Efficiency Improvement of Induction Motors using Advanced Construction Techniques- A Review

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***Abstract*—: In this paper various considerations for achieving near optimum efficiency including, advanced construction techniques material and design are considered. This paper also presents an accurate method for measuring rotational losses. Following these methods IEEE841 and even NEMA premium efficiency levels are easily achieved**.

Keywords— Premium efficiency, advanced construction techniques, machine lamination, quality, induction motor, Rotational losses.

I. Introduction

This paper reviews design and production techniques required for premium efficiency motors and introduces new research being done to further raise efficiency including better lamination steel, slot designs and die-cast copper rotors. History of premium efficiency motors will be reviewed referring various standards from IEEE, Canadian Standard association (CSA), International Electro technical commission (IEC) and Japanese Electro technical Commission (JEC) etc. The high efficiency levels of today's IEEE 841 motors have evolved over last 25 years. Several manufacturers introduced "premium" efficient motors in early 1920's. These motor used better lamination material, more active material (lamination and copper) and lower loss cooling fans. However there were no guidelines as to what efficiency the motor was required to produce to be called a high efficiency motor. The National Electrical Manufactures Association (NEMA) first made a definition between standard and energy efficient motors in MG1-1987 with their September 1990 revision. These "Energy efficiency" motor efficiencies have become the standards for the energy policy Act of 1994 (EPACT).

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In October 1997, EPACT took effect, mandating minimum efficiency levels for general purpose totally enclosed fans cooled (TEFC) and open drip-proof(OPD) 1-200hp two, four, six and eight pole foot mounted motors. This required that any EPACT motor sold in United States comply with minimum nominal efficiency, testing and labeling standards.

The consortium for energy efficiency (CEE) and NEMA harmonized their efficiency standards, establishing NEMA premium efficiency standards for OPD and TEFC 1-500 hp motors in low and medium voltage.

IEEE 841 covers 1-500 hp motors with adoption of IEEE 841-2001, minimum nominal motor efficiency was set at the EPACT level plus 1 NEMA efficiency level. The previous 841-1994 was at EPACT levels. Looking at the efficiencies of motors from most manufactures, their nominal efficiency complies with NEMA premium efficiency levels will be the new minimum for the next revision of IEEE841. A comparison of four-pole TEFC efficiencies is shown in table2.

Most Induction motor in the fractional and integral horsepower range of the sizes is made with Die-Cast aluminium rotor cages. With the present day push for higher efficiency of energy usage, the possibility of improving efficiency in such motor has become enough of a priority to cause renewed interest in the use of copper in the squirrel cage because of its substantially higher electrical conductivity.

Induction motor has been made with fabricated copper rotors since there were induction motors, and cast copper rotor appears in the literature of the forties. However, the higher melting point of copper leads to difficulties in casting. Short die life resulting from high temperature in the past, made cast copper rotors uneconomical. Because of higher energy cost and improvements to the metallurgy of casting apparatus, the economics of the situation appears to have changed.

By using die-cast copper rotor efficiency improves by reduction in fundamental rotor loss and the effect of stray load loss.

II. Improving Efficiency with Die-Cast Copper Rotor Cages

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Improvements in Efficiency

Conventional wisdom holds that lower starting torque is expected with higher rotor conductivity. This would be true for frequency independent motor parameters. For motors of integral horse power and larger eddy current cause substantial frequency dependence of motor parameters. The higher conductivity of copper gives the motor designer flexibility to take more advantage of diffusion effects.

Consider the loss budget for a high efficiency, 10 horse power industrial grade motor. The motor has 5.7" diameter stator bore, 35 mil air gap and an active length of 6". The armature winding has 144 turns in a 36-slot stator wound with the equivalent of an 8/9 pitch winding. A slot factor of 41% is assumed. The motor envelop is approximately 241mm in diameter with overall active length of 267 mm. Assuming Aluminium conductor in the squirrel cage at 40 degree, elements of motor loss are shown in table1.

