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Analysis of Induction Motor with die cast rotor

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Abstract: This paper presents the choice between the utilizing a lower cost die cast or fabricated aluminium rotor versus the more expensive copper bar rotor. In industrialized countries Induction motors account for approximately 50% of the overall electricity use. In every field whether it is agricultural sector or the economical sector. The power consumption by a.c motors is quite enough. On an average the cost of energy consumed by the motor is nearly 60-100 times the initial cost of the motor. So the efficiency of motor is of great importance whether during the selection or during the operation. Small increase in motor efficiency can make an overall big difference between the total electricity consumption. Using copper in place of aluminium would result in a motor efficiency higher than that of the original aluminium-based motor. Consequently, the motor can then be scaled down in size, thus decreasing the individual costs of many other steps in the manufacturing process and theoretically lowering motor cost as a whole. This paper discusses the implementation of Die cast rotors, Motor efficiency, and increasing the prospect of the country by using DCR technology.

Keywords: Induction motor, premium efficiency, efficiency improvement, die cast copper rotor, DCR technology, and efficiency standards

I. INTRODUCTION

The history of electric motor development starts since its invention by Nicola Tesla in 1888, with earlier effort aimed at improving power and torque and reducing cost. The need for higher efficiency came into existence by the late 1970’s and by the early 1980’s and also one British manufacturer started to market a premium range of motors with improved efficiency after that the trend started to increase the efficiency bitterly and so on the cost also .But it is not negotiable that this extra cost counts during the operating cost. With market conditions today, the economics are such that users and engineers are looking for the best fit for the application at the most reasonable cost.

Since, efficiency is the ratio of output power to input power i.e. amount of work produced to the amount of energy consumed. The Induction motor losses are the difference between these two powers i.e. output and input power, and can be classified into five categories:

1. Iron losses: magnetic losses in the core laminations i.e hysteresis, and eddy current losses, denoted as Pc
2. Stator I2R resistance losses: current losses in the stator windings, represented by Ps
3. Rotor I2R resistance losses: current losses in the rotor bars and end rings, denoted by Pr.
4. Wind age and friction losses: mechanical drag in bearings and cooling fans, Pw.
5. Stray load losses: mainly iron and joule losses. Also called additional load losses, increasing with load and result from a multitude of sources, such as surface and slot conditions, leakage flux, etc.

These five loss components of an induction motor depends on motor size .If we take example of a 4- pole induction motor loss distribution is shown in Figure 1. Accordingly, Mr. Fuchsloch and his SIEMENS colleagues provided the typical loss distribution, shown in Figure 1 in their recent research work concerning the next generation motors , and the areas for improvements of the efficiencies are shown in Figure 2.

Furthermore they analysed and evaluated all the factors responsible for the efficiency reduction and motor performances. The factors are inter dependent with each other. Sometimes the increase in the one factor may not increase the overall performance of the motor. So, the cost of the motor and the commercial impact of the motor have to be considered as well.

This paper deals with the various factors resulting the increase in the efficiency of the motors by using DCR technology and also the various problems and may be there solutions for using the DCR technology. It also includes the advantages of using DCR technology, its technical issues, various trends in markets and overview of the competitor. About the adoption of the DCR technology in India.

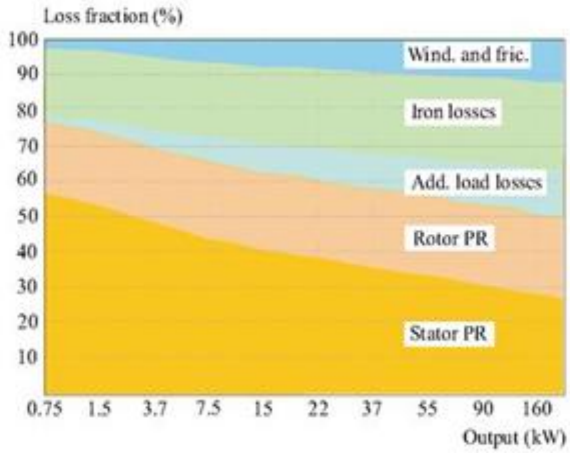

Fig. 1 Loss distribution for a 4-pole induction motor

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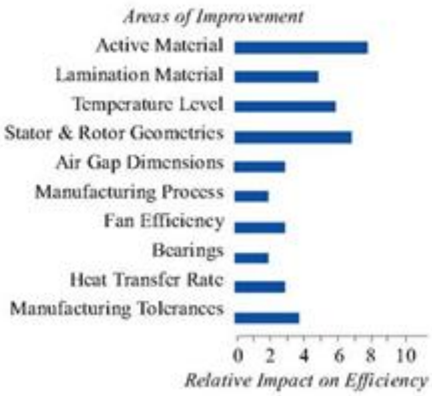

