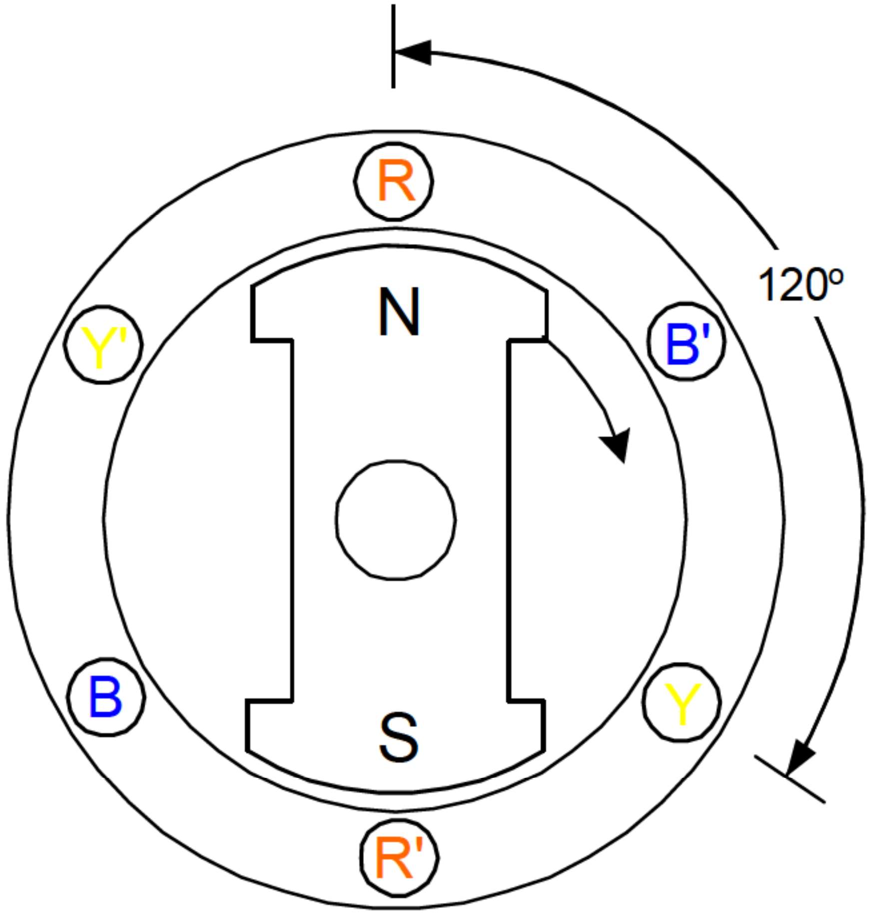
Three Phase Generator



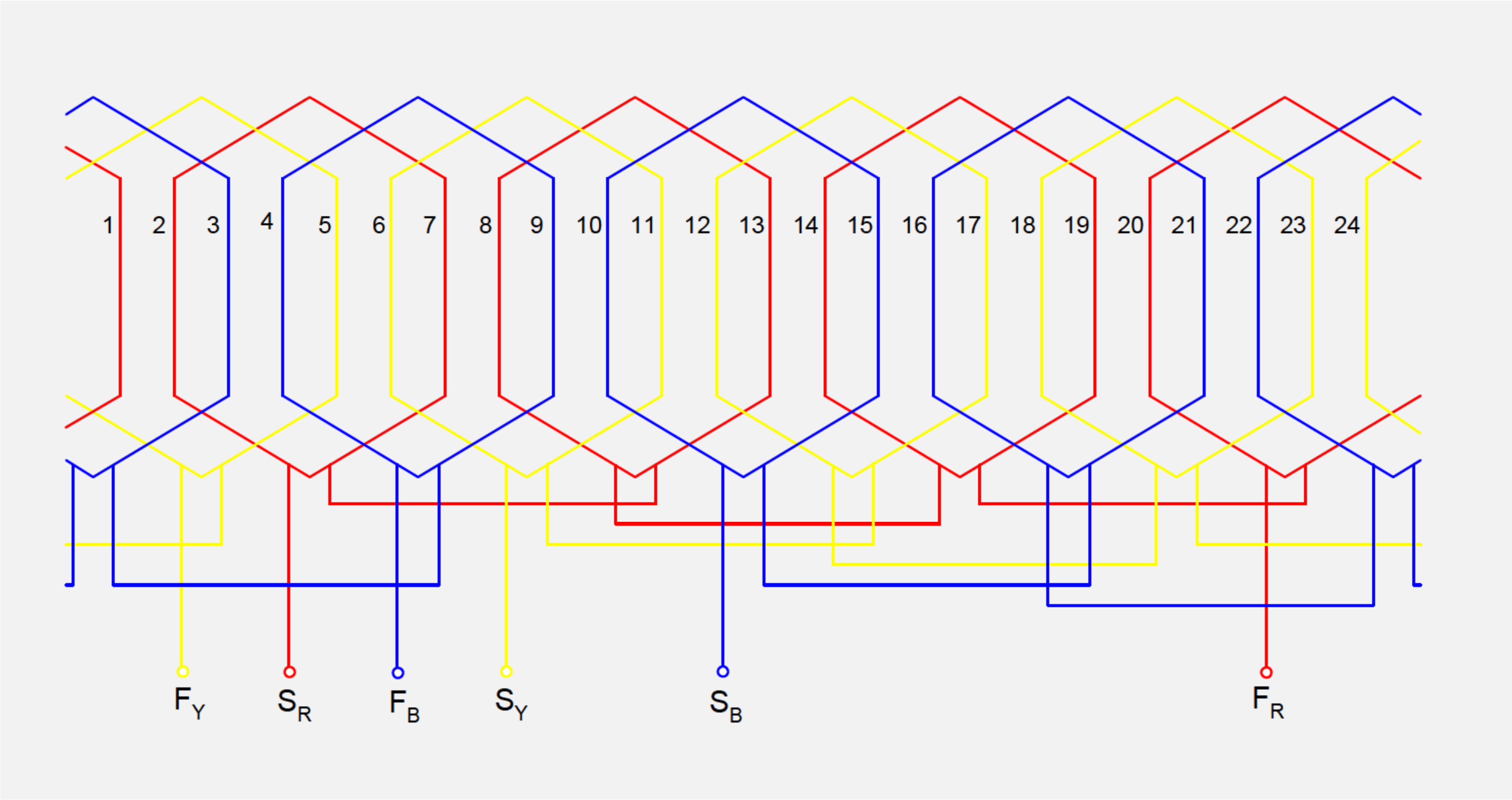
- There will be three sets of similar windings
- Windings are placed 120 degrees apart
- Practically each phase winding will be distributed across several slots

