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Measurement of the Thickness of Capacitor Paper

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Contents

Measurement of the Thickness of Capacitor Paper

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Accurate determinations of the thickness of thin papers present a number of problems that must be considered if adequate data are to be obtained with the equipment and methods available in the average physical laboratory. The definition of thickness is one factor that must be carefully analyzed before choosing an instrument for such measurements. Three methods are available for the measurement of the thickness of capacitor paper: (1) by direct observation across an edge section by means of a micrometer microscope, (2) by measuring the separation of two geometric surfaces between which one or more specimens are placed, and (3) by determining the mass of a definite area of sample and computing the thickness, using the density parameter. Each of these methods has some difficulties or limitations, but each supplies useful information.

Measurements have been made on some commercial thin capacitor papers, using the interferometer, micrometer microscope, mechanical micrometers, and the surface analyzer. These data have been analyzed. It has been found that the precision dial micrometer or the precision screw micrometer may be used for such measurements. The size and type of contact and the load to be applied will depend on the needs of the manufacturer and user of the paper.

1. Introduction

The measurement of the thickness of thin papers and similar materials presents a number of problems, some of which require particular analyses and skills if the equipment and methods available in the average metrological laboratory are to yield adequate data on this dimension.

Instruments are available that will indicate dimensions to millionths of an inch. Operators of interferometers and certain electronic (electric contact) indicating devices can adjust and control such instruments with ease and assurance of the required accuracy of each measurement, provided the item being measured possesses satisfactory uniformity and definiteness of dimension. Difficulties sometimes arise when an attempt is made to use a very special instrument for measuring a dimension, especially when the behavior of a material in service is different from its behavior in the measuring instrument.

Capacitor paper having nominal thicknesses of a few ten-thousandths of an inch is a vital component of electric devices. The precise operation and control of these devices are usually intimately related to the uniformity of the capacitors they contain and therefore to the thickness of the paper used in each capacitor.

Capacitor paper is usually made from cellulose fibers. Because of the method of manufacture, the surface is necessarily somewhat rough, and the thickness will vary from place to place on the sample.

2. Methods

Three methods are available for the measurement of the thickness of capacitor paper: (1) by direct observation across an edge section by means of a microscope, (2) by measuring the separation of two geometric surfaces, between which one or more specimens are placed, and (3) by determining the mass of a definite area of sample and computing the thickness, using the density parameter.

Each method has one or more difficulties. When the cut edge of the sheet is used, we assume the pattern and thickness of the cut edge will not be changed or different from its structure in the uncut condition. If the paper is mounted in a supporting medium, it is assumed no chemical attack or exchange will take place between the paper and the supporting medium and no distortions will be added when the medium supporting the specimen is sectioned. A sufficient number of observations should also be made to indicate the values for the thinnest, thickest, and average dimensions of a sheet of paper by tests on microscopic areas that represent an extremely small percentage of the entire sample.

Equally disturbing difficulties are encountered when the specimen is placed between two surfaces of a measuring instrument. Instruments that extend over the cut edges of the specimen will register the effects of disturbed fiber structures. The pressure, or load, applied to the paper by the plates of the instrument will compress the irregularities of the surface and cause the indicated thickness to vary over wide ranges. Not only is it necessary to specify the area of surface and load to be applied, but the type of contacts must also be described. Flat-surface contacts will yield thicknesses much greater than those obtained from an instrument that employs a sphere opposite a flat.

The density method yields values for comparatively large specimens. This method is not difficult to use and probably gives the most satisfactory estimate of the solid component of the specimen. Surface irregularities and nonuniformity of areas in the specimen are not indicated by this method.

It should be emphasized, however, that there is probably no single best way of measuring capacitor paper for specific type of processing. Each of the three methods referred to yield information that will be useful in evaluating the paper for different service applications.

3. Definitions

Some of the difficulties in making measurements of the thickness of capacitor paper and the sources of variation in the values obtained with different instruments and techniques have been pointed out. In addition, it seems desirable to suggest definitions that will be useful in reviewing the data and discussions that follow.

3.1. Thickness at a Given Point

The thickness at a given point is the distance perpendicular to the plane of the sheet between the surfaces of the sheet.

