Single Layer Winding Of Three Phase Induction Motor

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--**Abstract**--
The winding layout and diagrams of single or three phase induction motors of single layer windings have been a problem to Engineers and Technicians because of the different types of windings and lack of basic knowledge on the rewinding techniques. This paper presents the basic knowledge, simplified analytical methods and winding layout and diagrams of single layer windings.

Keywords: *Winding layout, single layer winding, induction motors, rewinding technique, three phase motor*

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I. INTRODUCTION

When each side of a coil occupies a slot completely without any other coil lying on top of it and the number of coils equals half the number of slots, the winding is known as single layer winding [1]. Concentric winding or chain winding types are common and in this type of winding, short-pitched coils cannot be used. The laying of concentrated winding depends on the coil span and the number of slots per pole per phase as in [2] and [3]. The concentric winding can be in form of unbifurcated (half-coiled) or bifurcated (whole-coiled) type. In unbifurcated concentric windings, the coils comprising a pair of pole phase groups under adjacent poles are concentric. The overhangs of these windings are usually arranged in two or three separate tiers or planes. This arrangement is provided in order to avoid the crossing of two coils under one phase group. In bifurcated concentric windings, each pole phase group is split up in to two sets of concentric coils and each set sharing its return coil sides with those of another pole phase group in the same phase [5], Mush winding and three tier winding are also of single layer winding. Single layer winding is common in small ac machines of power rating below 15hp, though this mainly depends on the manufacturer. And such machines have large number of conductors per slot. The single layer fractional slot winding is common in brushless dc machines and permanent magnet synchronous machines (PMSM). Single layer windings have higher efficiency and quieter operations due to the openings of their narrow slots. Single layer windings are highly insulated because of the end connections that are separated by large air spaces which make them suitable for high voltages. The absence of inter layer separator is due to higher space factor.

1.1 Parameters

Z= Number of stator slots
$2P$=Number of poles, where P is the number of pair of poles
q=Number of slots per pole per phase
m=Number of phase
y=Coil span
$\tau = Z/2P$ is the Pole pitch or full span

II. CONCENTRIC WINDING

In unbifurcated concentric windings, the first of the q coils which is the smallest is thrown from the qth slot having coil-span, $y = (\tau - q + 1)$ and the second coil which is larger than the first coil will be thrown from the second slot to its coil-span, $y = (\tau - q + 2)$, and if $q=3$, the third coil which is the largest coil will be thrown from first slot having its coil-span, $y = (\tau - q + 3)$ as in [4].Figure 1 shows the single layer concentric winding diagram of stator (armature) with 24 slots and four poles. Then $q = 24 / (4X3) = 2$. $\tau = 24/4 = 6$. The inner coil is thrown from the second slot having coil-span, $y = (\tau - q + 1) = 6 - 2 + 1 = 5$ to $(2+5) = 7^{th}$ slot. The outer coil which is larger than the inner coil is thrown from the first slot having coil-span, $y = (\tau - q + 2) = 6 - 2 + 2 = 6$ to $(2+6) = 8^{th}$ slot. The other coils are arranged in the same manner. There are 12 coils and two coil groups per each phase. The winding diagram is similar to unbifurcated concentric winding with two plane overhang. Figure 2 shows the connections of two coils that form the coil group of a phase of the winding.
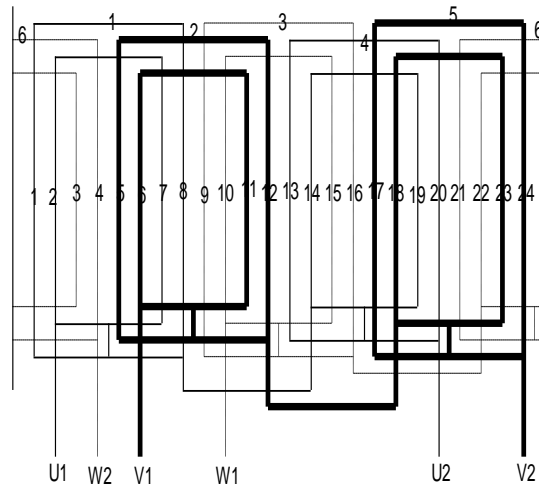
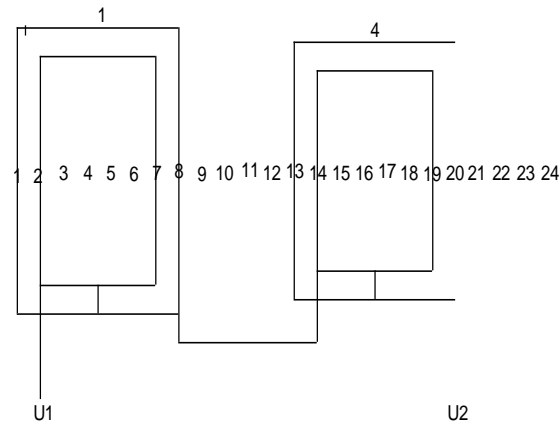Fig. 1: Single layer winding (concentric winding) with Z=24 and 2P=4

