REWINDING ELECTRICAL MACHINES TO MAINTAIN ENERGY EFFICIENCY AND IMPROVE PERFORMANCE

Paper No. PCIC Energy EUR24_13

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Abstract -. Whilst replacing a motor may make economic sense and it may in some cases also have a better energy efficiency, this needs to be considered against the carbon impact of the manufacture of a new motor but also its real operating conditions.

The motor repair specification IEC 60034-23 [1] for safe area machines is not widely known but was created to specify the best practice for the overhaul and repair of electric motors to ensure efficiency is maintained. This specification is backed up by industry studies on the effect of a rewind on the motor losses across a variety of frame sizes. IEC 60079-19 [2] for motors operating in hazardous areas is more widely known and is based in the same studies.

This paper will talk through the results of these studies, some of the technical techniques and controls needed to maintain and even slightly improve efficiency. The Electrical Apparatus Service Association (EASA) has developed an accreditation scheme to ensure energy efficiency and quality based on their specification AR100 [3]. Finally, this paper will discuss how to select and audit suitable potential repairers.

Index Terms — Motor efficiency, rewind, losses

I. INTRODUCTION

A. General Introduction

Electric motors are the largest consumer of electrical power worldwide and its no surprise that there are many Minimum Energy Performance Standards (MEPS) applicable to motors in all the major global markets. In Europe the MEPS scheme has been in place for 25 years and the US Premium motor schemes since 2003.

The legislations are clear as to what can and cannot be placed on the market and motor OEMs have plenty of guidance on these matters. What is less clear is what can be done should a motor fail or need a rewind or other repair. The decision is pushed back to the End User and information about what is possible can be confusing.

B. EASA

EASA is an international trade organization with members in nearly 80 countries whose members repair and service industrial electric motors., EASA acts as a technical authority and created codes of practice for their members. They also have a highly specialized technical team who offer technical training and advice to their membership. As well as this they participate in many different standards organizations including those on maintaining efficiency.

II. Glossary

EASA - Electrical Apparatus Service Association
IEC - International Electrotechnical Commission
AEMT - Association of Electrical and Allied Trades
MEPS - Minimum Efficiency Performance Standards

III. MOTOR EFFICIENCY STANDARDS – A EUROPEAN HISTORY

A. Eff1 and Eff2 scheme

Starting in 1999 after co-operation with the EC the Eff system was launched. Motors of certain sizes and frame sizes would be classified as either Eff1, Eff2 and Eff3. Each would describe a rage of efficiencies of the kw and speed of the motor. Eff1 being the highest efficiency and Efff3 being the lowest. Table I shows these values for some common motor outputs.

This scheme was by and large voluntary and poorly policed. There were other issues around testing and in the 2000s a different system was needed.

B. IEC 60034-30 Scheme

IEC introduced 60034-30 [4] in 2008 which has classes of efficiency with IE2 being the lowest up to IE4. Figure 1 shows these values for some common outputs.

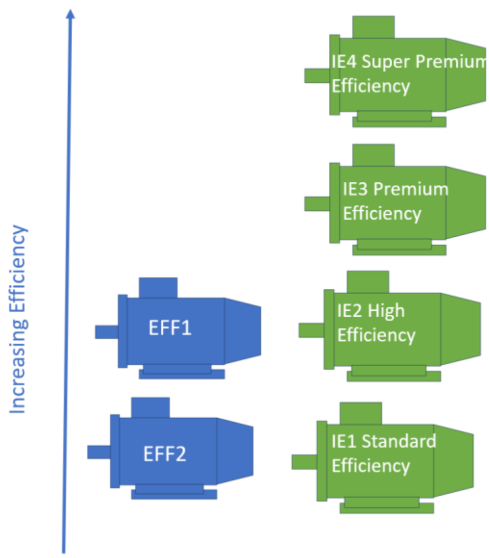

Figure 1 Efficiency Classes comparisons

This specification was superseded in 2014 by IEC 60034-30-1 to include more motor types (Ex machines etc) and has been adopted into National MEPS schemes (Minimum Efficiency Performance Standards). IEC 60034-30-2 was introduced in 2016 which covers variable speed applications up to IE5. This will be updated in 2025.

