# The Impact of Traditional Motor Repair Practices on Energy and Environment Including Meeting the Minimum Requirements of IEEE 1068-2009

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**Abstract: Electric motor repair has the potential to impact future motor life, energy efficiency and the environmental impact of the machine (electric motor, to be used interchangeably in this paper) even when meeting modern motor repair standards. In this paper we shall outline the impact of repair following repair standards versus traditional repair and relate both scenarios to Precision Motor Repair (PMR), or Reliability-Centered Motor Repair Practices (RCMRP). The outline of impacts will be based upon the allowable limits by standards, observations following traditional practices, the impacts measured through PMR, based upon three similar machines in which an IEEE 112 Method B (segregated loss) was performed. These evaluations will be based upon expectations of impact to new core steels in premium and energy efficient machines.**

## Introduction

In the 1970s and 1980s concern of the impact on efficiency due to core losses and repair practices became a concern in a number of industries. Both trade associations and new equipment manufacturers performed studies related to the impact of core losses due to burnout oven techniques and temperature. Recommendations on improving efficiency through reducing certain losses were proposed by motor repair trade associations. A few companies reviewed the potential of reducing these losses through alternate coil removal practices such as the Dreisilker/Thumm mechanical removal process. The studies of impact continued in the 1990s which included the Canadian Electrical Association[1] study of the impact of motor repair practices on a variety of losses when repair processes are tightly controlled. Additional work on the mechanical impact of traditional repair practices continued with research and published papers related to changes in soft foot and air gap[2], followed by additional work on motor repair impact by EASA (Electrical Apparatus Service Association) published in 2003.[3] Conclusions of the various studies were published with some repair facilities misinterpreting them as allowing for even more stressful repair practices. In particular, the relation to 680F and 750F for high grade core steel in burnout is related to the core temperature of the machine in which it has been documented by the cited studies that the core is an average of 120F higher than the oven temperature. Therefore, setting of temperatures at 650F and 750F exceed the acceptable limits as well as the loading of more than one stator at a time in an oven.

In this paper we will discuss the relationship of repair to the IEEE Std 1068-2010[4], traditional repair practices, observations and Precision Motor Repair (PMR) practices. The motors used in the examples are three electric motors evaluated for efficiency using IEEE Std 112-2004[5] Method B (Segregated Losses) at the Dreisilker Electric Motors, Inc. Glen Ellyn, Illinois facility. The changes applied to the losses and evaluated efficiency will be based upon allowable limits by standards and then field observed changes to machines that can be related back to changes in losses. The various impacts will then be related to Greenhouse Gas

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[1] CEA, Evaluation of Electric Motor Repair Procedures, CEA 9205 U 984, 1995

[2] IEEE EIC-1997, "The Mechanical Effects from Thermal Stripping Induction Motor Stators," EIC-1997 Proceedings, IEEE, 1997.

[3] EASA/AEMT, The Effect of Repairing/Rewinding on Motor Efficiency, EASA/AEMT, 2003

[4] IEEE Std 1068-2010, IEEE Standard for the Repair and Rewinding of AC Electric Motors in the Petroleum, Chemical and Process Industries, IEEE, 2010

[5] IEEE Std 112-2004, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators, IEEE, 2004

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Emissions as well as providing an understanding of the result related to the 'half-life of motor repair' determined within the reliability industry.

## Evaluated Machines

The three machines evaluated were vertical, solid shaft machines, 150 horsepower, 3 phase, 460 Volts AC, 167 Amp, 1780 RPM, being evaluated for efficiency at load points 25, 50, 75, 100, and 125% of load per IEEE Std 112 Method B. The dynamometer used is a 300 horsepower, 6000 RPM, eddy-current, water-cooled system, in which dynamometer losses were accounted for in each test. Electrical Data was collected using a micro-Ohm meter, ALL-TEST IV PRO 2000, and ALL-TEST Pro OL (ATPOL II) system.

Figure 1: Motor Under Test (Technician Tony Chau – left – and Evening Shift Production Manager Larry Ninis – right)

Figure 2: Electrical Data Being Collected (Dr. Penrose)

The results of testing are found in Tables 1-3 and are rounded for the purposes of this paper.

