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J. Electrical Systems 6-2 (2010): 144-158

Journal of Electrical Systems

Regular paper

Energy Conservation in Submersible Pump Sets through Efficiency Improvements using Modified Slot Design and DCR Technology

This paper presents the efficiency improvements in submersible pump sets by increasing the efficiency of squirrel cage induction motor by using Die-cast Copper Rotor (DCR) technology. A new slot design is proposed instead of conventional slot design for accommodating copper conductors for stator and rotor. The possible efficiency improvements are checked with three varieties of laminations in both motor and pump sides. The various electrical parameters including the low voltage performance are measured and compared with the existing Copper Fabricated Rotor (CFR) with proposed DCR technology in a range between (5– 10) HP 3 phase wet type watercooled inductionmotors inaccordance with IS9283. The overall performance of submersible pump sets is also practically verified in accordance with IS 8034. The cost comparison between the existing CFR and DCR's are also reported.

Keywords: Induction Motor, Efficiency Improvement, Submersible Pump Set, Die- cast copper Rotor, Copper Fabricated Rotor, Rotor Slot design, Energy Efficiency.

1. Introduction

For any country, power is a critical input for economic development and for improving the quality of life. In India, the achievement of increasing installed power capacity from 1,362 MW in 1947 to the current level of over 1,48,265.41 MW as of April 2009 is quite impressive in absolute terms. In spite of this addition in generation capacity, the growth in demand for power has far exceeded the generation capacity augmentation, as a result of which the country is facing both energy and peaking shortages. India is amongst the worlds largest emerging energy markets and faces a chronic 10% electricity shortage and up to 20% during peak periods. The per capita energy consumption of primary energy in India is only 277 kg of oil equivalent. It is just 3.5 per cent of the per capita energy consumption of the US, 6.8 per cent of Japan, 37 per cent of Asia, and 18.7 percent of the world average. India's energy consumption per unit of GDP, however, is high compared to Japan, the US, and Asia as a whole by 3.7, 1.55 and 1.47 times respectively. This indicates inefficient use of energy with a substantial scope for energy savings.

Based on the demand projections made in the Sixteenth Electric Power Survey, over 100,000 MW additional generation capacity needs to be added by 2012 to bridge the gap between demand and supply of power. This would necessitate mobilization of nearly Rs. 8,000 billion of investment for additional generation capacity and associated transmission and distribution system in the next decade. So, energy supply projects are highly capital intensive. They have long gestation period, thereby having a direct bearing on ecology and environment. Inadequate availability of energy resources affects the economic growth, and in fact, the lives of the citizens. Hence, it is imperative that energy resources are consumed rationally and economically, thereby eliminating wastages and losses to the extent possible.

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The goal of sustainable development, increasing concerns on environmental pollution, global climate change, and the ever-increasing gap between demand and supply has made energy conservation an integral part of our power development programme. The advent of the World Trade Organization regime has further accentuated the need for improving energy efficiency. The country has to bring down energy intensity per unit of GDP so that goods manufactured in India remain competitive.

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]. 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 % 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.

One of the important factors that contribute to the inefficiency in the pumping system is low efficiency of electric motor employed in it. Therefore, the overall efficiency of Submersible Pump can be increased by increasing the efficiency of its prime mover, which can be achieved by using DCR technology instead of conventional CFR Technology. The higher efficiency of DCR motors often have comparable or somewhat higher breakdown torque compared to the aluminum rotor counterpart, but when copper is simply substituted for aluminum, starting or locked rotor torque is reduced and starting currents are higher. This can be a problem in many applications. Hence in the present work, one of the new stamping designs for both stator and rotor are proposed. Apart from new stampings, the efficiency improvement in an existing submersible motor with DAR and proposed DCR is investigated using a superior lamination M47. At the same time, the cost effective production of submersible pumpset is also carried out by putting three different varieties of laminations called, Prime, LC and M47 in the both stator and rotor. The testing method followed for testing the motor confirms IS 9283 and IS 8034 for testing the pumpset. During this process, the overall efficiency level of the pump set is also monitored, which either within the level is stated by IS 8034:2002 or otherwise.

