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NASA-CR-54146
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IMPROVED MAGNETIC COMPONENTS FOR STATIC INVERTERS AND CONVERTERS

CONTRACT NO. NAS 3-2792
AMENDMENT NO. 2

FIFTH QUARTERLY REPORT FOR THE PERIOD
JUNE 28, 1964 TO SEPTEMBER 27, 1964

by

R. E. McVay et al

PREPARED FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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IMPROVED MAGNETIC COMPONENTS
FOR
STATIC INVERTERS AND CONVERTERS

NAS 3-2792, Amendment 2

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PREFACE

The following Westinghouse AED personnel have supported this program. Their cooperation is gratefully acknowledged.

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ABSTRACT

A literature review has been made on magnetic materials for use in improved magnetic components for static inverters and converters. The magnetic materials covered are grain-oriented silicon steels and high permeability Co-Fe and Ni-Fe alloys.

Special magnetic test equipment has been ordered and magnetic test procedures established.

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I. INTRODUCTION

The objective of this contract is to obtain improved magnetic components for static inverters and converters.

The magnetic materials, electrical conductors and insulations, and interlaminar insulations used in magnetic components specifically will be evaluated.

The literature is to be reviewed for pertinent data on materials for magnetic components. The environmental conditions to be considered are temperature, radiation, vacuum, shock, vibration, and noise. Operational conditions are to include sine wave and square wave excitation in the frequency range of 400 to 3200 cps. The magnetic materials to be evaluated are magnetic field annealed 49% Co -2% V-49% Fe; doubly grain-oriented, silicon steel (with and without a magnetic anneal); single grain-oriented, silicon steel; square loop 79% Ni-4% Mo -17% Fe; and oriented 50% Ni -50% Fe. The effects of processing are also to be evaluated.

The magnetic properties to be measured with square wave excitation are a-c core loss, a-c apparent core loss, a-c hysteresis, and constant current flux reset points (T, AT, DAT, SAT). The d-c magnetic properties to be measured are B vs. H curves and d-c hysteresis major loops.

Optimum materials and processing for magnetic components are to be selected.

II. MAGNETIC MATERIALS LITERATURE REVIEW

The first quarter of this program was used to conduct an extensive literature search. A considerable number of references on the magnetic properties of the material included in this study were obtained.

Appendix A lists the reference sources, including some foreign language references which were evaluated in the literature search. Individual references, classified according to environmental effect are listed chronologically within each group in Appendix B. Foreign literature contained relatively little information of direct interest except for several theoretical papers.

Base line magnetic, physical and mechanical properties of the materials considered in this study have been obtained primarily from commercial literature and previous Westinghouse sponsored programs. [2, 3, 7, 9, 12, 13, 14, 15, 18, 23, 25, 26, 27] * These data will be applied to this program and will be shown in the final technical report.

Among the environments considered in the program, the effect of temperature has received most attention in published information. No specific data were found on the effects of space vacuum and noise. The effects of mechanical shock and vibration on the magnetic properties of materials have recently received some attention but the tests were limited in scope and the only material studied was Hipernik V.

Most references dealing with radiation effects on magnetic materials cover neutron exposures. The effects of charged particle irradiation, such as protons and electrons (which are of primary interest in space environment studies), have been recently studied on pure iron and 5% Molybdenum Permalloy with some interesting results.

Magnetic evaluation of environmental conditions was in terms of d-c properties and 60 cps, sine wave a-c properties in most cases. Some tests on nickel-iron alloys were conducted using sine wave excitation at 400 and 1000 cps. Constant current flux reset (CCFR) properties, using sine wave excitation only, were used in evaluations of the temperature effect.

No published information was available on the combined effects of shock, vibration, noise, temperature, vacuum, processing, and radiation or on the counter-effect that temperature may have in cancelling the undesirable influence of shock, vibration, noise, vacuum, processing, and radiation on magnetic

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[ ]*Figures in square brackets refer to individual references listed in Appendix B.

properties. A statistically oriented program studying the above combined effects would be of considerable value.

