Mechanical Impact of High Temperature Stripping Of Induction Motor Stators

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Introduction

Over the past four decades interest in the impact of electric motor repair and its effect on energy efficiency and reliability has increased. A majority of the studies have dealt with efficiency and losses with very little attention on the mechanical issues and continued reliability of the motor.

Studies performed in the 1990s were performed by third party groups such as the Canadian Electrical Association (CEA). The first were blind studies performed by Ontario Hydro, BC Hydro and Hydro Quebec. The motors sent out in 1991 were standard efficiency motors that were sent out blind with all resulting in increased losses by motor repair shops that use burnout ovens. In 1993, BC Hydro sent out a group of motors with newer core steels and saw a lower impact of high temperature stripping on increased losses. They did, however, find increased losses due to low quality repair practices.

Figure 1: Burned Out Stator Core

In 1994, a controlled study of electric motor repair was performed by Hydro Quebec in which several new 50 hp energy efficient motors were stripped using both high temperature burnout and low temperature mechanical methods. It was found that in the standard efficient motors older core steels were used which were more susceptible to heat above 410F while newer core steels could withstand higher temperatures. It was also determined that the mechanical method used, the Dreisilker/Thumm stripping machine, operated faster, without damage to the core steel (including lamination separation even with improper operation of the equipment), and no change in core losses versus burnout. To date, no additional independent studies have been performed, only special interest studies.

However, in all of the independent and special interest studies at least two critical issues were overlooked. One was the mechanical effects on the different materials used for stator housings. The second was the resulting change in reliability in those motors once returned to service. A final comment was that all of the studies used brand new stators and none utilized machines taken from existing applications.

In this paper we will be taking another look at a study performed on twelve used electric motor stators of various materials, frame sizes and manufacturers subjected to controlled burnout temperatures of 650F and 800F. The primary purpose was to estimate the resulting effect on reliability by modeling the changes using software. This will provide the introduction to a new study in progress.

Theory

It is a known fact that many repaired motors do not last as long as new motors when repaired by traditional repair methods. This is commonly referred to in the reliability and maintenance industry as the ‘half life of motor repair.’ The cause has not been fully reviewed or studied but has been identified in Advanced Energy’s 2005 study, ‘Achieving More with Less: Efficiency and Economics of Motor Decision Tools.’ In this study it was identified that there was a Weyerhaeuser report that 50% of new motors failed in seven years and 50% of repaired motors failed in 3.5 years. This, of course, provides a reason for the perception of the half life.

The theory put forth in this research project was that reliability is reduced through thermal effects on the stator frame. As a result, the air gap is uneven, soft foot occurs, and stator deformation and twisting occurs adding other electrical and mechanical stresses, reducing machine life. Motor stators will begin to deform naturally, resulting in changes to air gap, soft foot, and other stresses, which are accelerated when heat is applied. Stator core deformation may also occur as the stator core and frame are generally made of different materials with different coefficients of expansion. Many shops that use burnout stripping processes may cool down stators quickly prior to removing windings. This will result in deformation as the different steels cool at different rates.

The Experiment

Two sets of six used electric motor stators were selected randomly. The first set (A Group) consisted of two cast aluminum, two extruded aluminum, and two cast iron frames. The second set (B Group) consisted of five cast iron and one rolled steel frames. Frame sizes varied (Table 1) Randomly.

Table 1: Frame Sizes

Motor	650F	800F
A	324T, Cast Aluminum	286T, Cast Iron
B	286T , Extruded Aluminum	324T, Rolled Steel
C	286T, Extruded Aluminum	365T, Cast Iron
D	254T, Cast Iron	284T, Cast Iron
E	324T, Cast Aluminum	326T, Cast Iron
F	365T, Cast Iron	254T, Cast Iron

Group A was measured (Appendix 1) and stripped using a temperature controlled burnout oven at 650F for ten hours then allowed to cool normally. The stators were then re-measured (Appendix 2) and visually inspected (Appendix 3).

