

Electrical Drawing

Fractional slot winding

All fractional slot windings are short pitched. When slot pitch and slot per pole per phase are not integers, it is a fractional slot winding.

Advantages of fractional slot windings:

- Reduction of harmonic emfs and mmfs
- Reduction of design cost and material cost
- Reduction of leakage reactance of windings
- Reduction of copper in overhangs

1. Draw AC winding diagram for a machine with 21 slots and 4 poles

a. Calculations:

Slot pitch: $\text{Slots/pole} = 21/4 = 5.25$ or $5 \frac{1}{4}$ which is a fraction

slot/pole/phase = $21/4/3 = 1.75$ or $7/4$ which is a fraction

Methods to find slot distribution:

Since the slot per pole per phase is not an integer, there is no equal distribution of slots for a pole.

Method 1: Rough method but faster

slot/pole/phase = $7/4$ which means that 7 has to be distributed into 4 parts, given by –

1 1 1 1

But $1+1+1+1$ gives 4, not 7.

3 has to be added to this set to make it 7. Add 1s to the first three ones

$1+1$ $1+1$ $1+1$ 1 making it 2 2 2 1 which makes it $2+2+2+1=7$

-OR-

Distribute 7 into 4 parts as 2 2 2 2 which makes it 8. So reduce it to 7 by subtracting 1 from the last number, making it 2 2 2 1

Note: If numbers are to be added, add to the first numbers,

if they are to be subtracted, subtract from the last numbers

$21/7 = 3$. So this pattern has to be repeated three times as -

2 2 2 1 2 2 2 1 2 2 2 1

Divide this pattern into 4 parts for the four poles

Slot distribution for the three phases under four poles

Pole 1	Pole 2	Pole 3	Pole 4
2 2 2	1 2 2	2 1 2	2 2 1

Slot phase table:

	Red	Blue	Yellow
Pole 1 (N₁)	1 2	3 4	5 6
Pole 2 (S₁)	7	8 9	10 11
Pole 3 (N₂)	12 13	14	15 16
Pole 4 (S₂)	17 18	19 20	21



Method 2: Lengthier, but more accurate method

$$\text{slot/pole/phase} = 21/4/3 = 7/4 = 1 \frac{3}{4}$$

$$\text{In general, } q = S/P/m = M/d = I n/d$$

where-

q - slot/pole/phase

S - number of slots

P - number of poles

m - number of phases (3)

M - slot/phase in each unit (numerator of 7/4)

d - number of poles in each unit (denominator of 7/4)

$$\text{Here, } q = 1 \frac{3}{4}$$

$$M = 7$$

$$S = 21$$

$$d = 4$$

$$P = 4$$

$$n = 3$$

$$m = 3$$

$$I = 1$$

Number of units = $P/d = 4/4 = 1$. There is only one unit, that is, the slot distribution pattern is not repeated.

Each phase in a unit contains $d-n$ groups of I coils, and n groups of $I+1$ coils each

Here, each phase in a unit contains 1 group of 1 coil, and 3 groups of 2 coils each (1 and 2-2-2, as derived in method 1)

Difference between slots is given by $D = (1+mMx)/d$

where x is the smallest number that makes D an integer

$$D = (1+3*7*x)/4 = (1+21x)/4$$

If $x=1$, $D = 22/4$ which is not an integer

If $x=2$, $D = 43/4$ which is not an integer

If $x=3$, $D = 64/4 = 16$ which is an integer

Draw a table with 3 rows (3 phases) and 7 columns ($21/3=7$). $D=16$

Red	1+0D	1+1D	1+2D	1+3D	1+4D	1+5D	1+6D
	1	17	33 (12)	7	2	18	13
Blue	1+7D	1+8D	1+9D	1+10D	1+11D	1+12D	1+13D
	8	3	19	14	9	4	20
Yellow	1+14D	1+15D	1+16D	1+17D	1+18D	1+19D	1+20D
	15	10	5	21	16	11	6