The following is a discussion of individual environmental effects:

A. Effect of Temperature.

Tables I and II display the d-c and a-c magnetic properties as a function of temperature for nickel iron alloys, and singly oriented 3% silicon iron respectively. [4, 7] The CCFR properties versus temperature of the materials covered in this study are shown in Tables III, IV and V. [23, 27] The data show that most materials follow the typical temperature pattern. As temperature increases, induction increases in low fields but decreases in fields above the knee of the magnetization curve, and the alloy saturates at progressively lower inductions. In addition, coercive force, remanence and losses decrease with increasing temperature. No satisfactory explanation can be given for the change in B_r and H_c in Table I after the temperature cycling and return to -60C (D. C. Properties, Group II). The CCFR properties show similar changes with increasing temperature; maximum induction and squareness ratio as well as the H values decreased with increasing temperature. This pattern applies primarily to the magnetic properties of both grain-oriented silicon-iron materials, in which, except for impurities, a single-phase structure exists up to the melting point.

All commercial high permeability nickel-iron materials as well as Supermendur (49% Co-2%V - 49% Fe) are subject to magnetic instability at elevated temperatures because of atomic-ordering reactions taking place in certain composition regions of these alloys. [9, 12, 13, 15, 16, 18, 19, 23, 25, 26] These critical temperatures vary, with composition and, to some extent, with heat treatment. Supermendur shows signs of magnetic instability in short-time tests at temperatures above 300 C. The characteristic square hysteresis loop of Hipernik V decreases progressively with increasing temperatures because of a relatively steep decrease in remanent induction. This decrease in remanence starts at 75 C and only 70% of loop squareness is maintained at 250 C.

Long time exposure at different temperatures and temperature cycling would be required to gain a complete picture regarding temperature stability of these materials. Heat treatments, particularly those used on Supermendur, can affect the time-temperature relationship of these alloys and should be better understood for maximum utilization of the temperature capability of these alloys.

Various phases of these problems have been treated in scientific publications, particularly certain aspects of heat treatment, grain-orientation and domain behavior. [5, 7, 8, 10, 11, 17, 18, 20, 23, 24, 89, 95, 97, 98]

Metallic permanent magnets, such as most Alnicos, display magnetic stability up to 400 C. At elevated temperatures[28-33]structural changes affect deterioration of the magnetic properties of Alnicos.

[ ] *Figures in square brackets refer to individual references listed in Appendix B.

TABLE I. Typical Values of Magnetic Properties at Various Temperatures - I, Hipernik: II. Hipernik V and Deltamax; III, Supermalloy, Mo-Permalloy, and Hymu 80 [14]

D-C Properties @ Temperature (C)

Group		-60 C	10 C	75 C	145 C	210 C	250 C	145 C	-60 C
I	B_r(KG)	10.3	9.2	8.1	6.9	5.9	5.4	6.9	10.3
	B_s(KG)	15.6	15.4	15.3	15.2	14.4	13.3	15.2	15.6
	B_r/B_s	0.660	0.597	0.530	0.454	0.410	0.406	0.454	0.660
	H_c(Oe)	0.064	0.058	0.050	0.039	0.035	0.034	0.039	0.064
II	B_r(KG)	14.8	13.8	12.4	10.4	8.5	7.0	10.4	13.4
	B_s(KG)	15.4	15.2	15.0	14.5	13.5	12.8	14.5	15.4
	B_r/B_s	0.963	0.908	0.826	0.717	0.629	0.584	0.716	0.870
	H_c(Oe)	0.058	0.070	0.078	0.084	0.085	0.080	0.084	0.052
III	B_r(KG)	5.5	5.3	5.2	4.9	4.4	4.0	4.9	5.5
	B_s(KG)	8.5	8.4	8.2	7.7	7.1	6.4	7.7	8.5
	B_r/B_s	0.647	0.633	0.634	0.636	0.620	0.620	0.636	0.647
	H_c(Oe)	0.019	0.009	0.007	0.006	0.005	0.005	0.006	0.019

