浙江大学电气工程学院

电机与拖动

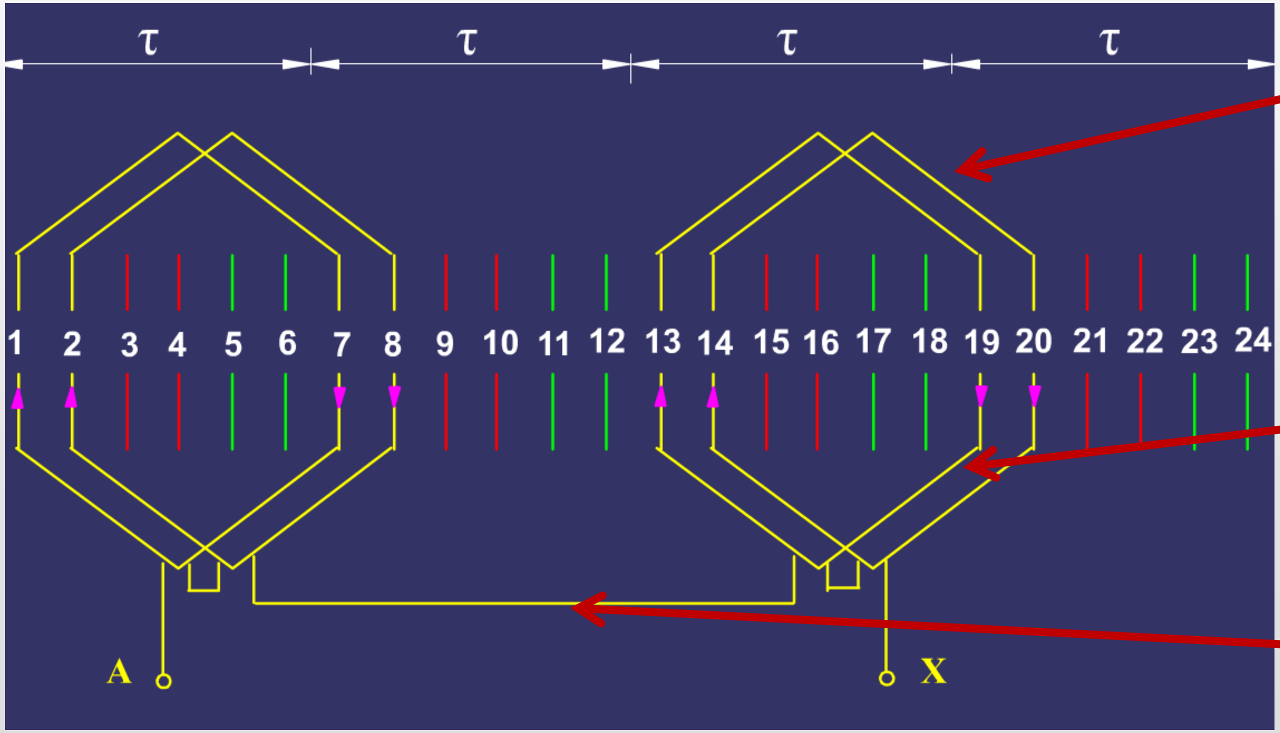
主讲：卢琴芬

3

交流绕组的感应电动势

磁场旋转

- 切割定子绕组 ⟹ 定子绕组感应电动势
- 切割转子绕组(若n不等于n_1) ⟹ 转子绕组感应电动势



单个(集中)绕组的基波电动势

线圈组的基波电动势

相绕组基波电动势

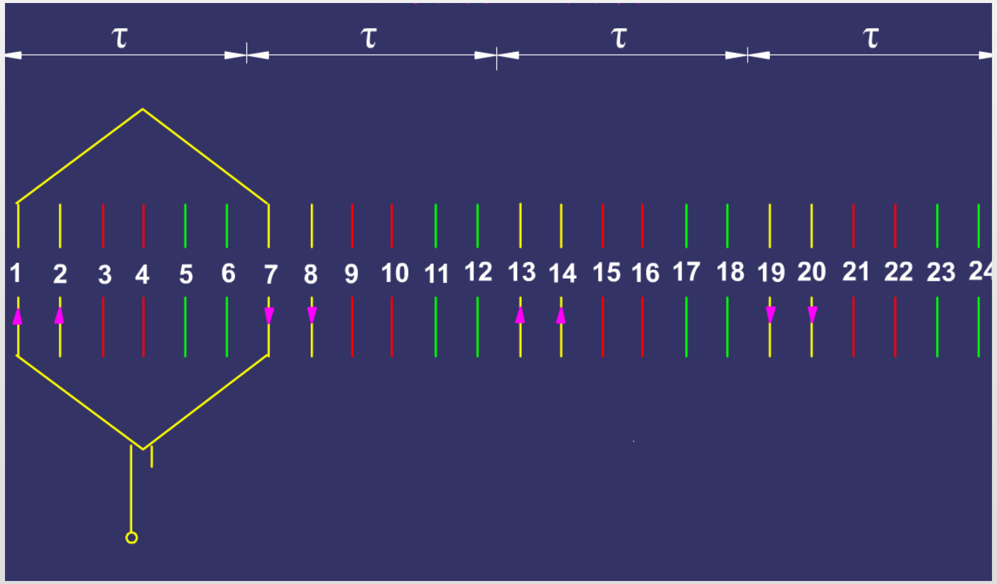
相绕组中的基波电动势

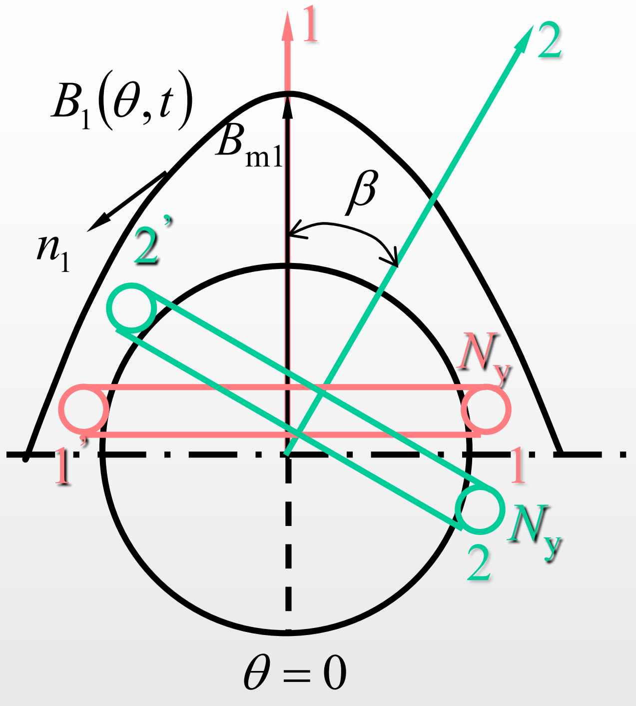
基波磁场:气隙磁场沿圆周正弦分布，极数等于电动机的极数。

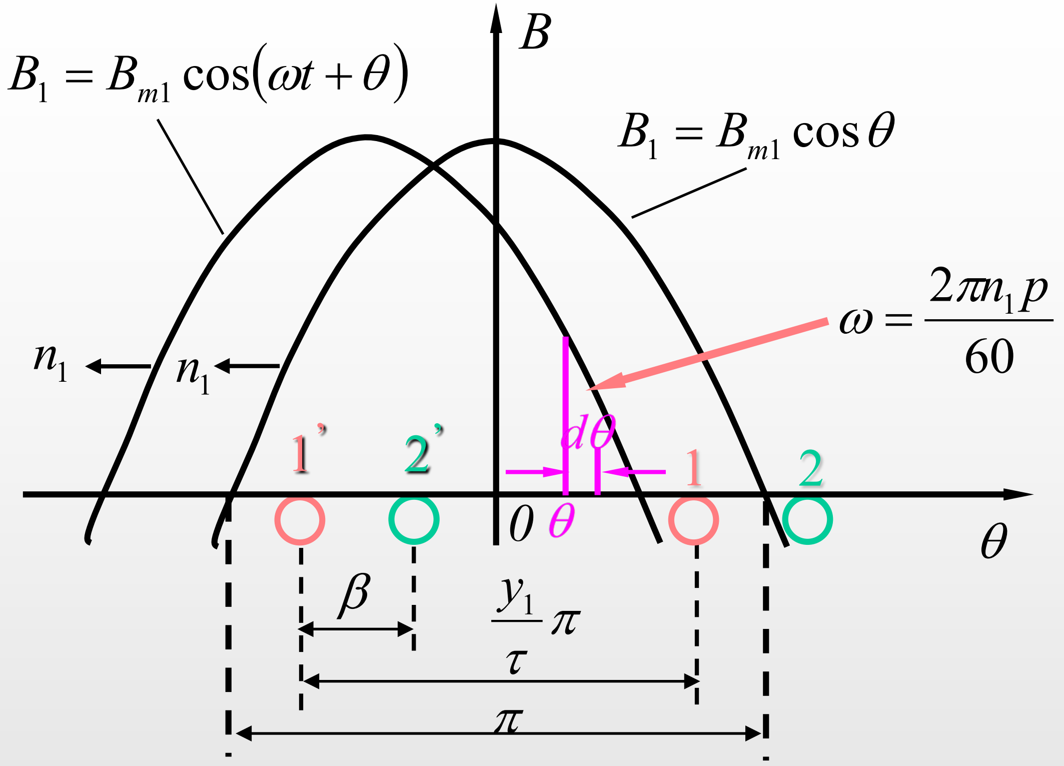
基波电动势:基波磁场在电机绕组中感应的电动势。

1.单个(集中)绕组的基波电动势

$$e_{y1} = -N\frac{d\Phi}{dt}$$