Table 1: Motor 1 (MTR1)

| % load | Power In (kW) | Losses (Watts) | Output (kW) | Efficiency |
|---|---|---|---|---|
| 125 | 150 | 9508 | 140.5 | 93.6 |
| 100 | 121.1 | 6594 | 114.5 | 94.5 |
| 75 | 91.8 | 4404 | 87.4 | 95.2 |
| 50 | 60 | 4022 | 56 | 95.0 |
| 25 | 21.5 | 3089 | 18.4 | 90.2 |

Table 2: Motor 2 (MTR2)

| % load | Power In (kW) | Losses (Watts) | Output (kW) | Efficiency |
|---|---|---|---|---|
| 125 | 151.1 | 8667 | 142.4 | 94.3 |
| 100 | 120.8 | 6636 | 114.2 | 94.5 |
| 75 | 92.5 | 5175 | 87.3 | 94.4 |
| 50 | 62.8 | 4039 | 58.8 | 93.5 |
| 25 | 32.67 | 3340 | 29.33 | 89.8 |

Table 3: Motor 3 (MTR3)

| % load | Power In (kW) | Losses (Watts) | Output (kW) | Efficiency |
|---|---|---|---|---|
| 125 | 149.7 | 9089 | 140.6 | 93.9 |
| 100 | 120.7 | 6660 | 114 | 94.5 |
| 75 | 91.5 | 4480 | 87 | 95.1 |
| 50 | 61.2 | 3138 | 58 | 94.9 |
| 25 | 31.5 | 2257 | 29.2 | 92.8 |

It was noted that the efficiency curves (Figures 3-5) were unusual in two of the machines which provided information to compare to alternative methods for estimating efficiency, which will be shown under a different paper. The losses were slightly unique between machines which provided for confirmation testing, which identified that the methodology was correct and repeatable.

The losses to be used for the remainder of this paper shall consist of the corrected losses used for the efficiency calculation as identified in IEEE 112-2004 and the appropriate worksheets.

Figure 3: MTR1 Efficiency Curve

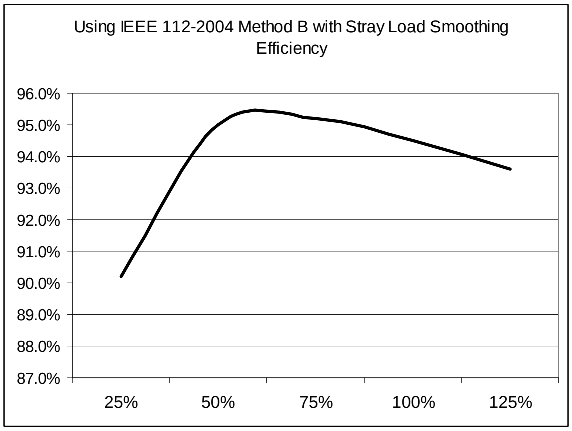



Figure 4: MTR2 Efficiency Curve

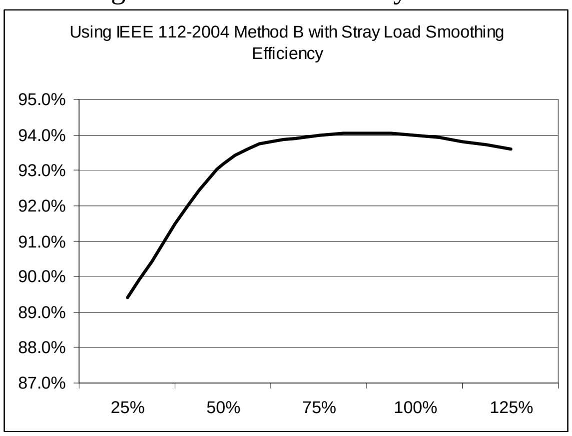
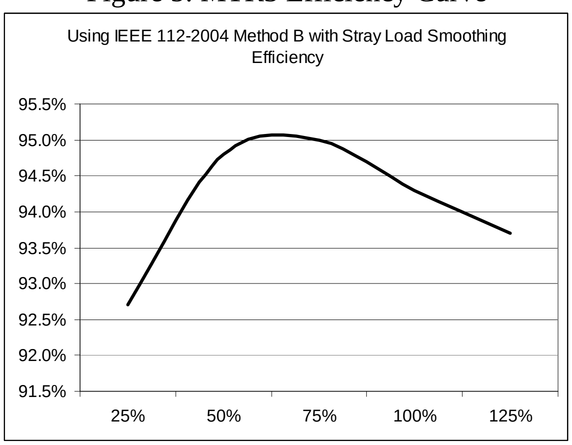



