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KNOLLS ATOMIC POWER LABORATORY

SCHENECTADY, NEW YORK

TESTING ELECTRICAL INSULATION FOR USE IN GAMMA-RAY FIELDS

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OPERATED FOR THE

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BY THE

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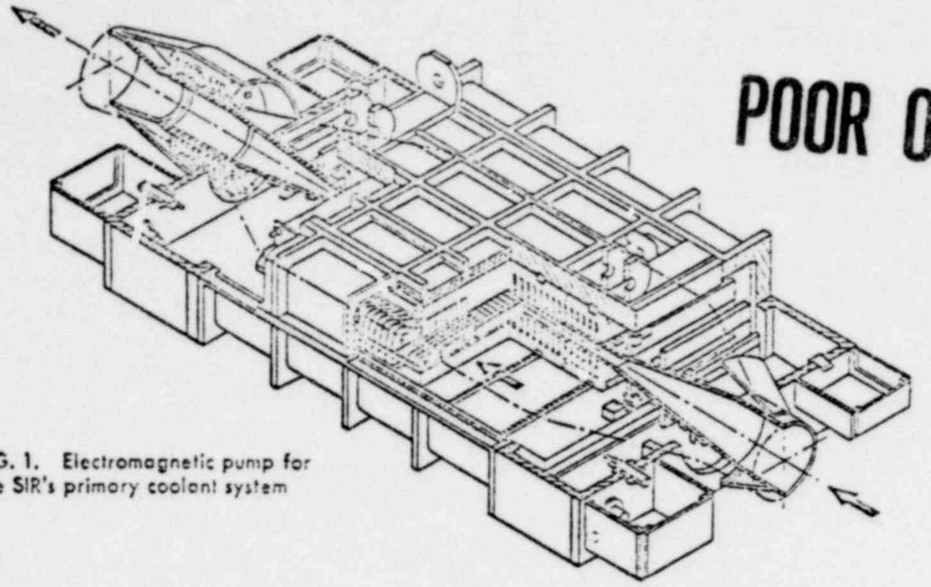

FIG. 1. Electromagnetic pump for the SIR's primary coolant system

Testing Electrical Insulation for Use in Gamma-Ray Fields

Submarine Intermediate Reactor's coolant pump will be subjected to gamma-rays from sodium. Tests of voltage breakdown, mechanical properties, and gas evolution of irradiated samples indicate that a silicone-resin-impregnated mica and glass tape insulation will be satisfactory up to 10^{10} r if it is not in a sealed container

By CLIFFORD MANNAL
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ELECTRICAL INSULATION used in the Submarine Intermediate Reactor's primary-coolant pump will be subjected to gamma radiation from the liquid-sodium coolant. Thus, development has required study of the effects of high-energy gamma radiation on electrical insulation. This article reviews the important findings.

Pump. Figure 1 shows the electromagnetic pump that will circulate liquid sodium in the reactor's primary coolant circuit (*1–5*). Laminated magnetic structures just above and below a 1-in.-high, 24-in.-thick duct in the pump are energized to move the sodium by the interaction between the magnetic field and a large current that flows across the duct.

Insulation. Because the sodium becomes thermally hot and intensely radioactive during its passage through the reactor, the stator's insulation is subjected both to high temperature and intense gamma radiation. Pump replacement will be difficult and costly once the reactor has been in operation for an appreciable time. Thus it is important to preserve and predict insulation life.

Experience with mica and glass has shown that they possess excellent radiation-resistant qualities. Although the high-temperature requirement dictates an insulation structure with as little organic material as possible, some organic binder must be added to provide necessary mechanical properties. It appeared that a silicone-resin-based varnish would be the most likely candidate for this application. Thus, the major portion of

* Operated by the General Electric Co. for the U. S. Atomic Energy Commission.

study has been on either glass and mica structures impregnated with silicone resin, or on silicone resin films alone.

Sources

Table 1 shows the radiation sources used for these experiments. In the SIR, the insulation will be subjected to primary gammas of 2.76 Mev and 1.38 Mev. Fast neutrons will be present at an intensity 10,000 times lower than the photon flux. Although it was desirable to subject the test specimens to an identical flux, no such source is available. Thus the difficult problem of extrapolation between quite dissimilar sources was faced.

Rate effect. It is customary to assume that the significant parameter is the total energy absorbed by the material as measured by the integrated dose (*7*). For small total dosages and for low rates, this seems true in many cases. However, the equivalence of a dose delivered at a very high rate to the same total dose delivered at, say, one-thousandth of this rate has definitely not been proved. There is evidence that measurably different results can be obtained. However, this study assumes the equivalence of equal doses independent of the rate of accumulation.

Beta-gamma equivalence. Since the primary effect of electromagnetic radiation of the energies under consideration is to produce Compton recoil electrons in the material, a direct equivalence between beta and gamma irradiation is fairly justified. As long as the electrons appear in the material with a given energy, it is not too important how they got there or how they received their energy.

