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Condensers[†]

By R. A. Lane*

IN looking into the history of condenser development, we find that the pioneer investigators discovered the ability of a dielectric to store electrical energy, before they understood the principle which governed the apparatus. This is indicated by the name condenser, a misnomer arising from early misconceptions of the electrical principles involved. The more recently applied term "capacitor" is more truly descriptive.

Like many other important developments the first condenser, in the form of the Leyden jar seems to have been arrived at by two investigators at approximately the same time: Dean Von Kleist of the Cathedral of Camin in Germany in October, 1745, and Von Muschenbroek of Leyden in January, 1746. Von Muschenbroek's results were the first to become generally known, hence the name of the apparatus.

The names of Volta, Cavendish and Franklin stand out among the many early investigators of dielectric phenomena. Volta in 1782 observed that when a Leyden jar was discharged and left on open circuit for a time, a charge reappeared. This opened up a field of investigation which has occupied the attention of physicists up to the present time.

Cavendish, from the hissing sound he heard just before the discharge of a Leyden jar developed his fluid theory of electricity.

As Americans, we should be particularly proud of Franklin's investigations, which began soon after the discovery of the Leyden jar.

Franklin seems to have been one of the first to put forward the idea that energy was stored in the dielectric. In one of his letters to Peter Collinson, of London, with whom he carried on an extensive correspondence on a variety of subjects, he says: "Thus the whole force of the bottle and power of giving shock is in the glass itself, the non-electrics in contact with the two surfaces serving only to give and receive to and from the several parts of the glass, that is to give on one side and take away on the other."

He later demonstrated this by making a plate condenser out of glass and lead foil, removing the plates after charging the condenser, and discharging with a second set of plates.

Franklin also noted that dry air is a good insulator, but as the amount of moisture increased, the insulating value decreased. He mentions in one of his letters a Leyden jar which held at least a portion of its charge for seven months.

Like most of the investigators of his time, Franklin spent considerable time in working up electrical tricks. He arranged a picture of the King in such a way that anyone who attempted to dislodge the crown would be bowled over by the discharge of a few Leyden jars.

Franklin also was keenly interested in the effect of the "electrical fire" on living things. He found that two large Leyden jars would kill a hen, but turkeys were tough, and while two jars would knock them out, it required five to kill them. He reports that "meat" killed in this way was particularly tender.

Most of the work done by the earlier investigators was of a qualitative nature, but as knowledge was enlarged the more forward looking workers began to seek quantitative results.

Faraday, in particular, appreciated the desirability of this sort of investigation, as shown by the opening paragraph of his paper on "Induction," read before the Royal Society in December, 1837, where he said:

"The science of electricity is in that state in which every part of it requires experimental investigation; not merely for the discovery of new effects, but what is just now of far more importance, the development of the means by which the old effects are produced, and the consequent more accurate determination of the first principles of action of the most extraordinary and universal power in nature."

In his efforts to obtain accurate information Faraday built several pieces of apparatus with which he studied the properties of dielectrics. One of these consisted of two concentric hollow brass spheres, the inner sphere being insulated from the outer with a space of about $\frac{5}{8}$ inch between the two. The outer sphere was made up of two hemispheres which could be screwed together. Two of these instruments were made and comparative tests made with air for insulation in one, and various other materials in the other. From this work Faraday arrived at the idea of specific inductive capacity, and gave values for several different substances. He also observed the phenomena of residual charge, at first finding that all dielectrics, including air, showed it; but finally deciding that the solid insulation used as a support for the inner sphere was responsible for the residual found with the air dielectric.

Maxwell, in 1873, gave out his theory of absorption, which later has been followed by other theories or modifications by Pellat, Boltzman, Van Schweidler, Wagner and others.

During the 125 years between the discovery of the Leyden jar and Maxwell's work on dielectric theory, the condenser was almost exclusively a laboratory device. Progress in the study of insulation had, of course, been made, but there had been no wide technical application of condensers to furnish the incentive for development.

