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The AEROVOX Research Worker

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Vacuum-Tube Methods of Measuring Insulation Resistance of Condensers

By the Engineering Department, Aerovox Corporation

USERS of condensers often do not have an accurate way of determining the insulation resistance or leakage of a paper condenser. The leakage of a good condenser is so small that ordinary milliammeters will not give a reliable indication. The methods usually employed by servicemen and experimenters are rather indefinite and leave the radioman still in doubt regarding the true condition of the condenser under test. In response to many requests this number of the Research Worker is devoted to the accurate measurement of insulation resistance of paper condensers by means of a vacuum-tube-voltmeter.

Fundamentally the measurement is very simple. Figure 1 illustrates the test circuit; the condenser under test, C, is connected across a direct current source of a convenient high voltage in series with a resistance, R. After the condenser is charged, a small current will still flow which is the leakage current. The equivalent circuit of Figure 2 shows the condenser as a condenser with a resistance R_L across it. It is now required to find the magnitude of R_L. This can best be done by measuring the voltage, drop, e, across R; the value of R can then be calculated if the voltage of the battery is known. How this is done is perhaps best shown by a numerical example.

Suppose the battery delivers 400 volts and the value of the resistor R is 1 megohm. After connecting the condenser in series with R and waiting for the condenser to be charged, the voltage drop across R is found to be 1 volt. Since 1 volt out of the 400 is across R the other 399 must be

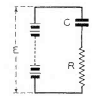

Fig. 1

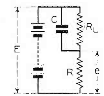

Fig. 2

across R_L. In a series circuit the voltage drops across two resistors are proportional to the resistance so R_L must be 399 megohms. Similarly, if the voltage across R had been 2 volts, the insulation resistance would have been 398/2 = 199 megohms. A voltage drop of .1 volt across R would mean that the insulation resistance R_L would be 3999 megohms.

Generalizing the above statements we can express the relations in an equation, as follows:

$$R_L = \frac{(E-e)\,R}{e}$$

In this equation the results will be in megohms when R is in megohms. E is the voltage of the battery and e is the voltage drop across R.

Let us postpone for a while the problems of getting a satisfactory sensitivity, the discussions of the limts for the values of R, etc. and concentrate on the circuit itself.

Figure 3 shows the simplest circuit of a vacuum tube voltmeter connected across R. In this case the vacuum tube voltmeter is used for measuring a steady voltage and therefore can work on the straight part of its characteristic and not on a bend. However, in order to have a larger range and to save on battery drain the bias of the tube can be larger than the regular amplifier bias so long as the operating point is still on the lower end of the straight portion.

In Figure 3 the switch SW1 has been introduced in order to charge the condenser first. The method of operation is now to heat the tube and connect the condenser, than to set the switch at a. The condenser will now be charged through the resistor R2. This resistor has been placed there for protection of the battery in case the condenser were shorted. In fact, it would be best to place a meter in series with R2 making the combination a voltmeter. The value of R2 should be such that together with the meter it makes a voltmeter with a maximum range equal to the voltage of the battery. It is also possible to use a neon light instead of a meter and R2. The neon light will first light up when the condenser is being charged, thereafter it should go out altogether. If the lamp remains glowing, the condenser is shorted; if it flashes intermittently the condenser is leaky.

Now that the condenser is charged and it has been established that it is not shorted or so leaky as to place a high voltage on the grid of the tube, set the switch SW1 to c. The vacuum

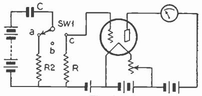

Fig. 3

tube voltmeter now should show an increased plate current and this can be read as a voltage across R. The value of RL is now found with the equation which was given above.

The circuit of Figure 3 would not be sensitive enough for most purposes but it can be improved upon by balancing out the steady plate current which will then permit the use of a more sensitive meter. There are several ways to accomplish this. One of them is shown in Figure 4; a 1.5 volt cell and a 1000 ohm rheostat will accomplish the desired result. These values are correct for most cases where a low resistance meter is employed (with a range of 0 — 1 ma.) More sensitive meters may have a higher resistance and then it is better to use a higher voltage source and a higher value of the rheostat R3. The rheostat is across the meter and con-

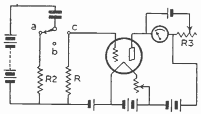

Fig. 4

stitutes a shunt; unless its resistance is large compared with the internal resistance of the meter, the sensitivity will be seriously reduced.

