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Life Test Data on Paper Condensers

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THE problem of testing paper condensers, with a view toward determining life and behavior under operating conditions, has been an elusive one. One condenser may apparently be as good as another under numerous tests, but may fail in a surprisingly short time when subjected to operating conditions such as are found in radio equipment.

Pursuing the policy of rigid test and inspection of all parts, the Fada laboratories realized the necessity of establishing some standard method of test which would determine the approximate performance and life of bypass and filter condensers. This is an attempt to outline the results of almost a year's study of the condenser problem and to point out shortcomings in some of the existing methods of rating condensers.

The first method which presents itself is the high-potential breakdown test. This has the disadvantage of ruining the sample tested, so completely, that analysis of the cause of breakdown, other than flash-over, is in almost all cases impossible. It is reasonable to expect flash-over and breakdown potentials will be several times the rated operating potential of the unit; this is standard practice not only with condensers, but with all electrical machinery. Tests have proven that condensers having relatively low breakdown potential have out-performed and out-lasted units which exceeded them by as much as 50 per cent. One manufacturer, through special processing, is able to obtain breakdown potentials in excess of 1500 volts on a condenser, the rating of which is 200 volts normal. This is an ordinary two-paper unit. It has also been found that there exists a wide variation in breakdown between condensers of the same make, although no appreciable difference in construction could be noted. This is especially true in Halowax impregnated units, possibly due to incomplete impregnation of the particular sample tested. Paraffin and Ceresin impregnations appear more uniform in general, but with lower breakdown value. High-potental testing, then, may be said to determine only the instantaneous breakdown potential of the particular unit under test, and as the unit is worthless after test, it can be used only at a minimum limit. Therefore, such a test is of no value as it is not definite.

Another test used by some, which is interesting, but irrelevant, may be mentioned. The unit is charged, either at normal or at a potential higher than normal, and placed aside for a definite period, after which it is discharged. Actually this determines only the leakage resistance of the unit, and as it is almost impossible to determine the current at discharge it tells nothing.

Various rituals have been developed in applying high-potential tests, and almost all other forms of testing fall under this group. Some manufacturers subject their condensers to both a.c. and d.c., while others test them for short periods at several times their rated potential. In no instance have these tests proven conclusive, and in almost all cases high-potential testing is detrimental to the operating life of the units.

Power-factor or, more correctly, "phase angle," is important, if the unit is to operate at fairly high a.c. potentials. The losses in such a unit may be traced to several sources. Briefly they are as follows: First, I^2R losses from direct conduction through the dielectric; second, dielectric absorption, etc.; lastly, series resistance of the condenser plates.

A condenser having losses may be thought of as a perfect capacity, having in parallel a resistance representing its losses. The current I_r through this resistance is in phase with the potential across the condenser "E," and leads the current through the capacity by 90°. The resultant I leads E by some angle less than 90°. This angle is termed the "phase angle" and its complement is the "phase difference ϕ". Tan. ϕ is given by the value of $\frac{1}{R\omega C}$ (See Fig. 1).

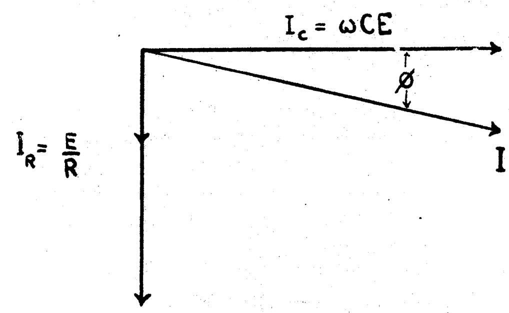

FIG. 1.

From this it is seen that losses due to actual conduction increase inversely with the frequency, but at all, except very low, frequencies, they form only a small portion of the total losses of the unit. A 1-mfd. unit having a resistance of only 10 megohms has a power-factor due to resistance of 0.003 at 50 cycles, which corresponds to a phase difference of 1′ 5″. This is about one third the measured power-factor, other losses contributing the difference.

