

# Comparing Magnetic Bearings with Symmetry of 3

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# AMBs: possible types

types of AMBs

types of AMBs

symm of 4

comparisons

ideas

symm of 3

symm of 3



# AMBs: possible types

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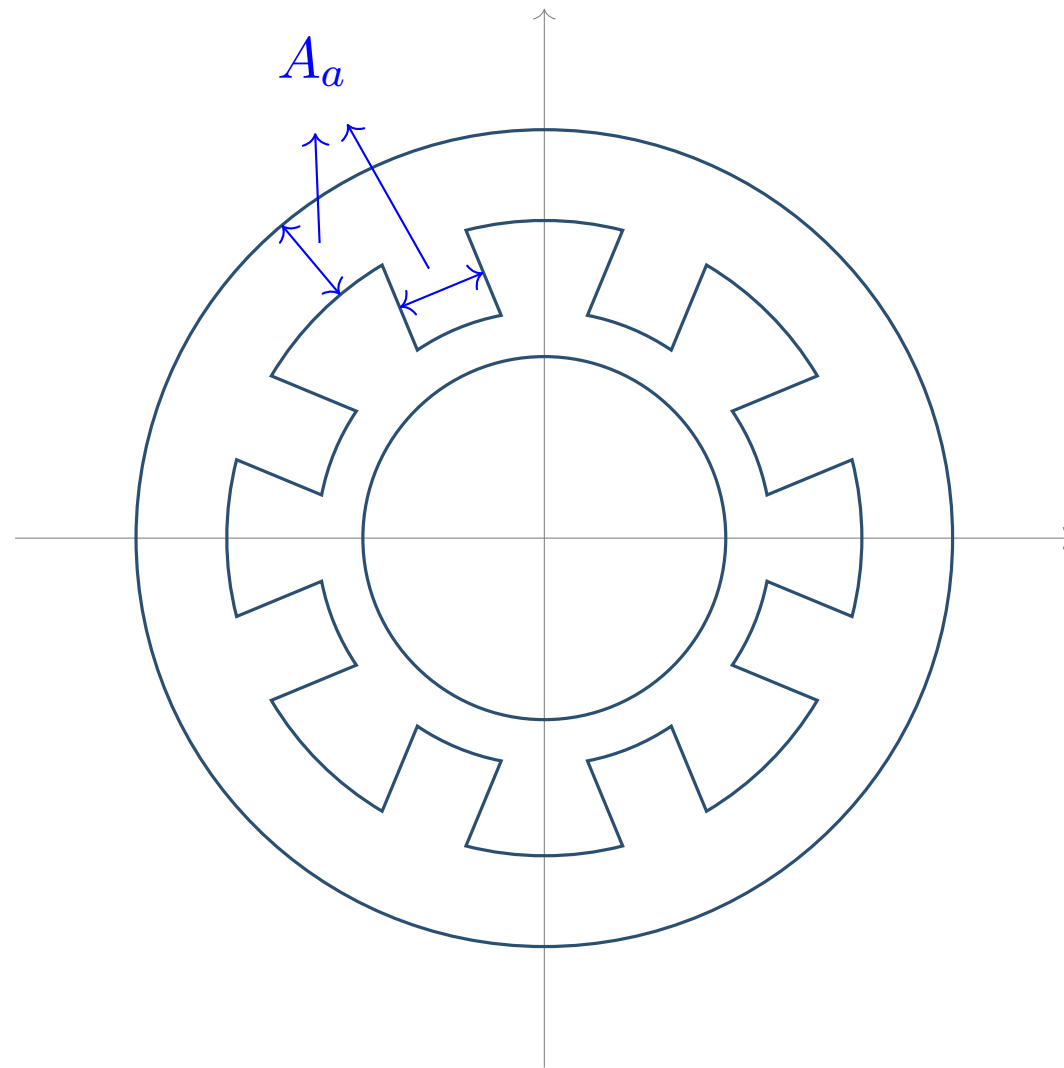
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symm of 3