Note: $1+2D = 1+32 = 33$, which is actually $33-21=12$. Same holds good for other values

By sorting the numbers in ascending order, slots for each phase given as-

Red: 1 2 7 12 13 17 18

Blue: 3 4 8 9 14 19 20

Yellow: 5 6 10 11 15 16 21

OR

Red	1 2	7	12 13	17 18
Blue	3 4	8 9	14	19 20
Yellow	5 6	10 11	15 16	21

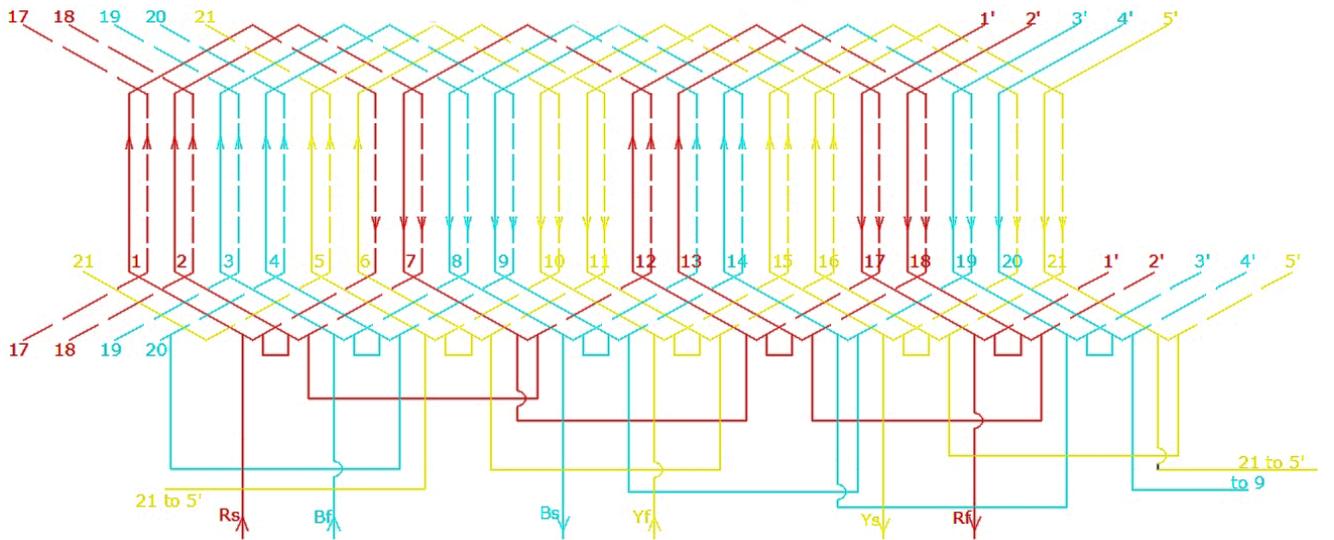
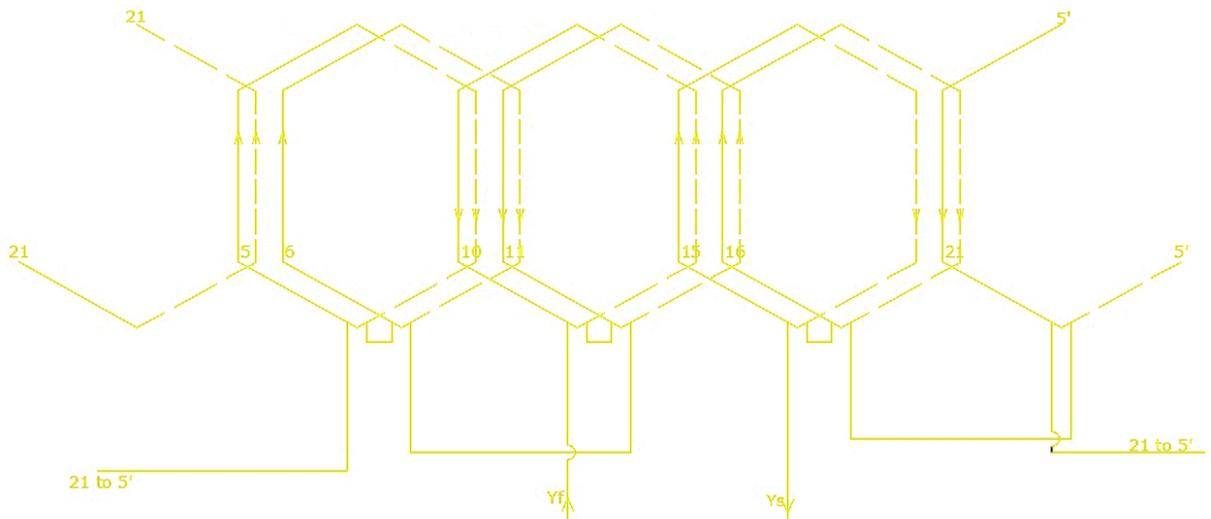
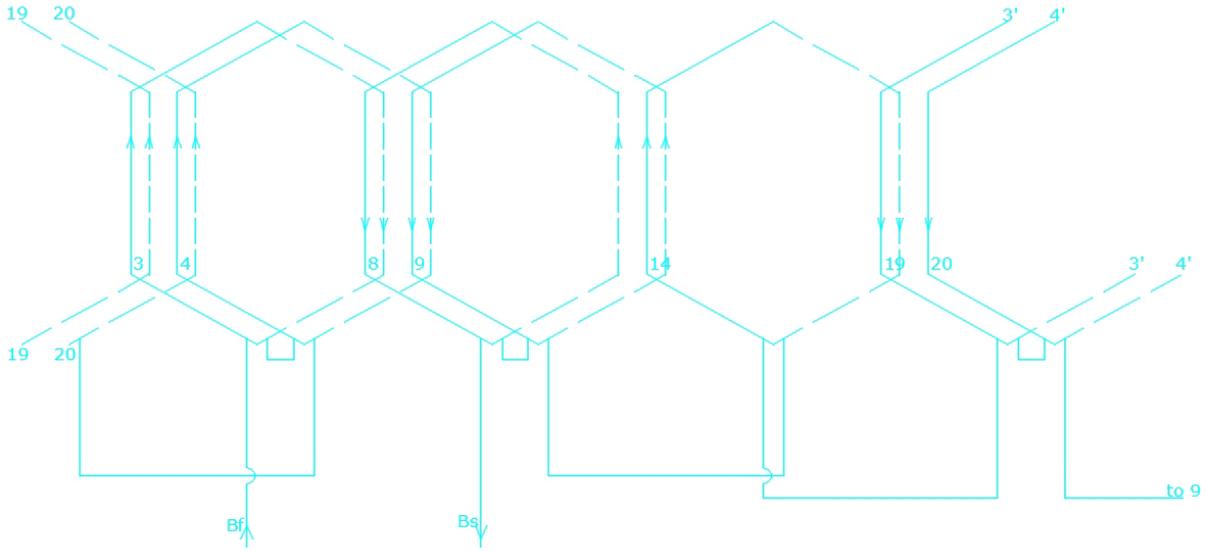
- which is the same as given by the slot phase table in method 1

Since there is only one unit, the slot pattern is just 2-2-2-1-2-2-2-1-2-2-2-1

If there were more units, then this pattern would have repeated for that many units

The pattern and the table above give the slot distribution for the top slots only. Since this is a double layer winding, slot distribution for the bottom layer must be found.