Fig. 2. Impact of the possible areas for improving the motor performance

II. HISTORY OF MOTOR EFFICIENCY STANDARDS

In the year 1992, Congress passed the Energy Policy Act (EPAct), which granted the USA Department of Energy (DOE) the authority to set minimum efficiency standards for certain classes of electric motors. EPActrules for motors became effective from Oct. 24, 1997. EPAct did not create new efficiency performance levels but rather established a minimum efficiency level in US. These efficiency levels increases motor efficiency by 2.3 %. In 1994, NEMA issued definitions for "energy efficient" motors. These motors must have nominal efficiencies meeting or exceeding NEMA MGI. EPAct covers general-purpose motors rated from 1 to 200 hp; 2-, 4- and 6-pole (3600, 1800 and 1200 rpm). Efficiencies of these so-called "EPAct motors are from one to four percentage points higher than the previous "standard-efficiency" motors. NEMA revised MGI-1993 to include the specification of a design E motor and they were specified to satisfy the International Electro technical Committee (IEC) standards. These standards allow motors to be designed for higher efficiency with lower restrictions on torque and starting current than design B motors.

In the year 1996, the Consortium on Energy Efficiency (CEE) launched its Premium Efficiency Motors Initiative. Motors meeting the criterias of CEE standards are known as "CEE Premium Efficiency" which means it is 0.8–4% more efficient than previous EPAct motors.The European Union (EU) and Committee of European Manufacturers of Electrical Machines and Power Electronics (CEMEP) have developed a new motor efficiency classification scheme for motors during the year June 2000. Motors covered under this agreement were defined as totally enclosed fan ventilated (IP 54 or IP 55) three phase A.C. squirrel cage induction motors in the range of 1.1 to 90 kW, with 2- or 4-poles, rated for 400 V-line, 50 Hz,S1, Duty Class, in standard design.

Motors sold in Europe had an efficiency marking designated as EFF1 for their best efficiency, and EFF2 for standard efficiency. There is lower EFF3 level classes of motors that the EU is discouraging from being manufactured. Motor efficiency of EFF1 is comparable to that of U.S. EPAct efficiency values.

Based on the above classifications, the Indian Electrical and Electronics Manufacturers Association (IEEMA) developed IEEMA-19: 2000. This formed the platform for the development of IS: 129615-2004 for Energy Efficient Motors by the Bureau of Indian Standards. Table 1 shows the comparison of efficiency levels as per different standards for a few 3 phase/4pole ratings. According to which the loss fraction due to stator is less than the rotor and the maximum loss fraction is due to the wind and frictional losses.

In May 2001 again NEMA announced a new motor efficiency standard; NEMA Premium efficiency. According to this new efficiency standard motors are required to have 20% lower losses than EPAct motors. NEMA Premium applies to single-speed, polyphase, 1 to 500 hp, 2-, 4-, and 6-pole (3600, 1800 and 1200 rpm) squirrel cage induction motors, NEMA Designs A or B, 600 V or less, (5 kV or less for medium voltage motors), and continuous rated. In the month of June 2001, NEMA and CEE agreed to align the NEMA Premium TM and the CEE Premium Efficiency SM efficiency levels to co-promote the standard. After NEMA released General Specification for Consultants, Industrial and Municipal: NEMA Premium Efficiency Electric Motors (600 Volts or Less) in 2003, most of the major motor manufacturers put more and more effort to meet or even to exceed the NEMA Premium Efficiency requirements.

The intent of this specification is to outline the minimum requirements for three- phase AC induction motors labelled with "Premium" applied to municipal and industrial applications for operation on voltages 600 volts or less, rated 500 horsepower or less, operating more than 2000 hours per year at greater than 75 percent of full load. The efficiency values for the NEMA Premium has been indicated below in Table 1 and the results will be up to only EFF1 level.

