increased by a factor of 20 or even more. Next there is a region (FG) where the voltage remains constant while the current increases, after which the voltage across the tube decreases as the current increases (GH), i.e., the incremental resistance of the tube becomes negative, and if the series resistance is low enough, the mode of operation passes suddenly into that of the " glow " discharge, when a bright glow appears on the cathode surface. Over the region HJ this glow spreads over a larger area of the cathode as the current increases. This is the region in which the more familiar cathode-glow stabilizers work. Finally, after the cathode is completely covered with the cathode glow, further increase in current again produces an increase in voltage across the tube.

It is well known that the stabilizing voltage ($V_s$) is dependent on both the field between the electrodes, and the gas pressure; the general relation between $V_s$ and pressure is shown in Fig. 2, and we shall examine this relationship in more detail later, but only over the region marked MN.

The work reported here was undertaken because a need had arisen for stabilizing the voltage supply to low voltage halogen quenched Geiger-Muller counter tubes[1]. The statement of requirements specified that the output voltage should be approximately 400 volts and should be stable over a wide range of input voltage; the current consumption should be as low as possible and the external dimensions should be as small as practicable. Work already published had been confined to tubes having stabilized outputs of 1 000 volts or more[2] and a preliminary survey in the same voltage range had also been made by Jaques[3] at A.E.R.E. It was decided to limit the work to electrodes consisting of concentric cylinders with the central cylinder or wire used as the anode.

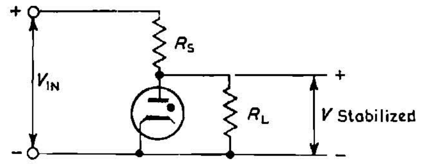



**Fig. 3. Basic circuit for stabilizer or regulator tube**

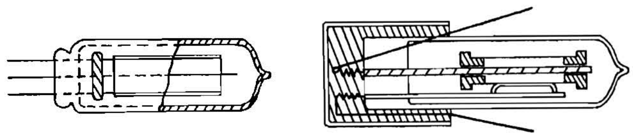


**Fig. 4. Construction of experimental corona discharge tubes**

### The Regulating Circuit

Circuit design considerations have been dealt with in considerable detail in a recent article by Lichtman[4] but we shall consider only the simplest statement of the circuit and tube relationship. The basic circuit is shown in Fig. 3. The slope of the voltage versus current curve for the tube from the commencement of the corona discharge to some chosen current within the allowable range, is very approximately constant; this incremental resistance we denote by $R_c$. The external series resistance is $R_s$. It can be seen by inspection, that when $R_1$ the load resistor is infinite, the ratio of voltage variation on the output to the voltage variation on the input is:—

$$s = \frac{\Delta V_s}{\Delta V_{in}} = \frac{R_c}{R_c + R_s}$$

This factor is referred to as the stabilization ratio.

It is obviously desirable for $s$ to be small, so $R_c$ must

* *Nucleonic and Radiological Developments, Ltd.*
† *Atomic Energy Research Establishment.*

be as small as possible, and $R_s$ as large as possible. In some applications the parallel load $R_1$ may be appreciable, in which case as the value of $R_1$ decreases or that of $R_s$ increases, the applied voltage must be made greater in order for the voltage on the tube to reach the striking potential $V_s$; the disadvantage of this is self-evident, and clearly $R_1$ should be kept as large as possible.

## Tube Construction and Processing

Fig. 4 shows two constructions used in experimental tubes. In Fig. 4(a) a tubular nickel cathode is shown mounted concentrically about a nickel anode wire. The two cathode support wires and the anode wire are held in position by a glass bead, and are sealed into a glass bulb. The tube in Fig. 4(b) employs a slightly different method of construction; the anode wire is held in position with the aid of a ceramic insulator at each end of the cathode. A single wire is welded to the cathode, the assembly then being sealed into a glass bulb. When processing is complete, a cover filled with a suitable wax is placed over the seal for protection and to enable the flexible leads to be anchored firmly at the seal.

