Evaluation of Induction Warming Stator Cores for Coil Removal

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***Abstract*—Past methods for warming stators for mechanical coil removal included: gas flame; oven warming; oil bath; and, electric heaters. Independent studies including the Canadian Electrical Association's "Evaluation of Electric Motor Repair Procedures," in 1995, and the US Department of the Navy (NAVSEA Motor Repair Manual), identified that these methods have no measureable impact on the core and environment. An induction warming method has been introduced with the intention to improve coil removal times and environmental impact. The purpose of this paper is to compare gas flame to inductive warming and review warming times, post-stripped core condition, and impact on the stator core on integral horsepower machines.**

Keywords-induction stripping; motor repair; stator core; environment; energy efficiency

I. Introduction

The more commonly known method for warming stators as part of a mechanical stripping method is the use of a gas or electric warming table. These tables provide a separation of the heat source and stator core to prevent any uncontrolled temperature. The temperature is observed by the operator using either a contact or infrared thermometer and the readiness for coil removal is determined manually by moving the coil head. The optimal method is to heat the insulating material by warming the core first and allowing the heat to move towards the bore of the stator. The use of an oven is also possible. However, most repair shop ovens are convection types which result in further drying and hardening of the insulation system which makes it more difficult to remove the coils.

Coils are removed using a mechanical puller. The preferred type is hydraulic, which results in more control versus pneumatic pullers. There are a variety of pulling methods, such as the one in Figure 1, which all require the coils to be warmed first.

Several independent sources site this mechanical approach as being both environmentally sound and having less impact on the core of the electric machine [1][2][3]. Labor times are similar to traditional burnoff oven methods and the total time from start to finish reduced by an average of 7-10 hours [4].

Induction bearing warmers to warm the core and warm the insulation system have been in use since the 1980s for small stators. Within the past several years control logic and methods for increasing the size of electric machines that can be stripped using induction warming have advanced. The newer systems resemble core loss testers with proprietary control strategies and temperature feedback.

Figure 1. *Hydraulic Stripping Machine*

The purpose of this paper is to compare a gas warming stripping method and induction warming method. The comparison is to include times, core loss, type of stator and frame, and general observations.

II. The Study

Six stators were selected varying in size from three horsepower to 45kW (~60hp), frame sizes from 213T to 324, and from 2 to 6 pole machines. These were first core loss tested and checked for hot spots. They were then put through the induction warming process, monitored with an infrared camera as well as the particular induction warmer's thermal control, and the core losses rechecked after cool down. The same stators were then warmed with the gas method, core losses checked and time noted.

The core loss tester was a Lexseco Model 2125E, 480 Volt, 270 Amp with 30/60/90 Volt and 2000/2000/1389 Amp outputs with a published accuracy of +/-0.25% of the reading in Watts. The infrared camera was a Fluke Ti30 with a 250°C range. The selected electric motors were as found in Table 1.

TABLE I. MOTOR STATORS FOR WARMING

Stator	HP	RPM	# of Slots	Frame Size	Ins Class	Material
1	50	3555	48	286T	F	Iron
2	35	1770	48	286T	F	Iron
3	45kW	4-Pole	48	Metric	F	Aluminum
4	25	1770	48	324	B	Iron
5	20	1760	48	256T	F	Steel
6	3	1160	36	213T	B	Iron

The core loss tester is supplied by a main transformer and it was noted that the power supply fluctuated during different times of the day. For the purposes of this paper, the raw data taken from the core loss tester will be presented with error ranges. Ambient temperatures remained between 20^{o}C and 22^{o}C throughout testing.

III. INITIAL CORE LOSS TESTS

The commercial core loss tester is set up to produce Watts/Pound (W/lb) measurements. A conversion factor of 1 W/lb to 2.20462262 Watts/kilogram (W/kg) was used to produce W/kg for this paper. Target and actual flux are determined by the instrument's software as is the W/lb output.

