Electric Motor Repair Practice Impact on Health, Reliability, Energy and Environment

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Abstract: The act of repairing or rewinding an electric motor is similar to that of performing major surgery: performed correctly, electric motor repair can return a motor to like-new, or better, conditions; performed incorrectly, it can cause unforeseen side effects damaging to the user and the environment. Sound alarmist? The US EPA attempted to bring stringent air quality standards to the use of specific repair practices and the US Department of Energy has been attempting to figure out how to maintain motor efficiency through the repair process. The impacts range from reduced electric motor efficiency, which increases operating costs, decreases reliability and dramatically increases greenhouse gas emissions to the local environment; effects which medical studies show can result in physiological and psychological injury. There are repair methodologies that are used to reduce and eliminate these issues combined under the term 'Motor Safe Repair,' which has the added benefit of faster turnaround times. The trade-off is investment by the motor repair vendor. In this white paper we will discuss the methodologies performed through the Dreisilker Motor Safe Repair process and their impact on energy, environment, reliability and health.

Introduction

In a study called "Achieving More with Less: Efficiency and Economics of Motor Decision Tools,"[1] it was identified that 50% of new motors fail in seven years and 50% of rewinds last only 3.5 years in a study performed by Weyerhaeuser. The result supports the concept that there is a 'half-life' of motor repair. In an EPRI study performed in the early 1980s[2], there were 1,472 failures across an inspection of 1,052 motors. In effect, 420 failures represented two, or more, failures of the 1,052 motors in a one year period. Why did this occur and why has this number remained fairly consistent from the 1980s through the present time? In fact, it was noted in an IEEE Study[3] that the failure rates had increased since a 1973 Study on the same subject.[4]

This problem had been a major topic within the electric machine and engineering community for decades prior to the advent of the Energy Policy Act of 1992 (EPACT), which brought the subject to the forefront. In particular was the discussion of repair versus replace and the identification through a number of studies related to the impact on efficiency through motor repair.

The Studies

In 1991, Ontario Hydro performed an experiment in which they identically failed 9 of ten standard efficiency, 20 horsepower motors.[5] These were then sent, blind, to nine separate electric motor repair facilities. When returned and tested, it was found that the average loss of efficiency was 1.1%, with the greatest reduction at 3.4%. The increase in losses averaged 2.2%, with a maximum of 46%.

In April of 1993, BC Hydro published a study on the repair of energy efficient electric motors.[6] In this case, eleven 20 horsepower electric motors were used with 10 being failed identically and sent out blind. When returned it was determined that the average decrease in efficiency was 0.5% with variable causes, although the majority was increased friction and windage (i.e.: bearings).

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[1] Advanced Energy, Achieving More with Less: Efficiency and Economics of Motor Decision Tools, Advanced Energy, USA, 2006

[2] Albrecht, Appiarius, McCoy, Owen and Sharma, "Assessment of the Reliability of Motors In Utility Applications – Updated," IEEE Transactions on Energy Conversion, Vol. EC-1, No. 1, March, 1986.

[3] Motor Reliability Working Group, "Report of Large Motor Reliability Survey of Industrial and Commercial Installations, Part 1," IEEE Transactions on Industry Applications, Vol. IA-21, No. 4, July/August, 1985

[4] IEEE Committee Report, "Report on Reliability Survey of Industrial Plants, Part 1: Reliability of Electrical Equipment," IEEE Transactions on Industry Applications, Vol. IA-10, No. 2, March/April, 1974

[5] Ontario Hydro, Rewound Motor Efficiency, TP-91-125, Ontario, 1991

[6] BC Hydro, Rewound High Efficiency Motor Performance, M101, British Columbia, 1993

In 1994, Hydro Quebec performed a study for the Canadian Electrical Association (CEA) which was compiled by Demand Side Research of Vancouver, BC (CEA Study).[7] In this study, 50 horsepower stators were stripped of copper using burnout ovens and mechanical stripping and were rewound. The process was repeated three times and evaluated following exacting procedures as well as burnout temperatures from 650F to 800F. Even though the Dreisilker/Thumm mechanical stripping process was performed incorrectly using an oven and too low temperatures, the core did not 'splay' as expected by the experimenters. In addition, it was noted by researchers that the burnout process produced significant ash while the mechanical method appeared to be 'environmentally clean.'