In this paper Section 2 presents the brief overview of three-phase submersible pump sets and disadvantages of existing CFR technology in the same. Section 3 gives the design, construction and characteristics of the proposed Die-Cast Copper Rotor with modified slot geometry. Section 4 deals with the test results and the analysis of these results signify that the efficiency of the DCR motor is well within limit. Section 5 describes the overall performance of the submersible pumps and a comparative analysis is made on the basis of cost and performance between the existing CFR and proposed DCR technology motors of various ratings/stages.

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 stator 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.

2.1 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. There are two methods used to secure the end ring to the rotor. 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 stress 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 [4].

2.2 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 [5]. 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^{o}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 [6]. 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 [7,8].

In addition to 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 re-windings, increasing motor life and decreasing maintenance costs [9-12].

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 [13-15].

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 [16, 17].

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 +/-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.

After modifying the proposed slot designs, the test are conducted in accordance with IS 9283:1995 [18]. The conventional slot design and the proposed slot design for stator and rotor are shown in Fig. 1, 2, 3 and 4 respectively. A locked rotor test and a no-load test can be used to determine the equivalent circuit parameters of an induction machine [19, 20]. So, these tests were performed on each of the motor for comparing its performance characteristics with old and new laminations (both laminations are M47) and its results are shown in Table1. The equivalent circuit model of an induction machine can be used to predict its performance characteristics. One such circuit is shown in Fig. 5.