2. Draw winding diagram for double layer AC machine with 30 slots and 4 poles

a. Calculations:

$$\text{slot pitch} = 30/4 = 7.5$$

$$\text{coil span} = 7$$

$$\text{slot/pole/phase} = 30/4/3 = 5/2 = 2 \frac{1}{2} \quad \text{- fractional slot winding}$$

$$\text{In general, } q = S/P/m = M/d = I n/d$$

$$\text{Here, } q = 2 \frac{1}{2}$$

$$M = 5$$

$$S = 30$$

$$d = 2$$

$$P = 4$$

$$n = 1$$

$$m = 3$$

$$I = 2$$

Number of units = $P/d = 4/2 = 2$. There are two units, that is, the slot distribution pattern is repeated twice

Each phase in a unit contains $d-n$ groups of I coils, and n groups of $I+1$ coils each

Here, each phase in a unit contains 1 group of 2 coils, and 1 group of 3 coils each

Using method 1, slot/pole/phase = $5/2$

5 is to be distributed into 2 parts, that is 2 2, which makes it 4. Add 1 to first number, making it 3 2

Slot pattern for one unit is repeated $15/(3+2) = 3$ times, that is: 3 2 3 2 3 2

Repeat this for slot pattern for both units: 3 2 3 2 3 2 3 2 3 2 3 2

Slot distribution for the three phases for both units

Pole 1	Pole 2	Pole 3	Pole 4
3 2 3	2 3 2	3 2 3	2 3 2

Slot phase table:

	Red	Blue	Yellow
Pole 1 (N₁)	1 2 3	4 5	6 7 8
Pole 2 (S₁)	9 10	11 12 13	14 15
Pole 3 (N₂)	16 17 18	19 20	21 22 23
Pole 4 (S₂)	24 25	26 27 28	29 30

For bottom connection,

	Pole 1	Pole 2	Pole 3	Pole 4
Top	3 2 3	2 3 2	3 2 3	2 3 2
Bottom	2 3 2	3 2 3	2 3 2	3 2 3

Slot distribution table for one unit with 15 slots and 2 poles:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Top	R	R	R	B	B	Y	Y	Y	R	R	B	B	B	Y	Y
Bottom	R'	R'	B'	B'	B'	Y'	Y'	R'	R'	R'	B'	B'	Y'	Y'	Y'

The same pattern repeats for the second unit

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Top	R	R	R	B	B	Y	Y	Y	R	R	B	B	B	Y	Y
Bottom	R'	R'	B'	B'	B'	Y'	Y'	R'	R'	R'	B'	B'	Y'	Y'	Y'

$$\text{slot angle} = 180/7.5 = 24^\circ$$

Red starts from 1st slot

Yellow starts from $1+120/24 = 6^{\text{th}}$ slot. Since it is an integer, no need to add 360

Blue starts from $1+240/24 = 11^{\text{th}}$ slot

3. Draw winding diagram for double layer AC machine with 96 slots and 10 poles

a. Calculations:

slot pitch = $96/10 = 9.6$

coil span = 9

slot/pole/phase = $96/10/3 = 16/5 = 3 \frac{1}{5}$ - fractional slot winding

In general, $q=S/P/m = M/d = I n/d$

Here, $q=3 \frac{1}{5}$
M=16

S=96
d=5

P=10
n=1

m=3
I=3

Number of units= $P/d = 10/5 = 2$. There are two units, that is, the slot distribution pattern is repeated twice

Each phase in a unit contains $\underline{d-n}$ groups of \underline{I} coils, and \underline{n} groups of $\underline{I+1}$ coils each

Here, each phase in a unit contains 4 groups of 3 coils, and 1 group of 4 coils each

Using method 1, slot/pole/phase = $16/5$

16 is to be distributed into 5 parts, that is 3 3 3 3 3, which makes it 15. Add 1 to first number, making it 4 3 3 3 3.

