GRAIN-ORIENTED ELECTRICAL STEELS

M-2, M-3, M-3X LITE CARLITE® GOES
M-2, M-3, M-4, M-5, M-6 MILL-ANNEAL GOES

Distribution Transformers

Current Transformers

Instrument Transformers

CLEVELAND-CLIFFS GRAIN-ORIENTED ELECTRICAL STEELS (GOES) are used most effectively in transformer cores having wound or sheared and stamped laminations with the magnetic flux path entirely, or predominately, in the rolling direction. They may be used in large generators and other apparatus when the design permits the directional magnetic characteristics to be used efficiently. LITE CARLITE and Mill Anneal GOES products are most suitable for wound transfomer cores utilizing a stress-relief anneal.

Product Description

Grain-oriented electrical steels are iron-silicon alloys that were developed to provide the low core loss and high permeability required for efficient and economical electrical transformers. First produced commercially by Cleveland-Cliffs, these magnetic materials exhibit their superior magnetic properties in the rolling direction. This directionality occurs because the steels are specially processed to create a very high proportion of grains within the steel which have similarly oriented atomic crystalline structures relative to the rolling direction.

In iron-silicon alloys, this atomic structure is cubic and the crystals are most easily magnetized in a direction parallel to the cube edges. By a combination of precise steel composition, rigidly controlled cold rolling and annealing procedures, the crystals of these oriented electrical steels are aligned with their cube edges nearly parallel to the direction in which the steel is rolled. Consequently, they provide superior permeability and lower core loss when magnetized in this direction.

Since the inception of grain-oriented electrical steels in 1933, Cleveland-Cliffs Research has continued to develop new and improved grades to provide the electrical industry with core materials for the manufacture of more efficient electrical apparatus.

Cleveland-Cliffs Oriented Mill-Anneal finish and LITE CARLITE Electrical Steels are suitable for those types of transformers where a stress relief annealing treatment of the magnetic core is used and the magnetic flux path is entirely, or predominately, in the rolling direction. The technology used for oriented LITE CARLITE provides superior transformer performance when compared to oriented electrical steels with Mill-Anneal finish. This is accomplished by:

- Excellent response to stress-relief annealing
- High tension CARLITE® 3 coating

FORMS AND STANDARD SIZES

Nominal Thickness
M-2: 0.007 in. (0.18 mm)
M-3: 0.009 in. (0.23 mm)
M-3: 0.011 in. (0.27 mm)
M-5: 0.012 in. (0.30 mm)
M-6: 0.014 in. (0.35 mm)

Width
Standard: 36.00 in. (914 mm)
Maximum: 36.22 in. (920 mm)
Minimum: 0.50 in. (12.7 mm)

Inside Coil Diameter
Master Coil 20.0 in. (508 mm)
Slit Width Coil 16.0 and 20.0 in. (406 and 508 mm)

MILL-ANNEAL SURFACE INSULATION

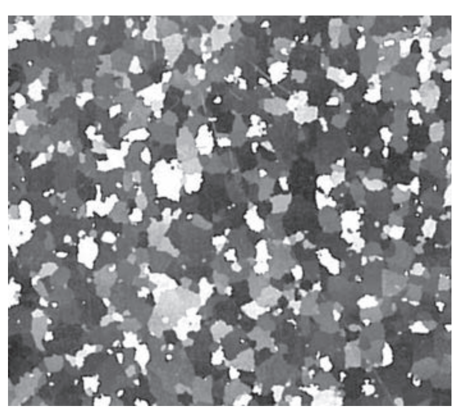
The Mill-Anneal insulation coating is formed at very high temperatures during the final annealing operation. It is a tightly adherent magnesiumsilicate type of coating equivalent to ASTM A976 C-2. Mill-Anneal coating provides insulative properties suitable for transformers operated at flux densities where the induced voltage is at or below 10 volts per turn such as distribution transformers and other devices.

The Mill-Anneal surface provides good resistance to abrasion during winding into core form and will withstand stress-relieving anneal without loss of insulative value. No danger of transformer oil contamination exists with this coating. Prolonged exposure to oils or air at transformer operating temperatures does not endanger insulating qualities.

CARLITE 3 SURFACE INSULATION

Cleveland-Cliffs' LITE CARLITE Grain-Oriented Electrical Steels (GOES) products are supplied with CARLITE 3 insulative coating, an inorganic coating equivalent to ASTM A976 C-5. LITE CARLITE is ideal for materials that will be used in distribution transformers and other magnetic apparatus with low to moderate volts per turn where the cores are stress-relief annealed. In addition to supplying the basic benefits of C-5 Insulation, LITE CARLITE provides other important advantages which include:

- Potential for reduced transformer building factor from added resistance to elastic strain damage
- Potential for reduction of magnetostriction related transformer noise
- High stacking factor
- Easy assembly due to smoothness of coating (low coefficient of friction)



Sample chemically etched to reveal grain structure.

Specifications

In terms of maximum core loss, Cleveland-Cliffs Oriented Mill-Anneal and LITE CARLITE Electrical Steel specifications are determined at 17 kG at 60 Hz. Induction is specified at 10 Oe. All test grading is conducted using stress-relief annealed Epstein test samples which are tested in the direction of rolling in accordance with ASTM testing procedure A343. Samples are secured from each end of the coil and the higher core loss value is used for certification of conformance to product grade guarantees.

TABLE 1 – GUARANTEED CORE LOSS

Product	Grade	Approximate ASTM Grades	Nominal Thickness, in. (mm)	Assumed Density, g/cm³	Resistivity, Ω-m, x10⁻⁸	Maximum Core Loss, W/lb.				Minimum Inducation at 10 Oe, kG
						50 Hz		60 Hz		
						15 kG	17 kG	15 kG	17 kG	
Oriented LITE CARLITE	M-2	–	0.007 (0.18)	7.65	51	0.307	0.479	0.395	0.609	18.0
	M-3X	–	0.009 (0.23)			0.305	0.453	0.395	0.580	18.0
	M-3	–	0.009 (0.23)			0.313	0.477	0.405	0.610	18.0
Oriented Mill-Anneal	M-2	18G041	0.007 (0.18)	7.65	51	0.307	0.488	0.395	0.620	18.0
	M-3	23G045 23H070	0.009 (0.23)			0.316	0.484	0.410	0.630	18.0
	M-4	27G051 27H074	0.011 (0.27)			0.390	0.560	0.510	0.740	18.0
	M-5	30G058 30H083	0.012 (0.30)			0.440	0.630	0.580	0.830	17.8
	M-6	35G066 35H094	0.014 (0.35)			0.500	0.710	0.660	0.940	17.8

Specifications

TABLE 2 – TYPICAL CORE LOSS

Product	Grade	Approximate ASTM Grades	Nominal Thickness, in. (mm)	Assumed Density, g/cm³	Resistivity, Ω-m, x10⁻⁸	Maximum Core Loss, W/lb.				Minimum Inducation at 10 Oe, kG
						50 Hz		60 Hz		
						15 kG	17 kG	15 kG	17 kG	
Oriented LITE CARLITE	M-2	–	0.007 (0.18)	7.65	51	0.292	0.446	0.375	0.567	18.4
	M-3X	–	0.009 (0.23)			0.301	0.449	0.390	0.575	18.4
	M-3	–	0.009 (0.23)			0.305	0.461	0.395	0.590	18.4
Oriented Mill-Anneal	M-2	18G041	0.007 (0.18)	7.65	51	0.295	0.462	0.379	0.587	18.4
	M-3	23G045 23H070	0.009 (0.23)			0.303	0.464	0.393	0.594	18.4
	M-4	27G051 27H074	0.011 (0.27)			0.352	0.525	0.461	0.680	18.4
	M-5	30G058 30H083	0.012 (0.30)			0.391	0.567	0.514	0.738	18.2
	M-6	35G066 35H094	0.014 (0.35)			0.440	0.614	0.582	0.806	18.2

The core loss and exciting power of the Cleveland-Cliffs Oriented Electrical Steel grades are determined by magnetic tests performed in accordance with general procedures approved by the American Society for Testing and Materials. The following conditions apply:

1. Epstein test specimens sheared parallel to the rolling direction of the steel from fully processed coils and stress-relief annealed per ASTM A876.

2. Tested per ASTM A343.

3. Density of all grades is 7.65 g/cm³ per ASTM A34.

ASTM A664 is a grade identification system for electrical steels. While this system has not been widely adopted by the manufacturers and consumers of electrical steels, it is used in ASTM A876 to designate various grades of grain oriented electrical steel.

Surface Insulation & Lamination Factor Curves

SURFACE INSULATION CURVES

The graph on the right shows the variation of surface insulation resistance versus pressure and provides a guide to users interested in knowing the relative insulative capabilities of the available surface finishes. Resistance values are typical of tests made on such surfaces by the Franklin Test (ASTM A717). However, the user should recognize that the normally small variations in mill oxide and coating thickness within a lot necessitate allowing for some test values lower as well as higher than those shown in the curves.

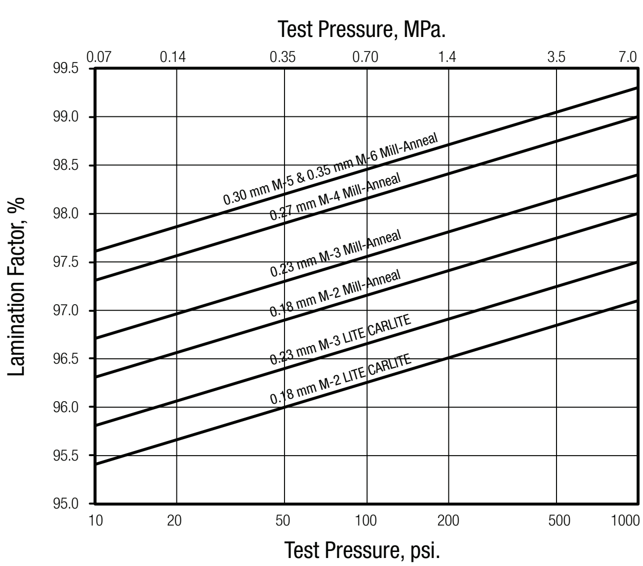
LAMINATION FACTOR

Lamination factor is the measure of compactness of an electrical steel core. This is also referred to as "stacking factor" and "space factor." Lamination factor is the ratio of the equivalent "solid" volume, calculated from weight and density of the steel, to the actual volume of the compressed pack, determined from its dimensions. Special processing gives Cleveland-Cliffs' Oriented Electrical Steels exceptionally and consistently high lamination factors.

TEST METHOD

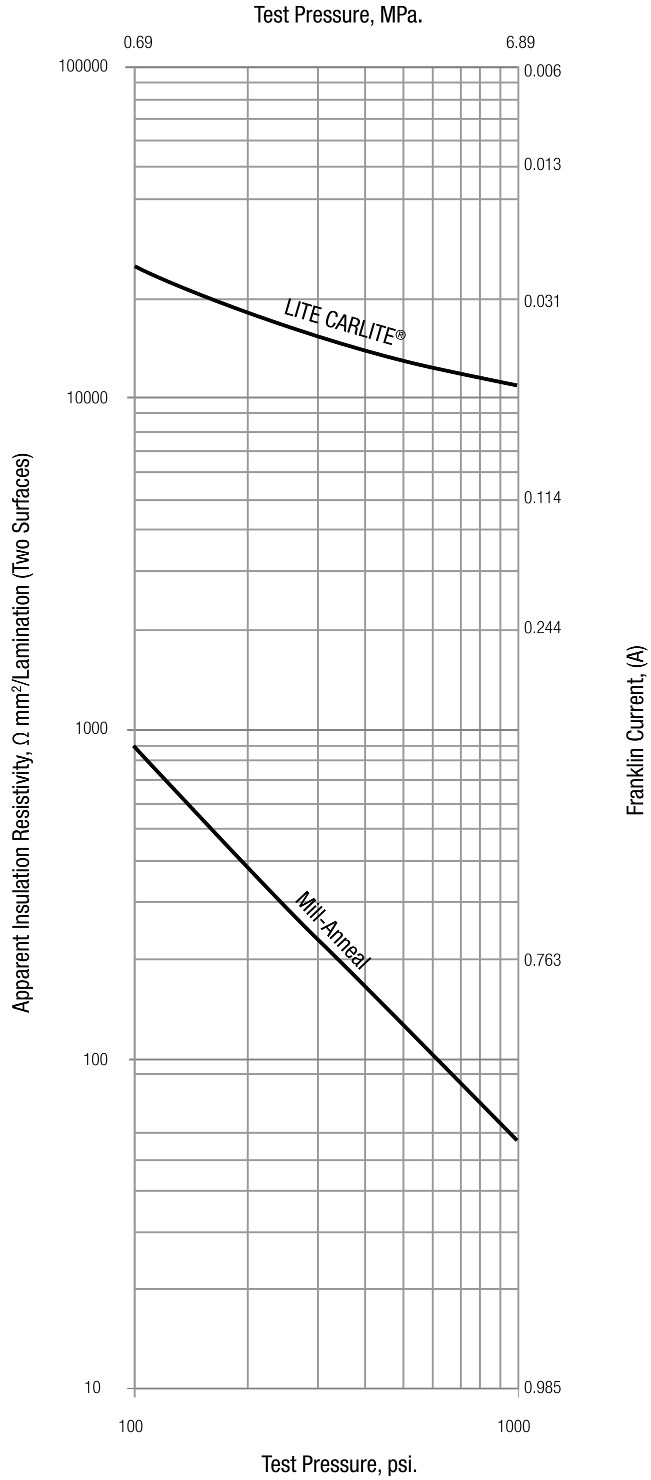
The lamination factor of electrical steels is determined from measurements of a stack of Epstein strips under known pressure in accordance with ASTM A719. The graph below illustrates how the ASTM lamination factor varies as a function of pressure for LITE CARLITE and Mill-Annealed Oriented Electrical Steels. The values shown are representative of the lamination factor determined by this test.

FIGURE 2



Representative lamination factors for Cleveland-Cliffs Oriented Electrical Steels at various pressures.

FIGURE 1



Typical surface insulation characteristics of Cleveland-Cliffs Oriented Electrical Steels at various pressures as determined by the Franklin Test.

Representative Mechanical Properties

TABLE 3

Ultimate Tensile Strength in rolling direction, psi (MPa)	51,000	(352)
Yield Strength in rolling direction, psi (MPa)	48,000	(331)
Percent Elongation in 2" (50.8 mm) in rolling direction	9	–
Microhardness (Knoop Hardness Number, HK)	167	–
Equivalent Rockwell B Scale Hardness	81	–
Modulus of Elasticity, psi (MPa)*		
in rolling direction	17,700,000	(122,000)
at 20° to rolling direction	20,800,000	(143,000)
at 45° to rolling direction	34,300,000	(236,000)
at 55° to rolling direction	37,500,000	(258,000)
at right angles to rolling direction	29,000,000	(200,000)

**Values may vary as much as plus or minus 5%.*

Magnetostriction

The magnetostriction coefficients are inherent to Mill-Anneal finish and LITE CARLITE Oriented owing to the degree of grain orientation.

The information below, while purely comparative in nature, is considered to be representative of Cleveland-Cliffs' Mill-Anneal finish and LITE CARLITE Oriented products.

TABLE 4 – COMPARATIVE MAGNETOSTRICTION

Product	Grade	Nominal Thickness, in. (mm)	Magnetostriction x 10^8 60 Hz 15 kG	Magnetostriction x 10^8 60 Hz 17 kG
Oriented LITE CARLITE	M-2	0.007 (0.18)	-64	-78
	M-3X	0.009 (0.23)	-67	-83
	M-3	0.009 (0.23)	-67	-83
Oriented Mill-Anneal	M-2	0.007 (0.18)	-55	-63
	M-3	0.009 (0.23)	-59	-69
	M-4	0.011 (0.27)	-77	-93
	M-5	0.012 (0.30)	-67	-86
	M-6	0.014 (0.35)	-66	-83

TEST METHOD

The above data is meant for comparative purposes only and was developed using stress-relief annealed Epstein specimens from representative samples which were prepared in accordance with ASTM A876 and tested in accordance with ASTM A343. While there are no agreed-upon standard testing methods for magnetostriction, these data were acquired using an accelerometer-based measurement of crossover-to-tip displacement of many individual Epstein strips, which were tested at a frequency of 60 Hz at the inductions shown above. The magnetostriction values are, to our best knowledge, believed to be representative of commercially produced materials.

Stress-Relief Annealing

In wound or formed cores, there is a substantial amount of both plastic and elastic strain which substantially degrades the magnetic properties of the electrical steel. When the strain is low, the strain will be elastic and removal of the load or restraining force will permit the steel to return to essentially a stress-free condition. However, if the steel is plastically deformed, it will retain stresses even after the load is removed. In these circumstances, stress-relief annealing is needed to return the material to a stress-free condition.

GENERAL REQUIREMENTS

Although a thermal-flattening treatment is part of the process for application of CARLITE 3 insulation coating to LITE CARLITE Oriented Electrical Steel, both Cleveland-Cliffs Oriented LITE CARLITE and Oriented Mill-Anneal products require stress-relief annealing to fully develop the magnetic properties. The annealing should be conducted for a suitable time and temperature in a protective atmosphere to prevent adverse changes to the steel chemistry. The parameters of time, temperature and atmosphere are not interchangeable with those procedures used for annealing of semi-processed non-oriented or carbon-lamination steel products. Conditions that create excessive thermal gradients should be avoided since these can reintroduce stresses and/or distort the shape of the steel.

TEMPERATURE CYCLE

While a soaking temperature of 1450 – 1500 °F (790 – 820 °C) for a time of at least 15 minutes is recommended, stress-relief annealing should be conducted for the shortest time possible without producing excessive thermal gradients. It is recommended that higher stress-relief annealing temperatures be employed only after experimentation with the cores being annealed shows it is clearly beneficial as higher annealing temperatures can result in increased “sticking” and/or “flaking” of the CARLITE coating.

Stress-Relief Annealing

Proper specification of annealing time must take into account the size and weight of the finished cores being annealed, the degree of exposure to heating and cooling during annealing and the amount of plastic deformation imparted by core fabrication. The furnace heat input should be adjusted so that the heating rate is not too great when approaching the soaking temperature. Forcing cores to heat rapidly to soak temperature should be avoided owing to incomplete annealing and/or thermal distortion is likely. If the cores are not well exposed, the length of the soaking period should be extended.

Proper specification of the cooling time requires similar consideration. It is recommended that the rate of cooling after annealing does not exceed 185 °F (85 °C) per hour from soaking temperature to 1400 °F (750 °C) and does not exceed 330 °F (165 °C) per hour to a temperature of 1200 °F (650 °C). Steel cores or laminations usually can be removed from the protective atmosphere at 600 – 700 ° F (325 – 375 °C) without ill effect.

