

# The Effect of Repair/ Rewinding on

## Premium Efficiency/IE3 Motors

### Executive Summary



# The Effect of Repair/ Rewinding on Premium Efficiency/IE3 Motors

## Executive Summary



EASA, Inc.  
1331 Baur Blvd. • St. Louis, MO 63132 USA  
+1 314 993 2220 • Fax: +1 314 993 1269  
[www.easa.com](http://www.easa.com)

Association of Electrical and Mechanical Trades (AEMT Ltd)  
Co. Reg. No. 00397289 (England and Wales)  
St. Saviours House • St. Saviours Place  
York, YO1 7PJ • North Yorkshire • England, UK  
+44 (0) 1904 674899 • Fax: +44 (0) 1904 674896  
[www.aemt.co.uk](http://www.aemt.co.uk)

### **Disclaimer**

The information in this Executive Summary was carefully prepared and is believed to be correct, but neither EASA nor AEMT make any warranties respecting it and disclaim any responsibility or liability of any kind for any loss or damage as a consequence of anyone's use of or reliance upon such information.

### Historical Overview of Evolving Efficiency Levels

#### United States

A governmental study by A.D. Little in 1976 found that applications using electric motors represented more than 2/3 of all generated electrical power consumed in industrial nations. That, coupled with increasing demands on “electrical grids” worldwide, made clear the growing need for energy conservation, with electric motors a key focus of this effort.

In 1977 the National Electrical Manufacturers Association (NEMA) established motor efficiency guidelines in MG 1: *Motors and Generators* (NEMA Stds. MG 1), which standardized how efficiencies are shown on motor nameplates and adopted IEEE Std. 112 Method B (IEEE Std. 112B) for efficiency testing. NEMA Stds. MG 1 first published “energy efficient” motor ratings in 1989 and added “premium efficiency” ratings in 2001.

#### Europe

Although energy efficient motors became available in Europe at the beginning of the 1980s, it took some time for customers to take advantage of the energy savings. Energy efficient motors were adopted by some original equipment manufacturers, but customers did not understand the benefit of paying a premium price for an energy efficient motor. The IEC efficiency test standard at that time was IEC BS EN 60034 Part 2: 1972, which handled stray loss differently than IEEE Std. 112. It was not until 2005 that a European Directive encouraged all European countries to legislate for higher motor efficiencies.

#### Past two decades

In response to various opinions about the feasibility of maintaining motor efficiency during

repair, including replacement of the stator winding, the Electrical Apparatus Service Association (EASA) and Association of Electrical and Mechanical Trades (AEMT) conducted a comprehensive rewind study using a third-party testing laboratory. Its primary purpose was to determine whether it was possible and practical to rewind motors and maintain efficiency. The results of the study published in 2003 clearly showed that motor efficiency could be maintained (and sometimes even improved) if the stator was rewound using established good practice procedures.

With the increased use of premium efficient motors brought about by regulation in various countries, the question once again was asked if the efficiencies of these units could be maintained during the rewind process. This report of the most recent study conducted in 2019—also using a third-party testing lab—clearly shows that the answer is YES.

### 2019 Rewind Study Objective and Test Protocol

#### Objective of the study

The primary objective of the study was to determine if efficiency can be maintained when premium efficiency and IE3 motors are rewound using the good practices described in the 2003 rewind study of energy efficient and IE2 motors. Comparable to the Group B motors of the 2003 study, the motors in this study were rewound once. Other options such as multiple rewinds and round robin testing were not needed since the 2003 study confirmed that efficiency was maintained and core loss was not increased under those scenarios.

#### Products evaluated

As with the 2003 study, this research focused on induction motors with higher power rat-

ings than those in previous studies (i.e., those most likely to be rewound). Ten new premium efficiency or IE3 motors ranging from 40 hp to 100 hp (30 kW to 75 kW) were performance tested at full load by an independent lab before and after rewinding. These low-voltage motors were totally enclosed fan-cooled enclosures (IP 54) and included:

- 50 Hz and 60 Hz motors
- IEC and NEMA designs
- 2-pole and 4-pole motors

### Standards for evaluating losses

Two principal standards are relevant to this work. IEEE Std. 112 is the American standard and IEC Std. 60034-2-1 is the international standard. IEEE Std. 112B was used for this study. Since the IEEE Std. 112 and IEC Std. 60034-2-1 are now harmonized, the results agree with both standards.

