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The AEROVOX Research Worker

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Practical Methods of Testing Condensers

PART 1

By the Engineering Department, Aerovox Corporation

THIS series of articles is devoted to a summary of the different methods of measuring the electrical constants of condensers. These electrical constants are: capacitance, power factor and/or equivalent series resistance, Q, and insulation resistance (or leakage). There are other tests customarily performed on condensers, such as life test, flash test, breakdown test, etc. but these will not be considered here.

Before discussing the measuring apparatus it is necessary to examine the electrical quantities closer. Most of these electrical constants vary somewhat with frequency, temperature, humidity, age, applied voltage, etc. In some cases the variation is only a few percent while in other cases the difference may be large. Such points should be kept in mind when making measurements and the test should preferably be performed under the conditions which will be encountered during the intended use of the condenser.

CAPACITANCE

The capacitance of a condenser varies somewhat with frequency—generally it decreases with increasing frequency. In the case of electrolytic condensers, the capacity decreases in the audio frequency range. At radio frequencies there may not be any capacitance left and the unit acts as an inductance due to the winding of the foil. The capacitance may also vary due to the applied voltage; so, a condenser which was formed at 500 volts and intended to be used at 450 volts increases its capacitance when it is used at only 300 volts.

Paper condensers also have a somewhat decreased capacitance at higher frequencies. In the case of mica condensers the same is true and the extent of the variation is only a few per cent. When a frequency of about 30 mc. is reached, however, the length and form of the leads becomes important and it is possible that the leads carry so much inductance as to offset any capacitance in the condenser.

The capacitance of electrolytics increases with increasing temperature while that of paper condensers decreases under the same conditions. Mica condensers may vary either way depending on the construction. The variation of the better types however is very low.

POWER FACTOR

Referring to Figure 1, the average practical condenser may be represented as a perfect condenser in series with a resistance. This is not an exact equivalent circuit but it is sufficiently accurate for our purpose. When an alternating current flows through this series circuit, the voltages across the resistive and capacitive part are 90 degrees out of phase and may be represented as in the vector diagram of Figure 2. We then have the following relations:

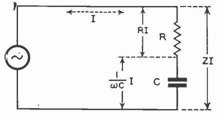

Fig. 1

$$\text{power factor} = \cos\phi = \frac{R}{Z}$$

$$\text{pf }(\%) = \cos\phi \times 100$$

$$\tan\phi = \frac{\frac{1}{\omega C}}{R} = \frac{1}{\omega CR}$$

A perfect condenser, therefore, has a power factor of zero while the worst power factor possible would be unity or 100 percent.

It should be noted that R in the equations above is alternating current resistance which is subject to variations with frequency. This is also the case when speaking of the power factor or the Q of a coil. In the case of an electrolytic condenser, the relatively high power factor is not due to leakage. If the leakage is translated into equivalent series resistance it accounts only for a small part of the actual equivalent series resistance. Most of the losses in electrolytic condensers are in the film which is formed on the foil, in the electrolyte and in the foil itself and its connections.

Power factor varies with frequency, temperature and humidity. It also depends on the age and the previous history of the condenser. The power factor of electrolytic condensers increases slowly with frequency in the audio frequency range. At radio frequencies, 500 kc., the power factor may be nearly unity. There is also an increase in the power factor of paper

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condensers with increasing frequency. There is practically no change in power factor of mica condensers below 30 mc. Above this limit the leads become the deciding factor as noted above. It is also interesting to see that at ultra-high frequencies resistors may have capacitive reactance.

The power factor of all types increases with temperature. Humidity has very little effect on the power factor of electrolytics. Paper condensers are much more effected by humidity, and there is only a slight increase in the power factor of mica condensers due to humidity.

EQUIVALENT SERIES RESISTANCE

In certain cases it is more convenient to deal with the "equivalent series resistance" of a condenser rather than the power factor. This is represented by R in Figure 1. Obviously, condensers of the same power factor and the same Q will have series resistance inversely proportional to the capacitance. Equivalent series resistance increases with frequency, temperature and humidity for all types of condensers. The variation with frequency is large, easily amounting to 100 percent and over within the audio frequency range. Unfortunately, so far no simple relation has been established between frequency and equivalent series resistance of the same condenser.

The changes with temperature and humidity are small following the same lines as power factor.

Q

The merit of a condenser is indicated by the factor Q which is the ratio of reactance to equivalent series resistance or the tangent of the phase angle, ϕ in Figure 2.

$$Q = \frac{1}{wCR} = \tan \phi$$

At low values of power factor, Q approaches the inverse of the power factor. This fact will make it clear that Q varies with frequency temperature and humidity in opposite directions as the power factor and to the same extent. It decreases when any of the above named quantities increases.

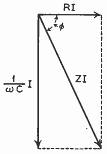

Fig. 2

INSULATION RESISTANCE

The resistance of the dielectric to direct current is called the insulation resistance. It can also be expressed in terms of leakage. In order to compare the quality of condensers of different capacitance it must be remembered that normally the leakage will be proportional to the capacitance and the insulation resistance will be inversely proportional to the same quantity. Therefore the insulation resistance is conveniently expressed in "megmikes", the product of the capacity in microfarads and the insulation resistance in megohms. A new paper condenser of good quality may be expected to have an insulation resistance of 2000 to 4000 "megmikes". In the case of electrolytic condensers one usually measures leakage in milliamperes. Being strictly a d.c. phenomenon, leakage does not vary with frequency but increases with temperature and humidity.