Figure 2: Burned Out Rolled Steel Stator

Group B was measured (Appendix 4) stripped using a temperature controlled burnout oven at 800F for six hours then allowed to cool normally. The stators were re-measured (Appendix 5) and visually inspected.

In both cases the same measuring instruments, procedures and personnel were used as controls for the experiment. The core inner diameter was measured in three positions, front and back. The core position and stator dimensions were recorded. Core concentricity was measured in eight positions as were the rabbet fits. Foot flatness was measured on each foot using feeler gauges and flat surfaces.

1. <u>650F Stripping Results</u>

As it was observed, there were significant changes in the soft foot and rabbet fit concentricity with all of the motors. These changes were most prevalent in the aluminum stators versus the cast iron, as would be expected. In the cast aluminum stators, there was a very significant change to the soft foot condition of the motors, enough so that the stators could be noticeably rocked back and forth on a smooth surface. The rabbet fit concentricity also changed significantly on all of the stators indicating warping of the ends of the stator frame. In all cases the core remained in acceptable shape.

It was noticed that there was oxidation on the surfaces of the core steel of all of the stators and oxidation on the machined fits of the cast iron stators when they were left in a temperature controlled space for over one day. It is suspected that the cause of the oxidation is due to the raw metal being exposed and the vapor used in the temperature control of the burnout oven. Loose laminations were also observed in all of the samples tested.

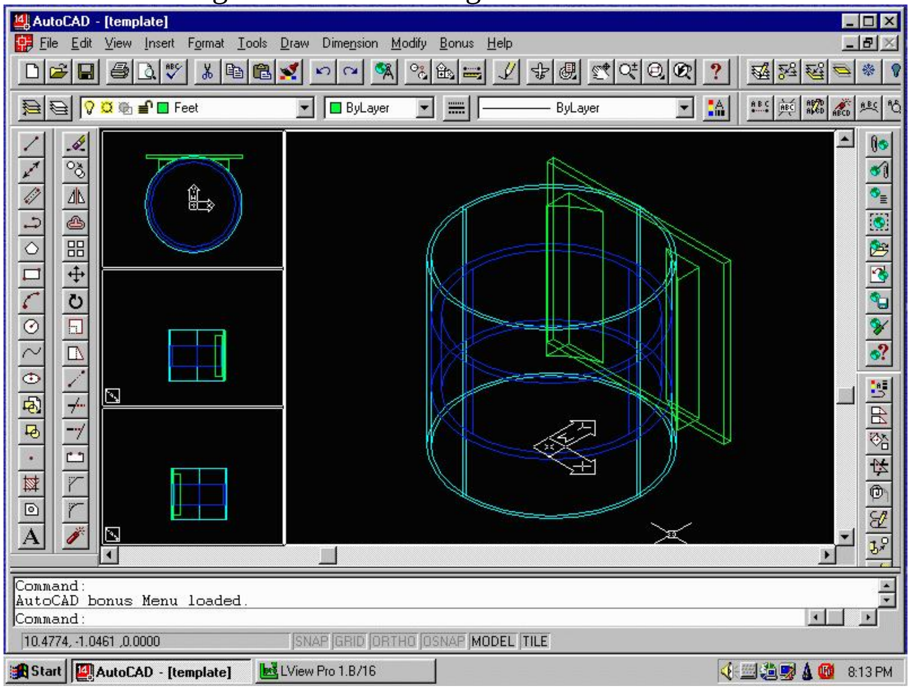
2. 800F Stripping Results

As there was a significant increase in soft foot and stator deformation in the aluminum stators at 650F, the 800F test was performed on cast and rolled steel stators only. There were significant changes in soft foot, rabbet fit concentricity and core steel position. Visually, the stators and some warping and oxidation was found on all stators within two days. There were severe instances of loose laminations in all of the stators.

3. Modeling Results

The results were formed into three dimensional models using AutoCAD Version 14 and 3D Studio Max. The purpose of modeling was to present an exaggerated visual as well as a true dimension determination of the effects of rotor position within the stator.