Figure 1: Stator Stripped In Burnout Oven

Utilizing the findings from the three studies, the US DOE recognized an average of 1% of loss of efficiency per rewind. However, the three studies left out an important factor in the coil removal process: what is the mechanical impact of the burnout process on the stator itself?

In a study published in 1997[8] it was found that the different frame materials distorted across all frame sizes to a degree depending upon temperature. At 650F the distortion was significant for steel and aluminum and at 800F it was significant regardless of material. The impact related to air gap distortion and increased soft foot.

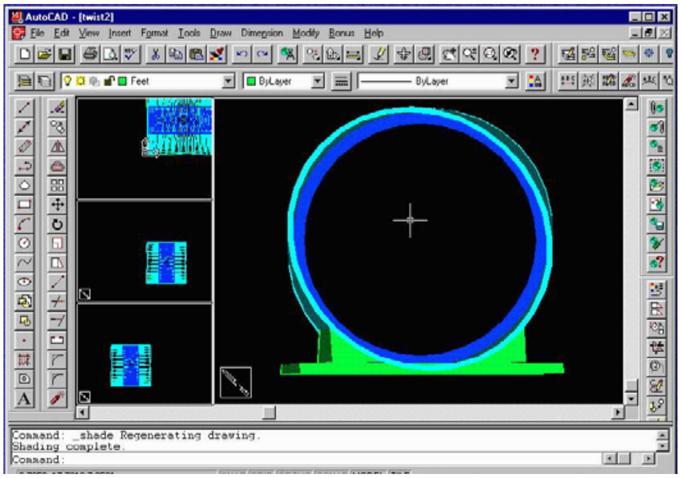

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Figure 2: Distorted Frame Mapping from Study

Also published in 1997 were the results of a review of motor repair practices for inverter duty applications.[9] This study reviewed the impact of varnishing methods on winding failures in variable frequency drive applications. The results were surprising, but made a lot of sense: trickle impregnation was the best methodology, dip and bake was effective, and vacuum pressure impregnation (VPI) was the least effective in preventing partial discharge in random wound motors.

Environmental and Health Impact

After the turn of the Century, two more items became important in relation to the motor repair community. The first was greenhouse gas emissions and the second was an emission impact based upon health. While it was considered in the 1990s, the impact of greenhouse

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[7] Demand Side Energy, Evaluation of Electric Motor Repair Procedures Guidebook, CEA 9205 U 984, 1994

[8] Penrose, Howard W and Dreisilker, Leo F, "The Mechanical Effects from Thermal Stripping Induction Motor Stators," 1997 EIC/EMCWA Conference Proceedings, IEEE, 1997

[9] Penrose, Howard W, "Electric Motor Repair for Low Voltage Induction Motors in PWM Inverter Duty Environments," 1997 EIC/EMCWA Conference Proceedings, IEEE, 1997

gas emissions, in particular carbon-based emissions, became a public concern in the 2000s. By 2010, the physiological and psychological impact of incinerator emissions based upon heavy metals, gasses, and ash hit the forefront and generated significant negative response from the motor repair and burnout oven community.[10]

Figure 3: Burned Out 150 hp Stator

The increase in kilowatts required to feed reduced efficiency in an electric motor relates directly back to greenhouse gas emissions put out by the energy supplier. The increase in CO2 emissions by kWh is 1.363lbs and in MWh is 0.606 Tons. This means that a repaired 150 horsepower electric motor that loses 1% of efficiency, or 94.5% to 93.5% operating at full load 8,760 hours per year will have an increase in kWh of:[11]

$$150hp * \frac{0.746kW}{hp} * 8760 * \left(\frac{1}{0.935} - \frac{1}{0.945}\right) = 11{,}094kWh$$

Equation 1: Example of 150hp with 1% loss of efficiency

Converted to MWh, this would be 11.094MWh resulting in an increase of 6.7 Tons CO2 per year from just this one motor. In a few cases we have seen claims that the increase might 'only' be 0.5% per rewind, which still results in 3.3 Tons CO2 per year.