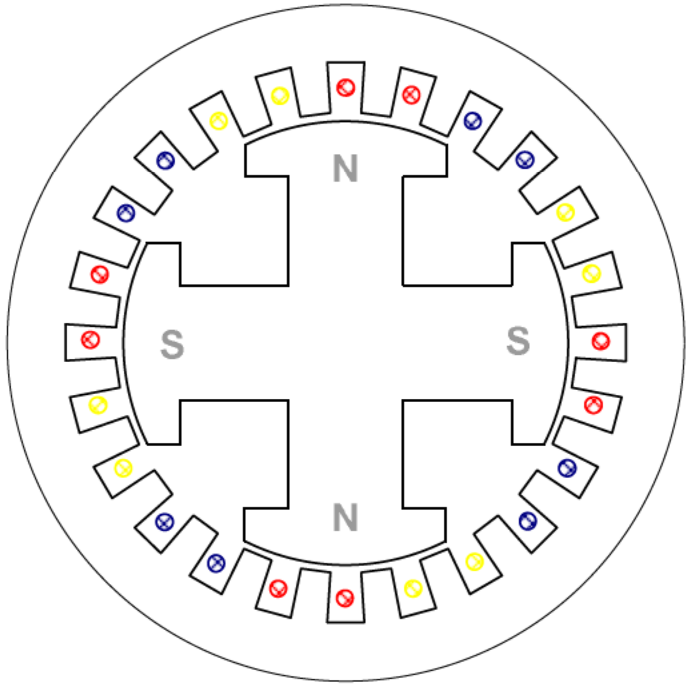
Practical Winding

Stator Windings Partially Completed

Stator Windings Completed

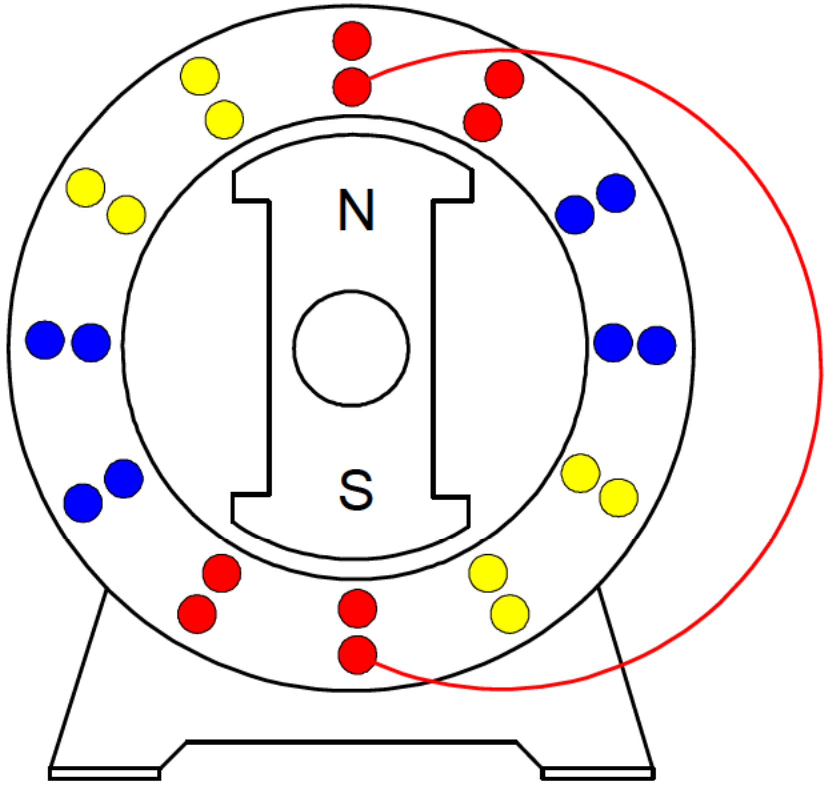
Single Layer Winding

