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A PRACTICAL APPROACH TO THE DESIGN AND IMPLEMENTATION OF A WATER COOLED SINGLE PHASE SUBMERSIBLE MOTOR

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ABSTRACT

A lot of research work has already been done in the case of Single 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. Larger manufacturers design Submersible motors based on the published procedure for design of Induction motors by making some necessary assumptions and changes. For small scale manufactures this design procedure is not easily accessible. 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 design water cooled single phase submersible motor which can be easily applicable to rapidly design such motors from 0.5 hp to 5 hp. 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 **-Single Phase Induction motors, pumps, Submersible motors, Running winding, Auxiliary winding, Core length**

I. INTRODUCTION

There is a huge demand for single phase submersible motors majorly due to the easily availability of the 1-Φ Power supply. Such motors are usually coupled with a single or multi-stage pump which can either be Radial or Mixed flow type. Single phase submersible motors are usually 2-pole type. They consist of a Primary or Main (Running) winding and a Auxiliary (starting) winding as shown in figure 1.0

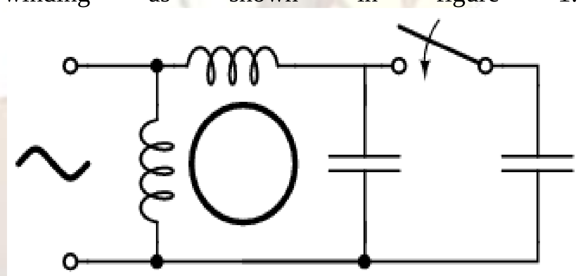

Figure 1.0 A Typical Capacitor Start Capacitor Run Single phase motor

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

II. Simplified design procedure

i) Number of turns in main winding:

The number of turns in the running winding can be calculated as below:

Stator induced voltage E= $4.44f\phi_m T_m K_{wm}$

Where T_m = number of turns in the running winding,
K_{wm}= winding factor for the running winding.
Number of turns in the running winding

$$Tm= \frac{E}{4.44f\phi_m K_{wm}} \quad \ldots(1)$$

Where, $\phi_m = \frac{flux}{pole}$

ϕ_m = flux density x slots per pole x L_i x W_{ts} Wb

The value of stator induced voltage E is approximately equal to 95 percent of supply voltage V. The winding factor for the running winding can be assumed between 0.8 to 0.955 max. L_i is the Iron length, Core length or Stack length. In this simplified procedure a trial length is used. 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 number of turns per series pole for the main (running) winding

$$T_{pm}= \frac{T_m}{p} \quad \ldots(2)$$

ii) Running Winding Conductors
Current carried by each running winding conductor

$$I_{rated}= \frac{hp x 0.746}{V\eta\cos\phi} \quad \ldots(3)$$

Where, η is the efficiency and cosϕ is the power factor. The values of Efficiency and power factor can be taken from Table 1.0

H.P.	Efficiency	Power factor
0.5	0.65	0.62
0.75	0.67	0.63
1.0	0.68	0.64
1.5	0.69	0.64
2.0	0.7	0.7
3.0	0.71	0.8
4.0	0.72	0.83
5.0	0.73	0.85
6.0	0.74	0.9

Table 1.0 Efficiency and power factor for single phase motors

Area of running winding conductor $a_m = \frac{Im}{\delta}$

Where δ is the current density in Amps/mm^2

Conductor size for the running winding can be calculated as follows-

Therefore area of running 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

$$d= \frac{\sqrt{Am \ x\ 4}}{\pi}$$

iii) Running winding Capacitor calculation

$$C=\frac{IratedxNo\ \ of\ turns\ of\ running\ \ windingxPower\ \ factor}{2\ x\pi x50xVratedxNo\ \ of\ starting\ \ winding\ \ turns}$$

iv) No of turns in starting winding
Assume K=1.25
K_{wm} =0.8 winding factor for main winding
K_{wa} =0.85 winding factor for auxiliary winding

$$T_a = \frac{kx T_m x K_{wm}}{K_{wa}}$$

Starting winding conductor size calculation:

$$d = \sqrt{\frac{A_m x4}{T_a x\pi}}$$

where, $A_m = \frac{T_m x\pi x dr2}{4}$

v) Starting capacitor selection

Starting capacitor can be selected from a chart which most of the leading manufactures follow as shown below in Table 1.1