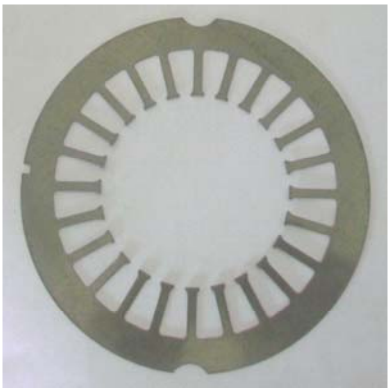


Fig. 1. Conventional Stator lamination

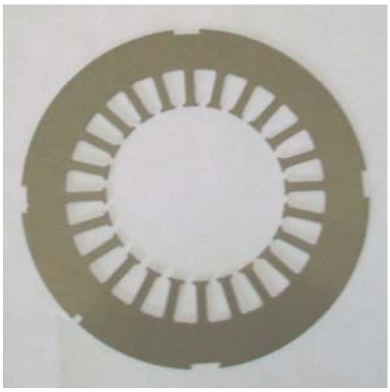


Fig. 2. Proposed Stator lamination

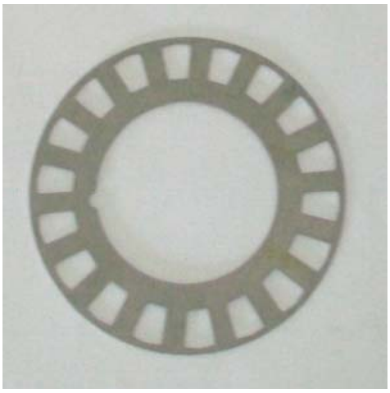


Fig. 3. Conventional Rotor lamination

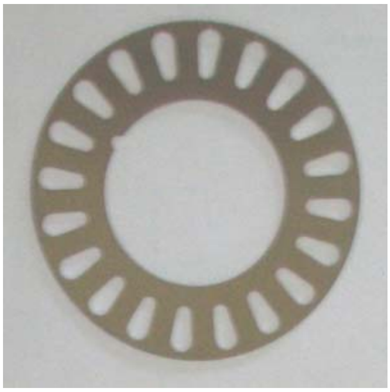


Fig. 4. Proposed Rotor lamination

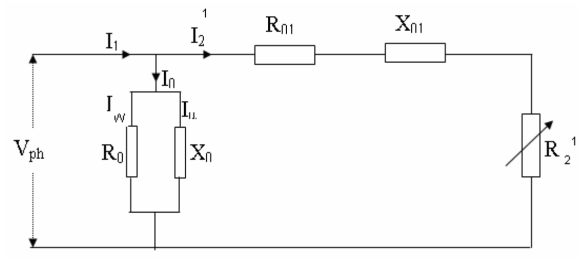


Fig. 5. Equivalent circuit of an induction motor

Table 1: Comparison of No load and Blocked rotor test Results

Type of Lamination	No load test		Blocked rotor test	
	CFR	**DCR**	**CFR**	**DCR**
Old Lamination	V=415 V	V=415 V	V=415 V	V=415 V
	I= 3.86 A	I= 4.36 A	I=37.58 A	I=44.86 A
	P=770 W	P=660 W	P=17663.64 W	P=18986 W
New Lamination	V=415 V	V=415 V	V=415 V	V=415 V
	I= 5.5 A	I= 5.6 A	I=52.2 A	I=56.83 A
	P=610 W	P=590 W	P=25189.70W	P=27026.44 W

In evolving the new slot configuration, the weight of copper has reduced as compared to rotor bar cross section of the conventional stamping. In spite of the increase in I^2R losses consequent upon the decrease of copper in the rotor, the efficiency of the motor has substantially increased. This is because of the substantial reduction in the iron loss due to the lower flux densities in the stator yoke. While the efficiency level has stood at 78.5 % in a 5 HP, 380 V, CFR construction and 79.2 % in a DCR construction using the new lamination. The authors are of the opinion that a further improvement in efficiency should be possible by retaining the area of the rotor copper bars of the conventional lamination. This trial is under progress.

The comparison of equivalent circuit parameters for both CFR and DCR motors made out of the old lamination and new lamination with M47 material are given in the Table 2. It is felt that, we shall discuss only one of the constructions namely DCR motors of old lamination and the new lamination. Because, the purpose of the current exercise is to establish the superiority of the new lamination. This is more so because the equivalent circuit parameters of the motors of the CFR and DCR motors made out of particular lamination design do not differ much.

The improvement in efficiency by using the new lamination would be explained as stated bellow. As already explained the quantum of rotor copper used is considerably lesser than what has been used in the old lamination. This has been deliberately done to increase the starting torque and to keep a tag on the cost of the motor.

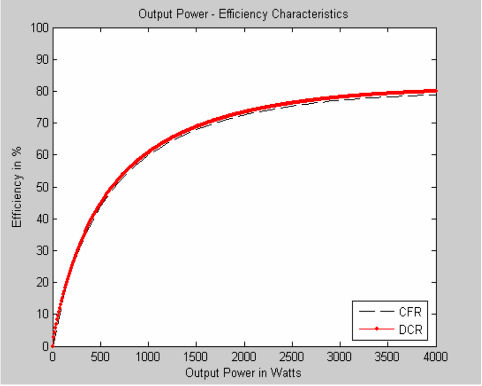
Table 2: Comparison of Equivalent Circuit Parameters of Old and New Laminations

Parameters	Old lamination		New lamination	
	CFR Motor	DCR Motor	CFR Motor	DCR Motor
Iw (A)	0.61847	0.53012	0.84722	0.81944
Iu (A)	3.8101	4.3277	5.4344	5.5397
I_0 (A)	0.61847-(i*3.8101)	0.53012-(i*4.3277)	0.84772-(i*5.4344)	0.81994-(i*5.5397)
R_0 (Ω)	671.01	782.84	283.28	292.88
X_0 (Ω)	108.92	95.895	44.163	43.323
Z_{01} (Ω)	9.251	11.043	4.5977	4.2231
R_{01} (Ω)	3.1448	4.1691	3.0815	2.6862
X_{01} (Ω)	8.7001	10.226	3.4122	3.2587
R_2^1 (Ω)	0.7538	1.7781	1.3495	0.9542
R_1 (Ω)	2.391	2.391	1.732	1.732