The surfaces of a sheet, for the purposes of measuring the thickness, is an envelope which encloses the contiguous or closely adjacent fibers that lie approximately in the plane of the sheet. This envelope is constructed so as to contain no folds or reentrant cavities and so that at no point is the radius of curvature less than the nominal thickness of the sheet. The reason for this somewhat elaborate definition of surface will be evident from inspection of photomicrographs showing the highly irregular structure of a section of paper (see figs. 1, 2, and 3). An inspection of the micrographs reproduced in the figures will show that values varying more than five to one may be expected with no certainty of being able to locate the thinnest or thickest point in a specimen.

3.2. Parallel-Plate, or Conventional Gage Thickness

The parallel-plate thickness of paper is the distance between two parallel plane surfaces of specified area applied to the paper under a specified load. The distance between the surfaces decreases as the load is applied. The force serves first to flatten the sheet and tends to eliminate any waves or wrinkles, and then to displace, or deform, the high spots, and finally, to a limited extent, to compress the fibrous mass itself. The volume compressibility of cellulose is very small, even under the highest localized pressures that are likely to obtain in loading a specimen, so that most of the compression of a specimen is the result of the flattening of the sheet and the deformation of the fiber structure.

In practice, the load is applied to a gage foot 0.56 to 0.65 in. in diameter. This area is large relative to the variations shown by the point or the ball-and-anvil thickness, but it does give a good indication of the maximum thickness.

3.3. Ball-and-Anvil Thickness

The ball-and-anvil thickness is the vertical distance between a small sphere and a plane surface, both of which are in contact with the paper. At the Bell Telephone Laboratories, which have had considerable commercial experience with capacitor paper, the ball used is 0.01 or 0.02 in. in diameter, and it is brought into contact with the paper under a load of 31 or 200 g. Even under this relatively light load, the contact pressure is quite high.

3.4. Thickness From Weight and Density

A limiting value for the average thickness can be found by dividing the weight per unit area by the density. This method is applicable only to areas large enough to be weighed and measured for dimensions with the requisite accuracy. The density of the paper substance can be determined by various methods, one of which will be described later. For some purposes it may suffice to use a value of the density of cellulose taken from the literature for the particular type of paper used.

3.5. Multiple, or Stacked, Sheet Thickness

The thickness of capacitor paper is often determined by measuring an assembly of 10 sheets, using a gage of the parallel-plate type. The value thus obtained for the thickness is less than 10 times the value obtained by the same gage for a single sheet by an amount that depends on the extent to which the thicker areas of one sheet coincide with the thinner areas of another sheet.

The value of the "packing factor" can be found by measuring the thickness of assemblies containing different numbers of sheets—say, 1 to 10—and plotting the values of thickness against the number of sheets (see fig. 6). The curve thus obtained is approximately linear and when extrapolated to zero gives an intercept on the thickness axis that is a convenient and practical index of the extent to which sheets pack together when used in an assembly such as a capacitor. This method gives more promise of revealing pertinent data than any other investigated (see tables 2, 3, and 4 and fig. 6).

From a practical standpoint, the multiple, or stacked, thickness-measurement values will be found to be more nearly uniform. The equipment and techniques are not complicated. The standard deviation between replicate readings, the coefficient of variation, and the expected error in value for such measurements made by operators of reasonable experience should be satisfactory for most production and acceptance testing.

For those cases in which questions arise concerning excessive surface irregularities it would be a simple matter to compare the apparent densities obtained by the area and thickness dimensions with those obtained by suspension in a liquid (see sec. 7). The greater the discrepancies in these two values for density the greater are the variations in thickness (particularly with a parallel-plate gage).

The following equipment, tests, and data are presented as an aid in the development of a method for determining thicknesses of capacitor papers, with the full knowledge that no instrument, technique, or numerical value is new or unique [1, 2, 3].[1]

[1] Figures in brackets indicate the literature references on page 10.

4. Instruments

4.1. Interferometer

The interferometer [4, 5], in its simpler forms, is one of the most convenient and accurate measuring instruments and is quite satisfactory where it is applicable. Values accurate to 0.00001 in. are available without question regarding the proper functioning of the instrument.

