APPLYING ELECTRODES FOR ELECTRICAL TESTING OF INSULATING MATERIALS*

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There are numerous papers and also some summaries which describe various forms of metal electrodes for testing insulating materials. Hartshorn[1] has made exhaustive investigations on the effect of electrodes on the measurements of permittivity and power factor and certain conclusions are drawn which could be used as basis for applying electrodes on solid dielectrics for these measurements. Churcher,[2] Dannatt and Dalgleish have given an account of the contact phenomena of some electrodes on dielectrics and have published results of their investigations on the effect on permittivity and power factor of applying some electrodes like mercury, graphite in the form of aquadag, tinfoil with a bonding medium and silvering applied to samples of ebonite, glass, varnished paperboard for measurements at 50 cycles per second. Hartshorn and Ward from N.P.L. and Sharpe and O'Kane from Liverpool University have given the effects of some of these electrodes over a wider range of frequencies up to 5 million cycles per second on samples of ebonite, plate glass and Mycalex. The use of tinfoil with vaseline fastened to the sample and application of graphite backed with metal plates have been found to give better contacts and values of permittivity and power factor nearer to the true values that are obtained with mercury or silvering although the use of aquadag has been found to give erroneous results at radio frequencies. As it is stated in the above papers and in the book *Pruefung und Bewertung elektrotechnischer Isolierstoffe*, by Nitzsche-Pfestorf, Berlin, 1940 (" Testing and Classification of Insulating Materials ") it is impossible to give a prescription for electrodes which are suitable for all materials. On the other hand one insulating material may be successfully tested with various types of electrodes. So during a series of determinations of dielectric constant and power factor, some typical insulating materials, which have not yet been tested with various electrodes have been investigated.

(1) *P.V.C. Sheets.*—Brass electrodes were constructed according to British Standard Specification B.S. 903. These consisted of:

* Part of this work was done in Australia.

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(1) Lower electrode .. 20 cm. diameter, 5 mm. thick
(2) Upper electrode .. 15 cm. diameter, 1 cm. thick
(3) Annular guard electrode .. Outer diameter 20 cm., inner diameter 15·4 cm., 5 mm. thick.

Thus this is separated from the upper guarded electrode by a space of 2 mm.

Some measurements were made using these placed directly upon the sample as suggested in *G.O.E.S.* 16 and some other publications. These were compared with results obtained by using electrodes of metal foil probably the most commonly used type for routine testing. Electrodes, the same size as the brass ones, were cut from thin lead foil 0·006 cm. thick and applied firmly to the sample using a little petroleum jelly as adhesive. The brass electrodes were placed on top of these as backing plates. A shielded Schering bridge was used for all measurements. Two sets were made, one at 50 cycles per second and one at 1000 cycles per second, about 400 volts being applied in each case. The results are shown in Table I.

TABLE I

Frequency cycles per sec.	Sample	Dielectric constant		Power factor	
		Brass	Tinfoil	Brass	Tinfoil
50	1 *b*	4·5	5·7	0·069	0·090
	10 *b*	4·5	6·2	0·069	0·088
1000	1 *b*	4·0	4·8	0·080	0·098
	10 *b*	4·0	5·0	0·084	0·099

Values obtained using thinner tinfoil (0·002 cm.) differed by less than 1% from those obtained from thicker tinfoil. Assuming that the difference in values are due to an air layer between the material and the brass electrodes one can calculate the thickness of the air layer from these values. With the thickness of the P.V.C. sheets of 2 mm. the inter air layer is found to be 0·094 mm. which seems quite likely.

Another electrode material tried was Aquadag—an aqueous solution of colloidal graphite. This was thinned with distilled water and painted on with a brush. Some difficulty was experienced in making the Aquadag adhere, but the addition of a small quantity of Aerosol O.T. (Dioctyl sulpho-succinate) to the distilled water used for mixing the aquadag was found satisfactory.