In the development work, many types of experimental tubes were made, until it was finally decided to standardize on a cathode of 6mm diameter and 30mm length, and an anode of 0·75mm diameter. Evacuation and gas filling were carried out through a small diameter glass tube

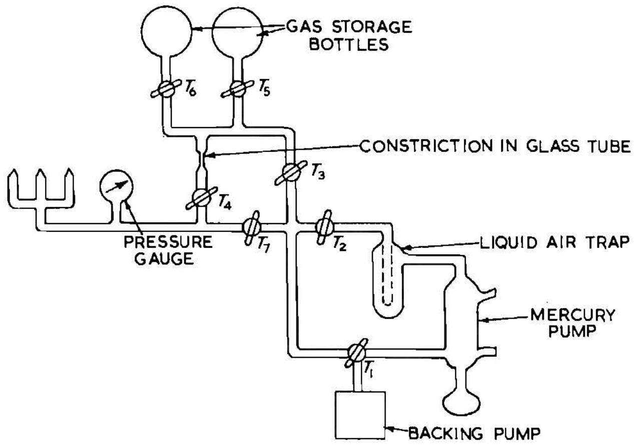



**Fig. 5. Exhaust and filling system for experimental tubes**

sealed to the end of the bulb. When the exhaust and filling operation was complete the tube was sealed off as shown.

The experimental tubes were processed to a schedule which consisted of baking at 360°C for 15 minutes while the tube was being pumped at a pressure of less than $10^{-5}$mm of mercury.

At the end of the bake, the tubes were allowed to cool and the cathodes were outgassed by eddy-current heating until a temperature of 700-800°C was reached. Gas filling took place after the tubes had cooled down to room temperature, and the performance as stabilizers was investigated while they were still on the filling system; after this they were sealed off for further tests.

The investigation of the behaviour of many gases and gas mixtures necessitated building a special pumping and filling apparatus; Fig. 5 shows this diagrammatically. When gas mixtures were prepared on the pump, the volume between $T_4$, $T_5$ and $T_6$ was evacuated via $T_3$ to eliminate the possibility of diffusion of the first gas into the storage bulb of the second gas. In order to let in small amounts of gas, a small bore constriction was included in the filling line between the storage bulbs and the manifold. By this means it was possible to increase the pressure very slowly.