The current due to dielectric absorption may or may not be in phase with E, depending upon the frequency. Without attempting a mathematical explanation of the condition the following effect occurs. After the electrostatic charge is impressed on the condenser, current will continue to flow. This is in excess of the current due to conduction. It is of large amplitude first, but diminishes, ultimately becoming zero. At discharge, exactly the reverse condition occurs, current flowing after the electrostatic charge has been removed. If the potential is reversed in polarity at this time, the apparent resistance of the unit will be low, due to the large value of absorption current. If an alternating source of potential is applied to the condenser, it can be seen that the total energy absorbed per alternation will depend upon the applied potential and the time period. With constant potential at low frequencies, therefore, a relatively large amount of energy is absorbed a few times per second, whereas at higher frequencies, owing to the diminished time period, less energy will be absorbed per alternation, but the total energy per second will be approximately independent of frequency. This statement is not exactly true, as the dielectric current varies with respect to time, but, as the time period per alternation is an extremely small percentage of the total time required for absorption, the current may be considered constant for all but extremely low frequencies, and the statement will hold for frequencies such as are found in radio equipment, where they are rarely below 25 cycles.

At high frequencies, where the reactance may be a very low value, I^2R losses in the plates of the condenser may become noticeable, but for all commercial frequencies they are negligible. The so-called non-inductive type of winding still further reduces the possibility of these losses contributing to power-factor.

It should be noted that all the foregoing losses increase with the second power of the potential. It is also important to note that both conductance and dielectric absorption, hence power-factor, increase rapidly with temperature, and, to a lesser degree, with age. These facts must be taken into consideration when measurements are made. For example, a condenser which had a measured resistance of 136 megohms per mfd. at 0.8° centigrade decreased to only 18 megohms per mfd. at 16° centigrade.

The actual measurement of losses in condensers of large capacity at low potentials is difficult, owing to the necessity of high-ratio bridge measurements, the absence of reliable standards having known losses, and the mechanical and electrical problems encountered in the design of such standards. Air condensers at low potentials are probably more nearly perfect than any other form of standard available, but as their capacity is necessarily small, large errors may be introduced by inaccuracies in the bridge arms, stray capacities in the standard arm, etc. It is the only method available to the average laboratory, however, and if care is used, fairly dependable results will be obtained. The results are certainly sufficiently accurate to enable an intelligent selection of condensers. It seems necessary, especially where filter condensers are to be tested, to check the condenser for power-factor, for if the dielectric absorption is excessive it may cause serious heating, materially curtailing the life of the unit.

Probably the most consistent and dependable way of checking condensers consists of selecting a number of condensers at random from the manufacturer's current production. The samples are divided into two groups, one of which is subjected to rated potential, and the other double rated potential. The condensers should be so arranged that a simple jack and plug system permits the insertion of a suitable microammeter in series with each unit under test, without disrupting the circuit. Readings of the leakage current, taken daily, together with notes on the temperature and humidity at the time, will give an excellent check on life and performance. Some interesting results have been observed.

In one group on double potential, failures occurred as early as 24 hours, 60 per cent. failed under 250 hours, and the resistance of the remaining samples was less than 50 megohms per mfd. at the end of 650 hours. This same make of condenser showed very erratic behavior on normal potential, the resistance varying from 50 megohms per mfd. to infinity in less than 500 hours, and while no breakdown occurred in a period of 2000 hours the resistance was less than 20 megohms per mfd. in 40 per cent. of the samples. These samples were Halowax impregnated two-paper units, and had an instantaneous breakdown of about 1100 volts r. m. s.

Paraffin impregnated condensers were much more regular in behavior than those impregnated with Halowax, although the breakdown potential was lower, and the initial resistance was much lower. Breakdown in this case occurred at about 850 volts r. m. s., 20 per cent. failed at 60 hours, and 40 per cent. at 500 hours on high voltage. On normal voltage these condensers were exceptionally regular in behavior, the resistance decreasing steadily with life. The average resistance was very low, being about 20 megohms per mfd. at 1000 hours. Temperature coefficient increased steadily, being −0.05 at 800 hours and −0.08 at 1900 hours. These condensers are still on test, and at the end of 2300 hours have an average resistance of about 18 megohms per mfd.