Neutron-gamma equivalence. Preliminary experiments indicated that a combined neutron and gamma flux is much more destructive than the gamma flux alone. This caused reactor irradiations to be of limited utility for these tests.

Dosimetry

Accurate high-level dosimetry was needed to determine accumulated doses. Further, because much of the insulation was (and will be) wrapped around copper and surrounded by iron, it was desirable to determine the actual dose received by the insulation *in situ*.

A ferrous-ferric sulphate solution dosimeter was used most. PVC dye-impregnated films (*8*) were extremely convenient for measurements very near the conductor bars. A scintillation counter also was used (*9*).

Samples

Irradiations were conducted on four kinds of samples: a facsimile stator, voltage-breakdown samples, abrasion bars and resin films.

Figure 2 shows the disassembled stator constructed with a winding that simulates the insulation of the electromagnetic pump. For assembly, the stator was slid into an annular container and a watertight cover was bolted in place. The entire assembly was placed over the Co^{60} source and the winding energized to obtain normal magnetic vibratory forces and copper temperatures.

Voltage-breakdown samples, consisting of narrow bars of glass-cloth laminate impregnated with silicone resin, were wound with nickel foil and covered with a few laps of mica-tape insulation using SR-32 resin as a binder. A number of these specimens were placed in the center of the Co^{60} pit in a gas-tight aluminum container. These were periodically removed and an external aluminum foil electrode wrapped around the outermost insulation. Voltage applied between this and the central foil was used to break down the insulation.

Abrasion bars were pieces of ⅜-in. square aluminum approximately 4 in. long on which mica laid on glass-tape insulation was applied.

Thin resin sheets (10–30 mils thick) also were tested. They were made by casting and curing resin films on metal plates.

Electrical Effects

The quantity of primary interest was the ability of the insulation to withstand applied voltage after a large accumulated radiation dose. Figure 3 shows the results of such a test. Unirradiated samples failed at breakdown voltages between 6.6 and 10.7 kilovolts. This range defines the normal range of variability of the samples. On the basis of three samples broken down after 2.4×10^6-r/hr irradiation, no reduction in voltage breakdown was detected up to 1.2×10^{10} r. This indicates that the insulation will be satisfactory for the SIR pump.

The liberation of large numbers of electrons by gamma absorption conceivably could provide initiators for an avalanche process. Breakdown then would occur at lower applied fields (*10–12*). Figure 4 shows 60-cycle, short-time voltage breakdown on Formex-insulated wire (Formex used for experimental convenience) at room temperature. The fact that voltage breakdown for irradiated specimens was substantially the same as that for specimens not under irradiation indicates that electron-liberation has a very minor effect for the case of interest.

A further experiment to shed some light on this process was carried out using the external electron beam

TABLE 1—Source Characteristics

Source	*Optimum sample size*	*Approximate dose rate*	*Ambient* — *Normal*	*Ambient* — *Changes*
GE Res. Lab. extern. beam	≤2 in. dia., 0.040 in. thick ($\rho \sim 1$)	10^9 r/hr (β)*	20° C air	possible
Oak Ridge reactor	6 in. long, 3½ in. sq. or 2 in. dia.	10^6 r/hr (γ) 10^{12} n/cm²/sec†	20° C air	difficult
Brookhaven reactor	6 in. long, 3½ in. sq. or 2 in. dia.	5×10^6 r/hr (γ) 5×10^{12} n/cm²/sec†	160–180° C air	difficult
HEW disch. fuel elem.	8 in. long, 1⅝ in. dia.	$1\text{–}2 \times 10^5$ r/hr‡	20° C water	practical
MTR disch. fuel elem. (*5*)	10 in. long, 3 in. sq.	8×10^6 r/hr‡	20° C water	practical
KAPL 3,000-c Co^{60} source (*6*)	6 in. long, 1¼ in. dia., or annular volume	2×10^5 r/hr§ 0.5×10^5 r/hr	20° C water	practical

* 0.8-Mev peak sinusoid. † Fission spectrum. ‡ Fission-product spectrum. § 1.33 and 1.17 Mev.