The conductivity of the aquadag layer was always checked with an Avometer before proceeding. A rough check was carried out by placing two metal foil disc about 1 cm. apart on the surface of the film. If the resistance between these was more than about 1000 ohms more aquadag was applied. A separate determination using electrodes of tinfoil 10 cm. long and 1 cm. apart placed on aquadag painted Perspex indicated the surface resistivity of this film to be 4000 ohms.

Silver electrodes were sprayed upon two samples. The method of spraying silver electrodes on the P.V.C. sheets was the same as used in the preparation of electro types or the preparation of the matrix of an original record. The two chemical solutions are sprayed simultaneously on the insulating material where the thin silver layer is formed by chemical reduction of the silver solution. These electrodes were the same size as the brass which were used as backing plates. Results are shown in Table II.

TABLE II

Frequency	Sample	Dielectric constant			Power factor		
		Silver	Aquadag	Tinfoil	Silver	Aquadag	Tinfoil
50	2 *a*	10·3	10·1	8·8	0·094	0·095	0·086
	7 *c*	9·9	10·1	8·5	0·098	0·100	0·091
1000	2 *a*	8·5	8·4	7·8	0·011	0·011	0·010
	7 *c*	8·2	8·3	7·3	0·012	0·012	0·011

Placing tinfoil between brass plates and the Aquadag electrodes caused no noticeable difference. Again, Table II shows similar differences between the values for the material with the new electrodes; however, with the higher permittivity of the material the thickness of the air layer will be only 0·018 mm.

Brushing on aquadag electrodes asks for a skilled man with a good hand. The process is rather slow. To get sharp edges of all the electrodes and a small gap between the shielded electrode and the guard ring a compass for Chinese ink has to be used for the contours while the rest of the electrode can be painted.

Silver spraying or silver cathode sputtering asks for rather expensive equipment and needs also careful handling for reliable results.

The big advantage of the tinfoil electrode lies in its easy handling and its easy application. It needs no big equipment for preparation. Therefore tin or lead foil is prescribed in some specifications. The small disadvantage even in the tinfoil electrode lies in the difficulty of having a clear-cut electrode with a fairly small distance between guard and shielded electrode. One way of doing it is to use a compass with one knife-edge instead of a pointer.

(2) *Porcelain Discs.*—Some measurements were made on non-porous high tension porcelain manufactured in India. The samples used were discs of about 7 cm. in diameter and 3–5 mm. thick. These discs were ground in a special grinding machine so as to obtain plain and parallel surfaces on both sides. The deviation from correct level was only ± ·001″ after the samples were ground in this machine.

Brass plate electrodes were constructed of the following dimensions:

1. Upper or high voltage electrode 6·2 cm. diameter, 7 mm. thick.
2. Lower or low voltage electrode 4·8 cm. diameter, 7 mm. thick.
3. Annular guard electrode outer diameter 6·2 cm., inner diameter 5·0cm.

Width of guard ring is thus 1 mm. The surfaces of these electrodes were also ground flat to ± ·0005″.

Measurements were made at 50 cycles/sec. using the shielded high voltage Schering Bridge at 6 and 8 kV with only brass electrodes. These were compared with results obtained with thin metal foil fastened to the sample with petrolatum and with the brass electrodes as back plates, the foil being cut to the same size.

Aquadag electrodes were also used on some samples. The solution of aquadag was thinned with distilled water and applied to the porcelain sample with a fine brush and dried. The measurements were made with the same brass electrodes as back plates. The results are given in Table III.

It could be noted from Table III, that the use of tinfoil-vaseline electrodes on porcelain at 6–8 kV voltage stress gives permittivity values which are considerably higher than the corresponding values obtained with only brass. Similar results are obtained with aquadag electrodes. The power factors obtained are also slightly higher with the tinfoil or aquadag electrodes than in the case of only brass electrodes. Churcher[2] in his paper has given a 15% increase in similar experiments. This may be accountable to the "contact" theory of Hartshorn,[1] the lower dielectric constant due to air film between the electrode and the dielectric in the case of only the brass electrodes, whereas the tinfoil with vaseline or aquadag gives better contact effect between the dielectric and the electrode.