S. No	H.P.	Recommended Starting Capacitor(μF)
1	0.5	80-100
2	0.75	100-120
3	1.0	120-150
4	1.5	120-150
5	2.0	120-150
6	3.0	150-200
7	4.0	200-250
8	5.0	200-250

Table 1.1 Starting Capacitor selection chart
(Courtesy : Sarda Capacitors, Bangalore, INDIA)

III. Design of 1 hp Single phase water cooled motor using the simplified method:

Input data:
Flux density=1.1Wb/m^2 ,Trial Core length= 189 mm (Finalized after a few trials), Teeth slot width=1.7mm ,No of poles=2 ,No of slots=24, Bore size=50mm

1. Flux per pole :

ϕ_m = flux density* slots per pole*L_i*W_{ts}

$$= \frac{1.1x24x1.7x10^{-3}x189x10^{-3}}{2}$$

$= 4.241 \text{ x}10^{-3}$Wb

Number of turns in Running winding

$$Tm= \frac{E}{4.44 f \phi_m K_{wm}}$$

$$= \frac{219}{4.44*50*0.955*4.241*10^{-3}}$$

= 243.55

Now,

$$\text{Rated current } I= \frac{hp \times 0.746}{V \eta \cos\phi}$$

$$= \frac{746}{230x0.55x0.78}$$

=7.56 *Amps*

Area of running winding conductor

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

$$= \frac{7.56}{13.0573}$$

$= 0.5789\ mm^2$

2. Diameter size of running winding conductor :

$$d= \frac{\sqrt{A_m x4}}{\pi}$$

$$= \frac{\sqrt{0.5789x4}}{\pi}$$

=0.8586 mm Say 0.8 mm

$$\text{No of conductors per slot} = \frac{\text{No of Turns}}{\text{No.of Poles x No.of coils}}$$

$$= \frac{243.55}{2 X 4}$$

=30.44 Say 30

By experience, 30 number of turns of 0.8 mm are the maximum number of turns which this particular slot can accommodate.

3. Running winding Capacitor calculation :

$$C=\frac{I_{rated} x \text{No of turns of running winding} x \text{Power factor}}{2 x \pi x 50 x V_{rated} x \text{No of starting winding}}$$

$$= \frac{7.56x30x0.78}{2x\pi x50x230x37}$$

=66μF say 61μF (36 + 25 μF)

Starting winding calculations:

No of turns in starting winding,
Assume K=1.25
K_{wm} =0.8 winding factor for main winding
K_{wa} =0.85 winding factor for auxiliary winding

$$T_a = \frac{k*T_m*K_{wm}}{K_{wa}} = \frac{1.25*30*0.8}{0.85}$$

= 35.3 say 37 (Maximum turns)

4. Starting winding conductor size calculation :

$$d = \sqrt{\frac{A_m \text{ x } 4}{T_a \text{ x } \pi}}$$

$$\text{where } A_m = \frac{T_m x \pi x dr2}{4}$$

$$A_m = \frac{30*\pi*0.8586^2}{4}$$

=17.37mm^2

$$d = \sqrt{\frac{17.37 \text{ x } 4}{37 \text{ x } \pi}}$$

=0.77 mm say 0.7

5. Starting capacitor selection :

Selecting 120-150 µF as the starting capacitor from Table 1.1.

Figure 1.2 show the winding distribution. There will be 8 coils for the running winding which will accommodate 16 slots of the stamping where as 2 Coils for starting winding which will accommodate the remaining 8 Slots.