Typical efficiencies are tabulated below for some ratings at one speed. For smaller ratings it is more economic to replace rather than repair. The rating at which this becomes viable depends on many variables, availability, special construction features, verification etc.

TABLE I
Efficiencies of selected 4 pole motors

kw	IE2	IE3	IE4
11	89.8	91.4	93.3
55	93.5	94.6	95.7
110	94.5	95.4	96.3
160	94.9	95.8	96.6

C. NEMA schemes

In the US, under 10 CFR Subpart B, all motors must meet Premium efficiency class which is defined in NEMA MG1 Table 12-12 [5]

IV. TYPES OF MOTOR REPAIR

In general, electric motors are extremely reliable, the table below (to be translated) shows that after bearing failures, winding failures are the most common source of failure.

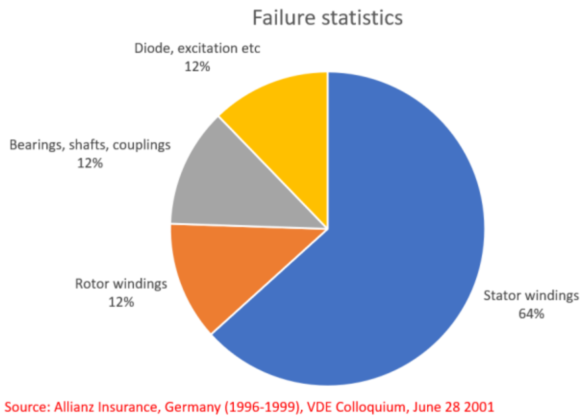

Figure 2 (Failure statistics)

V. MOTOR REWINDS

In the situation when a motor is to be rewound, the user has a decision to make over whether to replace with a new motor. The arguments for and against are well known - a replacement motor will most likely be more efficient than the original. But a rewind can be achieved in a matter of days. A well-maintained motor will last for many years and further potential site modifications and financial investment are not required (dimensions, electrical and mechanical interfaces).

If the decision is that the motor is to be rewound, then the process needs to be understood as to how that will impact the motor losses.

A. REWIND PROCESS

The process follows this general procedure:

1. The original winding is examined to also understand and prevent the real failure mode and all details recorded, these include number of wires, diameter of the copper wire and the number of turns/coil, connections etc.
2. Then the coils are removed from the core – normally using a burn out process. The stator placed in a pyrolysis oven for a number of hours to burn all the epoxy resin within the stator. The two ends of the coils are often removed prior to this to ease the process.
3. The coils are removed, and the slots cleaned.
4. New coils are manufactured and wound into the stator and phase barriers, tapes and bindings applied. The stator is wound and impregnated with a suitable resin. In most cases all the insulation materials and resins are modern class H materials.
5. The motor is assembled and tested, bearings and some other parts are replaced as necessary.

The question has been posed as to whether this process negatively impacts the efficiency of the motor. There have been many theories, anecdotal stories and exaggerations. So, an academic study was commissioned to identify best practice and to perform tests to evaluate the effects of repairs and rewind on efficiency.

B. DIFFERENCE BETWEEN HV AND LV REWINDS

The general principles for the rewind apply equally to low and high voltage windings. However, the actual windings themselves differ considerably. The two types are described below:

1. A low voltage winding would consist of round enameled coated copper wires wound on a simple winding fixture. The rewinder will measure the turn length, determine the number of turns, copper diameter and the number of copper wires in parallel per turn. Using this data he will rewind with coils having the same (or greater) copper cross sectional area per turn and the same (or smaller) length of turn. This ensures that the losses will not be increased. All the insulating materials will be the same or better than the original rewind.