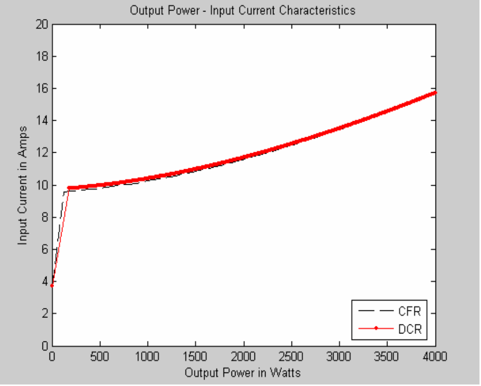
The number of conductors per slot used in the DCR motor is 29 as against the 31 conductors per slot used in the motor made with old lamination. This is reflected in the rotor resistance refereed to stator (R_2^1) value. The no load reactance (X_0) value of the DCR motor made out of new lamination is 43.323 Ω as against 95.895 Ω obtained in the motor using old lamination is also thus justified. Obviously, the total impedance of the motor referred to stator winding (Z_{01}) has also reduced from 11.043 Ω in the old motor to 4.2231 Ω in the new motor, which is responsible for substantial decrease in iron losses between the two motors and hence the increase in efficiency of the motor with new slot configuration.

3.1 Performance Characteristics of DCR with New lamination

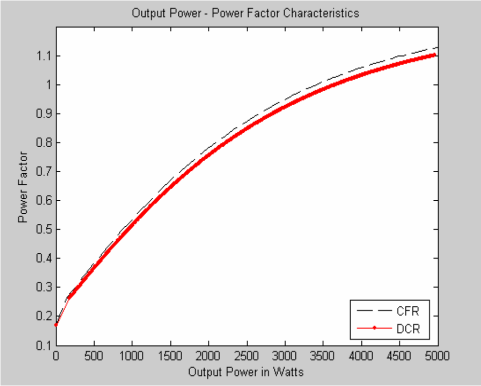
The variations (with output power) of its torque, current, input power factor, efficiency, etc. of the DCR with proposed new lamination M47 are determined using Matlab 7 software which is shown in Fig. 6 (a-e).



(a)



(b)



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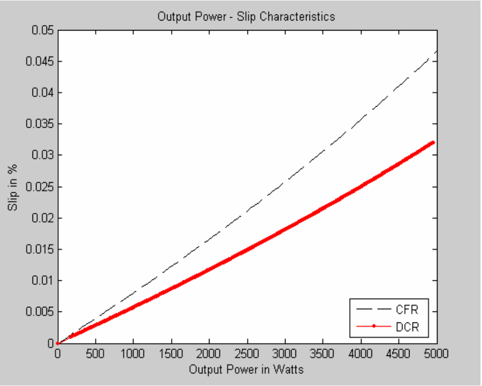
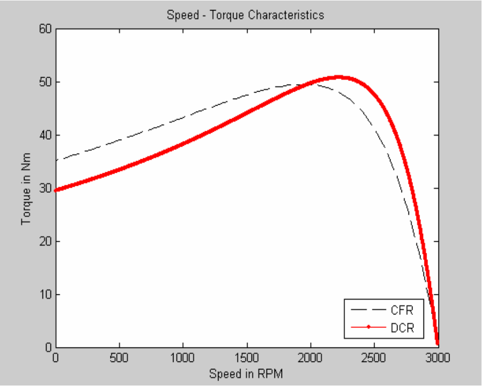


(d)



(e)

Fig. 6. Performance Characteristics of a 5HP Submersible motor with New Lamination

Comparison of Results from tests obtained on the 5 HP, 415V, 2-pole, 3-phase, 50 Hz submersible motor with existing and proposed M47 laminations are shown in Table 3. The important parameters responsible for the induction motor characteristics like Efficiency, Locked rotor Torque, Slip etc., are calculated from Matlab 7 software are compared from the tested results are shown in Table 4. Both the results are found almost tallying with each other**.**

As expected, the higher conductivity (copper) rotor material, the speed of DCR motor is increased slightly, the slip and input currents are reduced and the efficiency is increased. For the same output power, by merely replacing the CFR with DCR (with new lamination), the efficiency of the motor is increased by nearly 0.77% points.