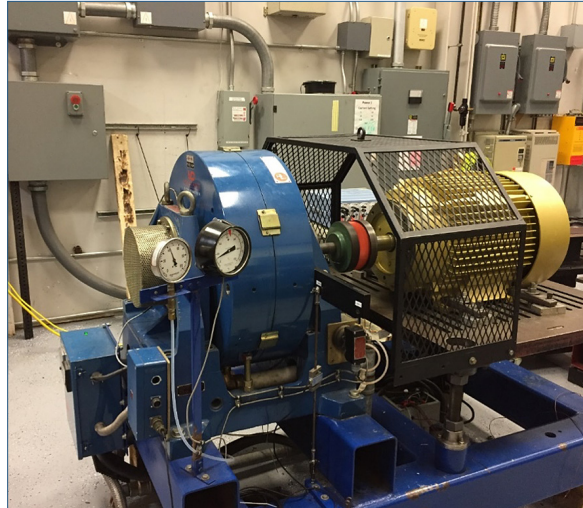
### Methodology

All stators were burned out with a controlled part temperature limit of 700°F (370°C). Other specific controls applied to stators included control of core cleaning methods and rewind details such as turns/coil, mean length of turn, and conductor cross section. The benefits of these controls are described in the EASA/AEMT *Good Practice Guide to Maintain Motor Efficiency* published in 2003.

All motor efficiency tests were performed at North Carolina Advanced Energy Corporation (Advanced Energy) in Raleigh, North Carolina (USA), and carried out in accordance with IEEE Std. 112B using the eddy current dynamometer test stand shown in Figure 1. At present (2020), Advanced Energy remains the only independent Laboratory Accreditation Program (NVLAP) accreditation for motor efficiency testing.

Each motor was initially operated at rated load

Figure 1: Motor being tested



Dynamometer test apparatus at Advanced Energy.

until steady-state temperature conditions were established and then load tested per the IEEE Std. 112B for motor efficiency results.

The motors were then shipped to an EASA Accredited Service Center, Excel Apparatus Services, Inc. (now Integrated Power Services, LLC) in North Charleston, South Carolina (USA). There they were dismantled, the stators were processed in a controlled-temperature oven, and the windings were removed. Next, each motor was rewound and reassembled.

In all cases core losses were measured before burnout and after coil removal using a commercial core loss tester at the motor service center. To minimize performance changes due to factors other than normal rewind procedures, bearings were not replaced, lubricant was not changed, and rotors were not balanced. All repair steps followed the good practices established in ANSI/EASA Std. AR100-2015 and the EASA/AEMT *Good Practice Guide to Maintain Motor Efficiency* from the 2003 rewind study.

Following reassembly, the rewound motors were transported to the Advanced Energy test lab and efficiency tested using the same test and measurement equipment as before.

### Test procedures

The tests for this study were performed in accordance with IEEE Std. 112B. As a precursor to the load test, each motor was operated at rated load until the temperature stabilized and the grease in the bearings settled. The motor was then de-energized, and the winding resistance was recorded. (This resistance measurement is used to capture temperature rise by resistance, and all subsequent measurements are temperature corrected with this value.)

Next, various load readings were taken, starting with the highest load and working down to the lowest load. Readings were taken quickly in each case, after allowing a very brief interval for the machine to settle to its new load. Following load testing, no-load voltage points were recorded, starting with the highest volt-

age and working down to the lowest voltage. These data are required for the segregation of losses calculations.

The techniques and equipment described above ensured test repeatability to within 0.2% at the Advanced Energy lab.

## Results of Efficiency Tests on Rewound Motors

### Summary of test results on rewound motors

The test results for the 10 motors in the 2019 study summarized in Tables 1, 2 and 3 show no significant change in the efficiency of premium efficiency or IE3 motors rewound using good practice repair procedures (within the range of accuracy of the IEEE Std. 112B test method). In several cases, efficiency actually increased. The change in efficiency ranged from -0.5% to +0.3%, with the overall average efficiency change of -0.1%. For purposes of comparison,

