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A Comparative Performance Analysis DCR and DAR Squirrel Cage 3-Phase Induction Motor

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Abstract: **The importance of energy saving in induction motor was emphasized about 15 years ago, in academic area, but the motor manufacturer's interest is focussed only on maximum benefit. As a customer, it is better to take into account not only the motor price, but also the cost of the used energy during the whole lifetime of the motor. The new requirement to improve the motor efficiency is a serious research subject, which must be about the possibility of loss minimization in the induction motor.**

On an average the cost of energy consumed by the motor is nearly 80 – 100 times the initial cost of the initial manufacturing 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 efficiencv can make an overall significant difference in total energy consumption.

The slightly higher initial cost of DCR motors is often misunderstood as a demerit. It is not all true. The increase in initial cost is offset by the energy saving.

This paper presents the comparative analysis of performance of a DCR motor and DAR motor . The method of analysis is based upon testing results. The only change in design is that the Die cast aluminium rotor is replace by die cast copper rotor. The other design parameters like stator core, winding , air gap length etc are remains same.

Keywords: **Induction motor, Squirrel cage rotor, Losses, Premium Efficiency, DCR , DAR, Circle Diagram , No load test , Blocked rotor test.**

1. INTRODUCTION

Three phases Squirrel-cage induction motor finds extensive applications in the industrial field as an electric drive. It has become quite an attractive drive motor, because of its simple rugged construction, low capital cost and absence of commutator problems. The power factor and efficiency of these motors are quite high.

The performance given by any machine is said to be good when the machine gives its maximum efficiency under certain operating conditions with permissible temperature rise, good power factor and low noise level for the same operating conditions.

The poor performance means the efficiency given by the machine does not match with expectations or it becomes low and the temperature rise goes beyond permissible limits with poor power factor and high noise level for the same operating conditions. The reasons of poor performance are the losses in the rotating machine. Efficiency and temperature rise both depend upon the losses.

The AC induction motor has been continuously improved by optimising stator and rotor design and electric material properties and quantities. With given exterior motor dimensions, the potential efficiency gain is limited and costly.

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DCR technology is a new development to reduce losses by using copper instead of aluminium for the conductor bars and end rings in rotors to make it more efficient.

2. DAR AND DCR 3-PHASE INDUCTION MOTOR

Die casting is a process involving injecting molten metal at a high pressure 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 size parts.

Based on the choice of conducting material for rotor winding and the after development of manufacturing techniques, following types of Die- cast rotors exist for a squirrel cage induction motor:

1. Aluminium Die Cast Rotor (DAR)
2. Copper Die Cast Rotor (DCR)

Die cast motor rotors were universally produced in aluminium because fabrication by pressure die casting is a well-established and economical method.

With changing market conditions, users and engineers were looking for the best fit for the application at the most reasonable cost. As a result they were looking at purchasing motors utilizing aluminium die cast rotors which were in ratings much greater horsepower than the conventional fabricated aluminium bar rotors.

The previous challenges of die casting copper, which are higher temperatures and pressures compared with die casting aluminium, have been solved with the development of a die casting process using nickel base alloy die inserts operated at elevated temperature.

Fig 1. Squirrel cage DAR rotors

Fig 2. Squirrel cage DCR rotors

Update recently reported that several motor manufacturers who directly submitted copper for aluminium, saw significant increase in efficiency in an agricultural irrigation application. Designers can also trade off efficiency, size and power against each other to optimize motors for given application.

3. ADVANTAGES OF DCR OVER DAR CAGE MOTOR

1. Reduced losses – greater efficiency :

The superior conductivity of copper over aluminium ensures reduction of motor losses by 14 – 23 % and rotor I^2R losses by 29 – 41%, leading to improvement of the overall efficiency of the motor by at least 2% - 5 %, for the same slot design.

2. Reduced manufacturing cost :

Due to the higher efficiency of the copper rotor, the overall length of the rotor (and motor) can be decreased, while still matching the performance of a motor utilizing an aluminium rotor.

3. Reduction in overall motor weight:

Shortening the motor eliminates some of the rotor and stator laminations, decreases the amount of stator windings, and reduces the length of shaft. By this way, the overall weight reduction of about 20% is expected.

4. Allows better momentary overload:

Compared to aluminium Die cast rotors Copper die cast rotors can withstand higher momentary overloads due to copper's inherent property of lower resistance.

5. Higher torque:

As copper resistivity is lower than aluminium, a copper die cast rotor helps the motor to develop approx. 80% higher torque compared to aluminium die cast rotors at the same slip.

6. Lower noise level:

Since the motor runs cooler because of reduced losses and low temperature rise, the cooling fan is smaller in size resulting in lower noise levels.