First Used in Submarine Cabling

This incentive was furnished by the demand for condensers, first for telegraphy and telephony, later for ignition, radio and power factor applications.

The story of condensers is, to some extent, the story of the development of high grade insulation, and the condenser engineer is primarily concerned with the selection of materials and development of processes which will produce the most economical condenser to fit the need at hand.

The necessity for high grade insulation is apparent when the square relation between working stress and volume is considered. Suppose, in making a 200-volt radio by-pass condenser, we used instead of 1 mil of insulation, 10 mils, which can easily be found on other apparatus rated at the same voltage:

[†] *Delivered before the Club, September 16, 1931.*
**Consulting Engineer.*

This by-pass condenser would then be 100 times as large as it is now.

Properties of Condensers

The electrical properties considered in selecting a condenser dielectric include dielectric constant, insulation resistance, dielectric strength and power factor. Since methods of processing affect most of these properties, process development must be carried on along with materials investigation. When enough information is available to determine probable safe working stress, cost of insulation per joule of energy stored may be determined, and the economic usefulness of the material considered. The ideal dielectric would have a high dielectric constant, negligible leakage and losses, and a high dielectric strength.

No ideal dielectric material has yet been developed, although almost every type of insulation has been tried for condenser dielectric at some time or other. For some, little or no commercial application has been found; others have properties which fit them particularly well for certain applications.

Some of the better known and more widely used dielectric materials are impregnated paper, mica, oil, glass and compressed gas.

The development of impregnated paper insulation is particularly interesting, since condensers insulated with paper impregnated with either wax or oil are widely used for a variety of purposes.

Early wax paper condensers, largely used on low, direct voltages, were, of course, far inferior to present condensers of that type, because neither materials nor processes had been highly developed.

A Bureau of Standards report, published in 1907, gives values of power factor from 1.3 per cent to 14.7 per cent for a number of condensers of various makes. In 1911 another set of tests was made on 13 condensers made by English, French, German, and American manufacturers. The minimum value found was .87 per cent, while most specimens ran many times this value. In 1912 the Bureau made some power factor and insulation resistance tests on paraffine impregnated condensers, some of which used metal foil as conductor and others metallized paper. Tinfoil condensers showed power factors from .4 to 4.1 per cent, Mansbridge type from .9 to 1.9 per cent. Insulation resistance in megohms per microfarad varied between 323,000 and 10 for the tinfoil type and between 74 and 100 for the Mansbridge type. Tests were made at room temperature at 100 cycles. It is interesting to note that the report that gives these values of insulation resistance states that while the values vary widely, even the lowest was satisfactory for the purpose for which the condenser was designed. Apparently the effect of leakage on the circuit in which the condenser was to be used was considered, rather than the leakage as an indication of the life of the condenser.

The Dielectric

The various types of paper, foil and impregnating compounds used in the manufacture of wax impregnated paper condensers were at first for the most part selected from available materials; later as requirements became better known special materials were developed.

The paper used in present-day condensers is the result of years of development by paper manufacturers in cooperation with condenser manufacturers. These efforts have produced an extremely thin closed sheet, practically neutral chemically, and remarkably free from conducting particles.

Materials in most general use as conductors include tinfoil, aluminum foil and metallized paper. Aluminum and tinfoil are both available in thicknesses of .0003 inch. Tinfoil makes a heavier condenser and is usually more expensive per sq. in. of coverage. Aluminum foil is more difficult to solder and condensers made with it do not press down as readily as those made with tinfoil. Some test results described further on seem to indicate, although perhaps not conclusively, a longer life for condensers wound with aluminum foil.

Metallized paper or Mansbridge condensers have not been used as extensively in this country as abroad. Instead of using a thin sheet of foil, metal is deposited on paper to form a conducting plate. One of the advantages claimed for this type of condenser is that when a failure occurs the metal around the point of failure is so thin it will be vaporized and the fault cleared. The disadvantages include high conductor resistance and difficulty of making a non-inductive winding.