In addition to this concern, both the US EPA and CEA study noted ash emissions from the use of burnout methods in industry, including electric motor repair. It is noted that the conversion from a solid material to ash results in the same amount of material, just broken down into gasses and ash. As noted in the 4th Report of the British Society for Ecological Medicine:[12]

> *Recent research has confirmed that particulate pollution, especially the fine particulate pollution, which is typical of incinerator emissions, is an important contributor to heart disease, lung cancer, and an assortment of other diseases, and causes a linear increase in mortality. The latest research has found there is a much greater effect on mortality than previously thought and implies that incinerators will cause increases in cardiovascular and cerebrovascular morbidity and mortality with both short-term and long-term exposure. Particulates from incinerators will be especially hazardous due to the toxic chemicals attached to them….*
>
> *Other pollutants emitted by incinerators include heavy metals and a large variety of organic chemicals. These substances include known carcinogens, endocrine disruptors, and substances that can attach to genes, alter behavior, damage the immune system, and decrease intelligence. There appears to be no threshold for some of these effects, such as endocrine disruption. The dangers of these are self-evident. Some of these compounds have been detected hundreds to thousands of miles away from their source.*

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[10] US EPA, Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units, EPA-HQ-OAR-2003-0119, 40 CFR Part 60, 2010

[11] Penrose, Howard W, "Don't Allow Motor Repair Practices to Degrade Motor Efficiency, " PlantServices.com, 2008

[12] Thompson and Anthony, The Health Effects of Waste Incinerators: 4th Report of the British Society for Ecological Medicine, 2nd Edition, June 2008

The range of incinerators covered under this study included municipal to parts cleaning incinerators. Their recommendation was that no further incinerators be built. The primary focus, here, relates to the fine particulate noted in the CEA study, in particular, which used the latest technology burnout process. Other contaminants depend on the insulation materials, stator materials, paints, and contaminants associated with the electric motor.

Comprehensive Impact of Core Losses

In 1984, David C. Montgomery published a paper which identified the impacts of core loss increases of 50%, 100%, 150% and 200% and related it to temperature rise, resulting insulation life, and impact on grease/bearing life. The machine example used was a 50 horsepower, 3600 RPM drip proof motor.[13] He also related that the impact is greater as the motor size increases.

Core Loss Increase	Watts/lb Increase	Temp Rise Increase	% Potential Insulation Life	Approx. Grease Life
50%	515	7C	62%	85%
100%	1030	14C	38%	69%
150%	1545	21C	24%	58%
200%	2060	29C	14%	46%

Table 1: Impact of Increased Core Losses on Motor Reliability

It is important to note that in the 150 horsepower example given in Equation 1, a two amp increase from 179 Amps to 181 Amps related an increased core loss of 97% which, based upon Table 1, would help identify a 'half-life' of repair. Through 'traditional' repair practices increases in current before and after repair can be significantly higher. This is due to a reduced power factor as the core steel must be fed more energy when developing magnetic fields.

Other Impacts of Motor Repair

In 2003, a joint project by EASA and AEMT called "The Effect of Repair/Rewinding on Motor Efficiency,"[14] identified a number of practices that can impact motor efficiency. As noted in this introduction, a fair amount of the focus was on controlling burnout oven temperatures and how to order equipment in the burnout oven. *It is equally important to identify that the burnout oven process was the only process reviewed in the repair study.*

The impacts outlined in the report included:

1. Stator Core Losses
    a. Excessive heating during burnout
    b. Mechanical damage to core
2. Rotor Losses
    a. Machining rotor
    b. Damage to the rotor
    c. Improper rotor bar replacement
3. Friction and Windage
    a. Over greasing
    b. Journal and housing fits
    c. Seals
    d. Bearings
    e. Operating temperature
4. Stray Losses
    a. Damage to air gap surfaces
    b. Uneven air gap
    c. Damage to end laminations
5. Stator Losses
    a. Changing wire size
    b. Changing number of turns
    c. Converting from concentric to lap

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[13] Montgomery, David, "The Motor Rewind Issue – A New Look," IEEE Transactions on Industry Applications, Vol IA-20, No. 5, September/October 1984

[14] EASA/AEMT, The Effect of Repair/Rewinding on Motor Efficiency, Electrical Apparatus Service Association, Inc. and Association of Electrical and Mechanical Trades, Inc., USA and UK, 2003

Overview

All of the studies outlined in the introduction recommend or imply the need for excellent motor repair practices and standards. These must include all aspects of the repair both through the rewind process and standard overhauls. Modifications and substandard repair practices have a direct impact on health, machine reliability, energy and environment.