Now a word of warning; it is unlikely when first adjusting the circuit that R3 will be set at once to the correct position for zero current through the meter. Consequently there might be a rather high current flowing through it which might damage the meter. Therefore, wherever we show a measuring instrument in this article it is advisable to employ a sensitive instrument with several shunts so as to prevent any overload. Suppose the meter to be an 0 — 100 micro-ampere range, it should have shunts for 0 — 1, 0 — 10 and 0 — 100 ma. and an off position. In this way, the balance can first be approximated on the higher ranges where the danger of overload is not present. Then, if the balance is obtained, switch to a lower range and make finer adjustment and repeat this until the instrument shows zero current at its lowest range.

Another method of cancelling the steady plate current is by means of the bridge circuit of Figure 5. A load resistor, R4 is in series with the plate circuit of the tube. Its value should be calculated so as to obtain the rated voltage at the plate of the tube with the plate current which is desired. Also, instead of the added C-battery for the tube, a bias resistor can be employed. This is possible in Figures 3 and 4 as well. The meter — with its

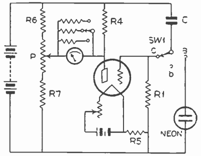

Fig. 5

shunts — is connected between the plate of the tube and a point on the bleeder resistance having the same voltage so that no current will flow. The potentiometer, P, will enable the user to find the correct point.

This circuit has the advantage that the adjustment and calibration will not be affected very much by the dropping of the battery voltage. On the other hand it increases the drain on the high voltage battery but the total drain need not be high. The tube itself might draw about 2 ma. and the bleeder about the same. It is possible to obtain a similar balance by omitting the bleeder and connect P across one or two cells of the battery but then the adjustment will not be so well maintained with the variations in battery voltage. The value of R6 and R7 can so be chosen as to make the potentiometer P less critical which will also be a safeguard against overloading the meter.

CALIBRATION

There are two ways of actually reading the desired voltage, e. The vacuum tube voltmeter can be calibrated with known battery-voltages or the slide-back method can be used. This latter method requires no calibration.

A suitable circuit for calibration is shown in Figure 6. The presence of a high resistance in the grid circuit of the tube may result in some gas current with consequent lowering of the input impedance of the tube which might change in turn the value of R1. We shall show later how to test for this error but when calibrating the meter, the resistance should not be parallelled by a low resistance. The series resistance R8 might be nine times R1 and then the voltage applied to the grid of the tube is one tenth of that shown on the voltmeter V.

Changes in battery voltages and in the tube characteristics may affect the calibration. It is a good idea to check it frequently. If different ranges are to be obtained by using different values of R1, a separate calibration should be made for each range. It may be that it is satisfactory to multiply all readings with a fixed number, but this had better be checked.

For a fixed battery voltage and a fixed value of R1 the meter can be calibrated directly in megohms.

The slide-back method really provides a new calibration for each reading and the accuracy is not influenced by the changes in battery voltages or tube characteristics. Moreover if there is any voltage drop across R1 due to gas currents, this voltage would not cause any error. The only critical part is the circuit of the tube containing the resistance R1. It is important that there be no leakage in the socket or insulation and that the input impedance of the tube is sufficiently larger than R1 so as not to lower its value.

Figure 7 shows the slide-back circuit added to Figure 5. It consists in adding a negative voltage to the grid bias in opposition to the voltage drop across R1. When this voltage is equal to e, the meter will again indicate zero. The value of e is then indicated on the meter, M2. The procedure of a measurement is now as follows. Set SW1 on a and connect the condenser;

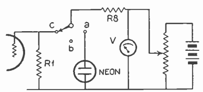

Fig. 6

assuming that the light goes out after the charge we proceed with the measurement. With the tube filament heated, obtain the balance of the meter M1 by adjusting P. This must be done with R9 on the off position. For purposes of accuracy it is best to adjust the meter M1 to some sharply defined division on the scale preferably as near as possible to the zero point rather than to zero itself. It should be a fine line so that the least change in the position of the needle can be easily detected. When the adjustment of P has been made, set SW1 on c and the needle should move up. Now adjust R9 until the needle returns to its original position. When this is done read the milliammeter M2. Suppose R10 is 100 ohms and the meter M2 a 0 — 1 ma. meter, a meter reading of .5 would mean that the voltage drop across R10 (and also across R1) is .05 volt. In order to get different ranges it might be found advisable to switch R10 and to use values of 100, 1000 and 10000 ohms or to use a multi-range meter or both. In reality the meters M1 and M2 can be the same. They can be switched as shown in Figure 8. The resistance R11 should equal the meter resistance so that the adjustment of R9 can be done while the meter is in the other circuit; the switching over then will not change the current through R10. It is also possible to calibrate the rheostat R9 using a dial and do away with M2 altogether.