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FIG. 2. Test stator whose winding simulates electromagnetic pump stator

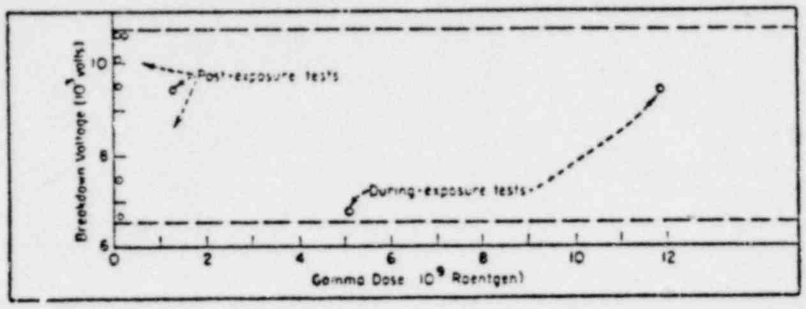

FIG. 3. Short-time breakdown voltage as function of accumulated radiation dose for glass-backed mica tape impregnated with SR-32 resin

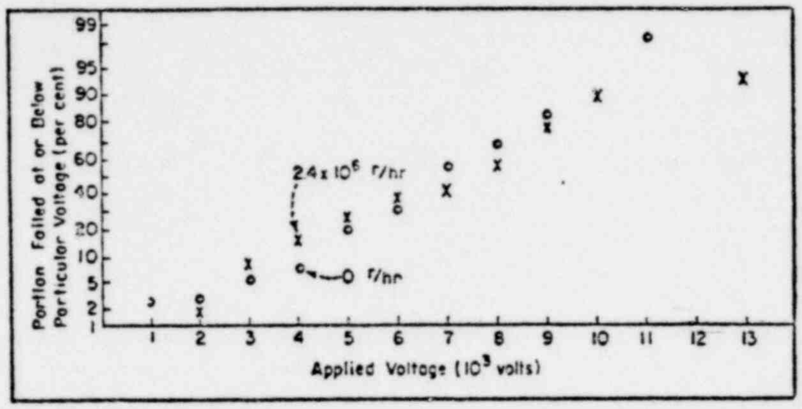

FIG. 4. Short-time, 60-cycle breakdown voltage on irradiated and unirradiated Formex insulated wire at 20° C

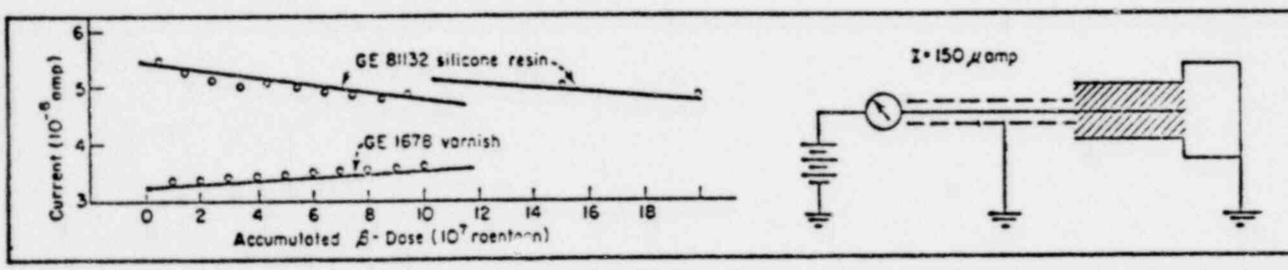

FIG. 5. Current passing through resin films as function of accumulated radiation dose

facility. Two thin films of resin were contained between very thin outer aluminum foils. As shown in Fig. 5, a central foil was maintained at a positive potential and the current flow from the central foil to ground measured on a microammeter. A certain number of the incident electrons terminated on the central foil and thus produced a static current in the circuit and decreased the total sensitivity of the experiment. If the insulation had changed from an essentially nonconducting to a conducting state under the influence of the radiation field, there would have been an increase in current as irradiation continued. Such an increase was not observed, and it was concluded that the specific resistivity of the material did not undergo a catastrophic decrease for irradiations up to 2×10^8 r. The silicone-resin curve is broken because a second sample of different thickness was used.

These results were corroborated by measurements on the stator windings. Resistance and power factor measurements of unirradiated insulation and on the stator after 6×10^4 r are within the normal range and actually show a slight improvement after irradiation. This is undoubtedly due to the evolution of water and solvent vapors and to additional polymerization.

Although power factor measurements have been used extensively to determine changes in molecular structure (*13*), our extensive measurements from low audio frequencies to the megacycle range on thin films of resin in various stages of irradiation showed no consistent variations. In spite of its ease of application and nondestructive nature, this technique was not fruitful for the resins of major interest at this time.

Mechanical Properties

The mechanical properties of insulation are next in importance to the electrical properties. The evaluation of which mechanical properties are necessary, and to what degree, is a question that has never been settled on a quantitative basis.