ANNEALING ATMOSPHERE

The Mill-Anneal finish (sometimes referred to as Glass Film) is developed at very high temperatures in a hydrogen atmosphere. Consequently, it is completely compatible with hydrogen-nitrogen mixtures ranging from 0 to 100% nitrogen without adversely affecting the interlaminar resistance quality of the insulation coating. However, for economy and safety, the hydrogen content usually is maintained below 10%. Vacuum annealing gives very satisfactory results with a Mill-Anneal surface, but may be too costly.

Cleveland-Cliffs Oriented LITE CARLITE is supplied with a CARLITE 3 type of insulation coating. The qualities of the CARLITE coating are best maintained or enhanced when stress-relief annealing is conducted in an atmosphere that is neutral or slightly oxidizing to iron. An oxygen-free nitrogen atmosphere or a nitrogen-hydrogen mixture containing 5% hydrogen or less is recommended for batch annealing where exposure times in excess of one hour are typical. Vacuum annealing of CARLITE insulated materials is not recommended.

Continuous stress-relief annealing of slit widths or single laminations may be carried out in air if the exposure time is only a matter of minutes.

ANNEALING ATMOSPHERE CONDITIONS TO AVOID

Cleveland-Cliffs Oriented Electrical Steels are produced under exacting controls of composition and processing to provide a steel that is extremely low in impurities, such as carbon, nitrogen and oxygen. The Mill-Anneal insulation coating provides very limited protection to contaminants in the annealing atmosphere. Significant degradation of the magnetic properties will occur if these impurities are reintroduced into the steel. The CARLITE insulation coating of the Oriented LITE CARLITE Electrical Steels does provide some protection, but degradation of the magnetic properties will also occur if these above mentioned impurities are reintroduced into the steel. Annealing atmospheres which contain high chemical potentials of carbon, oxygen or their compounds may contaminate the steel under certain circumstances and should be avoided.

Thickness, Width, Camber & Flatness Tolerances

TABLE 5 – THICKNESS TOLERANCES

Grade	Nominal Thickness, in. (mm)	Thickness, in. (mm)	
		Minimum	Maximum
M-2	0.007 (0.18)	0.0060 (0.152)	0.0080 (0.203)
M-3	0.009 (0.23)	0.0075 (0.191)	0.0100 (0.254)
M-4	0.011 (0.27)	0.0095 (0.241)	0.0120 (0.305)
M-5	0.012 (0.30)	0.0105 (0.267)	0.0130 (0.330)
M-6	0.014 (0.35)	0.0125 (0.318)	0.0150 (0.381)

The thickness values are based on the test sample weight plus typical coating thickness such as would be measured using a contacting micrometer. The typical coating thickness is 0.0002 – 0.0004 in. (0.005 – 0.010 mm). Thickness measured at any point on the sheet not less than 0.375 in. (10 mm) from an edge shall not deviate more than +/- 0.0008 in. (0.020 mm) from the average thickness of the test lot or coil.

TABLE 6 – WIDTH TOLERANCES

Specified Width, in. (mm)	Tolerance over, in. (mm)	Tolerance under, in. (mm)
To 4 (102) inclusive	0.005 (0.127)	0.005 (0.127)
Over 4 to 9 (102 to 229) inclusive	0.007 (0.178)	0.007 (0.178)
Over 9 to 15 (229 to 381) inclusive	0.010 (0.254)	0.010 (0.254)
Over 15 (381) inclusive	0.016 (0.406)	0.016 (0.406)

CAMBER TOLERANCES

The deviation of a side edge from a straight line over a length of 80 in. (2 m), or a fraction thereof, shall not exceed 0.1 in. (2.54 mm).

FLATNESS TOLERANCES

While a thermal-flattening treatment is part of the process for application of CARLITE 3 insulation coating, the conventional flattening methods for electrical steel products were not used in the production of Cleveland-Cliffs Oriented LITE CARLITE due to their effects on magnetic quality after stress-relief annealing. Because of this circumstance, Cleveland-Cliffs Oriented LITE CARLITE typically has a small amount of coil set remaining in the delivered product. Thereby, it is not feasible to employ flatness tolerance tables for flat rolled steel. Some applications, and certain types of fabricating techniques for construction of magnetic cores, are tolerant of certain flatness deviations. However, it is generally recognized that sharp, short waves and buckles are objectionable and should be avoided as much as possible. The producer should determine the flatness requirements for its particular application and the suitability of this electrical steel.

Manufacturing Specifications

TABLE 7

Thickness	0.007 in. (0.18 mm) Oriented M-2 0.009 in. (0.23 mm) Oriented M-3 0.011 in. (0.27 mm) Oriented M-4 0.012 in. (0.30 mm) Oriented M-5 0.014 in. (0.35 mm) Oriented M-6	
Width	Master coils are available in widths up to 36.0 in. (914 mm) and 36.22 in. (920 mm) For the 36.22 in. (920 mm) width, we reserve the option of furnishing cutdowns, in 35.43 in. (900 mm) and 34.65 in. (880 mm) widths, not to exceed 10% of the ordered quantity. For the 36.00 in. (914 mm) width, we reserve the option of furnishing cutdowns, in 33.07 in. (890 mm) and 34.25 in. (870 mm) widths, not to exceed 10% of the ordered quantity.	
Coils-Slit	Minimum width Narrower Inside diameters	0.5 in. (12.7 mm) Inquire 16.0 in. (406 mm) 20.0 in. (508 mm)
Coils-Not Slit	Inside diameter	20.0 in. (508 mm)
Approximate Coil Weight	335 lb. per in. of width (600 kg per 100 mm of width)	

Typical Values of Core Loss

TABLE 8 – AT 50 AND 60 HZ FOR TYPICAL EPSTEIN SPECIMENS OF CLEVELAND-CLIFFS ORIENTED ELECTRICAL STEELS

Flux Density (kG)	Core Loss (W/lb.) – ASTM A343							
	0.007 in. M-2 LITE CARLITE		0.009 in. M-3X LITE CARLITE		0.009 in. M-3 LITE CARLITE		0.007 in. M-2 Mill-Anneal Oriented	
	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz
1	0.00140	0.00182	0.00150	0.00195	0.00155	0.00202	0.00148	0.00193
2	0.00528	0.00688	0.0056	0.00734	0.00576	0.00753	0.00547	0.00716
3	0.0117	0.0152	0.0123	0.0160	0.0126	0.0164	0.0119	0.0156
4	0.0205	0.0265	0.0214	0.0279	0.0219	0.0285	0.0206	0.0269
5	0.0316	0.0409	0.0329	0.0429	0.0336	0.0437	0.0316	0.0412
6	0.0451	0.0584	0.0469	0.0611	0.0478	0.0621	0.0450	0.0585
7	0.061	0.0788	0.0633	0.0824	0.0643	0.0836	0.0607	0.0789
8	0.0791	0.102	0.0821	0.107	0.0833	0.108	0.0788	0.102
9	0.0995	0.129	0.103	0.135	0.105	0.136	0.0994	0.129
10	0.122	0.158	0.127	0.166	0.129	0.167	0.122	0.159
11	0.148	0.191	0.154	0.200	0.155	0.202	0.148	0.192
12	0.176	0.228	0.183	0.239	0.185	0.241	0.177	0.230
13	0.208	0.269	0.217	0.282	0.219	0.285	0.210	0.271
14	0.246	0.317	0.255	0.331	0.258	0.335	0.248	0.320
15	0.292	0.375	0.301	0.390	0.305	0.395	0.294	0.379
16	0.352	0.451	0.360	0.464	0.367	0.473	0.358	0.459
17	0.446	0.567	0.449	0.575	0.461	0.590	0.462	0.587
18	0.607	0.768	0.603	0.767	0.617	0.784	0.638	0.807
19	0.797	1.00	0.796	1.01	0.805	1.02	0.84	1.06

Typical Values of Core Loss

TABLE 9 – AT 50 AND 60 HZ FOR TYPICAL EPSTEIN SPECIMENS OF CLEVELAND-CLIFFS ORIENTED ELECTRICAL STEELS

Flux Density (kG)	Core Loss (W/lb.) – ASTM A343							
	0.009 in. M-3 Mill-Anneal Oriented		0.011 in. M-4 Mill-Anneal Oriented		0.012 in. M-5 Mill-Anneal Oriented		0.014 in. M-6 Mill-Anneal Oriented	
	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz
1	0.00147	0.00194	0.00194	0.00256	0.00212	0.00281	0.00261	0.00343
2	0.00556	0.00735	0.00719	0.00953	0.00789	0.0105	0.00956	0.0129
3	0.0122	0.0161	0.0155	0.0205	0.0170	0.0228	0.0205	0.0275
4	0.0212	0.0279	0.0265	0.0351	0.0293	0.0391	0.0350	0.0470
5	0.0326	0.0428	0.0402	0.0532	0.0446	0.0596	0.0528	0.0709
6	0.0465	0.061	0.0565	0.0747	0.0631	0.084	0.0741	0.0994
7	0.0628	0.0822	0.0756	0.0998	0.0847	0.113	0.0988	0.132
8	0.0817	0.107	0.0976	0.129	0.109	0.145	0.127	0.170
9	0.103	0.135	0.122	0.161	0.138	0.182	0.159	0.212
10	0.127	0.166	0.150	0.198	0.169	0.224	0.194	0.258
11	0.154	0.201	0.181	0.238	0.204	0.271	0.233	0.310
12	0.184	0.239	0.216	0.284	0.242	0.320	0.276	0.368
13	0.217	0.283	0.255	0.335	0.285	0.377	0.324	0.431
14	0.256	0.333	0.299	0.393	0.334	0.440	0.378	0.501
15	0.304	0.393	0.351	0.461	0.391	0.514	0.439	0.582
16	0.367	0.472	0.423	0.551	0.464	0.606	0.512	0.677
17	0.465	0.594	0.527	0.680	0.569	0.738	0.611	0.806
18	0.627	0.795	0.688	0.881	0.723	0.931	0.768	1.010
19	0.806	1.02	0.876	1.11	0.899	1.15	0.953	1.24

Typical Values of RMS Exciting Power

TABLE 10 – AT 50 AND 60 HZ FOR TYPICAL EPSTEIN SPECIMENS OF CLEVELAND-CLIFFS ORIENTED ELECTRICAL STEELS

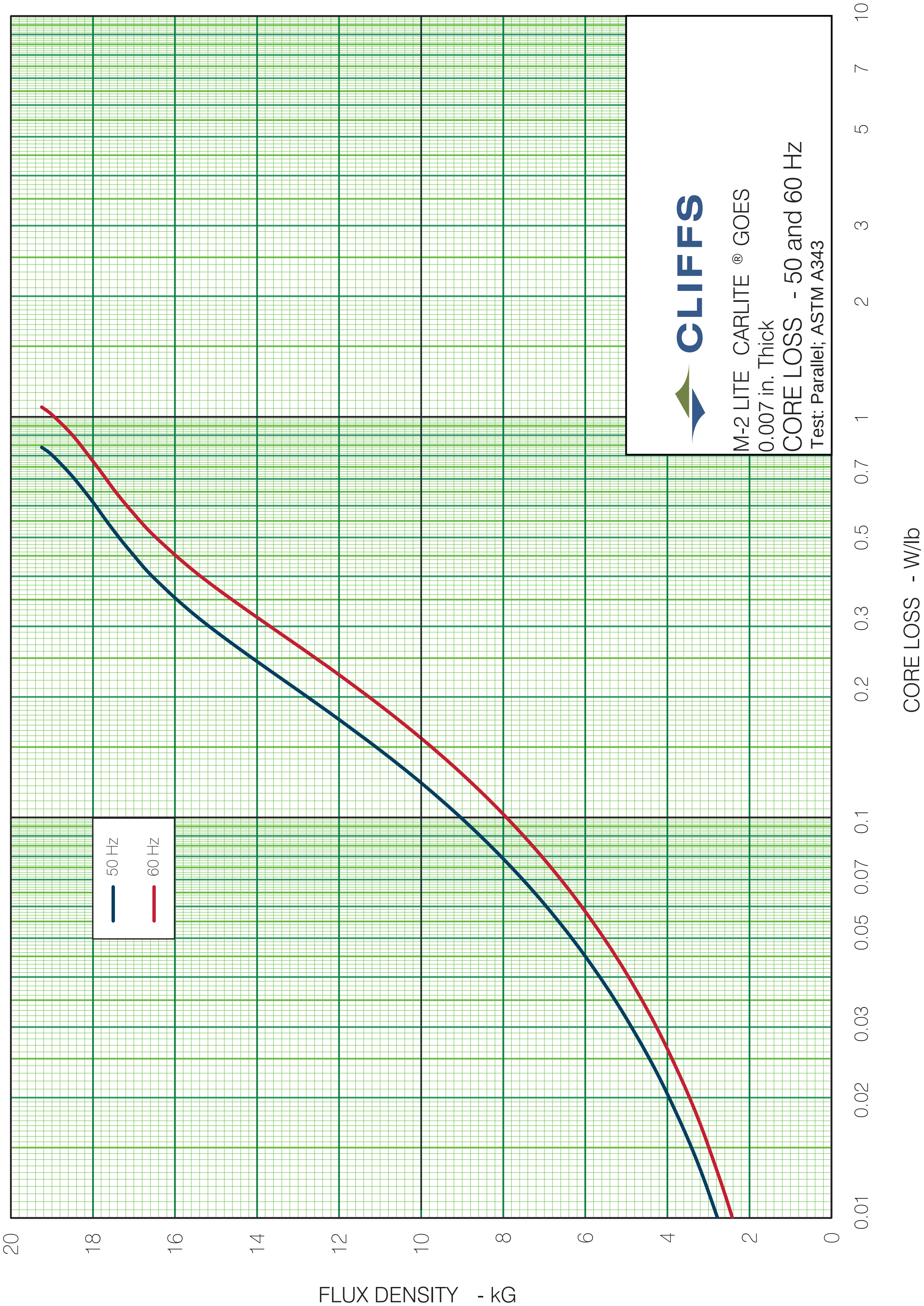
Flux Density (kG)	Exciting Power (rms VA/lb.) – ASTM A343							
	0.007 in. M-2 LITE CARLITE		0.009 in. M-3X LITE CARLITE		0.009 in. M-3 LITE CARLITE		0.007 in. M-2 Mill-Anneal Oriented	
	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz
1	0.00399	0.00486	0.00379	0.00463	0.00403	0.00493	0.00347	0.00426
2	0.0134	0.0164	0.0127	0.0156	0.0135	0.0165	0.0115	0.0142
3	0.0269	0.0330	0.0255	0.0314	0.0269	0.0332	0.0228	0.0283
4	0.0433	0.0533	0.0412	0.0510	0.0434	0.0536	0.0366	0.0455
5	0.0621	0.0765	0.0593	0.0737	0.0622	0.0772	0.0526	0.0655
6	0.0829	0.102	0.0796	0.0991	0.0834	0.104	0.0703	0.0879
7	0.106	0.131	0.102	0.127	0.107	0.133	0.0900	0.113
8	0.131	0.162	0.127	0.158	0.132	0.165	0.112	0.140
9	0.158	0.196	0.154	0.192	0.160	0.200	0.136	0.171
10	0.188	0.234	0.184	0.230	0.191	0.240	0.162	0.205
11	0.223	0.277	0.218	0.273	0.227	0.284	0.193	0.243
12	0.263	0.328	0.257	0.323	0.268	0.336	0.228	0.288
13	0.314	0.390	0.306	0.383	0.319	0.399	0.272	0.343
14	0.382	0.474	0.370	0.463	0.387	0.483	0.332	0.416
15	0.490	0.604	0.469	0.582	0.491	0.610	0.426	0.531
16	0.698	0.853	0.652	0.803	0.686	0.843	0.608	0.749
17	1.23	1.50	1.11	1.35	1.18	1.43	1.08	1.32
18	3.43	4.17	3.00	3.64	3.23	3.92	3.00	3.66
19	15.0	18.3	13.4	16.3	14.1	17.2	12.7	15.5

Typical Values of RMS Exciting Power

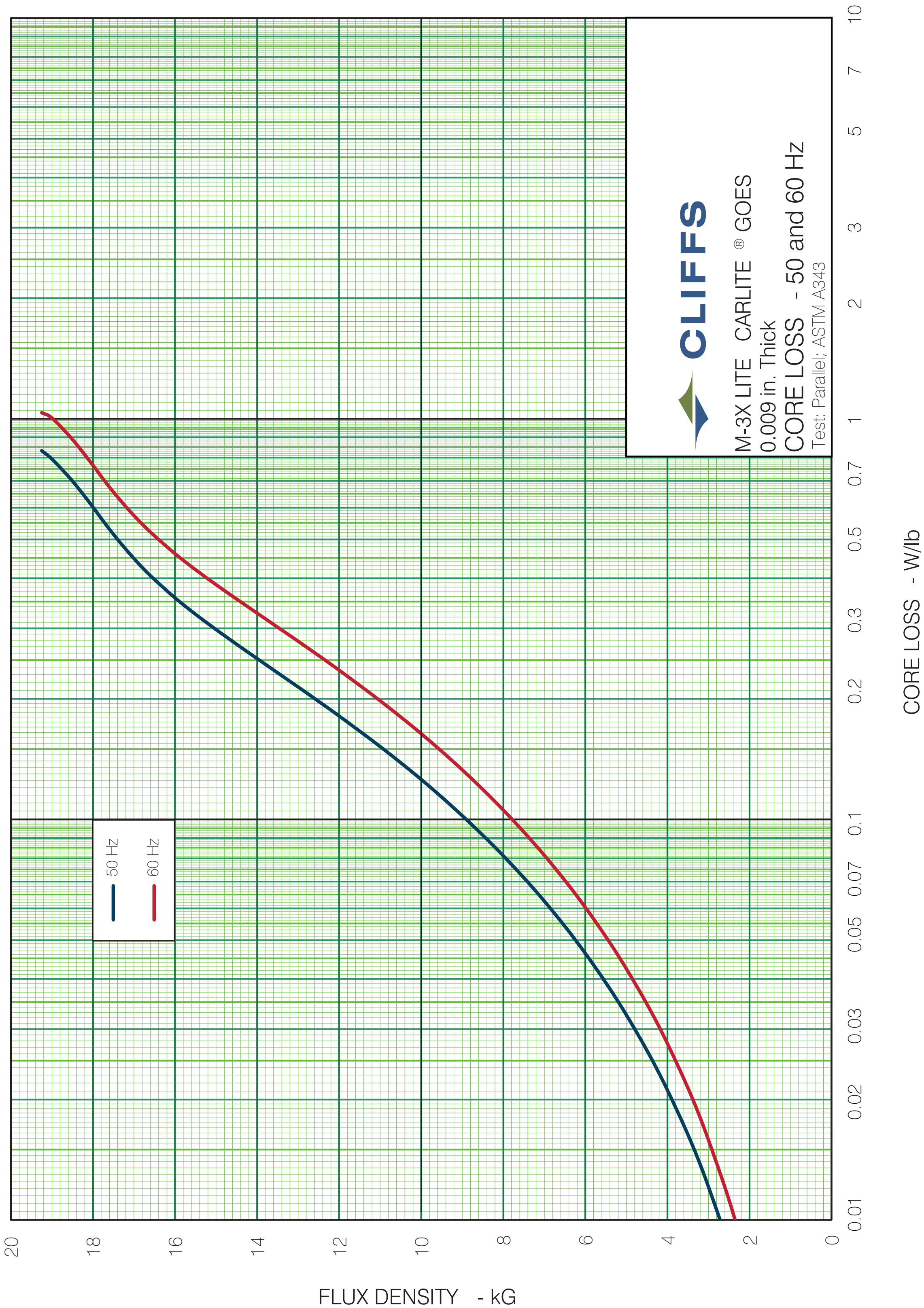
TABLE 11 – AT 50 AND 60 HZ FOR TYPICAL EPSTEIN SPECIMENS OF CLEVELAND-CLIFFS ORIENTED ELECTRICAL STEELS