TABLE II. CORE LOSS OF SAMPLES BEFORE WARMING

Stator	Target Flux	Actual Flux	W/lb	W/kg	Error in W/kg
1	652	643	4.273	9.420	+/- 0.025
2	750	761	3.463	7.635	+/- 0.020
3	1086	1094	3.548	7.822	+/- 0.020
4	563	564	2.730	6.019	+/- 0.015
5	345	351	2.667	5.880	+/- 0.015
6	118	117	3.482	7.676	+/- 0.020

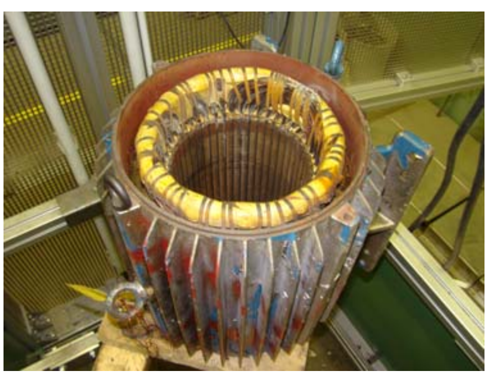

Figure 2. *Test Stator Mounted in Induction Warmer*

IV. INDUCTION WARMING AND CORE LOSSES

The stators were warmed using the induction warming machine. In addition to the built-in sensors, the cores were monitored periodically with an infrared camera in order to observe heat distribution through the core, winding and frame, as shown in Figure 3.

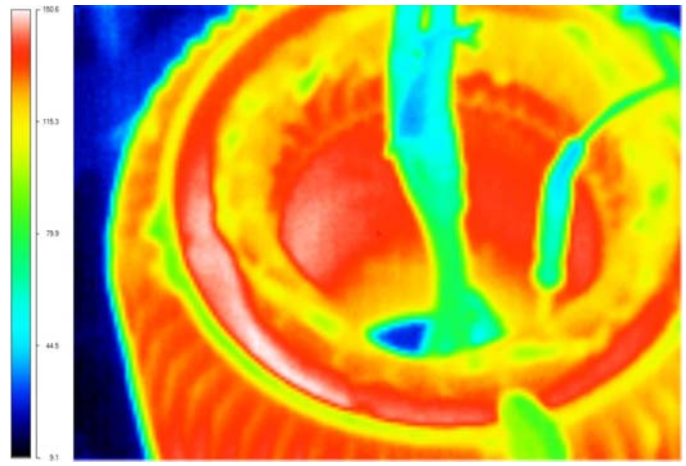

Figure 3. Infrared Image of Stator During Induction Warming

Table III shows the target temperatures, actual temperature, frame temperature and time to temperature. Table IV shows the post-induction warming core loss using the same set-up as Table II measurements.

TABLE III. INDUCTION WARMING TEMPERATURES AND TIME

Stator	Target ^{o}C	Actual ^{o}C	Frame ^{o}C	Time (Minutes)
1	195	188	~188	32
2	200	193	226	20
3	200	190	200	90
4	200	196	~196	20
5	200	169	171	45
6	200	188	197	15

TABLE IV. CORE LOSS OF SAMPLES AFTER INDUCTION WARMING

Stator	Target Flux	Actual Flux	W/lb	W/kg	Error in W/kg
1	652	646	4.203	9.266	+/- 0.025
2	750	765	3.643	8.031	+/- 0.020
3	1086	1091	3.503	7.723	+/- 0.020
4	563	574	2.770	6.107	+/- 0.015
5	345	346	2.563	5.650	+/- 0.015
6	118	119	3.617	7.974	+/- 0.020

It was noted that core losses increased in three of the stators versus the other three. In these cases the controls were set above normal levels in order to see what effect improving the warming time further would have on the stator core losses. It is believed that the rapid temperature increase may have affected the inter-laminar insulation whereas the three normal heating times and settings resulted in improved core losses. Most likely this was caused by de-stressing the cores.

A general observation was that additional caution must be taken if hot spots are detected in the laminations during the pre-heating core loss test. If a significant (>10^{o}C) hot spot is detected, the induction warming method must be applied at lower power levels and monitored closely, if the hot spot cannot be cleared prior to warming.

Figure 4 is a post-induction warming infrared of the hot spot test on one of the stators following the core loss test. As noted, no hot spots were identified. A before and after check on the feet to determine possible stator distortion was also performed and no perceived changes found, indicating that the mechanical properties of the stators were maintained.