Figure 5: MTR3 Efficiency Curve




For the remainder of the paper we shall concern ourselves with the 100% load point. It is important to note that the impact of certain losses increases as load decreases from 100%. The losses are broken down as follow:

- √ Core Losses: consist of eddy-current and hysteresis losses. Eddy current losses are the result of stray currents in the core and are reduced by dividing the core into laminations insulated from each other. In effect, eddy currents losses can be considered ‘induction heating.’ Hysteresis losses are due to the resistance of the core steel to change magnetic direction. Hysteresis losses are proportional to efficiency and eddy current losses are proportional to the square of the frequency applied, which becomes important in variable frequency drive applications. IEEE papers show variations in the difference between eddy current and hysteresis losses at 25% to 75% eddy currents, so we will determine 50% for the purposes of this paper. The limit for core losses per the standard cited is 6.6 Watts per pound with 3% being optimal for energy and premium efficient motors. This is considered a ‘constant’ loss in a constant frequency environment.
- √ Friction and Windage Losses: fans, bearings and surface friction of the machine. This is considered a ‘constant’ loss.
- √ Stator $I^2R$ Losses: are due to the current passing through the DC resistance of the stator. This loss varies with the amount of current (load).
- √ Rotor $I^2R$ Losses: are due to the current in the rotor as with stator $I^2R$ losses.
- √ Stray Load Losses: are all of the other losses, including magnetic fringing, not included in the above listing of losses.

The IEEE 112-2004 Method B test used for the purposes of this paper segregates the above losses with the exception of eddy current and hysteresis and the various causes of friction and windage.

All of these losses are converted to heat, meaning the less efficient the motor, the more heat produced. Increased temperature due to losses has a direct relationship to component life.

## Impact of Core Losses through Repair

As one of the more significant discussions for roughly 40 years, the impact of core losses through the repair process will be addressed first. In the case of the example, the base core losses are: MTR1 – 1396 Watts; MTR2 – 2661 Watts; and, MTR3 – 1625 Watts. As published in several Canadian Electrical Association studies (BC Hydro and Ontario Hydro repair studies), the loss of efficiency through repair varied by an average of 1% per rewind. The US Department of Energy determined that the average loss would be 0.5% efficiency per rewind. What would that mean in the case of core losses?

First, let us assume that the eddy current losses make up half of the total core losses[6]. Next, a review of IEEE Std 1068-2010 indicates that there is an allowable increase of 20% core losses per repair. If we assume that standard temperatures were applied on a premium efficient or energy efficient (efficient) motor, it can be assumed per the Canadian Electrical Association repair study that there were no changes in hysteresis losses (found through 800F and assumed up to 1,000F). That would indicate that the increased allowable losses were completely due to eddy currents and the breakdown of insulation between laminations. The changes across the three sample machines and three rewinds can be found in Table 4, the resulting efficiencies can be found in Table 5.

Table 4: Increased Core Losses within Limits at 100% Load in Watts

| | Original | 1st | 2nd | 3rd |
|---|---|---|---|---|
| MTR1 | 1396 | 1675 | 2010 | 2412 |
| MTR2 | 2661 | 3193 | 3831 | 4598 |
| MTR3 | 1625 | 1950 | 2340 | 2808 |

As noted, the increased eddy current loss in MTR1, alone, would be 279, 614, and 1016 Watts respectively.

