MASTER

GENERAL ELECTRIC REF. No. CCR-80-07

DEVELOPMENT OF NON-CELLULOSIC INSULATION
FOR TRANSFORMERS

DOE CONTRACT No. DE-AC02-79ET29343

QUARTERLY REPORT No. 2

APRIL, 1980

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TECHNICAL RESOURCES OPERATION

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WASHINGTON, D.C.

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SUMMARY

Work has continued on the development of an analytical model to demonstrate the advantages in both materials and losses to be gained by the utilization of thin insulation in transformers. Measurement of mechanical and electrical properties of film materials is underway. The aging and material compatibility of synthetic films in transformer oil, silicone and R113 is being studied in a sealed-tube aging program. Several materials are on test and others are being readied for test.

Task 1

DEVELOPMENT OF PARAMETRIC MODEL FOR SOLID INSULATION IN TRANSFORMERS

Progress

After reviewing the transformer design programs currently used in General Electric, it was decided early in the quarter that the duration and funding of this project did not permit us to write a new optimization program that would satisfy our needs. For this reason, we decided to make use of existing programs to generate designs of transformers having varying thicknesses of insulation and to explore the effect of changes in other variables in resulting transformer designs. The Distribution Transformer Department's design program, CALOP*, appeared to be the most advantageous for our needs. This is a flexible program that allows the user to select and specify the values of many of the design options. For our purposes one of the most useful features of CALOP is a sweeping mode option. CALOP will sweep through a range of core and coil sizes, giving design results at user specified increments. The range of the sweep is determined by specifying the minimum and maximum dimensions in the input. It is also possible to sweep a range of flux densities. It is possible to select up to five of a possible thirty-two characteristics of interest and specify the maximum and minimum value of each. The choices can include electrical parameters, dimensions or cost related parameters.

By varying the basic insulation level (BIL) value and the operating stress in the program input, design parameters can be obtained for a range of insulation thicknesses in the high voltage (HV) and low voltage (LV) windings. The size of the coils and core as well as the losses in the core and coil vary as the insulation thickness changes. These values are directly related to the cost of materials in the core and coil and to the cost evaluation of the losses. While it is possible to vary the HV insulation and the LV insulation thicknesses independently

*CALOP is the name of a General Electric proprietary design program used in the design of distribution transformers.

over a selected range, for the initial development of model it was decided to express the insulation thickness as a fraction of a reference thickness (5 mil for the LV and 10 mil for the HV) and to use as the independent variable the ratio of the insulation thickness to the reference thickness. This ratio has been called $f\Delta x$. When the ratio $f\Delta x$ equals 0.5 for example, the LV insulation is 2.5 mil and the HV insulation is 5 mil.

The variation of insulation thickness ($f\Delta x$) can be combined with variations of loss evaluation constants (\$/watt). The loss evaluation constants (K) determine the operating cost of the transformer. There are two constants used in the program; one for core or no-load loss and one for load loss. The ratio of core loss evaluation to load loss evaluation is maintained between 1.0 and 1.5.

For each combination of $f\Delta x$ and K (approximately 5 of each), the sweeping mode option will be used to vary other design parameters listed in Table 1-1 and select the design with the minimum "owner cost". Owner cost is the combination of material cost and operating cost based on losses. This should produce a family of curves showing minimum owner cost as a function of loss evaluation constant and insulation thickness for cellulose insulation.

Since these material costs and the losses are both based on cellulosic insulation, correction for each non-cellulosic insulation can be made based on the cost and thermal properties of the insulation. The material costs can be adjusted by allowing for the difference in cost between paper and the insulation of interest.

$$\text{Adjusted Cost} = \text{Material Cost in Design} + \text{Volume of Paper} \times \\ (\text{Unit Cost of Non-Cellulosic} - \text{Unit Cost Paper})$$

The correction for the losses can be made using an existing thermal model which adjusts temperature rise and losses on the basis of the thermal characteristics of the insulation. When these corrections are implemented, the data set will represent the optimum owner cost as a function of insulation thickness and loss evaluation constant for each material.

Table 1-1
RANGE OF DIMENSIONS FOR SWEEPING DESIGN CALCULATIONS

<u>Feature</u>	<u>Min.</u>	<u>Max.</u>	<u>Increment</u>
Core window height	8.4	8.6	0.1
LV Turns	52	60	2
Core strip width (wound core)	5.6	6.7	1.1
Flux density	0	115	1

This approach is summarized in Figure 1-1.