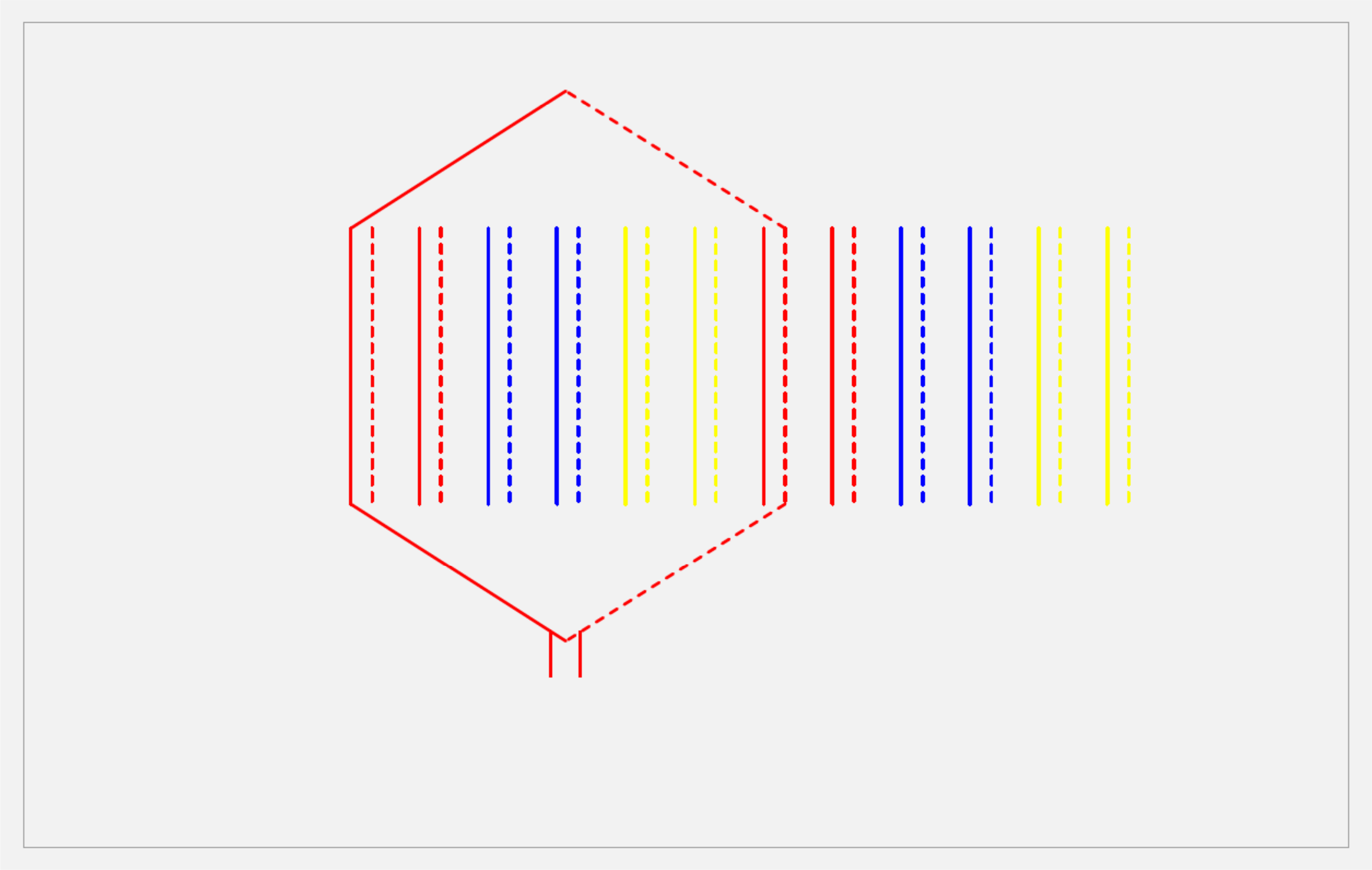




Winding example (Full pitch)

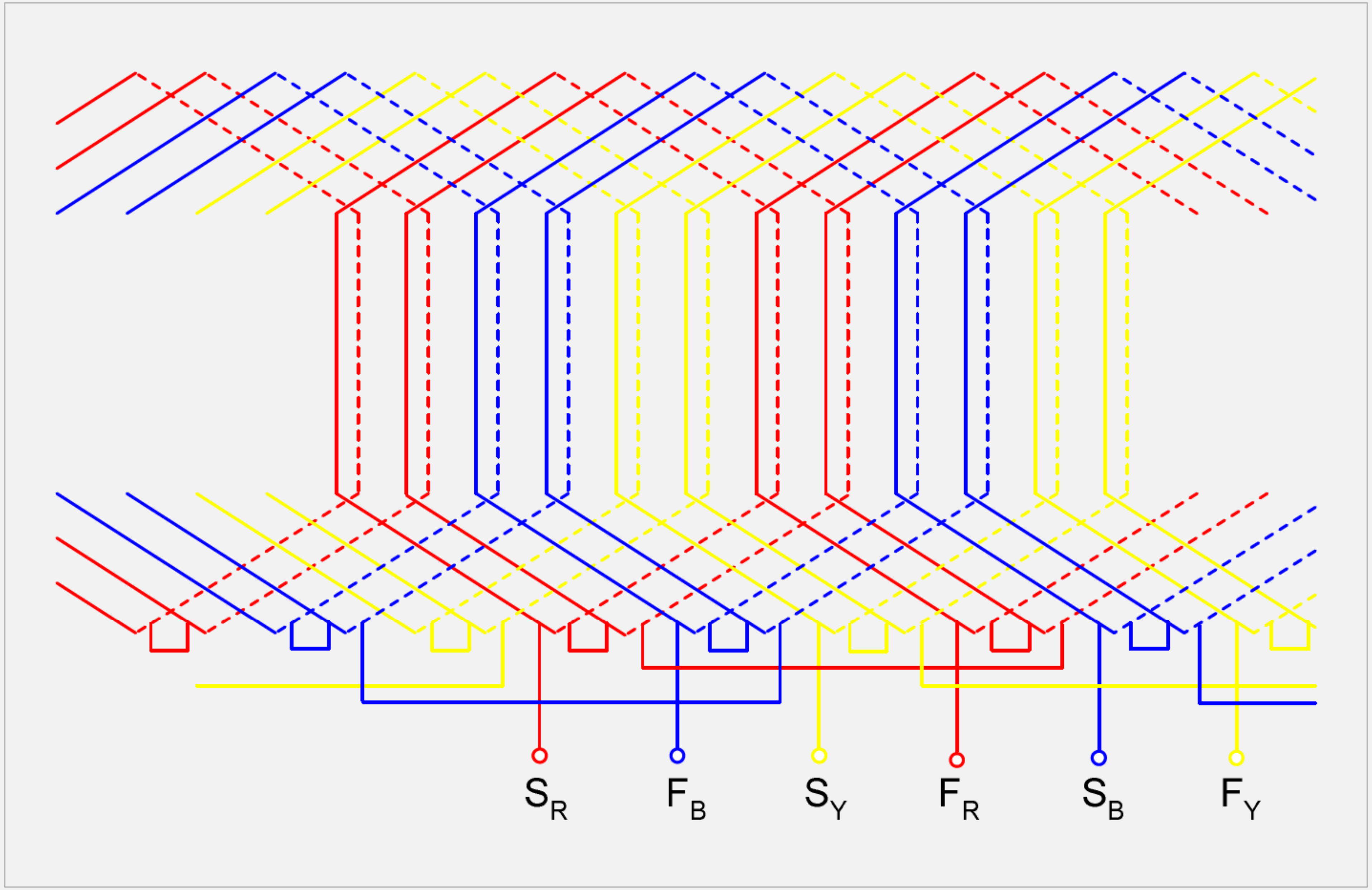
No of poles: 2, No of slots: 12, Double layer → Slots/pole/phase = 12/(2x3) = 2