An empirical method of evaluating comparable kinds of insulation is provided by an "abrasion tester" (*14–16*). The total number of turns required for a striking and rubbing motion to cause failure is a measure of the abrasion resistance of the insulation. Figure 6 gives results of tests on specimens irradiated in the Oak Ridge and Brookhaven reactors. The general conclu-

TABLE 2—Summary of Gas Evolution from Various Samples

Quantity	*Sample*: Dielectric breakdown	Cable coil	Stator
Resin wt. (gm)	10	4	89
Added heat cure before irradiation	None	None	24 days; 140° C
Comparison with pump winding	Similar	Very diff.	Nearly ident.
Radiation from	Co^{60}	HEW slugs	Co^{60}
Irradiation (equiv. avg. pump days)	170	400	63
Irrad. temp. (°C)	25	25	45
Total gas evolved (cm^3)	54	8.7	982
Gas factor (cm^3/[eq. day × gm])	0.033	0.49	0.16
Gas retention by insul. structure	High	Negligible	Moderate
Gas analysis (CH_4 = 1)			
CO_2	Trace	0.46	2.5
H_2	1.23	None	4.4
C_6H_6	None	None	1.1
Xylene	0.19	None	None
O_2	0.1	Trace	None
Major uncertainties	Degree of cure	Mass spectrom. anal., rad. level	Corr. for leak, gassing by top gask. in stator can

TABLE 3—Gases Evolved* from Impregnated† Glass Tape During Gamma Irradiation‡

Catalyzed	Sized	H_2(%) In N_2	H_2(%) In vac.	CH_4(%) In N_2	CH_4(%) In vac.	N_2 or CO(%) In vac.	C_6H_6(%) In N_2	C_6H_6(%) In vac.
Yes	Yes	49.5	38.9	39.3	40.6	2.7	11.0	15.9
Yes	No	51.8	42.0	41 3	41.8	2.0	6.9	12.1
No	No	17.5	10.4	32.9	13.6	3.8	49.6	70.3
No	Yes	15.9	10.7	30.4	19.1	4.9	53.6	65.3

* Approximately 0.6 cm^3 gas evolved per gm of resin, both in nitrogen and *in vacuo*. Nitrogen pressure over samples sealed in N_2 = 150 mm.
† With 3.25 wt. % zinc octoate catalyzed SR-32.
‡ 4 × 10^8 r accumulated dose from discharged MTR elements.

TABLE 4—Gas Evolution from 10^{-3} mm Films of SR-32 During Pyrolysis

Time	Temp. (°C)	Evolution rate (10^{-4} liter/min)	Composition
15 min	90	0.5	Methyl trimer, tetramethylsilane and low mol. wt. silanes
30 min	95		
40 min	135	0.25	95% C_6H_6, 4% H_2O, 1% trimer
70 hr	135	0.0042	95% C_6H_6, 4% trimer
3 hr	150		C_6H_6, H_2O, cyclic trimer, tetramers
16 hr	220		30% C_6H_6
			20% hexamethyltricyclosilane

sions are that mechanical properties of silicone-resin-and-mica-tape insulation are not particularly affected by 30-day irradiation at 100–180° C, but 60-day irradiation at this temperature greatly reduces mechanical strength.

It is generally felt that insulation should withstand thousands of turns before failure and any that withstand only a few hundred turns will not be satisfactory. The significance of loss of abrasion resistance as relates to life of the insulation *after* the insulation has been installed will depend to a very large degree on the individual piece of equipment. Equipment in which insulation has reached a condition that would give a very low abrasion-resistance measurement can give long reliable service under severe conditions. Thus, this change in abrasion resistance should not be interpreted in terms of proportional decrease in insulation life.

The behavior of the phosphoasbestos paper (shown as a range of values) is extremely interesting. This material, initially poor, apparently suffers no further deterioration and in its final condition is apparently superior to the silicone resin and mica tape.

The entirely empirical results of the abrasion tester and the inability of a device of this kind to evaluate the "weak link" (i.e., the resin) in the insulation structure has led to an investigation now in progress. It is believed that more useful information can be derived from study of penetration times of styli in thin films of resin irradiated by the external electron beam.

Gas Evolution

Initially it was believed that considerable insight into mechanisms of decomposition could be obtained by study of components present in the resin off-gas. Table 2 summarizes the first data obtained. Two facts were evident: 1, evolution of gas was of sufficient magnitude to cause concern in a sealed container; 2, the "signature" of decomposition products was substantially different from one sample to the next. While some small differences in degree were anticipated, the differences in kind that were observed seemed beyond any reasonable limit.

A systematic approach to the problem was taken by attempting to isolate significant variables as shown in Table 3. One of the presumed variables is the catalyst, in this case about 3¼ weight % of zinc octoate added during