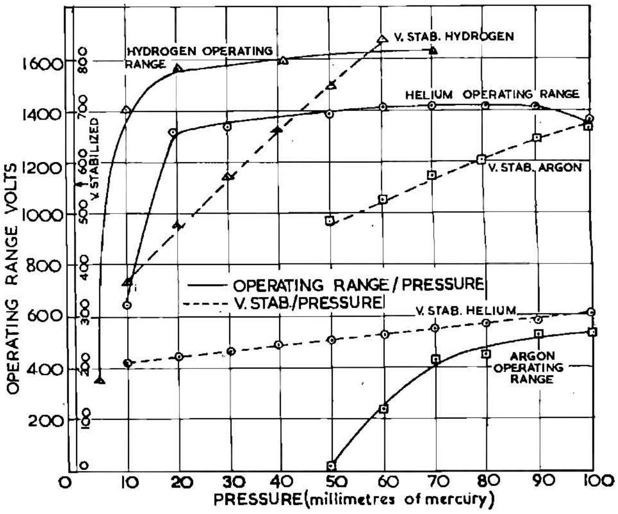



**Fig. 6. $V_s$ and operating range versus pressure**

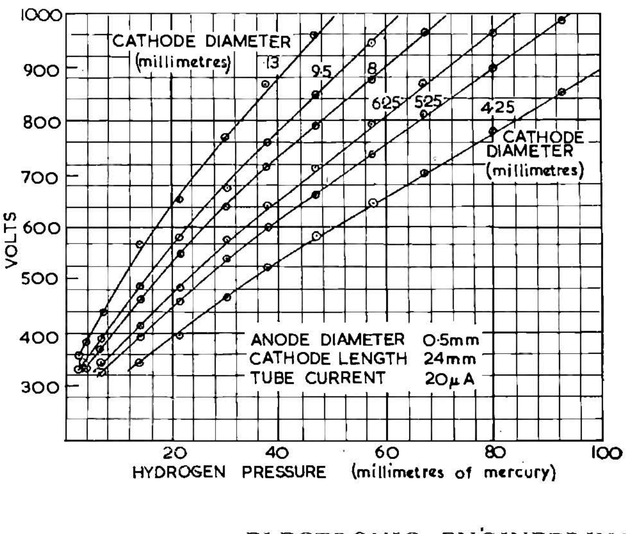
## Tube Characteristics—Experimental Results

The corona discharge tube characteristics to be investigated are, the stabilizing voltage $V_s$, the incremental or A.C. resistance $R_c$, and corona range or the range of current over which the regulating action is satisfactory. "Operating range" for the purpose of the investigations recorded in Fig. 6, is defined as the change of input voltage necessary to increase the tube current from $I_{min}$ to 100$\mu$A at $V_s$. Throughout the experiments related to Fig. 6, the value of $R_s$ was 20M$\Omega$, and that of $R_1$ was 10M$\Omega$. The top limit of 100$\mu$A was chosen because small current consumption was one of the requirements stated at the commencement of this work. Later work has shown that tube currents of several hundred microamperes may be passed before $I_{max}$ is reached. In some gases it has been found that $I_{max}$ is set by the onset of the glow discharge, but with hydrogen it is the commencement of oscillations which is the determining factor. When the tube current is reduced, it is found that there is a limit, viz., $I_{min}$ set either by a type of oscillation, or by the sudden cessation of the discharge.

It is reasonable therefore, to state the useful range of a given tube by quoting $I_{max}$ and $I_{min}$; it will also be necessary to state maximum and minimum safe operational currents to be observed by users of these tubes.

Fig. 6, which is a plot of $V_s$ and operating range

**Fig. 7. $V_s$ versus pressure with various cathode diameters**



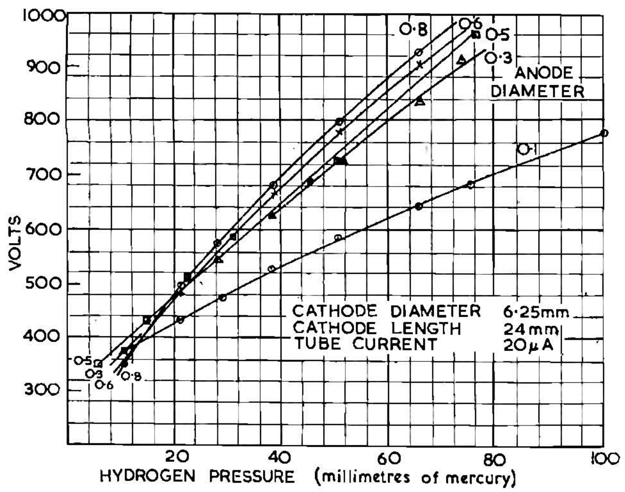



**Fig. 8.** $V_s$ versus pressure with various anode diameters

against filling pressure, shows the differences which can arise from the choice of the filling gas. Fig. 7 gives the results obtained for $V_s$ when the anode diameter, cathode length, and tube current are maintained constant, and cathode diameter and gas pressure are varied.

Fig. 8 is a similar plot for fixed cathode diameter, cathode length, and tube current, while anode diameter and gas pressure are varied. The general (and not unexpected) conclusion from these results is that $V_s$ increases with gas pressure, cathode diameter, and anode diameter.