Table 3: Comparison of Test Results of 5 HP Submersible Motor with Old and New Laminations

Parameters	Old lamination		New lamination	
	CFR	DCR	CFR	DCR
Efficiency (%)	72.67	75.39	78.47	79.24
Speed (RPM)	2835	2872	2898	2917
Full load current (A)	8.37	8.52	8.93	8.97
Starting torque (% of full load torque)	225.47	195.26	252.64	256.68
Slip (%)	5.5	4.26	3.39	2.76
p.f	0.85	0.80	0.74	0.72

From Table 3, it is observed that the value of starting (locked rotor) Torque is reduced somewhat when DCR is substituted for CFR with slots designed for old lamination and the reverse is true when substituting the new lamination. From the mechanical characteristics shown in Fig. 6 (e) the DCR motor has the advantage of a higher torque at running speed. This characteristic of a DCR motor often finds very useful in applications such as centrifugal pumps, which need high torque at high speed. The pull out torque observed in DCR motor is high.The p.f of the motor under various load conditions of both the CFR and DCR motors are nearly equal.

Table 4: Comparisons of Tested and Calculated values of 5HP Submersible Motor with New Lamination Under Rated Conditions

Parameters	Results	CFR Motor	DCR Motor
Efficiency (%)	Calculated	78.555	79.624
	Tested	78.47	79.24
Speed (RPM)	Calculated	2901	2931
	Tested	2898	2917
Power factor	Calculated	0.73845	0.72889
	Tested	0.74	0.72
Input Power (W)	Calculated	4638.1	4565.6
	Tested	4636	4568
Output Power (W)	Calculated	3730	3730
	Tested	3730	3730

Three varieties of laminations are used to make both stator and rotor. One is inferior in quality called as 'PRIME'. Secondly, Low Carbon (LC) electrical steel, which is cold rolled steels containing relatively low amounts of carbon and silicon. But these materials are comparatively better than the previous one. The third material is CRNO steel called as M47.

The comparison of load test result values of various ratings of CFR and DCR motors with M47 stampings are shown in Table 5. With a rated voltage, almost irrespective of the ratings of motor, the efficiency values are found high in DCR motor compared to CFR motor. Due to lower slip, the full load speed of a DCR motor is high during rated voltage and a reduced voltage. The starting Torque value is increased in the new slot configuration than CFR counter part. The p.f value of DCR motor is nearly equal than that of CFR motor. But it is not at all a problem if a pump application is concerned. It should be noted that the increased speed of a low slip DCR motor could be an advantage in pump applications when higher flow rates are desired.

Table 5: Test Data 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

Rating (HP)	Core Length (mm)	Voltage (V)	Efficiency (%)		Full load Current (Amps)		Full load Speed (Rpm)		Slip (%)		Starting Torque (% of Full load Torque)	
			CFR	DCR	CFR	DCR	CFR	DCR	CFR	DCR	CFR	DCR
5	180	380	79.1	80.1	8.8	8.9	2875	2906	4.2	3.1	252.6	252.6
		415	78.5	79.2	8.9	9.0	2898	2917	3.4	2.8	252.6	256.7
7.5	250	380	81.2	82.5	10.9	10.6	2866	2867	4.5	4.4	202.5	218.9
		415	80.4	81.4	11.2	11.0	2860	2868	4.7	4.4	185.8	218.9
10	300	380	84.0	84.9	16.0	15.7	2890	2886	3.7	3.8	188.8	201.1
		415	83.2	84.4	16.4	16.3	2901	2915	3.3	2.8	222.6	237.1

Table 5: Test Data 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 (continued…)