[6] Jamil, Baldassari, Demerdash, "No Load Induction Motor Core Losses Using a Combined Finite-Element/State-Space Model," IEEE Transactions on Magnetics, September, 1992, IEEEXplore.

Table 5: Efficiency Changes due to Allowable Core Loss Increase in Percent Efficiency

| | Original | 1st | 2nd | 3rd |
|---|---|---|---|---|
| MTR1 | 94.5 | 94.3 | 94.0 | 93.7 |
| MTR2 | 94.5 | 94.0 | 93.5 | 92.9 |
| MTR3 | 94.5 | 94.2 | 93.8 | 93.5 |

Therefore, per the latest motor repair standard, the allowable increase in core losses requested by the motor repair representatives generates losses within the level estimated by the US Department of Energy through core losses alone.

The increased input necessary to generate the same loading on the dynamometer which would result in an increased current as shown in Table 6.

Table 6: Increased Current Reading Due to Losses (Total Current in Amps)

| | Original | 1st | 2nd | 3rd |
|---|---|---|---|---|
| MTR1 | 179.0 | 179.4 | 179.9 | 180.5 |
| MTR2 | 177.8 | 178.5 | 179.5 | 180.7 |
| MTR3 | 177.1 | 177.6 | 178.1 | 178.8 |

This would be the additional energy necessary to energize the additional core losses. This also would relate to a reduction in the power factor of the machine. Yet, in the repair world, it is often found that motors operate with even higher current draw when returned from standard repair.

If we assume that all other areas are equal, and we see the above 179.0 Amp motor come back and operate at 181.0 Amps after repair (minor increase compared to some), how does that relate to the treatment of my machine? The increased losses would have to be on the order of 1,353 Watts of loss in the core, or an increase of 97%! If we assume that the machine is seeing 3 Watts per pound, or the stator core is 465 lbs, then the combined losses of 2749 Watts would make the core 5.9 Watts per lb. So, this would pass a core loss test if just looking at the limit of 6.6 Watts per lb. The impact on efficiency would be a reduction to 93.4%, or a loss of 1.1% efficiency! With losses almost doubled in the core, the heat generated would significantly impact the expected life of the insulation system.

## Increased Stator $I^2R$ Losses

In the 2003 Motor Diagnostics and Motor Health Study[7], the paper research determined from US Department of Energy studies and EASA internal surveys, that 81% of motor repair shops modify windings through the repair process. 73% of the facilities made the changes for convenience, which included such things as converting from concentric to lap windings and winding modifications to make it easier to insert wire. Each of these methods impact the efficiency and reliability of the machine.

A common method to fit tight wires into the slots of efficient machines is to reduce wire size, especially where thicker ground wall and other insulations are concerned, and/or the wire enamel is thicker than original. On average, the decrease of one size (AWG) increases the resistance by 125%. The impact on the motors in this study would be as found in Table 7.

Table 7: Impact of Resistance on Losses

| | Orig Ohms | Orig Losses | New Ohms | New Losses |
|---|---|---|---|---|
| MTR1 | 0.053 | 2547 | 0.066 | 3172 |
| MTR2 | 0.04 | 1897 | 0.05 | 2371 |
| MTR3 | 0.05 | 2303 | 0.063 | 2964 |

The result of the reduced wire size would be a decrease in efficiency to: MTR1 = 94.0%; MTR2 = 94.1%; and, MTR3 = 93.9%.

## Friction and Windage

An area that was found to be interesting in the Canadian studies was the loss of 3% efficiency attributed to the change of standard bearings to contact sealed bearings. If we assume the same in the example machines of a decrease from 94.5% efficient to 91.5% efficient, then the increase in losses would relate as follow:

- √ MTR1: an increase from 197 Watts to 3633 Watts;
- √ MTR2: an increase from 225 Watts to 3624 Watts; and,
- √ MTR3: an increase from 185 Watts to 3621 Watts.

Most of the bearing related friction and windage losses would be seen in the bearings and the rest would be seen in the increased $I^2R$ losses necessary due to the general temperature increase.