Within the following pages of this white paper we shall outline the Dreisilker Motor Safe Repair solution, including advances in the Dreisilker practice. While traditional repair practices have remained unchanged and unimproved for close to a century, with few exceptions, the Dreisilker Motor Safe Repair practice has continued to improve with focus on health, reliability, energy and environment as a focus.

Dreisilker Motor Safe Repair Overview

The concept of the Dreisilker Motor Safe Repair method is to ensure an environmentally sound, healthy, reliable and energy efficient electric motor repair every time. This is accomplished through precision repair practices summarized as follows:

1. Overall
    a. Communication through the process
    b. Documentation including repair reporting
    c. Following recognized standards
    d. Incoming and outgoing digital photos
    e. Repair report with Cause of Failure
2. All information related to the machine is recorded including special instructions and known issues.
3. The machine is disassembled and inspected
    a. Stator winding tested visually and electrically
    b. Mechanical fits are measured and inspected
    c. All components are inspected, as required
4. Machining repairs performed, as required
    a. Weld and turn
    b. Sleeve
    c. Make new
5. Rewind practice, as required
    a. Check connections
    b. Remove coils using Dreisilker/Thumm method or Induction Stripping method
    c. Insulate with Class H materials
    d. Coils wound with automatic auto-tension winding machines
    e. Conductor sizes and winding style duplicated unless otherwise agreed or requested
    f. Trickle, Dip and Bake, VPI, Or UltraSeal winding
6. All rotors and associated rotating parts are precision balanced.
7. Bearings checked and replaced using induction warming or special manufacturers' devices
    a. Bearings duplicated
    b. Original manufacturer's specs where available
    c. Greased
8. All parts cleaned and painted/primed
9. Assembled and tested
    a. Testing performed 30 minutes unloaded
    b. Loaded when requested (all DC machines loaded)
10. Painted to original or requested color as well as for application (i.e.: food processing, rolling table motors, etc.).

Machine Incoming

Communication is extremely important in any process. This includes both internal and communication with the machine owner related to all aspects of the repair. As many communications are routine, they are included as part of a detailed quality control process. Additional communications would include such things as pick-up and delivery expectations, the urgency of the repair, information on the events surrounding the failure, changes in delivery, etc.

Incoming pictures are important to take from multiple angles. This provides the ability to compare the machine before it is returned to ensure that all components are included. It also provides a map in case issues come up in relation to the assembly of the motor and orientation of external components. Using digital photos also allow technicians to provide additional information on unusual causes of failure.


Figure 4: Incoming Motor Picture

Taking complete motor and nameplate information and recording it along with any instructions and communications for production and technicians. This also provides another phase in determining repair versus replace decisions. When necessary, an assembled test of the motor using an ALL-TEST Pro 33® or SKF/Baker AWA-IV® in order to determine if the repair is a rewind. This is normally done upon receipt with borderline motors providing a faster repair versus replace decision opportunity.

Disassembly and Inspection of the Machine

Components are marked and anything special is noted and/or photographed. When possible, the motor is tested and then run in order to detect any unusual conditions, then it is disassembled. The conditions of all machined components are checked and conditions noted on test forms. If the windings are not obviously in poor condition, then they are tested using:

1. Low ohm resistance check
2. Insulation resistance
3. Dielectric absorption or polarization index
4. High potential test
5. Surge comparison test
6. ALL-TEST 4 Pro 2000® when required
7. Energized spin test

The visual inspection of windings and mechanical components carry as much weight as the electrical and mechanical tests. A failed visual inspection is a failed component.


Figure 5: Visual Inspection of Winding

Machining Repairs

All of the mechanical fits must be inspected. Any measuring instruments used must be calibrated. The critical areas that effect both efficiency and reliability include the housings and journals with shaft runout and dimensions effecting reliability. If the fits of the housings and journals are too tight or too loose, both the efficiency and bearing life will be significantly reduced.