A-C Properties

Group	Frequency (cps)	Induction (KG)	Core Loss, watts per pound, @ Temperature (C)				
			-60 C	10 C	145 C	210 C	250 C
I	60	6	0.047	0.042	0.034	0.030	0.028
		12	0.156	0.146	0.124	0.114	0.108
	400	6	0.51	0.46	0.38	0.32	0.29
		12	1.70	1.52	1.20	1.04	0.93
	1000	6	1.75	1.56	1.25	1.09	1.00
		12	5.75	5.20	4.15	3.65	3.33
II	60	6	0.068	0.064	0.056	0.052	0.050
		12	0.180	0.172	0.159	0.153	0.149
	400	6	0.76	0.66	0.48	0.39	0.34
		12	1.99	1.80	1.44	1.26	1.16
	1000	6	2.49	2.18	1.58	1.30	1.10
		12	6.70	5.99	4.55	3.90	3.50
III	60	3	0.0008	0.0008	0.0007	0.0006	0.0005
		6	0.0025	0.0025	0.0022	0.0019	0.0017
	400	3	0.090	0.087	0.078	0.070	0.065
		6	0.296	0.282	0.251	0.235	0.220
	1000	3	0.30	0.29	0.24	0.21	0.19
		6	1.02	0.99	0.91	0.86	0.80

TABLE II. Magnetic Properties of Hipersil at Various Temperatures [7]

D-C Properties

Temperature C	Permeability Initial	Permeability H=0. 10 Oersted	Permeability Maximum	Coercive Force H_c Oersteds+	Residual Induction B_r Gausses+
30	5,200	39,000	54,400	0.1	12,430
150	14,200	53,000	59,400	0.08	11,630
300	18,360	63,000	65,000	0.068	10,260
400	20,250	71,000	71,400	0.06	9,130
500		75,000	80,800	0.052	8,020
600		73,000	94,000		
700	55,000	60,000	132,700		

A-C Properties

Temp. C	Normal Hysteresis Loss (P_h, ergs/cc/cycle) at B_m (Gausses) 10,000	12,000	15,000	Total Core Loss, P_c (ergs/cc/cycle) at B_m, Gausses 10,000	12,000	15,000
30	368	451	836	940	1320	2280
150	293	382	730	910	1230	2190
300	234	337	606	730	1080	1900
400	178	299	596	670	1000	1760
500	140	240	590	580	880	1730
600	114	238		530	820	

+ Taken from B_m = 15,000 Gausses

TABLE III. Constant Current Flux Reset (CCFR) Properties 400 cps (Sine Wave) [23]

Material	B_m Kilogauss		Gain G x 1000		Curve Mid-point H_o, Oersteds	
	27 C	250 C	27 C	250 C	27 C	250 C
Hipernik V	14.90	10.10	424	212	-0.248	-0.136
Hipernik	15.40	11.60	238	213	-0.272	-0.200
Hipersil	17.70	16.60	187	208	-0.617	-0.443
Hipernom	8.06	5.97	386	321	-0.033	-0.016
Supermendur Heat "A"	20.50	19.40	154	109	-0.667	-0.595
Supermendur Heat "B"	21.53	21.96	287	144	-0.450	-0.553

TABLE IV. Effect of Temperature on Constant Current Flux Reset (CCFR) Properties of Hipernik V Tape, 400 cps (Sine Wave) [27]

	-80 C	-40 C	0 C	80 C	160 C	200 C
B_m(KG)	15.7	15.5	15.1	14.3	12.6	11.4
B_m-B_r(KG)	0.36	0.37	0.38	0.44	0.71	0.97
$\triangle$H(Oe)	0.23	0.215	0.205	0.2	0.223	0.225

TABLE V. Constant Current Flux Reset (CCFR) Properties (400 cps - Sine Wave)

