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Enriched Efficiency with Cost effective Manufacturing Technique in 3.7 kW Submersible pump sets using DCR Technology

S. Manoharan, N. Devarajan, M. Deivasahayam, and G. Ranganathan

Department of Electronics and Instrumentation Engineering, Karpagam College of Engineering, Coimbatore-32. <u>manoish07@yahoo.co.in</u>

Abstract: This paper describes the overall efficiency improvement in Submersible pump sets with reduced cost by increasing the efficiency of the submersible motor using die cast rotor (DCR) technology. The important parameters responsible for the submersible motor characteristics like Efficiency, Locked rotor Torque, Slip etc., are compared with the existing Copper Fabricated Rotor (CFR) and proposed DCR in a 5HP 3phase wet type water cooled induction motors in accordance with IS 9283. The overall performance, possible efficiency improvements in Submersible pump sets and cost comparisons between the existing CFR and DCR's are also practically verified and reported in accordance with IS 8034.

Keywords: Induction Motor, Efficiency Improvement, Submersible Pump Set, Diecast copper Rotor, Copper Fabricated Rotor, Energy Efficiency

1. Introduction

It is estimated that about 30 % to 40 % of electrical energy produced in India is consumed by motorized pump sets employed in agricultural sector [1]. Pumps and pumping systems use 60% of the new motors in the OEM supply chain. Any improvement in efficiency of motor would therefore result in increased efficiency of the system at end use. Low-voltage motors of up to 37.5 kW consume most of the energy size, which offer maximum potential for energy savings. Most of the energy is consumed by low-voltage motors of up to 37.5 kW size which offer maximum potential for energy savings. One of the ways to address the problem of energy shortage is to reduce demand mainly by increasing end use efficiency. As motors are the largest users of the electrical energy, even small efficiency improvements can produce very large savings across the country, Energy conservation measures taken by individual consumers in this direction will increase the comprehenses of the national economy and benefit the environment on a global scale.

The total number of irrigation pump sets in India during the year 2001 was 12.5 million. In the year 2002-03 the Annual power consumption was 118,059 GWh by Agri-pump sets, based on this information, the number of pump- sets works out to 15.7412 Million. The demand is seen to be increasing year after year and also the resulting shortage of electrical energy. In the states of Andhra Pradesh and Gujarat, the agricultural sector alone accounts for 37.45 % and 40 % of total power consumption respectively [2,3]. Based on the statistics, the total electricity consumption during the year 2002-03 was 562,572 GWh and the consumption by Agri-pump sets was 118,029 GWh, which works out to only 20.98%. By considering the average connected load of the pump as 6.5 kW per pump set and 1800 pumping hours annually, the total power consumption by agri-sector will be 184,172 GWh, and the percentage works out to 32.7%, which reasonably matches with the other studies. Numerous field studies have revealed that 90% of the agri-pump sets used in India are far inefficient and are wasting power worth of Crores of Rupees. Because there is no energy classification for pumps due to large variety of pumping systems.

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Three-phase induction motor finds extensive applications in industry and agriculture. Its performance is based on efficiency, power factor, temperature rise and noise level. The performance of the machine is said to be adequate when it gives its maximum efficiency, temperature rise within permissible limits and acceptable power factor and noise level for specified operating conditions. The reasons for inadequate performance are losses, noneffective heat dissipation and improper design and deviation in operating conditions from normal. Efficiency and temperature rise both depend on losses. Variation in supply voltage gives rise to additional losses compared to rated operating voltages. This causes degradation in performance of the motor. Nowadays the voltage variation may range up to 20% in time and over the length of a distribution feeder (particularly on remote agricultural pumping loads). Some manufacturer started designing motors for less than rated voltages [4]. Now a day's majority of submersible pump set manufacturers uses submersible motor with CFR. The pumping rate and overall efficiency of the pump set purely depends on speed and efficiency of the induction motor. Hence, objective of this paper is for obtaining the desired improvements in the performance of the motor by appropriate modifications in the design. For the purpose of study the authors have taken up two identical motors one of them being a conventional CFR and another one being the same motor replaced with a DCR.