Progress

A program to determine the minimum useful insulation thickness based on mechanical and electrical loading has been written. This should allow the determination of the minimum insulation thickness to give performance comparable to paper.

The input data files for CALOP have been prepared, and the variation of insulation thickness and cost factors has been completed. These results are being tabulated for further analysis.

Future Activity

The optimization of owner cost through a sweep of dimensions is underway. When this is completed, the correction will be applied for each non-cellulosic material.

Figure 1-1. Flow Chart for Task 1.0.

Task 2

SELECTION OF CANDIDATE MATERIALS

2.1 Film and Sheet Materials

Progress

The standard characteristics of commercially available films are summarized in Tables 2-1 and 2-2. These data are taken from the 1979-1980 Modern Plastics Encyclopedia. Samples of several of these films have been ordered. These are listed in Table 2-3. These materials represent a wide range of polymer types.

2.2 Film From Conductor Coatings

Most of the commercially available film materials are based on thermoplastic polymers. Many of these materials are subject to mechanical creep, especially at elevated temperatures. Creepage of this type may limit the range of application of thermoplastic films in transformers. Magnet wire coatings which are either a combination of thermoplastic and thermoset resins or are cross-linked thermoplastics have been designed to have adequate creep resistance. Formvar enamel is a mixture of polyvinylformal (thermoplastic) and a Cresol formaldehyde resin (thermoset) is an example of the former type of wire coating. Cross-linked polyethyleneterephthalate is an example of the latter.

Many combinations of thermoplastic and thermo-setting resin systems have been used for solution and powder coating on magnet wire. Some of these may be suitable to make thin thermoset films for transformer application.

Progress

Films have been made from a combination of polyvinylformal, phenolic and epoxy resin by solution casting from Cresol/dichloromethane mixed solvent. The films were formed on a mold release treated steel plate at 200°C for one hour. The film was removed from the steel plate and heated for 8 to 10 minutes at 250°C. The film thickness was approximately 50 microns (2 mil). Problems have been encountered in removing the film from the

