for the production of satisfactory orifice openings and in other phases of the work.

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A Line-Operated Vacuum-Tube Voltmeter

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SINCE the introduction by Goode (*4*) of the vacuum-tube device for measurements in electrochemistry, many circuits employing this device have been described (*3*). In general they have been battery-operated and in many cases of single-tube assemblies their sensitivity has proved inadequate.

The recent circuits of Dubridge (*1*, *2*) and others (*7*, *9*) have been designed for high sensitivities. The same principles may be used in the construction of a line-operated device. However, it is impossible to attain the same degree of stability without an accompanying loss of sensitivity because of the high line-voltage fluctuations as compared to battery fluctuations.

The balanced single-tube circuits of Dubridge and Turner were designed primarily for special electrometer tubes in which the filament formed part of the balancing network. The direct adaptation of these circuits to ordinary commercial radio tubes, where alternating current line operation is desired, proves difficult in practice because of the necessity of rectifying the relatively high filament currents (0.3 to 2.5 amperes).

The bridge circuits of Wynn-Williams (*10*), Nottingham (*6*), and others (*5*) avoid this difficulty, but depend upon the selection of matched tubes for successful operation.

A stable and yet sensitive circuit which will operate from both alternating and direct current lines can be designed by combining the mu-balance (*8*) and conventional bridge circuits. A circuit design based on these considerations which was found practical is shown in Figure 1.

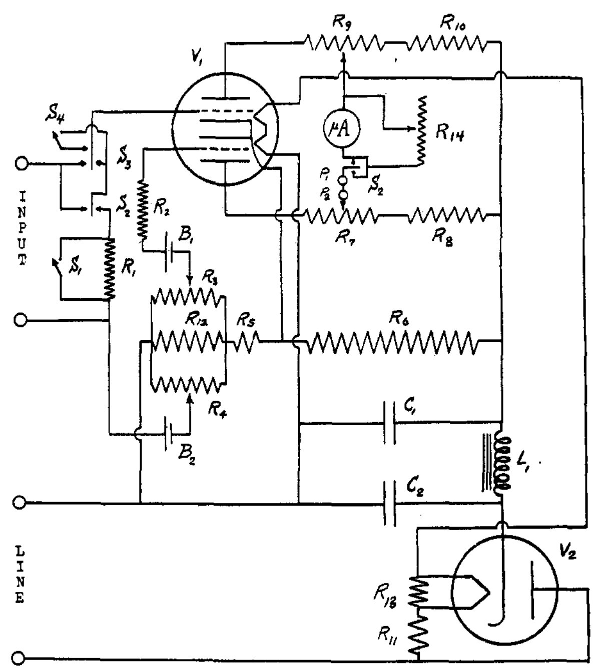

FIGURE 1. CIRCUIT DESIGN

R_1, R_2.	1 megohm, 1 watt	C_1, C_2.	8-mfd. electrolytic condenser
R_3, R_4.	400-ohm control	S_1.	S. P. S. T. Yaxley jack switch
R_5.	200 ohms, 15 watts	S_2.	D. P. D. T. Yaxley push-button switch
R_6.	8000 ohms, 30 watts	S_3.	D. P. D. T. Yaxley jack switch
R_7, R_9.	5000-ohm control	S_4.	S. P. S. T. Yaxley jack switch
R_8, R_{10}.	20,000 ohms, 2 watts	V_1.	6A6
R_{11}.	140 ohms, 100 watts	V_2.	84
R_{12}.	300 ohms, 15 watts	μA.	Weston 0-200 microammeter
R_{13}.	20 ohms, 15 watts		
R_{14}.	10,000-ohm tapered control		
L_1.	30 H. choke, 200 ohns		
B_1, B_2.	3v. flashlight batteries		

A duo-triode (6A6) tube is used in which the plate impedances of the tube form two arms of the bridge and the resistors R_9–R_{10} and R_7–R_8 the other two arms. Balance is determined by a microammeter connected across the bridge R_7–R_9. The difficulty of matching has been minimized by the use of the 6A6, since its two triode sections were manufactured at the same time and operate in the same environment.

While a certain degree of stability is attained by the use of the matched triodes in the bridge circuit, the stability of the device has been further increased by placing the two sections of the tube in individually balanced mu-balance circuits (*2*, *8*). The ratio of the resistance R_6 to the effective resistance of the network R_5–R_3–R_{12}–R_4 is chosen to be slightly higher than the amplification factor (manufacturer's specifications) of the tube, so that individual adjustments to compensate for slight differences in the two sections can be made by adjusting the resistors R_3 and R_4.

Batteries B_1 and B_2 are introduced to increase the sensitivity by opposing the high negative grid potentials which would normally result from the mu-balance network (*8*). These batteries are small, since there is no current drained from them.

The apparently complex switching arrangement adapts the instrument to a variety of purposes.

The power supply is designed with an 84-type rectifier and appropriate filter system to permit operation on alternating and direct current.