Flux Density (kG)	Exciting Power (rms VA/lb.) – ASTM A343							
	0.009 in. M-3 Mill-Anneal Oriented		0.011 in. M-4 Mill-Anneal Oriented		0.012 in. M-5 Mill-Anneal Oriented		0.014 in. M-6 Mill-Anneal Oriented	
	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz
1	0.00336	0.00414	0.00378	0.0047	0.00346	0.00436	0.00367	0.00471
2	0.0112	0.0140	0.0125	0.0157	0.0115	0.0147	0.0124	0.0161
3	0.0225	0.0281	0.0249	0.0315	0.0233	0.0299	0.0253	0.0331
4	0.0364	0.0455	0.0403	0.0511	0.0383	0.0494	0.0418	0.0549
5	0.0524	0.0659	0.0582	0.0740	0.0562	0.0728	0.0618	0.0813
6	0.0706	0.0890	0.0786	0.100	0.0770	0.100	0.0850	0.112
7	0.0908	0.115	0.101	0.130	0.101	0.131	0.112	0.147
8	0.113	0.143	0.127	0.162	0.128	0.166	0.141	0.187
9	0.138	0.175	0.155	0.199	0.158	0.206	0.175	0.231
10	0.166	0.211	0.186	0.239	0.191	0.249	0.212	0.279
11	0.197	0.251	0.221	0.285	0.230	0.303	0.254	0.334
12	0.235	0.298	0.262	0.337	0.274	0.357	0.300	0.394
13	0.281	0.356	0.310	0.398	0.327	0.424	0.354	0.465
14	0.344	0.433	0.371	0.475	0.396	0.510	0.420	0.549
15	0.441	0.552	0.459	0.583	0.498	0.635	0.509	0.661
16	0.627	0.774	0.613	0.769	0.687	0.862	0.658	0.842
17	1.11	1.36	1.01	1.24	1.21	1.49	1.04	1.30
18	3.21	3.81	2.90	3.53	3.67	4.46	3.04	3.70
19	13.8	16.3	12.7	15.4	14.7	18.0	12.8	15.6