There are several ways to return bearing fits, which include:

- Peening: this is the practice of punching or marring the mechanical fit to create a tighter fit. This practice is not recommended for repair as it is uncontrolled. There is life reduction as the internal surfaces of the bearing emulate the shape and roughness of the housing or journal.

- Metalizing: consists of a one or two-part spray process that requires metal to be removed first, the surface machined and then the material to be sprayed on. This process is susceptible to separation from the material to which it is attached to in instances of non-symmetrical pressure, such as pulley application or misalignment, or when the surfaces have not been properly repaired. This practice should not be used for world-class energy or reliable motor repair.
- Welding: similar to metallizing. However, it creates a strong metal-to-metal bond when properly applied. Should only be performed on direct drive applications. If a repair requires adding metal, this is the preferred method.

Figure 6: Machining Components

- Sleeving: is the process of returning fits by machining and sleeving a motor shaft or housing. This results in a more accurate method of motor repair that allows for more control and less chance of chatter.
- Chrome and Grind: is a method used to place a relatively thin layer of chroming on a fit, usually a shaft, especially for high precision fits, high speed applications and hydrodynamic bearing journal surfaces.
- Refabrication: while expensive, this method is the best for machining severely worn parts, shafts in particular.

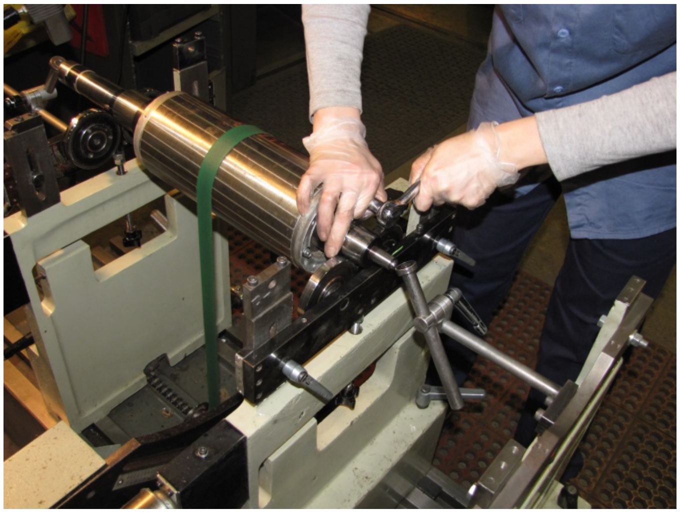

Figure 7: Balancing Rotor

Ball, roller and thrust bearings must always be replaced during the repair process, with few exceptions. Babbitt style bearings should be evaluated and either repaired or replaced if the surfaces are damaged or there is too much clearance.

Coil Removal Processes

Assuming the machine requires a rewind repair the original windings will have to be ‘stripped,’ meaning the copper windings will have to be removed before re-insulating and rewinding the motor. As noted by organizations and researchers, this has a significant potential impact on the efficiency and reliability of an electric motor. The best practice is to perform a core loss test before and after the stator is stripped and the wattage per pound recorded. A successful coil removal process results when there is either no increase in core loss or the loss decreases.

In all of the different practices one end of the coil winding is removed. The length of the coil end turns must be measured first and any connection or other information collected and recorded.

- Direct Flame: a flame from a torch or other source is directed into the core and winding. In some cases, the stator is physically placed in a bonfire. The temperature is uncontrolled and severe damage to the core will occur. The winding is reduced to ash and the winding removed.
- Chemical Stripping: the core is lowered into a chlorinated solvent bath and kept submerged until the varnish is dissolved enough for coil removal. Chemical stripping is ineffective in many cases, such as with overloaded stators and form windings. The chlorinated solvent presents health, environmental, and disposal problems. In some cases, the solvent is not completely removed when the stator is rewound and the solvent works against the new motor insulation.
- Burnout: The stator is placed into a burnout oven that is set for a recommended temperature of 650F. It is kept at this temperature until all of the varnish and insulating materials are turned to ash (8 hours or more). If the temperature exceeds this, damage to the stator core and frame will result, reducing motor efficiency and reliability. Gasses and other byproducts are exhausted through a 'smoke stack' into the atmosphere.