Rating (HP)	Core Length (mm)	Voltage (V)	Input Power (W)		Full load Copper loss (W)		Rotor Output (W)		Constant Losses (W)		Total Losses (W)	
			CFR	DCR	CFR	DCR	CFR	DCR	CFR	DCR	CFR	DCR
5	180	380	4680	4620	405.1	408.8	3702.2	3700.7	392.7	371.8	797.8	780.6
		415	4720	4670	414.4	418.1	3703.6	3700.6	452.8	418.0	867.2	845.1
7.5	250	380	6780	6680	532.6	506.5	5505.3	5510.5	455.0	379.3	987.6	885.8
		415	6850	6760	559.3	541.4	5508.9	5504.7	482.3	431.2	1041.6	972.6
10	300	380	9020	8840	645.4	587.1	7502.0	7503.9	578.3	414.5	1223.7	1001.6
		415	8940	8890	613.6	632.2	7504.9	7500.5	496.5	500.7	1132.8	1110.1

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 [21, 22].

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. To evaluate the performance of a pump the following combinations of CFR and DCR submersible pump set are analyzed.

- 5 HP / 8 stage, 6”submersible pump
- 7.5 HP/ 12 stage, 6”submersible pump
- 10 HP / 12 stage, 6”submersible pump

The testing setup and the discharge diagram under full load condition of 5HP submersible motor is shown in Fig. 7 and 8 respectively. The overall performances of the submersible pump of various ratings/heads are shown in Fig. 9. Due to high rotational speed of DCR, the discharge rate is high compared to CFR. The low voltage performances of all ratings were tested.

Fig.7 Test bench

Fig. 8 Flow - Discharge diagram of 5 HP Submersible pump set

Table 6: Comparison of Test Data of submersible Pump set for various Ratings and core lengths with M47 Stampings

Rating (HP)	Core Length (mm)	Voltage (V)	Maximum Current (Amps)		Temp.Rise (Deg.C)		Total Head (m)		Discharge (lps)		Number of Stages		Efficiency	
			CFR	DCR	CFR	DCR	CFR	DCR	CFR	DCR	CFR	DCR	CFR	DCR
5	180	380	9.2	9.3	25	25	72.7	73.4	3.1	3.15	8	8	48.22	49.33
		415	9.5	9.5	25	25	73.4	73.5	3.2	3.2	8	8	47.67	48.01
7.5	250	380	11.7	11.0	24	24	76.8	76.2	4.1	4.1	8	8	50.49	52.24
		415	11.3	10.8	24	24	77.5	76.5	4.1	4.1	8	8	49.24	50.61
10	300	380	19.5	19.4	26	26	110.5	109.4	5.3	5.2	12	12	54.25	55.55
		415	19.2	18.6	26	26	110.5	110.1	5.3	5.3	12	12	53.78	55.86

The comparison of test Data of submersible pump set for various Ratings and core lengths with M47 Stampings are shown in Table 6. A comparison of test data of 5HP, 415V, 50Hz, star connected wet type water-cooled submersible pump set with PRIME, LC and M47 Stampings are shown in Table 7. A large number of literatures have been published in the past few years on the benefits to the performance of the induction motor by using copper as the conductive material in the rotor and CFR was considered inferior when compared to DCR [23]. Due the new slot geometry, the performance parameters and efficiency of CFR motor is improved, which is nearly equal to DCR motor. ie) the efficiency of CFR motor is improved by 4.0 % to 5.0 % compared to same capacity and core length of CFR motor. Still, it could not rise to the level of DCR, as the efficiency of DCR was still higher by 1% to 1.5%. At rated voltage, for the same core length of 180 mm and 5HP rating, DCR produces overall efficiency of the submersible pump is 48.01 % whereas the overall efficiency of CFR is 47.67 %. But at the reduced input voltage of 380 V, the DCR produces 1% more efficiency than CFR motor.

