Dr. Virajit A. Gundale,Mangesh S. Kulkarni/ International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 1,Jan-Feb 2012, pp.508-514

OPTIMIZATION OF THE CORE LENGTH OF A WATER COOLED THREE PHASE SUBMERSIBLE MOTOR

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ABSTRACT

A lot of research work has already been done in the case of Three Phase Induction motors. But comparatively, very little work has been done on Submersible motors. Submersible motor manufacturers find it very difficult to design by themselves such motors as very little literature is available on the same. In India, Bureau of Indian standards gives only an overall configuration about such motors. It is not providing any design related data or information. Most of the Indian manufacturers produce such pumps and motors on pure trial and error basis. They make their own winding combination to optimize the performance. The Induction motor design calculations are very lengthy involving huge number of variables. These results do not work properly in case of Submersible motors. There is a need to modify some steps and make some necessary adjustment which is also not an easy task. This paper presents a practical and working procedure to optimize the Core length of a water cooled three phase submersible motor which can be easily applicable to rapidly design such motors from 1.0 hp to 50 hp. If such motors are designed with optimized Core lengths then this will be the competitive edge for the manufacturer. A smaller size motor capable to deliver better torque will save cost considerably. This paper also examines some of the leading manufacturers existing designs and compares with this new one. The calculations presented in this paper are based on available market stampings and do not include its design. The designs are verified and validated by a reputed manufacturer and will give its recommendation.

Keywords –**Three Phase Induction motors, pumps, Submersible motors, Core length**

I. INTRODUCTION

There is a huge demand for submersible motors majorly due to the trouble free and smooth operation. Such motors are usually coupled with a single or multi-stage pump which can either be Radial or Mixed flow type. Three phase submersible motors are usually 2-pole type. They are available in Star as well as Delta connection as shown in Figure 1.0 and 1.1

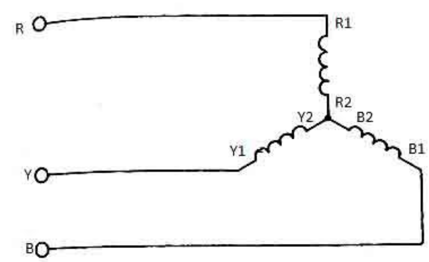

Figure 1.0 Star connection

The cooling medium employed in such motors is usually oil or water. The later very common nowadays due to maintenance and ease of rewinding.

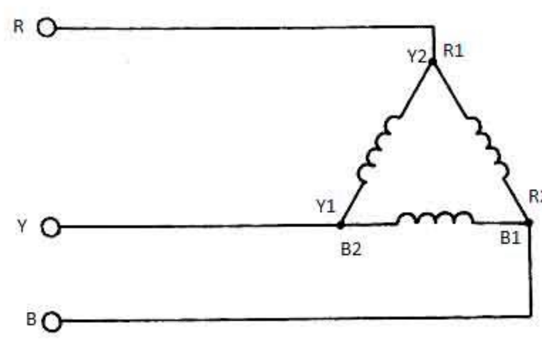

Figure 1.1 Delta connection

This paper focuses on the water cooled type operating on 50 Hz. For such motor the recommended winding wire as per IS 8783(Part 2) is PVC insulated. Star connection is employed up to 7.5 hp after this the Delta connection is used.

Figure 1.2 shows the cross sectional diagram of a typical water cooled Submersible motor on which a Submersible pump is coupled with.