Efficiency is generally defined as a ratio of the output work done by a mechanical device to the input energy consumed and is usually expressed as a percentage. There are several levels of efficiency related to the consumption of energy for the pumping ground water. They include efficiency of 1) the pump; 2) the prime mover, usually an electric motor; 3) the drive systems; 4) the hydraulic system (pipes, shafts, tubes) between the pump intake and discharge; and 5) the electric system if any.

Though overall efficiency of the pumping system consists of number of factors, this paper presents the possible improvement in Prime mover (motor) efficiency, which is used to raise the overall pumping efficiency. By using DCR technology instead of conventional CFR Technology, this enhancement in efficiency is easily possible.

A. Pump industry in India

The first electric motor in India was manufactured in Coimbatore in 1930 and thereafter the motor pump industry expanded rapidly there. Today 60% of India's requirements of domestic and agricultural pump sets are made in Coimbatore. The Southern India Engineering Manufacturers' Association (SIEMA), which is established in 1952 has 215 members, most of whom manufacture motors and pumps of various types. Indian pumps are made according to the specifications of the Bureau of Indian Standards (BIS). Besides Coimbatore, Ahmedabad, Baroda, Calcutta and Dewas are the other places where agricultural pump industries are situated [5].

In many of the Indian states, free electrical power supply is given to agriculture. So, even though lot of saving potential is available in pump sets, the poor farmer has no interest in replacing in-efficient pump sets nor in incorporating capacitors or to spend any money on existing pump set other than for rewinding burnout motors etc. Subsidized or free power situation largely pampers this mind-set to go for slightly costly efficient pump set. Hence the authors have tried and succeeded in decreasing the cost of the submersible pump set, by decreasing the core length of DCR without sacrificing the overall efficiency level stated by IS 8034:2002.

In this paper Section II presents the brief overview of three-phase submersible pump sets, disadvantages of existing CFR technology and motors with proposed DCR. Section III deals with the test results and its analysis. Section IV describes the overall performance of the submersible pumps. A comparative analysis is made on the basis of cost and performance between the existing CFR and proposed DCR technology in a 5 HP / 8 Stage, 415V, 2-Pole, Three Phase, 50 Hz, 6"Submersible Pump Motors with various core lengths. The Discharge Vs Total Head graph is also drawn in the above combinations for analysis.

2. Three-Phase Submersible Pump Sets

Submersible motors are designed to operate with 250/450 volts, 50 Hz, 3 phase AC supply. They are fitted with wet type, water-filled, water-lubricated squirrel cage induction motors. The motor casing is of stainless steel. The starter winding is made of PVC/Polyester film, wrapped around waterproof copper winding wires. The rotor laminations are fitted with electrolytic grade copper rods, and the ends are brazed with forged copper end rings, mounted on a stainless steel shaft, which is hardened and ground to ensure long life. The shaft is supported by two sets of leaded bronze journal bearings lubricated by water. The axial thrust generated by the pump is absorbed by a thrust bearing fitted at the bottom of the motor. The motor is seated on radial seal rings.

The pump is of multistage centrifugal design, with radial or mixed flow impellers, which are of bronze and dynamically balanced. The diffusers are designed to give best possible efficiency and are built into the casings with replaceable guide bushes for easy maintenance. The pump shaft is made of stainless steel hardened and ground. A strainer is fitted at the inlet of pump to prevent entry of solid particles.

A. Motors with Existing Copper Fabricated Rotor and its Disadvantages:

When a copper bar rotor is manufactured, the copper bars are pushed through the rotor lamination stack. The end rings are brazed onto both ends of the rotor. This process ensures that all rotor bars are in place as illustrated in Figure 1. There are two methods used to secure the end ring to the rotor. The first method is "rolled ring" or the "under-bar" configuration and the second method is 'side-bar' end ring method. The under-bar method is a more economical method of rotor design and manufacture however; it does have some distinct disadvantages. Rolled copper end rings need to be brazed to close the ends, this induces stresses, which can result in cracking of the end ring. Starting torque exerted on the end ring causes deflection and stresses which after repeated starting leads to cracked rotor bar brazing and ultimately complete motor failure. Moreover, some manufacturers still use the practise of merely punching the rotor bars with a chisel or merely spot weld some of the laminations at the core ends together. These practises lead to loose laminations after a few months of operation, which then creates vibration and noise problems. Such a fabricated copper rotor involves intensive hand labor and therefore is expensive. Large HT motors and a few smaller rating submersible pump/special purpose motors with copper in the rotors are assembled by a slow and costly fabrication technique that is not economical for production of the millions of integral and fractional horsepower motors sold annually [6].