Fig. 2: Connection of coil group per phase

Figure 3 shows the winding diagram of a three plane overhang bifurcated concentric winding of 24 stator slots with four poles. There are twelve coils in the sator and four coils form a group per phase. The end connections is like that of double layer winding. There are six slots per pole and two slots per pole per phase. Figure 4 shows the connection of the coils of a phase.
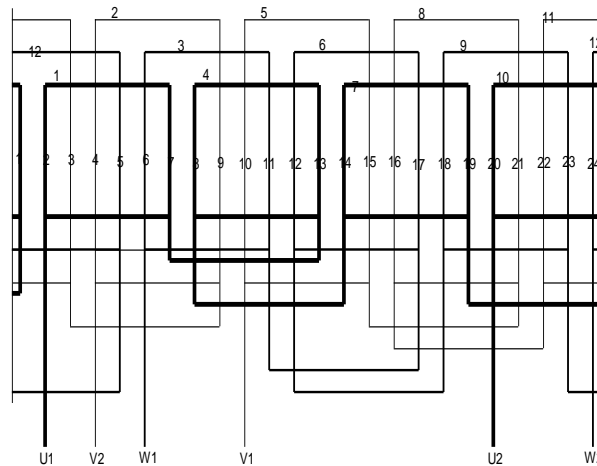

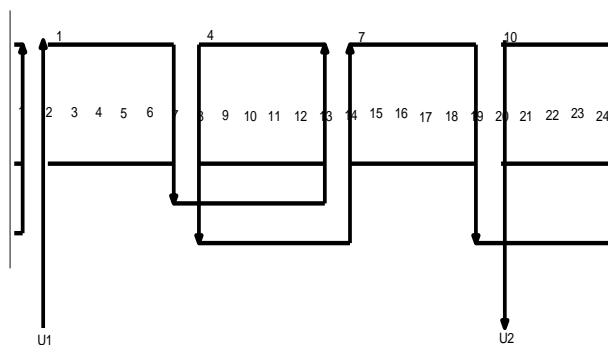Fig. 3: Bifurcated concentric winding with Z=24 and 2P=4

Fig. 4: Connection of coils in a phase

Figure 5 shows three-tier winding diagram with 36 slots and two poles. The number of slots per pole per phase, q = 36 / (2X3) = 6. The pole pitch, τ = 36/2 = 18. The smallest coil of the three coils is thrown from the third slot having coil-span, y = (τ – 6 + 1) = 18 – 3 + 1 = 13 to (3+13) = 16th slot. The second larger coil is thrown from the second slot having coil-span, y = (τ – q + 2) = 18 – 6 + 2 =14 to (2+14)= 16th slot. The third coil which is the largest is thrown from the third coil having its coil-span, y = (τ –q + 3)=18-6+3=15 to (1+15)=16th slot. UI, V1 and W1 start from the 1st, 3rd and 5th coil respectively of the total coils of the three phase.
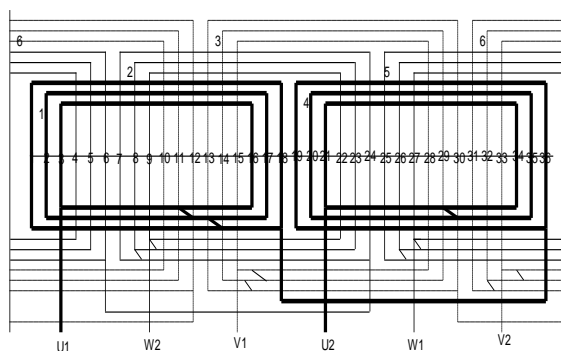