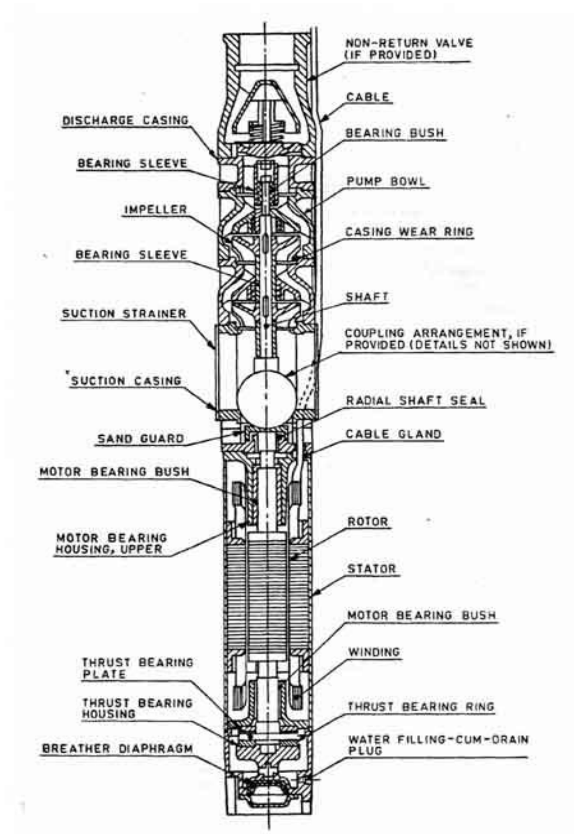

Figure 1.2 Wet Type Water Filled Submersible Motor

The motor consists of a stator and a rotor. The stator is made up of block of laminations mounted in a cast iron or die cast aluminum alloy frame. The stator has tapered slots with parallel sided teeth. The slots house the windings.

Figure 1.3 shows typical lamination or stamping of the stator.

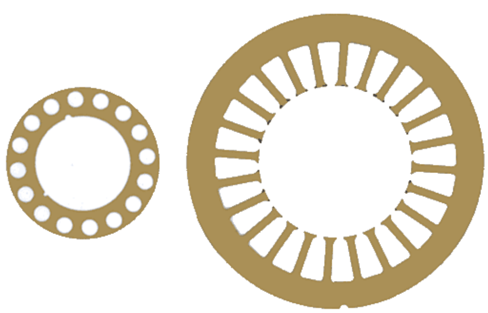

Figure 1.3 V6 150 mm (6") Submersible Motor Stator and Rotor Stamping (Courtesy VIRA PUMPS)

The rotor consists of a block of slotted laminations mounted on a shaft. The slots form a series of tunnels when the rotor is assembled. The tunnels are filled with aluminum, poured in the molten state. The bars, end rings and fan blades form one homogenous casting. In some motors copper bars and copper end rings are used, the former being brazed into the latter. The rotor slots are skewed so that a quieter operation is obtained. Figure 1.4 and 1.5 shows the Rotor and a typical stator with windings.

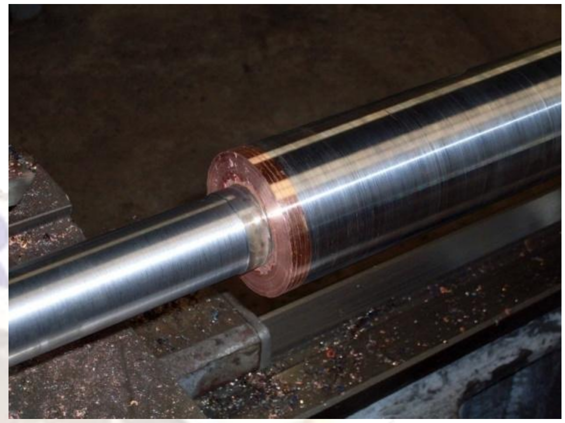

Figure 1.4 A typical squirrel cage rotor for submersible motor being machined (Courtesy VIRA PUMPS)

All the material used for such motors is corrosion resistant or stainless steel. The rotor is coated with an epoxy coating. This is due to the fact that these motor are permanently submerged inside the water.

In India KSB, PLUEGER, SABAR, LUBI, CALAMA, VIRA PUMPS etc. were among the first very few Industries who

Figure 1.5 A submersible motor stator with windings (Courtesy VIRA PUMPS)

manufactured such motors and pumps in the early 80's. Motors which were designed were based on pure trial and error basis only. The characteristics of such motors were that their Core lengths were large. The full load speeds were marginally acceptable and the Torque was just satisfactory. So, there was a need to design compact submersible motor which were powerful as well as economically viable for competition.

II. PROPOSED NEW DESIGN PROCEDURE

The three phases of the winding can be connected in either start or delta depending upon starting methods employed. The squirrel cage induction motors are usually started by start delta starters and therefore their stators are designed for delta connections and the six leads are brought out to be connected to the starter.