$$\phi_{11'}=\int_{-\frac{y_1}{2\tau}\pi}^{\frac{y_1}{2\tau}\pi} B_{m_1}\cos(\omega t+\theta)\cdot l\cdot\frac{\tau}{\pi}d\theta=\frac{2}{\pi}\underbrace{B_{m1}\cdot\tau l\cdot\cos\omega t}_{\phi 1}\cdot\underbrace{\sin\frac{y_1}{\tau}\frac{\pi}{2}}_{k_{y1}}$$

$$\phi_{11'} = \int_{-\frac{y_1}{2\tau}}^{\frac{y_1}{2\tau}\pi} B_{m_1}\cos(\omega t+\theta)\cdot l\cdot\frac{\tau}{\pi}d\theta = \underbrace{\frac{2}{\pi}B_{m1}\cdot\tau l}_{\phi 1}\cdot\cos\omega t\cdot\underbrace{\sin\frac{y_1}{\tau}\frac{\pi}{2}}_{k_{y1}}$$

$$d\phi = B_1 l dx = B_{m_1}\cos(\omega t+\theta)\cdot l\cdot\frac{\tau}{\pi}d\theta = B_{m1}\cdot\frac{\tau l}{\pi}\cos(\omega t+\theta)d\theta$$

$$e_{y1} = -N_y\frac{d\phi_{11'}}{dt} = -N_y k_{y1}\frac{d\phi_1\cos\omega t}{dt} = \underbrace{\omega\phi_1 N_y k_{y1}}_{E_{1m}}\sin\omega t = \sqrt{2}E_1\cos(\omega t-90^0)$$