B. Motors with Proposed Die Cast Copper Rotor:

As squirrel cage motors started dominating the Industrial scene, R&D got on to eliminate or minimize the rotor problems of the brazed construction. Then as a technology improvement and enabling mass and defect free production at lower cost, the die cast aluminium rotors got developed totally eliminating bars insertion and end rings brazing etc. This successful development was readily adopted all over and today it dominates the entire world of LT squirrel cage induction motors [7]. Die cast motor rotors are universally produced in aluminium today because of fabrication by pressure die-casting, which is a well- established economical method.

The basic losses in an induction motor consist of resistance losses in the stator winding and rotor cage, iron losses, friction and windage losses, and stray loss. The resistivities of copper and aluminium for circular mil, per foot at 20°C are 10.37 Ω and 16.06 Ω respectively. Hence, for the same current requirement, the substitution of copper for aluminium results in 35.4 % reduction in resistance losses [8]. Therefore, by replacing the aluminium material in the rotor bars and end rings with copper, the overall efficiency of the machine gets increased. This idea leads to implementation of DCR technology [9, 10].

In addition to the increase in efficiency, the copper reacts with much more stability to changing loads, especially at low speeds and frequencies, operates cooler and has fewer repairs and rewindings, increasing motor life and decreasing maintenance costs [11-14].

The DCR is constructed utilizing the following steps:

- 1. Stack rotor punching on a stacking mandrel
- 2. Insert punching /mandrel stack in end connector mold
- 3. Die cast (i.e., inject copper) rotor
- 4. Insert shaft into hot rotor core
- 5. Machining the rotor in order to remove the ingates resulting from the injection of mould material.
- 6. Perfect balancing of the rotor assembly.

The die-cast as a state-of-the-art technology makes an increase of rotor size each year due to the manufacturing advancements. The previous challenges of die casting copper, which are higher temperatures and pressures compared with die casting aluminum, have been solved with the development of a die casting process using nickel-base alloy die inserts operated at elevated temperature. Substantial progress in understanding and managing the porosity problem characteristic of high-pressure die-casting has also been reported in [15-17].

Active development of the die-cast copper rotor motor begun in 1997 has now resulted in a growing market with about 250,000 units in service and still growing at a rapid rate. The DCR technology has been a significant effort of the world copper industry through the International Copper Association Ltd (ICA) managed by the Copper Development Association (CDA). This DCR project has been conducted jointly with die casters, motor manufacturers in all major motor markets word wide and academia. A sizeable data bank of motor performance test results now exists illustrating the several advantages to using the DCR [18, 19].

3. Test Results and Analysis

As a part of this research project to test the suitability of the DCR technology, upgraded motors used in water pump in agriculture were used. Though low-tension supply of 415V with a variation of \pm -6% is to be maintained as per the Indian standard, in many parts of India particularly in the rural networks, the above supply voltage is never maintained. Due to heavy transmission and distribution losses in carrying electricity to distant places and overloading of the existing transformers, the supply voltage drops down to 300 Volts with a 47.5 to 51 Cycle frequency instead 415 Volts and 50 Cycle frequency. Average power supply is 6 to 8 hours daily during summer and most of the time, power supply is around 300 - 320 Volts. Therefore most realistic supply voltage in rural network is around 300 - 320 Volts during the day, which steps up to 440 - 460 Volts during night. In the single phase, voltage varies from 140 - 250 Volts. During summer the ambient temperature is 35° to 40 °C with dry humidity, when heat dissipation by motors. Hence pump sets are designed for such extreme conditions. Such a voltage variation gives rise to a serious problem to the motor unless the same are designed to take care of such wide fluctuation of voltage. Hence the performance of DCR motor with and without pump during low voltage supply was also tested.