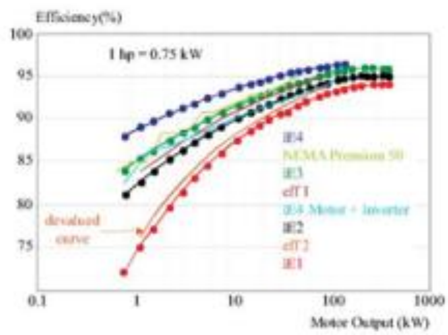

Fig. 3. Different efficiency levels comparison by CEMEP

Table 1. Comparison of Efficiency Levels as per Different Standards for a few 3 Phase/4 Pole Ratings

kW	EPACT	IEEE 841.2004	CEMEP/IEMA-19 /BIS 12615 EFF1	EFF2	NEMA Premium
0.75	82.5	84	82.5	73	85.5
1.1	84	85.5	83.8	76.2	86.5
3.7	87.5	–	88.3	84	89.5
7.5	89.5	90.2	90.1	87	91.7

(A)-INTERNATIONAL STANDARDS FOR MOTOR EFFICIENCY ASSESSMENT

It is very difficult that motor efficiency comparisons be made using a uniform product testing method. There is no common standard efficiency testing method that is used throughout the industry. The most common standards are:

- IEEE 112 –1984 (United States)
- IEC 34-2 International Electro technical Commission (Europe)
- JEC-37 (Japanese Electro technical Committee)
- BS-269 (British)
- C-390 (Canadian Standards Association)
- ANSI C50.20 same as IEEE 112 (United States)
- IS 12615 – 2004 read with IS 4889 – 1968 (India)

The common practice for testing of motors from 1 to 125-hp size range is to measure the motor power output directly using a dynamometer. The standards for testing of motor efficiency differ primarily in their treatment of stray load losses. The Canadian Standards Association (CSA) methodology and IEEE 112 - Test Method B determine the stray load losses by measuring the mechanical output which was indirect method. The IEC and JEC differ in their views relating to stray load losses, the former considers the stray load losses to be fixed at 0.5 percent of input while the later assumes there are no stray load losses .when the efficiency of motor is measured using different conventions it varied by several percentages. Table 2 shows a full load efficiency test results of 7.5 hp and 20 hp motors using different international standards.

Although the IEC method is easy to use, it underestimates them slightly for motors larger than 700 kW and overestimates efficiencies by up to 2% for motors smaller than 10 kW. The IEEE is more accurate, but is not perfect either because it relies on the accuracy of the torque Transducer.

III. DIE CASTING THE SQUIRREL CAGE

Die Casting is a process involving injecting molten metal at a high pressure (1,500 – 25,000 psi) into a mold or cavity (called a "die") in order to manufacture a part quickly and repeatedly. Typically, die casting is done with low melting temperature metals, given their typically lower cost of processing. Occasionally, higher melting temperature metals such as ferrous alloys are also used in die casting, but this is rare given the higher processing costs. Die casting is commonly used in high production volume applications to manufacture small- or medium-sized parts. An analogous process for plastics is injection molding.

Just as with any casting process, die casting requires a gating system. In fact, the gating system for die casting is often more complex than for other metal casting methods due to the high-pressure of the injected molten metal. Such a high pressure causes a significant amount of turbulence in the molten metal which can hamper filling of the mould cavity. As a result, a significant amount of engineering goes into the development of the gating system to promote as laminar a flow as possible. The die is usually significantly more complex than a pour-casting mould.

IV. ROTOR CONSTRUCTION METHODS

Four types of rotor construction exist today: aluminum die cast (ADC), copper die cast (CuDC), fabricated aluminum bars (AlBar), and fabricated copper bar (CuBar). In general, only the aluminum die-cast, fabricated aluminum, and copper bar rotors are in common use today.

Aluminum Die Cast Construction (ADC):

Aluminum die-cast rotors have been manufactured since the 1930's. Although this process has been utilized for a long time, the rotor sizes that can be die cast increase each year due to manufacturing advancements in die cast technology. Current state of the art technology makes it possible to die cast aluminum rotors with a 30" diameter and a 50" core length. This is the size rotor that would be capable of producing 10,000 Hp. However, due to tooling costs and demand it is unusual to see ADC rotors used in ratings above 1750 HP.

Copper Die Cast Construction (CuDC):

CuDC construction does not differ significantly from ADC construction. The CuDC imposed manufacturing challenges that only recently have been met .In essence the manufacturing details for CuDC are identical to ADC. The additional manufacturing challenges are increased temperatures and pressures required to die cast copper. Although CuDC is a much newer technology, current state of the art technology makes it possible to die cast similarly sized rotors in copper as can be cast in aluminum. The integrity and reliability of CuDC is just as good as in ADC. The primary reason CuDC rotors are not commonplace yet is because it's a new technology and requires a large capital investment.