Fig. 5: Three-tier winding with Z=36 and 2P=2

III.   MUSH WINDING

This type of winding is applicable in alternating current armature winding and the coil span is odd. It consists of long and short conductors and the number depends on the number of slots per pole per phase. The longer conductors occupy odd slots while the short conductors occupy even slots. The long and short conductors are connected. A mush winding with Z=36 and 2P=4 is shown in Figure 6 below. The number of slots per pole per phase is q=36/(4X3)=3 and the coil span, τ =36/4=9 which is an odd number. The U1, V1 and W1 start from the 1st, 5th and 3rd coils respectively of the total coils in the three phase. Figure 7 shows the connection of coils of one of the phase.
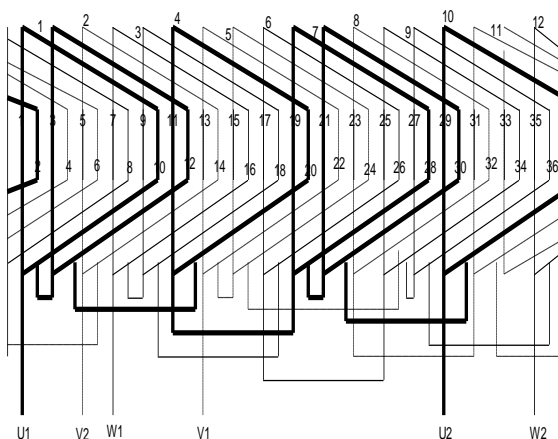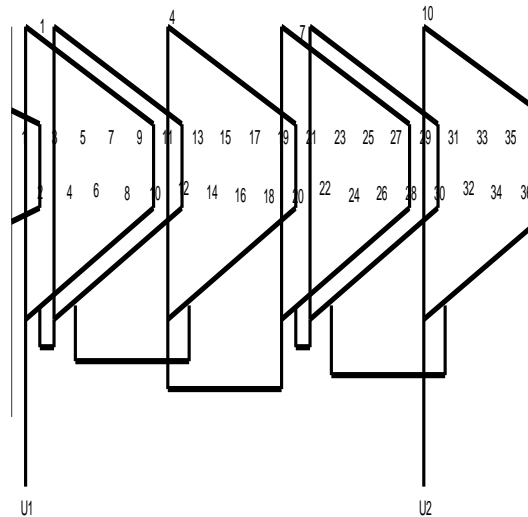

Fig. 6: Mush winding with Z=36 and 2P=4

Fig. 7: Connection of coils per phase

3.1 Single layer fractional slot winding:

If the number of slots in a stator is Z, the number of poles is 2P and the number of phase, m. The number of slots per pole per phase is given by

$$q = \frac{number\ of\ slots}{number\ of\ phases\ X\ number\ of\ poles}.$$

$$q = A\frac{B}{C} = A + \frac{B}{C} = \frac{AC+B}{C} = \frac{D}{C},$$ where A is an integer. B/C is reduced so that the numerator and the denominator are the smallest possible integers, and cannot be mutually divisible. If the denominator C is an odd number, the winding is said to be a first grade winding, and when C is an even number, the winding is of the second grade. The most reliable fractional slot winding is constructed by selecting C=2. The winding of this type can be designed for fractional slot permanent machines by selecting q=2. The total coil groups present in three phase winding consist of B coil groups of (A+1) coils and (C-B) coil groups of A coils. The total coil groups present in three phase winding consist of B coil groups of (A+1) coils and (C-B) coil groups of A coils. The single layer winding parameters are shown in Table 1.

Table 1. Parameters for connecting single layer winding

S/N	Three-phase	Single-layer winding
1	Connection of coils in coil groups of the three phase	U1–1 V1–2 W1–3 and U1-1, V1-5 and W1-3 for the unbifurcated concentric and mush. - 4 - 5 - 6 - 7 - 8 9
2	Number of parallel branches, **a**	In integral slot winding, p/a=integer and in fractional slot winding, P/aC=integer
3	Orderly connection of coil groups of each phase	End (E) of first coil group to the start (S) of next coil group and the end of that coil group to the start of the next coil group of the same phase (E-S-E-S-E-S) or End (E) to End (E) and Start (S) to Start (S) of the next coil group of the same phase depending on the number of poles of the winding
4	Winding type	Concentric, lap or wave type, mush and 3-tier
5	Number of slots Z=2Pmq	Z=2Pmq and **a** max≤P
6	Pole pitch Coil span	τ =Z/2P y=Z/2P + 1, y=Z/2P - 1
7	Conditions of symmetry	P/C ∈ N, meaning P cannot be 1 and for three phase C/m ∉ N

Single layer fractional slot winding with Z=30, and 2P=4

$$q = 2\frac{1}{2}\ or\ \ q = \frac{5}{2} = \frac{D}{C}.$$ **A**=2, **B**=1 and **C**=2 and **D**=5. There are **B** coil groups of (**A+1**) coils, that is, 1 coil group of 3 coils. Also there are (**B-C**) coil groups of **A** coils, that is, 1 group of 2 coils. There are D coils in each phase. The configuration can be written as 3 – 2 or 2 – 3. Configuration 3 – 2 is chosen. This configuration can appear only 3 (number of phases) times so that the total number of coils in the winding is equal to **Dm**=5x3=15.

There are two coil group per phase and a total of six (**Cm**) coil groups in the winding. The configurations are 3 2 – 3 2 – 3 2. Table 2 shows the distribution of coils belonging to each phase.