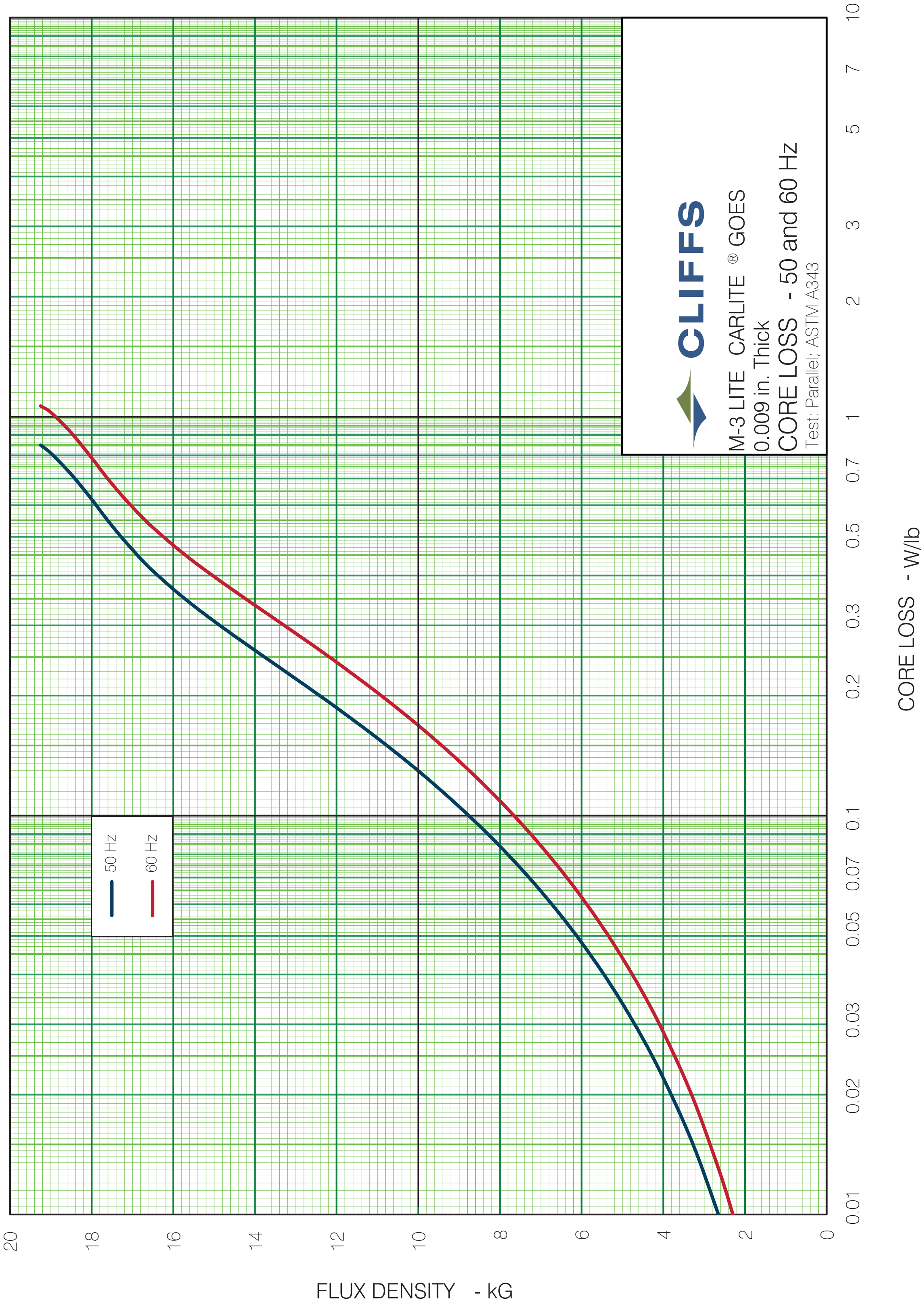
Core Loss Curve – M-2 LITE CARLITE



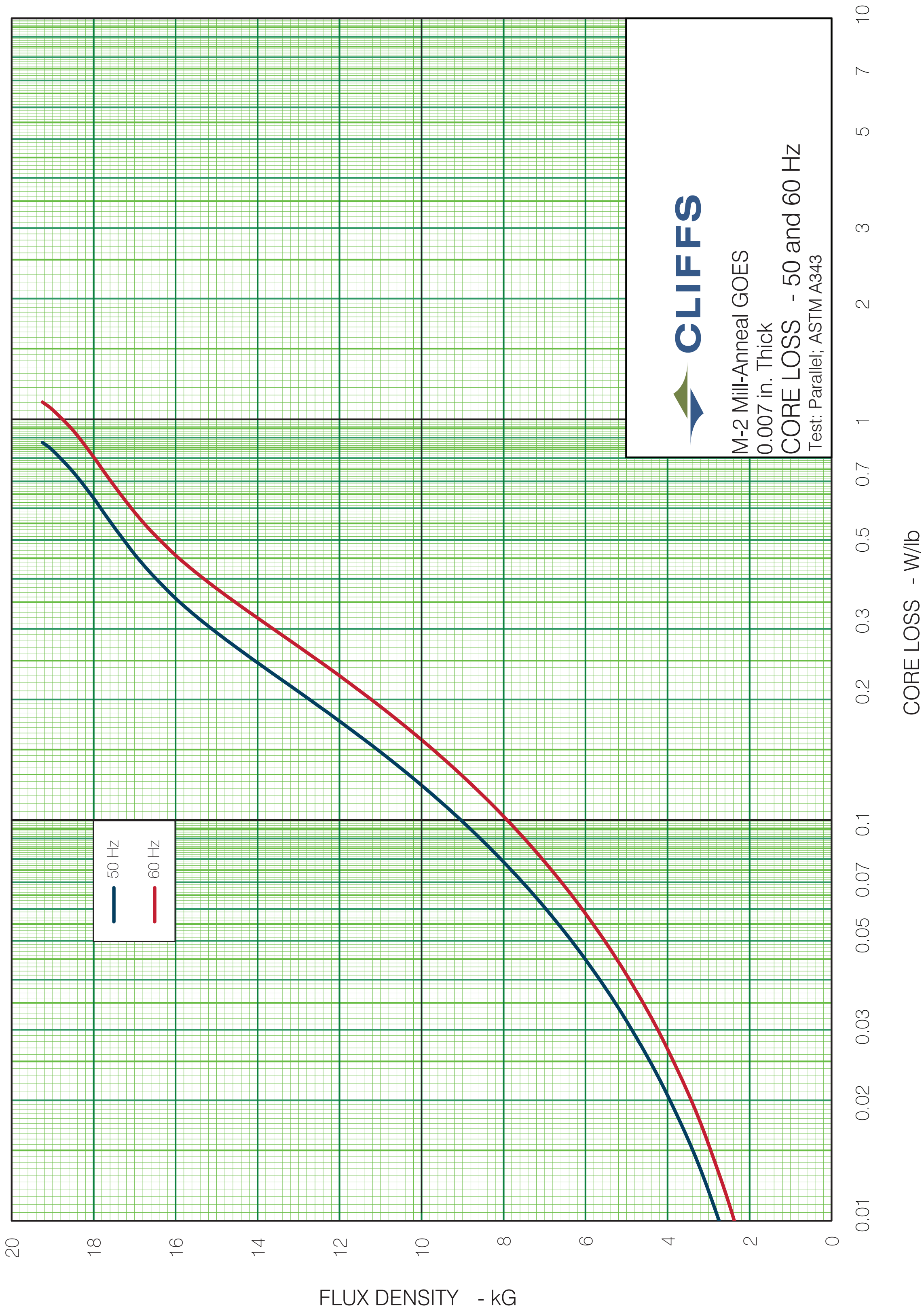
Core Loss Curve – M-3X LITE CARLITE



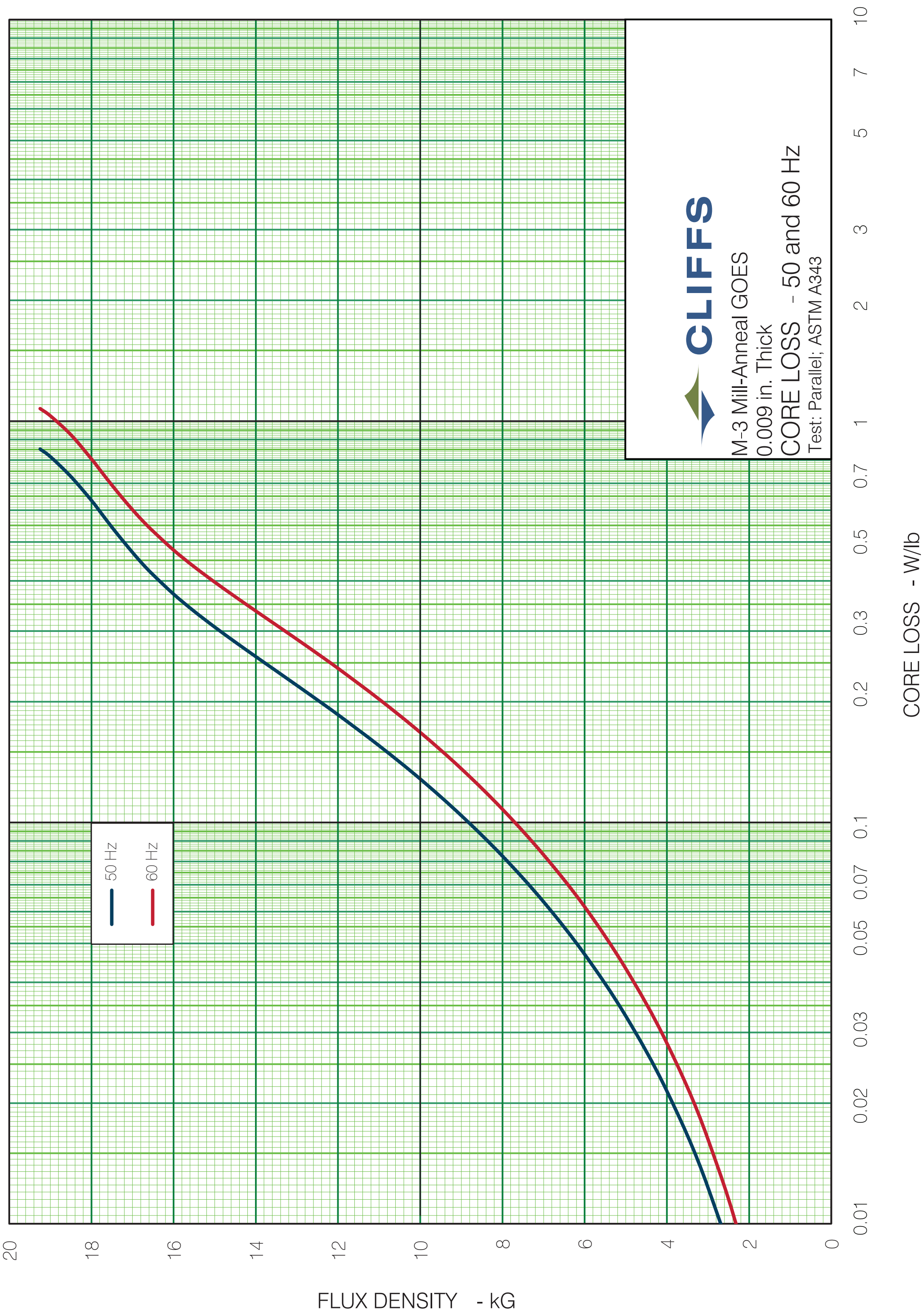
Core Loss Curve – M-3 LITE CARLITE



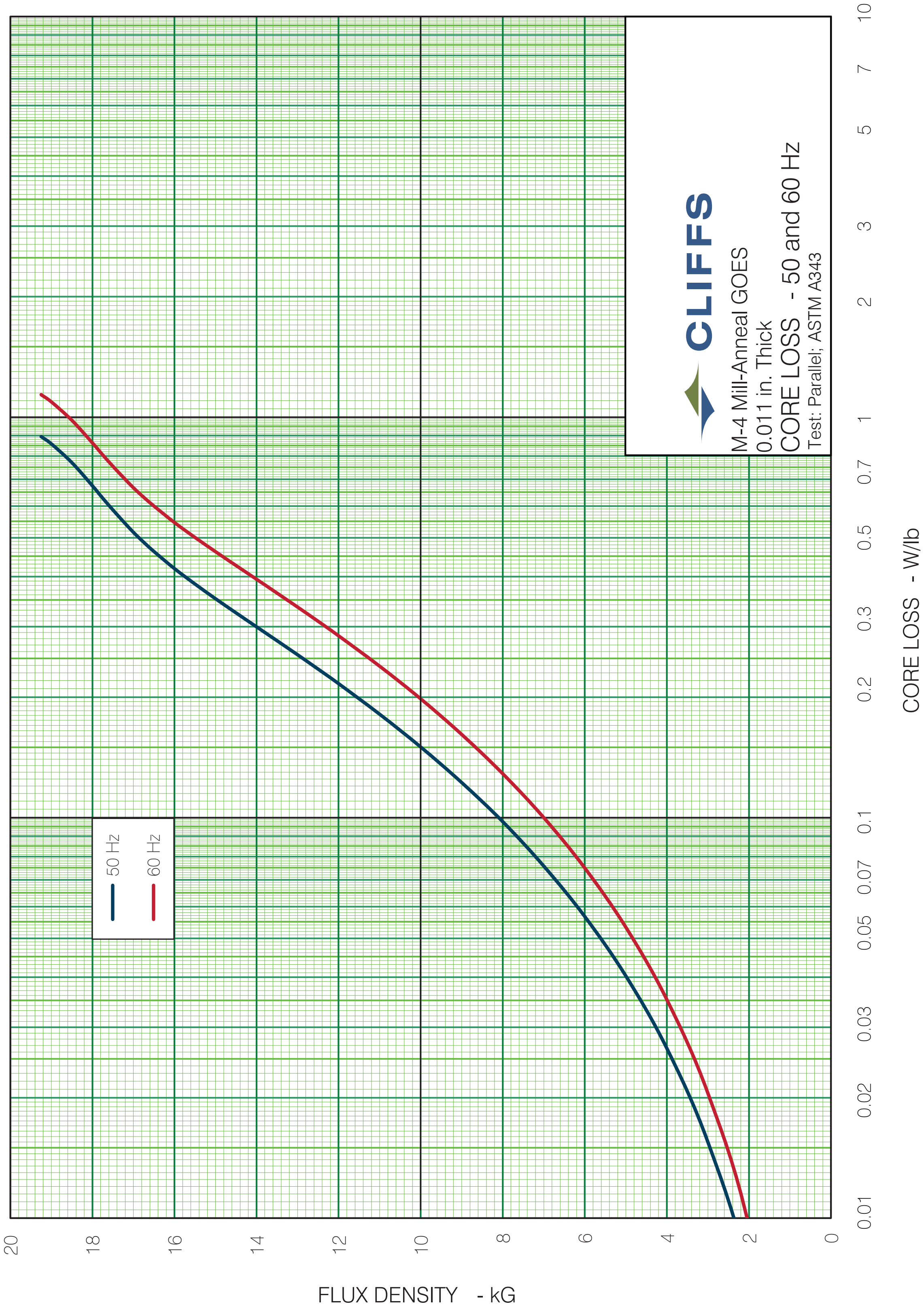
Core Loss Curve – M-2 Mill-Anneal



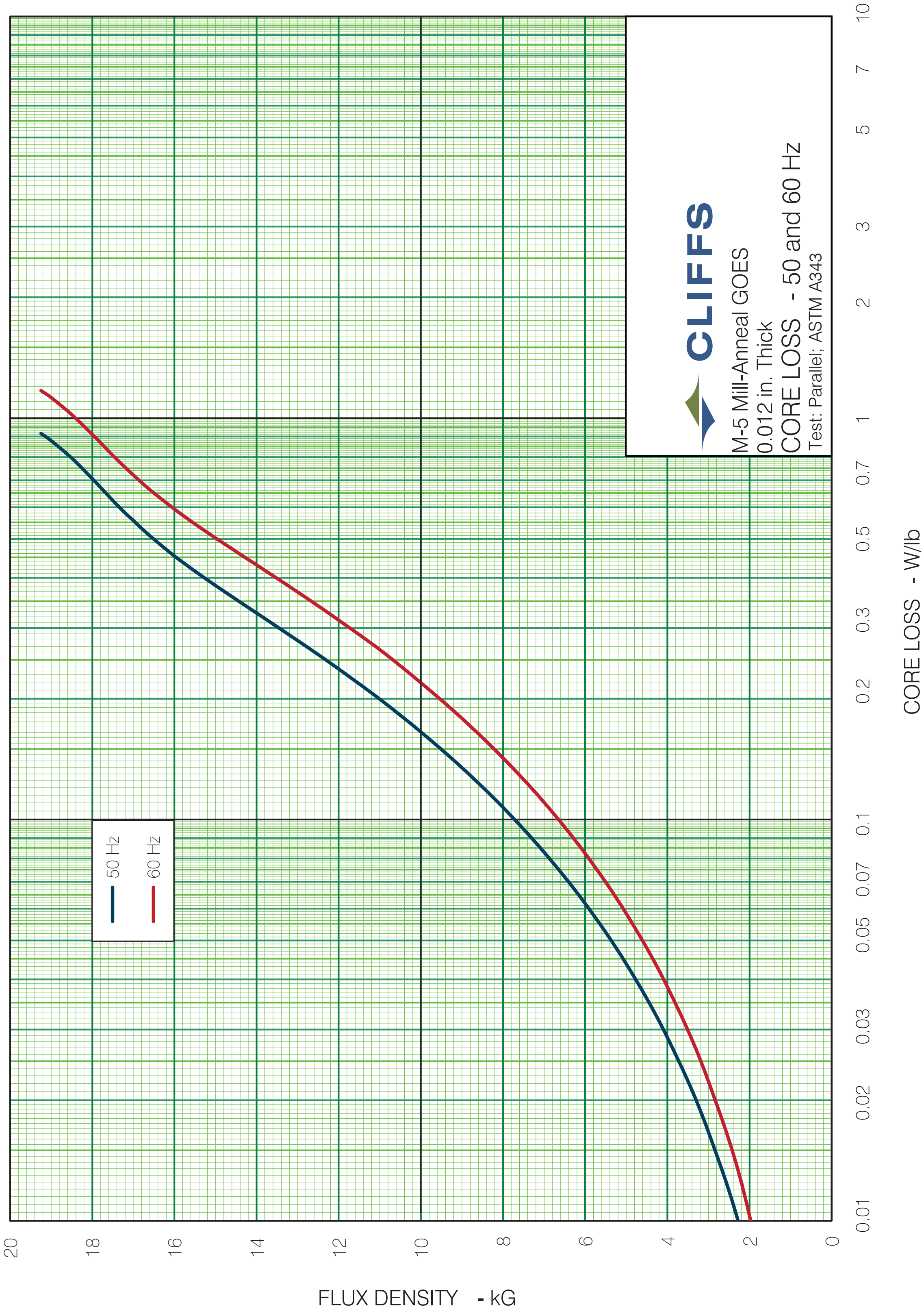
Core Loss Curve – M-3 Mill-Anneal



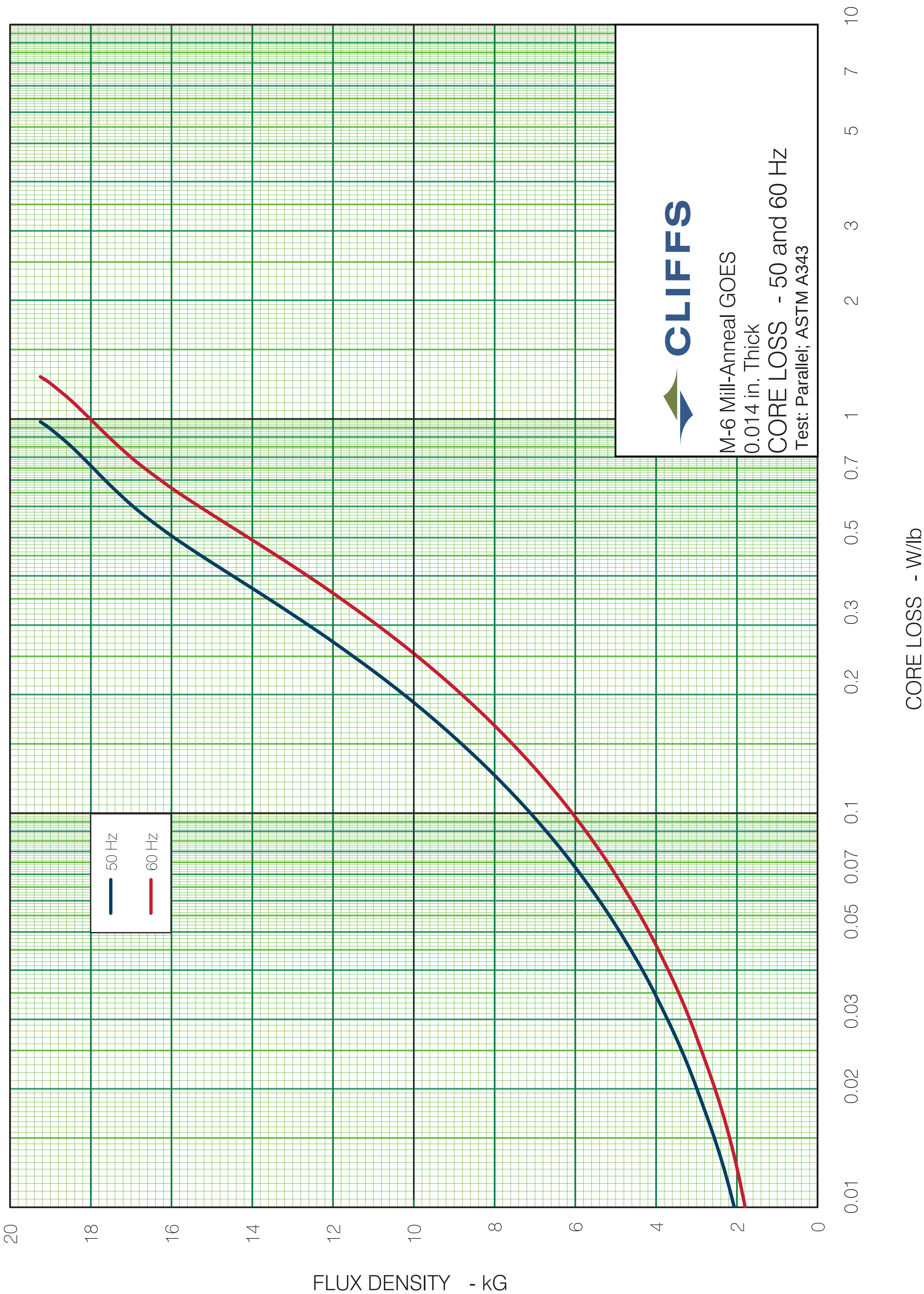
Core Loss Curve – M-4 Mill-Anneal



Core Loss Curve – M-5 Mill-Anneal