Since there are two units, each unit contains $96/2=48$ slots

$48/16=3$. The pattern is repeated three times to make it 48

4 3 3 3 3 4 3 3 3 3 4 3 3 3 3

Slot distribution for the three phases under 5 poles for one unit

Pole 1	Pole 2	Pole 3	Pole 4	Pole 5
4 3 3	3 3 4	3 3 3	3 4 3	3 3 3

Slot phase table for one unit:

	Red	Blue	Yellow
Pole 1 (N₁)	1 2 3 4	5 6 7	8 9 10
Pole 2 (S₁)	11 12 13	14 15 16	17 18 19 20
Pole 3 (N₂)	21 22 23	24 25 26	27 28 29
Pole 4 (S₂)	30 31 32	33 34 35 36	37 38 39
Pole 5 (N₃)	40 41 42	43 44 45	46 47 48

For bottom connection, in one unit:

	Pole 1	Pole 2	Pole 3	Pole 4	Pole 5
Top	4 3 3	3 3 4	3 3 3	3 4 3	3 3 3
Bottom	3 3 3	4 3 3	3 3 4	3 3 3	3 4 3

This pattern repeats for the second unit, for slots 49 to 96

$$\text{slot angle} = 180/9.6 = 18.75^\circ$$

Red starts from 1st slot

Yellow starts from $1 + 120/18.75 = 7.4$. Add 360 or multiples of 360 to 120 to get an integer $1 + (120 + 360 \times 3)/18.75 = 65$, that is, Yellow starts from 65th slot, which is in the second unit. 65 in second unit means 17 (65-48=17) in the first unit. So Yellow can start from 17th slot

Blue starts from $1 + (240 + 360)/18.75 = 33$, that is, Blue starts from 33rd slot

4. Draw winding diagram for double layer AC machine with 33 slots and 4 poles

a. Calculations:

$$\text{slot pitch} = 33/4 = 8.25$$

$$\text{coil span} = 8$$

$$\text{slot/pole/phase} = 33/4/3 = 11/4 = 2 \frac{3}{4} \quad \text{- fractional slot winding}$$

In general, $q = S/P/m = M/d = I n/d$

$$\text{Here, } q = 2 \frac{3}{4} \\ M = 11$$

$$S = 33 \\ d = 4$$

$$P = 4 \\ n = 3$$

$$m = 3 \\ I = 2$$

Number of units = $P/d = 4/4 = 1$. There is one unit, that is, the slot distribution pattern is not repeated

Each phase in a unit contains $d-n$ groups of I coils, and n groups of $I+1$ coils each

Here, each phase in a unit contains 1 groups of 2 coils, and 3 groups of 3 coils each

Using method 1, slot/pole/phase = 11/4

11 is to be distributed into 4 parts, that is 3 3 3 3 which makes it 12. 1 is subtracted from last number to make it 11. Pattern is 3 3 3 2

$33/11=3$. This pattern is repeated three times as-

3 3 3 2 3 3 3 2 3 3 3 2

Slot distribution for the 4 poles-

Pole 1	Pole 2	Pole 3	Pole 4
3 3 3	2 3 3	3 2 3	3 3 2

Slot phase table:

	Red	Blue	Yellow
Pole 1 (N₁)	1 2 3	4 5 6	7 8 9
Pole 2 (S₁)	10 11	12 13 14	15 16 17
Pole 3 (N₂)	18 19 20	21 22	23 24 25
Pole 4 (S₂)	26 27 28	29 30 31	32 33

For bottom connection,

	Pole 1	Pole 2	Pole 3	Pole 4
Top	3 3 3	2 3 3	3 2 3	3 3 2
Bottom	3 3 2	3 3 3	2 3 3	3 2 3

slot angle = $180/8.25 = 21.8182^\circ$

Red starts from 1st slot

Yellow starts from $1 + 120/21.8182 = 6.5$

$1 + (120 + 360)/21.8182 = 23$, that is, Yellow starts from 23rd slot

Blue starts from $1 + 240/21.8182 = 12^{\text{th}}$ slot