The comparison of Performance test result values of 3.7 kW (5 HP) 415 V, 50 Hz Star connected, Wet type Water Cooled CFR and DCR motors with M47 stampings are shown in Table I . The testing method followed for testing the motor confirms IS 9283 [20]. For the same core length of 170 mm, with a rated voltage, the efficiency values are found nearly 1.5% high in DCR motor compared to CFR motor. An increase in full load current of 0.66A is observed in DCR motor. Due to lower slip, the full load speed of a DCR motor cannot be a problem in pump applications when higher flow rates are desired. Energy can be wasted in the CFR substitution because the power increases with the cube of the rotational speed to produce the increased flow rate. Starting (locked rotor) torque and p.f in DCR motor is reduced than its

CFR counter part. A total loss in DCR motor is nearly 45 Watts lesser than CFR motor. This is due to reduction in constant losses in DCR motor. Copper rotors generally result in reduced motor operating temperatures compared to its CFR counterpart. Due to reduction in operating temperature in DCR motor the insulation life gets increased.

In India, the overall efficiency of a 5HP, 2 pole, 8 stage, and 150Ø mm borehole submersible pump set with existing CFR motor is 45% and above [21]. But the features suggested in the proposed technique using DCR, under data set 5 of the Table 2, should be able to improve the overall efficiency to around 51% and even a little more. For the purpose of improving the efficiency of the pumps, a "Standard Pump" was chosen whose details of performance and raw material costs are shown in data set 1 of Table 2. While only 6 data sets are given in Table 2, the large number of tests and assembly/manufacturing combinations were tried and the 6 sets are just milestones in the development process. This project is aimed to improve the over all efficiency of the submersible pump set together with the reduction in manufacturing cost. So, to achieve these goals variety of diffuser/impeller combinations are tried, which overlap in terms of discharge, and those combinations, which render the same discharges in different, pipe diameters. This would go a long way in conserving lot of energy and at the same time bringing the cost of production lower than what is prevailing now. In the data set 2, using Noryl impeller and Diffuser has improves the overall efficiency by about 4% points and the more appropriately designed combination should render much more improvements. The use of carbon thrust bearing in the motor has improved the overall efficiency by about 3% points.

Water Cooled With M47 Stampings Der Motor Compared To Cfr Motor							
Rotor Conductor	CFR	CFR	DCR	DCR			
Core Length (m.m)	205	170	170	150			
F.L Current (Amps)	8.72	8.37	8.93	9.00			
p.f	0.76	0.85	0.78	0.82			
F.L Speed (Rpm)	2896	2835	2877	2884			
Starting Torque (% FLT)	208.39	225.47	142.62	181.06			
Slip (%)	3.45	5.5	4.11	3.85			
F.L Input Power (Watts)	4790	5100	5000	5320			
Stator Copper Loss (Watts)	483.15	493.48	539.24	599.72			
Constant Losses (Watts)	449.92	665.05	575.04	795.12			
Stator Output (Watts)	3856.9	3941.5	3885.7	3925.2			
Rotor Output (Watts)	3705.19	3706.1	3707.5	3755.12			
Total Losses (Watts)	933.07	1158.5	1114.3	1394.8			
Stator Resistance at 50 deg $c(\Omega)$	2.118	2.348	2.254	2.468			
Efficiency (%)	77.35	72.67	74.15	70.58			
Temperature Rise Test at 353 V (deg c)	26	26	16.70	26			

Table 1. Performance Test Result Values Of 3.7 Kw (5 Hp) 415 V, 50 Hz Star Connected, Wet Type Water Cooled With M47 Stampings Dcr Motor Compared To Cfr Motor

The DCR used in data set 5 and 6 has contributed about 2% improvements in the overall efficiency. Under data set 5 in

Table 2, it has been achieved a reasonably optimized design giving a higher efficiency at the lower cost of the submersible motor portion. In short it should be pointed out that an improved pump set consuming 25% less power has been achieved at 90% of the cost of the conventional CFR pump set under reference. As one could see, the efficiency improvements obtained are quite substantial meaning a reduction of 25% in the energy consumed. This project is extended to all ratings and models in vogue should considerably save energy through not necessarily 25% noticed here, but at least 10 to 15% conservation should be possible. The overall cost of

the pump sets shown in Table 2 are bill of material costs and is taken on at the end of February 2009.