**TABLE 1: MOTOR INFORMATION AND EFFICIENCY TEST RESULTS FROM 2019 STUDY**

Motor	IEC or NEMA	Poles	Rating	Voltage	Hz	NEMA/IEC Nom	Pre-wind by test	Pre-wind vs Nom	Post-wind by test	Post-wind vs Nom	Post-wind vs Pre-wind
A	NEMA	4	75 hp	460	60	95.4	94.9	-0.5	95.2	-0.2	0.3
B	NEMA	4	60 hp	230/460	60	95.0	94.4	-0.6	94.2	-0.8	-0.2
C	NEMA	4	75 hp	230/460	60	95.4	95.1	-0.3	94.9	-0.5	-0.2
D	IEC	2	75 kW	400	50	94.7	94.6	-0.1	94.7	0.0	0.1
E	IEC	4	30 kW	460/796	60	94.1	94.5	0.4	94.3	0.2	-0.2
F	IEC	4	37 kW	400/690	50	93.9	93.5	-0.4	93.5	-0.4	0.0
G	NEMA	4	50 hp	208-230/460	60	94.5	93.7	-0.8	93.2	-1.3	-0.5
H	IEC	4	30 kW	460/796	60	94.1	94.5	0.4	94.5	0.4	0.0
I	IEC	4	30 kW	400/690	50	93.6	93.1	-0.5	92.8	-0.8	-0.3
J	IEC	4	30 kW	400/690	50	93.6	93.6	0.0	93.4	0.2	-0.2
								-0.2		-0.4	-0.1

**Note:** The nominal efficiency (Nom) on a nameplate represents an average efficiency of a large population of like motors. The actual efficiency of the motor is guaranteed by the manufacturer to be within a tolerance band of this nominal efficiency.

## The Effect of Repair/Rewinding on Premium Efficiency/IE3 Motors

**TABLE 2: MOTOR INFORMATION AND EFFICIENCY TEST RESULTS FOR MOTORS IN THE 2019 STUDY FORMATTED TO ALIGN WITH 2003 STUDY TABLE 10 (TABLE 4 ON PAGE 6)**

Motor	Test (before or after rewind)	Winding resistance (ohms)	Temp (°C)	Corr. resistance (ohms)	% load	Stator loss (kW)	Rotor loss (kW)	Core loss (kW)	Windage & friction (kW)	Stray loss (kW)	Efficiency (%)	Change (%)
A 75 hp, 4 pole	before	0.086	79.0	0.067	100.1	0.98	0.48	0.52	0.20	0.83	94.9	
	after	0.087	83.0	0.069	100.2	0.98	0.46	0.54	0.14	0.71	95.2	0.3
B 60 hp, 4 pole	before	0.137	69.1	0.112	100.3	0.98	0.50	0.48	0.35	0.35	94.4	
	after	0.133	69.2	0.110	100.3	0.95	0.51	0.46	0.36	0.48	94.2	-0.2
C 75 hp, 4 pole	before	0.064	80.2	0.051	100.2	0.69	0.60	0.64	0.30	0.68	95.1	
	after	0.068	76.5	0.052	100.0	0.74	0.64	0.63	0.31	0.66	94.9	-0.2
D 50 Hz 75 kW, 2 pole	before	0.045	98.7	0.034	100.8	1.16	0.65	0.71	1.16	0.60	94.6	
	after	0.045	99.6	0.034	100.8	1.15	0.64	0.79	1.04	0.65	94.7	0.1
E 30 kW, 4 pole	before	0.167	79.0	0.135	100.2	0.56	0.30	0.56	0.18	0.13	94.5	
	after	0.168	74.1	0.140	100.1	0.58	0.29	0.55	0.15	0.25	94.3	-0.2
F 50 Hz 37 kW, 4 pole	before	0.112	80.1	0.090	100.0	0.80	0.45	0.70	0.21	0.44	93.5	
	after	0.119	79.2	0.097	99.4	0.83	0.43	0.73	0.21	0.36	93.5	0.0
G 50 hp, 4 pole	before	0.212	80.3	0.162	100.0	1.13	0.61	0.42	0.13	0.19	93.7	
	after	0.224	90.6	0.171	100.3	1.22	0.59	0.48	0.16	0.31	93.2	-0.5
H 30 kW, 4 pole	before	0.164	75.0	0.135	99.5	0.54	0.28	0.56	0.22	0.12	94.5	
	after	0.150	69.1	0.125	100.3	0.51	0.29	0.57	0.19	0.17	94.5	0.0
I 50 Hz 30 kW, 4 pole	before	0.174	109.9	0.132	100.9	0.80	0.59	0.45	0.25	0.15	93.1	
	after	0.184	110.2	0.137	100.3	0.84	0.60	0.44	0.24	0.23	92.8	-0.3
J 50 Hz 30 kW, 4 pole	before	0.187	80.7	0.145	100.1	0.94	0.41	0.42	0.09	0.19	93.6	
	after	0.192	79.8	0.148	100.3	0.99	0.43	0.45	0.09	0.16	93.4	-0.2