Core	Material Thickness (inches)	Core Size	Treat-ment	Temper-ature (F)	Test Environ-ment	H_m Oersted	B_m Kilogauss	B_m-B_r Kilogauss	B_r/B_m	H_0 Oersteds	H_1 Oersteds	H_2 Oersteds
						Cubex Alloy ++						
1	0.002	L*	SRA**	72	Air	10.0	16.15	4.52	0.720	0.570	0.474	0.696
				500	Air	10.0	15.33	6.98	0.545	0.363	0.252	0.554
				1100	Argon	10.0	11.75	6.15	0.477	0.128	0.083	0.212
				72+++	Air	10.0	16.42	5.15	0.686	0.582	0.514	0.680
2	0.002	L	MFA***	72	Air	10.0	19.00	1.18	0.938	0.453	0.418	0.484
				500	Argon	10.0	17.76	2.32	0.869	0.305	0.277	0.340
				1100	Argon	10.0	13.68	4.18	0.694	0.126	0.108	0.148
				72+++	Air	10.0	18.96	2.80	0.852	0.509	0.448	0.567
3	0.006	L	SRA	72	Air	10.0	16.46	3.83	0.768	0.526	0.436	0.604
				500	Air	10.0	15.84	4.44	0.720	0.393	0.318	0.469
				1100	Argon	10.0	12.62	5.35	0.580	0.156	0.116	0.206
4	0.006	L	MFA	72	Air	10.0	16.42	4.18	0.746	0.554	0.464	0.640
				500	Argon	10.0	15.60	4.74	0.696	0.418	0.338	0.498
				1100	Argon	10.0	12.04	5.20	0.569	0.156	0.113	0.204
						Supermendur++						
1	0.002	L*		72	Air	5.0	21.71	2.73	0.874	0.58	0.544	0.604
				500	Argon	5.0	24.10	1.99	0.917	0.466	0.428	0.504
				1100	Argon	5.0	21.16	2.15	0.898	0.418	0.36	0.481
				72+++	Air	5.0	21.16	4.63	0.781	0.917	0.85	0.975
2	0.002	L		72	Air	5.0	22.77	2.09	0.910	0.64	0.62	0.665
				500	Argon	5.0	10.80	0.66	0.939	1.01	0.806	-----
				1100	Argon	5.0	10.09	1.47	0.854	-----	-----	-----
				72+++	Air	5.0	20.84	2.77	0.867	0.906	0.88	0.941

*Toroid 3-1/2 inch I. D. x 4 inch O. D. x 1/2 inch Ht.

**Stress Relief Anneal

***Magnetic Field Anneal

+Test Procedure for Toroidal Magnetic Amplifier Cores, AIEE No. 432, January, 1959

++Data obtained on Westinghouse sponsored programs

+++Room temperature test after 1100 F exposure

B. Effect of Charged Particle Irradiation.

According to the Radiation Effects Information Center at Battelle Memorial Institute, information regarding proton and electron radiation effects on magnetic materials is extremely limited in scope. [48] The data indicates that the threshold of damage occurs at approximately 10^{16} protons per cm^2. [42-52] This is based on proton radiation experiments which were conducted on pure iron and 5-Molybdenum Permalloy. [45, 47, 48, 49, 50, 51] In the case of the iron sample, 1.5 Mev protons were used. For the 5-Mo Permalloy, both 1.5 and 4 Mev protons were used in separate experiments. Both magnetic materials were irradiated to integrated proton fluxes of approximately 10^{16} and 10^{17} protons/cm^2. The temperature was maintained at 100 C. The results of these experiments are summarized in Table VI. [45]

As can be seen from these data, much of the damage for iron occurs after exposure to 10^{16} protons/cm^2. For Permalloy specimens, slight changes were indicated for a dose of up to 10^{16} protons/cm^2, but pronounced changes occurred when the exposure was increased to 10^{17} protons/cm^2. The remanence and maximum permeability of the Permalloy decreased by about 35%. This is of the same order of change produced by neutron irradiation of 10^{17} neutrons per cm^2 in this material. However, changes in coercive force and initial permeability due to proton irradiation of the Permalloy were relatively small as compared with neutron irradiation effects. The decreases in residual induction and maximum permeability of pure iron were on the order of 10 to 20%. The changes due to proton irradiation are thought to be caused by proton-induced disordering.