Figs. 9 and 10 show the general dependence of $R_c$ on electrode geometry and gas pressure. It will be seen that $R_c$ increases with gas pressure and cathode diameter, but that it decreases as the anode diameter increases.

The effect of asymmetry of the cylindrical electrode structure has also been investigated, and it has been found to have relatively little effect on $V_s$, but a very marked effect in lowering $I_{max}$. This is illustrated in Figs. 11(a) and (b).

## Life Tests

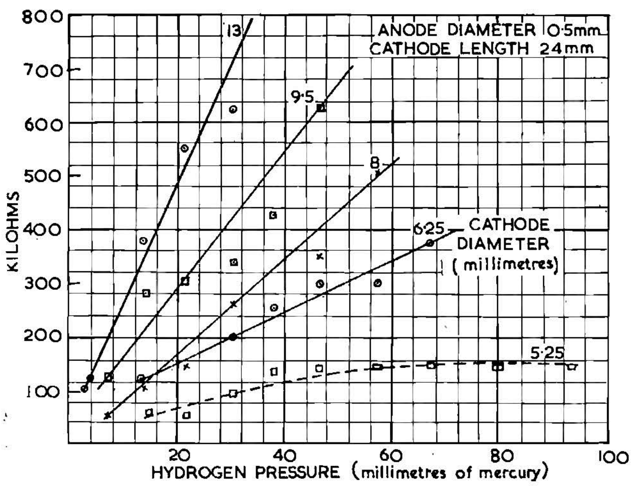
The life of a tube in operational hours, and the shelf life, are of paramount importance to both users and manufacturers, so tests were carried out from the earliest experimental stages to investigate these two qualities of the corona discharge tube. In one set of tests four tubes from a batch were put on shelf test and four others on continuous operation life test. Table 1 shows the results of the shelf test over a period of nearly three months; these can be considered satisfactory.

**TABLE 1. Shelf Life Test Results**

| TUBE NUMBER | $V_s$ (30-10-50) | $V_s$ (23-1-51) |
|---|---|---|
| 4 | 395 | 400 |
| 7 | 403 | 400 |
| 8 | 399 | 395 |
| 10 | 395 | 395 |

The results on continuous life test, however, showed quite clearly that the gas filling and processing of these tubes was not satisfactory. There was a large drop in the value of $V_s$ over the first 300 hours. Table 2 gives these results