Films	ASTM test method	Fluoroplastics								Polypropylene								Polysulfone	Polyetherimide
		Ethylene-chlorotrifluoroethylene copolymer (E-CTFE)	Ethylene-tetrafluoroethylene copolymer (ETFE)	Fluorinated ethylene propylene copolymer (FEP)	Polychlorotrifluoroethylene copolymer (CTFE)	Polytetrafluoroethylene (PTFE)	Polyvinyl fluoride (PVF)	Polyvinylidene fluoride (PVDF)	Polycarbonate	Polyester, thermoplastic, polyethylene terephthalate (PET)	Polyimide	Extrusion (cast)	Biaxially oriented	Polyparabanic acid	Poly-methyl-pentene				
1. Production method	—	Extrusion	Extrusion	Extrusion	Casting, extrusion	Sawing, casting, extrusion	Extrusion	Extrusion	Casting, extrusion	Extrusion, biaxially oriented	—	Extrusion (cast)	Orientation (also coated)	Casting	Extrusion, casting	Extrusion	Casting, extrusion		
2. Forms available	—	Rolls, sheets, tubes	Rolls, sheets, tubes	Rolls, sheets, tubes	Rolls, sheets, tubing	Sheet, tapes, tubing	Rolls	Rolls, sheets	Rolls (cast & extr.), sheets (cast)	Rolls, sheets, tapes, tubes	Rolls, tape	Rolls, sheets, tubes	Rolls	Rolls	Rolls, sheets	Rolls, sheets	Rolls, sheets		
3. Thickness range, in.	—	0.0005-0.050	—	0.0005-0.030	0.0005-0.030	Up to 0.030	0.0005-0.004	0.002-0.020	0.00025-0.350	0.00008-0.014	0.00025-0.005	0.0075-0.010	0.0045-0.006	0.001-0.005	0.003-0.030	0.0001-0.030	0.0001-0.030		
4. Maximum width, in.	—	54	48	48	54	48	138	50	45 cast, 54 extr.	67-120	60	69	77-80	52	48	52	52		
5. Area factor (sq. in./lb./mil)	—	16,600	16,300	11,900	13,000	12,800	17,200-20,000	16,000	23,100	19,800-22,600	19,400	30.5-31,300	30,600 (uncoated)	20,500	33,360	22,355	20,000		
6. Specific gravity	D1505	1.66-1.68	1.7	2.15	2.08-2.15	2.1-2.2	1.38-1.57	1.76	1.20	1.310-1.410	1.42	0.885-0.905	0.902-0.907	1.35	0.83	1.24-1.25	1.37		
7. Tensile strength, p.s.i.	D882	8000-10,000	7000-8000	2500-3000	5000-10,000	1500-4500	7000-18,000	5500-6500	8400-8800	20,000-35,000 (tensile)	25,000	4500-10,000	7500-40,000	16,000	2700-4000	8400-10,600	10,000-12,000		
8. Elongation, %	D882	150-250	300	300	50-150	160-350	115-250	300-500	85-105	60-165, 50 (tensile)	70	550-900	35-475	70	10	64-110	20-150		
9. Bursting strength, 1-mil thickness, M.p.s.i.	D774	—	—	11	23-31	—	19-70	—	No break, 4 mil, 25-35	50-80	75	—	—	—	—	60 p.s.i. (0.002-mil)	—		
10. Tearing strength, g./m. ²	D1922	900-1300	600-900	125	2.5-400	10-103	12-100	50	20-25	12-27	8	660-1025-MD	3-10	8	—	9-12	7-16		
11. Tearing strength, lb./in. ²	D1004	—	—	600	330-900	—	997-1400	—	700-1000	1000-3000	1120	—	1000-1500	1000	400-650	236-243	420-950		
12. Folding endurance	D2116	250,000 (1-mil)	—	—	Good	—	5000-47,000	176,040 (4-mil)	250-400	100,000	10,000	Very high	Very high	10,000	600	—	—		
13. Water absorption 24 hr., %	D570	<0.02	<0.02	<0.01	Nil	Nil	<0.5	0.04	0.35	<0.8	2.9	<0.035	<0.005	2.8	0.005	0.3	2.1		
14. Permeability to gases, cc./100 sq. in./mil thickness/24 hr./atm. at 25° C.	D1434	CO ₂ : 110 H ₂ : 10 N ₂ : 25 O ₂ : 25	250	1570-2900 380 750	16-40 220-330 2.5 7-15	—	11.1 58 0.25 3	5.5	1075 1600 50 300	15-25 100 0.7-1.0 3.0-4.0	45 250 6 25	500-600 1700 40-4E 150-240	Uncoated 540 Coated 0.5-5.0 10-7.0 0.5-2.0 0.5-5.0	—	—	950 40 230	405 40 90		
Resistance rating ^a																			
15. Strong acids	D543	G	G	C	G	G	G	G	G	G	G	G	G	G	G	G	G		
16. Strong alkalis	D543	G	G	C	G	G	G	G	P	P	P	G	P	P	G	G	G		
17. Grease and oils	D722	G	G	C	G	G	G	G	G	G	G	G	G	G	F	G	G		
18. Organic solvents	D543	G	G																

Table 2-2

	Fluoroplastics							Polycarbonate	Polyester, thermoplastic—polyethylene terephthalate (PET)	Polyimide	Polypropylene		Polyparabanic acid	Polymethylpentene	Polysulfone	Polyethersulfone
	Ethylene-chlorotrifluoroethylene copolymer (E-CTFE)	Ethylene-tetrafluoroethylene copolymer (ETFE)	Fluorinated ethylene propylene copolymer (FEP)	Polychlorotrifluoroethylene copolymers (CTFE)	Polytetrafluoroethylene (PTFE)	Polyvinyl fluoride (PVF)	Polyvinylidene fluoride (PVDF)				Extrusion (cast)	Biaxially oriented				
Crystalline Melt Point, °C	245	270	200	218	327		170		260			165		240		
Heat Deflection Temp. °C/PSI		71/264	70/66	123/66	60/264		80/264	130/264	40/264	300/264		68/264		40/264	175/264	200/264
Temperature Index (UL) Continuous Use °C	150	160						65-115	105	200-210		80-120	T _g 290°C		140	170
Maximum Use Temp., °C	180	180	250	150	150	250	150	130	150	275		140	260	205	150	180

Table 2-3
FILMS SELECTED FOR INVESTIGATION

<u>Material</u>	<u>Thickness (microns)</u>	<u>Status</u>
Polyester	50	Received
Polyethersulfone	75 100	Received Received
Polysulfone	12	Received
Aromatic Polyamide	10 25 40	Received Received Received
Polyamide Fiber Paper	75	Received
Polyimide	25 125	On Order On Order
Polyimide-Thermoplastic	12 25	On Order On Order
Polyvinylfluoride	25 100	On Order On Order
Polyvinylidene fluoride	25 50	On Order On Order
Polyparabanic Acid	25 125	On Order On Order

steel plate and a more effective mold release agent is desirable.