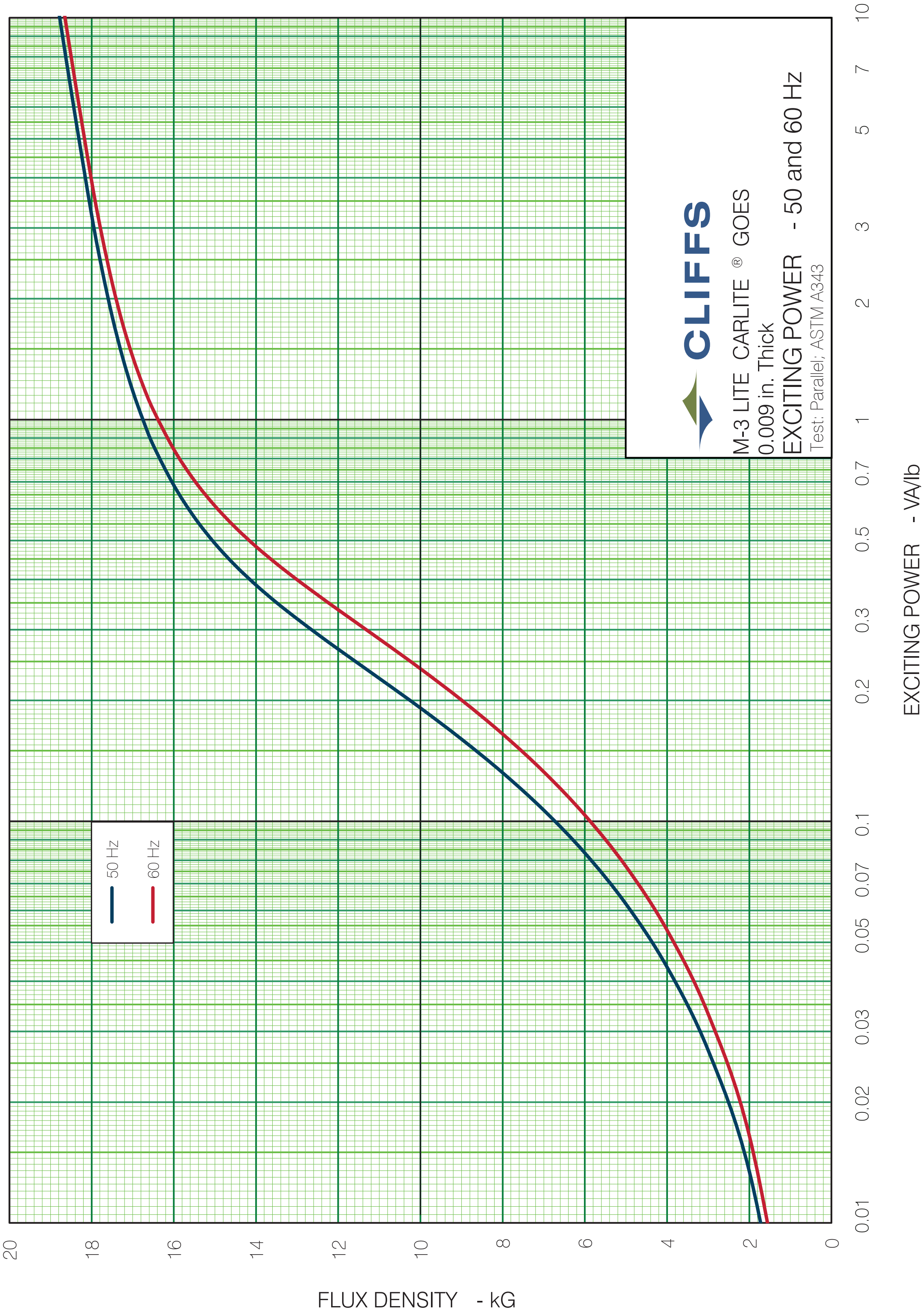
Core Loss Curve – M-6 Mill-Anneal



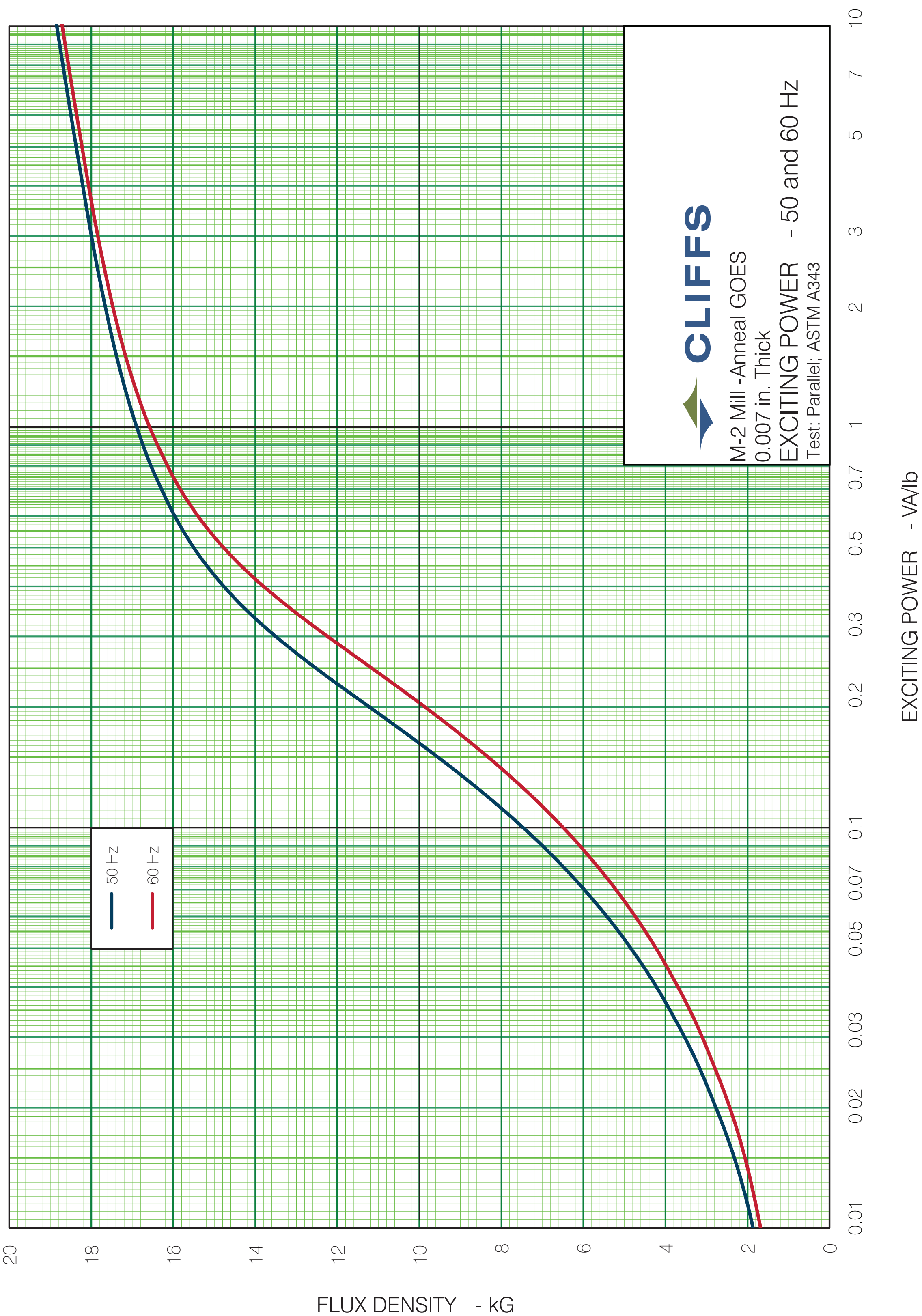
Exciting Power Curve – M-2 LITE CARLITE

Exciting Power Curve – M-3X LITE CARLITE

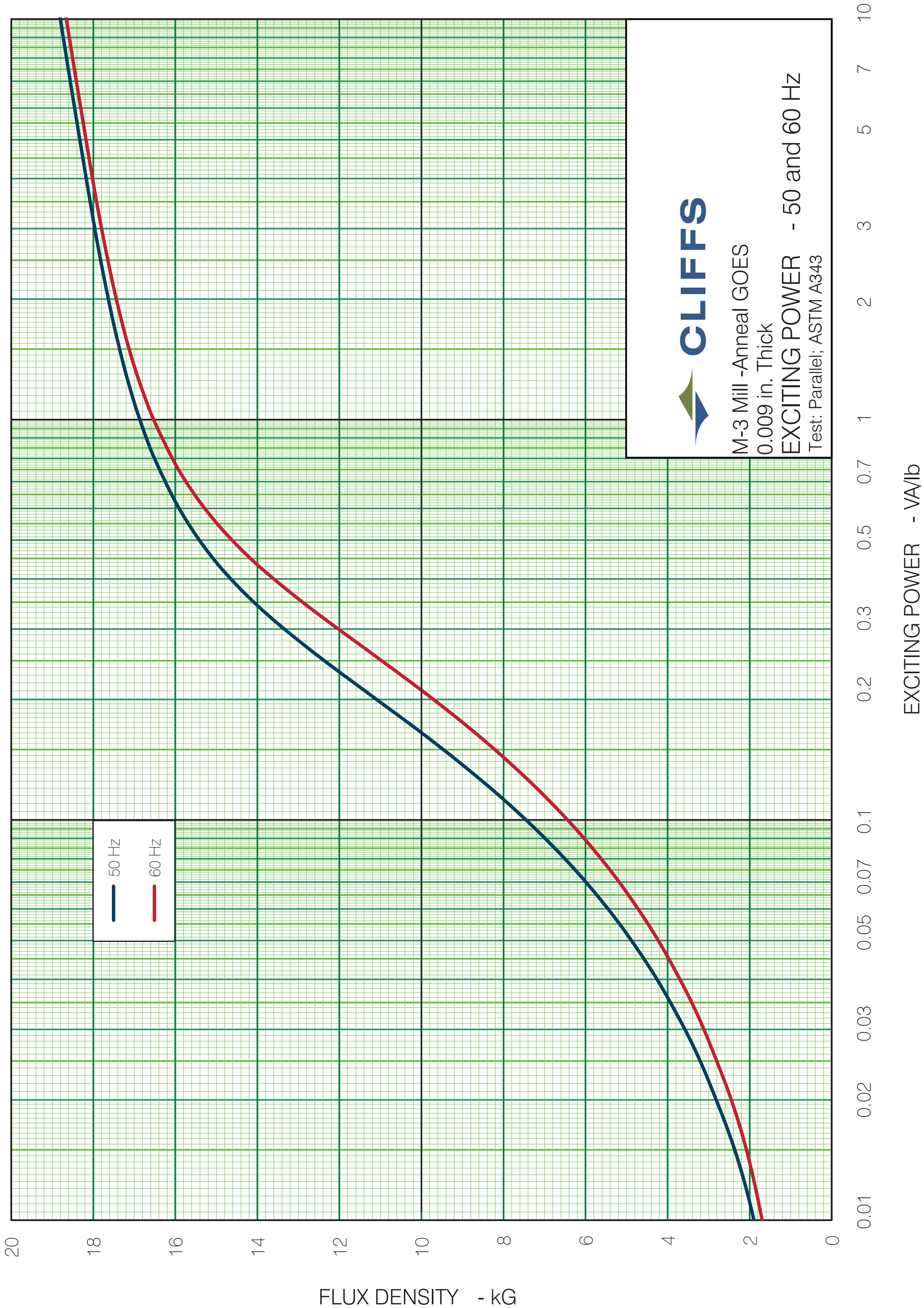
Exciting Power Curve – M-3 LITE CARLITE



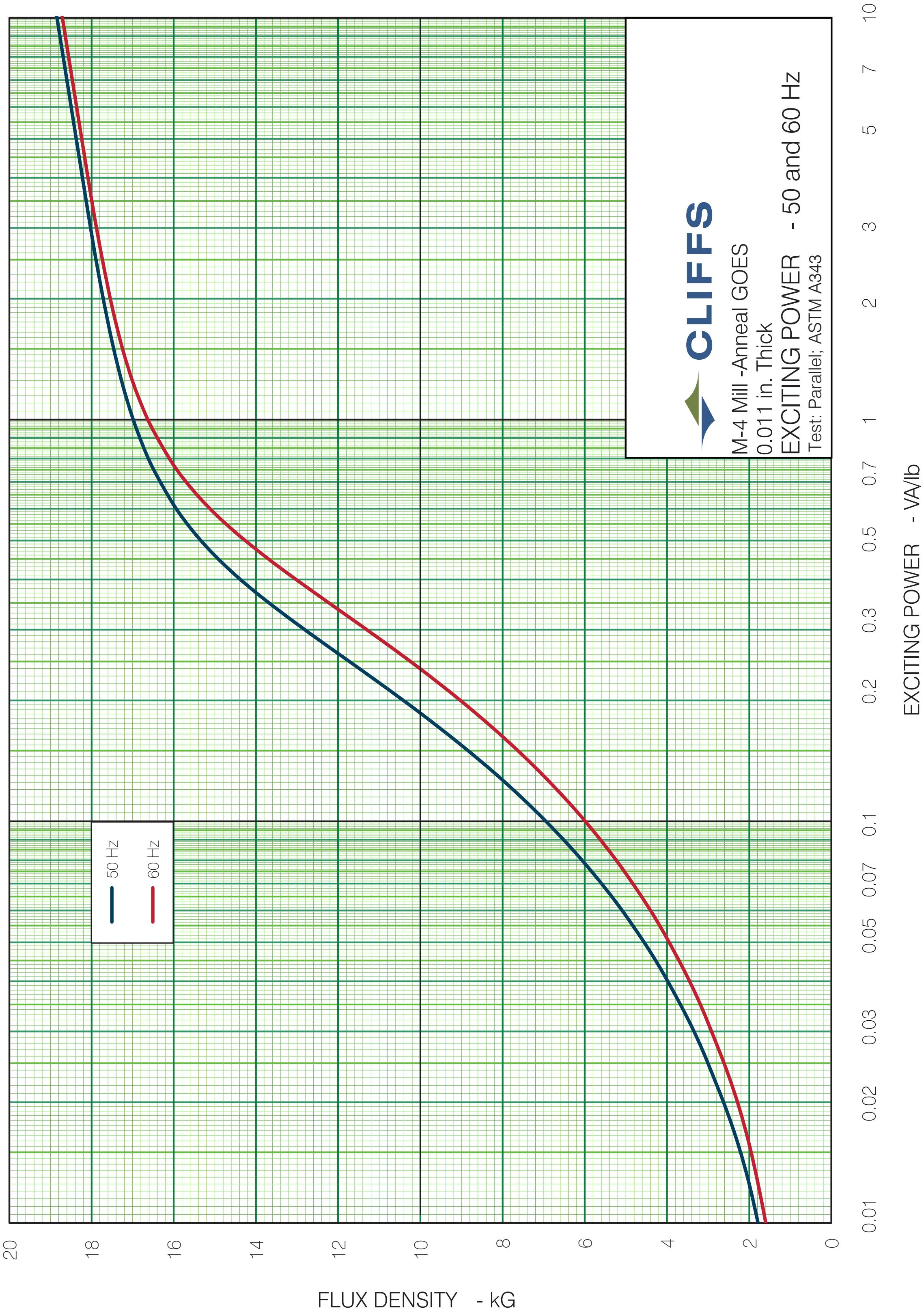
Exciting Power Curve – M-2 Mill-Anneal



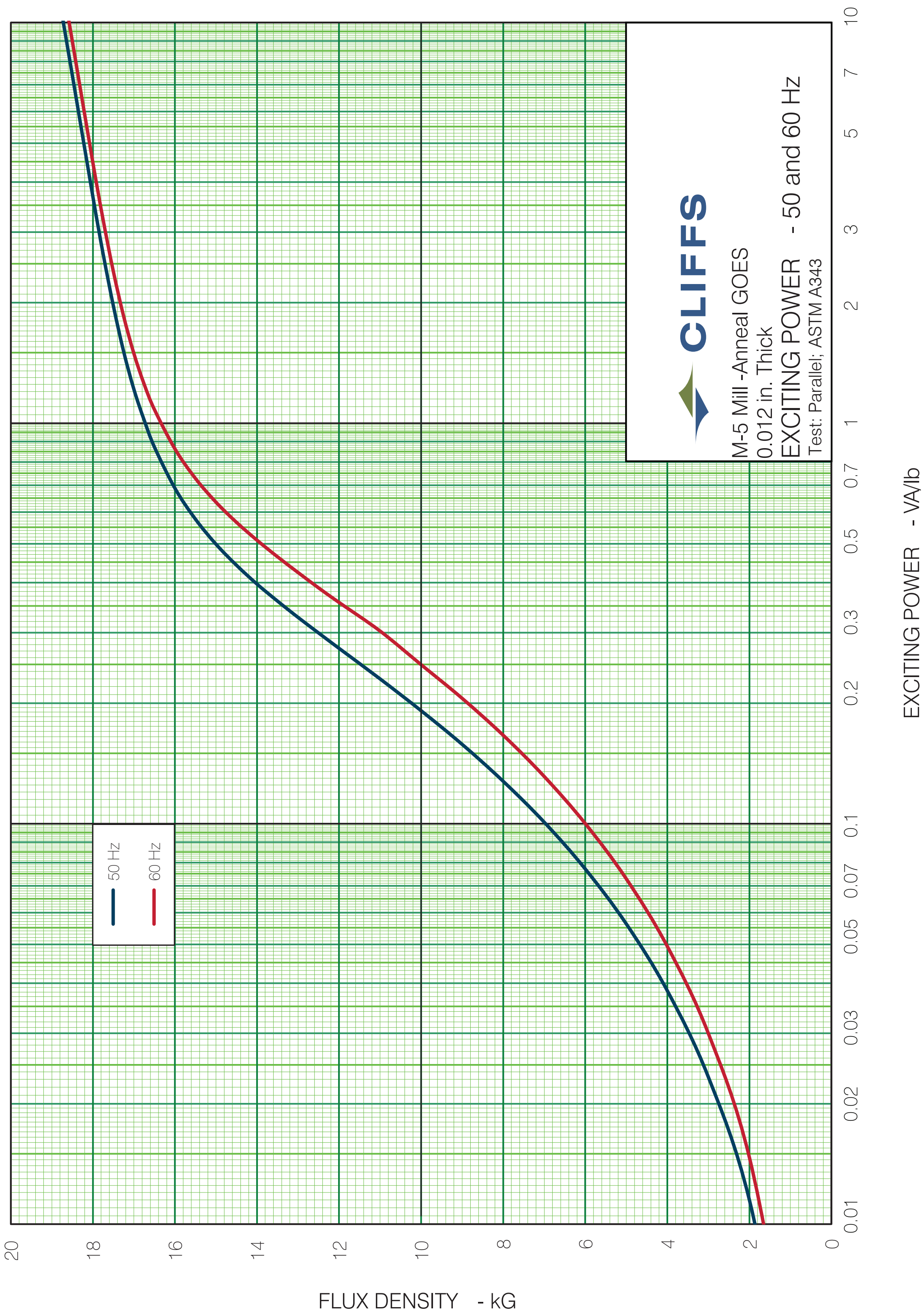
Exciting Power Curve – M-3 Mill-Anneal



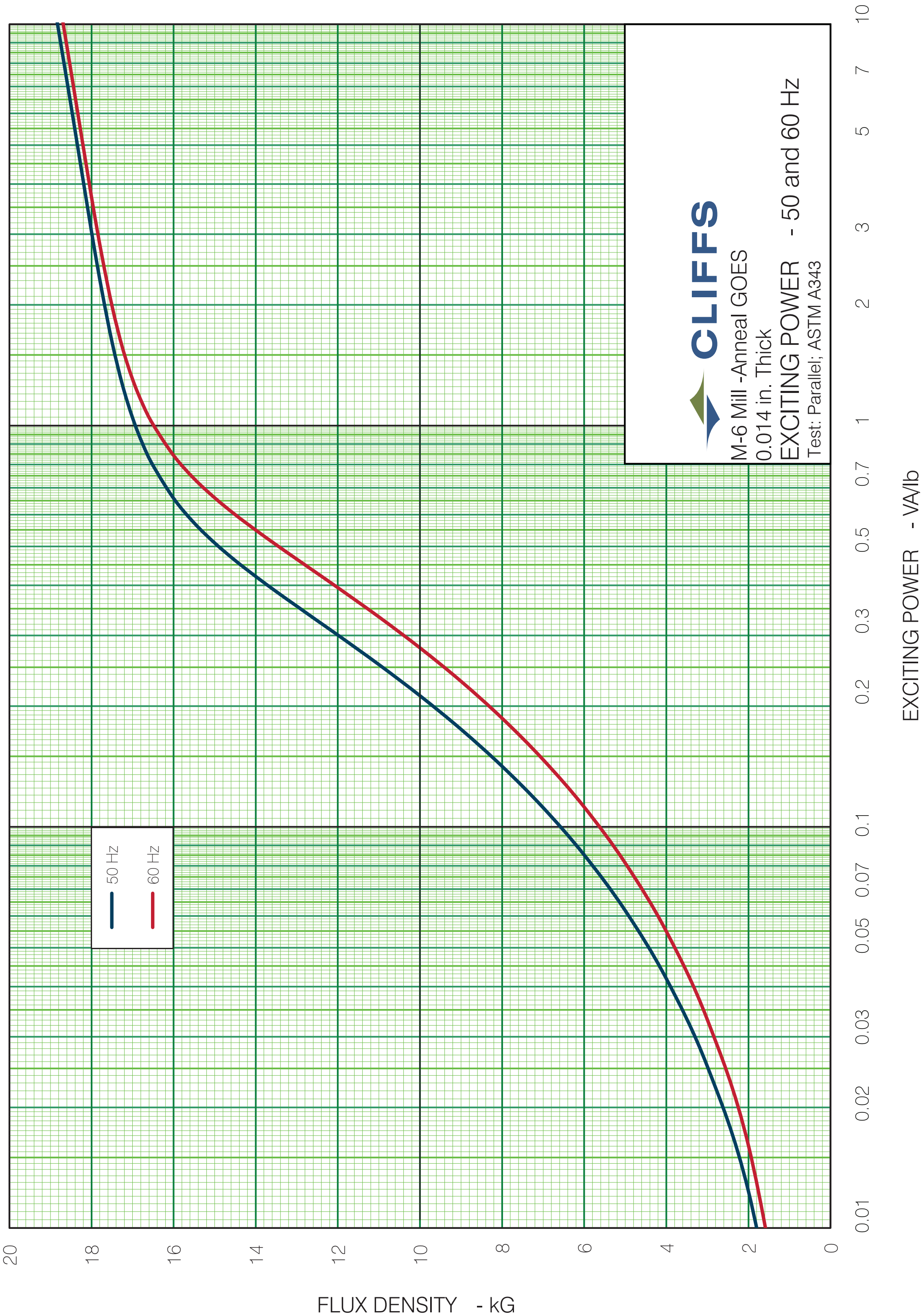
Exciting Power Curve – M-4 Mill-Anneal