The comparisons between DCR's of 170 mm and 150 mm core lengths with M47 stampings is shown in Table 2. From Table 2, it can be inferred that though DCR with 170 mm core length produces low discharge as compared to DCR with 150 mm core length. Also, the overall efficiency of DCR pump set with 150 mm core length is 40.14%, which is 3.64 % higher that overall efficiency of submersible pump set prescribed by IS 8034 [22]. The cost of DCR with 150 mm core length is found to be Rs.10, 078/- which is Rs.983/- less than that of DCR with 170 mm core length.

	P	ump Motor	TS S	,	,	
Core Length (mm)	205	205	205	170	170	150
Stamping Grade	M47	M47	M47	M47	M47	M47
Winding Design	(1.1) 34 CPS	(1.1) 34 CPS	(1.1) 34 CPS	(1.1) 34 CPS	(1.1) 35 CPS	(1.1) 35 CPS
Rotor Used (Copper)	CFR	CFR	CFR	CFR	DCR	DCR
Thrust Bearing	LTB	LTB	Carbon	Carbon	Carbon	LTB
Diffuser Material	CI	Noryl	Noryl	Noryl	Noryl	CI
Impeller Material	LTB	Noryl	Noryl	Noryl	Noryl	LTB
Motor Efficiency (%)	75.78	75.78	77.35	72.67	74.15	70.58
F.L Speed (Rpm)	2875	2875	2896	2835	2877	2884
F.L Current (Amps)	8.7	8.7	8.72	8.37	8.93	9.00
Starting Torque (% FLT)	175.5	175.5	208.39	225.47	142.62	181.06
Over all Efficiency (%)	41.6	45.32	48.51	48.31	51.00	40.14
Head (m)	60.99	55.92	56.00	56.25	56.34	65.69
Discharge (lps)	3.28	3.00	3.02	3.02	3.02	3.53
Motor Raw Material Cost (Rs.)	8,700	8,700	8,812	7847	8,147	7,164
Pump Raw Material Cost (Rs.)	3,814	2,914	2,914	2,914	2,914	2,914
Total Cost of Raw Material for the Pump set Incl. Motor & Pump (Rs.)	12,514	11,614	11,726	10,761	11,061	10,078

Table 2	
41 5	~

Various Parameter Values Of 5 Hp / 8 Stage, 415v, 2-Pole, Three Phase, 50 Hz, 6"Submersible

But from the point of energy conservation and hence the overall efficiency of pump set, DCR with 170 mm core length would be the apt one to opt for. The overall efficiency of this pump set is 51%, which is 11% higher compared to DCR with 150 mm core length. Though the total cost is higher compared to DCR with 150 mm core length, it would be able to compensate the extra costs in the payback period.

4. Pump Performance

The submersible pump set consists of a pump and motor assembly, a discharge column, a head assembly and a waterproof cable to conduct the electric current to submerged motor. The pump and the motor are directly coupled and the pump is placed above the motor. The motor depends on the water pumped for cooling, and a failure of the water supply can result in serious damage to the unit. The pump is dimensioned for use in bores and is very long in comparison to its diameter [23, 24].

Enriched Efficiency with Cost effective Manufacturing Technique

Pump performance is routinely measured as a combination of two factors;

Flow rate and pressure (head). Every pump will have a performance curve showing how its output (flow rate) changes when it is required to pump water to different heights. There is a trade off between flow rate and head, with flow rate decreasing as head increases. When choosing a pump, one should consider both the volume of fluid to be pumped and the vertical distance required to be pumped. In addition to taking into account the negative effect head will have on the performance of a pump, attention should also be shown to friction loss. Whenever water flows through pipe work, fittings, valves, elbows and even straight connectors, it will encounter differing degrees of resistance and therefore friction. The performance curve of the pump does not take friction losses into account. The testing setup for measuring Torque and other performance parameters of 5HP submersible pump are shown in Figure 2.