Core Loss	99W
Stator winding loss	313W
Rotor core loss	110W
Stray loss	12W
Friction & Wind age loss	43W
Motor efficiency	92.8%

Table1: calculated losses in a high efficiency Aluminium Rotor motor

A cast copper rotor with conductivity of 100% of IACS is predicted to have a rotor cage loss of 60W, which by itself would increase motor efficiency to 93.5% [2]. Fig below shows four examples of possible rotor bar shapes of many that might be cast. Generally it is appropriate for the bar shape to taper from a wide form at the top to a somewhat narrower form at the bottom. This permits the magnetic materials between the rotor bars (the teeth) to be of nearly uniform width, making the magnetic circuit working well.

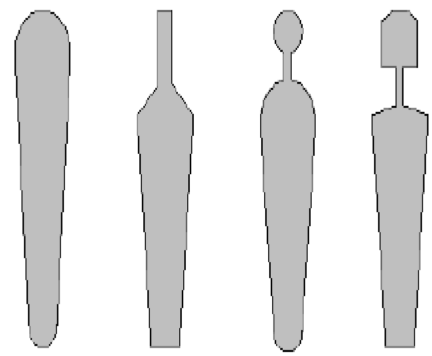

Fig 1: Examples of bar shapes

III. Development of electrical grade steel lamination

Over the last 25 years development and refinement of motor designs have reduced internal loss producing efficiency levels consistent with NEMA premium. The primary advancement is better electrical grade steel. Lamination coatings have evolved from basic organic (C3) to various inorganic / combinations (C4/ C5/ C6) and recently to oxide coatings. Actual losses in the steel have gone from 4.5W per pound of steel to less than 2W per pound.

C5 inorganic core plate is specified for low electrical loss and a good resistance to degrading during any burnout and rewinding process. Damage of lamination steel during an improperly performed motor rewind burnout causes increased core loss. If the rewind was incorrectly performed, it will not take long for the operating cost of a poorly rewound motor to cost more than the rewind.

NOMINAL EFFICIENCY FOR FOUR-POLE TEFC MOTORS

HP	KW	EPAct	IEEE 841-2001	NEMA Premium™
1	0.75	82.5	84.0	85.5
1.5	1.1	84.0	85.5	86.5
2	1.5	84.0	85.5	86.5
3	2.2	87.5	88.5	89.5
5	3.7	87.5	88.5	89.5
7.5	5.5	89.5	90.2	91.7
10	7.5	89.5	90.2	91.7
15	11	91.0	91.7	92.4
20	15	91.0	91.7	93.0
25	19	92.4	93.0	93.6
30	22	92.4	93.0	93.6
40	30	93.0	93.6	94.1
50	37	93.0	93.6	94.5
60	45	93.6	94.1	95.0
75	55	94.1	94.5	95.4
100	75	94.5	95.0	95.4
125	95	94.5	95.0	95.4
150	110	95.0	95.4	95.8
200	150	95.0	95.4	96.2
250	190	-	95.0	96.2
300	220	-	95.4	96.2
350	260	-	95.4	96.2
400	300	-	95.4	96.2
450	340	-	95.4	96.2
500	370	-	95.4	96.2

IV. Rotor with copper bars included in the slots before the aluminium die cast

The presence of copper bars in the rotor slots allows a reduction of the rotor resistance and, as a consequence, a reduction of the rotor joule losses. It is important to remark that the new slot arrangement has not to influence in negative manner the motor starting performances both in terms of current and torque.

Core axial length increase

The axial core length increase is a simple method for getting a higher efficiency motor. In this way, the new motor uses the same stator and rotor laminations of the original one. Obviously, from the company point of view, the axial core increase has to be compatible with the external frame of the original motor or with other stoked frames. It is important to underline that the increase of the motor axial length with a constant rated power can be considered equivalent to a power derating of a bigger machine. In other word, the material constraints (i.e. airgap flux density and current density) in the "lengthened machines" are lower than in the standard motors
and, as consequence, lower motor losses can be obtained. Furthermore, since the voltage supply is generally constant, a modification of the stator winding turn number is required. In this case, due the more material quantity used for its productions, the new motor will be a little bit more expensive respect to the original one. It is well evident that the additional costs involved in the production of these motors have to be compatible with the company budget.