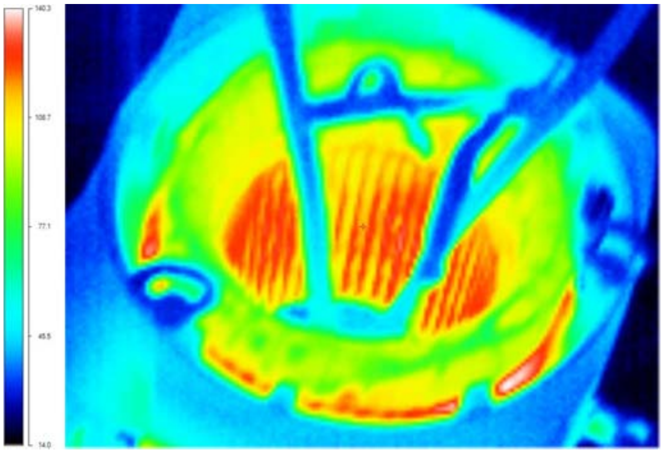

Figure 8: Infrared Monitoring of Induction Stripping Method

- Mechanical Stripping (Dreisilker/Thumm Method): using a heat source, such as gas jets, a distance away from the core, the back iron and insulation is warmed until the windings become soft and pliable (approximately 10C above the insulation class of the varnish insulation). The coils and insulation are removed using a slow, steady hydraulic pull. Temperatures remain low, stripping times extremely fast (i.e.: 2.5 hours for a 350hp motor), and there are no airborne products or disposal problems. "Warming and pulling is the preferred method for stripping the stator. This method is to be used on motors with sealed insulation systems and can also be used with aluminum frame motors. This method uses lower temperatures, so it does not damage the laminations."[15]
- Induction Stripping: improved version of the Dreisilker/Thumm method introduced in 2012. Improved stripping times and improves core losses, in most cases, with no increase in core losses recorded.[16]

Once the windings have been removed, the stator may have to be cleaned or repaired. Cleaning may be done with file, scraper and/or glass beads or corn cob. In some cases, copper may have fused itself to the core which would have to be removed or previous damage to the core due to poor stripping practices may require core repair or replacement.

Stator Winding

Common rewind practice dictates that the insulation system used be of Class F insulating material or better, depending on the original insulation class. The most common used is Class H to allow the motor insulation to survive any hot-spots that may have been missed during core loss testing and by those repair shops that do not perform core loss testing. The additional benefit if the insulation class is improved is to extend the thermal life of the electric motor.

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[15] US Navy, Technical Manual; Electrical Machinery Repair; Volume 1, Electric Motor, Shop Procedures Manual, 0910-LP-108-0244, S6260-BJ-GTP-010, NAVSEA, July 2009

[16] Dreisilker, Leo F., Penrose, Howard W., "Evaluation of Induction Warming Stator Coils for Coil Removal," Conference Record of the 2012 IEEE International Symposium on Electrical Insulation, IEEE, 2012

It is best practice to rewind the motor with the same wire size and type of coil winding (lap or concentric). In some cases this is not possible and care must be taken in converting from one style to the other. If the wire size must change the cross section must be maintained. The rule of thumb for converting is that for every three wire sizes smaller, two wires will be equivalent. For instance, if one number 15 wire is required, two number 18 wires may have to suffice. If the total cross section is decreased, then the I^2R losses will increase, decreasing motor efficiency and reliability; if it is made larger, there is the chance of increasing the motor's inrush current causing nuisance tripping.

Figure 9: Winding Medium Voltage Motor

- Hand-Winding: performed with a 'tower-type' winding machine and mechanical counter. The winding technician must maintain correct tensioning and layering of the coils, or the coils will be difficult to lay in the stator slots. In the worst-case, there will be wires crossing, which will increase the turn-to-turn potential in the wire, creating an area that may short under certain conditions. Improper tensioning of the coils may cause changes to the circuit resistance and impedance resulting in unbalances that will reduce the reliability of the machine. Hand winding is the least reliable method of winding.
- Automatic coil winding machines: maintain constant tension and proper count of the coils. Still requires a technician to observe operation, but will succeed in reducing labor time.
- Computer coil winding machines: the technician is free to perform other tasks while the machine winds the stator coils. Proper tension and turn count are maintained.
- Form Coil Manufacturing: Selection of materials is critical as is utilizing the best turn-strength and coil wall thickness (layers of tape).