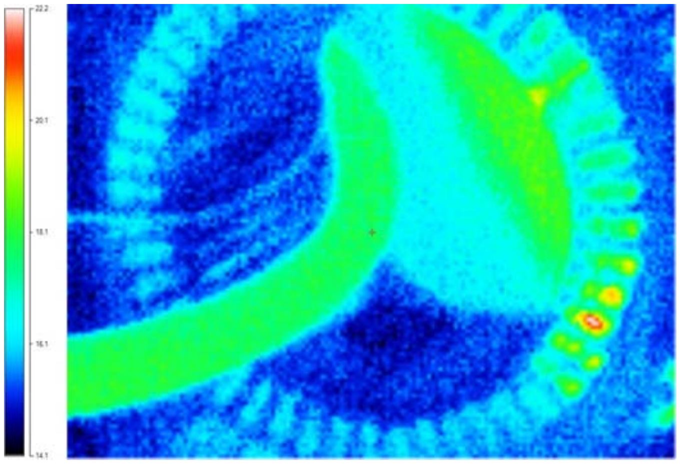

Figure 4. *Core Loss Test on Post-Induction Warming – No Hot Spots*

V. GAS WARMING METHOD

The gas warming method involves a source of gas, burners, and baffles to direct heated air towards the core of the stator. The stator is mounted vertically to act as a chimney and it warms from the outer part of the core towards the bore and from the side closest to the warming source towards the top. The arrangement is similar regardless of the warming source, other than convection oven heating.

For this portion of the study, the stators used for induction warming were re-warmed using this method. The windings remained in the stators, the temperatures were monitored through the warming process, and the times observed. The stators were then core loss tested in order to observe any changes.

TABLE V. GAS WARMING TEMPERATURES AND TIMES

Stator	Target °C	Actual °C	Frame °C	Time (Minutes)
1	195	194	194	105
2	200	195	195	125
3	200	199	199	85
4	200	201	201	50
5	200	196	196	70
6	200	195	195	35

TABLE VI. CORE LOSSES OF STATORS AFTER GAS WARMING

Stator	Target Flux	Actual Flux	W/lb	W/kg	Error in W/kg
1	652	651	4.263	9.398	+/- 0.025
2	750	759	3.491	7.696	+/- 0.020
3	1086	1068	3.306	7.288	+/- 0.020
4	563	574	2.848	6.279	+/- 0.015
5	345	347	2.604	5.741	+/- 0.015
6	118	117	3.327	7.335	+/- 0.020

It is noted that the losses have changed again with only Stator #3 continuing to increase in losses. All others had a value less than, or close to, the original core loss. No hot spots were recorded resulting from this process.

VI. REVIEW AND CONCLUSION

One of the very first production related conclusions that can be noted from the comparison is that the time required to warm a stator for stripping is greatly reduced. However, forcing the warming process faster than recommended methods, such as the under 20 minute warming in this study, can have a negative effect on core loss and, as a result, motor efficiency. Even in these cases the greatest increase noted was 3.9% (Stator #6), well under the no more than 20% allowable increase noted in IEEE Std 1068-2009. Improvements in core losses in the three stators that followed standard warming power levels for the machine used indicate that there is the potential for improvements in efficiency as a result of the methodology. A future study will review the impact of multiple warming processes on a stator using this methodology in order to compare to a Canadian Electrical Association (CEA) [1] study performed in 1994.

It was identified during the study that core location measurements are critical in case the stator housing warms enough to allow the stator core to slip. This should be a standard in any stripping process and is worth noting when mechanical stripping methods are used. No stator core movement was identified during the study.

While studies, including the previously mentioned CEA study, identify the gas warming method as having no negative environmental impact, the induction warming method eliminates any of the low level emissions that do exist in the older method. Both methods eliminate the larger amounts of green house gasses and particulate emissions from traditional methods such as burn off ovens [5].

Outside of the study stators on machines through 1.1 Megawatt have been warmed for stripping using this method. It is expected that further development will allow continued expansion of the technology to much larger machines. Continued research including a closer look at how quickly a stator may be warmed without negative impact continues, including a correlation between the initial core loss and length of time to warm the stator.

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