Table 7: Comparison of Test Data of 5HP, 415V, 50Hz, Star Connected Wet Type Water-Cooled Submersible Pump Set With PRIME, LC And M47 Stampings

Stamping Grade	**Prime**		**LC**		**M47**	
Winding Design	(1.1) 29 CPS	(1.1) 29 CPS	(1.1) 29 CPS	(1.1) 29 CPS	(1.1) 29 CPS	(1.1) 29 CPS
Rotor Used (Copper)	CFR	DCR	CFR	DCR	CFR	DCR
Thrust Bearing	Carbon	Carbon	Carbon	Carbon	Carbon	Carbon
Diffuser Material	CI	CI	CI	CI	CI	CI
Impeller Material	Gun metal	Gun metal	Gun metal	Gun metal	Gun metal	Gun metal
Motor Efficiency (%)	70.50	73.10	74.26	76.58	78.5	79.2
F.L Speed (RPM)	2764	2875	2772	2882	2898	2917
F.L Current (Amps)	9.20	9.10	9.07	9.03	8.9	9.00
Starting Torque (% FLT)	259.51	259.00	257.01	258.00	252.64	256.68
O.A. Efficiency (%)	42.6	44.76	45.36	46.80	47.67	48.01
Motor Raw Material Cost	Rs. 6,803	Rs.7, 053	Rs.7, 103	Rs.7, 353	Rs. 7,403	Rs. 7,653
Pump Raw Material Cost	Rs. 3,708	Rs. 3,708	Rs. 3,708	Rs. 3,708	Rs. 3,708	Rs. 3,708
Total Cost of Raw Material for the Pump set Incl. Motor & Pump	Rs.10,511	Rs.10,761	Rs.10,811	Rs.11,061	Rs.11,111	Rs.11,361

At rated voltage, the maximum current drawn by DCR is 0.1A more than that of CFR ie) DCR draws a maximum current of 9.0 A compared to CFR that draws a current of 8.9 A. Though the temperature rise in DCR and CFR remains unchanged to 25°C, the total head of DCR is 73.5 m compared to the total head of 73.4 m in CFR. Similarly, the comparisons between CFR and DCR can be made for different core lengths of 250 mm and 300 mm. From the above comparisons, it can be inferred that DCR has slight edge over CFR on its performance.