The coils are inserted by hand or, in the case of concentric windings, may be inserted with the help of machines. It is important to include phase insulation in random windings and 'in betweens' in the slots to ensure coil and phase shorts are less likely to occur. In small machines some repair shops will leave this insulation out in order to reduce time and material costs. However, this practice reduces the reliability of the machine, especially when placed in inverter environments.

In all electric motors mechanical strength of the winding is critical to reliability. Random wound machines must have 'tie string' placed through every slot in order to secure all of the conductors and strengthen the end turns. In form wound stators, blocking, surge rope, and other means are used in order to secure the windings and reduce coil end movement.

Post Winding Tests

Insulation resistance tests and continuity tests are performed to ensure that the winding is in a condition that insulation 'stress tests' can be performed in order to evaluate the suitability of the winding for operation. The value of 5 MegOhms for windings rated under 600Volts and 100 MegOhms for form wound machines is used to determine suitability for high voltage testing. Simple resistance tests using a 4-wire Kelvin bridge, or similar, usually calls for an unbalance of no more than 3-5%. Impedance tests should be within 3% phase to phase with dielectric absorption or polarization index tests performed in order to verify that contaminants and moisture are not present in the coils. Once the pre-tests are complete, then the stress/proof tests can be performed.

The first would be a DC high potential test performed in order to determine the suitability of the ground wall insulation. This is performed at twice the nameplate voltage plus 1000 Volts with the total times 1.7. The leakage current should be tracked during the application of the test voltage and should not sharply increase with the total voltage applied for one minute. The winding is discharged and then a surge comparison test is performed to twice the rated voltage plus 1000 Volts in which the phases must balance. Once complete, a spin test is performed in which voltage is applied until the stator is using rated nameplate current, usually about 10% of the nameplate voltage. Then a false rotor or ball bearing is spun inside the stator in order to identify that there are no reversed coils.

Figure 10: Wound and Preparing for Testing

All test data must be recorded for future reference.

Varnish Insulation Systems

The final step in the rewind process is to varnish the stator, in effect 'gluing' the materials together. As with the slot insulation system, it is common practice to use a Class F or H varnish insulation system. As per IEEE Std 1-1986[17], the actual rating for the complete insulation system is rated upon the lowest insulation class used in the machine. For instance, if the slot liner and phase insulation is Class H, the varnish is Class N, and the lead wire is Class B, the complete insulation system is Class B.

Figure 11: Testing Stator

- Dip and Bake: the stator is pre-heated, then dipped into a tank full of insulating varnish. This is normally done a minimum of two times to ensure a full coat of varnish. Care must be taken as voids, which may collect moisture or other contaminants, may be left within the stator coils. All of the surfaces including machined areas are covered with varnish which must be removed. While slots are receiving a reasonable amount of varnish to allow for heat conductions, a blanket of varnish collects on the outer surface of the motor reducing the ability to cool itself.
- Trickle Varnishing: the stator is placed on a turntable and connected to three-phase power.

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[17] IEEE, <u>IEEE Std 1-1986: IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and the Evaluation of Electrical Insulation</u>, IEEE Standards, 1992

This both serves as a heating source for the windings as well as an additional powered test. The stator is heated horizontally and monitored with infrared sensors. Once the windings have reached a pre-determined temperature, the turntable is tilted to 35-45 degrees and varnish is trickled onto the windings through several tubes. The varnish is drawn through the slots by both gravity and capillary action, creating a solid slot fill and it also collects on the end turns. In considerably less time than two dips and bakes, the stator windings will have the equivalent of three dips and bakes (1-2 hours versus 16-20 hours). There is little to no excessive varnish, decreasing cleaning time and varnish waste. Using a pour-through varnish does not result in the same results.