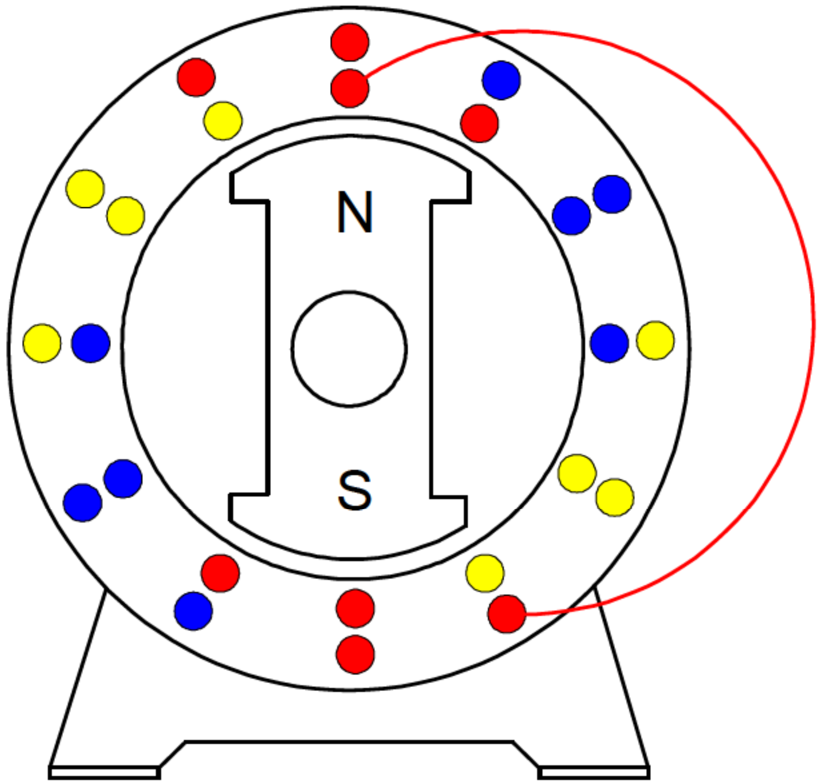
Winding example (Full pitch)