Large changes in the structure-sensitive magnetic properties of bulk polycrystalline 5% Molybdenum Permalloy result from irradiation with 2 Mev electrons at a dose of 10^{17} electrons/cm^2 at temperatures ranging from 60 to 170 C. [47, 48, 49, 50, 51] These changes include a considerable increase in coercive force and decreases in remanence and permeabilities. An approximately linear dependence on sample thickness from 0.10 to 0.25 mm as well as extreme rectangularities in the magnetization curves and hysteresis loops were demonstrated. This unusual loop steepness is evidence of the effectiveness of electron irradiation in inducing atomic order in the Permalloy at temperatures well below the ordering temperature and without an applied magnetic field. Iron, irradiated under the same conditions shows no changes in its magnetic properties.

According to a report by the Bell Telephone Laboratories [43], the total energy flux due to protons with energies greater than 5 Mev that penetrate the outer skin of a space probe has been reported as 3.5×10^6 Mev per cm^2 per second. The flux of electrons greater than 600 Mev is approximately 4×10^5 Mev per cm^2 per second for the inner Van Allen region. The energy flux which penetrates the skin is approximately 8.5×10^5 Mev per cm^2 per second. A total continuous exposure for a one year period can be approximated as follows:

[ ]*Figures in square brackets refer to individual references listed in Appendix B.

Inner Van Allen Region Protons	4.2×10^6 ergs-gm^{-1}
Inner Van Allen Region Electrons	0.5×10^6 ergs-gm^{-1}
Outer Van Allen Region Electrons	1.0×10^6 ergs-gm^{-1}

As can be seen by comparing the above with column four of Table VI, the proton flux in the Van Allen layers is far below that needed to cause damage in the above magnetic materials.

C. Effect of High Vacuum.

Although no specific references were found in the literature regarding the behavior of metallic magnetic materials in high vacuum, none of the materials considered in this study are expected to show a significant weight loss in space vacuum at elevated temperatures. However, the effects of high vacuum on both interlaminar insulation and welding of insufficiently insulated tape layers or laminations should be considered as a potential problem.

D. Effects of Vibration and Shock.

A shock of 30 blows with a peak acceleration of 50 g causes no significant damage to the magnetic properties of grain-oriented 50% Ni -50% Fe, toroidal cores, placed in aluminum cases and tested in several different damping media. However, shock testing above this limit does cause permanent degradation in some instances. [59]

Vibration studies indicate that damping media are critical when resonant conditions are to be avoided. Silicone oil with a viscosity of 18,000 centistokes was a preferred damping medium. [59] Vibration was also reported to reduce the coercive force and remanence of a soft-annealed iron wire resulting in a considerable decrease of the size of the normal hysteresis loop of this material. [60]

Blows with a one-pound weight from a height of 30 inches caused a small decrease in the remanence of permanent magnets. [58] The first few blows had the greatest effect, decreasing the remanence by 4-1/2%. An additional one-thousand blows, decreased the remanence by another 0.5% or a total decrease of 5%. Thermal shock produced by cyclic heating and cooling between 25 and 75 C caused a decrease in the remanence of permanent magnets by 3% after the first 100 cycles. [60]

E. Effect of Acoustical Noise.

No recent references were found on the effect of acoustical noise. This property may be associated with vibration which affects the domain structure of magnets. [57]

[ ] *Figures in square brackets refer to individual references listed in Appendix B.

TABLE VI. Changes in Magnetic Properties Caused By Proton Irradiation of Iron and Permalloy Materials [45]

Magnetic Material	Integrated Proton Flux, Protons-cm^{-2}	Proton Energy Mev	ergs-gm^{-1}	Per Cent Change From Initial Parameter Value			
				Permeability (Initial)	Coercive Force	Maximum Permeability	Residual Induction
Iron	10^{16}	1.5	2.4 x 10^{10}	0(a)	+7(b)	-10(c)	-11(b)
5-Mo Permalloy	10^{16}	1.5	2.4 x 10^{10}	0	+5	-15	-8
Iron	10^{17}	1.5	2.4 x 10^{11}	-7	+2	-22	-18
5-Mo Permalloy	10^{17}	1.5	2.4 x 10^{11}	-10	+7	-36	-33
5-Mo Permalloy	10^{17}	4.0	6.4 x 10^{11}	0	+11	-49	-34

(a) Accuracy of ± 10 percent.
(b) Accuracies of ± 5 percent.
(c) Accuracies of ± 3 percent.