Fabricated Aluminum Bar Construction (AlBar):

Although many people associate 'aluminum rotors' to mean 'Aluminum Die-cast', fabricated aluminum bar rotors can be built. The primary advantage of AlBar over CuBar is cost. The primary advantage of AlBar over ADC is that most manufacturers have some finite limitation on the size that they can successfully manufacture an ADC rotor and the tooling cost required to die-cast a rotor.

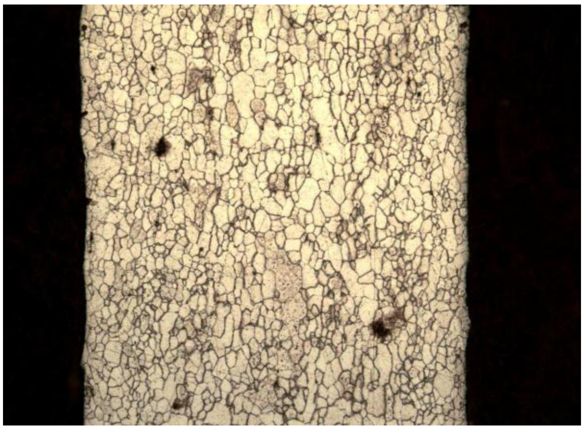

Fig:4- Not annealed laminate

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Fig:5- Annealed laminate

V. CAST - COPPER ROTORS

Induction motors with cast-copper rotor (CCR) bars rather than aluminum rotor bars operate at lower temperatures because they are more efficient. The degree to which Siemens' CCR motors exceed the National Electrical Manufacturers Association's premium-efficiency specifications (NEMA Premium) varies with individual motor sizes and speeds. On average, the higher conductivity characteristic of copper reduces motor energy losses by 10 to 20 percent, boosting efficiency 1 to 2 percentage points higher than that of premium-efficiency motors with aluminum rotors, as well as potentially increasing motor life. Other motor types exceed NEMA Premium specifications without resorting to copper rotors, but they often sacrifice motor speed and torque to increase efficiency, which limits the applications in which they can be used.

In the past, the problem with manufacturing CCRs was that copper's melting point is more than 400 degrees Celsius (760 degrees Fahrenheit)—higher than that of aluminum. The temperatures necessary to keep copper hot enough for a long enough time to cast high-quality rotors would quickly destroy the conventional steel dies used in the casting process. That problem was resolved in 2001 when a group spearheaded by the Copper Development Association successfully completed research into new die-casting materials. In 2006, Siemens became the first manufacturer to offer CCR motors to the North American market. These motors all surpass the NEMA Premium specification, and in some motor classes they are the most efficient motors available on the North American market. Because copper rotors are heavier than aluminum rotors, acceleration time may be slightly longer, but this limitation does not affect most applications. The price of CCR motors depends on many factors, including the motor's size and speed specifications, vendor discounts, the cost of copper, and purchase quantities. In some cases, they may cost the same as NEMA Premium motors. In other cases, the cost of CCR motors may be 10 to 20 percent higher than that of other NEMA Premium motors, making them cost effective for only certain applications.

VI. PROBLEMS IN DCR TECHNOLOGY

There are various problems in the DCR technology and one of them is the manufacturing problem. The melting point for aluminum alloys is in the range of 676 ◦C (1250F). The material used for the rotor's die-casting mould is not highly stressed at these temperatures. The die life can be one of hundreds depending upon the die complexity and the manufacturing of rotors. Due to the high melting temperature of copper i.e 1083 C the conventional die fails because of the thermal fatigue of the surface in less than 100 shots.

The solution to the problem of tooling of copper die-casting have been identified and they are acceptable now. THT Presses, Inc has demonstrated economical means to die cast copper utilizing equipment developed specifically for Copper Rotors Cast Vertically task. Now theDCR is being used by the several manufacturers as a cost effective way to achieve EPAct and Eff1 efficiency levels and also to reach or exceed NEMA Premium levels.