- Vacuum Pressure Impregnation: due to expense and effectiveness, this process is not recommended for low voltage stators, but is a must for medium voltage, form-wound cores. It consists of a voidless slot fill (in form wound only). The stator is warmed in an oven then placed in a dry tank. A vacuum is drawn in the tank for a specific period of time, usually 4 hours, then varnish is flooded into the tank. A pressure is immediately applied for a time to be determined with monitoring in the form of capacitance on the winding. Just as with dip and bake, the stator is then placed in an oven for curing.

Final Tests

Once the stator has been varnished and cleaned, noting that abrasives on the stator laminations may cause shorting between laminations, the motor is assembled. An insulation resistance test is performed once the motor has been assembled and should measure at least a GigOhm. The electric motor is then tested at no-load and all rated voltages for 30 minutes. The current and voltage are measured and recorded. The temperature of the stator and bearings are checked and should remain cool to the touch. The measured currents readings are compared and, if found to be in excess of 5% of each other, the phases are rotated and rechecked. If the unbalance remains in the same phase at the motor, then there is an issue with the motor, otherwise there is an issue with the supply.

Figure 12: Final Testing Motor

Motor current should also not exceed the nameplate rating during a no-load test. The rule of thumb for two-, four-, and six-pole motors is that the no-load current shall be in the area of 25-50% of the nameplate.

Once all the running tests are complete and acceptable, the motor is electrically and mechanically suitable for operation. The above is not all-inclusive and additional tests are normally performed and may be requested by the motor owner.

Conclusions

As shown, there is more to an electric motor repair than a good-looking paint job. The type and quality of work required for returning a 'good-as-new' electric motor following a rewind repair is extensive. It is now apparent that a motor repair customer must work closely with a motor repair center to ensure that the equipment that is sent out for rewind is handled in a manner that does not reduce efficiency, reliability, nor have a negative impact on health and the environment.

The methods outlined in this paper ensure improved reliability, emissions, and efficiency including reducing the health impacts on the local community. The summary of an outstanding repair includes:

- Quality control program in place.
- Lifting equipment capable of handling the motors and generators the end-user wishes to have repaired.
- Field repair and testing capabilities to include field balancing, vibration analysis, infrared testing, installation and removal, laser alignment, and controls support.

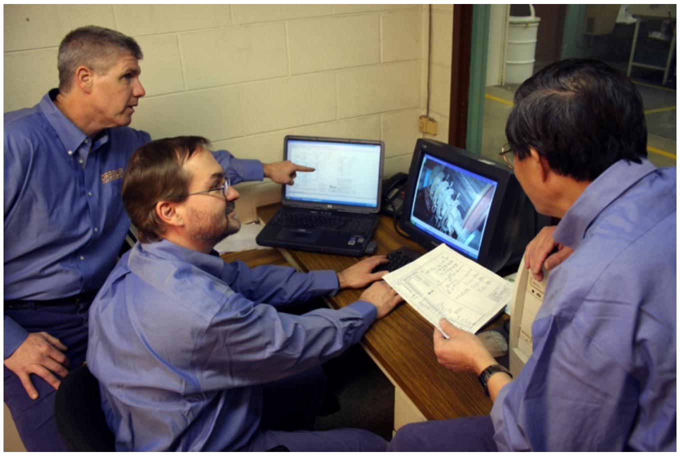

Figure 13: Engineering and Service

- Dedicated customer service representatives and in-house engineering staff.
- A repair versus replace policy agreed to between the repair shop and end user.
- In-house, calibrated test equipment suitable to perform all previously outlined testing.
- In-house machine tooling and balancing capabilities to handle the equipment. Machining should include policies not to peen or metalize journals and housings.
- In-house ability to test motors.
- A mechanical stripping process with induction warming as an option.
- Automatic or computer controlled winding equipment.
- Utilize Class H insulation systems, or as required.
- Trickle varnish machines, dip and bake capabilities, and Vacuum Pressure Impregnation (VPI) equipment.
- Access to the appropriate NEMA, IEEE, AFBMA, and ASME, standards governing the repair of electric motors.

Figure 14: Field Repair of Generator

The correct selection of a repair facility protects the health, safety, reliability and efficiency of your equipment and will go a long way to making your company a solid global citizen.

About the Author

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