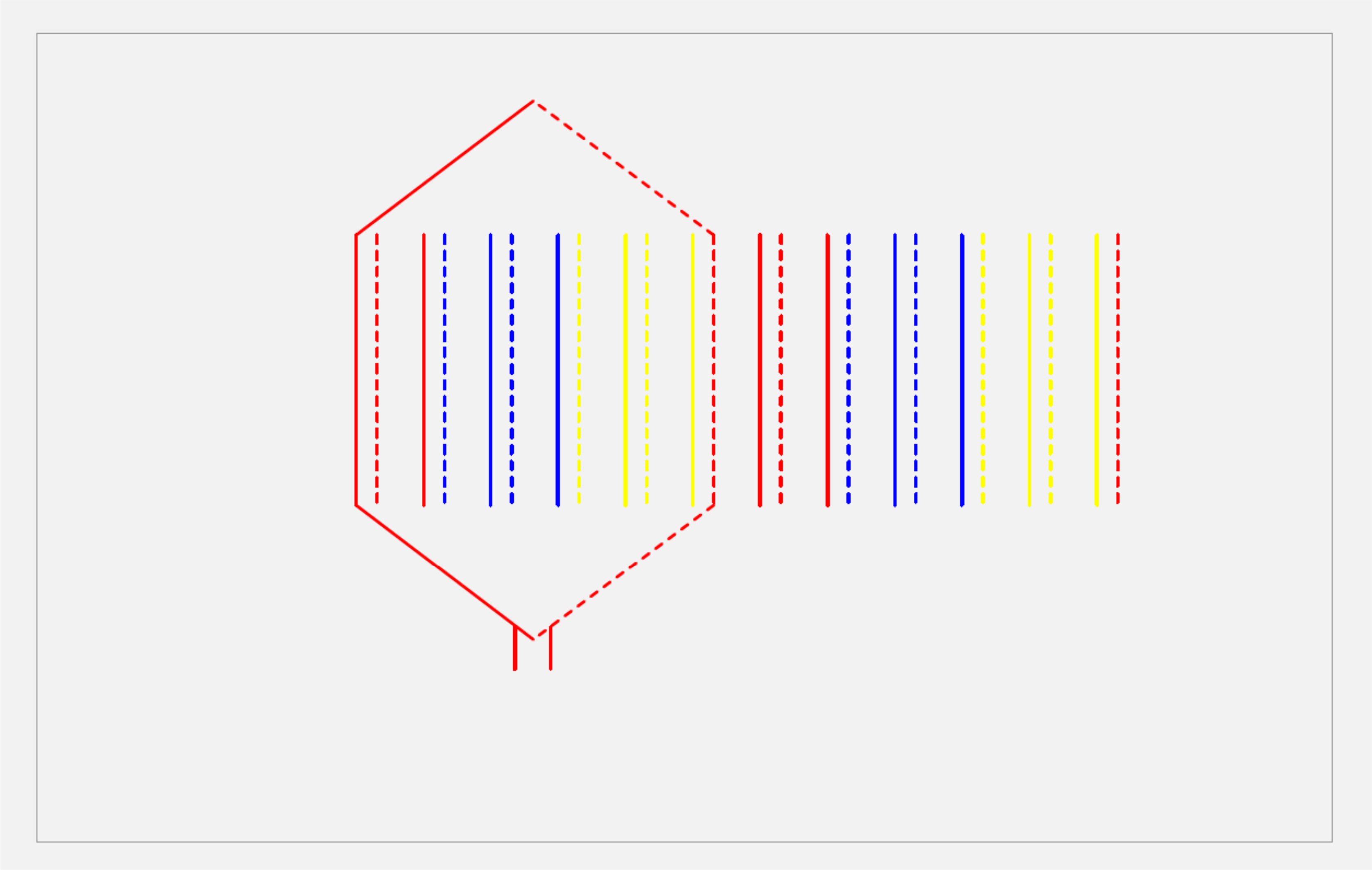
3 phase
2 pole
12 slot
Double layer winding



Winding example (Short Chorded)

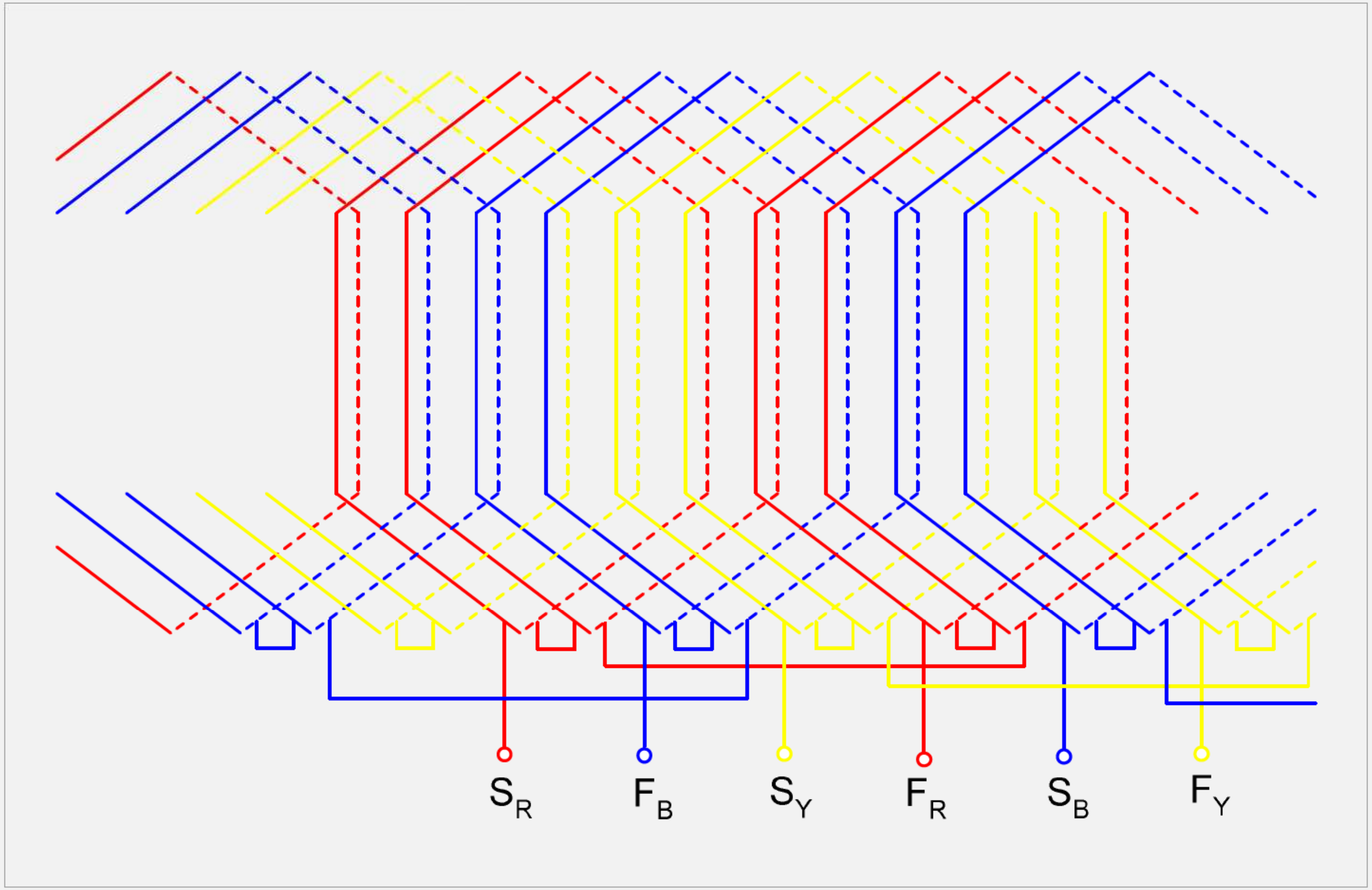
No of poles: 2, No of slots: 12, Double layer → Slots/pole/phase = 12/(2x3) = 2