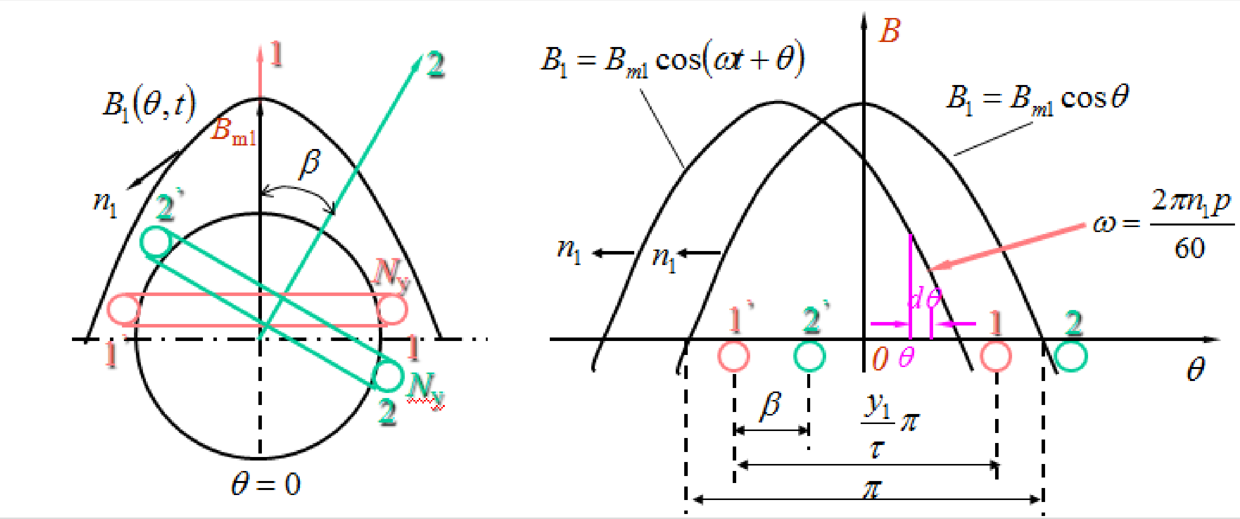
$$E_1 = \frac{E_{1m}}{\sqrt{2}} = \frac{\omega\phi_1 N_y k_{y1}}{\sqrt{2}} = \frac{2\pi f\cdot\phi_1 N_y k_{y1}}{\sqrt{2}} = 4.44 f N_y k_{y1}\phi_1$$

$$\phi_{22'} = \int_{-(\frac{y_1}{2\tau}-\beta)}^{\frac{y_1}{2\tau}\pi+\beta} B_{m_1}\cos(\omega t+\theta)\cdot l\cdot\frac{\tau}{\pi}d\theta = \underbrace{\frac{2}{\pi}B_{m1}\cdot\tau l}_{\phi 1}\cdot\cos(\omega t+\beta)\cdot\underbrace{\sin\frac{y_1}{\tau}\frac{\pi}{2}}_{k_{y1}}$$

$$e_{y2} = -N_y\frac{d\phi_{22'}}{dt} = -N_y k_{y1}\frac{d\phi_1\cos(\omega t+\beta)}{dt} = \underbrace{\omega\phi_1 N_y k_{y1}}_{E_{1m}}\sin(\omega t+\beta) = \sqrt{2}E_1\cos(\omega t+\beta-90^0)$$

$$e_{y1} = \sqrt{2}E_1\cos(\omega t-90^0)$$

$$E_1 = \frac{E_{1m}}{\sqrt{2}} = \frac{\omega\phi_1 N_y k_{y1}}{\sqrt{2}} = \frac{2\pi f\cdot\phi_1 N_y k_{y1}}{\sqrt{2}} = 4.44 f N_y k_{y1}\phi_1$$



总结

(1)感应电动势的频率与旋转磁场的频率相同

$$f_1 = \frac{pn_1}{60}$$

(2)感应电动势的有效值

线圈的匝数

$$k_{y1} = \sin\left(\frac{y_1}{\tau}90^\circ\right)$$

短距系数

短距绕组

$$E_{y1} = \sqrt{2}\pi f_1 N_{y1} k_{y1} \Phi_1 \approx 4.44 f_1 N_{y1} k_{y1} \Phi_1$$

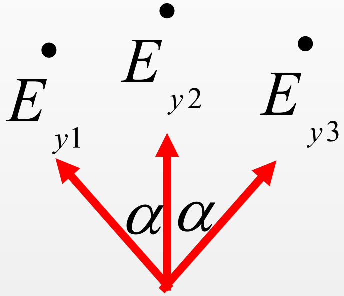
整距绕组 $E_{y1} = \sqrt{2}\pi f_1 N_{y1} \Phi_1 \approx 4.44 f_1 N_{y1} \Phi_1$ 与变压器相同