Paraffine, probably the first material used for condenser impregnation, had when first used, widely varying characteristics due to different methods of refining and different places of origin. Characteristics are more closely controlled at present and the material is still quite widely used, either alone, in combination with other waxes such as carnauba, or with a certain amount of mineral oil. Other petroleum derivatives having higher melting points are also available. Most of these have a dielectric constant of 2 to 2.5. Halowax, a synthetic material, is widely used, because it combines good electrical properties with high dielectric constant.

Assembly

The steps involved in producing a condenser include putting the paper and foil in proper relation, either by winding or stacking, removing moisture from the paper, impregnating, cooling and sealing.

Stacking, that is, building up the condenser section with sheets of paper and foil cut to size, is very seldom used in making wax impregnated condensers, since the number of sheets of paper between foil is usually small enough to permit winding, which is a much cheaper operation.

Winding may be either inductive or non-inductive. Inductive windings use foil which is ⅜ to ½ inch narrower than the paper. The section is wound up with equal margin on each side and tinned copper strips laid in to enable a connection to be made. The non-inductive winding uses foil the same width as the paper, foils of opposite polarity protruding ¼ inch or so on the opposite ends of the winding. Inductive windings require less weight of foil per microfarad, because all foil used is active. Winding labor is greater because connecting strips must be put in. For certain radio applications, the non-inductive winding is necessary, and it is desirable when the condenser is to be used on alternating current, because this foil arrangement facilitates heat dissipation.

Early methods of processing often did not involve the use of vacuum for removal of moisture from the paper, the sections being placed in the impregnating bath, kept there for a few hours, then removed from the wax and pressed. Sometimes vacuum was used on the impregnating tank, with no previous vacuum treatment of the wound sections. This, of course, made a better condenser than when vacuum was not used at all, probably as much due to the removal of entrapped air as to moisture removal.

One method of pressing was to remove the sections from the wax bath, a few at a time, and press in a hydraulic or compressed air press, in a water cooled die. One objection to this method was the rough treatment the section had to stand. Another was the fact that sections would cool rapidly on the outside, remain hot inside and open up when removed from the press.

In many cases the detrimental effect of exposure to moisture laden air during cooling and assembly was not thoroughly understood, which resulted in a product which was extremely variable in quality.

Details of present practice vary rather widely, due to different materials in use and different production apparatus employed. In general, the wound sections are stacked in clamps, separated by metal spacers. Loaded clamps are then placed in a drying oven, heated and evacuated. Since the amount of moisture drawn off during the first hour or so of pumping is large, two vacuum systems are often employed, one for primary and one for final evacuation.

In some cases wax is run into the vessel in which drying took place and the impregnation completed without handling the loaded clamps. Another method involves moving the clamps from drying oven to impregnating tank. A few systems, after vacuum impregnating for a period of hours finish up by putting the impregnating tank under air pressure of about 50 lbs. per sq. in. for a time.

Cooling starts in the impregnating tank when the heat is cut off. Since it is desirable to cool the condensers out of contact with any moisture laden atmosphere, the cooler they are when removed from the wax the better. Sometimes when steam jacketed impregnating tanks are used, the cooling is hastened by cutting off the steam and running water into the steam jacket.

When removed from the impregnating tank the clamps are cooled off in oil or in air from which the moisture has been removed.

To guard against penetration of moisture during the life of the condenser the section or group of sections is usually dipped in a bath of wax after the leads have been soldered on, and just before placing in the container. After the block is in the container, pitch is poured in to insure complete protection against outside atmospheric conditions.

Tests

Capacity and over voltage tests are made before assembly is started to eliminate faulty sections before any work is done on them. Preliminary tests of this type are often made at three times rated voltage. After assembly the capacity is rechecked, insulation resistance checked and a final over-voltage test made. On condensers for d-c. service power-factor tests are often not made on total production, tests being made frequently on a few samples selected at random.

The minimum value of insulation resistance specified as acceptable is often set at 1,000 megohms per microfarad at 25° C. Most carefully processed condensers run considerably higher than that.