Turns per phase :
Flux per pole,
$\phi_m = B_{av}\tau L = B_{av} \text{ x } (\pi DL)/p$
Where, τ = Pole per pitch
p= number of poles
Stator voltage per phase,
$E_s = 4.44f\ \phi_m T_s K_{ws}$
Where,
T_s= number of turns per phase in stator
K_{ws} = stator winding factor.
The winding factor may be initially assumed as 0.955 which is the value of winding factor for infinitely distributed winding with full pitch coils.
$\therefore$ Stator turns per phase $Ts = \frac{Es}{4.44\ f\phi_m\ K_{ws}}$

The current density in the stator windings δ_m in

Hp	Efficiency	Power factor
1.0	0.55	0.78
1.5	0.56	0.79
2.0	0.57	0.8
3.0	0.58	0.81
4.0	0.59	0.82
5.0	0.6	0.83
6.0	0.6	0.83
7.5	0.62	0.84
10.0	0.63	0.84
12.5	0.64	0.85
15	0.65	0.86
20	0.66	0.87

A/mm^2 for submersible motor winding wire or conductor can be calculated as per the manufacturer's recommendation.
Conductor size for the running winding can be calculated as follows-

Area of winding conductor
$A_m = \frac{I_{Rated}}{\delta}$

Practical procedure for determining current density δ:

By experience, 1.0 mm diameter conductor can carry maximum 10.25 amp of current, and area of 1.0 diameter conductor is 0.785

Therefore current density $\delta = \frac{I_{Rated}}{A}$ or
$\delta = \frac{10.25}{0.785}$ = 13.0573 Amps/mm^2

This value can be used directly.

Diameter size of running winding conductor
$d = \frac{\sqrt{Am \text{ x } 4}}{\pi}$

For Star connection,
Stator current per phase $I_s = \frac{Q}{3 \text{ x } \frac{V}{\sqrt{3}} \text{ x } \eta\cos\phi}$

For Delta connection,
Stator current per phase $I_s = \frac{Q}{3 \text{ x } V \text{ x } \eta\cos\phi}$

Where , η is the efficiceny and $\cos\phi$ is the power factor. The values of Efficiency and power factor can be taken from Table 1.0

Further,
Conductors per stator slot $Z_{sg} = 3 \text{ x } 2\ (T_S/\ S_g)$
$= 6\ T_S/\ S_g$ for 3 Coil Groups and 2 Pole motor. Where S_g is the number of stator slots.

III. DESIGN OF A 5 HP (3.7 KW) WATER COOLED SUBMERSIBLE MOTOR

Input Data-

Hp : 5 or 3.7 Kw
Stamping bore Size : 72 mm
No. of Slots : 24
Poles : 2
Frequency : 50 Hz

Table 1.0 **Efficiency** and power factor for three phase Submersible motors

Voltage : 415 Volts
Trial Core Length : **180 mm**

(i) Flux per pole,
$\phi_m = B_{av}\tau L = B_{av} \text{ x } (\pi DL)/p$
Taking $B_{av} = 0.45$
So, $\phi_m = 0.45 \text{ x } (\pi x 0.072 * 0.180)/2$
$= 9.16 \text{ x } 10^{-03}$ Wb/m^2

∴ Stator turns per phase Ts = $\frac{Es/\sqrt{3}}{4.44\ f\phi_m K_{ws}}$

$$\frac{415/1.73}{4.44 \times 50 \times 9.16 \times 10^{-3} \times 0.955} = 124 \text{ Turns}$$

and Conductors per stator slot $Z_{sg} = 6T_S/S_g$
= 6 x 124 / 24
= 31 turns

To find conductor size :

$$I_s = \frac{Q}{3 \times \frac{V}{\sqrt{3}} \times \eta\cos\phi} =$$

$$\frac{5 \times 745}{3 \times \frac{415}{\sqrt{3}} \times 0.6 \times 0.83}$$

= 10.4 Amps or say 11 Amps (considering a maximum value)

Therefore area of winding conductor

$$A_m = \frac{I_{Rated}}{\delta}$$

= 11/13.0573
= 0.8424 mm^2

Diameter size of running winding conductor

$d = \frac{\sqrt{0.8424 \times 4}}{\pi}$ = 1.03565 say 1.1 mm (considering a maximum value)

The calculation is repeated a number of times till optimum number of main winding turns per slot are not achieved. Optimum number of turns can be calculated either by calculation of the area of one slot, area of the total number of conductors and multiplying the same by some gap factor.