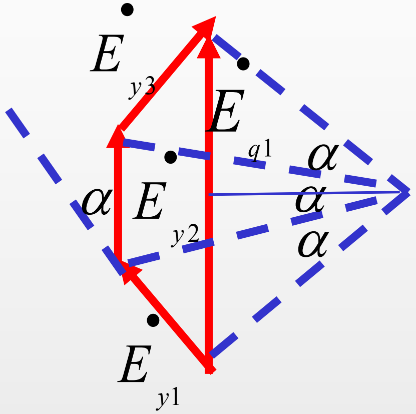
(3)线圈在电枢的位置不同时，感应电动势有相位差。

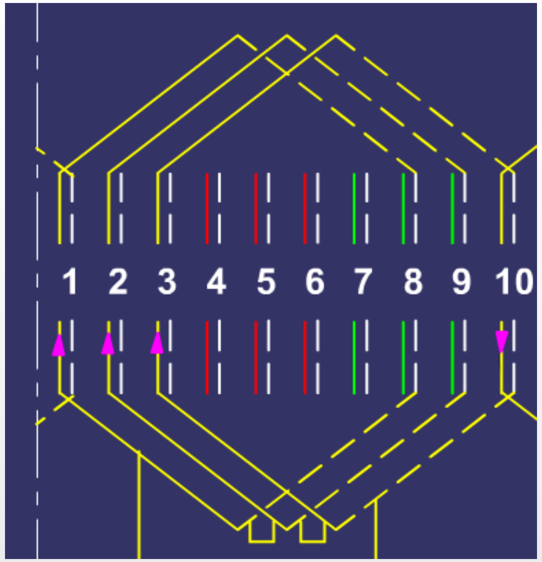
$$e_{y1} = \sqrt{2}E_1 \cos\left(\omega t - 90^0\right) \qquad e_{y2} = \sqrt{2}E_1 \cos\left(\omega t + \beta - 90^0\right)$$

线圈组的基波电动势

由q个N_{y1}相同的线圈，空间上互差α角个线圈组成







$$\dot{E}_{q1} = 2R\sin\frac{q\alpha}{2}$$

$$\dot{E}_{y1} = 2R\sin\frac{\alpha}{2}$$

$$\Rightarrow \frac{E_{q1}}{E_{y1}} = \frac{\sin\frac{q\alpha}{2}}{\sin\frac{\alpha}{2}} \Rightarrow E_{q1} = qE_{y1}\frac{\sin\frac{q\alpha}{2}}{q\sin\frac{\alpha}{2}} = qE_{y1}k_{q1}$$