A few measurements conducted on some porcelain samples at higher frequencies are given in Table IV. These results were obtained from measurements conducted with a 1–50 Megacycle dielectric measuring equipment

TABLE III

Dielectric constant and power factor of non-porous porcelain samples at 50 cycles/sec. with different electrodes on the high voltage Schering Bridge

Sample	Thickness of sample	Type of electrode	Voltage applied in kV (r.m.s.)	Dielectric constant (k)	P. F.
Porcelain disc No. 313	0·191″	1 Flat brass plates with guard	6	6·1	0·032
			8	6·2	0·036
		2 Tinfoil with petrolatum fastened to sample	6	6·9	0·037
			8	7·0	0·038
Porcelain disc No. 314	0·169″	1 Flat brass plate	6	5·3	0·047
			8	5·5	0·059
		2 Tinfoil fastened to sample	6	5·8	0·047
			8	5·9	0·062
Porcelain disc No. 215	0·199″	1 Flat brass plate	6	5·6	0·035
			8	5·6	0·036
		2 With aquadag on samples and brass plate electrode	6	6·4	0·039
			8	6·5	0·043

at a frequency of 24 megacycles per second, manufactured and supplied by the General Electric Co. in U.S.A., based on the substitution in resonant circuit susceptance variation method due to Hartshorn.[3]

The instrument used has a special sample holder with rigid metal electrodes with a micrometer screw and the effect of tinfoil electrodes were noted. The considerable increase in the dielectric constant of the porcelain sample due to the application of tinfoil could be seen from Table IV. There is also a slight increase in the power factor due to tinfoil electrode. At the order of frequencies used in these experiments, not only the tinfoil but the proper fixing of tinfoil with a bonding agent seems to be of importance as could be seen from Table IV. The bonding agent could be vaseline or paraffin oil and both these were tried in the experiments.

The application of aquadag electrodes at 24 megacycles gives on both porcelain and glass samples more than 100% increase in power factor. Hartshorn[1] has described both increase and decrease in power factors of nearly 300% in some cases at the order of frequencies of 5 megacycles per second.

(3) *Paper*.—Some measurements were made at 20 megacycles per second on different paper samples for determining their dielectric constant and power factor on the high frequency bridge used above. The samples were cut to circular shape of 2″ diameter, same as the diameter of the upper metal electrode of the specimen holder. The single layers of the samples of thickness

TABLE IV

Permittivity and power factor of non-porous porcelain and glass at 24 megacycles/sec. with different types of electrodes

Sample	Thickness of sample	Type of electrode	Dielectric constant (k)	Power factor
Porcelain disc No. 313	0·191″	1 Rigid metal electrodes only	5·0	0·008
		2 Tinfoil without bonding agent	5·0	0·008
		3 Tinfoil with bonding agent, *viz.*, paraffin oil	5·8	0·009
		4 Aquadag	5·3	0·022
Porcelain disc No. 213	0·183″	1 Rigid metal	5·5	0·009
		2 Aquadag	5·5	0·018
Porcelain disc No. 325	0·200″	1 Metal electrode only	5·9	0·009
		2 Tinfoil without bonding agent	5·9	0·009
		3 Tinfoil with bonding agent, *viz.*, petrolatum	6·6	0·012
		4 With aquadag applied to sample	5·9	0·029
Porcelain disc No. 216	0·166″	1 Rigid metal electrodes only	3·6	0·009
		2 Tinfoil with petrolatum	6·6	0·011
Porcelain disc No. 314	0·169″	1 Rigid metal electrodes only	4·3	0·008
		2 Tinfoil with petrolatum	6·3	0·015
Glass disc No. 8	0·202″	1 Rigid metal electrodes only	5·8	0·002
		2 Tinfoil with no bonding agent	5·8	0·002
		3 Tinfoil fastened with paraffin oil	5·9	0·003
		4 With aquadag electrodes	5·9	0·021