Fig. 2 LV coil showing slot liners in place

2. A high voltage winding consists of rectangular section copper formed into a rectangular shaped coils. As with a LV winding the rewinder will take care to measure and replicate the copper section and turns etc. to maintain the performance and to not increase the losses.

Fig. 3 HV winding showing coil leads

VI. 2003 REWIND STUDY

A. Objectives

In 2003 a joint study by the AEMT and EASA [6] looked into the effect on repair on motor efficiency. This project was sponsored by the UK Navy, the US Department of Energy, and other independent authorities. Motors and technical support were provided from ten motor manufacturers. All the repairs were performed by one UK repair company and the testing was performed by the University of Nottingham.

The objectives included studying the effects of:

1. Rewinding motor with no specific controls regarding stripping the motor.
2. Over greasing bearings
3. How different burn out temperatures affect stator core losses.
4. Repeated rewinds
5. Rewinding LV vs MV motors
6. Using different winding configurations and slot fills
7. Mechanical damage to the stator core during the rewind

Two further objectives included correlating the running and static loss tests results and finally to identify procedure that help or hinder the efficiency or a rewound motor. The outcome for this project was hoped to be a comprehensive best practice document.

C. Products Evaluated

The study involved 24 new motors ranging from 37.5kW up to 225kW and included both 50 and 60Hz motors, IEC and NEMA designs 2 and 4 pole motors.

All tests were performed to IEEE standard 112 Method B using a dynamometer as the load. A ‘Round Robin’ test was performed on a 30kW motor which was tested at the University of Nottingham and three other facilities to calibrate the test method accuracy.

TABLE II

Location	Measured efficiency	RPM
Nottingham	92.3%	1469
Location A	91.8%	1469
Location B	91.9%	1470
Nottingham	93.5%	1776
Location C	92.6%	1774
Location B	93.1%	2774

The 22 motors were split into 4 groups to measure different variables.

D. Results

Groups were split as

1. No control on stripping and rewind process with burn out temperature of 350°C
2. Controlled stripping process with burnout temperature of 360- 370°C
3. Five motors were rewound two or three times with controlled stripping and rewind process and two motors burnt out three times and rewound once burnout temperature 360-370°C.
4. One MV motor was rewound once with controlled processes and a burn out temperature of 360-370°C

The variation in efficiency was within the range of the variations seen on the Round Robin test. The variation also falls within the range of accuracy for the test method (± 0.4%)

TABLE III
Variation in measured efficiency

Case	Variation
1	-0.4
2	-0.0.
3	+0.325
4	-0.2

VII. 2019 REWIND STUDY

The 2003 study was performed using motors with predominantly IE2 efficiency class, During the intervening years legislation changes meant that higher efficiency IE3 motors were more common and the study was repeated with ten IE3 motors to investigate the rewind effect on the losses.

The full results can be found in [8] and summarised below. The table below shows the post-rewind change in efficiency values varied from an increase of 0.5% to a reduction of 0.5% and the overall average decreased by 0.1%. Overall, there were no efficiency changes that were greater than the accuracy of the test method.

TABLE III
Efficiencies before and after rewind

Rating	Pre-Rewind	Post-rewind	Δ
75HP	94.9	95.2	0.3
60HP	94.4	94.2	-0.2
75kW	95.1	94.9	-0.2
75kW	94.6	94.7	0.1
30kW	94.5	94.3	-0.2
37kW	93.5	93.5	0.0
50HP	93.7	93.2	-0.5
30kW	94.5	94.5	0.0
30kW	93.1	92.8	-0.3
30kW	93.6	93.4	-0.2

VIII. LESSONS LEARNT AND BEST PRACTICE

A. Motor Losses

Motor losses comprise 4 general groupings and the rewind process should look to minimize the effects on each

1. Core loss
   These are the losses seen in the stator and rotor iron cores. They comprise of hysteresis and eddy current losses in the iron laminations. The laminations are insulated from each other to minimize losses and the strip process must ensure there is no damage to the inter-laminar insulation.

