New Developments in Measuring the Resistivity of Paper

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Abstract

The importance of the resistivity of the paper used in toner-based printers and copiers has now been well established and accepted by the paper industry. In the '70s, studies were made of the relationship between resistivity and the runnability, imaging, and release properties. Most of this work was done with the first generation of Keithley Instruments test fixtures, electrometers, and picoammeters, using a DC test voltage.

A newly available system has two major changes: The test fixture applies much higher pressure to the test sample, and an alternating polarity test voltage is used to eliminate offset errors.

Preliminary test data is presented. An industry-wide study is proposed to verify the procedure for correlating new data with existing results.

Introduction

The importance of resistivity of paper for toner-based printers and copiers is well established and accepted by the paper industry and the OEMs. With the introduction in the early '70s of high speed laser printers, such as the Xerox 9000 Series and IBM 3800, Xerox and IBM have pioneered the studies of resistivity of paper to understand the runnability, imaging, toner transfer, and release properties.

Meters and fixtures produced by Keithley Instruments have been widely used for measuring resistivity of paper in the production environment. For this reason, the paper industry has accumulated most of the resistivity data using Keithley equipment. Over the last two decades, there have been steady improvements in the constant voltage source and the picoammeter, with technology evolving from vacuum tubes to solid state circuitry and from analog instruments to digital, computer-controllable ones.

Until recently, the test fixture electrodes and sample chamber design have remained unchanged. However, a new chamber design increases the pressure applied to the sample. Keithley has also developed a new test method that alternates the polarity of the test voltage in order to correct for offset currents. As a result, data collected with the new test fixture (Model 8009) and test method (Alternating Polarity) is more accurate but will differ from the existing industry-wide data measured with the older instrumentation.

Test Fixture Differences

The Model 6105 Resistivity Chamber was designed more than thirty years ago to conform with the recommended dimensions given in ASTM D 257, a standard for the measurement of insulation resistance. It has been used with various electrometers and picoammeters by the paper industry to monitor the resistivity of paper.

The Model 6105 has one shortcoming—the amount of pressure it applies to the sample. The 6105 applies only 0.57 kPa to the sample, far less than the ASTM recommended pressure of 140—700 kPa. Sufficient pressure is required to ensure good contact with the sample.

The newer Model 8009 chamber has a different spring tension than the old chamber, so it can apply more pressure—about 4 kPa.

Figure 1 shows a cross-sectional view of the electrodes of the two chambers. Note that two of the 8009's three electrodes are faced with conductive pads to ensure better contact with rigid samples

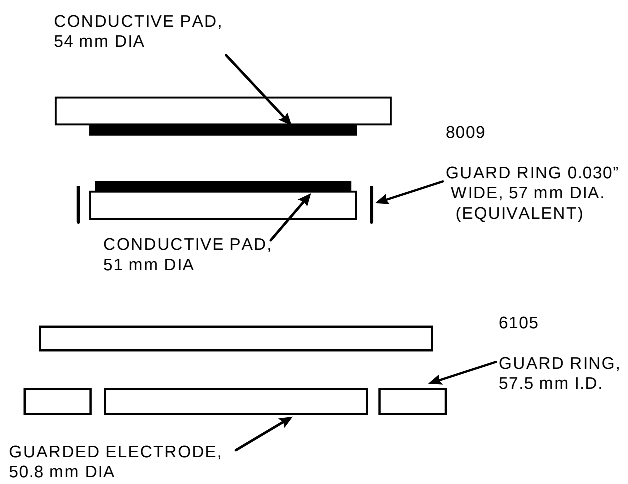


Figure 1. Cross-Sectional View of Electrodes

The dimensions of the 8009's electrodes are such that the factors used to convert measured resistance to resistivity (surface or volume) are the same as for the 6105.

With the higher pressure applied to the sample, it is inevitable that the measured resistance for a given type of paper will be much lower. Initial observations using Xerographic copy paper show that values for surface resistivity obtained with the 8009 should be multiplied by a factor of between 2 and 3 to match the results obtained with the 6105. The difference is much more pronounced when measuring volume resistivity—these results should be multiplied by at least one hundred.

Determining the actual conversion factors for a particular sample requires measuring the sample's resistivity with both fixtures and comparing the results. The following data is presented to assist in correlating surface and volume resistivity measurements taken with the 8009 with historical data obtained with the 6105.

Surface Resistivity

All measurements were made with the felt side down on copy paper with the following properties:

Basis Weight lbs./3000 sq. ft.	47.1
Brightness, TAPPI %	86.3
Caliper, mils	3.94
Coefficient of friction	
Static	.62
Dynamic	.55
Moisture %	6.0
Porosity, Gurley – Sec.	11.90
Resistivity	
Surface (ohm/square)	3.04 E+11
Volume (ohm-cm)	1.87 E+12
Sizing cobb	0.42
Smoothness Sheffield	
Top (Felt)	155.00
Bottom (Wire)	168.00
Smoothness Parker Print Surf CTD/UNC	
Top (Felt)	5.73
Bottom (Wire)	6.13