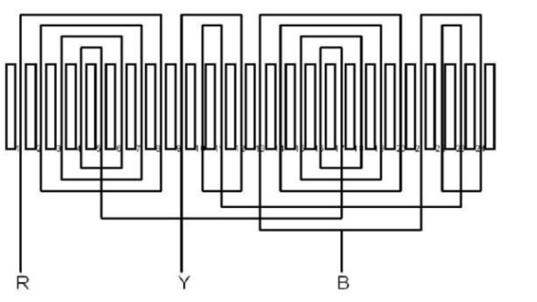

Figure 1.2 Winding Distributions

III. 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 1.2 and 1.3 show the difference between the existing design and this new design.

1.	Core length	175 mm
2.	Running winding wire size	0.7 mm
3.	Running winding turns	37
4.	Starting winding wire size	0.5 mm
5.	Starting winding turns	50
6.	Running Capacitor	36+25= µF
7.	Starting Capacitor	120-150 µF

Table 1.2 Existing design (Courtesy: VIRA PUMPS)

1.	Core length	189 mm
2.	Running winding wire size	0.8 mm
3.	Running winding turns	30
4.	Starting winding wire size	0.7 mm
5.	Starting winding turns	37
6.	Running Capacitor	61 µF
7.	Starting Capacitor	120-150 µF

Table 1.3 New Design

The new motor was manufactured exactly as per these results. A thorough test was conducted on at VIRA PUMPS Digital test bench which consisted of Locked rotor test as well as full load performance test. The earlier motors are approved by the BIS and are manufactured under the ISO 9001 system for years. Table 1.4 shows the Torques of single phase submersible motors as per IS : 996

1.	Minimum Pull Out Torque	200 % of rated torque
2.	Minimum Pull Up Torque	170 % of rated torque
3.	Minimum Breakaway Torque	200 % of rated torque

Table 1.3 Torques of Single Phase Capacitor Start Capacitor Run Submersible motor

Table 1.4 shows the Torque values for the existing 1.0 hp Submersible motor.

1.	Minimum Pull Out Torque	206 % of rated torque
2.	Minimum Pull Up Torque	174 % of rated torque
3.	Minimum Breakaway Torque	211 % of rated torque

Table 1.4 Torques of Existing Design

After implementation of the new design, Table 1.5 shows the new torque values of the same motor which shows a remarkable improvement. This was a great surprise to the manufacturer. They had never such results since last 8 years after they had started this product.

1.	Minimum Pull Out Torque	212 % of rated torque
2.	Minimum Pull Up Torque	198 % of rated torque
3.	Minimum Breakaway Torque	231 % of rated torque

Table 1.5 Torques of New Design

These results were greatly appreciated by M/s VIRA PUMPS as well as M/s UPAG Engineering Pvt. Ltd, Ahmedabad, Gujarat, INDIA. Both jointly decided to conduct a full load test with this new motor. An 18 Stage Radial Type pump suitable for 1 hp motor was selected. The test was directed to check the duty point of the pump. This particular pump was supposed to give a discharge of 18 lpm at 76 meters of Head as declared by the Impeller manufacturer.

Table 1.6 represents earlier results for the 1 hp/ 16 stage submersible pump set whereas Table 1.7 displays the results of the new design. There is a encouraging improvement in the performance. The speed has improved greatly as a result of which the discharge has increased proportionately. This is the win win situation for the manufacturer. He can now compete in the market based on these parameters.

1.	Voltage	220 Volts
2.	Frequency	49.9 Hz
3.	Current	6.6 Amps
4.	Speed	2723 rpm
5.	Head	76 m
6	Discharge	19.7 lpm

Table 1.6 Full load test of existing design

1.	Voltage	220 Volts
2.	Frequency	49.8 Hz
3.	Current	6.9 Amps
4.	Speed	2998 rpm
5.	Head	76 m
6	Discharge	27 lpm

Table 1.7 Full load test of new design

V. CONCLUSION

The new practical approach of designing water cooled Submersible motors presented in this paper is a combination of both mathematical calculations as well as a practical approach. This method was implemented from all motors from 0.5 hp to 5 hp. There was an overwhelming response from the industry. There is an overall 25-30% improvement in the performance of the motors. This new method involves a few calculations only and the experience of the winder is also one of the inputs to the calculations. A small computer based program can be made to speed up all the calculation thus enabling the designers.

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