## Overall Expectations from Traditional Repair Practices

The allowable core losses exist within the latest standards, the wire change is not truly accepted, but does occur and many are getting away from changing the bearings. As noted, you can keep the loss of efficiency down through the use of motor repair standards that are strictly enforced, but not eliminated. This fact has been identified through numerous studies within and outside of the industry for over the past forty years.

Using the above examples, the impact of the repairs should the motors be operating 6,000 hours per year at a cost of $10/kW demand and $0.06 per kWh following a first rewind would be, as segregated for each type of modification above:

1. Core Losses by Example (additional):
   a. MTR1:
      i. $134 per year
      ii. 1 Ton Carbon Emissions
   b. MTR2:
      i. $256 per year
      ii. 2 Tons Carbon Emissions
   c. MTR3:
      i. $156 per year
      ii. 1.2 Tons Carbon Emissions
2. Wire Resistance by Example (additional):
   a. MTR1:
      i. $300 per year
      ii. 2.3 Tons Carbon Emissions
   b. MTR2:
      i. $228 per year
      ii. 1.7 Tons Carbon Emissions
   c. MTR3:
      i. $317 per year

[7] Penrose, O'Hanlon, Motor Diagnostics and Motor Health Study, SUCCESS by DESIGN, 2003.

        ii. 2.4 Tons Carbon Emissions
3. Friction and Windage by Example (additional)
    a. MTR1 (3436 Watts)
        i. $3,710 per year
        ii. 12.5 Tons Carbon Emissions
    b. MTR2 (3399 Watts)
        i. $3,670 per year
        ii. 12.4 Tons Carbon Emissions
    c. MTR3 (3436 Watts)
        i. $3,710 per year
        ii. 12.5 Tons Carbon Emissions

In the core loss example with the increase in amp draw, the result would have been 1353 Watts which results in an annual cost increase of $1,460 per year in energy costs plus 5 tons carbon emissions per year.

The losses are generated as heat, and heat has a direct impact on the expected life of components, insulation systems, and lubricants. As there are other issues associated with the quality of repairs that would result in such losses, it can be expected that motor reliability is greatly reduced due to such practices.

## Precision Motor Repair (Conclusion)

The key to improved motor repair practices is to move beyond the standards and specifications designed to work with average motor repair facilities and have expectations for excellence. The program must include methods to eliminate the problems cited within this paper. Additional features will be covered in future papers.

To eliminate the problem with core losses, a before and after core loss test must be performed to prove no increased losses. The tolerance must be within the tolerance of the core loss tester. Any variation must be reported and agreed to by the machine owner. The method that has proven through independent tests not to increase core losses is the Dreisilker/Thumm mechanical stripping process.

It is important to understand, as well, that previous damage is difficult to mitigate and that increases to core losses by any practice following the first improper repair can be expected.

Windings must be replaced with the same wire cross section and configuration unless specifically requested otherwise. Bearings must be appropriately replaced with either original bearings or non-contact seals.

The appropriate application of Precision Motor Repair practices results in efficiencies as original or better and the potential to operate as long as the original machine. Proper PMR will also identify the original cause of failure with information provided to an organization's reliability department in order to improve system life.

## About the Author

Howard W Penrose, Ph.D., CMRP is the Vice President of Engineering and Reliability Services for Dreisilker, the Web Editor-in-Chief of the IEEE Dielectrics and Electrical Insulation Society, and the Director of Membership for the Society for Maintenance and Reliability Professionals (SMRP). He has won five consecutive UAW and General Motors People Make Quality Happen Awards (2005-2009) for energy, conservation, production, and motor management programs developed for GM facilities globally and is an SMRP Certified Maintenance and Reliability Professional (CMRP). Dr. Penrose is the author of the Axiom Business Book Award (2008 Bronze and 2009 Bronze) winning "Physical Asset Management for the Executive (Caution: Do Not Read This If You Are on an Airplane)," and the 2008 Foreword Book of the Year Finalist textbook, "Electrical Motor Diagnostics: 2nd Edition." Dr. Penrose may be contacted by email at hpenrose@dreisilker.com.