Plans

Sufficient film will be prepared to evaluate its mechanical, electrical and aging characteristics.

One additional polymer system will be investigated.

2.3 Conductor Coatings and Methods of Application

The use of thin, uniform, high dielectric strength polymeric film on aluminum would result in a number of benefits in transformer design.

The major problem associated with the coating of thin aluminum sheets is the attainment of adequate dielectric strength at the edges. Conventional techniques like the roller coating and spraying of polymeric solution result in poor edge coverage as a result of surface tension effects which pull the coatings away from the edges during the cure cycle. Electrodeposition of thin polymeric film on the conductor surface offers the advantage of excellent edge coverage prior to cure. Care must be taken, however, in selecting and formulating the system to avoid edge pull-back. Aluminum is especially difficult to coat electrolytically because of its electrochemical passive nature. During deposition, the aluminum is made the anode and immersed in a solution or dispersion of a polymeric material which possesses the negative charge as a result of its inherent structure or as a result of some absorbed ions from solution. On passing DC current through the cell, the following reaction occurs:

with the H^+ neutralizing the negative charge on the polymer and resulting in the precipitation of the polymer on the aluminum strip. During deposition, the aluminum invariably passivates with part of the current resulting in the following reaction at the aluminum surface:

The H^+ continues to precipitate polymer on the surface but the coating develops pinholes and voids as a result of the trapped O_2 gas.

It is possible to live with the oxygen evolution by formulating the electro-deposition medium so that the bubbles escape during the cure. Of course, extensive flow-out is required during cure. This approach is essentially that used in the manufacture of electro-paints. The major problem in this approach is that appreciable edge pull-back occurs with reduced edge coverage relative to the flats.

If excellent edge coverage is required, then a deposit with little or no flow-out is required. If this restriction is put on the system, then one cannot live with O_2 evolution and it must be eliminated completely. An approach which seems feasible is the deposition of a more electrochemically active material on the aluminum surface prior to electro-deposition. Zinc deposited from a zincate solution (via immersion) appears to be electrochemically active and might possibly eliminate the evolution of oxygen. The presence of zinc on the aluminum should result in the following electrochemical reaction:

with Zn^{++} precipitating the polymer. The effect of Zn^{++} on the aging characteristic of the polymer would have to be investigated as would the optimum condition of zincate treating.

Previous work has centered around the development and application of an electrocoatable amide-imide polymer on aluminum strip. This is a polymer system determined to be adequate for oil/paper insulation systems as well as for dry-type transformers.

While other electrocoatable material systems have been considered, including electrocoatable acrylics and epoxies, neither has proven successful for extended life in an oil/paper insulation system. However, the elimination of paper offers the opportunity to consider these materials more seriously. This is true also of electrocoatable ester-imides and recently developed amide-imide polymer suspensions. All of these should be lower in material cost and processing cost than the amide-imides.

Progress

Electrocoating of conductor with an amide-imide polymer suspension is

underway. Coating and curing parameters are being explored on a laboratory scale apparatus.

Plans

Samples of electrocoated conductor will be prepared for mechanical, electrical and aging evaluation.

An attempt will be made to coat aluminum conductor by polymer coagulation techniques.

Task 3
EVALUATION OF MECHANICAL CHARACTERISTICS

Progress

The mechanical characteristics have been measured at room temperature for all of the films that have been received. These data are summarized in Tables 3-1 to 3-5. For comparison, the mechanical properties of Kraft paper are summarized in Table 3-6. These measurements were made using standard test procedures, as follows:

Thickness	ASTM D645	Method C
Basis Weight	ASTM D646	
Tear	ASTM D689	
Burst	ASTM D774	
Tensile	ASTM D828	
Elongation	$E = \frac{B-A}{A} \times 100$	

where: A = distance between the jaws at
the start of the tensile test.
B = distance between the jaws at
the moment of break.