**TABLE 3: SEGREGATED LOSS DATA FOR MOTORS IN THE 2019 STUDY**

Study ID	Pre Sta I <sup>2</sup> R	Post Sta I <sup>2</sup> R	Δ Sta I <sup>2</sup> R %	Pre Rot I <sup>2</sup> R	Post Rot I <sup>2</sup> R	Δ Rot I <sup>2</sup> R %	Pre Core	Post Core	Δ Core%	Pre F&W	Post F&W	Δ F&W %	Pre Stray	Post Stray	Δ Stray %
A	0.98	0.98	0.0	0.48	0.46	-4.2	0.52	0.54	3.8	0.20	0.14	-30.0	0.83	0.71	-14.5
B	0.98	0.95	-3.1	0.50	0.51	2.0	0.48	0.46	-4.2	0.35	0.36	2.9	0.35	0.48	37.1
C	0.69	0.74	7.2	0.60	0.64	6.7	0.64	0.63	-1.6	0.30	0.31	3.3	0.68	0.66	-2.9
D	1.16	1.15	-0.9	0.65	0.64	-1.5	0.71	0.79	11.3	1.16	1.04	-10.3	0.60	0.65	8.3
E	0.56	0.58	3.6	0.30	0.29	-3.3	0.56	0.55	-1.8	0.18	0.15	-16.7	0.13	0.25	92.3
F	0.80	0.83	3.7	0.45	0.43	-4.4	0.70	0.73	4.3	0.21	0.21	0.0	0.44	0.36	-18.2
G	1.13	1.22	8.0	0.61	0.59	-3.3	0.42	0.48	14.3	0.13	0.16	23.1	0.19	0.31	63.2
H	0.54	0.51	-5.6	0.28	0.29	3.6	0.56	0.57	1.8	0.22	0.19	-13.6	0.12	0.17	41.7
I	0.80	0.84	5.0	0.59	0.60	1.7	0.45	0.44	-2.2	0.25	0.24	-4.0	0.15	0.23	53.3
J	0.94	0.99	5.3	0.41	0.43	4.9	0.42	0.45	7.1	0.09	0.09	0.0	0.19	0.16	-15.8
Average			2.4%			0.2%			3.3%			-6.5%			8.2%



see Tables 4 and 5 for equivalent results from the 2003 study.

### Discussion of test results

The most important test result for any of the motors is the post-rewind versus pre-rewind efficiency change. These values range from an increase of 0.3% to a reduction of 0.5%, with an overall average decrease of 0.1 percentage points. Thus, individually and overall, there was no efficiency change to any motor other than that which would normally be expected due to inaccuracies in the testing methods.

### Significance of tests results

The average efficiency change for the entire test group falls within the range of accuracy for the test method ( $\pm 0.2\%$ ), showing that premium efficiency and IE3 motors rewound following good practices maintained their original efficiency, and in several instances, motor efficiency improved.

### Why the results of both studies should be the same

The fundamental reason for consistent changes in loss values between the 2019 and 2003 studies deals with the methods used to remove the original winding and replace it with an equivalent new one. The method of winding removal was the same in both studies, and any change in electrical steel grades did not affect a deterioration in the lamination insulation. In fact, in many cases the insulation was changed from an annealed insulation to a fully processed core plate which has even better insulation and durability than annealed steel insulation.

The stator loss usually was maintained by copy rewinding. In some cases, the wire area was increased. This was facilitated because all rewinds were hand inserted whereas the original windings were machine wound, typically with lower slot fill capability

The rotor loss, including windage and friction loss, basically remained unchanged because the rotor, bearings and cooling fans were not disturbed.

The stray losses, which make up the balance of the motor losses, were only affected by the way the original winding was removed from the stator. As noted, in both studies this process was the same.

Hence, the results of the 2019 study reaffirm the results of the 2003 study.