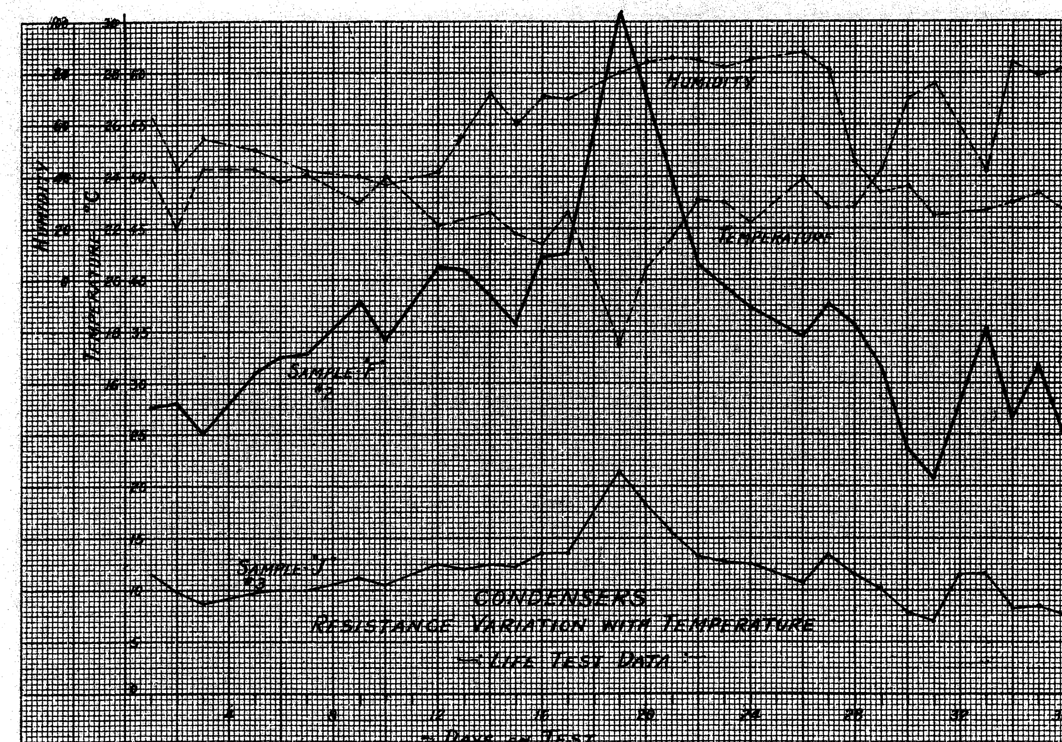

FIG. II.

Condensers with impregnation other than wax have shown up exceptionally well on life test. Operated at double voltage, only one breakdown occurred in each group on test. This was probably due to flash-over rather than actual puncture of the dielectric. Of 19 samples on test the lowest resistance at 2000 hours was 6000 megohms per mfd. and 14 of the samples still had infinite resistance. The breakdown potential of these condensers was approximately 1200 volts r. m. s. Owing to the excellent showing of these samples at high potential, no test was run at normal.