Figure 3: 3D Modeling with AutoCAD 14



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Command:
AutoCAD bonus Menu loaded.
Command:
10.4774, -1.0461 ,0.0000
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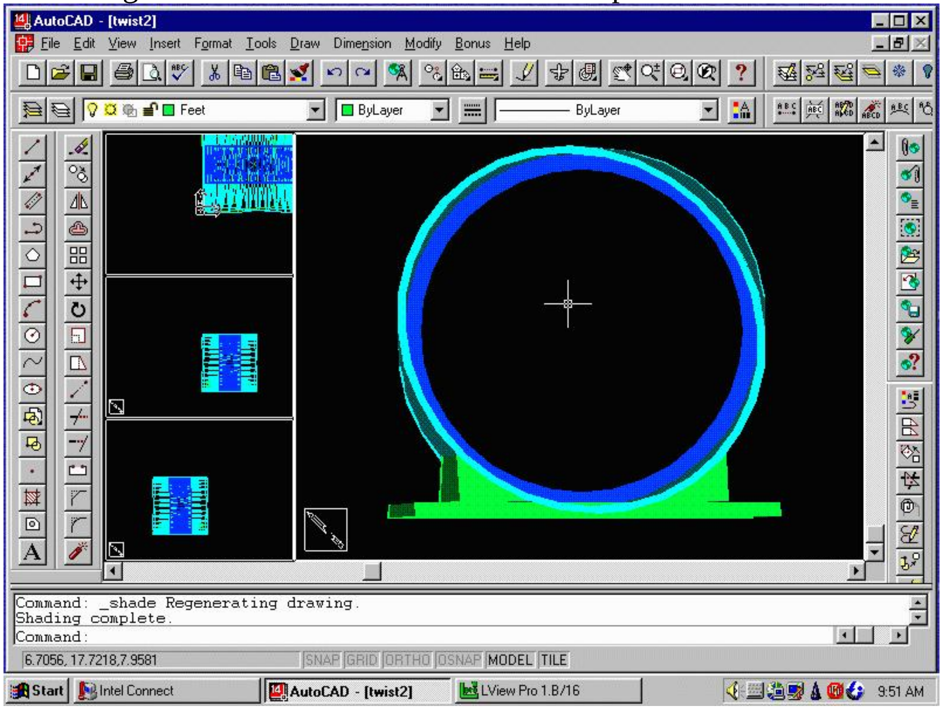
Modeling the results created an understanding of what was truly happening to a motor in which even minor distortion was occurring. Those results were fairly dramatic and go a long way to help determine why some repairs do not seem to last as long as others.

Figure 4: Model Modified in AutoCAD per Measurements



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Command: _shade Regenerating drawing.
Shading complete.
Command:
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6.7056, 17.7218,7.9581

4. Effect of Distortion on Reliability

The effects of frame distortion are more profound than was expected at the outset of this study. While other studies have shown an increased resistance to heat by the core, this study has shown that even existing burnout oven techniques can affect the reliability of repaired electric motors.

One of the significant findings was an increase in soft foot which, in this case, is a sign of frame twisting as the motors were mounted vertically in the burnout oven. Once placed back into service, these motors may see an increase in frame stress, reduced air gap, or cracking of the frame or base if the soft foot is not properly compensated for.

Loose laminations indicate that the insulation between the laminations has been destroyed. This could cause increased core losses if the stator is improperly varnished. This situation may also cause additional noise in motors used in inverter applications. The stators in which the laminations had turned blue indicate low grade lamination materials and is a result of changes in the steel itself. The impact on reliability include:

1. 120 Hz (twice line frequency) electro-mechanical vibration. This results in reducing bearing life and other vibration related defects.

2. Shaft currents due to impressed currents onto the shaft. If these are severe enough, reduced bearing life will occur due to Electrical Discharge Machining, or bearing currents.
3. Rotor rub in severe instances. This occurs most often in motors which have tight air gaps, low grade steel, or aluminum frames.

Bearing life is also reduced due to increased bearing stresses as the end shields are moved from the original position due to rabbet fit and other frame dimensional changes. The bearing may have the outer race slightly off center from the inner race, causing the balls to run out of center. In severe cases this phenomenon will show on vibration analysis as a cocked bearing or the paths may be evident using an inspection microscope.