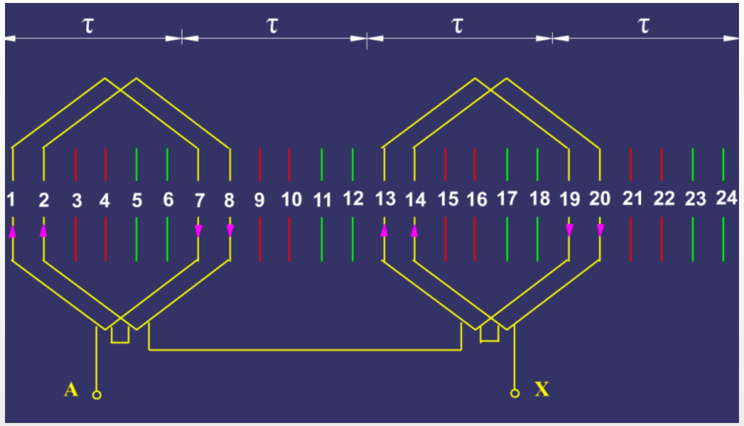
分布系数

$$k_{q1} = \frac{q\text{个分布线圈线圈基波电动势矢量和}}{q\text{个分布线圈线圈基波电动势代数和}} < 1$$

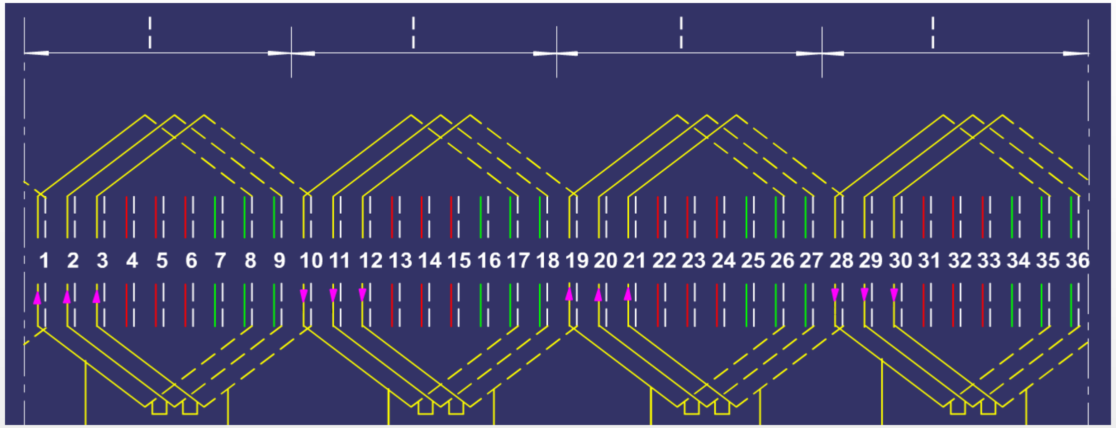
主讲：浙江大学卢琴芬

相线圈的基波电动势

每相绕组由2*p*(双层)或*p*个(单层)线圈组而成。



$$E_{q1} = qE_{y1}k_{q1}$$



$$E_{\Phi 1}$$

$$E_{\Phi 1} = E_{q1}\frac{2p}{a} = \frac{2p}{a}qE_{y1}k_{q1} = 4.44 f_1 N_1 k_{w1} \Phi_1$$

双层绕组每相串联匝数 $N_1 = \dfrac{2p}{a}qN_{y1}$

单层绕组每相串联匝数 $N_1 = \dfrac{p}{a}qN_{y1}$

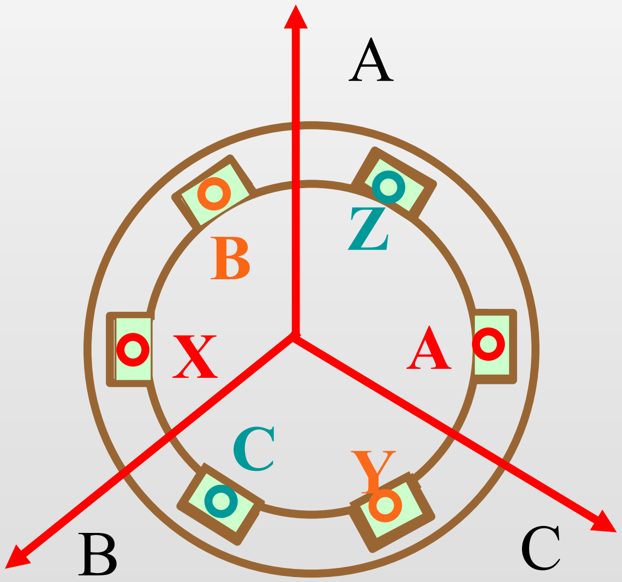
$k_{w1} = k_{q1}k_{y1}$

基波电动势
绕组系数

$$E_{\Phi 1}=4.44f_1\Phi_1\left(N_1k_{w1}\right)$$ 相绕组的基波电动势

$$E_{y1}=4.44f_1\Phi_1N_{y1}$$ 单个整距的基波电动势

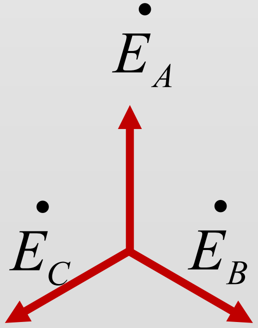
一个分布短距的实际相绕组 $\xrightarrow[\text{等效}]{\text{基波电动势相等}}$ 一个匝数为N_1k_{w1}的单个整距线圈