SEWEurodrive and Siemens AG in Germany, in particular, have made extensive investments in designing the motor using copper in the rotor. Consequently, it looks that the process of die casting copper rotors can be robust and reliable. By using copper rotor the energy loss can be reduced by 15-23%, which is due to the friction and wind age losses. Furthermore, advancements can be done such as optimization of steel laminations while designing the rotor and slot shape can extend copper's efficiency. The one way used during the rotor manufacturing may be achieving tight rotor bars. In the use of DCR the price is also the one major cause. By using the DCR the cost goes higher by about 15% as compared to the motors of existing efficiency levels when replacing aluminium by copper die casting without any other change. But this extra cost may prove to be nominal because as earlier said that the cost of power consumed by the motor becomes 60-100 times the initial cost of the motor. So it is of great importance to invest one time rather than investing for a long time. If all the other parameters of the motor are kept the same, using copper instead of aluminum leads to a higher efficiency. In this case, the higher cost of the motor will be compensated by a lower running cost, resulting in net cost savings after the pay-back period. It is estimated that a copper rotor in a 15 hp motor could result in a 1.2% efficiency gain and difference in retail list price of $ 10 to $ 12 per motor. For a $ 900 to $1 500 motor, the payback may be measured in months.

The cost of the DCR may be reduced by using under given methods:

1. By developing dedicated motor design and configurations of laminations optimized for DCR's
2. By identifying and sourcing the appropriate electrical steel for the core packs.
3. There is a need for motors with copper die-cast rotors for a more perfected technology of melting and die casting. Then only mass-production of rotors at an affordable cost is possible.
4. The last one is, by using the new manufacturing technologies for reducing the losses and by making the rotor bars.

VII. ADVANTAGES OF DCR

A lot of studies have been done in USA on die casting of the rotors. The overall conclusion of all the studies says that in case of efficiency in the copper rotors the high

efficiency can be obtained by improving the steel quality and modifying the rotor conductor bar shape. Using magnetic steel with lower losses and higher permeability in combination with die-cast copper rotor makes it possible to achieve the highest efficiency levels (E®1 and above) without major design problems and without increasing the volume of the motor.
In another context If the higher electrical conductivity of copper is not fully used to improve efficiency, the rotor can be made smaller. This has a downsizing effect on the overall motor design. The reduced volume leads to the reduced weight of the motor. The rotor will increase in weight due to the higher density of copper (8.92 kg/l compared to 2.70 kg/l for aluminum), but this is more than compensated by the reduction in steel weight in rotor and stator, in stator windings, and motor housing.

VIII. TECHNICAL ISSUES

STARTING TORQUE

The advantage of using copper rotor motor is of high torque at running speed and starting torque is lower than in aluminium rotor motors which increase the life of gear box. In some applications where lower starting torque is a problem then a modified design of rotor slots is used. It is found that the measured interbar resistance due to inter bar currents is lower in DCR than in cast aluminium rotors. This causes reduction in pull out torque and increase in stray load losses .This characteristic of copper rotor makes it suitable for applications such as centrifugal pumps which need high torque at high speed.

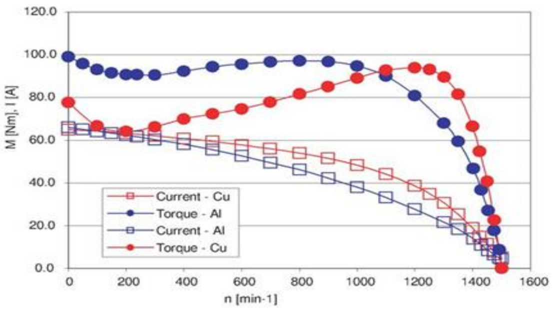

Fig:6- Torque-speed and current-speed curve For a 5.5 kW motor

Higher start up current

The lower electrical resistance of copper results in a highly start up current keeping the slot area same. The use of soft starter can avoid the higher current which effects the electricity system. Since motors are increasingly driven by motors, inrush and starting currents are of less issue.

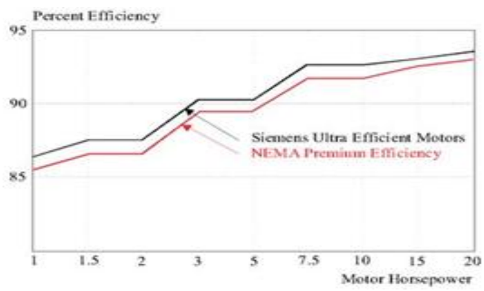

Fig.7- Siemens Ultra Efficient Motor and its efficiency compared with Premium Efficiency (IE3)

ROTOR INERTIA

The inertia of the rotor depends on the weight of the rotor ,so the higher rotor weight increases the rotor inertia. This can increase the motor efficiency but there are problems for the motors which frequently switch direction at high speed. A study of survey shows that the copper rotor motor has now become a accepted technology. A massive majority is ready to copper rotor due to its major advantages such as higher efficiency, lower heat production, and reduced cost. The main application is for industrial low voltage motors.