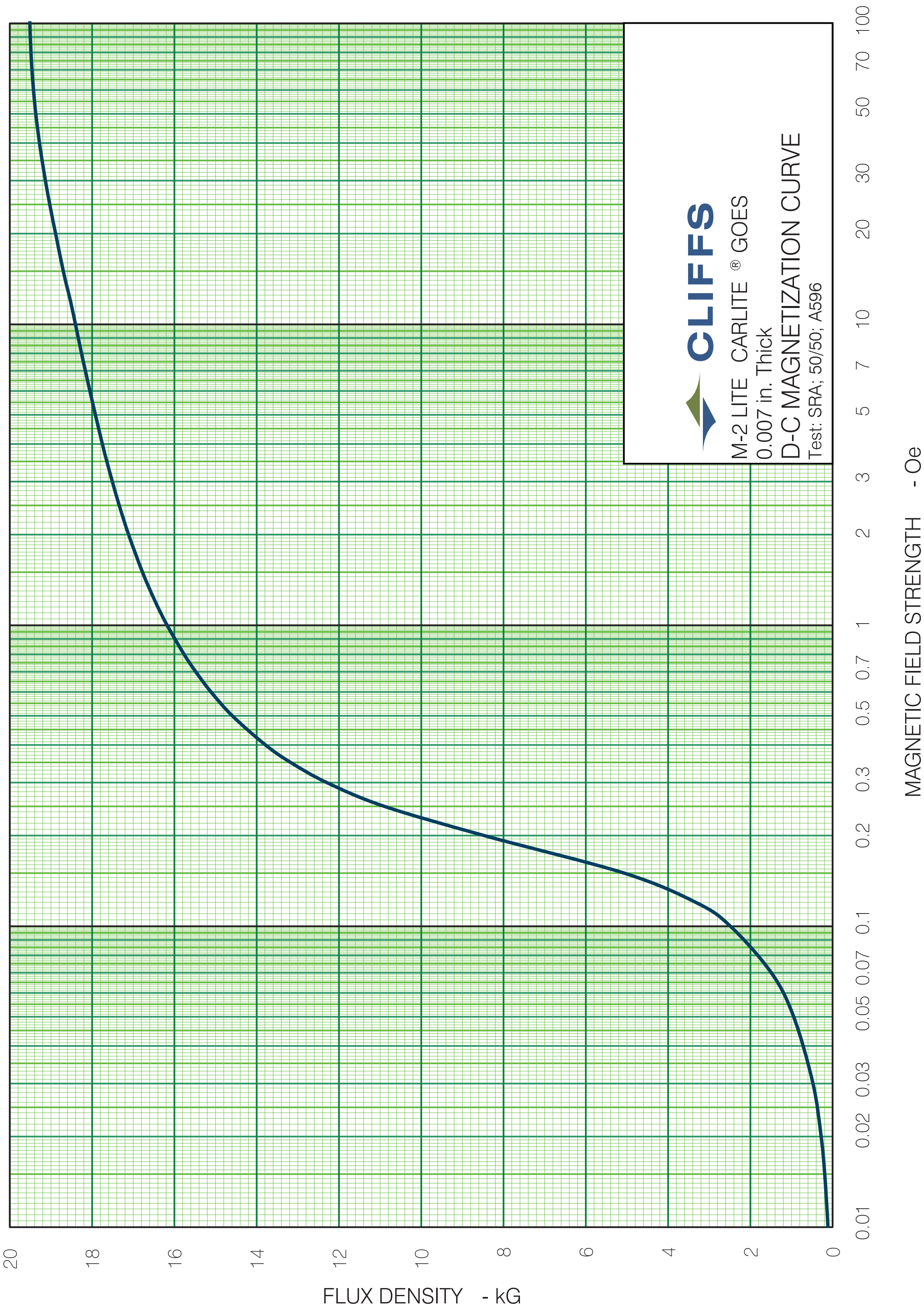
Exciting Power Curve – M-5 Mill-Anneal



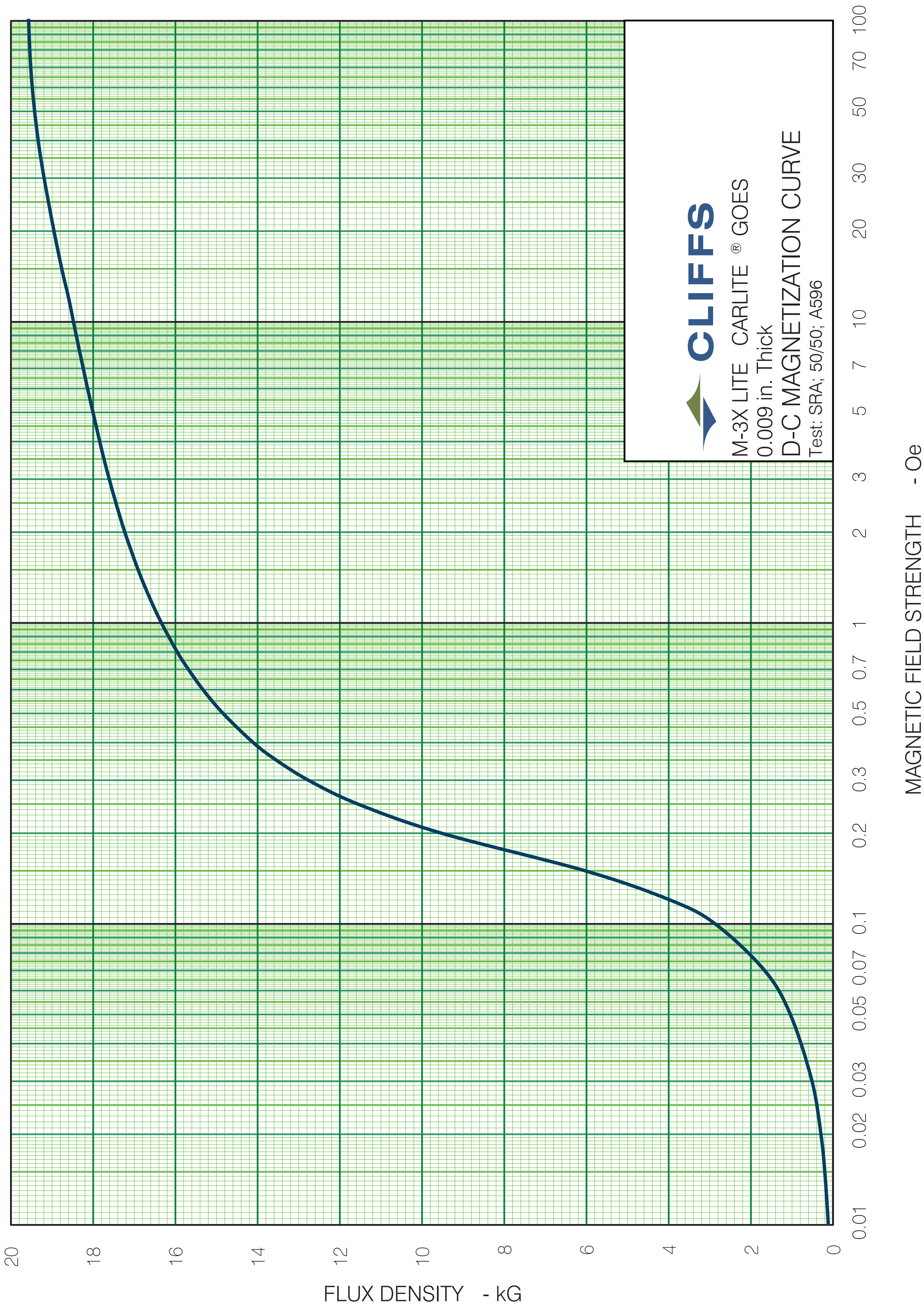
Exciting Power Curve – M-6 Mill-Anneal



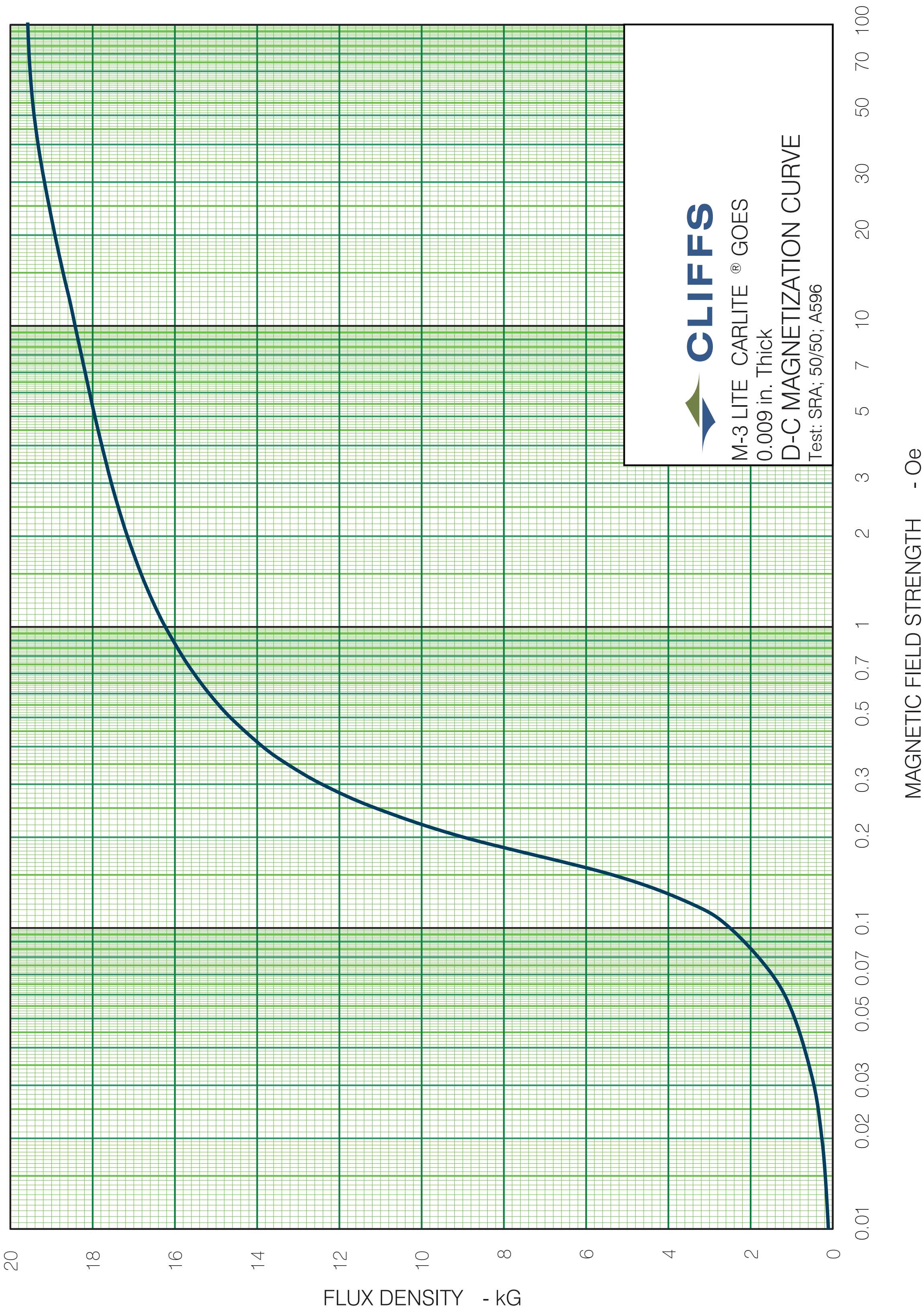
D-C Magnetization Curve – M-2 LITE CARLITE



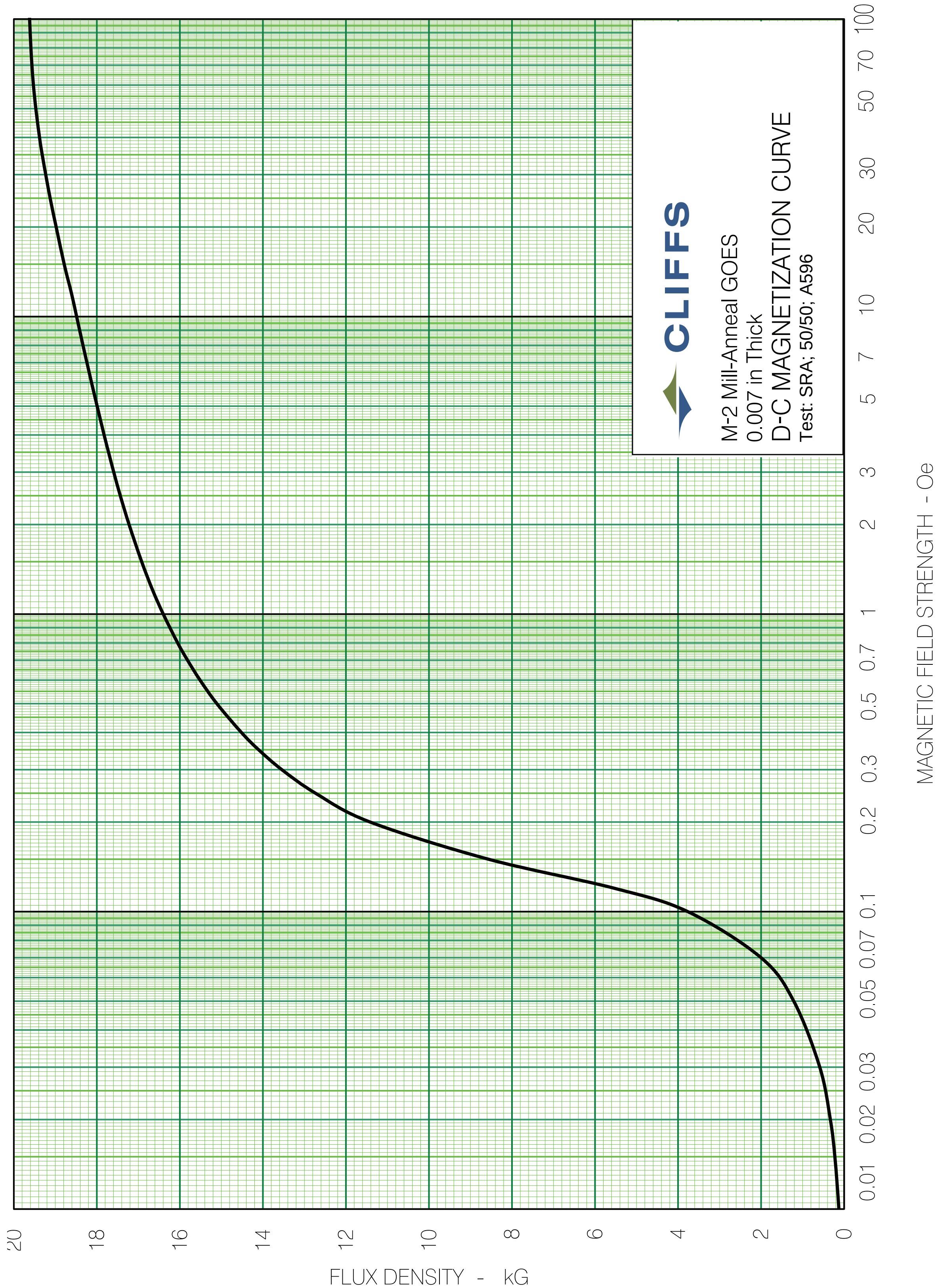
D-C Magnetization Curve – M-3X LITE CARLITE



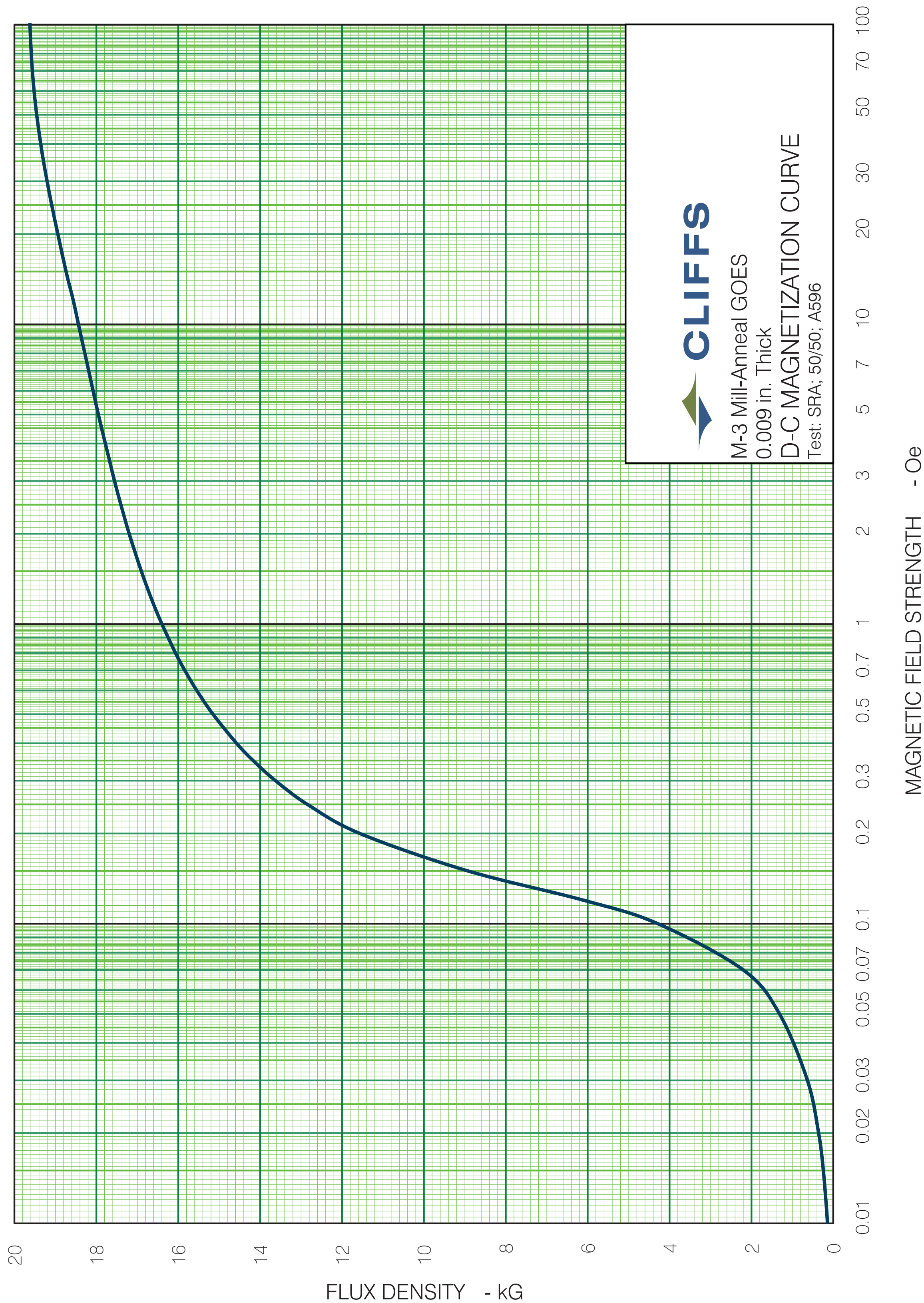
D-C Magnetization Curve – M-3 LITE CARLITE



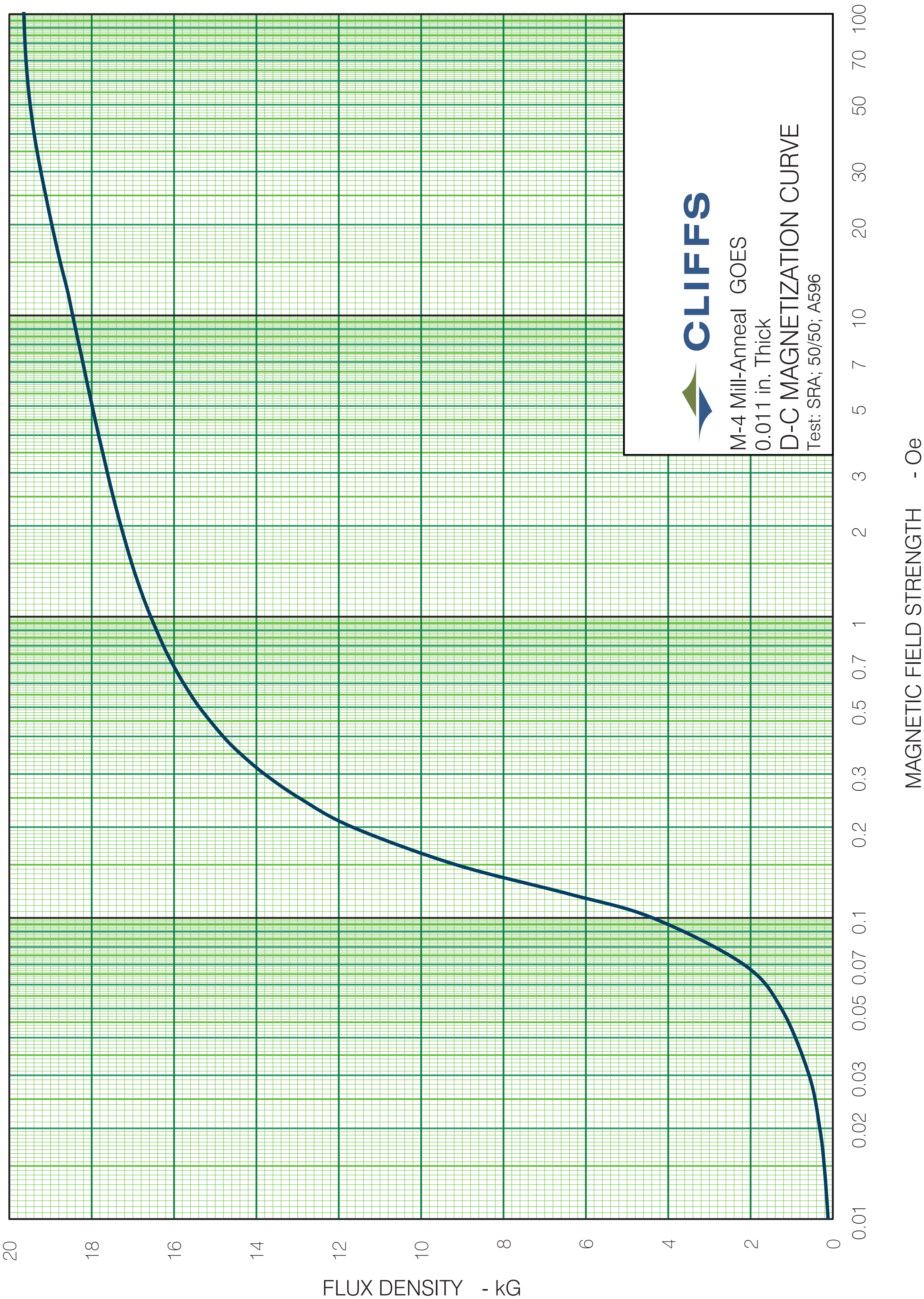
D-C Magnetization Curve – M-2 Mill-Anneal