Even a poorly processed condenser will often stand a 15 second breakdown test at a value far above twice or even three times its rated voltage, so that while the over-potential test will eliminate sections weakened by mechanical defects it is not a good check on process. The insulation resistance test is better in this respect, although by no means infallible. Best results by the manufacturer are obtained by combining routine tests with a very careful check on every step in the process of manufacture; and best results for an organization using condensers but not making them lie in patronizing a manufacturer known to do this.

Long time life tests at two or three times rated voltage are widely used to determine the quality of condensers. They are, of course, useful in the development of processes and materials rather than as a means of controlling production. 1,000 hours is often specified as the minimum time for operation at double rated voltage. There is considerable difference of opinion as to the interpretation of the results of these accelerated life tests. It is sometimes considered that the life of the condenser on d-c. varies as the fourth or fifth power of the voltage applied.

Thus, if a condenser operated at double voltage for 1,000 hours it would operate between 16,000 and 32,000 hours at normal voltage. In drawing conclusions from tests of this kind it must be kept in mind that "normal operation" means operation at varying temperatures, often with an a-c. component, and with the condenser subject to frequent surges.

Such tests are, however, valuable in making comparisons when materials or process have been varied. Some time ago, when working with both aluminum and tinfoil it appeared to me as though aluminum foil sections stood exposure to moist air much better than tinfoil sections. To find out if this was true when conditions were controlled, two sets of sections were made up and impregnated at the same time. Samples of both types were exposed to moist atmosphere at the same time for the same length of time, then assembled in the same way and put on double voltage life test. All the sections made up with aluminum foil remained on test well over 1,000 hours with no failures, while failures started on the tinfoil section in about 10 hours and very few lasted as long as 500 hours. Insulation resistance of the two sets of samples was about the same at the start of test. Unfortunately power-factor tests were not made on either set of sections.

Oil Impregnated Paper

The use of oil impregnated paper insulation has been largely in condensers for power factor correction, although some have been used in radio work, particularly in broadcasting apparatus.

Oil impregnated paper is superior to wax impregnated for a-c. service, particularly at the higher voltages when insulation is thicker. The combination of oil and paper is a much better conductor of heat than that of wax and paper, so that heat is passed out of the case for dissipation much more rapidly.

Several types of paper have been used in oil impregnated condensers, including Kraft, a combination of wood pulp and cotton and pure linen tissue. Processing must be modified to fit the particular material used, paper containing wood pulp being much more quickly affected by high temperature than pure linen tissue.

Mineral oil of about the same grade used in transformers is commonly used as an impregnating material. Some vegetable oils having high dielectric constants have been tried.

Process in impregnating paper with oil is similar to that used with wax, drying being completed before admitting the oil, and the oil preheated before being run into the condensers. Care must be taken to get any occluded air out of the oil before it becomes hot enough to damage it by oxidation. In many cases the condenser is assembled completely, then dried out and impregnated in its own container.

Condensers for a-c. service at 1,328 volts and above are tested for 1 minute, at twice rated voltage plus 1,000, sometimes at 2¼ rated voltage plus 2,000.

Dielectric losses are of particular importance in a condenser designed to operate on alternating voltage and must be kept at a low value, usually not so much because of the power cost as to insure long life for the condenser itself. Maximum allowable losses are set from .35 to .5 per cent of the normal operating KVA, measurements being made at 25° C.

Dielectric Losses

Many methods of measuring dielectric losses have been developed, but most of them require delicate apparatus, which takes considerable time to set up and adjust. A fair idea of losses may be obtained by preparing a dummy container identical outside with the condenser under test but containing a heating element instead of a condenser. By adjusting the input to the heater until the case temperature is the same as that of the condenser under test the condenser losses may be considered equal to the input to the heater.

One method which has proved successful in production testing is the use of an inductance of known losses with which the power factor of the condenser is corrected to approximate unity. Losses in the combination may be measured with an ordinary wattmeter and correction made for the losses in the inductance.

Book Review

"EXPERIMENTAL RADIO ENGINEERING." By John H. Morecroft. Published by John Wiley and Sons, Inc., New York City, 1931. *Price,* $3.50 (345 *P.P.—illustrated—cloth*).