SIMPLE MEASUREMENTS OF CAPACITANCE

The most obvious way of measuring capacitance follows directly from its definition. It is done by employing the ballistic galvanometer. A condenser is charged to a known voltage and then discharged through the ballistic galvanometer. The instrument then indicates the number of coulombs which was stored in the condenser. The capacitance is then

$$C_{(\text{farads})} = \frac{\text{coulombs}}{\text{volts}}$$

RATIO METER

A very convenient type of direct reading instrument is the "ratio meter". Its circuit is shown in Figure 3. Alternating current of a suitable frequency, this may be 60 cycles or higher, is applied to the coil L. This establishes an alternating magnetic field inside the coil. Inside this field are located two small coils which are fastened together at a fixed angle and can be rotated while being attached to a pointer. In series with one of the coils is a standard condenser while the other is in series with the unknown. The reactance of the condensers is very large compared with the reactance of the individual small coils so the current passing through each coil is nearly proportional to the capacitance of the two condensers. The resultant of the two magnetic fields established by the two small coils will cause the assembly to turn until it coincides with the field of L. So there is a fixed position for each capacitance value of C_X. The scale can then be calibrated directly. This type of movement does not require springs; the angle between the two movable coils being equal to the arc of the scale, the pointer will never go off scale. The ratio meter is employed for condensers of medium size, from .01 mfd. to .4 mfd. When it is desired to measure smaller condensers, and C1 is made smaller it becomes difficult to obtain enough torque for the rotation of the assembly. The remedy is then to use a higher frequency or a higher voltage or both.

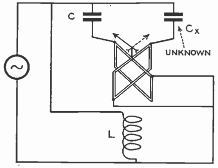

Fig. 3

VOLTMETER-AMMETER METHOD

A popular method which is being used in modified form by servicemen is the voltmeter-ammeter method. In its simplest form, the circuit of Figure 4 is employed. When a condenser is connected in series with an a.c. ammeter across a source of alternating current of known frequency and potential, the capacitance is easily found from the well known fundamental relations:

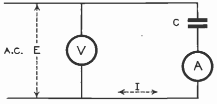

Fig. 4

$$X_c = \frac{E}{I} \qquad X_c = \frac{1}{2\pi fC}$$

$$C = \frac{I}{2\pi fE}$$

These equations neglect any equivalent series resistance the condenser may have and also assumes that the impedance of the ammeter is zero. Under these conditions the scale will be linear and for 110 volts 60 cycles, the ammeter shows 41.5 ma. per microfarad. As a quick check on the capacity of electrolytic motor starting condensers, this method has been employed. One should be sure, however, to establish that the condenser is not shorted before connecting it in series with the ammeter across the line. Also, the motor starting condenser can carry this high current for a very short time only.

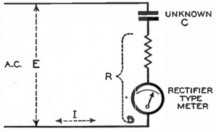

Fig. 5

When measuring smaller condensers, the serviceman often employs his a.c. voltmeter as the indicating instrument, the multiplier resistance serving as a safeguard in case the condenser is shorted. In that case, the circuit becomes as in Figure 5. Assuming the use of a rectifier type meter with a sensitivity of 1000 ohms per volt, the full scale reading of the instrument is 1 ma.; on the 100 volt range the total resistance of the meter plus its multiplier is 100,000 ohms. Placing a condenser in series with the meter and connecting the combination across an a.c. source, the meter will indicate in proportion to the capacitance for small condensers but the scale becomes more and more crowded for large condensers. The capacitance can be calculated from the equation

$$C = \frac{I}{2\pi f}\sqrt{\frac{1}{E^2 - RI^2}}$$

When employing the 100 volt range on a 1 ma. meter, the smallest capacity to give some indication is .00025 mfd. but the deflection is only half a division. On the other end of the scale, a .5 mfd. will probably be the largest to be measured with accuracy. In order to measure smaller condensers it is necessary to employ higher voltages, or a higher frequency or a more sensitive meter. The high-voltage winding of a typical power transformer may be utilized but it will still not be satisfactory for small mica condensers. This type is best measured at radio frequency by a method to be described later.

Measuring larger condensers by means of the a.c. voltmeter, it is best to shunt it so that the resistance of the combination becomes one-tenth that of the previous range. For instance, if the 100 volt range was used for the small condensers, a resistor of 11,000 ohms can be connected in parallel with the voltmeter as in Figure 6. The values of capacitance found for the previous range when multiplied by 10 will then give the calibration points for the new range. The process can be repeated, obtaining a multiplication factor of 100 by placing a 1000 ohm resistor in parallel with the 100 volt range.

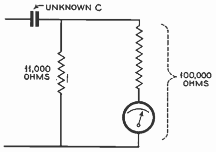

Fig. 6

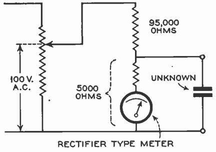

Fig. 7

Ranges for high capacity can also be conveniently obtained if the unknown condenser is placed in parallel with some part of the voltmeter circuit. An example is shown in Figure 7. The potentiometer is adjusted until the applied potential is exactly 100 volts. On the 100 volt range of the voltmeter, the needle will indicate full scale but when a condenser is placed across the 5 volt tap, a portion of the current will be bypassed and the meter indicates less and less when the capacity is increased. The scale will not be linear because the currents in the branches add vectorially. Assuming the total current to remain constant, I_1 being the reading of the meter without the shunting condenser and I_2 with the shunting condenser,

$$C = \frac{1{,}000{,}000}{2\pi\ fR\sqrt{\left(\frac{I_1}{I_2}\right)^2 - 1}}\text{microfarads}$$

If a sufficiently high range is to be obtained it is best to shunt the 5 volt range by 1000 ohms and place 20,000 ohms in series with the combination. A device of this kind was described in the Research Worker for November 1934 where a calibration curve is given. See also September 1934 issue which contains another example of the voltmeter ammeter type.

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