F. Effect of Processing.

The degradation effect of processing variables, primarily the influence of elastic and plastic stresses, was discussed in a few papers, mostly with respect to the materials and gauges used in utility power applications. [67-74]

All iron nickel alloys are well known for their strain sensitivity, particularly in thin gauges. The degrading effects of strains can be considerably reduced by stress relief annealing most of the materials considered in this program provided no damage to orientation or other basic properties has resulted from the strain.

[ ]*Figures in square brackets refer to individual references listed in Appendix B.

III. EQUIPMENT AND TEST PROCEDURES

Equipment has been ordered or purchased for magnetic testing required in this program. A d-c amplifier and power supply have been purchased by Westinghouse. The equipment has been calibrated and is ready for use. A 7.2 kw square wave power supply (4 kw sine wave power) and a square wave CCFR tester have been ordered by Westinghouse. The equipment will have a maximum drive of 50 oersteds using square wave excitation and a one lb sample. This equipment was designed and modified to Westinghouse requirements.

A wattmeter and associated current transformer modified to Westinghouse requirements capable of measuring square wave core loss has been ordered with NASA approval.

Test specifications to ASTM standards have been established where appropriate. Although test standards for square-wave excitation have not been established by industry, the tests will be conducted using procedures similar to those established for sine wave testing.

A vibration test fixture has been designed.

The double window transformer size has been set at 4 in. x 4.8 in. with a stack height of 0.250 in. The window size is 0.8 in. x 2.4 in. The Rowland ring lamination size has been set at 3.89 in. O.D. x 3.256 in. I.D. with a stack height of 1 in.

IV. PLANS FOR FUTURE WORK

In the next quarter, magnetic test equipment will be installed and calibrated. Magnetic tests will be conducted. The conductor insulation and interlaminar insulation review will be completed.

V. CONCLUSIONS

The literature review has indicated the following:

1. Magnetic testing with square wave excitation is not reported in the literature for the frequencies of interest.
2. There is limited information on the effects of shock, acoustical noise, vibration, temperature, Van Allen radiation, and processing on magnetic materials.
3. The effects of combined environments of outer space as well as the effects of missile launch conditions on magnetic materials are not covered in the literature.
4. The environments most likely to affect magnetic materials based on the information to date are temperature, processing variables, noise and vibration.

APPENDIX A

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APPENDIX B

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Effect of Temperature On Soft Magnetic Materials

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APPENDIX C

Symbols and Definitions

PART I

A. Symbols Used in Magnetic Testing. *

B - Normal induction, magnetic induction, or magnetic flux density.

B_d - Remanent induction

B_{dm} - Remanence

B_m - Maximum induction in a hysteresis loop

B_r - Residual induction

B_s - Saturation induction

H - Magnetizing force, magnetic field strength

H_c - Coercive force

P_c - Total core loss

P_h - Normal hysteresis loss

μ - Normal permeability

μ_m - Maximum permeability

μ_o - Initial permeability

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*See page WAED64. 59E-34

B. Definitions of Terms Used in Magnetic Testing. *

Coercive Force, H_c

The d-c magnetizing force at which the magnetic induction is zero when the material is in a symmetrically cyclically magnetized condition.

Core Loss (Total), P_c

The power expended in a magnetic specimen in which there is a cyclically alternating induction, normally sinusoidal.

Hysteresis Loss, Normal, P_h

The power expended in a ferro-magnetic material, as a result of hysteresis when the material is subjected to a symmetrically cyclically magnetized excitation.

Induction, Normal, B

The maximum induction, in a magnetic material that is in a symmetrically cyclically magnetized condition.

Induction, Remanent, B_d

The magnetic induction that remains in a magnetic circuit after the removal of an applied magnetomotive force.

Induction, Residual, B_r

The magnetic induction corresponding to zero magnetizing force in a magnetic material that is in a symmetrically cyclically magnetized condition.