Conclusions of Original Experiment

It has been found that there are definite mechanical effects due to burnout stripping (incineration) of electric motors even at temperatures of 650F. This phenomenon is more severe in metals which have high rates of thermal expansion resulting in distortion. Part of this is due to the original manufacture of the electric motor with ‘green metals,’ however, a great deal is due to the expansion, contraction, and distortion of the metals at high temperature. Also, as the higher temperatures often remove protective coatings from the core steel and frames, if they are not coated quickly they begin to oxidize. This may even be further aggravated by adding additional contaminants to the burnout environment.

The result of the changes to a motor stator is reduced repair reliability. This reduction is due to stator stresses, bearing stresses, increases in soft foot, and air gap eccentricity. These causes can greatly reduce the life of repaired electric motors significantly. The following should be observed in any motor repair in order to ensure reasonable reliability:

1. Use the lowest possible temperatures for as short a time as possible when stripping motors;
2. Remove the shells of aluminum frames when using temperatures of 600F, or more. It is important to understand that doing this will present a whole list of new potential challenges;
3. Measure changes to the rabbet fits and foot flatness before and after stripping and using temperatures in excess of 600F; and,
4. Whenever possible, immediately coat the stator laminations, after burning out, so that the parts will not oxidize.

Upcoming Experiments on Mechanical Systems and Reliability

The original experiments identified the potential issues related to the reliability of electric motors due to core inter-laminar insulation incineration and mechanical impact using burnout ovens. Planned studies are in development which will provide accurate impacts on bearing housings and air gap. Temperatures will be maintained at the same values as the experiments outlined in this paper.

Bibliography

Penrose, Howard W and Dreisilker, Leo F., “The Mechanical Effects from Thermal Stripping Induction Motor Stators,” EIC/EMCWA 1997 Proceedings, IEEE, 1997.

About the Author

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Dreisilker Electric Motors, Inc. is located just outside of Chicago, Illinois, at 352 Roosevelt Road, Glen Ellyn, Illinois.

Appendix 1: Before Thermal Stripping: 650F Stators

Measurement	A	B	C	D	E
Core					
0	-0.0005	0	0	0	0
90	0.003	-0.005	-0.0035	0.003	0.0055
180	-0.0005	0.003	-0.003	0.005	0
270	-0.001	0	-0.004	0.005	-0.0035
Rabbet Fit					
0	0	0	0	-0.0005	0
45	-0.0005	-0.003	0.0015	0	0
90	0	-0.0035	0.0035	0.001	0.0015
135	0.0005	-0.0075	0.004	0	0.002
180	0	0	0	0	0
225	0.001	0	0.005	0.001	0
270	0	-0.003	0.0035	0.001	0.0015
305	-0.0035	0	0.003	-0.0005	0.0025
Foot Flatness					
1-F2, DE	0.001	0.005		0.001	0.001
2-F2, ODE	0.005	0.001		0.001	0.001
3-F1, DE	0.001	0.001		0.001	0.005
4-F1, ODE	0.005	0.001		0.001	0.005

Concentricity readings are taken from different points, depending on the motor. F1 is the left side of the stator facing the shaft end, F2 is the right side of the stator facing the shaft end. DE stands for Drive End, ODE stands for Opposite Drive End.

Appendix 2: After Thermal Stripping: 650F Stators

Measurement	A	B	C	D	E
Core					
0	0	0.0025	0	0	0
90	-0.0035	0.005	-0.006	-0.009	0.0045
180	-0.024	0.01	-0.011	-0.0065	0.007
270	-0.018	0.0025	-0.004	0.004	0.009
Rabbet Fit					
0	-0.0005	0	0	0.002	0
45	0	0.002	-0.008	0	0
90	0.004	0.003	-0.011	-0.0005	-0.007
135	0.0105	-0.018	-0.011	0.002	-0.003
180	-0.0005	0	0.0005	0.0005	0
225	0.035	-0.006	-0.01	0	0
270	0.004	0.0025	-0.011	0.0015	-0.0065
305	-0.0005	0.003	-0.005	0.0065	-0.0055
Foot Flatness					
1-F2, DE	0.025	0.065		0.002	0.001
2-F2, ODE	0.015	0.001		0.002	0.001
3-F1, DE	0.01	0.001		0.001	0.005
4-F1, ODE	0.005	0.05		0.013	0.005