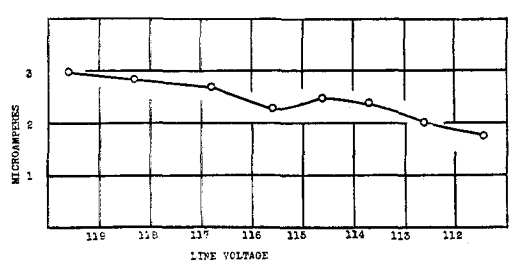

FIGURE 2. STABILITY CURVE

Operation

The proper operating condition may be determined by performing the following operations:

Open S_1; throw S_2 to the right and S_3 to the left; S_4 should be closed. Disconnect the microammeter from the circuit by removing the "jumper" across binding posts P_1 and P_2 and connect a 0–2 milliammeter between R_9 and R_{10}. Adjust resistor R_4 until the change in plate current with change in line voltage becomes a minimum. Changes in line voltage can be most easily secured by placing a variable resistance in series with the

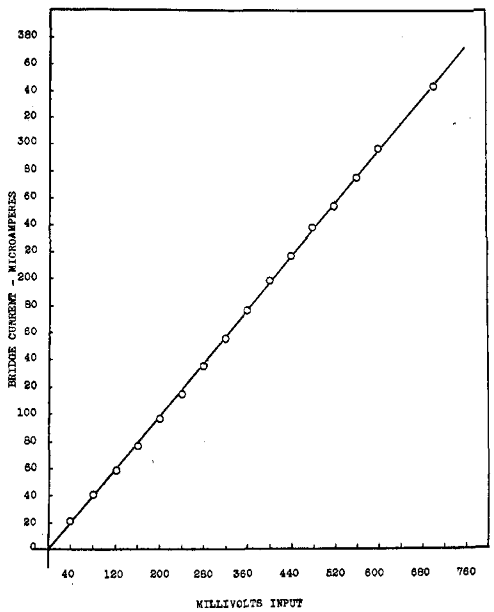

FIGURE 3. SENSITIVITY CURVE

line. The same operation should now be repeated with the other section of the tube. For very high stability readjustment of R_4 may now be necessary. The operating stability may be judged by reconnecting the microammeter and noting the change in its reading with line voltage. Improvement in stability can often be obtained by further critical readjustment of R_3 and R_4 until maximum stability is indicated by the microammeter. Once this adjustment is completed, no further changes are required until replacement of the tube is made.

Before using the instrument, the microammeter should be made to read zero, with zero input, by adjusting resistors R_7 and R_9. This compensates for differences in the plate impedances of the two sections of the tube.

The switching arrangement permits the voltmeter to be used in the following ways:

1. S_1 open, S_2 to the right, S_3 to the left, S_4 closed.

The instrument is now a high resistance voltmeter with a range 0 to 1 volt.

2. S_1 open, S_2 to the right, S_3 to the left, S_4 open.

These operations disconnect the grid leak and make the instrument available for electrometric titrations and other potential measurements where low current drain is important. Under these conditions the maximum current will be 10^{-8} ampere.

3. S_1 closed, S_2 to the left, S_3 to the right, S_4 any position.

Under these conditions the instrument serves as a galvanometer which may be used in the usual Poggendorf method. When balanced, the meter will show equal deflections when S_2 is moved from left to right. When the external electrode resistance is high, S_1 should be left open. It should be noted that the second section of S_2 serves to disconnect the microammeter during the transition of the first section of S_2, thus preventing the meter from reading off-scale during the interval the grid is open.

Stability and Sensitivity

The degree of stability that is obtained is shown in Figure 2. The variation produced by ordinary changes in line-voltage will produce imperceptible changes on the 0–200 microammeter recommended.

The sensitivity curve, Figure 3, shows that the microammeter readings are linear with input voltage and that a 0–200 microammeter provides ample range for all electrometric titrations.

Summary

A self-contained vacuum-tube voltmeter is described which is capable of operating on alternating and direct current lines and designed to minimize the effects of line-voltage variations. It is adaptable to a variety of uses where low voltages are to be measured with a minimum current drain.

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A Simple Rotating Ball Mill

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FOR certain investigations it was necessary to design a simple, compact, efficient, and portable ball mill. Several modifications were tried, of which the mill described below has proved the most satisfactory. It consists of two horizontal rotating shafts upon which is placed a cylindrical container made of steel or glass, holding the material to be pulverized, and rotated by the revolving shafts. The mill may be easily constructed at a small cost in the average laboratory. Many substances, such as soils, pure minerals, plant materials, bacteria, glass, etc., have been ground in this mill.

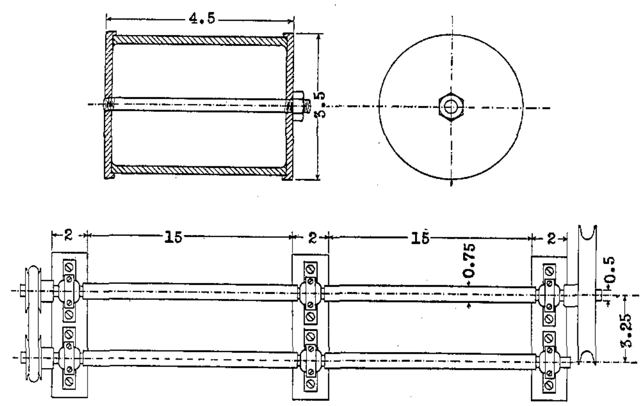

FIGURE 1. DIAGRAM

Upper left, cross section of container. Upper right, end view of container. Lower, top view of rotating shaft assembly.

Figure 1 gives a general idea of the principles of this mill The shafts are steel, 0.5 inch by 3 feet or longer and are 3.25 inches apart from the center of each shaft. The bearings are common, split pillow blocks with a hole drilled through the top for oiling purposes. The shafts between the bearings are covered with ordinary rubber tubing which is slipped on with the aid of powdered talc. The rubber tubing quiets the operation and gives better traction to the mill. There is a 2-inch pulley at one end of each shaft, connected by a 0.25-inch round belt. The other end of one shaft has a larger pulley, approximately 4 to 6 inches in diameter, connected to an electric motor of about 0.25 horsepower by an endless belt.