Induction, Saturation, B_s

The maximum intrinsic induction possible in a material.

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*See page WAED64. 59E-34

Magnetizing Force (Magnetic Field Strength), H

That magnetic vector quantity at a point in a magnetic field which measures the ability of electric currents or magnetized bodies to produce a magnetic induction at the given point.

Permeability, Initial, μ_o

The limiting value approached by the normal permeability as the applied magnetizing force, H, is reduced to zero.

Permeability, Maximum, μ_m

The maximum value of normal permeability for a given material.

Permeability, Normal, μ

The ratio of the normal induction to the corresponding magnetizing force.

Remanence, B_{dm}

The maximum value of the remanent induction for a given geometry of the magnetic circuit.

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*ASTM STANDARDS, PART 8, 1964, ASTM Designation: A 340-64, "Standard Definitions of Terms, Symbols, and Conversion Factors Relating to Magnetic Testing".

PART II

A. Symbols Used in CCFR Testing of Toroidal Magnetic Amplifier Cores. *

AT - Same as H_1

B_m - Peak induction or peak flux density

$2B_m$ - Maximum flux density swing

B_r - Residual induction or residual flux density

$B_m - B_r$ - Squareness

$\frac{B_r}{B_m}$ - Squareness ratio

ΔB - Delta induction or delta flux density

ΔB_0 - Delta induction, fixed

ΔB_1 - Delta induction, fixed

ΔB_2 - Delta induction, fixed

CCFR - Constant current flux reset

DAT - Same as ΔH

G - Gain

H_m - Peak magnetizing force

H_0 - Magnetizing force, dependent

H_1 - Magnetizing force, dependent

H_2 - Magnetizing force, dependent

ΔH - Incremental magnetizing force

SAT - Same as B_m

T - Same as $\frac{B_r}{B_m}$

*See page WAED64. 59E-38

B. Definitions Used in CCFR Testing of Toroidal Magnetic Amplifier Cores. *

Constant Current Flux Reset, CCFR

This test employs an excitation current consisting of half-wave sine current pulses of sufficient and constant magnitude to drive the core flux into positive saturation. A direct-current magnetizing force of adjustable magnitude is applied to the core so as to reset the magnetic flux away from positive saturation during the intervals between pulses of excitation current. The resultant cyclic flux change is measured by means of a sensitive flux voltmeter connected to a separate pickup winding on the core.

Flux Density Swing, Maximum; $2B_m$

The maximum flux density swing equal to the absolute total value of positive and negative peak induction or $2\ B_m$. ($2\ B_m = 2$ SAT)

Gain, G

$G = \frac{\Delta B_2 - \Delta B_1}{\Delta H}$, a measure of loop steepness in terms of incremental permeability.

Induction, Delta (Delta Flux Density); ΔB

Delta induction is the change in induction (flux density) when a core is in a cyclically magnetized condition.

Induction, Fixed Delta; ΔB_1, ΔB_0, ΔB_2

1. $\Delta\ B_1$ - delta induction equal to one third of $2\ B_m$, maximum flux density swing.
2. $\Delta\ B_0$ - delta induction equal to one half of $2\ B_m$, maximum flux density swing.
3. $\Delta\ B_2$ - delta induction equal to two thirds of $2\ B_m$, maximum flux density swing.

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*See page WAED64. 59E-38

Induction, Residual (Residual Flux Density), B_r

Residual induction is the magnetic induction at which the magnetizing force is zero while the material is cyclically magnetized with a half-wave sinusoidal magnetizing force of a specified peak magnitude. (This definition differs from the standard definition which requires symmetrically cyclically magnetized conditions).

Induction, Peak (Peak Flux Density), B_m

Peak induction is the magnetic induction corresponding to the peak applied magnetizing force. The peak induction will usually be slightly less than the true saturation. (B_m = SAT)

Magnetizing Force, Dependent; H_1, H_0, H_2

1. H_1 - The d-c reset magnetizing force required to produce a cyclic change of induction $\triangle B_1$ (H_1 = AT).
2. H_0 - The d-c reset magnetizing force required to produce a cyclic change of induction $\triangle B_0$ (H_0 = AT + 1/2 DAT).
3. H_2 - The d-c reset magnetizing force required to produce a cyclic change of induction $\triangle B_2$ (H_2 = AT + DAT).