Concentricity readings are taken from different points, depending on the motor. F1 is the left side of the stator facing the shaft end, F2 is the right side of the stator facing the shaft end. DE stands for Drive End, ODE stands for Opposite Drive End.

Appendix 3: Visual Inspection and Notes for 650F Post Burnout of Stators

Stator	Notes
A	Laminations loose ¼ inch on either side of the stator core. Over 50% of exposed surfaces had become oxidized after two days.
B	All laminations loose. All varnish on the core surfaces gone. Approximately 25% of the visible portions of the laminations, particularly around the teeth, discolored/blued. Approximately 25% of exposed surfaces oxidized after two days.
C	Laminations loose over ¼ inch from either side. Less than 25% of exposed surfaces oxidized after two days.
D	Over 40% of exposed surfaces oxidized after 2 days. All laminations loose with no varnish on exposed surfaces.
E	Laminations loose over ¼ inch from either side. Less than 25% of exposed surfaces oxidized after two days.

Appendix 4: Before Thermal Stripping: 800F Stators

Measurement	A	B	C	D	E
Core					
0	0	0	0	0	0
90	-0.0025	-0.012	-0.004	-0.0045	-0.0075
180	-0.0015	-0.009	0.003	-0.011	-0.012
270	0	0.0025	0.0015	-0.008	0.0005
Rabbet Fit					
0	0	0	0	0	0
45	-0.001	0.0005	-0.0015	0.0005	0.002
90	-0.0005	0.003	0.006	0.004	0.006
135	0.001	0	-0.006	0.002	0.0055
180	0	0.0005	0	0	0
225	-0.0005	-0.004	-0.012	0	-0.002
270	-0.0005	0.0015	0.0055	0.005	0.006
305	-0.003	-0.001	-0.006	0.002	-0.0035
Foot Flatness					
1-F2, DE	0.0025	0.012	0	0	0.0015
2-F2, ODE	0.001	0.008	0.003	0	0.006
3-F1, DE	0.0085	0.008	0	0	0.003
4-F1, ODE	0	0	0	0	0.006

Concentricity readings are taken from different points, depending on the motor. F1 is the left side of the stator facing the shaft end, F2 is the right side of the stator facing the shaft end. DE stands for Drive End, ODE stands for Opposite Drive End.

Appendix 5: After Thermal Stripping: 800F Stators

Measurement	**A**	**B**	**C**	**D**	**E**
Core					
0	0	0	0	0	0
90	-0.009	-0.0135	-0.009	-0.009	0.005
180	-0.013	-0.006	0.006	-0.0135	-0.0025
270	-0.003	0.001	-0.0015	-0.0065	0.0045
Rabbet Fit					
0	0	0	0	0	0
45	-0.0015	-0.0025	-0.0015	0.0015	0.003
90	0.001	-0.002	-0.0095	-0.006	0.006
135	0.0005	0.0025	0.005	-0.0035	0.0035
180	0	0	0	0	0
225	-0.0005	0.002	0.006	0.0005	-0.005
270	0.001	-0.0015	-0.009	-0.006	0.006
305	-0.0035	-0.0025	0.0015	-0.003	-0.0025
Foot Flatness					
1-F2, DE	0.011	0.008	0.003	0.001	0.008
2-F2, ODE	0.014	0.004	0.009	0	0.011
3-F1, DE	0.013	0.025	0.002	0	0.003
4-F1, ODE	0.002	0.01	0.011	0	0.004

Concentricity readings are taken from different points, depending on the motor. F1 is the left side of the stator facing the shaft end, F2 is the right side of the stator facing the shaft end. DE stands for Drive End, ODE stands for Opposite Drive End.