**Fig. 9.** $R_c$ versus pressure with various cathode diameters



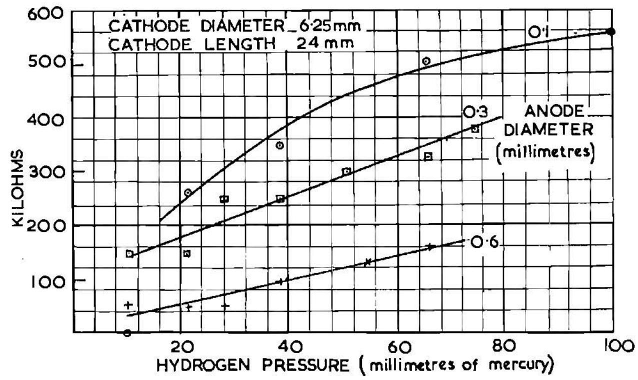




**Fig. 10.** $R_c$ versus pressure with various anode diameters

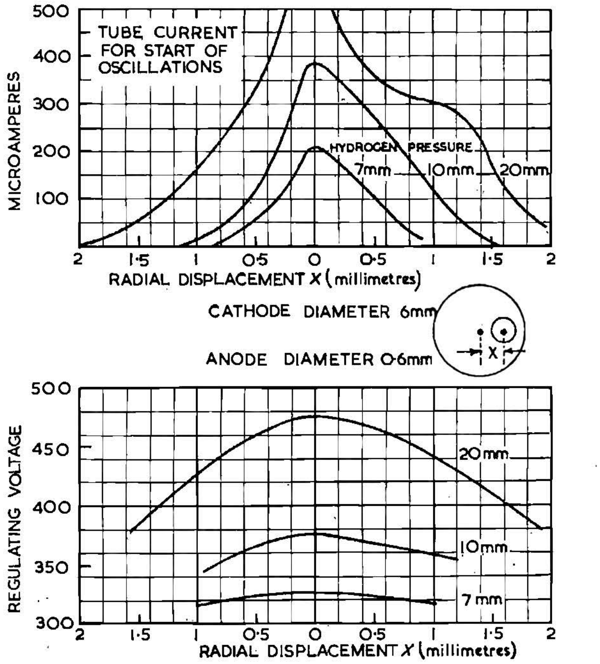



**Fig. 11.** Effect of radial displacement of the anode within the cathode. (a) on $I_{max}$ (b) on $V_s$

**TABLE 2. Early Life Test Results (showing partial recovery)**

| TUBE NUMBER | $V_s$ AT START OF LIFE TEST | $V_s$ AT END OF 300 HOURS' LIFE TEST | $V_s$ AFTER 11 WEEKS' REST |
|---|---|---|---|
| 1 | 412 | 272 | 390 |
| 3 | 402 | 235 | 380 |
| 6 | 400 | 325 | 390 |
| 11 | 410 | 398 | 410 |

together with the value of $V_s$ measured after the tubes had been resting for a further period of eleven weeks. It will be seen that $V_s$ recovers partially on standing idle.

Considerable experimentation was carried out to improve the life performance of the corona discharge tube. One interesting experimental tube used a sectioned cathode[5], constructional details of which are shown in Fig. 12. The larger portion of the cathode was processed to have a clean bright finish and the smaller upper portion, a slightly oxidized surface. This combination was used because it

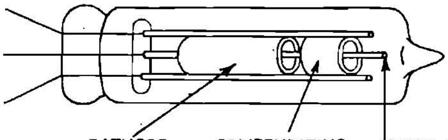



**Fig. 12. Construction of sectioned cathode**

had been found that an oxidized surface gave a life curve with rising $V_s$ while that of the bright finish gave a curve falling with time. Greatly improved results were obtained with this type of tube. Improvements were steadily made to the processing and filling techniques for the single element cathode with bright finish, and Table 3 gives the values of $V_s$ for a typical set of three tubes taken from a larger batch.

TABLE 3

| HOURS OF CONTINUOUS RUNNING | TUBE NO. 2105 | TUBE NO. 2128 | TUBE NO. 2120 |
|---|---|---|---|
| Initital | 932 | 890 | 903 |
| 24 | 933 | 888 | 900 |
| 96 | 935 | 889 | 900 |
| 120 | 933 | 888 | 901 |
| 144 | 933 | 889 | 901 |
| 168 | 934 | 888 | 900 |
| 312 | 935 | 888 | 900 |
| 336 | 935 | 889 | 901 |
| 360 | 935 | 890 | 901 |
| 432 | 935 | 889 | 902 |
| 456 | 935 | 890 | 901 |
| 480 | 935 | 890 | 902 |
| 504 | 935 | 891 | 902 |
| 528 | 935 | 890 | 902 |

Other life tests have been conducted on tubes with various fillings and with various processing procedures, and from these it has been determined that:—

(a) The major change of regulating voltage during continuous operation takes place in the first 20 hours.

(b) Unsuitable exhaust and filling treatment can produce tubes with very short lives, the fault being falling $V_s$.

(c) It is possible to make tubes with lives which considerably exceed 1 000 hours, and this figure is now regarded as a minimum.

In consequence of (a) it was decided that all tubes should be aged for 20 hours or more as the final manufacturing process before test.

### Conclusion

The work reported above gives sufficient data for the design of tubes with any regulating voltage between 400 and 1 000, operating at currents up to at least 100$\mu$A. Such tubes can be made with characteristics which are stable for considerably more than 1 000 hours.