7. Smoother Operation:

Compared to fabricated copper rotors, Copper die cast rotors offer better dynamic balancing, ensuring smooth operation of submersible pump

4. TECHNICAL ISSUES IN DCR MOTOR

1. *Starting Torque :*

The copper motor has the advantage of high torque at running speed and its starting torque is lower than in aluminium rotor motors. So it is not suitable in the applications where hight starting torque is required.

1. ***Higher start-up current:***

The higher conductivity of copper, i.e. its lower electrical resistance, will result in a slightly higher start-up current .

2. Rotor Inertia :

The higher rotor weight increases rotor inertia. This improves the motor's efficiency, but can be a problem in certain applications – for example motors that frequently switch direction at higher speeds.

5. ENERGY EFFICIENT DCR MOTOR

The various losses encountered in the motor are:

Motor Component Losses	Share on Total Loss
Stator copper loss	37 %
Rotor copper loss	18%
Core loss	20%
Friction and Windage loss	9%
Stray loss	16%

Various attempts are made to reduce the above losses in induction motors, primarily to reduce rotor copper loss using DCR technology Energy – efficient motors, also called premium or high efficiency motors. Motors qualify as 'energy efficient ' if they meet or exceed the efficiency level standards .

In conventional design, the cost of motor increases while attempting to reduce the losses. The task of efficiency improvement by various methods is illustrated in figure for a 20 H.P. motor.

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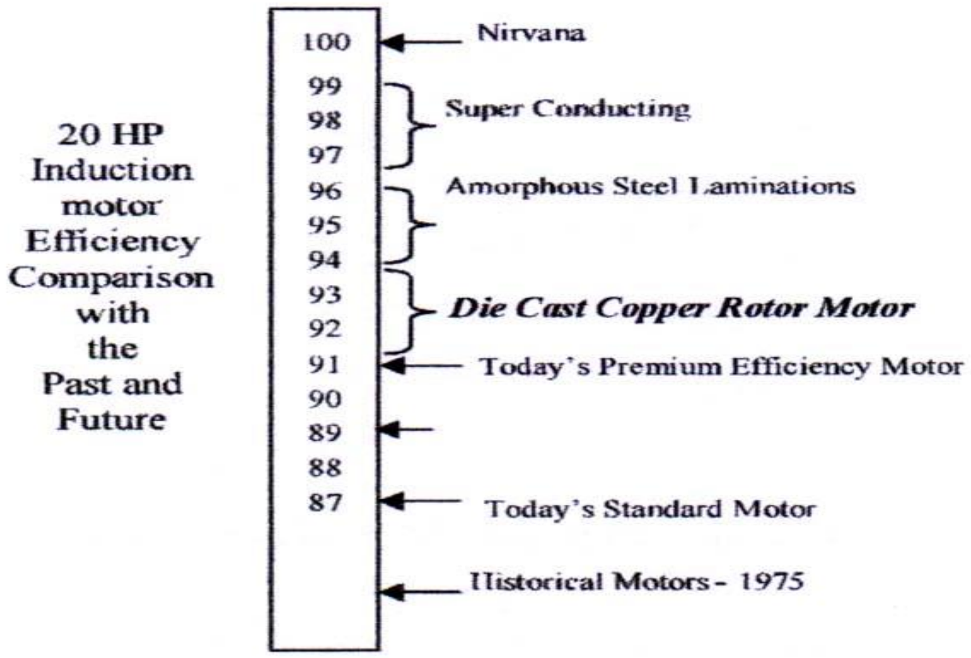

Fig 3.Improvement in motor efficiency with chaning technology

DCR has helped to achieve efficiencies to meet Eff 1 standards. It gives the confidence that with optimisation of design, it may be possible to achieve efficiency above Eff 1 level.

The DCR technology increases the efficiency of motor with a normal increase in cost. It is interesting fact that, two – third (2/3) of electricity generated globally is used to run the motors. It is equal to 2 Trillion (2 x 10^{12}KWhr/ Year). Out of this, about 8.5 % of all electricity is consumed to meet the loss in Electric motors.

6. PERFORMANCE ESTIMATION

The equivalent circuit parameters needed for computing the performance of a poly-phase induction motor under load can be obtained from the results of following tests:

1. no-load test
2. blocked-rotor test
3. measurement of the dc resistance of the stator windings

Performance analysis is done with the help of following two methods:

1. Circle Diagram Analysis
2. Equicalent circuit Analysis

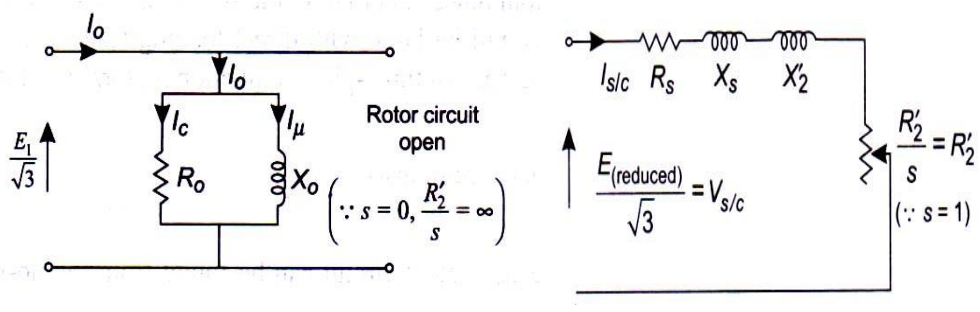

Fig: 4. No load and Blocked rotor circuit

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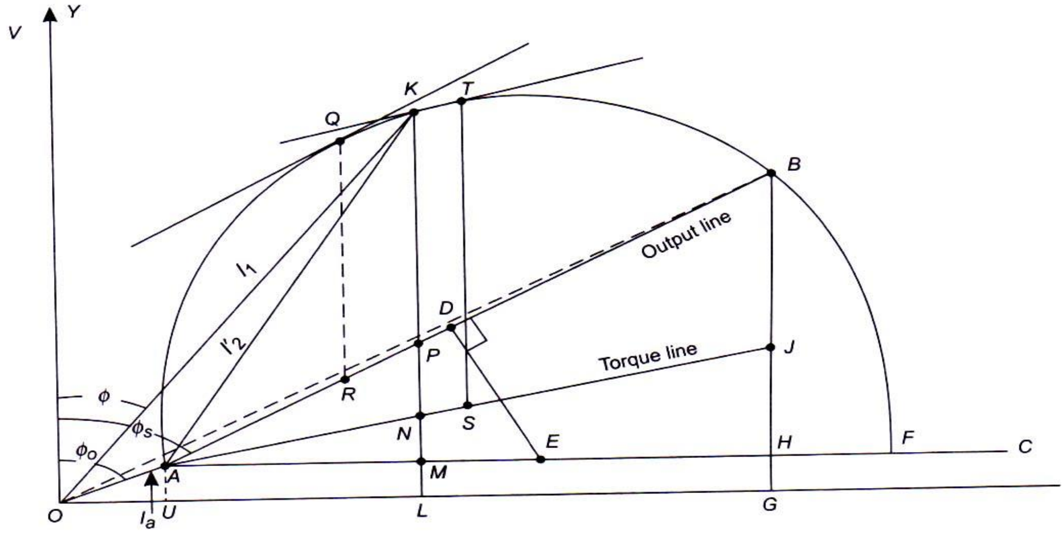

Fig 5. Circle diagram

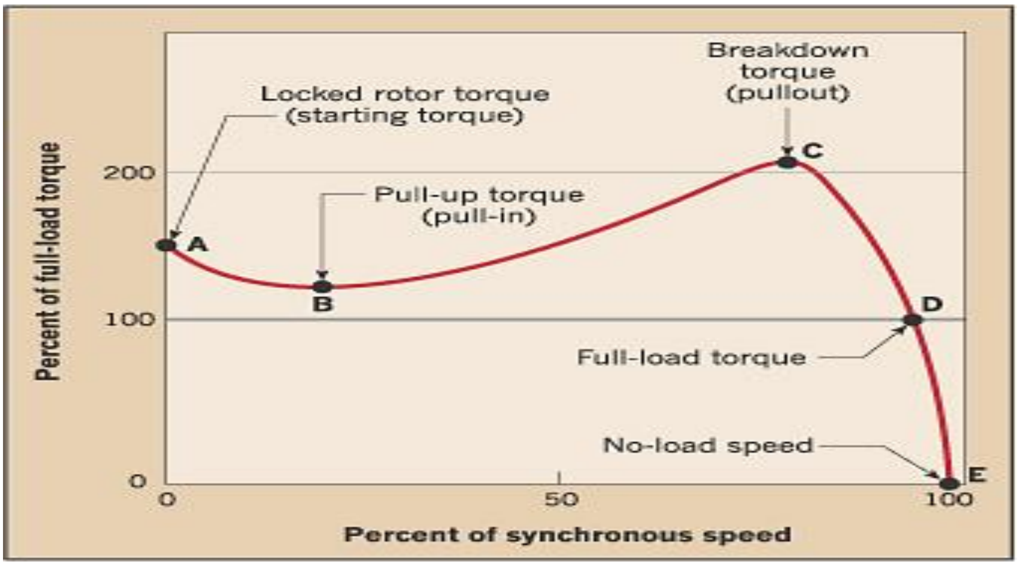

Fig 6.Induction motor Toque slip characteristic

1. The electromagnetic torque developed by the induction motor:

$$T_e = \frac{3\ R_2'\ V_1^2}{\omega_s\, s\left\{\left(R_1 + \frac{R_2'}{S}\right)^2 + \left(X_1 + X_2'\right)^2\right\}} \text{ Nm}$$