### Conclusion—2019 Study

This report is the work of a team of leading international personnel from industry and manufacturers. Following in the footsteps of the 2003 rewind study, the 2019 study results clearly demonstrate that the efficiency and reliability of premium efficiency and IEC3 motors are maintained when repairers use the methods outlined in ANSI/EASA Std. AR100, IEC Std. 60034-23 and EASA's *Good Practice Guide to Maintain Motor Efficiency*.

### Acknowledgments

EASA and AEMT would like to acknowledge and sincerely thank the following companies who contributed new motors for this study:

- ABB Motors and Mechanical, Inc.
- Avonmore Electrical Co., Ltd.
- Menzel Elektromotoren
- Lafert North America
- Siemens
- Toshiba
- WEG

In addition, Advanced Energy contributed funding to reduce the cost of motor testing. Also, sincere thanks to Doug Hinson of Excel Apparatus Services, Inc. (now Integrated Power Services, LLC), whose company performed the rewind work at greatly reduced fees.

# The Effect of Repair/Rewinding on Premium Efficiency/IE3 Motors

**TABLE 4: MOTOR INFORMATION AND EFFICIENCY TEST RESULTS FROM TABLE 10 OF THE 2003 STUDY**

Motor	Test (Before or after rewind)	Winding resistance (ohms)	Temp (°C)	Corr. resistance (ohms)	% load	Stator loss (kW)	Rotor loss (kW)	Core loss (kW)	Windage & friction (kW)	Stray loss (kW)	Efficiency (%)	Change (%)
6F 150 hp, 2 pole	before	0.0359	31.60	0.0350	100.4	1661.9	1637.1	988.5	1586.4	743.0	94.4	
	after	0.0390	30.63	0.0382	99.8	1729.8	1624.2	1058.2	1624.8	662.5	94.3	-0.1
9E 60 hp, 2 pole	before	0.1308	45.57	0.1212	99.8	1055.4	1124.2	647.7	1674.7	392.5	90.1	
	after	0.1266	43.17	0.1183	100.1	1026.0	1206.0	679.8	1645.0	497.8	89.9	-0.2
10D 125 hp, 4 pole	before	0.0347	28.95	0.0341	100.0	1317.9	931.1	785.3	986.8	602.1	95.4	
	after	0.0360	36.67	0.0344	100.1	1286.9	964.3	847.5	936.4	750.6	95.2	-0.2
11F 200 hp, 2 pole	before	0.0203	50.48	0.0185	99.8	1721.1	1020.7	1333.3	1439.7	113.8	96.4	
	after	0.0208	47.47	0.0192	100.1	1799.3	1250.9	1291.6	1291.1	114.3	96.3	-0.1
14H* 50 Hz 55 kW, 4 pole	before	0.0675	47.42	0.0621	100.0	1577.0	1215.7	1650.2	664.9	1069.7	89.9	
	after	0.0600	47.30	0.0553	99.9	1405.2	1165.3	2447.6	750.7	882.7	89.2	-0.7*
16H 50 Hz 150 kW, 4 pole	before	0.0196	45.75	0.0182	99.0	2304.3	1053.0	2122.9	740.1	904.8	95.4	
	after	0.0171	36.85	0.0163	100.1	1981.1	1017.6	2075.1	772.9	1112.0	95.6	+0.2
18G 50 Hz 55 kW, 4 pole	before	0.0775	48.70	0.0711	99.2	1334.6	803.1	733.2	219.6	277.6	94.2	
	after	0.0710	34.75	0.0685	100.0	1310.9	824.6	737.5	229.3	303.3	94.2	0.0
19H 50 Hz 132 kW, 2 pole	before	0.0296	43.97	0.0276	99.6	2537.6	1704.8	1925.3	3434.0	475.1	93.0	
	after	0.0259	36.15	0.0248	99.7	2167.1	1684.8	1863.0	3722.7	403.9	93.0	0.0
20H 50 Hz 45 kW, 2 pole	before	0.0773	41.53	0.0727	101.0	801.8	697.0	722.1	386.4	363.1	93.9	
	after	0.0712	39.03	0.0676	100.3	707.9	669.6	664.1	451.2	427.3	93.9	0.0
21J 50 Hz 75 kW, 2 pole	before	0.0468	44.55	0.0435	99.6	1319.6	870.0	1146.0	566.2	1087.9	93.7	
	after	0.0435	40.38	0.0411	99.9	1239.9	856.7	1126.8	510.4	1093.2	93.9	+0.2
24E 100 hp, 4 pole	before	0.0951	39.58	0.0900	100.4	1389.4	759.4	876.9	389.2	415.7	95.1	
	after	0.0936	34.99	0.0902	100.0	1465.7	775.3	1032.6	420.0	274.5	95.0	-0.1