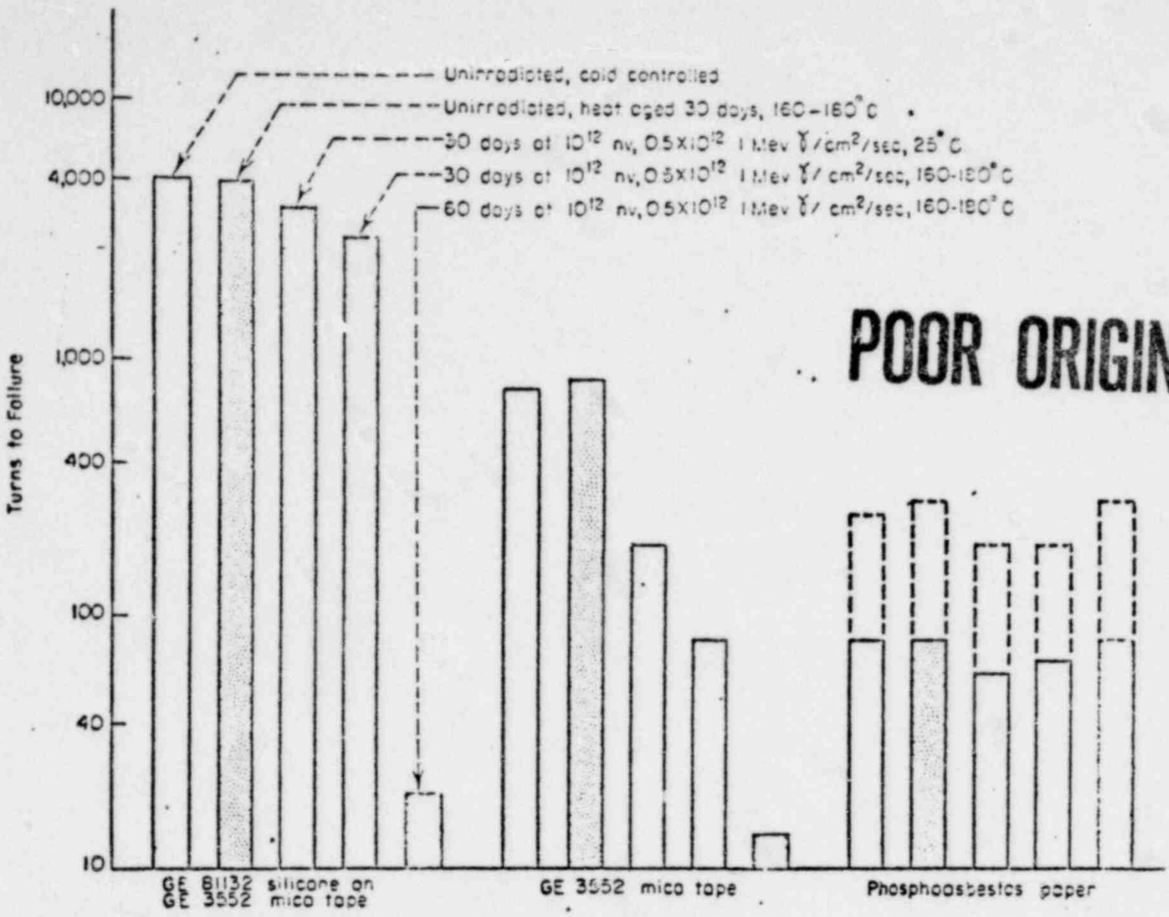

FIG. 6. Effect of radiation on abrasion resistance of 8-mil thick insulation tapes

final formulation of the resin to "body" it. As the resin ages, this zinc octoate will break down providing some free zinc and octoic acid. Thus the composition of the resin was to some extent a function of time, and it was expected that the catalyst might be particularly vulnerable to disintegration under irradiation. Another variable related to the sizing already on the glass tape before impregnation with the resin.

Examination of the data shows no substantial difference between the sized and unsized samples. In one instance, comparison of the nitrogen and vacuum atmosphere results shows a discrepancy that seems to be considerably beyond experimental error; in all other cases the agreement between the nitrogen and vacuum atmosphere is good. There is a marked difference between the catalyzed and uncatalyzed results. These results were obtained at a time when the total gas pressure could not be measured, and it is not possible to tell whether the results differ because the percentage composition differs, or whether the catalyzed resin simply produces much more hydrogen.

Whatever the differences due to the variations exhibited in Table 3 the process is substantially different than that which the resin experiences in pyrolysis. Table 4 follows the decomposition of an extremely thin film of resin deposited on the inside of a quartz bulb (*17, 18*). Extensive low-temperature degassing was undertaken prior to the pyrolysis. The molecular fragments observed as a function of time and temperature are entirely different from those observed as a consequence of irradiation. It seems reasonable to conclude that the thermal and radiation degradation processes are essentially different in detail.

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This article is based on a paper presented at the Radiation Damage Conference, Oak Ridge National Laboratory, March 24, 1953.