The measurement of the temperature dependence of tensile strength and elongation is underway. These tests are run on a Universal Testing Instrument (Instron), Model TTCM-1, to which an Environmental Chamber, Model A74, is attached. The chamber is set for the desired temperature and allowed to reach equilibrium. The chamber door is opened, a tensile strip of the film under investigation is placed in the jaws of the tester, the door closed, and the chamber and test specimen allowed to reach equilibrium again (about 10 minutes). A total of five tests per film per temperature are run.

Jaws separation - 5 inches
Jaw speed - 1 inch/min.

Tensile strength and elongation are recorded on a strip chart.

Table 3-1
POLYESTER FILM MCHANICAL PROPERTIES

<u>Property</u>	<u>50 Micron</u>
Thickness, microns (mils)	
Avg.	48.3 (1.9)
Max.	55.9 (2.2)
Min.	43.2 (1.7)
Density, gms/cc	1.43
Basis Wt., gms/m ² (lbs/3000 ft ²)	68.9 (42.3)
M.D. Tear, gms.	
Avg.	69
Max.	71
Min.	65
C.M.D. Tear, gms.	
Avg.	81
Max.	83
Min.	79
Burst, pascals (psi)	
Avg.	759x10 ³ (110)
Max.	774x10 ³ (112)
Min.	732x10 ³ (106)
M.D. Tensile, pascals (psi)	
Avg.	140,800x10 ³ (20,420)
Max.	155,700x10 ³ (22,580)
Min.	128,500x10 ³ (18,630)
C.M.D. Tensile, pascals (psi)	
Avg.	141,200x10 ³ (20,470)
Max.	147,700x10 ³ (21,420)
Min.	122,700x10 ³ (17,790)
M.D. Elongation, %	
Avg.	49
Max.	73
Min.	36
C.M.D. Elongation, %	
Avg.	47
Max.	52
Min.	26

Table 3-2
POLYETHERSULFONE FILM MECHANICAL PROPERTIES

<u>Property</u>		<u>75 Micron</u>	<u>100 Micron</u>
Thickness, microns (mils)			
	Avg.	75.7 (3.0)	96.5 (3.8)
	Max.	111.8 (4.4)	116.8 (4.6)
	Min.	55.9 (2.2)	81.3 (3.2)
Density, gms/cc		1.4	1.48
Basis Wt., gms/m ² (lbs/3000 ft ²)		104.9 (64.4)	143.5 (88.1)
M.D. Tear, gms.	Avg.	74	114
	Max.	112	123
	Min.	57	106
C.M.D. Tear, gms.	Avg.	64	109
	Max.	79	146
	Min.	53	89
Burst, pascals (psi)			
	Avg.	494x10 ³ (72)	622x10 ³ (90)
	Max.	719x10 ³ (104)	707x10 ³ (103)
	Min.	421x10 ³ (61)	524x10 ³ (76)
M.D. Tensile, pascals (psi)			
	Avg.	93,940x10 ³ (13,620)	70,410x10 ³ (10,210)
	Max.	104,100x10 ³ (15,100)	78,930x10 ³ (11,450)
	Min.	72,880x10 ³ (10,570)	63,510x10 ³ (9,210)
C.M.D. Tensile, pascals (psi)			
	Avg.	91,160x10 ³ (13,220)	64,410x10 ³ (9,340)
	Max.	97,180x10 ³ (14,090)	72,580x10 ³ (10,530)
	Min.	82,140x10 ³ (11,910)	57,150x10 ³ (8,290)
M.D. Elongation, %			
	Avg.	5.9	6.3
	Max.	6.2	6.7
	Min.	5.2	5.9
C.M.D. Elongation, %			
	Avg.	6.8	5.7
	Max.	8.0	5.8
	Min.	6.0	5.1