Corona discharge tubes have already been incorporated in low power E.H.T. units for use with proportional counters (Holton and Sharpe[6]) and designs of equipment for use with Geiger counters are well advanced at A.E.R.E. Doubtless there are many other applications where the tubes described can be used with advantage.

It is known that the range of $V_s$ can be extended to many kilovolts with appropriate increases in electrode size and gas pressure.

**Acknowledgments**

This work was done partly at A.E.R.E. and partly in the laboratories of N.R.D. Ltd., under a development contract from the Ministry of Supply. The writers wish to thank the Director, Atomic Energy Research Establishment, Harwell, and the directors of Nucleonic and Radiological Developments Ltd., for permission to publish this paper, and J. Sharpe of A.E.R.E. for advice freely given.

**REFERENCES**

1. LOOSEMOORE AND FRANKLIN. A Survey Equipment Using Low Voltage Halogen Quenched Geiger-Muller Counters. *Proc. Instn. Elect. Engrs. 98*, Pt. II, No. 62 (1951).
2. BLIFFORD, ARNOLD and FRIEDMAN. Voltage Stabilization by Means of Corona Discharge Between Coaxial Cylinders. *U.S. Naval Research Laboratory Report* N.3140.
3. JAQUES. Corona Discharge Tube Stabilization. *A.E.R.E. Memo.* EL/M/42.
4. LICHTMAN. High Voltage Stabilization by Means of Corona Discharge Between Coaxial Cylinders. *Proc. Inst. Radio Engrs., 39*, 419 (1951).
5. British Patent Application No. 7044/51.
6. HOLTON, P., SHARPE, J. A Corona Stabilizer E.H.T. Supply for Proportional Counters. *Electronic Engng.* (To be published.)

## Ultrasonics in the Foundry

The ultrasonic technique for soldering aluminium is so well known and it is being used for an increasing number of industrial processes. One particularly interesting field of application is in the foundry, where it is proving of great value for the surface treatment of faulty light-alloy castings and for the modification and repair of aluminium patterns.

The main causes for the rejection of light-alloy castings in foundries are blow-holes, dross inclusions and cracks. If these defects are severe, the faulty castings are returned to the melt. In practice, however, in spite of the care that is taken, a number of light-alloy castings are rejected on account of surface blemishes. The reclamation of such castings has for long been a pressing problem in the foundry.

In the past this problem has to some extent been overcome by filling in the surface defects with metallized glues or molten aluminium. The results, however, have never been entirely satisfactory and the repaired areas could often be detected, even after painting. With the aid of an ultrasonic soldering iron, however, surface blow-holes and cracks can now be quickly and permanently filled, and an excellent finish obtained.

The great advantage of this new soldering technique is that a strong and permanent bond is obtained between the solder and the base metal. Moreover, tin-zinc solder is used which has a texture and colour similar to that of aluminium. This means that after machining the treated areas are almost indistinguishable from the surrounding parts of the casting.

The casting is first pre-heated to the melting point of the solder used. The cavity is then filled with molten solder and the bit of the soldering iron is applied. The erosive action of the vibrating bit removes the oxide film on the sides and bottom of the hole, and rapid and effective tinning occurs. The bit is then withdrawn. If necessary further solder can be added and allowed to solidify, after which the surface can be machined to the shape of the casting.

Although the ultrasonic soldering process is quite effective for the rectification of surface defects in castings, it cannot, however, be considered suitable for jointing castings where the design is such that appreciable stresses occur across the repaired break. If, however, the part of the casting to be treated is used only for ornamentation, lap and butt joints can be used. These will withstand all normal usage.

Arrangements are being made for the Mullard Ultrasonic Soldering Equipment to be demonstrated in foundries in various parts of the country. Information regarding this, and further technical details relating to the equipment, can be obtained on request from the Equipment Division, Mullard Ltd.