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

Executive Summary

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THE EFFECT OF REPAIR/REWINDING ON PREMIUM EFFICIENCY/IE3 MOTORS

EXECUTIVE SUMMARY

HISTORICAL BACKGROUND ON EVOLVING EFFICIENCY LEVELS

Historical Overview — United States

As a result of a governmental study during the 1970s, it became increasingly clear that applications using electric motors represented more than 2/3 of all generated electrical power consumed in industrial nations (A.D. Little report of 1976). Couple this with the concerns for increased demands on the "electrical grids" around the world, and it became apparent that there was a growing need for energy conservation, with motors a key focus in this effort.

The National Electrical Manufacturers Association (NEMA) established motor efficiency guidelines in MG1-1977, which standardized how efficiencies would be shown on the nameplates and that the motors would be tested in accordance with IEEE 112, method B. In 1989, the NEMA motors and generators standard MG1 was published with "energy efficient" motor ratings; in 2001, "premium efficiency" motor ratings were published in MG1.

Historical Overview — 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. They 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, with some difference versus IEEE 112 in how the stray loss was handled. It was not until 2005 that a European Directive encouraged all European countries to legislate for higher motor efficiencies.

Overview — Past Two Decades

In order to respond to the wide variety of 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) after the stator was rewound if established good practice procedures were used.

With the increased use of premium efficient motors brought about by regulation in various countries, the question once again was asked if motor efficiency could be maintained during the rewind process of these higher efficient units. 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 ratings 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 full load performance tested at 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

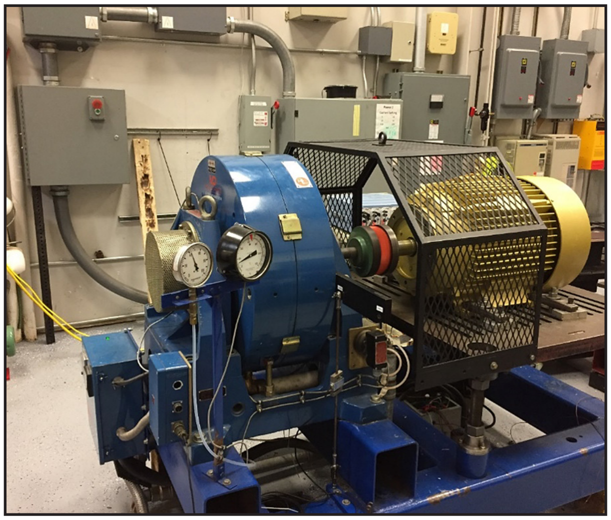
Two principal standards are relevant to this work. IEEE 112 is the American standard and IEC 60034-2-1 is the international standard. IEEE 112 Method B (IEEE 112B) was used for this study. Since the IEEE 112 and IEC 60034-2-1 standards are now harmonized, the results agree with both standards.

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 were described in the *Good Practice Guide to Maintain Motor Efficiency* published in 2003.

All motor efficiency tests were performed at North Caro-

FIGURE 1: MOTOR BEING TESTED



Dynamometer test apparatus at Advanced Energy.

lina Advanced Energy Corporation (Advanced Energy) located in Raleigh, North Carolina, and carried out in accordance with IEEE 112 Method B using the eddy current dynamometer test stand shown in Figure 1. At present (2020), Advanced Energy remains the only independent motor lab in North America to hold the National Voluntary Laboratory Accreditation Program (NVLAP) accreditation for motor efficiency testing.

Each motor was initially operated at rated load until steady-state temperature conditions were established and then load tested per the IEEE 112 Method B standard 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, where they were dismantled, the stators were processed in a controlled-temperature oven, and the windings were removed. Next, each motor was rewound, reassembled and transported back to the Advanced Energy test lab using the same test and measurement equipment as before. 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 AR100-2015 and the Good Practice Guide from the rewind study published in 2003.

Test Procedures

The tests for this study were performed in accordance with IEEE 112 Method B. As a precursor to the load test, each motor completed a thermal stabilization by running at rated load until the temperature stabilized and the grease in the bearings settled. The motor was then de-energized and winding resistance recorded. This resistance measurement is used to capture temperature rise by resistance and all ensuing 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 voltage and working down to the lowest voltage. These data are required for the segregation of losses calculations.

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.