\* Faulty core iron

**TABLE 5: SEGREGATED LOSS DATA FOR MOTORS IN THE 2003 STUDY TABLE 10**  
REFORMATTED TO ALIGN WITH 2019 STUDY (TABLE 2)

Study ID	Pre Sta I <sup>2</sup> R	Post Sta I <sup>2</sup> R	Δ Sta I <sup>2</sup> R %	Pre Rot I <sup>2</sup> R	Post Rot I <sup>2</sup> R	Δ Rot I <sup>2</sup> R %	Pre Core	Post Core	Δ Core%	Pre F&W	Post F&W	Δ F&W %	Pre Stray	Post Stray	Δ Stray %
6F	1.66	1.73	4.1	1.64	1.62	-0.8	0.99	1.06	7.1	1.59	1.62	2.4	0.74	0.66	-10.8
9E	1.06	1.03	-2.8	1.12	1.21	7.3	0.65	0.68	5.0	1.67	1.65	-1.8	0.39	0.50	26.8
10D	1.32	1.29	-2.4	0.93	0.96	3.6	0.79	0.85	7.9	0.99	0.94	-5.1	0.60	0.75	24.7
11F	1.72	1.80	4.5	1.02	1.25	22.6	1.33	1.29	-3.1	1.44	1.29	-10.3	0.11	0.11	0.4
16H	2.30	1.98	-14.0	1.05	1.02	-3.4	2.12	2.08	-2.3	0.74	0.77	4.4	0.90	1.11	22.9
18G	1.33	1.31	-1.8	0.80	0.82	2.7	0.73	0.74	0.6	0.22	0.23	4.4	0.28	0.30	9.3
19H	2.54	2.17	-14.6	1.70	1.68	-1.2	1.93	1.86	-3.2	3.43	3.72	8.4	0.48	0.40	-15.0
20H	0.80	0.71	-11.7	0.70	0.67	-3.9	0.72	0.66	-8.0	0.39	0.45	16.8	0.36	0.43	17.7
21J	1.32	1.24	-6.0	0.87	0.86	-1.5	1.15	1.13	-1.7	0.57	0.51	-9.9	1.09	1.09	0.5
24E	1.39	1.47	5.5	0.76	0.78	2.1	0.88	1.03	17.8	0.39	0.42	7.9	3.83	3.97	3.6
Average			-4.7%			2.6%			0.8%			1.6%			6.2%

### Bibliography

ANSI/EASA Std. AR100-2015: *Recommended Practice for the Repair of Electrical Apparatus*. Electrical Apparatus Service Association, Inc. St. Louis, MO, 2015.

“Good Practice Guide to Maintain Motor Efficiency,” *The Effect of Repair/Rewinding on Motor Efficiency*. Electrical Apparatus Service Association, Inc. St. Louis, MO, 2003.

IEC Std. 60034-2-1: *Rotating Machines—Part 2: Methods for Determining Losses and Efficiency for Rotating Electrical Machinery From Tests (Excluding Machines for Traction Vehicles)*. International Electrotechnical Commission. Geneva, Switzerland, 2014.

IEEE Std. 112-2017: *IEEE Standard Test Procedure for Polyphase Induction Motors and Generators*. Institute of Electrical and Electronics Engineers, Inc. New York, NY, 2017.

NEMA Stds. MG 1-2016 (Rev. 2018): *Motors and Generators*. National Electrical Manufacturers Association. Rosslyn, VA, 2016.

*The Effect of Repair/Rewinding on Motor Efficiency*. Electrical Apparatus Service Association. St. Louis, MO, 2003.

**NOTE:** A full report encompassing the 2003 study results will be made available in the coming months. In the meantime, you can download the 2003 “EASA/AEMT Rewind Study” and “Good Practice Guide To Maintain Motor Efficiency” at [\*The Effect of Repair/Rewinding on Motor Efficiency\*](#) or at <https://www.theaemt.com/technical-info/technical-documents>.