It is a pleasure to acknowledge the assistance of numerous associates. S. S. Jones was responsible for correctness o dosimetry and for procurement and many of the details of the Co[60] pit; H. Rudolf, E. L. Mincher, J. W. Ryan, and L. F. Wardell, of the G. E. General Engineering Laboratory, carried out many of the tests and prepared and analyzed samples; C. Doyle prepared the SR-32 resin; W. B. Lewis at MTR, W. Powell at BNL, O. Sisman and C. D. Bopp at ORNL assisted in the use of facilities at their sites; P. H. Klein assisted in the gas analysis problem; H. Mattraw performed numerous mass spectrographic analyses; D. H. Ware and R. Rhody of GE's Small and Medium Motor Department had samples prepared according to factory procedures; E. Flynn and K. Mathes contributed to numerous discussions relating to properties of commercial insulations; A. Pletcnik took extended data relating to power factor and the penetration of irradiated plastic films by means of styli; E. J. Lawton of GE's Research Laboratory irradiated resin samples with the 0.8-Mev peak external electron beam facility; R. Dewes of GE's General Engineering Laboratory designed and constructed equipment; C. S. Hofmann and R. Washburn helped build the penetration device, and P. Zemany supplied pyrolysis data.

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FAN DRIVE MOTOR

for

REACTOR CONTAINMENT BUILDING
VENTILATION & COOLING SYSTEM

The proposed unit will be a squirrel cage induction motor, totally-enclosed, water-cooled, with torque and current characteristics typical of NEMA design B, suitable for driving a fan or blower. The specific horsepower, speed, voltage, and other characteristics for the particular application are listed at the end of this description.

The construction is designed to keep the expected ambient atmosphere from contacting the bearings, windings, rotor and other internal parts of the motor during normal conditions, and during the accident conditions described with the specific motor rating.

Exclusion of the ambient atmosphere will be accomplished by a positive, pressurized, rubbing seal between the bearing housing and drive shaft.

Enclosure -

Stator - Double shell, round frame construction, of heavy fabricated steel, designed for cooling water to be circulated between inner and outer shell, in a helical pattern around the diameter.

Enclosure - Drive end shield will be fabricated of heavy steel. Opposite drive end shield will be cast of nodular iron. Shields will be bolted to the stator frame and a seal between the shields and stator will be made by means of "O" rings at the rabbet fits.

Stator Core and Windings -

Punchings are stacked and clamped together securely, by a welded cage, prior to being inserted in the stator frame in the same manner as the typical Custom 8000 construction. (Described in more detail in standard publications)

Windings are inserted in the stator core, connected, braced and fully impregnated before the core is installed in the stator frame.

The inside diameter of the stator frame has machined slots running the length of the frame. The ribs of the cage used to clamp the punchings together extend outside the diameter of the punchings, and these ribs fit in the slots cut in the stator frame.

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POOR ORIGINAL

Stator Core and Windings (Cont'd)

A positive interference fit between the stator frame and core is obtained by heating the frame before the core is inserted.

Insulation -

Class H materials which have demonstrated, by prior, documented testing, an ability to retain satisfactory insulating properties after radiation dosages of 10^{10} rads are used throughout the stator windings.

Bearings -

Grease lubricated, antifriction bearings are used. The drive end has a roller bearing. The opposite drive end has a ball bearing. The ball bearing is designed to take thrust loading. Both bearings have calculated lives in excess of 100,000 hours. A special grease suitable for the radiation and temperature requirements will be used.

Rotor -

Rotor punchings are stacked and clamped together. Rotor bars and end rings are made of aluminum which is cast in the rotor punchings. This is described in more detail in standard publications.

Shaft Seal -

The drive end shaft seal is a rubbing double seal unit using water under a pressure greater than the expected ambient pressure to maintain the seal. The only parts of the seal in contact with the shaft are two O-rings.

The seal is designed to allow enough axial movement of the shaft to accomodate shaft expansion.

The seal will be a "John Crane" DBL type 8·1 as manufactured by Crane Packing Company, or equal. The seal design will be tested for the pressure, temperature humidity and chemical conditions which are specified for post-accident operation.

Terminal Connectors -

Terminal connectors will be ceramic insulated bushings, similar to spark plugs. Threaded studs will be provided for connection of users main power cable and accessory wiring. Connections for accessories will be brought out at a different location from main power connections. No conduit boxes are furnished.

Accessories -

1. Temperature Detectors: Thermocouples will be mounted on the inside of the frame to measure temperature.

2. Moisture Detectors: A moisture detector will be mounted on the bottom of the frame to detect condensation buildup or seal leakage.

3. Space Heaters: Low voltage single phase space heaters will be supplied to maintain internal temperature slightly above ambient temperature during motor shutdown periods.

4. Vibration Detector: A vibration switch will be mounted on the motor to detect excessive vibration Separate electrical connections to this switch must be made at installation since it is externally mounted on the motor frame. Typical switch is Robertshaw Vibraswitch or equal.

Test -

1. Seal Test: To be performed by seal manufacturer.

2. Standard Motor Tests:
   1) Running light current
   2) Resistance (stator)
   3) 1 phase impedance at 1/4 voltage
   4) Running light watts
   5) Hipot test
   6) Cold insulation meggar
   7) Observe undue noise
   8) Air gap measurement

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Quality Control

A complete quality control procedure in accordance with MIL-Q-9358a and DECAS requirements is in effect in our factory. Additional procedures will be set up as required for special features of these specific motors.