Two types of interferometers were used. The first was the wedge type, in which a ribbon specimen of paper is placed between two glass flats near one edge of the pair of flats. The thickness of the wedge of air, from the glass-glass contact to the glass-specimen-glass contact, was determined by observing the interference pattern and counting the number of fringes. (It was realized that there are films of air at each area of contact. It is not thought that these introduced any inaccuracies in the studies, although they would have to be evaluated for precision measurements or absolute values of paper thickness.)

The second interferometer involved the placing of three small specimens of paper between the flat plates, near the circumference and on radii separated by angles of 120°. Approximate thicknesses of the specimens were first determined with a machinist micrometer before they were placed between the flats. From this approximate thickness and the fractional values of the interference fringes it is possible to compute the distance between the glass flats (thickness of the paper).

These techniques are quite satisfactory for rigid materials, such as gage blocks made of metal, glass, and similar materials that can be shaped to a desired dimension and which retain this dimension with a reasonable degree of permanence.

All thickness values determined by the interferometer were significantly and excessively high. Specimens having a nominal thickness of 0.00020 in. were measured as having a single-sheet thickness of 0.00043 in. Machinist micrometers were used to obtain additional information bearing on this confused condition. These micrometers gave values of from 0.00016 to 0.00034 in., depending upon the kind of contacts used, the sphere-to-flat contacts giving the smaller values and the flat-to-flat contacts the larger values. One difference between the interferometer and the micrometer is the position of the edges of the cut specimen. When a specimen is placed in the interferometer, the cut edges are between the flats; when in the micrometer, the cut edges are not between the measuring anvils. It was not possible to eliminate the effects of these edge injuries. Consequently, all measurements with the interferometer are subject to question. Although the specimens were "ironed" between the flats of the interferometer and under pressures approaching 100 lb/in.^{2}, no thickness below about 0.00034 in. was found when the pressures were reduced. It was known that injuries to the fibers would occur when the paper was folded, torn, or sheared, but it was not fully realized that these injuries are permanent and cannot be eliminated by ordinary means. This indicated the necessity for avoiding such injuries by using contact areas that did not include cut or distorted edges of paper. Interferometers designed for such contacts (excluding edges of specimens) are somewhat complicated for use by inexperienced operators.

4.2. Micrometer Microscope

Figures 1, 2, and 3 show the thickness irregularities in 0.00040- and 0.00020-in. capacitor paper. In figure 1 the paper was mounted in resin and sectioned after the resin hardened. The technique for mounting and sectioning is not difficult.

A piece of capacitor paper as long as the body of a number 00 gelatin capsule (0.80 in. in length and 0.33 in. in diameter) was cut from the sample. The paper was then folded into a **Z** shape and inserted into the capsule with the diagonal of the **Z** as a diameter of the circular section of the capsule. The parallel arms of the **Z** hold the paper in place by resting against the sides of the tube.

Monomeric *n*-butyl methacrylate containing about 0.5 percent of catalyst (2,4-dichlorobenzoyl peroxide) was then poured into the capsule and the cap applied to the body. The filled capsule was polymerized in an oven at 40° C for several hours. The gelatin was removed from the hard casting by soaking it in water, and the block was sectioned as described by Newman [6]. The sections were flattened by floating them on a 50-percent aqueous solution of 1,4-dioxane. They were then fastened to slides, the matrix dissolved off, and finally mounted in Canada balsam.

Figure 2 is a photomicrograph of the paper edge prepared by a different method. The paper was placed between two sheets of 0.001-in. tinfoil, compressed and cut with a razor-edged tool. The displaced and torn fibers are shown, which build up the thickness to about 0.00090 in., with thin sections of approximately 0.00016 in. Failure to get a negative showing uniformly good focus for the entire length of the edge is attributed to bends,