IX. APPLICATIONS

The main fields where copper rotors can be applied or being considered are listed below:

1. Ceiling conveyor belt (low weight)
2. Refrigeration compressors (high efficiency)
3. Aeronautic applications (low volume, high speed)
4. Rolling curtains (low volume, high speed)
5. Airport baggage handling (low volume
6. Agricultural pumps (efficiency, torque)

X. WORLD SCENARIO FOR ADOPTING DCR MOTOR

India the second largest emerging energy market after china at the world level is facing a shortage of power up to 20% during peak periods while the demand is increasing heavily. In the rural areas of the India where the 63% of the house hold do not have electricity it is a major problem. International Copper Promotion Council India (IPCPI), took one step and it was being supported in part by a grant from an arm of the Small Scale Industries Development Bank of India and funded by the USAID Eco Project. In India the majority of the population depends upon the agriculture and irrigation is one of the major need of the agriculture, so the council tested the copper rotor motors used for pumping water .Tp test the performance and reliability of the Indian made die cast copper rotors and various other important parameters, a project was conceived and carried out in Coimbatore Motors and Pumps cluster by International Copper Promotion Council (India) — ICPCI during the year 2003. With the combined effort of the Small Industries Development Bank of India (SIDBI) and Technology Bureau for Small Enterprises (TBSE) which provided Motors and Pumps cluster by ICPCI the study went on. Small Industries Development Bank of India (SIDBI) and Technology Bureau for Small Enterprises (TBSE) provided assistance for the same. The concept was developed by Nexant Inc. (USA) in formulating various dimensions, schedules, etc for the project. During the selection of the motors all the motors were kept in mind related to the industrial sector, agricultural sector as well as house hold appliances. The samples included both single phase and three phase induction motors with the aluminium and copper bar rotors. The ten die cast rotors were chosen from Indian manufacturers based on drawings and supply of rotor stampings by different manufacturers. These were assembled with motors with conventional type of rotors to perform the study. Field tests were also conducted later to confirm performance and reliability under actual field conditions. Based on these tests a comparison is made between the die cast aluminium and copper rotor without any change.

Table 2. Comparison of various performance parameters between DCR and die-cast aluminium rotors

Parameters Factor	Variation
Reduction in slip	2%
Increase in starting current	10%
Decrease in starting torque	17%
Improvement in Efficiency	2.8%
Decrease in Temperature	7.5 c
Decrease in Full load Current	4%
Chance in Full load p.f	Negligible

The comparative study of the die cast aluminium and die cast copper rotor is shown through the above table and it should be noted that the motors are tested with DCR and conventional aluminium die cast rotor without any change in rotor.

(a) Adoption of DCR in Agricultural pump set:-

At the world level after china majority of India is employed in agricultural activities. It can be concluded that 30-40% of electrical energy consumption is by motorized pump sets employed in agricultural sector. Many surveys and data shows that the agricultural pumps used in India are not efficient and they are just wasting the valuable electrical energy of crores of rupees. Due to large variety of pumping systems there are no energy classifications of pumps. One of the major factors is the low efficiency of these pumps. So the overall efficiency of these pumps used in agricultural works can be increased by increasing the efficiency of its prime mover and this can be done by using DCR technology instead of conventional copper fabricated rotor technology.

In this paper it is tried point out the overall efficiency of the induction machine by using DCR (die cast copper rotor) technology. The cost comparison between the existing CFR and DCR's are also reported and found that by merely replacing CFR with reduced core length DCR we can save 20% of the initial cost without sacrificing the overall efficiency of the pump.

XI. CONCLUSION

As could be seen that various factors of the DCR technology ,energy efficiency, energy potential, it's advantages ,problems occurring in manufacturing of die cast rotor ,application of DCR in India and in agricultural industrial as well as commercial sector have been discussed in this paper. It is found that that in India the pumps used in agricultural sector is not efficient .The buyer buys the cheap pumps due to high cost of efficient pumps which results in a long term loss. Apart from energy saving it is also reduces the production of green house gases. The main advantages of this new technology are higher efficiency, or for the same efficiency, lower volume, weight and cost.

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BIOGRAPHIES

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