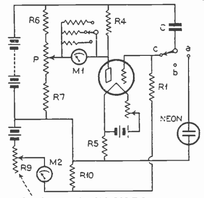

Fig. 7

When the value of e has been found, the insulation resistance of the condenser is found from the equation

$$R_L = \frac{E\ R1}{e}$$

Note that the equation for the slide-back method is slightly different than the one for the calibrated meter.

SENSITIVITY

The equations indicate that the sensitivity depends on the value of the battery voltage and the resistor R1 as well as on the sensitivity of the voltmeter. The apparatus can be made more sensitive by increasing the value of R1. Since it is necessary to measure insulation resistances as high as say 10,000 megohms it is important to know how far we can go in increasing R1.

All tubes have some gas left in them; if a high resistance is used in the grid circuit, the gas current flowing through this resistor will cause a voltage drop across it which may cause an error with a calibrated meter. However, the presence of the gas current means that the tube acts as a resistance connected across R1 and thus may considerably change the resistance of the circuit. In that case the wrong value for R1 is used in the computation and this causes another error. Poor insulation of the grid terminal will have the same effect.

The remedies are to employ a tube which has its grid coming out on top, such as the 32, 36, 24, etc. These can be used as triodes by connecting plate and screen together. A gridleak of 1 megohm can usually be employed with these tubes. It may be possible to go to 5 megohms, but then the following test is recommended. Employing the slide-back voltmeter, connect a known high resistance of 20 or more megohms (but accurately known) in series with R1 as in Figure 5 and measure a known voltage. This should then check up with the reading on M2.

The voltage E should be some convenient high voltage near the rating of the condenser under test. 400 or 500 volts is recommended; even 200 volt condensers can be tested at this voltage. Unfortunately it is not practical to employ a power pack here; batteries must be used. The customary power supply is subject to continuous small fluctuations in the voltage. These small fluctuations charge and discharge the condenser which results in amplified variations in the voltage across R1. These are amplified still more by the tube and result in violent variations in the meter reading. This is especially so for large condensers. It is then quite impossible to obtain a balance or a reading. None

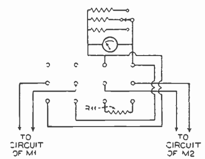

Fig. 8

of the usual schemes for automatically regulating the supply have been found accurate enough to permit their use with this measuring instrument at its sensitive settings. Consequently batteries are the only solution.

RANGES

There is considerable variation in the insulation resistance of condensers. The large ones have considerable more leakage and it will be found that a single value of R1 will not be found satisfactory for all purposes. It is recommended to use two or three different values of R1 so as to obtain different ranges. In addition the resistor R10 may have to be changed.

INTERPRETATION OF READINGS

The insulation resistance of paper and mica condensers is inversely proportional to their capacity. A .1 mfd. condenser will have ten times the insulation resistance of a 1 mfd. condenser of the same type. Consequently in order to compare the merits of condensers of different sizes, the insulation resitsance is multiplied with the capacity. The insulation resistance is then expressed in megohm-microfarads; this quantity being the same for condensers of different sizes. A good condenser would have an insulation resistance of say 450 megohm microfarads. This means that its resistance would be 450 megohms for a capacity of 1 mfd., or 4500 megohms for a capacity of .1 mfd.

Finally, the fact that a condenser has an insulation resistance which is low, is no definite indication that it cannot be used. It all depends in what circuit it is to be placed. This subject was discussed in detail in the Research Worker for March 1935.

AEROVOX WINS PATENT DECISION

A suit brought by Aerovox Corporation against Micamold Radio Corporation for infringement of two of its patents for electrolytic condensers was decided in favor of Aerovox Corporation in a decision handed down May 14th, 1936 by Judge Marcus B. Campbell of the Federal Court for the Eastern District of New York. The decision was in favor of Aerovox Corporaion in all claims involved in the suit and an injunction and an accounting was ordered.

These patents had been previously held valid and infringed by the United States Circuit Court of Appeals in the Southern District of New York. In the present suit the Micamold Radio Corporation alleged newly discovered evidence. Judge Campbell found such new evidence irrelevant.