Design Considerations

In order to obtain an efficiency improvements with a NTC approach, a correct motor axial length increase have to be done. As a consequence, it is convenient to define some general design guidelines when the motor axial length is increased. Starting from a standard efficiency induction motor design the following motor quantities are considered:

Cage losses and bar current

Starting from the new length L_* of the rotor stack and from the new rotor current density, imposed by the new turn number of the stator winding, it is easy to calculate the Joule losses of the cage in rated operating conditions.

Iron losses

The iron losses in the new motor may be evaluated from the no-load test of the original motor. With reference to Fig. 2, we can estimate that the original motor would dissipate a power P_β, when its supply voltage becomes β times the rated one. The new motor has a rated induction β times the old one and is λ times longer, so its iron losses may be evaluated by:

$$(P_{iron})_{new\ motor} = \lambda P_\beta$$

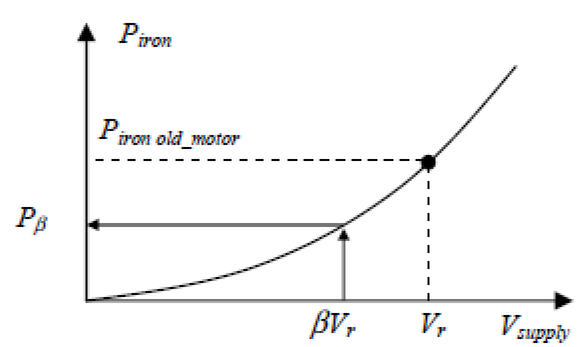

Fig 2: Reduced Iron Loss P_β Determination

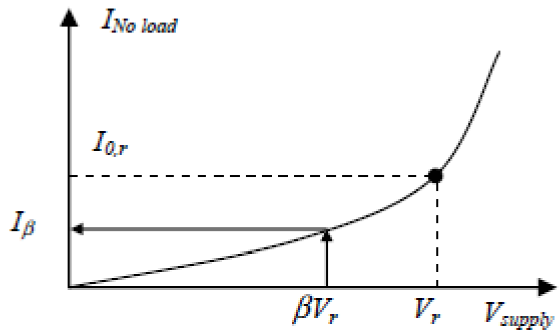

Fig 3: Reduced No-Load Current I_β Determination

Process for Measuring Rotational Losses

Under rotating flux conditions, a magnetic material will exhibit rotational hysteresis losses and eddy current losses. As early as in 1896, Baily [4] showed that hysteresis losses under rotational flux conditions are very different from those obtained due to an alternating flux. Since then, various authors have confirmed that total iron losses under rotational flux conditions may be much larger **than** losses due to alternating flux. As a first step towards establishing the rotational power loss, we consider rotational hysteresis.

Rotational hysteresis losses can be measured using the arrangement of Keithley arbitrary waveform generator is used to create two quadrature sinusoidal voltages. These are fed to a power amplifier which energizes two pairs of coils **on** a yoke. A rotating magnetic field is **induced** in an 8 cm square sample which **has** search coils wound **through** two sets of holes. Two tangential field-strength sensing coils are orthogonally wound **on** a 2 cm square form. The sample sits centred **on this** double H coil. Signals proportional to B_x, By, dH_x / d t , and dHy/dt are fed into a Keithley DAS16F analog to digital conversion board for processing. A personal computer is used for data storage, signal processing, and calculation of the rotational losses.

Annealed stator core

The annealing process applied to the stator core allows to recovery the magnetic and energetic properties of the laminations after the punch process. A reduction of the specific iron losses and of the magnetizing current corresponds to a reduction of the motor no-load losses[4].

Conclusion

Through the use of higher conductivity copper and better steel, the efficiency of Induction motor can be improved as much as 1% - 2% above what is currently possible.

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