Magnetizing Force, Incremental; $\triangle H$

The incremental change in magnetizing force equal to $H_2 - H_1$. ($\triangle H$ = DAT)

Magnetizing Force, Peak; H_m

Peak magnetizing force is the maximum value of applied magnetomotive force per mean length of path of the core.

Squareness; $B_m - B_r$

The delta B induction change between the peak induction, B_m, and the residual induction, B_r.

Squareness Ratio; $\frac{B_r}{B_m}$

The ratio of residual induction, B_r, over peak induction, B_m $\left(\frac{B_r}{B_m} = 1 - \frac{B_m - B_r}{B_m} = T \right)$

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*Where applicable, AIEE, No. 432 (Jan. 1959) "Test Procedure for Toroidal Magnetic Amplifier Cores" has been used.

PART III

General Definitions of Terms

Acoustic

Pertaining to the science of sound.

Atomic Ordering

Forming a superlattice which is an ordered arrangement of atoms in a solid solution superimposed on the normal solid solution lattice.

Base Line Property

Those initial magnetic, physical or mechanical properties that are normally present at room temperature, i. e. - saturation induction, thermal expansion, tensile strength.

Critical Temperature

The temperature at which a change in crystal structure, phase or physical properties occurs under constant pressure conditions.

Converter

A device which changes or converts a-c current to d-c current.

Disordered Structure

The crystal structure of a solid solution in which the atoms of different elements are randomly distributed with respect to the available lattice sites.

Domain

A small region, in ferromagnetic materials, where the atomic magnetic moments are all aligned parallel to one another.

Dose (Integrated Flux)

The total radiation exposure to which the specimen has been subjected (expressed as the number of particles per square centimeter).

Double Window Transformer

A transformer built from laminations from which two square openings have been punched.

Doubly Grain-Oriented Silicon Steel

An iron base alloy containing about 3% silicon where the phase that is present (α iron) is body centered cubic. The individual re-crystallized grains of this alloy are oriented such that the cube face plane is in the plane of the material and a cube edge direction is parallel to the rolling direction.

Field

The space where an electric or magnetic force is being exerted.

High Vacuum (Space Vacuum)

This term, as used in this report, refers to a vacuum equal to or higher than 10^{-6} torr (m. m. Hg).

Inverter

A device which changes d-c current to a-c current.

Magnetic Field Annealing (MFA)

Annealing a magnetic material in the presence of a magnetic field so as to align the magnetic domains in a direction parallel to the field.

Neutron

One of the elementary particles which, together with the proton, comprises the nucleus of all elements. It has no charge.

Ordering Temperature

The temperature at which atomic ordering of different elements occurs.

Proton

One of the elementary particles which, together with the neutron, comprises the nucleus of all elements. It has a positive charge.

Rowland Ring

A continuous ring of magnetic material of uniform radial width and cross-sectional area with no joints or welds. The ratio of its mean diameter to its radial width is ten to one or greater.

Singly Grain-Oriented Silicon Steel

An iron base alloy containing approximately 3-1/4% silicon where the phase that is present is body centered cubic α iron.

The individual recrystallized grains of this alloy are oriented in the rolling direction such that the cube edge direction and the rolling direction are parallel. The face diagonal plane is in the plane of the material.

Centistoke

A unit of kinematic viscosity.

Stress Relief Annealing (SRA)

Heating to a suitable temperature, holding long enough to reduce residual stresses and then cooling slowly enough to minimize the development of new residual stresses.

Structure Sensitive Properties

The properties that are structure sensitive in magnetic materials are permeability (μ), coercive force (H_c), and hysteresis loss (P_h). The factors that affect these properties are composition, impurities, strain, temperature, crystal structure and crystal orientation.

Tape

A thin strip of magnetic material a few mils thick which is normally wound into the shape of a round core.

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