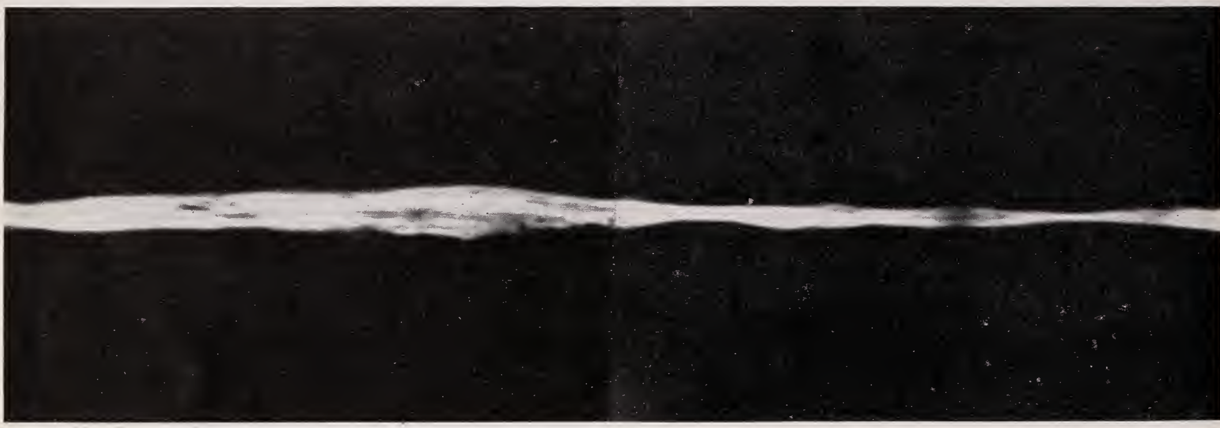

FIGURE 1. *Edge section of 0.00040-inch capacitor paper embedded in monomeric n-butyl methacrylate.* Linear magnification ×450.

FIGURE 2. *Edge section of 0.00020-inch capacitor paper cut between 0.001-inch sheets of tinfoil with a razor-edged tool.* Note torn and displaced fibers, also poor focus where the edge has been bent in cutting. Linear magnification ×430±20.

FIGURE 3. *Surface of 0.00020-inch capacitor paper showing large fibers piled across each other.*

Linear magnification $\times 430 \pm 10$.

tears, or creases along the edge of the cut paper. Figure 3 shows some of the larger fibers, apparently flattened, but stacked over each other and not conducive to uniformity or flatness of surfaces.

These experiences with the interferometer and with the micrometer microscope, where cut edges play such important parts in measuring dimensions, leave much to be desired. It seems impossible to eliminate these difficulties completely. These edge effects, while real, represent a very small part of the effective or operating area of a capacitor. It seems proper, therefore, to eliminate the interferometer (with its unquestioned accuracy) and the micrometer microscope (with its excellent portrayal of details) as effective instruments for measuring the thickness of capacitor paper, although they do contribute definite information for a more nearly complete understanding of some of the problems encountered.

4.3. Machinist Micrometer (Including Dial Indicators)

The machinist micrometer and the dial indicator (see fig. 4) with flat contact anvils approximately 0.250 in. in diameter or spherical contacts having radii of about 0.2 in. have advantages over the interferometer and the microscope as edge irregularities in thickness may or may not, at the option of the operator, be included in the measurements. Specimens of paper cut to a convenient size of about 1 by 2 in. may be measured singly or stacked, all measurements being free of edge effects. The

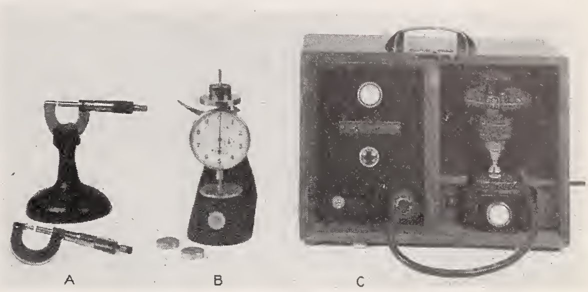

FIGURE 4. *Instruments suitable for use in measuring the thickness of capacitor paper.*

A, Machinist precision-micrometer vernier graduated to 0.0001 inch; estimates are made to 0.00001 inch. B, Dial indicator graduated to 0.0001 inch; estimates are made to 0.00001 inch. Contacts may be flat or spherical. C, Electric-contact micrometer graduated to 0.0001 inch; estimates are made to 0.00001 inch.

values for stacked sheets are relevant as they tend to reduce the effects of larger fibers which may fit into thinner areas on adjacent sheets just as they do in the finished product.