Table 3-3
POLYSULFONE FILM MECHANICAL PROPERTIES

<u>Property</u>		<u>12 Micron</u>
Thickness, microns (mils)		
	Avg.	11.7 (0.46)
	Max.	12.7 (0.50)
	Min.	11.1 (0.44)
Density, gms/cc		2.2
Basis Wt., gms/m ² (lbs/3000 ft ²)		16.8 (10.3)
M.D. Tear, gms.	Avg.	9.7
	Max.	14
	Min.	8
C.M.D. Tear, gms.	Avg.	9.8
	Max.	11
	Min.	9
Burst, pascals (psi)		
	Avg.	159x10 ³ (23)
	Max.	165x10 ³ (24)
	Min.	152x10 ³ (22)
M.D. Tensile, pascals (psi)		
	Avg.	67,450x10 ³ (9780)
	Max.	83,940x10 ³ (12170)
	Min.	56,960x10 ³ (8260)
C.M.D. Tensile, pascals (psi)		
	Avg.	55,460x10 ³ (8040)
	Max.	59,960x10 ³ (8700)
	Min.	50,960x10 ³ (7390)
M.D. Elongation, %		
	Avg.	6.7
	Max.	9.6
	Min.	3.7
C.M.D. Elongation, %		
	Avg.	4.6
	Max.	6.0
	Min.	3.4

Table 3-4
AROMATIC POLYAMIDE FILM MECHANICAL PROPERTIES

Property	10 Micron	25 Micron	40 Micron
Thickness, microns (mils)			
Avg.	9.90 (0.39)	22.70 (0.90)	40.2 (1.58)
Max.	10.80 (0.43)	24.50 (0.96)	41.0 (1.61)
Min.	9.50 (0.38)	21.60 (0.85)	39.4 (1.55)
Density, gms/cc	1.40	1.30	1.35
Basis Wt., gms/m ² (lbs/3000 ft ²)	13.8 (8.5)	28.2 (17.3)	54.6 (33.5)
M.D. Tear, gms.			
Avg.	9	16	25
Max.	10	17	27
Min.	9	15	24
C.M.D. Tear, gms.			
Avg.	9	17	25
Max.	9	18	26
Min.	9	16	25
Burst, pascals (psi)			
Avg.	177x10 ³ (26)	340x10 ³ (50)	585x10 ³ (85)
Max.	195x10 ³ (28)	366x10 ³ (53)	616x10 ³ (89)
Min.	165x10 ³ (24)	329x10 ³ (48)	549x10 ³ (80)
M.D. Tensile, pascals (psi)			
Avg.	122,000x10 ³ (17,700)	121,700x10 ³ (17,600)	136,500x10 ³ (19,800)
Max.	134,400x10 ³ (19,500)	131,000x10 ³ (19,000)	142,200x10 ³ (20,600)
Min.	114,900x10 ³ (16,700)	109,400x10 ³ (15,900)	131,700x10 ³ (19,100)
C.M.D. Tensile, pascals (psi)			
Avg.	122,000x10 ³ (17,700)	122,500x10 ³ (17,800)	147,800x10 ³ (21,400)
Max.	127,300x10 ³ (18,500)	126,300x10 ³ (18,300)	157,400x10 ³ (22,800)
Min.	118,400x10 ³ (17,200)	117,900x10 ³ (17,100)	143,000x10 ³ (20,700)
M.D. Elongation, %			
Avg.	9.6	9.3	14.1
Max.	11.6	10.0	18.1
Min.	5.0	8.4	11.4
C.M.D. Elongation, %			
Avg.	9.6	10.5	8.7
Max.	14.0	12.9	12.3
Min.	7.6	8.1	6.8

Table 3-5
POLYAMIDE FIBER PAPER MECHANICAL PROPERTIES

<u>Property</u>		<u>75 Micron</u>
Thickness, microns (mils)		
	Avg.	71.1 (2.8)
	Max.	81.3 (3.2)
	Min.	66.0 (2.6)
Density, gms/cc		0.72
Basis Wt., gms/m ² (lbs/3000 ft ²)		51.0 (31.3)
M.D. Tear, gms.		
	Avg.	98
	Max.	103
	Min.	94
C.M.D. Tear, gms.		
	Avg.	146
	Max.	169
	Min.	114
Burst, pascals (psi)		
	Avg.	241x10 ³ (35)
	Max.	280x10 ³ (41)
	Min.	201x10 ³ (29)
M.D. Tensile, pascals (psi)		
	Avg.	59,840x10 ³ (8680)
	Max.	63,780x10 ³ (9250)
	Min.	54,670x10 ³ (7930)
C.M.D. Tensile, pascals (psi)		
	Avg.	25,860x10 ³ (3750)
	Max.	27,830x10 ³ (4040)
	Min.	22,160x10 ³ (3210)
M.D. Elongation, %		
	Avg.	6.5
	Max.	8.4
	Min.	4.4
C.M.D. Elongation, %		
	Avg.	4.6
	Max.	6.0
	Min.	2.9