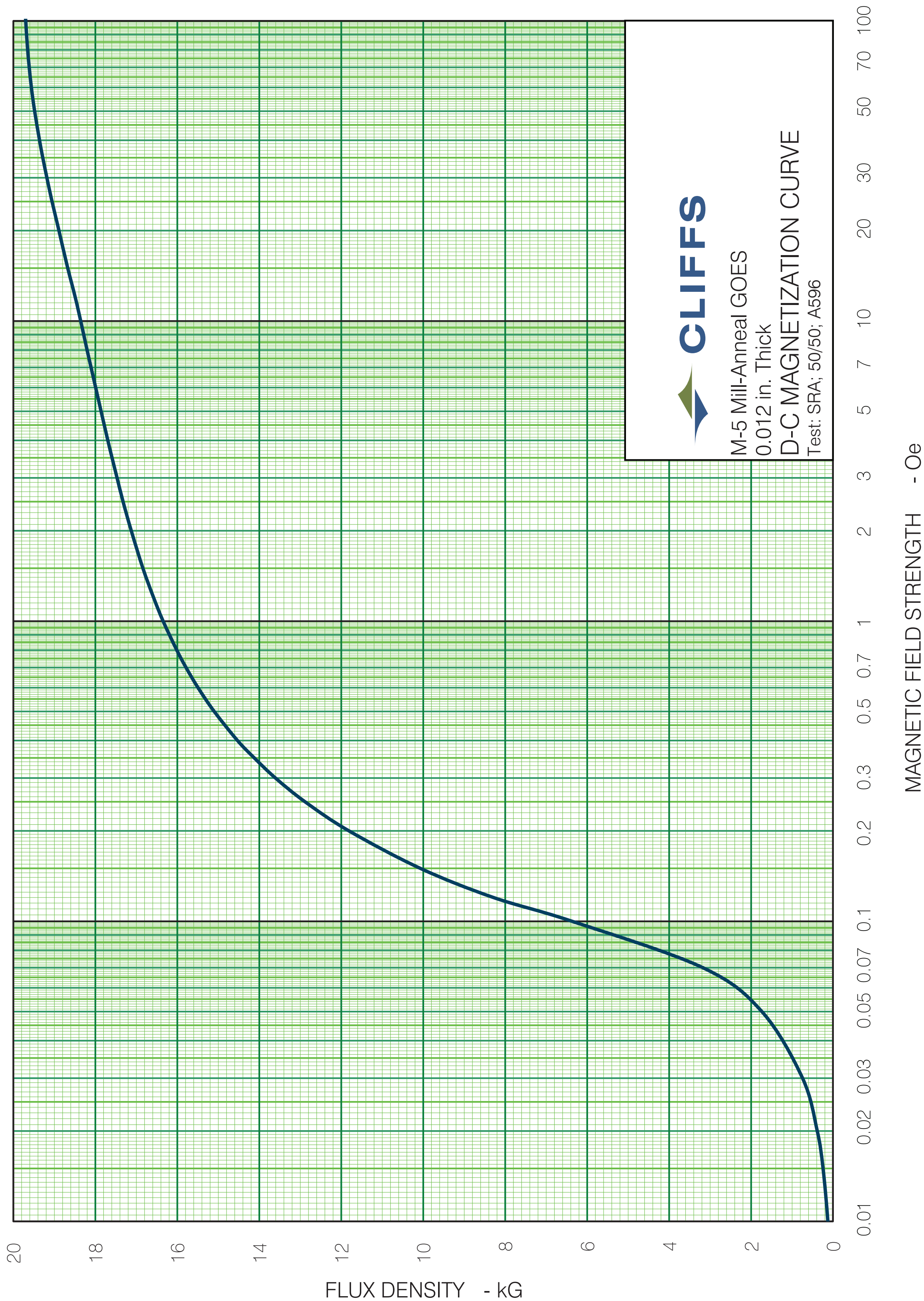
D-C Magnetization Curve – M-3 Mill-Anneal



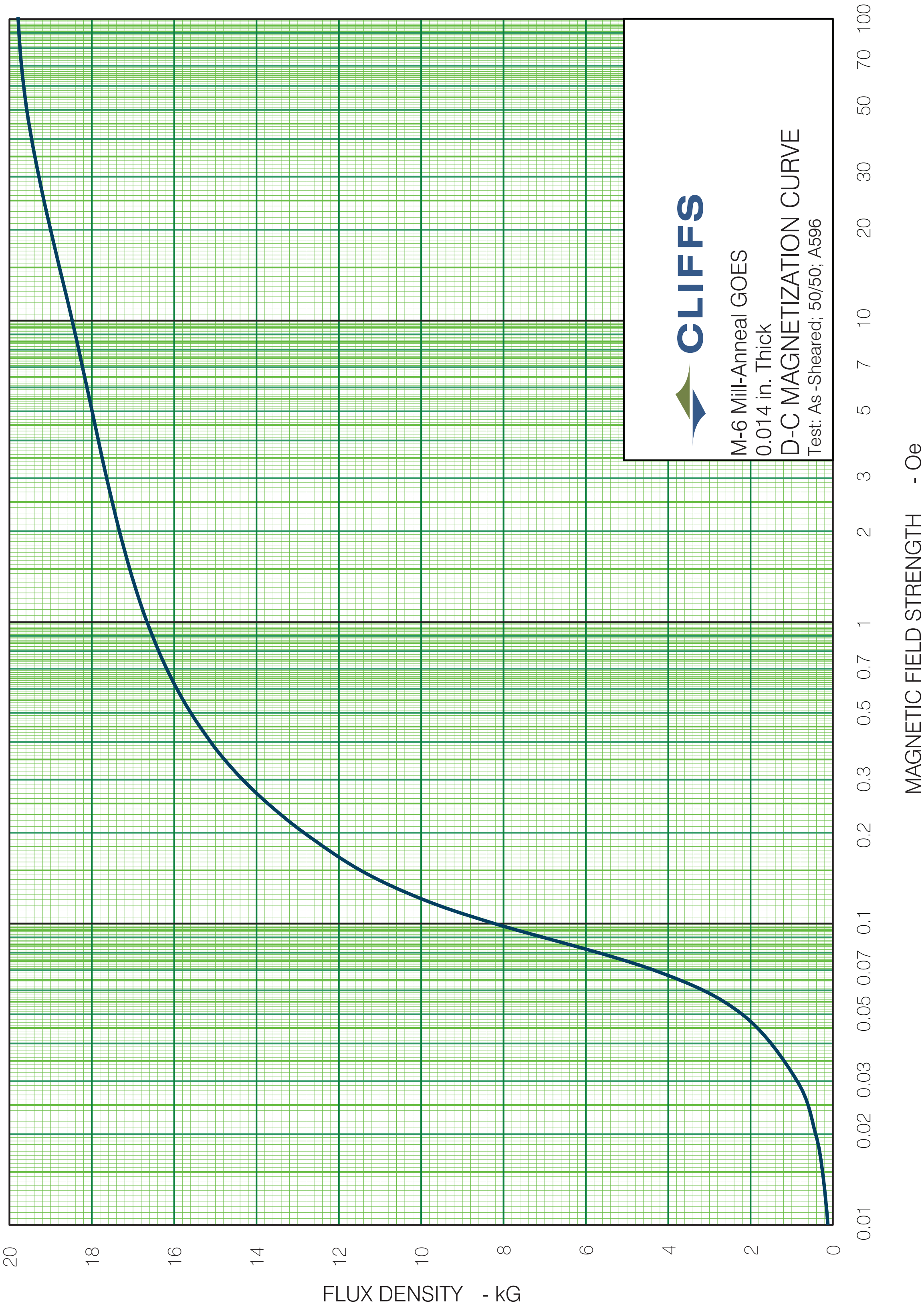
D-C Magnetization Curve – M-4 Mill-Anneal



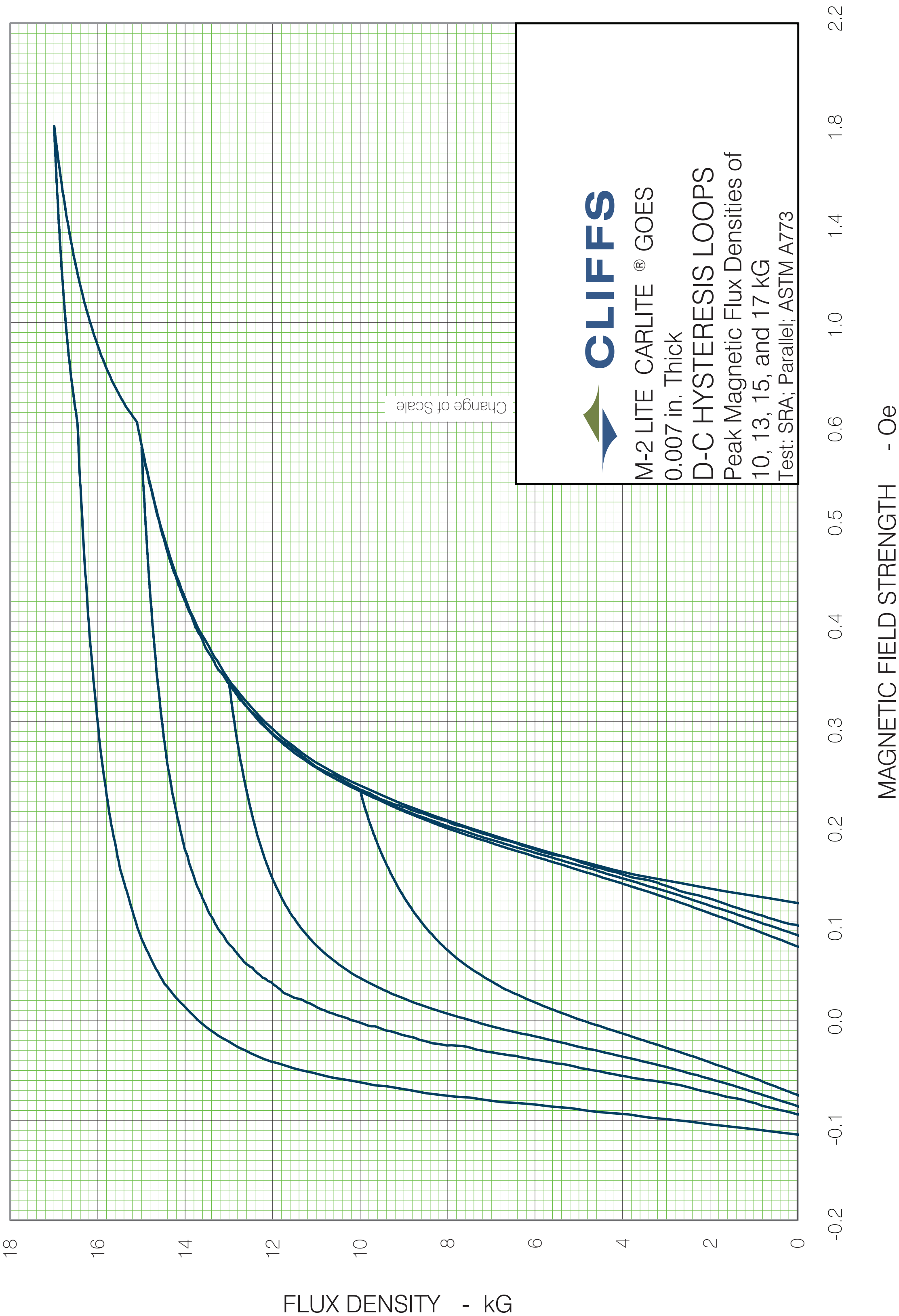
D-C Magnetization Curve – M-5 Mill-Anneal



D-C Magnetization Curve – M-6 Mill-Anneal



D-C Hysteresis Loops – M-2 LITE CARLITE



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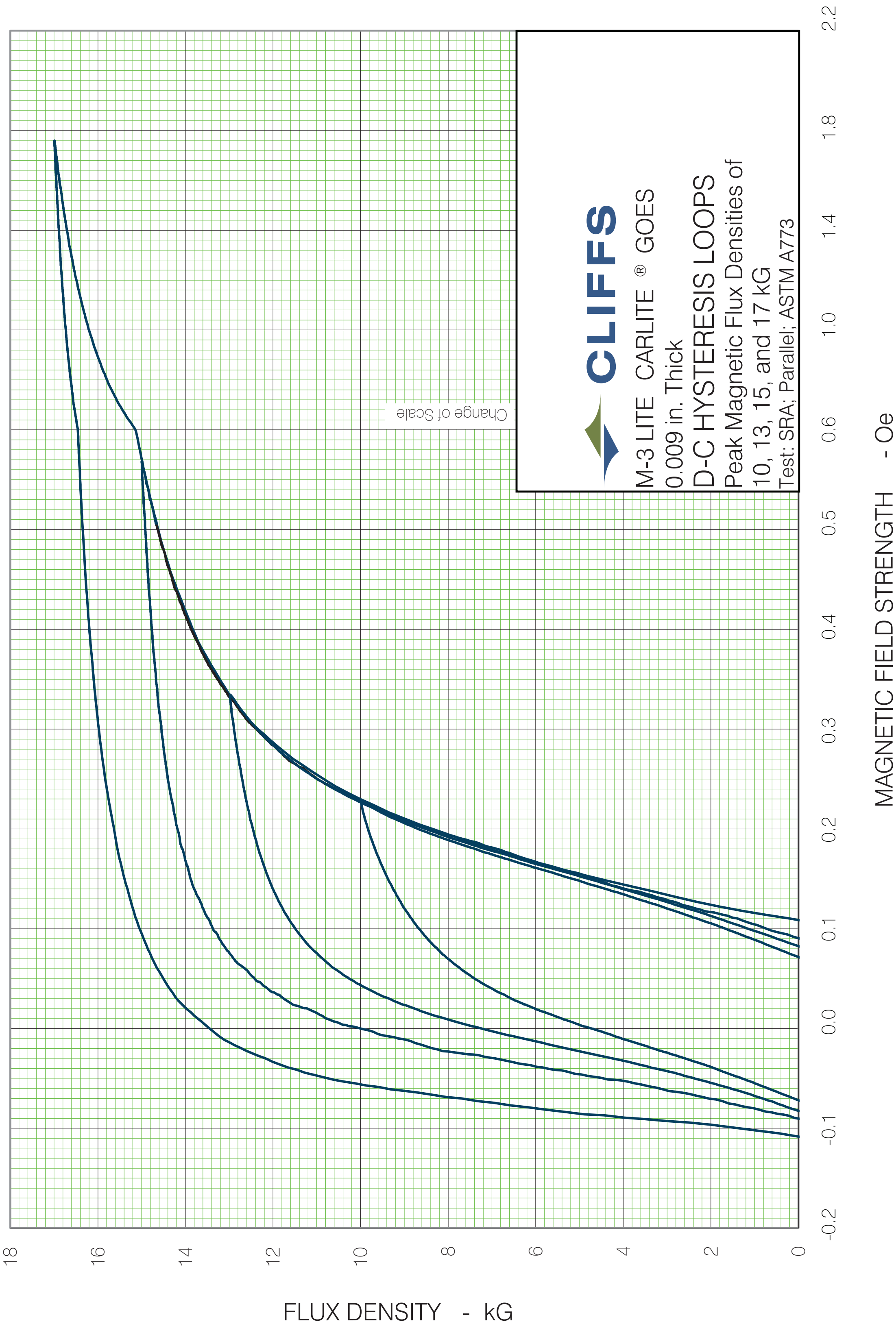
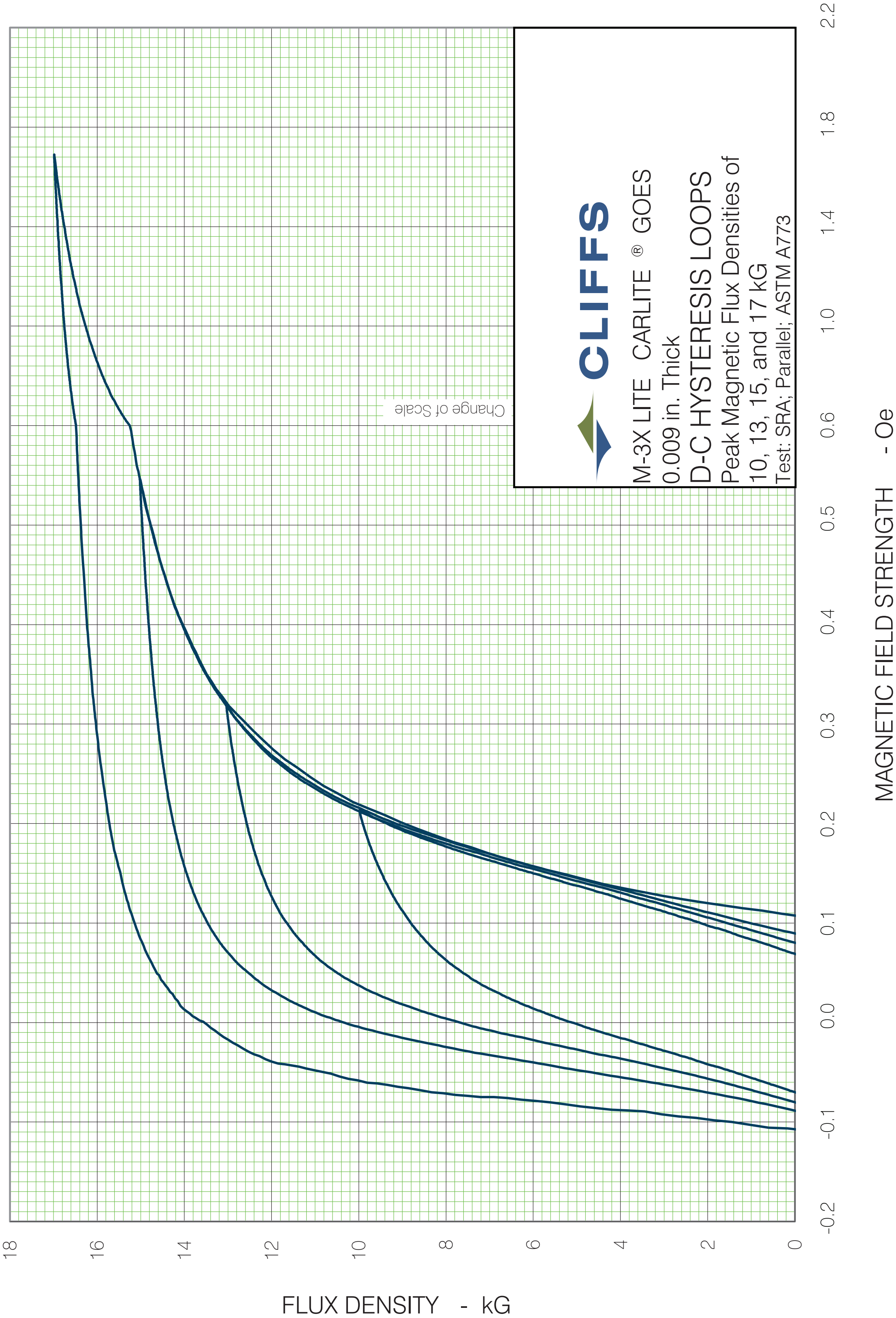
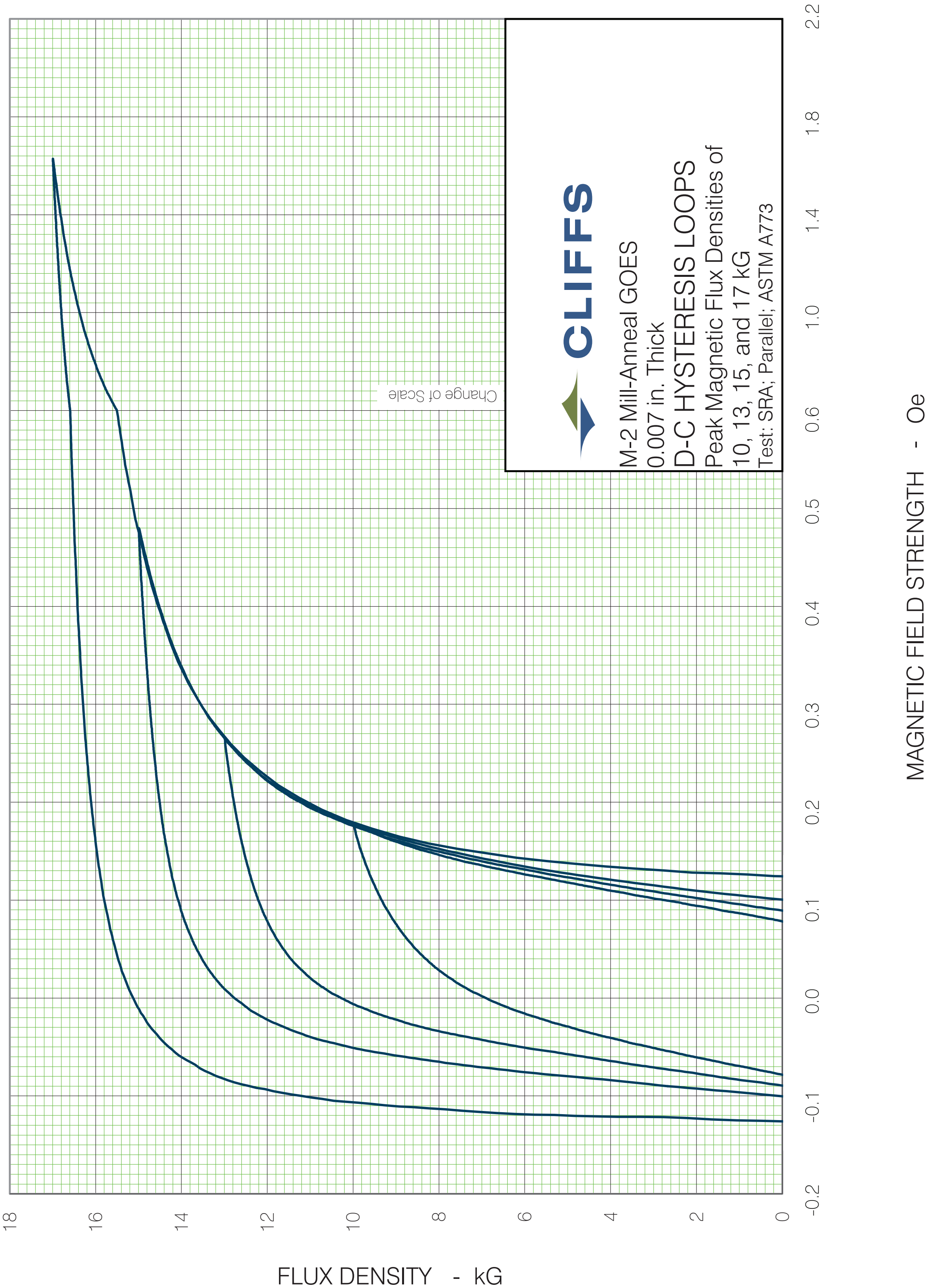