The more accurate way to assign the optimum number of turns for a specific stamping or lamination slot is to consult the motor winder as he is the true judge to recommend the maximum number of turns of a particular wire size which the slot can accommodate.

The optimum number of turns with 1.1 mm PVC double coated winding wire is 38. So, the calculations are repeated till the conductors per slot are not equal to 38. To facilitate fast calculation, one may set formulae in a Microsoft Excel spreadsheet as shown in Figure 1.6

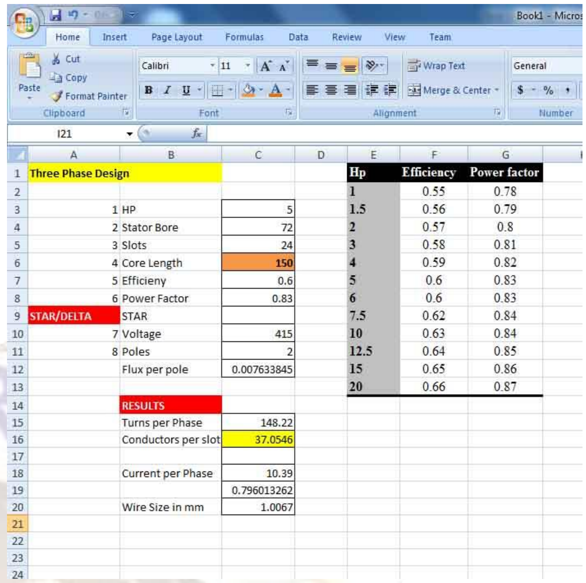

Figure 1.6 Three phase motor design calculations using Microsoft Excel worksheet

Using this worksheet, the Core length came as 150 mm where the Optimum numbers of turns are 38. Figure 1.7 shows the winding distribution diagram. Here, 8 slots will be accommodated by each group of 4 coils per phase. There will be three coil groups so, 8 x 3 = 24 Slots.

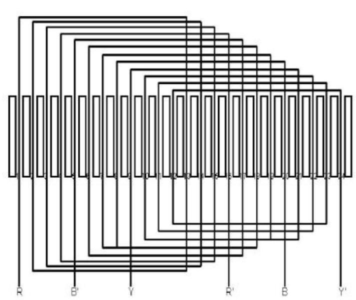

Figure 1.7 Winding distribution diagram

IV. RESULTS AND DISCUSSIONS

The results thus obtained were implemented at M/s VIRA PUMPS, Kolhapur, Maharashtra, INDIA, a leading manufacturer and Exporter of Submersible Pumps and motors. Table 1.1 and 1.2 show the difference between the existing design and this new design.

1.	Core length	180 mm
2.	Winding wire size	1.0 mm
3.	Turns	40

Table 1.1 Existing design (Courtesy: VIRA PUMPS)

1.	Core length	**150 mm**
2.	Winding wire size	1.1 mm
3.	Running winding turns	38

Table 1.2 New design

The new motor was manufactured exactly as per these results. A through test was conducted at VIRA PUMPS Digital test bench which consisted of Locked rotor test as well as full load performance test. The earlier motor design is approved by the BIS and is being manufactured under the ISO 9001 system for years. Figure 1.8 shows IS 9283 Performance characteristics for three phase Submersible motors whereas Table 1.3 presents the Torque comparison of the existing and the new design.

After this a Full-load test was conducted with a standard 5 hp , 8 Stage Radial type pump which was designated to deliver 180 lpm at 64 Meter Head. Figure 1.8 shows the Assembly.