A、B、C三相线圈有效匝数N_1k_{w1}相同，相位互差120电角度，同一个基波旋转磁场在三相绕组中产生的基波电动势大小相等，频率相同，相位互差120度，互相对称

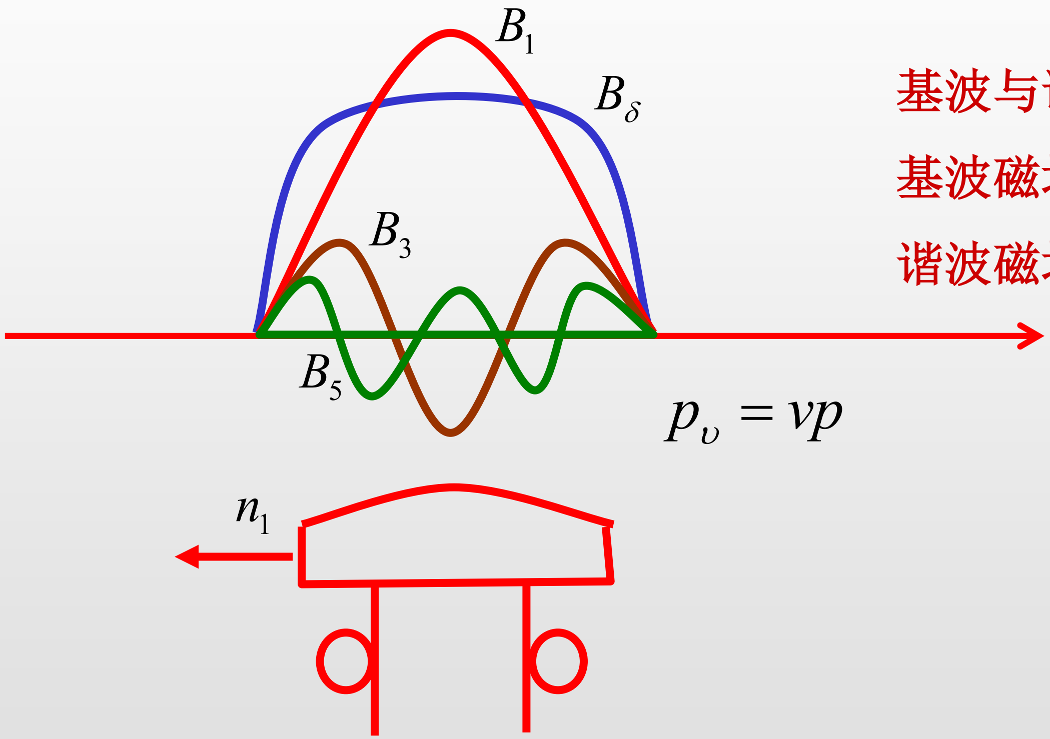
$$E_A=E_B=E_C=4.44f_1N_1k_{w1}\Phi_1$$

$$f=\frac{pn_1}{60}$$



相绕组中的谐波电动势

实际电机中，定转子铁芯表面开槽及同步电机的磁极形状等原因，气隙中的磁场沿圆周并非按正弦规律分布。



$p_\upsilon = \nu p$

基波与谐波都要切割定子绕组，产生感应电动势，
基波磁场产生的感应电动势为基波电动势，
谐波磁场产生的感应电动势为谐波电动势。

频率 $f_\upsilon = \dfrac{\nu p n_1}{60} = \nu f_1$

大小 $E_\upsilon = 4.44 f_\upsilon N_1 k_{w\upsilon} \Phi_\upsilon$

$$k_{y\upsilon} = \sin\left(\upsilon \frac{y_1}{\tau} 90^\circ\right); k_{q\upsilon} = \frac{\sin\left(\upsilon \dfrac{q\alpha}{2}\right)}{q \sin \dfrac{\upsilon\alpha}{2}}$$

$$\Phi_\upsilon = \frac{2}{\pi} B_{m\upsilon} \tau_\upsilon l = \frac{2}{\pi} B_{m\upsilon} \frac{\tau}{\upsilon} l$$