Table 3-6
TRANSFORMER PAPER MECHANICAL PROPERTIES (TYPICAL VALUES)

<u>Property</u>	<u>125 Micron</u>
Thickness, microns (mils) Avg. Max. Min.	129.5 (5.1)
Density, gms/cc	1.02
Basis Wt., gms/m ² (lbs/3000 ft ²)	132 (81.3)
M.D. Tear, gms. Avg. Max. Min.	133
C.M.D. Tear, gms. Avg. Max. Min.	217
Burst, pascals (psi) Avg. Max. Min.	591x10 ³ (86)
M.D. Tensile, pascals (psi) Avg. Max. Min.	140,600x10 ³ (20,392)
C.M.D. Tensile, pascals (psi) Avg. Max. Min.	29,740x10 ³ (4314)
M.D. Elongation, % Avg. Max. Min.	2.0
C.M.D. Elongation, % Avg. Max. Min.	5.7

The number of pinholes or conducting particles in the films has been measured using an Electrical Formation Test (EFT). The Electrical Formation Tester consists of a brass plate electrode, 14" x 26" with a smoothly machined surface; a hand roller (with an insulated handle), one-inch wide and two inches in diameter; a six-lane slotted insulation board to provide one square foot of test area; and, the necessary electrical components to vary the voltage from 0 to 5,000 volts DC.

It was designed originally to measure electrically the formation (pinholes and conducting particles) of capacitor tissue. It also has been used to test polymeric films.

The brass plate is covered with the material to be tested and the slotted board positioned on top. The voltage is raised to 100 volts and the roller is passed over the test specimen. After each pass, the voltage is increased in 100-volt increments until the first break occurs. The voltage at which the first break occurred is recorded. The results of this test are summarized in Table 3-7.

Plans

The measurement of the physical and mechanical properties will be continued as additional samples become available.

When all of the data are complete, they will be summarized in a matrix table for easier comparison of all the materials.

Table 3-7
CONDUCTING PATHS AND PINHOLES IN FILM INSULATION BY EFT TEST

Polyethersulfone	75 microns 1 ply	First break	2600 volts D.C.
	100 microns 1 ply	No breaks	5000 volts D.C.
Polysulfone	12 microns 1 ply	First break	100 volts D.C.
	2 ply	" "	300 volts D.C.
Polyester	50 microns 1 ply	First break	2200 volts D.C.
Aromatic Polyamide	10 microns 1 ply	First break	700 volts D.C.
	25 microns 1 ply	" "	600 volts D.C.
	50 microns 1 ply	" "	3000 volts D.C.

Task 4

EVALUATION OF ELECTRICAL CHARACTERISTICS

Progress

Preliminary 60-Hz breakdown tests were made in air on several of the candidate films in order to establish safe upper limits of voltage stress for the dielectric measurements. As a result of these tests, which were made on polyamide fiber paper and polyethersulfone film, it has been decided to make 60-Hz dielectric measurements (on these materials, at least) at voltage stresses of 100, 200, 500 and 1000 volts per mil. Measurements of DC volume resistivity will be made at voltage stresses of 100, 500 and 1000 volts per mil. Both the 60-Hz and DC measurements will be made at room temperature, 60, 100 and 125°C, in both air and transformer oil. These measurements, which will be made using a rigid electrode system, will be supplemented by 60-Hz measurements using the fluid-displacement method described in ASTM D150. The technique to be employed for the 60-Hz measurements on the remaining film insulations will be determined on the basis of the results obtained on the initial two materials evaluated.

Plans

The dielectric measurements will be completed on polyethersulfone, polysulfone, and polyester film and a polyamide fiber paper. Additional materials will be tested as they are received.

Breakdown values (60-Hz and impulse) will be determined for all the materials.

Task 5

EVALUATION OF SYSTEM COMPATIBILITY AND AGING

Compatibility and aging tests are designed to determine the interaction of materials and to ascertain the extent to which one material will be likely to impair the performance of others. These tests provide a measure of the insulation system's ability to function over extended periods of time.

Work with cellulosic insulation systems has led to the development of sealed tube test methods which simulate the performance of materials in life test transformers. While the extension of these tests to synthetic solids has not been investigated, the sealed tube evaluation should provide a means of prescreening these materials. The results of these tests can be evaluated by comparison to the extensive data-base of paper/mineral oil systems.