Table 2: Position of coil groups in each phase of winding

A	3			2		
B		2			3	
C			3			2

Figure 8 is the arrangement of coil groups and the various slots occupied by them. Each phase A, B and C contains two coil groups with the first phase, **A** occupying the first and the fourth coil group. The winding diagram is shown in Figure 6
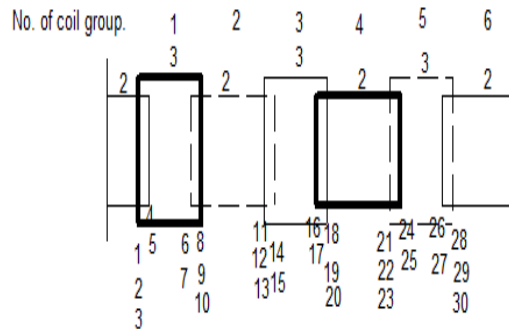

Fig. 8: Coil group diagram of a single layer fractional slot winding with Z=30 and 2P=4
The winding diagram of a single layer fractional slot winding with Z=30 and 2P=4 is shown in figure 9 below
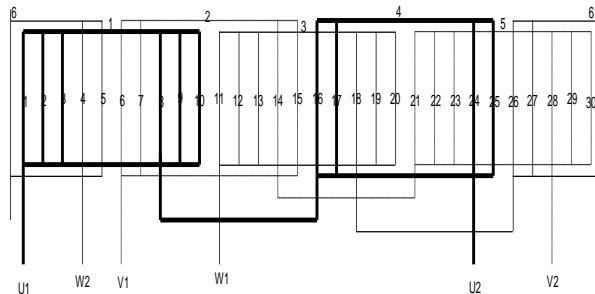

Fig. 9: Fractional slot winding with Z=30 and 2P=4
Single layer fractional slot winding with Z=36 slots and 2P=10

Table 3 shows the coil distribution per phase of a 3-phase stator winding have 36 slots and 10 poles. The number of slots per pole per phase, q=Z/(2Pm)=36/(3x10)=1.2=$1\frac{1}{5}$. A phase consists of B coil groups of (A+1) coils=1 group of (1+1) coils. 1 coil group of 2 coils and (C-B) coil groups of **A** coils. (5-1) groups of 1 coil=4 groups of 1 coil. $q = \frac{6}{5} = \frac{D}{C}$. D is the number of coils in each phase of the winding and D is (2+1+1+1+1)=6. The total coil groups in the winding is equal to **Dm**=6x3=18. One of the coil groups consists of two coils. The coil groups are:
1 coil group has two coils
q1=2
4 coil groups having one coil   q2=q3=q4=q5=1
  A-B-C-A-B-C-A-B-C-A-B-C-A-B-C
  2-1-1-1-1-2-1-1-1-1-2-1-1-1-1
  Figure 10 shows the layout of coil group and their slot positions

Table 3. Distribution of coil groups in each phase of the winding

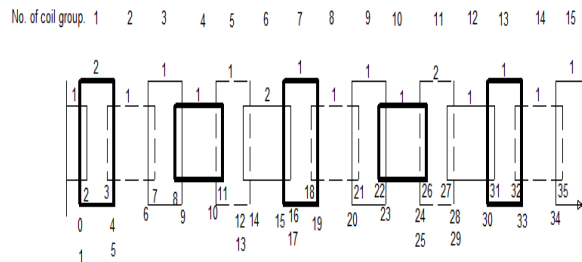|	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A	2			1			1			1			1		
B	1			1			1				2			1	
C		1				2			1			1			1

Fig. 10 : Coil group diagram of a single layer fractiional slot winding with Z=36 and 2P=10

The coil group schema defines the number of coils in the coil groups of a phase. The design of the winding is shown in figure 11. There are five coil groups per phase and six coils per phase because one of the coil groups contains two coils. The total coil group is fifteen (**cm**) while the total coils in the three phase is equal to eighteen.
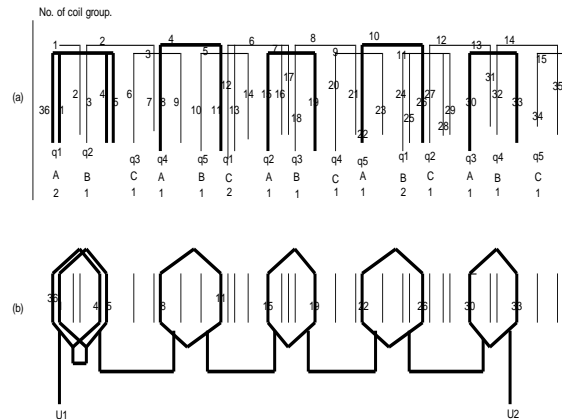

Fig. 11: A phase of single layer fractional slot winding with Z=36 and 2P=10

IV.   CONCLUSION
The simplified method of winding configurations, layout diagrams and winding diagrams help the Engineers and Technician working in rewinding workshop to have the basic knowledge of three phase single layer winding of three phase induction motor.

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