E.N.D.
11-11-68

1415 200

MOTOR DATA

HP - 150/75
RPM - 1200/600
Volts - 440
Service Factor - 1.0
Temp. Rice (by resist) 80°C
Space heater voltage - 115
Load WK^2 - 3000 lb. ft^2
Overhung load 1200 lb @ 8"
Method of conn. to load - fan to be mounted on motor shaft
Axial thrust capacity - 800 lbs. continuous, 3000 lbs. momentary
Ambient conditions:

Normal: 50°C
50%
15 psia

Accident: 150°C
100%
70 psia
plus chemical solution spray

Cooling water temp. - 35°C max.
Cooling water pressure - 150 psig max.
Cooling water pressure - 70 psig design

Bearings - Drive End - Roller - 222
Opp. Drive End - Ball - 319

1415 201

GENERAL ELECTRIC

Class H Insulation
for
Nuclear Radiation Application

Turn Insulation:

Quadruple coated aromatic polymide (QML)

Ground Insulation:

Wrapped or taped with a combination of mica and glass.
Coils are dipped and baked with a silicon resin varnish.

Connections:

Wrapped or taped with a combination of mica and glass.

Wedge & Filler Material:

Sheet silicone glass cloth, staple fiberglass base.

Coil Bracing Ring: (When required)

Steel wrapped with a glass and mica silicone treated tape.

Coil Tie Material:

Continuous filament glass cord treated with silicone
resin varnish.

Finish:

The finished stator is given multiple dips in silicone
resin varnish and baked after each dip.

E.N.D.
11-15-68

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GENERAL ELECTRIC

STATOR CONSTRUCTION—PRE-WOUND CORES CUSTOM 8000® MOTORS AND GENERATORS

STATOR

SUMMARY

Pre-wound stator cores increase the life expectancy and reliability of General Electric Custom 8000 motors and generators. Improved quality is gained by the complete accessibility possible during manufacturing.

Simplified winding combined with the rugged core and frame, more than adequate bracing, and thorough penetration of the bonding agents, easily verified by inspection and test, produces a reliable machine.

Rapid replacement or repair, should this become necessary, is an added advantage of pre-wound core design. Many purchasers stock a core for back-up protection because the design of the machine makes replacement of cores easy with a minimum of costly down time.

CONSTRUCTION

High-grade silicon steel, carefully selected for lower electrical losses, is used for stator laminations. The laminations are assembled on a mandrel between a top and bottom flange. While the assembly is held by a compressive force of more than 50 tons, heavy longitudinal straps are welded to the end flanges and form a rugged cage for clamping the laminations.

Space blocks separate sections of laminations to provide a path for circulating cool ventilating air. The air ducts correspond with similar ducts in the rotor and are strategically placed so that incoming cool air is distributed evenly over the entire length of the wound core. Uniformly cooled stators minimize hot spots and result in longer insulation life.

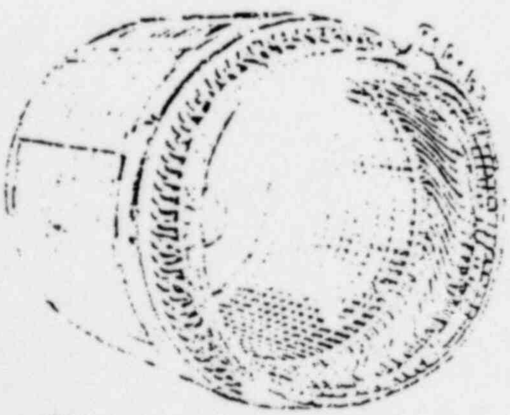
Cores are completely wound before they are inserted into the frames. Free access to the windings permits use of the optimum bracing system and permits complete visual inspection of manufacturing operations. This wound-core assembly, impregnated to form a fully supported rigid structure, contributes to longer machine life even in the most severe applications.

Pre-wound cores have lifting lugs permanently installed. No special tools are required for handling, removing, or replacing the core in the frame. Actual experience shows that pre-wound cores can be replaced in less than two hours.

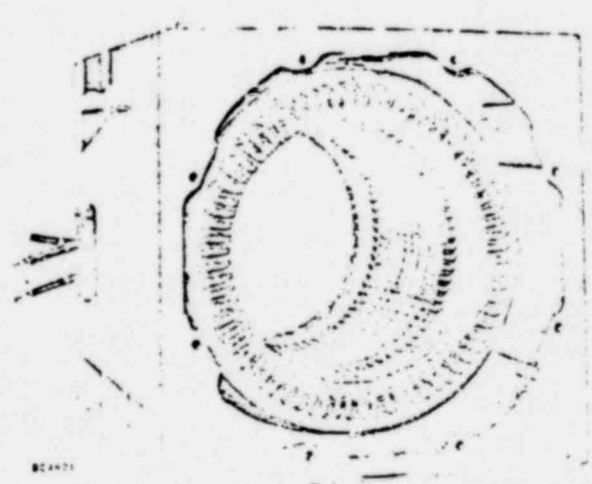
TESTS

Assembled cores are subjected to both static and dynamic tests. To assure rigidity, forces are applied in increments of 500 pounds. Deflection and stress measurements taken along the entire length of the stack verify the ruggedness of the core structure.