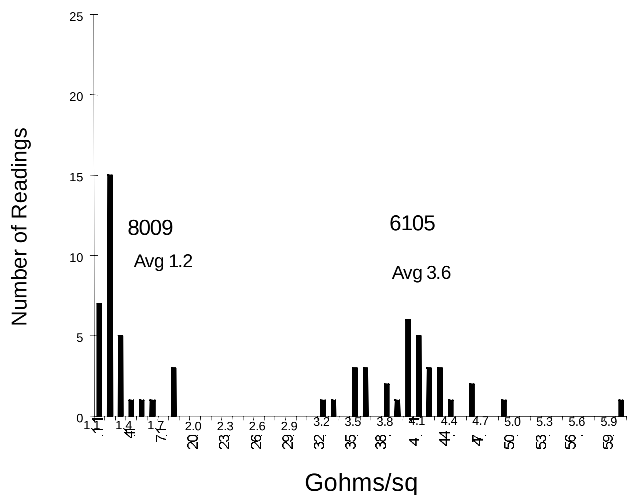
Table I. Surface Resistivity, Gigohms/Square

Sample	7/15/98	7/18/98	7/20/98
Taken with 8009:			
1	6.6	6.1	4.7
2	4.2	7.1	4.8
3	4.5	7.1	4.9
4	4.5	7.0	4.9
5	4.6	7.0	5.0
6	5.3	8.0	5.3
Avg	5.0	7.1	4.9
Taken with 6105:			
1	13.5	15.6	10
2	9.9	13.9	12
3	9.7	14.8	11
4	10.3	15.6	11
5	9.5	17.2	10
6	12.8	16.7	12
Avg	11.	15.6	11
Ratio of 6105 to 8009	2.2:1	2.2:1	2.2:1

To convert readings taken by the 8009 to a 6105 basis number, multiply by a factor of 2.2. This is because the ratio of the 6105 average reading to the 8009 average reading is 2.2:1. The exact conversion factors to be used must be determined by experimentation and will depend upon the sample material.

As a further check on how the 8009 compares with the 6105, both fixtures were placed in an environmental test chamber running at 23°C, 67% relative humidity. Two sets of six samples were tested over five days. The histogram in Table II shows a closer grouping of the 8009 data when compared to data obtained using the 6105, indicating a more stable connection to the sample. The alternating polarity method of determining resistivity (discussed below) was used, with the first reading discarded, three readings stored, a measure time of 60 seconds , and a test voltage of 90V. An insulating film was placed between the sample and the top electrode as discussed in ASTM D-4949.

Table II. 8009 vs. 6105 for Surface Resistivity



Volume Resistivity

Volume resistivity measurements of paper were also taken using both the 8009 and 6105 chambers, then compared. As shown in Table III, the differences were more pronounced than for surface resistivity.

In this case, the ratio of the 6105 average reading to 8009 average reading is 114:1. Again, the exact conversion factor must be determined by experimentation.

Table III. Volume Resistivity, Gigohms-cm

Taken with 8009:

Sample	
1	1.02
2	1.12
3	1.21
4	1.07
5	1.10
6	1.47
Avg	1.16

Taken with 6105:

Sample	
1	98
2	137
3	142
4	149
5	119
6	146
Avg	132

Ratio of 6105 to 8009 is 114:1

Test Method Differences

Traditionally, the resistivity of paper has been measured by applying a DC voltage for a known period of time (usually 60 seconds), measuring the resulting current, and calculating the resistivity. However, this method may introduce error due to background currents generated by piezoelectric effect, triboelectric effect, dielectric absorption or charge stored in the sample. This offset current may result in a lower than expected resistivity reading if the offset current is positive or even a negative resistivity if the offset is sufficiently negative.

Keithley recently developed a test method that virtually eliminates errors due to these effects. The Alternating Polarity Method uses a series of test voltage reversals to compensate for spurious offset currents that may be present. The method was first implemented using a computer program (Model 6524). The essential feature of this method was later added to the 6517 electrometer, now called the Model 6517A.

Table IV. Surface Resistivity using Alternating Polarity and DC Methods, Gigohms/square

Sample	AltPol	DC
1	8.4	8.9
2	9.1	9.7
3	9.1	9.2
4	9.5	9.1
5	9.5	8.8
6	10.5	10.1
Avg.	9.4	9.3
Second set of readings made on different paper samples:		
1	5.6	5.2
2	5.5	5.7
3	5.9	5.9
4	5.8	6.1
5	5.9	5.4
6	6.1	6.5
Avg.	5.8	5.8

After a series of voltage reversals, a weighted average of the measured currents is used to calculate the sample resistance. It is recommended that the first one or two readings should be discarded, then at least three readings should be stored for use in the calculation.

For comparison purposes, surface resistivity measurements of paper were taken using both the alternating polarity and the DC methods. As shown in Table IV, there is little difference between measurements taken with these two methods. However, if unusual results occur, such as negative resistivity values, then it is best to use the alternating polarity method. Insulators such as plastic and silicone rubber have a much higher resistivity and show greater benefit from the alternating polarity method.

The measurements in Table IV were taken with both test methods. The alternating polarity method used a measure time of 60 seconds at 100V. The first reading was discarded and the next four readings were stored. The DC method used a test time of 60 seconds at 100V.

Conclusion

Of these two developments, the new test fixture and the alternating polarity method, the test fixture has, by far, the greatest significance for the paper industry. There is an urgent need to establish a data conversion procedure to correlate old data with new data in order to establish and handle quality control procedures and update paper property specifications.

A series of round-robin tests are needed to determine the precision and bias of this new system.

Biographies

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John R. Yeager, who was born in Cleveland, Ohio, received his B.S. in Electrical Engineering from Case Institute of Technology in 1950. From 1950 to 1975, he worked in the Engineering Department of Keithley Instruments. Since 1975, he has been a member of the Applications Engineering Group at Keithley, specializing in low-level measurements. He can be reached at:

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