2. Copper losses
   These are the losses due to currents flowing through the stator windings and rotor bars. The rewinder should take care to maximise the copper in the stator slot and ensure the coils length of turn is not increased.

3. Windage and Friction losses
   These are the losses due to the shaft fans, the rotor ducts and the losses due to friction in the bearings.

4. Stray load losses
   This are made up of many different losses including high frequency harmonics on the rotor surface which can be increased if the rotor surface is damaged.

B. Lessons Learned and Best Practices

1. Stator windings
   The motor should be rewound with a combined copper wire section the same or greater than the original machine. Often a motor winder can get more copper section into a hand wound stator that the OEM can with a machine wound stator.

   Care should be taken to ensure that the copper turn length is no greater in length than the original

2. Stator stripping
   The original study showed that when mechanical damage occurred during the stripping of the stator windings there was an increase in the stray losses. This was sometimes seen in the core loss as well. Clearly use of a burn out oven removed the need for mechanical removal and is the preferred method coil removal.

   The burn out oven maximum temperature is of major importance to ensure that the interlaminar insulation is not damaged. The best practice is to keep the temperature to a maximum of 360-370°C. The burn of oven needs to be able to control this temperature, usually with some form of water quenching system to prevent thermal runaway,

3. Mechanical losses
   It was noticed that over greasing bearings had a negative impact on the efficiency.

4. Stator core condition
   A start core flux test should be performed on the stator core after stripping to identify of there are any hot spots in the stator lamination packs. This test is usually performed prior to stripping of the windings as an additional check.

IX. INDUSTRY STANDARDS

Some best practices were already being adopted by most repairers, but there was a need to collate these into an official document and have it peer reviewed. With their large global membership, EASA and the AEMT took this on and incorporated the learnings and best practices globally. The result of this was the EASA AR100 specification, [3] which was approved as an ANSI document in 1998. The document is updated every five years.

IEC followed with an international version, TS60034-23 in 2003 and issued as IEC 60034-23 in 2019.This has been accepted as a Euronorm.

X. CARBON FOOTPRINT

Whilst replacing an old motor with a new higher efficiency motor (eg from IE3 to IE4) can may be offer a cost benefit to the user in terms of losses when running and the corresponding carbon emissions associated with that. But this needs to be offset against the carbon involved in the manufacture and shipping of the motor.

A rewound motor will retain over 90% of the original material and only the stator copper and bearings will be replaced. The old material is 100% recycled.

XI. SELECTION OF REPAIR SHOP

When sending a motor for a repair, it is essential to know that the repairer is working to the current best practices when repairing the motor. These are listed in documents such as IEC 60034-23 and AR100 but it is down to the repairer to adhere to this and how they can verify this. And how to prove that the repairer follows best practice.

EASA decided that an accreditation scheme would be the solution and created such a scheme. Repair shops would be audited by a third party to ensure that they were following the guidelines and best practices. The audit checks items such as:

(i) Calibration of instruments
(ii) Process sheet

(iii) Test records
(iv) Burn out oven temperature records
(v) Balance
(vi) Training and Competence
(vii) Housekeeping
(viii) Internal audits

XI. HAZARDOUS AREA (EX) MACHINES

For machines that are to classified and operated in a hazardous area there are additional requirements for the repairer (and the user) to consider. Theses motors Exe, Exd etc are designed and manufactured to operate safely in a hazardous area and there are aditionl checks ad tests that must be performed before they can be returned to service. In some cases the machine cannot be repaired to the required standard and must be declassified. IEC 60079-19 [2] describes the procedures that must be followed.

I. REFERENCES

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II. VITA

Richard Emery graduated from the University of Bradford in 1984 with a BEng degree in Electrical Engineering. He has been involved in designing, R&D and Servicing of electric motors and generators all his career. He has Head of Electrical-Mechanical Services Engineering for Sulzer Services for 10 years he is currently Vice-President of the European Chapter of EASA and has co-authored two previous PCIC papers.
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