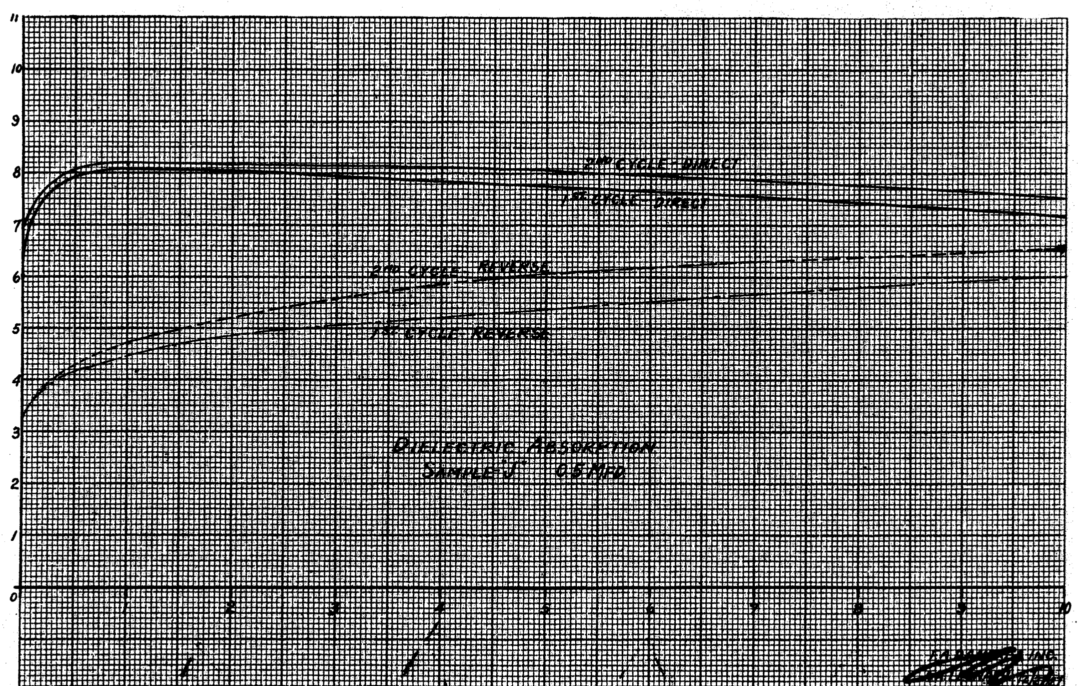

FIG. III.
Showing the apparent resistance due to dielectric absorption current.

Fig. 2. shows the variation of condenser resistance with temperature. The relative humidity is also plotted daily, but it has no bearing on condenser resistance, other than possible surface leakage, if the units are well sealed by the impregnating compound. Sample "F" was a 1-mfd. two-paper unit, rated at 200 volts normal and was Halowax impregnated with a paraffin seal. Sample "J" was also a two-paper unit of the same rating but had a composition wax impregnation of Ceresin plus other waxes, and showed high power-factor as well as low resistance.

Fig. 3 shows the apparent resistance due to the dielectric absorption current of sample "J." The polarization is very marked, possibly due to electrolysis in the dielectric. These curves are obtained by placing the unit in series with a 90-volt constant-potential source. A microammeter with a short-circuiting switch was also in the circuit. The switch was opened immediately after the condenser received its electrostatic charge and the current was noted at intervals of 15 seconds. The condenser was then discharged through a high resistance, and after the electrostatic charge was removed, the unit was short-circuited for 30 minutes to allow a complete dissipation of the absorption current. The potential was then applied in the reverse direction and the current again noted at intervals of 15 seconds. This process was repeated to give the second series of curves. As 15 seconds was the shortest time which could be accurately observed, it was impossible to obtain the actual value of the absorption current for short periods but the general trend of the curve will give a good idea of its amplitude. If the test be prolonged, it will be found that the resistance with either polarity will ultimately become identical—in this case, approximately 30 minutes.

SUMMARY

FROM the foregoing it is evident that there is no known method by which the life of a condenser may be checked, other than operating the unit over a considerable period of time at greater than normal potential. A good idea of condenser behavior will be had from operation at double potential for about 500 hours. This is about 25 days, and is a sufficiently short period to allow its general use. Mr. Houck of the Dubilier Condenser and Radio Corporation has determined that the life of a condenser varies approximately as the 5th power of the applied potential. Tests indicate that this ratio will be attained, and possibly exceeded, and no failures of samples have been had on normal potential over a period of 2400 hours, although power factor and resistance have large negative temperature coefficients, and breakdown seems likely on some of the poorer grade units. In every instance, a good check is had between results obtained at double and those obtained at normal potential, erratic resistance variations with increasingly large negative temperature coefficients occurring much earlier at high potentials.

Increase in power-factor may be expected with age, but this does not hold in all instances. Power-factor measurements are necessary, however, as they are the only possible check of dielectric absorption.

In conclusion the writer wishes to thank the Aerovox Wireless Corporation, the Condenser Corporation of America, the Dubilier Condenser and Radio Corporation, and the Polymet Manufacturing Company, for their coöperation and generosity in supplying samples for these tests; also Mr. L. M. Clement, Mr. F. X. Rettenmeyer, and members of the engineering department of F. A. D. Andrea, Incorporated, for valuable suggestions and assistance in compiling this paper.

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