Drop tests are also used. Here, the sample core is first dropped horizontally, then on end, and then at an angle so that the core strikes the surface at 45 degrees. These tests show that the core used in General Electric machines can take impact loads without distorting the stack. Cores built to prevent dimensional instability virtually eliminate abrading of the insulated winding from this cause.



Stator core



Stator core in frame.

ROTORS-FOUR OR MORE POLES CUSTOM 8000® 8[illegible]-8200 FRAMES

ROTOR

SUMMARY

General Electric induction motor rotors are designed to meet the exacting requirements of starting duty, high peripheral speeds, electric pulsations, and thermal contractions and expansions during normal operation. Advanced casting techniques and modern equipment combine to produce a uniform high-quality rotor. Simplified construction, a minimum number of parts, and continuous quality assurance audits contribute to reliable performance.

CONSTRUCTION

Simplified construction, a key factor in reliable rotor performance, requires a design with minimum numbers of parts and materials. In the Custom 8000 design, one-piece punchings eliminate the conventional spider and thereby eliminate fits and tolerances between the spider and the rotor laminations. The result is a rigid stack of punchings that reduces vibration problems caused by differential thermal expansions.

The punching has large air passages to distribute air throughout the rotor assembly to cool the entire core structure uniformly. Radial air ducts channel the cool air through the rotor punching assembly and around the squirrel-cage bars. The rotor ducts are aligned with stator ducts so that the rotor acts as a centrifugal blower, forcing air through the stator.

Advanced casting techniques and modern equipment combine to produce a uniform high-quality rotor squirrel cage. Molten aluminum is forced through closed slots in the rotor punchings to form the solid, one-piece winding. The special casting techniques prevent voids, thus assuring windings of high conductivity and exceptional mechanical strength. The use of aluminum throughout results in a lighter-weight rotor with lower stress concentration under centrifugal force.

Integrally cast fans on the squirrel-cage end ring provide efficient air circulation and conduct heat from the squirrel cage to the air stream. Closed slot construction in the rotor reduces noise by presenting a smooth unbroken surface.

The finished rotor structure is shrunk on a high-carbon steel shaft which is sized to withstand the stresses. Finally, each rotor is machined and dynamically balanced.

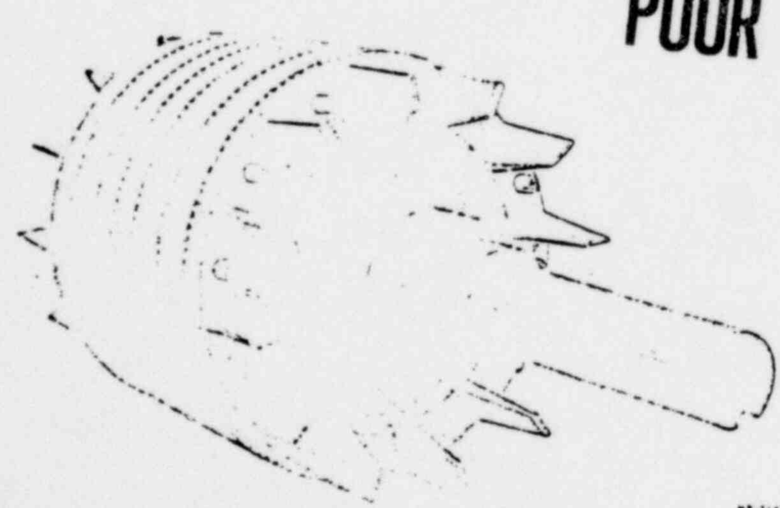
RELIABILITY ASSURANCE

To maintain the uniformly high quality of Custom 8000 rotors, materials are constantly subjected to incoming quality assurance audit, and both materials and finished products are subjected to exhaustive tests.

Each rotor is dynamically balanced prior to assembly to give vibration-free operation. Balancing is later verified when the assembled motor is tested.

Rotors of this construction were subjected both to raised temperature and overspeed tests up to 6000 rpm which tested punchings, end rings, fans, and balance weights to three times normal operational forces.

Tests were conducted not only on the materials and rotors individually, but also on the complete motor assemblies. Subjection to more than 50,000 plugged reversals under carefully controlled laboratory procedures produced no rotor damage, no movement of the punchings, or disturbance of machine balance.



Typical cast aluminum rotor