Addressing the radio fraternity in general, no radio engineer needs an introduction to Professor Morecroft's *"Principles of Radio Communication."* His *"Elements of Radio Communication"* is likewise written in a similar workmanlike manner which makes this text especially valuable to radio students and beginners. And now comes the third of a trio of fine radio works written by this recognized author and teacher of experience.

The new book, *"Experimental Radio Engineering,"* is in the form of a laboratory manual compiled especially for the engineering student who is interested in knowing the "how" and "why" of radio principles. It is written in true Morecroft fashion and is direct to the point, considering in concise manner the various fundamentals necessary to understand radio frequency and operating phenomena. By use of illustrations and simple mathematical formulae, the work is clearly presented which in conjunction with the actual experiments to be worked out forms an interesting and instructive radio course for the serious-minded student.

The book consists of fifty-one experiments considering the principle and important circuit components employed in radio communication. The experiments are preceded by an introduction wherein various instruments of electrical measurement, used in conducting experiments, are described and reviewed in general. The choice of material for the fifty-one experiments is worthy of comment since all of the subjects are of common nature whose idiosyncrasies one encounters in the usual routine of radio practice or study covering the broad field of the radio art. The information proves effective even if merely read over. For actual benefit, however, the experiments should be conducted in the form of progressive problems by which routine of study the reader will most appreciate the work outlined in this radio engineering course.

Among the experiments included in this work are measurements of the fundamentals constituting the simple tuned electrical circuit and a study of their characteristic properties, followed by various considerations of circuits comprising instruments for electrical measurement. Succeeding this material the student is then introduced to the study of the thermionic valve; considering its various forms of construction and its applications in radio circuits. In addition there is an interesting study of antennae, the oscilligraph, filters, rectifiers, super-sonic reception, and modulation, etc. From this brief list it may be seen that the book considers both the receiving and transmitting phases of radio communication.

Prof. Morecroft's new work is recommended to all readers having an interest in radio principles and there is no doubt but that it will receive the same respect accorded to the other previous works of this series.—*Reviewed by Louis F. B. Carini.*

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OBITUARY

DONALD F. WHITING of Port Washington, N. Y., a Fellow of the Radio Club of America since 1926, was killed in an accident at his home on September 7, 1931.

He was born April 13, 1891, at Lowell, Mass. After attending the public schools, he entered Worcester Polytechnic Institute, from which he obtained his Bachelor of Science degree. During his sophomore year he became a member of the Worcester Polytechnic Institute Wireless Association, of which he was president during his junior and senior years. During these years he collaborated in the design and installation of the Worcester Polytechnic Institute wireless transmitter. Immediately after graduation he entered the employ of the Marconi Wireless Telegraph Company of America as assistant engineer, which position he occupied until 1916, when he entered the engineering department of the Western Electric Company. From 1916 to 1927 he served as technical consultant and supervisor of the engineering department of the Western Electric Company and its successor, Bell Telephone Laboratories. During this time he invented numerous transmission circuits and devices, on which some 15 patents have been issued, and was responsible for a number of valuable contributions to the communication art. A number of Mr. Whiting's inventions made during this period are now being utilized in radio receivers and public address equipment. In 1922 he submitted a thesis on "Measurement of the Transmission Efficiency of Telephone Apparatus" to Worcester Polytechnic Institute and during the same year received the degree of Electrical Engineer from this institution. During 1927 Mr. Whiting became staff engineer in charge of testing and research for the Fox Case Corporation, and in 1930 was appointed technical director of Fox-Hearst Corporation, a position he held until a few weeks before his death. Mr. Whiting was an active member of many technical organizations, having served on the:

Membership committee of the Radio Club of America, papers committee of the Radio Club of America, projection committee of the Society of Motion Picture Engineers, and standardization committee of the Institute of Radio Engineers.

He was a Fellow of:

The American Institute of Electrical Engineers, the Radio Club of America, and the American Association for the Advancement of Science, also a member of the Institute of Radio Engineers.

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