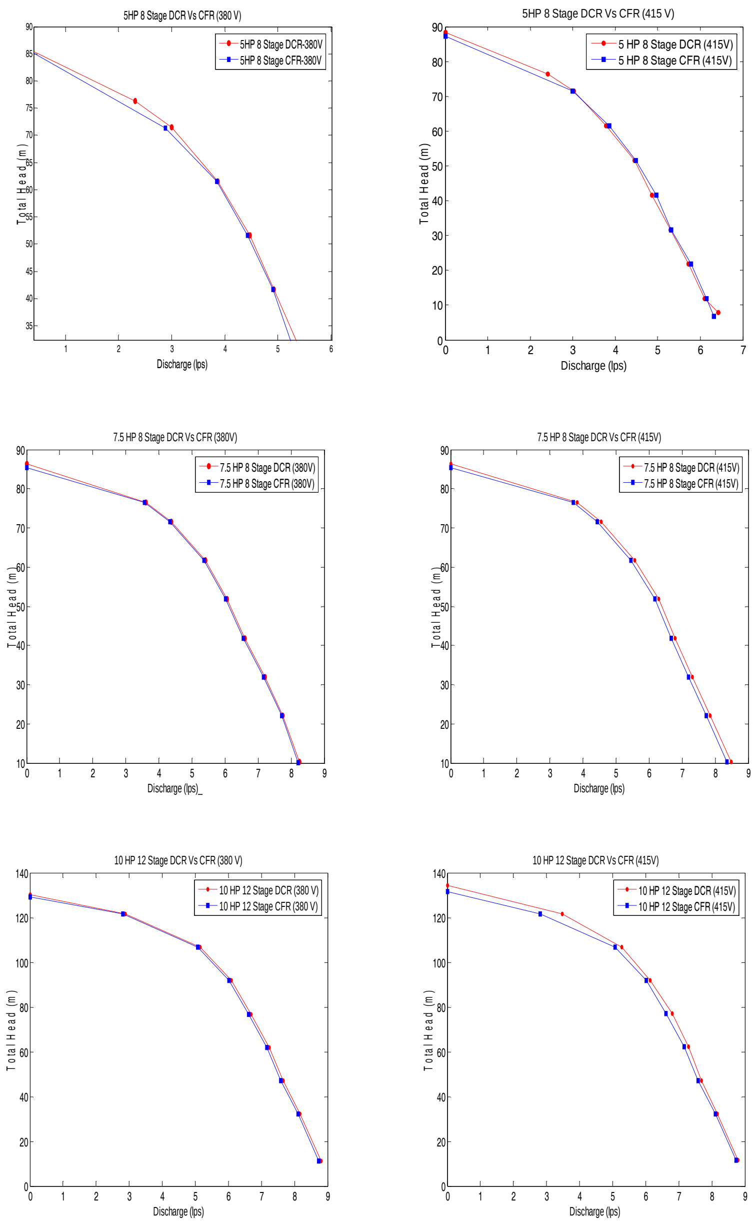


Fig. 9 The Discharge Vs Head diagrams of various ratings of the submersible pumps

M47 fitted with DCR produces a maximum motor efficiency of 79.2 % compared to other grading. It can produce maximum full load speed of 2917 Rpm. The DCR motor with M47 Lamination also produces maximum starting torque, which is 256.68 times the full load torque. This combination can result in a maximum overall efficiency of the pumpset is 48.01%. Apart from new slot configuration with M47 lamination, the diffuser and impeller materials are changed to “Noryl” then further improvement in overall efficiency (minimum of 3% more) is possible.

Hence, from the above comparisons shown in Table 7, it can be inferred that M47 grade fitted with DCR motors are much more effective than PRIME and LC stamping grades having DCR motors. Though the cost of M47 grade fitted with DCR motors is slightly higher it is hardly felt due to most of the above advantages.

5. Cost Analysis

The cost comparisons for various ratings are shown in Table 8. The overall efficiency of a 5 HP/8 stage DCR Submersible pump set is more than that of CFR motor. The over all cost of the same is Rs. 11,361/- whereas the net cost of a CFR pump set for a core length of 180 mm is Rs. 11,111/-. Even though DCR is costlier than CFR by Rs. 250/- it is highly preferred due to various advantages stated in section 2. Similarly the cost comparison for other ratings has been made and it is found that DCR motor can be preferred than CFR motor both cost and performance wise. All the above cost of the pump sets is bill of material costs and is taken on at the end of January 2009.

Table 8: Cost comparison of Motor Pump Set

H.P/Stage	Core length (mm)	Motor Cost (Rs)		Pump Cost (Rs)		Net Cost of Pump set (Rs)	
		CFR	DCR	CFR	DCR	CFR	DCR
5/8	180	7403	7653	3708	3708	11111	11361
7.5/8	250	8280	8620	4500	4500	12780	13120
10/12	300	8810	9280	5500	5500	14310	14780

6. Conclusion

This paper describes the efficiency improvements in the submersible motor using a new slot design and DCR technology instead of conventional CFR technology. Due to the adoption of proposed slot design in the existing CFR motor, efficiency of the submersible motor increases by 4% - 5% and hence the over all efficiency of the submersible pump set is also increases. Even though, the increase in over all efficiency of the submersible pump set of about 1% to 1.5% more than CFR motor is arrived in DCR motor with new slot geometry. In addition to increase in efficiency, there is also an increase in the starting torque of DCR motor with new lamination compared to the CFR motor. 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. Apart from energy savings, the DCR motor also reduces the production of greenhouse gases and push down the total environmental cost of electricity generation. Therefore the adoption of these motors can give immense benefits to the user as well as the country and the global environment.

Acknowledgement

The authors would like to thank the management of Karpagam College of Engineering, M/s Megala Machine Works India Ltd and M/s Challenger pumps (P) Ltd, Coimbatore, Tamilnadu, India for their infrastructure and testing facilities provided to complete this research work.

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