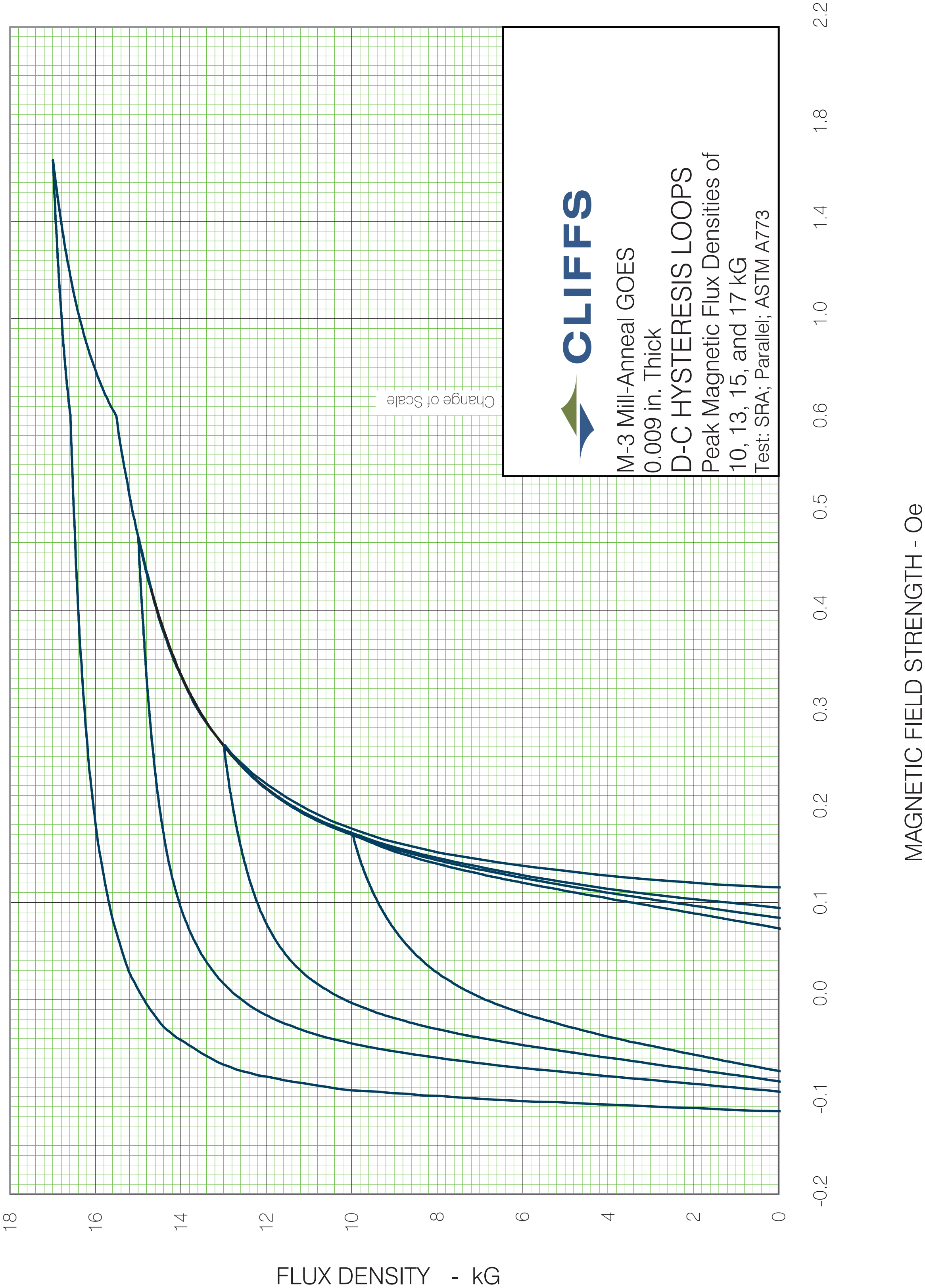
D-C Hysteresis Loops – M-3X LITE CARLITE



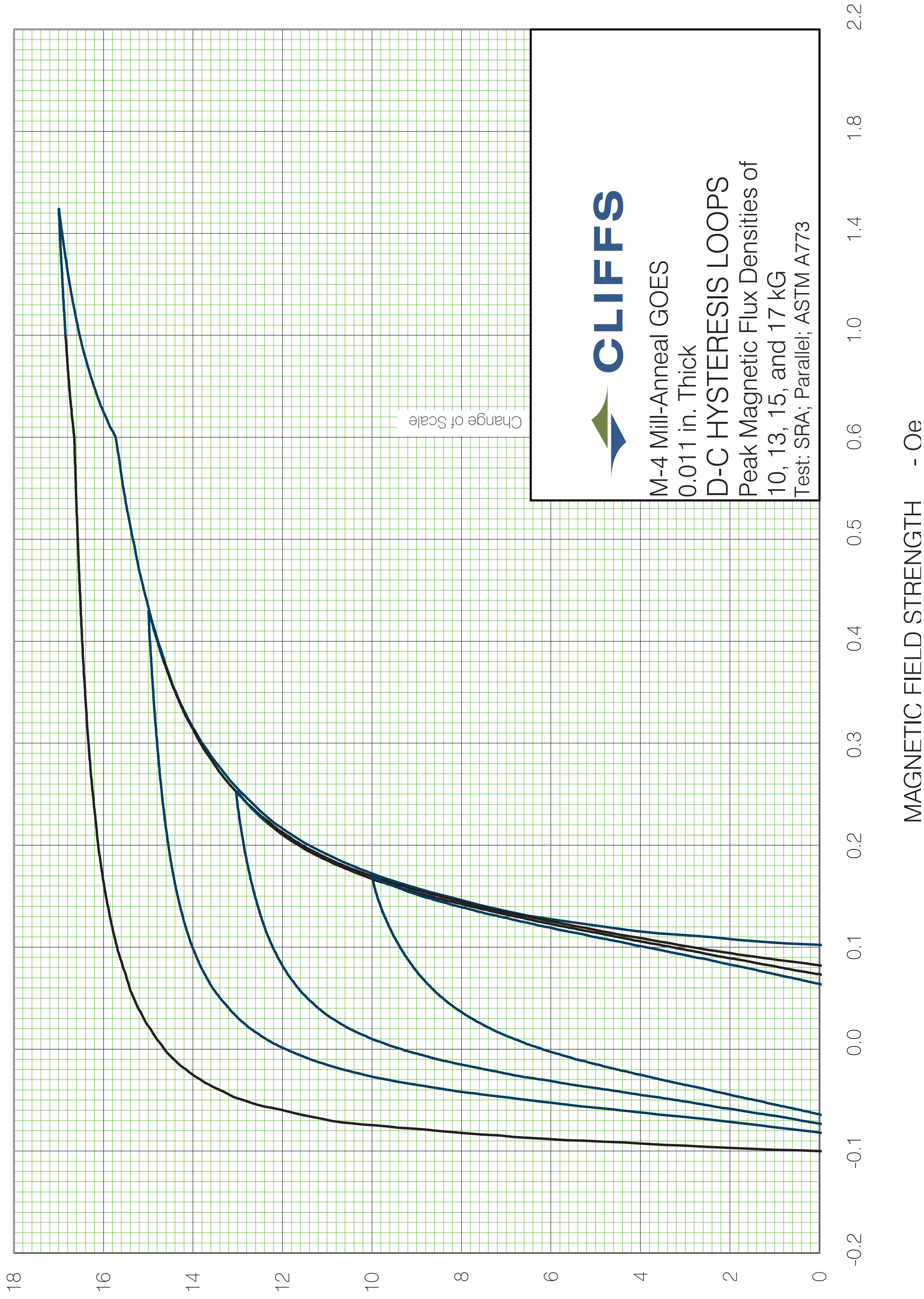
D-C Hysteresis Loops – M-2 Mill-Anneal



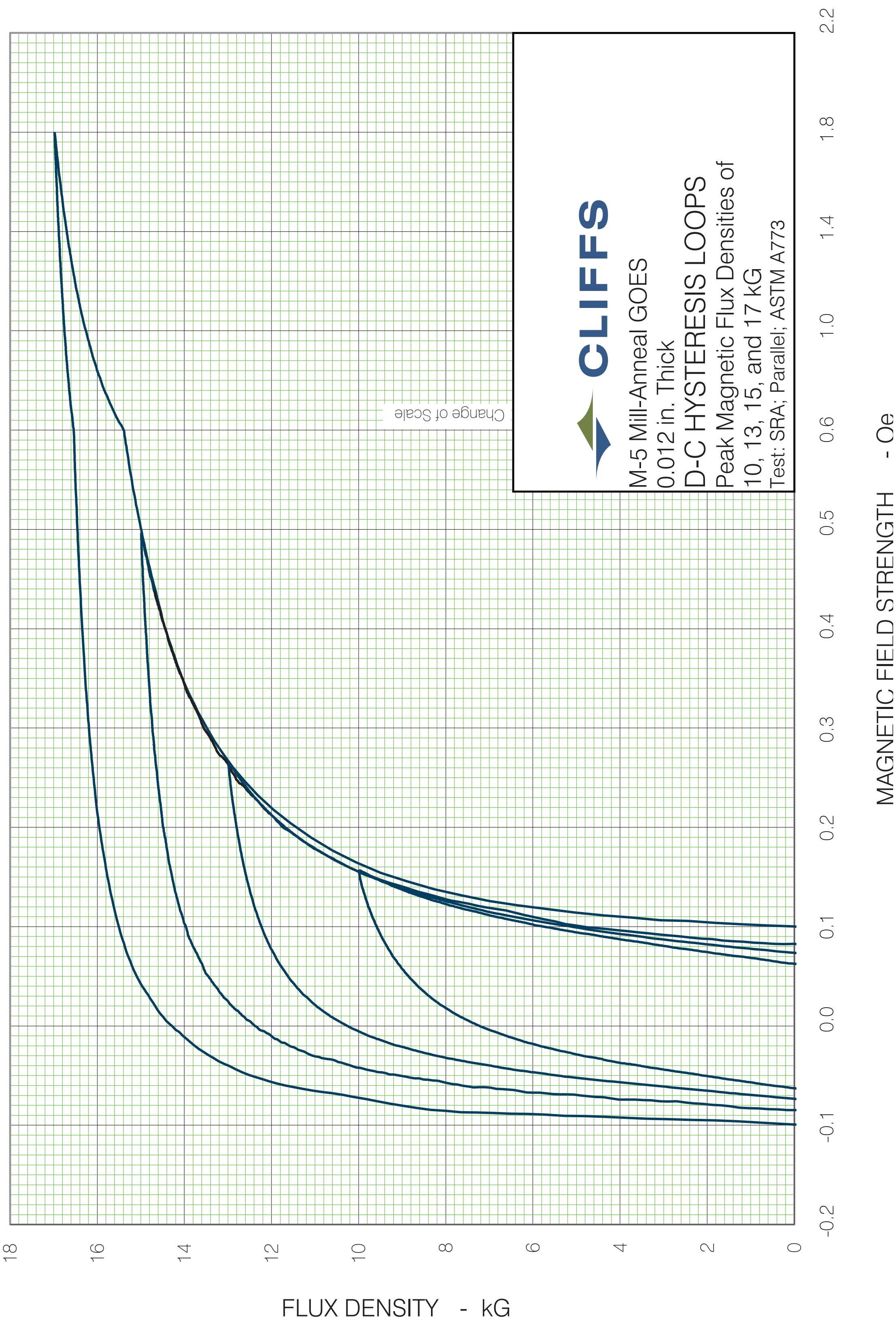
D-C Hysteresis Loops – M-3 Mill-Anneal



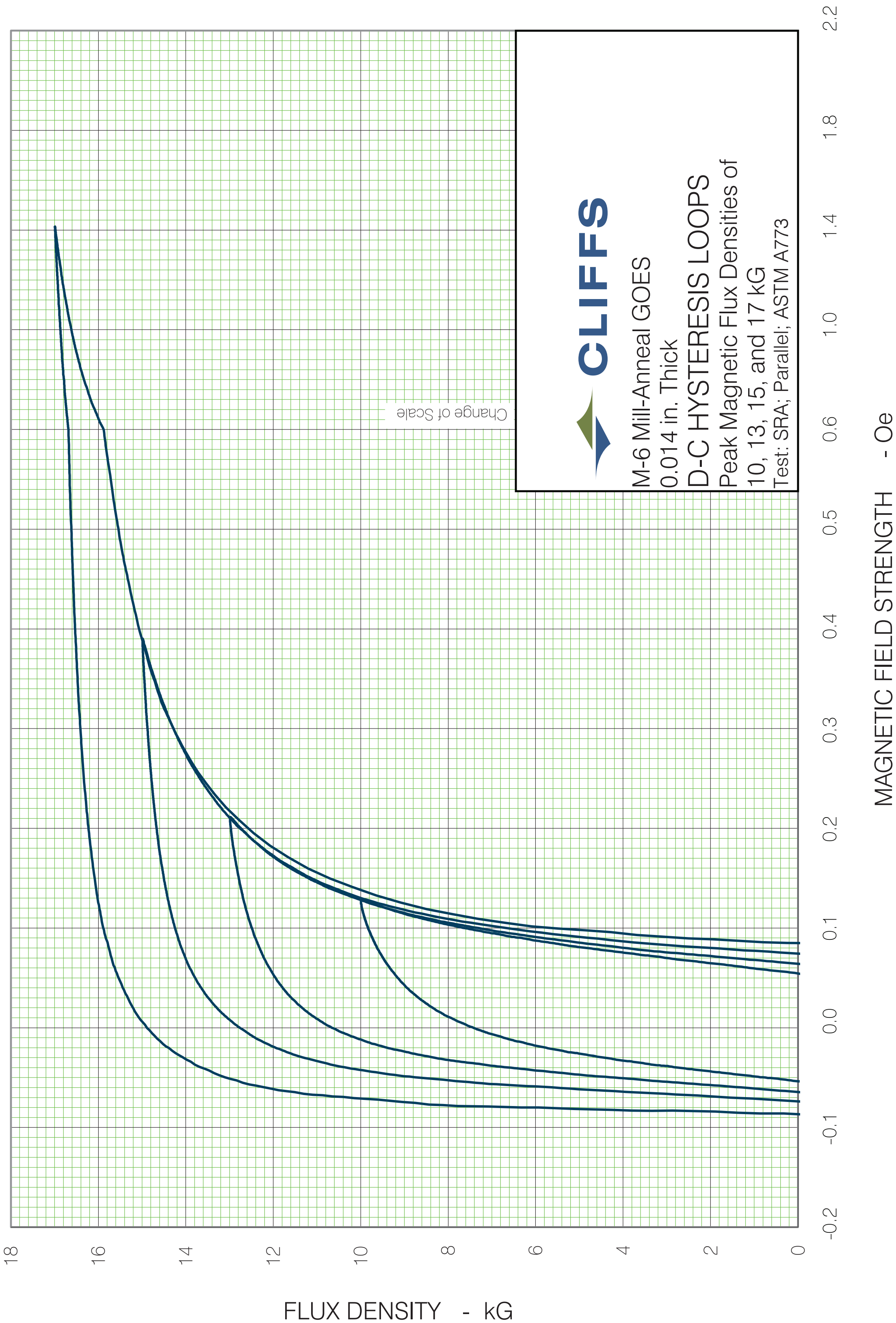
D-C Hysteresis Loops – M-4 Mill-Anneal



D-C Hysteresis Loops – M-5 Mill-Anneal



D-C Hysteresis Loops – M-6 Mill-Anneal



LITE CARLITE® AND MILL-ANNEAL

About Cleveland-Cliffs Inc.

Cleveland-Cliffs is the largest flat-rolled steel producer in North America. Founded in 1847 as a mine operator, Cliffs also is the largest manufacturer of iron ore pellets in North America. The Company is vertically integrated from mined raw materials, direct reduced iron, and ferrous scrap to primary steelmaking and downstream finishing, stamping, tooling, and tubing. The Company serves a diverse range of markets due to its comprehensive offering of flat-rolled steel products and is the largest supplier of steel to the automotive industry in North America. The Company is headquartered in Cleveland, Ohio with mining, steel and downstream manufacturing operations located across the United States and in Canada. For more information, visit www.clevelandcliffs.com.

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