A wide range of loads, or pressures, is available from low on the flat anvil to very high on the smaller spherical contacts. The thicker areas will be detected more readily with the flat anvil. The thinner areas may be found with the spherical contact. The exact dimensions of flat anvils and spherical contacts, and the loads to be applied will depend upon the methods of assembling the paper in the capacitor. In section 7 a technical discussion is presented bearing upon ultimate pressures and complete solidity of paper. There is little reason for attempting to apply this ultimate pressure in a specification for use in the selection of capacitor paper.

4.4. Surface Analyzer

Attempts to chart the surface irregularities on an electronic surface analyzer [1], such as is used on gage blocks and steel bearings, were not successful. Irregularities were graphed by the pen, but the pressure on the diamond tracing stylus (0.001 in. in diameter) could not be reduced sufficiently to prevent it from cutting and pulling the fibers or leaving a groove on the surface of the paper. Obviously, the surface analyzer in its present state of development and adjustment is not suitable for precision testing of capacitor paper.

5. Results

Tables 1 to 4, inclusive, report measurements made with the instruments shown in figure 4. Preliminary measurements with these instruments gave fairly concordant values for each instrument. All measurements were made at a temperature of 72° F and a relative humidity of 65 percent. The loads applied with the dial indicator are usually lower and are more reliable than those applied with machinist micrometers. The torque on the drum of the micrometer, applied through the torque ratchet, will usually produce several ounces of thrust, or load, on the paper.

Table 1 contains a series of measurements made by three operators on specimens cut from a roll of 0.00040-in. capacitor paper to obtain a statistical estimate of the precision of measurements and skills of the operators in using the deadweight micrometer with dial indicator. The dial indicator shown in figure 4, B, was used for these tests. The specimens were about 1 by 2 in. No discards of parts of the sheets were made. The order of the specimens and numberings are indicated in figure 5. Each operator made four readings on each specimen.

Operators 1 and 3 are regarded as experienced operators, having made similar measurements over a period of years with various types of equipment. Operator 2 had only limited experience. Each operator was requested to verify the zero of the instrument before and after each reading, to allow the contact to approach the paper slowly, and after first contact to lift the contact slightly and allow it to come to rest. Operator 3 tapped the frame

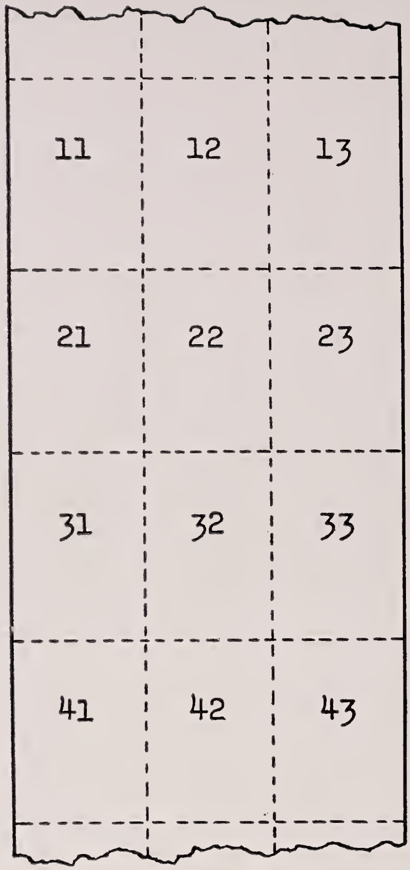

FIGURE 5. *Positions of numbered specimens of capacitor paper before cutting from the roll.*

TABLE 1. *Thickness of paper*

Flat contacts, 0.250 in. diameter and 5-oz load. Multiply all thickness values by 10^{-5} in.