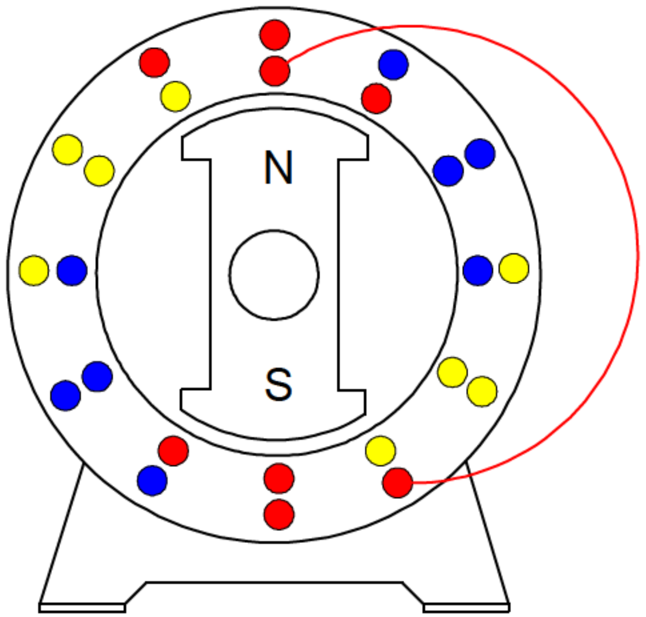


Winding example (Short Chorded)

3 phase
2 pole
12 slot
Double layer winding



Features of Short Chording

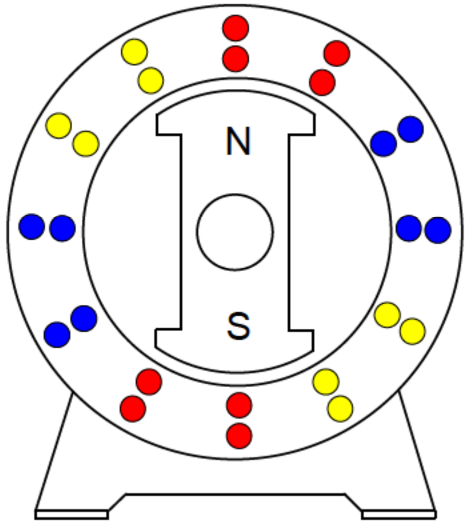


- Saves copper in end connections
- Improve wave shape (reduce harmonics)
- Reduce losses – both copper loss and core loss
- Reduced voltage compared to full pitch

Slot Angle

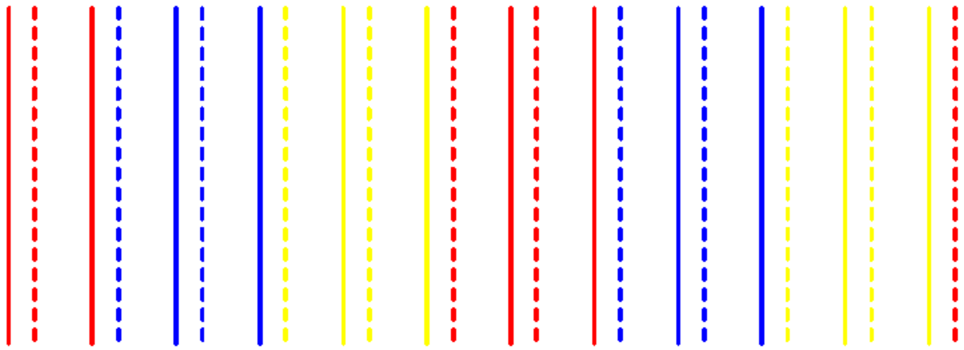
Slot angle is the electrical angle between two slot positions

$$\text{Slot angle} = \frac{180}{\text{Slots/pole}}$$



In this case (2 pole, 12 slot):

$$\text{Slot angle} = \frac{180}{6} = 30°$$



For a 4 pole 36 slot machine:

$$\text{Slot angle} = \frac{180}{9} = 20°$$

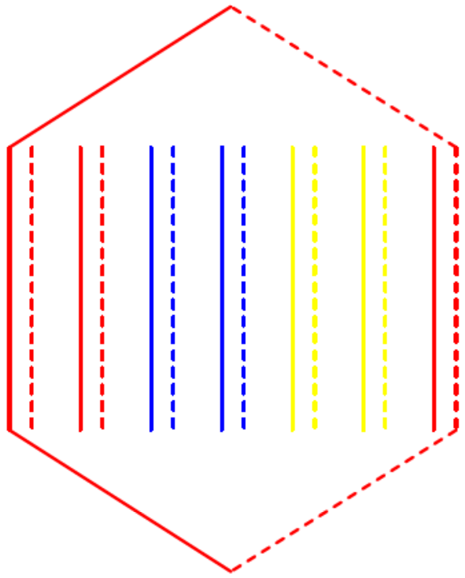
Pitch Factor

Also known as **coil span factor**

Let the voltage induced in a conductor is E

If the coil is full pitched,

Total induced voltage in a coil $= 2E$

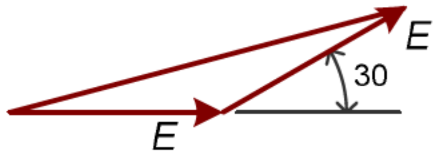


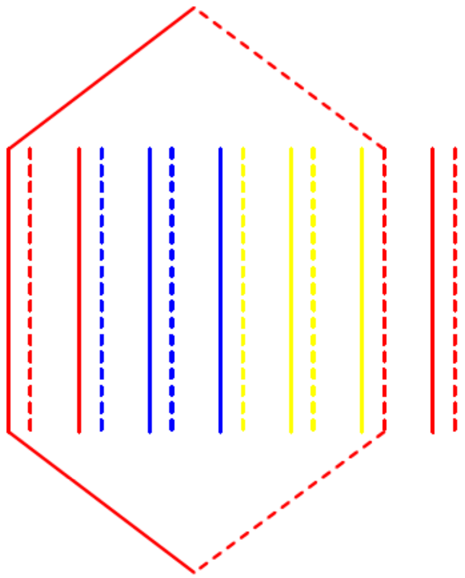
If the coil is short pitched by an angle α

Total induced voltage $= 2\,E\,\cos\dfrac{\alpha}{2}$

Pitch factor, $K_c = \dfrac{\text{Resultant emf of chorded coil}}{\text{Resultant emf of full piched coil}}$

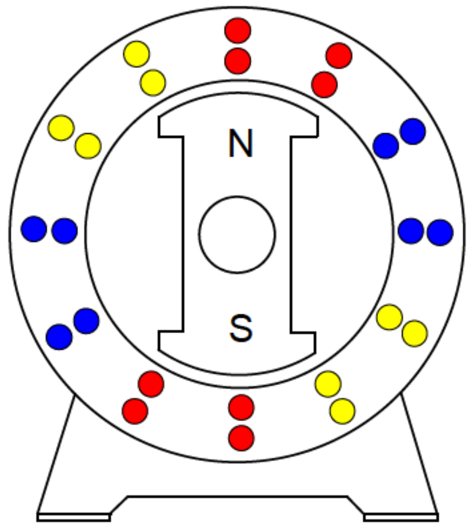
$$= \frac{2E\cos\dfrac{\alpha}{2}}{2E} = \cos\frac{\alpha}{2}$$





Distribution factor

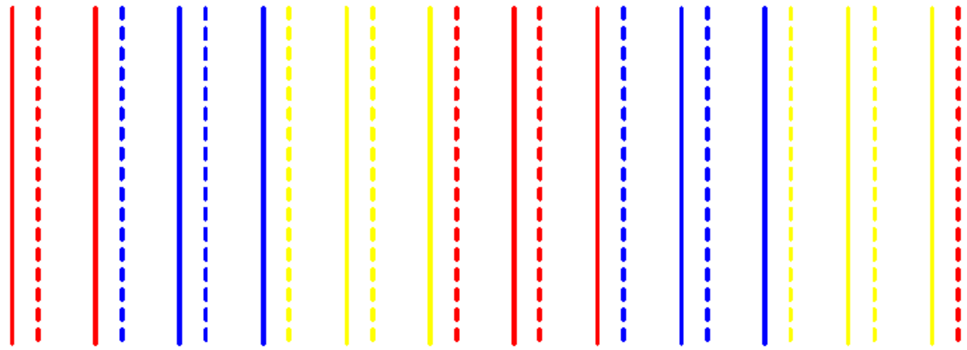
$$\text{Distribution facor, } K_d = \frac{\text{emf with distributed winding}}{\text{emf with concentrated winding}}$$



$$\text{Slot angle, } \beta = \frac{180}{\text{Slots/pole}}$$

$$m = \text{Slots/pole/phase}$$

$$m\beta = \text{phase spread angle}$$



Distribution factor

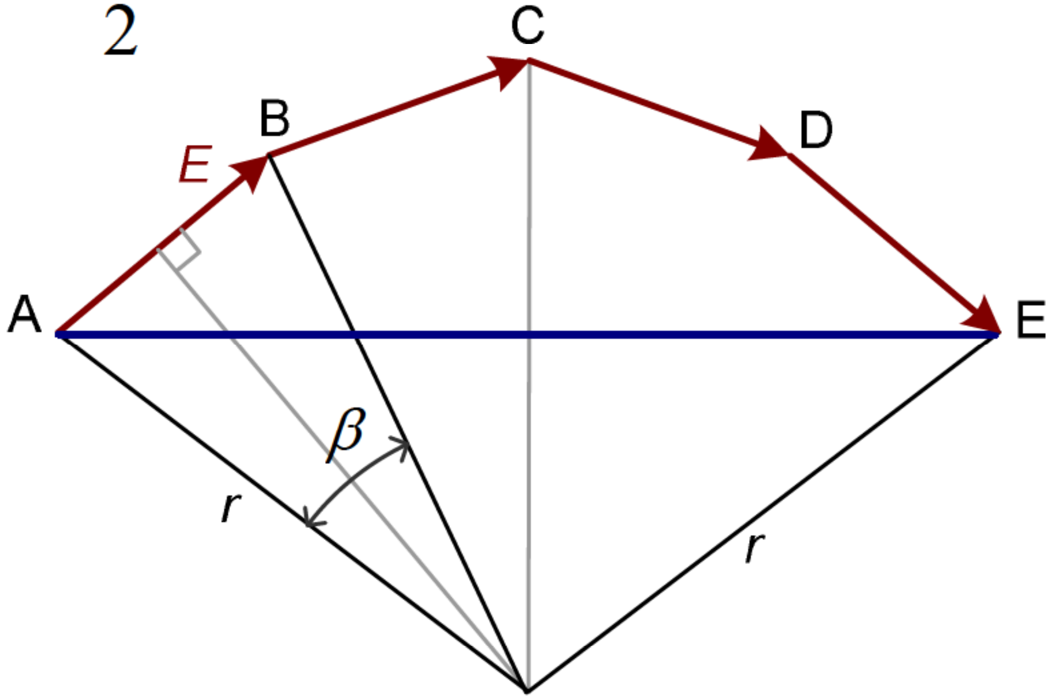
$$\text{Distribution facor, } K_\text{d} = \frac{\text{emf with distributed winding}}{\text{emf with concentrated winding}}$$