Table 1 Values of Performance Characteristics for 2-Pole 415 V, Three-Phase Submersible Motors for Borewell Size 100, 150 and 200 mm

(*Clause* 7.1)

Motor Rating	Maximum Current as per IS 9283	Permissible Limit of Maximum Current in the Operating Head Range for Checking the Non-overloading Requirements	Minimum Starting Torque (in Terms of Percentage of FL Torque)
(kW)	(Amp)	(Amp)	(percent)
(1)	(2)	(3)	(4)
1.1	3.25	3.48	125
1.5	4.50	4.82	125
2.2	6.50	6.96	125
3	8.50	9.09	125
3.7	10.00	10.70	125
4.5	12.00	12.84	125
5.5	14.50	15.52	125
7.5	19.50	20.87	125
9.3	25.00	26.75	125
11	29.00	31.00	125
13	34.00	36.38	125
15	39.00	41.73	125

Figure 1.8 IS 9283 Performance characteristics

SI. No.	Design	Minimum Starting Torque (In Terms of Percentage of FL Torque)
1	Existing Design	137 %
2	New Design	**196 %**

Table 1.3 Torque Comparisons

Figure 1.9 5 HP Motor coupled with 8 stage Radial type Submersible pump (Courtesy: VIRA PUMPS)

Table 1.4 & 1.5 shows the Full-Load test results for the existing and the new design:

Head in m	Q in lpm	Speed rpm	Current
75	0	2801	5.3 Amps
70	63	2767	7.9 Amps
64	183	2739	8.1 Amps
47	281	2718	9.1 Amps
03	351	2691	9.8 Amps

Table 1.4 Full load test results of existing design

Head in m	Q in lpm	Speed rpm	Current
81	0	2894	5.1 Amps
70	79	2807	8.0 Amps
64	205	2789	8.1 Amps
47	281	2718	9.1 Amps
04	372	2711	10.1 Amps

Table 1.5 Full load test results of New design

There is a drastic improvement in the Torque as a result of which there is improvement in Speed, Head as well as discharge. The new design motor Core length is 30 mm shorter that the earlier yet far more powerful.

IV.CONCLUSION

This paper thus demonstrates a new concept of designing a Three phase Submersible motor where Core length is treated as the design input. This new method involves a few calculations only and the experience of the winder is also one of the inputs to the calculations. This will be like a magic tool in the hands of the manufacturer to cut down its cost and win the market. By using this new design method manufacturers are able to reduce the overall cost by

20 % which will make a big difference in their business operations. Leading manufactures like M/s VIRA PUMPS as well as M/s UPAG Engineering Pvt. Ltd, Ahmedabad, Gujarat, INDIA used this method to investigate all its designs from 0.5 hp to 25 hp Submersible motors. They have recommended this method to optimize the Core lengths which is a necessity today to produce powerful yet economical Submersible motors.

ACKNOWLEDGEMENTS

We are heartily thankful to VIRA PUMPS, Kolhapur, Maharashtra, INDIA and UPAG Engineering Pvt. Ltd , Ahmedabad, Gujrat, INDIA for sharing us valuable information for this paper and providing necessary resources and setup for performing necessary research and trials.

REFERENCES :

[1] A.K. Sawhney and A. Chakrabarti, *Electrical Machine Design*, Dhanpatrai & Co., 2006

[2] M.G. Say, *The performance and Design of Alternating Current Machines*, CBS Publishers & Distributors, 2002, ISBN: 81-239-1027-4.

[3] G. Madescu, I. Boldea, T.J.E. Miller, *Optimal Lamination Approach for Induction Motor Design*, IEEE Trans Vol.IA-34, No. 2, 1998, pp.1-8

[4]. Boldea, S. A. Nasar, *The induction machine handbook*, CRC Press, 2002 - Technology & Engineering

[5] Virajit Avinash Gundale, 2010, '*A new design approach for water cooled submersible motor and radial flow type pump with emphasis on both Electrical and Mechanical consideration'* PhD Thesis, UNEM, Costa Rica.

[6] IS 9283 : 1995, Motors for Submersible Pumpsets-Specification(First Revision).

[7] IS 8034 : 2002, Submersible Pumpsets – Specification (Second Revision).

[8] IS 8783(Part 2) : 1995 Winding wires for Submersible motors-Specification (Reaffirmed 2005, Edition 2.1)

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