Specimen	Individual values				Mean	Individual values				Mean	Individual values				Mean
	Operator 1					Operator 3					Operator 2				
11	57	56	58	56	57	54	57	59	56	56	57	56	58	54	56
23	59	56	55	61	58	60	59	57	57	58	57	58	58	54	57
32	56	58	57	55	56	57	58	58	59	58	57	56	59	55	57
41	58	58	60	57	58	58	59	59	59	59	56	59	59	59	58
	Operator 2					Operator 1					Operator 3				
12	58	58	53	56	56	59	58	57	59	58	60	58	59	58	59
21	60	51	56	52	55	56	62	55	54	57	57	61	57	57	58
33	61	54	55	54	56	59	58	62	57	59	55	60	57	58	58
42	58	54	59	52	56	60	54	56	57	57	53	54	53	52	53
	Operator 3					Operator 2					Operator 1				
13	58	54	55	55	56	57	57	59	53	56	57	56	58	60	58
22	56	53	57	58	56	52	58	55	56	55	56	58	54	56	56
31	61	58	53	55	57	53	53	58	52	54	55	57	56	58	56
43	57	58	58	53	56	53	56	58	59	56	52	56	53	54	54

support of the indicator lightly with a pencil before each reading.

Table 2 contains values for 0.00040-in. paper (by operator 1) in single- and multiple-thickness stocks for:

(a) flat contact dial indicator with light load,

(b) flat-contact machinist micrometer, with heavy load,

(c) spherical-contact micrometer with light load, and

(d) spherical-contact machinist micrometer with heavy load. The values for (a) are shown in figure 6.

Table 2. *Thickness of condenser paper*

[Nominal thickness 0.00040 in.]

Sheets in stack	Flat-contact micrometers Dial-indicator: Contact face: 0.250-in. diam. Load: 5 oz Machinist: Contact face: 0.235-in. diam. Load: 16¾ oz				Spherical-contact micrometers Electric Contact: Contact sphere: 0.215-in. diam. Load: 2 oz Machinist: Contact sphere: 0.200-in. diam. Load: 13¾ oz			
	Dial Indicator		Machinist		Electric Contact		Machinist	
	Thickness	Mean	Thickness	Mean	Thickness	Mean	Thickness	Mean
	in.	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
1	56×10^{-5}	56×10^{-5}	51×10^{-5}	51×10^{-5}	48×10^{-5}	48×10^{-5}	32×10^{-5}	32×10^{-5}
2	97	48	94	47	86	43	65	32
3	136	45	132	44	121	40		
4	182	46	165	41	158	40	119	30
5	223	45	207	41	200	40		
6	266	44	249	42	244	41		
7	304	43	284	41	281	40		
8	349	44	325	41	322	40	238	30
9	389	43	361	40	356	40		
10	427	43	403	40	397	40		
11	474	43						
12	516	43						
16							481	30

Table 3. *Thickness of condenser paper*

Nominal thickness 0.00020 in.

Sheets in stack	Flat-contact micrometers Dial-indicator: Contact face: 0.250-in. diam. Load: 5 oz Machinist: Contact face: 0.235-in. diam. Load: 16¾ oz				Spherical-contact micrometers Electric Contact: Contact sphere: 0.215-in. diam. Load: 2 oz Machinist: Contact sphere: 0.200-in. diam. Load: 13¾ oz			
	Dial Indicator		Machinist		Electric Contact		Machinist	
	Thickness	Mean	Thickness	Mean	Thickness	Mean	Thickness	Mean
	in.	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
1	34×10^{-5}	34×10^{-5}	33×10^{-5}	33×10^{-5}	26×10^{-5}	26×10^{-5}	16×10^{-5}	16×10^{-5}
2	56	28	53	26	48	24	33	16
3	80	27	75	25	69	23		
4	100	25	99	25	85	21	59	15
5	124	25	120	24	109	22		
6	146	24	143	24	130	22		
7	171	24	165	24	149	21		
8	194	24	184	23	172	22	127	16
9	216	24	205	23	194	22		
10	239	24	224	22	218	22		
16							249	16

Table 3 contains values for 0.00020-in. paper obtained under the same conditions as those listed in table 2.

The data in table 4 were taken as specified in tables 2 and 3 under condition (a), and show the results of doubling the loads when compared to tables 2 and 3.