$$\text{Arithematic sum} = m\, 2r \sin\frac{\beta}{2}$$

$$\text{Vector sum} = 2r \sin\frac{m\beta}{2}$$

$$\boxed{K_\text{d}} = \frac{2r\sin\frac{m\beta}{2}}{m\,2r\sin\frac{\beta}{2}} = \boxed{\frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}}}$$

$$\text{AB} = 2r\sin\frac{\beta}{2}$$



Example 1.1

For a 3 phase 36 slot 4 pole winding find the distribution factor.

$$\text{Slot angle, } \beta = \frac{180}{\text{Slots per pole}} = \frac{180}{9} = 20°$$

$$\text{Slots/pole/phase, } m = \frac{36}{4 \times 3} = 3$$

$$\text{Distribution factor, } K_d = \frac{\sin \frac{m\beta}{2}}{m \sin \frac{\beta}{2}} = \frac{\sin \frac{3 \times 20}{2}}{3 \sin \frac{20}{2}} = 0.956$$

EMF Equation

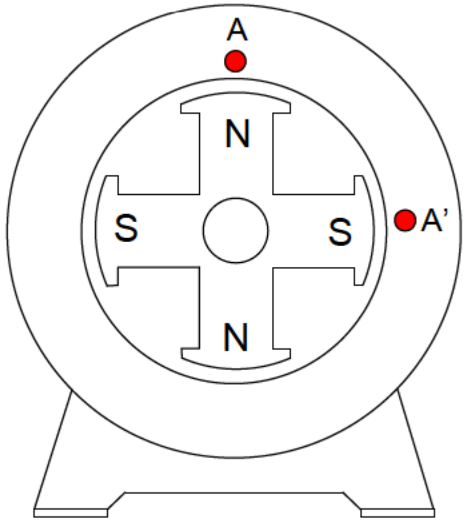
$Z =$ Number of coil sides in series per phase

$P =$ Number of poles

$f =$ Frequency

$N =$ Speed in RPM

$\Phi =$ Flux per pole



In one revolution each conductor is cut by ΦP webers

$$d\Phi = \Phi P \qquad dt = \frac{60}{N}$$

$$\text{Average emf induced} = \frac{d\Phi}{dt} = \frac{\Phi P}{60/N} = \frac{\Phi N P}{60} \text{ volts}$$

Substituting for N

$$\text{Average emf induced} = \frac{\Phi P}{60} \times \frac{120 f}{P} = 2 f \Phi \text{ volts}$$

EMF Equation

$$\text{For the total winding, average emf } = 2f\Phi Z$$
$$= 4f\Phi T$$

$$\text{RMS value } = 1.11 \times 4 f\Phi T$$
$$= 4.44 f\Phi T$$

Considering pitch factor and distribution factor,

$$K_c = \cos\frac{\alpha}{2}$$

RMS value of per phase voltage, $\boxed{E = 4.44\, K_c\, K_d\, \Phi\, f\, T \text{ volts}}$

$$K_d = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}}$$

Example 1.2

A 4 pole 3 phase star connected alternator having 60 slots with 4 conductor per slot runs at 1500 rpm. Coils are short pitched by 3 slots. If the phase spread is 60 degrees, find the line voltage induced for a flux per pole of 0.75 Wb distributed sinusoidally in space. All turns per phase are in series.

$$\text{Slots/pole/phase, } m = \frac{60}{4 \times 3} = 5$$

$$\text{Slot angle, } \beta = \frac{180}{\text{Slots/pole}} = \frac{180}{15} = 12^\circ$$

$$\text{Coil pitch} = (15-3) \times 12 = 144^\circ \qquad \text{Short chording angle, } \alpha = (180-144) = 36^\circ$$

$$\text{Number of turns, } T = \frac{60 \times 4}{2 \times 3} = 40$$

$$K_c = \cos\frac{\alpha}{2} = \cos\frac{36}{2} = 0.951$$

$$K_d = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}} = \frac{\sin\frac{5\times 12}{2}}{5\times\sin\frac{12}{2}} = 0.957$$

$$\text{Per phase voltage} = 4.44\ K_c\ K_d\ \Phi\ f\ T$$
$$= 4.44 \times 0.951 \times 0.957 \times 0.75 \times 50 \times 40 = 6061.3 \text{ volts}$$

$$\text{Line voltage} = \sqrt{3} \times V_{ph}$$
$$= \sqrt{3} \times 6061.3 = 10498.5 \text{ volts}$$