3–6 mils could not be successfully measured on the bridge and hence several layers from 6–26 were piled up and inserted between rigid metal electrodes of the specimen holder so as to get the required resonance condition. The effect of inserting metal foil in between the rigid metal electrode and the sample pile of paper layers both with and without bonding agent, *viz.*, petrolatum were also noted. The results are given in Table V, Cols. 5–8 on three samples. Though the dielectric constant as measured with tinfoil with and without bonding medium is slightly higher than the values obtained with only rigid metal electrodes there is not much increase in the power factors that are measured. On the other hand there is a tendency towards a decrease in the power factor due to tinfoil electrodes. This effect may be due to non-homogeneity of the sample as they are made up of several layers with the inevitable existence of air pockets in between several layers.

The effect of conditioning the paper for 24 hours at 60° C. in an oven prior to the measurements were also noted and these are compared with measurements of dielectric constant and power factor at 25° C. and these results are also given in Table V, Cols. 1–4.

TABLE V

Measurements on different kinds of paper at 20×10^6 cycles per second on the Hartshorn Bridge

Sample description	Before drying at 25° C.		After conditioning for 24 hrs. at 60° C. "dry paper"		With application of tinfoil but no bonding agent		With application of tinfoil with petrolatum	
	Dielectric constant	Power factor	Dielectric constant	Power factor	Dielectric constant	Power factor	Dielectric constant	Power factor
Indian Kraft ..	2·2	·037	2·1	·036				
German Kraft ..	3·0	·055	2·6	·039				
English Kraft ..	1·9	·046	1·4	·042				
American Kraft ..	2·1	·057	1·6	·044				
White glaze ..	2·8	·048	2·7	·044				
Mg. Manila ..	1·8	·034	1·5	·03				
White cartridge 60 lb.	2·0	·051	1·8	·038	2·0	·05	2·3	·047
White cartridge 40 lb.	1·9	·038	1·6	·034				
White cartridge 52 lb.	1·9	·038	1·7	·039				
Mg. Book cover ..	2·3	·042	1·7	·035				
Unglazed book cover	1·9	·037	1·64	·032				
Azurie Laid 28 lb.	2·0	·047	1·74	·036				
Do 24 lb.	2·0	·036	1·7	·023				
Mysore bond 16 lb.	1·9	·033	..	..				
Swedish Crown ..	2·8	·069	2·36	·052	2·8*	·066	2·83	·065
Dwg. Paper ..	2·0	·086	1·6	·056	2·0	·070	2·26	·067

* For this measurement tinfoil already used with petrolatum was cleaned with a cloth and used again. The result shows that even traces of the bonding material have an effect on the measurement.

An examination of these results shows a considerable reduction in the dielectric constant and power factor of " dry paper " as compared with the values at 25° C. The higher values for dielectric constant and power factor may be accountabie to the adsorption of moisture in the untreated paper at lower temperatures.

CONCLUSIONS

Measurements of D.C. and P.F. on insulating materials have to be critically examined in the light of the effect of electrodes.

Tinfoil without bonding agent does not give the correct values of the materials.

Bonding agents like paraffin oil and petrolatum, give the same result.

Aquadag electrodes or graphite increase the power factor at higher frequencies considerably and must not be used. The D.C. of porcelain increases by 15–25% due to the application of tinfoil electrodes with bonding agent the P.V.C. values increase by 20–30%.

The measurements on piles of dry paper show also an increase cf D.C. though smaller as the pile of paper contains plenty of air pockets. Even traces of bonding agent on the electrodes have some effect on the measurements.

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