The data in tables 2, 3, and 4 were plotted and the straight-line relationship shown in figure 6 established for all these data. The slopes of these straight lines provide estimates for the increase in thickness corresponding to the addition of a single sheet to the stack. Comparisons of the slopes corresponding to the various measuring methods give an objective method for their relative evaluation.

TABLE 4. *Thickness of condenser paper*

Flat contacts 0.250-in. diameter, 10-oz load.

Sheets in stack	Nominal thickness 0.00040 in.		Nominal thickness 0.00020 in.	
	Observed thickness	Mean	Observed thickness	Mean
	in.	*in.*	*in.*	*in.*
1	54×10^{-5}	54×10^{-5}	37×10^{-5}	37×10^{-5}
2	94	47	61	30
3	134	45	83	28
4	176	44	104	26
5	216	43	122	24
6	259	43	144	24
7	298	43	164	24
8	339	42	188	24
9	382	42	210	23
10	420	42	232	23

6. Statistical Analyses

Statistical analyses were made of the data shown in table 1 and of another set of measurements made in similar fashion on paper of 0.00020-in. nominal thickness to determine the reproducibility of readings on the same section. The results are as follows:

Data on 0.00040-in. paper:

(a) Standard deviation between replicate readings for operators 1 and 3: $2.1\text{x}10^{-5}$ in.; for operator 2: $2.6\text{x}10^{-5}$ in.

(b) Coefficient of variation for operators 1 and 3: 3.8 percent; for operator 2: 4.7 percent.

The corresponding values for data (not tabulated) on 0.00020-in. paper are:

(a) Standard deviation between replicate readings for operators 1 and 3: $2.0\text{x}10^{-5}$ in.; for operator 2: $2.3\text{x}10^{-5}$ in.

(b) Coefficient of variation for operators 1 and 3: 5.5 percent; for operator 2: 7.0 percent.

It is also of interest to note that operator 2 tends to obtain slightly lower results than the other operators.

From the data in table 1 it may be concluded that the values on the thickness of single sheets of capacitor paper, when measured by experienced operators, should not be in error by more than 7.5 and 11 percent, for papers of 0.00040- and 0.00020-in. thickness, respectively. The expected error for single thickness, determined from five or more sheets stacked and measured as a unit, is much less.

A similar conclusion is available from figure 6, where the thicknesses of 1 to 12 stacked sheets are shown. In most instances the observations are on the line within ±0.00002 in. Attention is directed to the 0.00015-in. zero intercept on this figure. This represents the "not nested" surface irregularities. As the number of sheets in the stack increases, the mean thickness decreases, up to about five sheets. At this number, it seems that the surface irregularities on each individual sheet have found areas between high spots on adjacent sheets into which they may be almost completely absorbed or hidden.

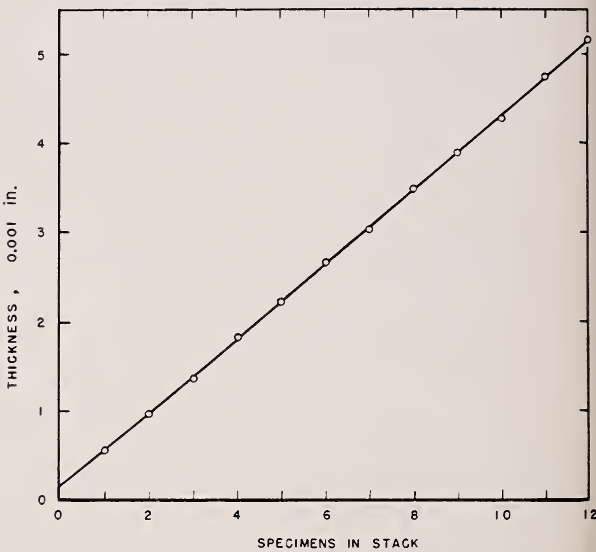

FIGURE 6. *Thickness of stacked specimens of 0.00040-inch capacitor paper under 5-ounce load, between flat contacts 0.250 inch in diameter.*

(See table 2, dial indicator.) Zero specimen intercept, 0.00015 inch.