The Discharge Vs Head diagrams of a 5 HP submersible pump with various core lengths are compared in Figure 3. The testing method followed for testing the submersible pump confirms IS 8034-2002. Due to high rotational speed, it is observed that DCR produces maximum discharge compared to CFR for the same core length of 150 mm as shown in Figure 3(a). As core length increases, the discharge rises rapidly as shown in



Figure 1. Copper rotor bars in electrical steel rotor pack



Figure 2. Testing setup for measuring Torque and other Performance parameters

Figure 3(b). In Figure 3(c), it can be concluded that for the same core length of 170 mm, DCR gives the maximum discharge as compared to CFR. When the efficiencies of CFR and DCR are compared for the same core lengths of 170 mm, DCR has a slight edge over CFR as seen in Table 1. The Standard pump set is provided with CFR with 205 mm core length uses LTB for its thrust bearing and impeller and CI for its diffuser. But when its thrust bearing is replaced by Carbon and Noryl is used in diffuser and impeller, the discharge is found to have increased, which is shown in Figure 3(d). The modified CFR is denoted by 205*.









Figure 3. The Discharge Vs Head diagrams of various core lengths of a 5HP Submersible pump set

5. Conclusions

This paper describes the overall efficiency improvements in submersible pump set with reduction in manufacturing cost using DCR technology. In this work, by decreasing the core length of DCR, the various performance parameters are measured and compared with existing CFR technology. The results shows that with M47 stamping material the development of cost effective DCR motor model with 170 mm core length would give the overall efficiency of about 51%, which means an improvement of 10% points over conventional CFR submersible pump set with 205 mm core length at 10% of lower cost. Thus it has been demonstrated that 25% of energy could be saved in the pumping operations by this newly developed pump set, which costs only 90% of the cost of CFR pump set. If proper attention is given to limit the

various losses such as, Hydraulic losses, Leakage losses, Mechanical losses and Disc friction losses in submersible pump set, then further more enrichment in overall efficiency of submersible pump sets are possible.

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S. Manoharan took his B.E degree in Electrical and Electronics Engineering from Government College of Technology, Coimbatore in 1997, M.E degree in Electrical Machines from PSG College of Technology, Coimbatore in 2004 and Ph.D. in the area of Electrical Machines and drives from Anna University Chennai in July 2010. He has over 17 years of teaching experience. He is currently working as Professor and Head, Department of Electronics and Instrumentation Engineering in Karpagam College of Engineering,

Coimbatore, Tamilnadu. He has published research papers in both National and international journals of repute and presented papers in National and International Conferences. He has published more than half a dozen-text books on Electrical and Electronics related fields. He is a life member of ISTE, SSI and member of IE (India) and IEEE.



N. Devarajan, Professor, EEE Dept., Government College of Technology, Coimbatore. He received B.E (EEE) and M.E (Power Systems) from GCT Coimbatore in the year 1982 and 1989. He received Ph.D in the area of Control Systems in the year 2000. He published 85 papers in the national and international conferences. He published 27 papers in international journals and 10 in national journals. Under his supervision currently 10 research scholars are working and 4 scholars completed their Ph.D. His areas of interests are control systems, electrical machines and power systems. He is

member of system society of India, ISTE and FIE.



M. Deivasahayam received his B.E degree from P.S.G College of Technology, Coimbatore, in 1972. He has 35 years of experience in the field of Design, Erection and Commissioning of power plants with Government of India & abroad. He has published research papers in both National and international journals and presented papers in National and International Conferences. He is currently working as Joint Managing Director of Mehala Machines India Ltd., Coimbatore, India.



G. Ranganathan is a graduate in Electrical Engineering from P.S.G College of Technology, Coimbatore. He has 45 years of rich & varied experience in the fields of design, development, standardization & quality assurance of rotating electrical machines. He has been heading the Coimbatore unit of the erstwhile multinational GEC ALSTOM India Ltd. He is currently a consultant engineer of repute. He has contributed greatly in the design & development and energy efficiency improvements of asynchronous motors. He is the life member in various societies like IE (India) and Institute of Standards

Engineers. His research papers have been published in National and international journals.