削弱的方法：

合理设计同步电机的磁极形状、

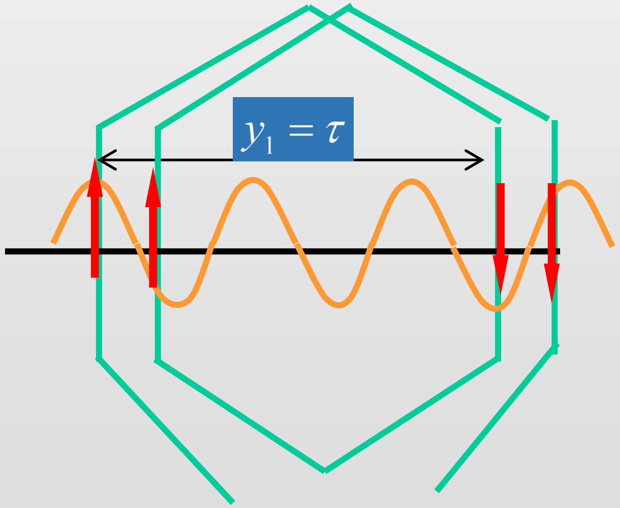
斜槽（感应电机）或斜极（同步电机）减小齿槽效应、

Y 或Δ接法，消除线电动势中3倍次谐波电动势

分布短距（双层）。

采用分布绕组削弱高次谐波电动势。

$$\begin{matrix} q = 2 \\ \alpha = 30^{\circ} \end{matrix} \Rightarrow \begin{cases} k_{q1} = 0.966 \\ k_{q5} = 0.2588 \\ k_{q7} = -0.2588 \end{cases}$$



采用绕组短距削弱高次谐波电动势。

$\frac{y_1}{\tau}=\frac{5}{6} \Rightarrow k_{y1}=0.966, k_{y5}=0.2588, k_{y7}=0.2588$

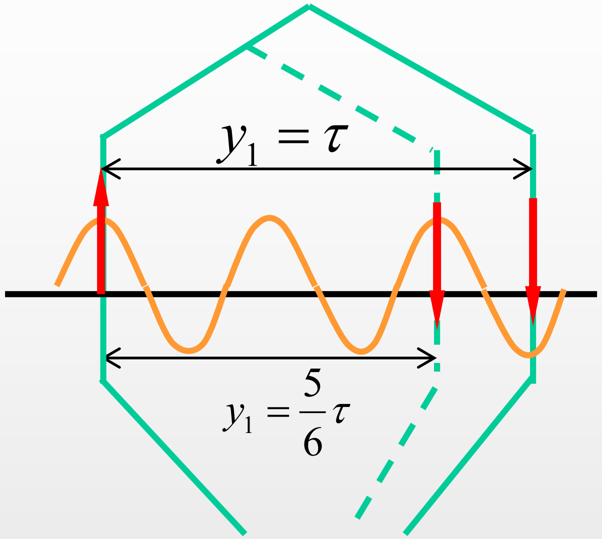
$\Rightarrow$ 消除 5 次、7次谐波

$\frac{y_1}{\tau}=\frac{7}{9} \Rightarrow k_{y1}=0.94, k_{y5}=-0.174, k_{y7}=0.766$

$\Rightarrow$ 消除 5 次谐波

$\frac{y_1}{\tau}=\frac{8}{9} \Rightarrow k_{y1}=0.985, k_{y5}=0.643, k_{y7}=-0.342$

$\Rightarrow$ 削弱7次谐波



分布短距 $\left\{\begin{array}{l}\text{基波电动势受到削弱，但影响不大}\\ \text{谐波电动势受到很大的削弱(5,7)}\end{array}\right\}$ 基本为正弦波

浙江大学电气工程学院

T H A N K S

主讲：浙江大学卢琴芬