2. .Breakdown or Maximum torque: $T_{max} = \frac{3\, V_1^2}{2\,\omega_s\, X_2'}$ Nm

3. Breakdown Slip : $S_b = \frac{R_2'}{X_2'} = \frac{R_2}{X_2}$

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1. Breakdown Slip :

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$$S_b = \frac{R_2'}{X_2'} = \frac{R_2}{X_2}$$

7. RESULTS

Motor test results help to find out the equivalent circuit parameters of the motor. Motor analysis can be done using (i) Circle Diagram method (ii) Equivalent circuit analysis. An experimental and theoretical method helps to find the change in parameters with change in rotor design technology.

Table 1. No –Load Test Results : 2.2 kW (3 HP), 415 volts , 50 Hz, 2-pole, 3- phase induction motor

Parameters	DAR Motor	DCR Motor
No load voltage / phase	240 V	240 V
No load current / phase	2 A	1.9 A
No load power	220 W	180 W

Table 2. Blocked Rotor Test Results:2.2 kW (3 HP), 415 volts , 50 Hz, 2-pole, 3- phase induction motor

Parameters	DAR Motor	DCR Motor
No load voltage / phase	240 V	240 V
No load current / phase	2 A	1.9 A
No load power	220 W	180 W

Table 3.No – load Equivalent Circuit Parameters

Parameters	I_w (A)	I_m (A)	I_0 (A)	R_0 (Ω)	X_0(Ω)
DAR Motor	0.305	1.97	2	785.4	121.4
DCR Motor	0.25	1.88	1.9	960	127.4

Table 4.Blocked – Rotor Equivalent Circuit Parameters: Stator winding resistance / phase = 2.73 Ω

Parameters	Z_{01} (Ω)	R_{01}(Ω)	X_{01}(Ω)	R_2'(Ω)
DAR Motor	10.54	6.45	8.33	3.72
DCR Motor	10.59	5.33	9.15	2.6

Table 5. Performance results from equivalent circuit analysis

Full load values	DAR MOTOR	DCR MOTOR
Voltage (Volts)	**415**	**415**
Current (Ampere)	**4.63**	**4.5**
Input Power (Watt)	**2687**	**2598**
Speed (RPM)	**2874**	**2918**
Output power (Watt)	**2203**	**2223**
Efficiency (%)	**81.87**	**84.68**
Power factor	**0.82**	**0.82**
Break down torque	**23.94 N-mt**	**24.93 N-mt**

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Table 6. Results comparison at full load

Parameters	**Results**	**DAR motor**	**DCR motor**
Rotor copper loss	**C. D. A**	**216 watt**	**168.48 watt**
Break-down slip	**C. D .A**	**0.43**	**0.33**
Full load slip	**C. D. A**	**.06**	**.053**
	E.C. A	**.042**	**.027**
Full load power factor	**C.D.A**	**0.83**	**0.848**
	E.C.A	**0.82**	**0.82**
Full load Efficiecny	**C.D.A**	**82.5 3 %**	**87 %**
	E.C.A	**81.87%**	**84.68%**
Break down Torque	**C.D.A**	**22 N-mt**	**22.98 N-mt**
	E.C.A	**23.94 N-mt**	**24.93 N-mt**

C.D.A – Circle diagram analysis E.C.A. – Equivalent circuit analysis

8. CONCLUSION

After analysing the performance results, following points can be concluded:

1. Rotor copper losses in DCR rotor as compare to DAR rotor, is less. The % decrease in rotor copper loss (216 – 168.48) / 216 = 22 % .

Reduction in rotor copper loss is due to the reduced rotor resistance of DCR rotor as compare to DAR rotor (3.72 – 2.6) / 3.72 = 30 %.

2. Breakdown slip in DCR motor is less as compare to DAR motor.

Change in breakdown slip is (0.43 – 0.33) / 0.43 = 30 % . It shows that a DCR motor can produce maximum torque on higher speed.

3. Change in full load slip is (.,042 - .027) / .042 = 35 % . It means a DCR motor runs at higher speed than DAR motor when producing the rated output.

4. There is also change in motor power factor at full load from 0.83 to 0.848. So it can be concluded that on producing the rated power DCR motor draws less current.

5. A significant change in breakdown torque is also there. The % increase in breakdown torque is (22-22.98) / 22 = 4.45 %. DCR motor develops higher maximum torque than DAR motor.

6. The full load efficiency of DCR motor is higher than DAR motor. The % increase in efficiency is (81.87 – 84.86) / 81.86 = 3.4 %.

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