For spherical contacts the relative pressures per unit area are much greater and tend to reduce the effects of the high spots (see table 2, spherical-contact micrometers). The mean thicknesses approach a uniform value after the second sheet is added in the stack.

Tendencies to approach a uniform and minimum thickness at higher pressures for both flat and spherical contacts have been pointed out from the data in tables 2 and 3. One is tempted to speculate on the possibility of selecting such contacts and loads that the paper may be reduced to a uniform mass of maximum solid, or true, density, without internal voids or surface irregularities. In view of this possibility, it is pertinent to pursue it further by measuring the densities of these papers.

7. Density

Data on mass-volume relations were used to determine the apparent density of the capacitor papers. A selected rectangular sheet of the 0.00040-in. paper had a 164.5-cm^2 area. Its mass was 0.168 g. This computes to a density of approximately 1. If this were the true density, it should have remained suspended when placed in water at its maximum density. However, the paper sank rapidly. Therefore, its density was greater than 1, which is in agreement with the observations of Finch [7].

Thickness values as low as 0.00030 in. were obtained on some specimens of this sample of paper when tested under the spherical-contact micrometer. This thickness gives an indicated density of 1.33. The sample sank in a liquid of this density.

Density determinations were made on 0.00040- and 0.00020-in. capacitor paper by placing it in a liquid that would hold the paper suspended for hours with little or no tendency for it to rise to the top or settle to the bottom. This liquid was composed of about 95 percent of carbon tetrachloride and 5 percent of benzol. There seemed to be no attack on the paper. Liquid applied to the paper and then allowed to drop onto a glass surface evaporated and left no trace greater than that from the original liquid. A bag made from the 0.00040-in. paper held the liquid for several days (until it evaporated) with no indication of leakage. It was not possible to contain the liquid in 0.00020-in. paper without definite penetration and loss through the paper. The density of the liquid that would suspend the 0.00040- and 0.00020-in. papers, without apparent difference in their positions, was obtained by weighing 50 ml of the liquid and computing the density from the formula density=mass/volume. This value is 1.516. This experiment was repeated for general verification but not for a precise value of true density. A value of 1.52 $\pm$0.02 seems generally accepted for the density of native cellulose. Computations based on X-ray data [8] yield a density of 1.59 for crystalline cellulose. The question of finding what load would be necessary to compress paper to this density was not answered as the loads appear to be such that the paper would be subjected to loads beyond those necessary for normal service. Computing the thicknesses for paper compressed to show a density of 1.52, we find values of 0.00026 and 0.00014, respectively, for the 0.00040- and 0.00020-in. papers. These values for thickness are much lower than those for normal loads used in determinations made in any of the regular tests. However, in these measurements, compression was exerted in only a single direction, and density calculated from such thickness measurements cannot be expected to reach that of cellulose, regardless of the sensitivity of the micrometer or of the pressure employed. Three dimensional compressions would be needed to attain the true density.

8. Comments and Conclusions

The problem of setting up a method for the determination of the thickness of capacitor paper has not been completely solved. Much of the data presented here will be helpful in the preparation of the most practical method. It seems necessary to employ two or more instruments in measuring thickness. One is needed to measure the maximum and representative thickness. The dial indicator with flat contacts (graduated to at least 0.0001 in.) may be selected for this measurement. For the thin spots and other irregularities, the same type of indicator with a spherical contact should give satisfaction. The diameter of the flat contact, the diameter of the spherical contact, and the loads to be applied are proper items for further study by the producers and users of these papers.

When the values obtained by flat-contact gages differ excessively from those by spherical-contact gages, it will be helpful to make density determinations to verify or disprove the natural assumption of excessive surface irregularities.

Three methods for measuring the thickness of capacitor paper have been studied, and the following conclusions are presented: (1) The precision dial indicator or the machinist precision micrometer may be used for such measurements, (2) the size and type of contact and the load to be applied will depend upon the needs of the manufacturers and users of this paper, (3) at least five specimens should be stacked and measured to obtain data for practical applications, and (4) for a more thorough investigation of surface irregularities and porosity, a determination of density is necessary.

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