Progress

Standard aging tubes are underway at 175°C and 160°C. These tubes contain 8 grams of film material (pre-cut tensile strips), 6 wire pairs with Formvar enamel on copper, one piece of 1.27 cm x 17.8 cm core steel, and 72 ml of degassed transformer liquid. Tubes containing transformer mineral oil and silicone are under test. The electrical properties of the mineral oil are summarized in Table 5-1 and those of the silicone are summarized in Table 5-2. There are four tubes for each material combination at each temperature. Films under test thus far include polyester, polyethersulfone, and polyamide fiber paper. Tubes being prepared for test include polysulfone and aromatic polyamide films.

In order to measure the change in dielectric characteristics as a function of time, flat electrode test pieces (Figure 5-1) have been designed and constructed. An attempt to use a miniature coil structure was not successful due to the inability to find a suitable non-cellulose winding form for the test coil. Flat electrode pieces have been used to test

Table 5-1

DIELECTRIC PROPERTIES OF MINERAL OIL FOR NON-CELLULOSIC
INSULATION PROGRAM (WATER CONTENT: 2 PPM)

Temp. (°C)	60-Hz Dissipation Factor - %					60-Hz. Diel. Const.	D-C Volume Resistivity (x10 ¹² ohm-cm)		
	Volts/mil						Volts/mil		
	5	10	20	40	50		10	40	80
24	.009	.010	.011	.012	.012	2.17	4330	7980	8740
60	.042	.042	.043	.046	.048	2.10	502	1020	1320
99	.126	.130	.139	.153	.162	2.03	59.8	103	123
123	.265	.272	.284	.324	.343	1.99	17.4	28.7	32.4
60	.030	.034	.035	.039	.040	2.10	165	219	223
23	.006	.007	.008	.009	.010	2.17	1140	1620	1860

Table 5-2

DIELECTRIC PROPERTIES OF SILICONE LIQUID FOR NON-CELLULOSIC
INSULATION AGING PROGRAM (WATER CONTENT: 6 PPM)

Property Measured	Temp. (°C)	Property at Electrical Stresses of 5, 10, 20 and 40 volts/mil			
		5	10	20	40
60-Hz Dissipation Factor - %	23	<.001	<.001	.003	.012
	61	<.001	.003	.007	.015
	100	.005	.010	.017	.021
	124	.016	.019	.025	.026
	100	.006	.009	.011	.017
	61	<.001	<.001	<.001	~.001
	23	<.001	<.001	~.002	.009
60-Hz Dielectric Constant	23	2.73	2.73	2.73	2.73
	61	2.59	2.59	2.59	2.59
	100	2.47	2.47	2.47	2.47
	124	.239	2.39	2.39	2.39
	100	2.45	2.45	2.45	2.45
	61	2.58	2.58	2.58	2.58
	23	2.72	2.72	2.72	2.72
D-C Volume Resistivity* (x10 ¹² ohm-cm)	23	-	1400	370	180
	61	-	600	160	95
	100	-	230	110	82
	124	-	150	96	87
	100	-	250	140	100
	61	-	560	210	100
	23	-	1300	360	100

*Based upon current measured one minute after applying voltage.
Specimen shorted and grounded 5 minutes between measurements of
different electrical stresses.

Flat Electrode Test Piece

Fig. 5-1. Assembly held together by three peewee binder clips and sealed, after drying and filling, in a 25 x 300 mm T.T.

cellulose aging, especially when it is desirable to increase the quantity of insulation between the electrodes.

Test pieces assembled and ready for test include polyester film, polyethersulfone film, and polysulfone film. Each of these in transformer oil, silicone liquid and R113 (trichlorotrifluoroethane) for a total of nine insulation systems. All oil and silicone samples will be aged at 175°C. The R113 samples will be aged at 145°C.

An attempt to seal test samples in SF₆ failed because of the breakdown of SF₆ at molten glass temperature resulting in the etching of the glass by HF.

Plans

The tubes on test will be continued for the planned time intervals.

Tubes in preparation will be placed on test when they are ready. Additional test pieces will be assembled and tested, as the materials become available.

Task 6
EVALUATION OF THERMAL CHARACTERISTICS

No work planned during second Quarter.

Task 7
TRANSFORMER DESIGN ASSESSMENT

No work planned during second Quarter.