TABLE 2: MOTOR INFORMATION AND EFFICIENCY TEST RESULTS FOR MOTORS IN THE 2019 STUDY FORMATTED TO ALIGN WITH 2003 STUDY TABLE 10 (TABLE 4 BELOW)												
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	before	0.086	79.0	0.067	100.1	0.98	0.48	0.52	0.20	0.83	94.9	
75 hp, 4 pole	after	0.087	83.0	0.069	100.2	0.98	0.46	0.54	0.14	0.71	95.2	0.3
B	before	0.137	69.1	0.112	100.3	0.98	0.50	0.48	0.35	0.35	94.4	
60 hp, 4 pole	after	0.133	69.2	0.110	100.3	0.95	0.51	0.46	0.36	0.48	94.2	-0.2
C	before	0.064	80.2	0.051	100.2	0.69	0.60	0.64	0.30	0.68	95.1	
75 hp, 4 pole	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	before	0.045	98.7	0.034	100.8	1.16	0.65	0.71	1.16	0.60	94.6	
75 kW, 2 pole	after	0.045	99.6	0.034	100.8	1.15	0.64	0.79	1.04	0.65	94.7	0.1
E	before	0.167	79.0	0.135	100.2	0.56	0.30	0.56	0.18	0.13	94.5	
30 kW, 4 pole	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	before	0.112	80.1	0.090	100.0	0.80	0.45	0.70	0.21	0.44	93.5	
37 kW, 4 pole	after	0.119	79.2	0.097	99.4	0.83	0.43	0.73	0.21	0.36	93.5	0.0
G	before	0.212	80.3	0.162	100.0	1.13	0.61	0.42	0.13	0.19	93.7	
50 hp, 4 pole	after	0.224	90.6	0.171	100.3	1.22	0.59	0.48	0.16	0.31	93.2	-0.5
H	before	0.164	75.0	0.135	99.5	0.54	0.28	0.56	0.22	0.12	94.5	
30 kW, 4 pole	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	before	0.174	109.9	0.132	100.9	0.80	0.59	0.45	0.25	0.15	93.1	
30 kW, 4 pole	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	before	0.187	80.7	0.145	100.1	0.94	0.41	0.42	0.09	0.19	93.6	
30 kW, 4 pole	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^2R**	**Post Sta I^2R**	**Δ Sta I^2R %**	**Pre Rot I^2R**	**Post Rot I^2R**	**Δ Rot I^2R %**	**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%

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	before	0.0359	31.60	0.0350	100.4	1661.9	1637.1	988.5	1586.4	743.0	94.4	
150 hp, 2 pole	after	0.0390	30.63	0.0382	99.8	1729.8	1624.2	1058.2	1624.8	662.5	94.3	-0.1
9E	before	0.1308	45.57	0.1212	99.8	1055.4	1124.2	647.7	1674.7	392.5	90.1	
60 hp, 2 pole	after	0.1266	43.17	0.1183	100.1	1026.0	1206.0	679.8	1645.0	497.8	89.9	-0.2
10D	before	0.0347	28.95	0.0341	100.0	1317.9	931.1	785.3	986.8	602.1	95.4	
125 hp, 4 pole	after	0.0360	36.67	0.0344	100.1	1286.9	964.3	847.5	936.4	750.6	95.2	-0.2
11F	before	0.0203	50.48	0.0185	99.8	1721.1	1020.7	1333.3	1439.7	113.8	96.4	
200 hp, 2 pole	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	before	0.0675	47.42	0.0621	100.0	1577.0	1215.7	1650.2	664.9	1069.7	89.9	
55 kW, 4 pole	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	before	0.0196	45.75	0.0182	99.0	2304.3	1053.0	2122.9	740.1	904.8	95.4	
150 kW, 4 pole	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	before	0.0775	48.70	0.0711	99.2	1334.6	803.1	733.2	219.6	277.6	94.2	
55 kW, 4 pole	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	before	0.0296	43.97	0.0276	99.6	2537.6	1704.8	1925.3	3434.0	475.1	93.0	
132 kW, 2 pole	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	before	0.0773	41.53	0.0727	101.0	801.8	697.0	722.1	386.4	363.1	93.9	
45 kW, 2 pole	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	before	0.0468	44.55	0.0435	99.6	1319.6	870.0	1146.0	566.2	1087.9	93.7	
75 kW, 2 pole	after	0.0435	40.38	0.0411	99.9	1239.9	856.7	1126.8	510.4	1093.2	93.9	+0.2
24E	before	0.0951	39.58	0.0900	100.4	1389.4	759.4	876.9	389.2	415.7	95.1	
100 hp, 4 pole	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^2R	Post Sta I^2R	Δ Sta I^2R %	Pre Rot I^2R	Post Rot I^2R	Δ Rot I^2R %	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%

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 motors rewound using good practice repair procedures (within the range of accuracy of the IEEE 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 comparison purposes the equivalent results from the 2003 study are summarized in Tables 4 and 5.

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 ranged from an increase of 0.3% to a reduction of 0.5%, and the overall average was a 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 (± 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 two studies deals with the method of handling the removal of the original winding and replacing it with a new equivalent 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 was maintained by copy rewinding in most cases. In some cases the wire area was increased. This was facilitated because all rewinds were hand inserted as opposed to the original winding being 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 motor efficiency and reliability are maintained when repairers use the methods outlined in ANSI/EASA AR100, IEC 60034-23 and the Good Practice Guide to Maintain Motor Efficiency.

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- WEG

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