traditional AMB structure



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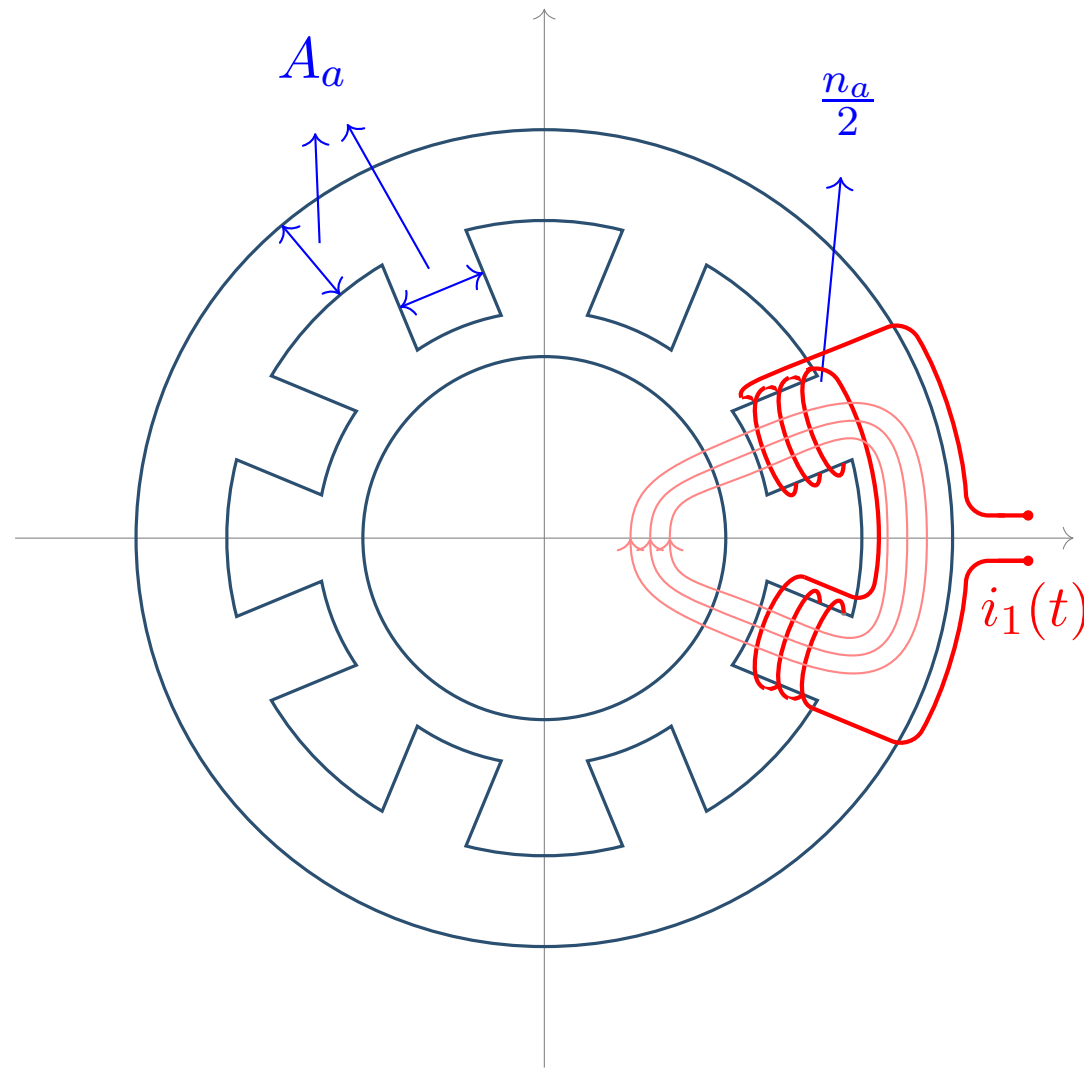
symm of 4

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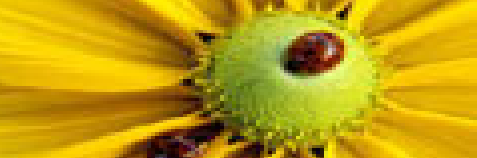
symm of 3

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traditional AMB structure

injecting  
current  $i_1(t)$   
in the right side



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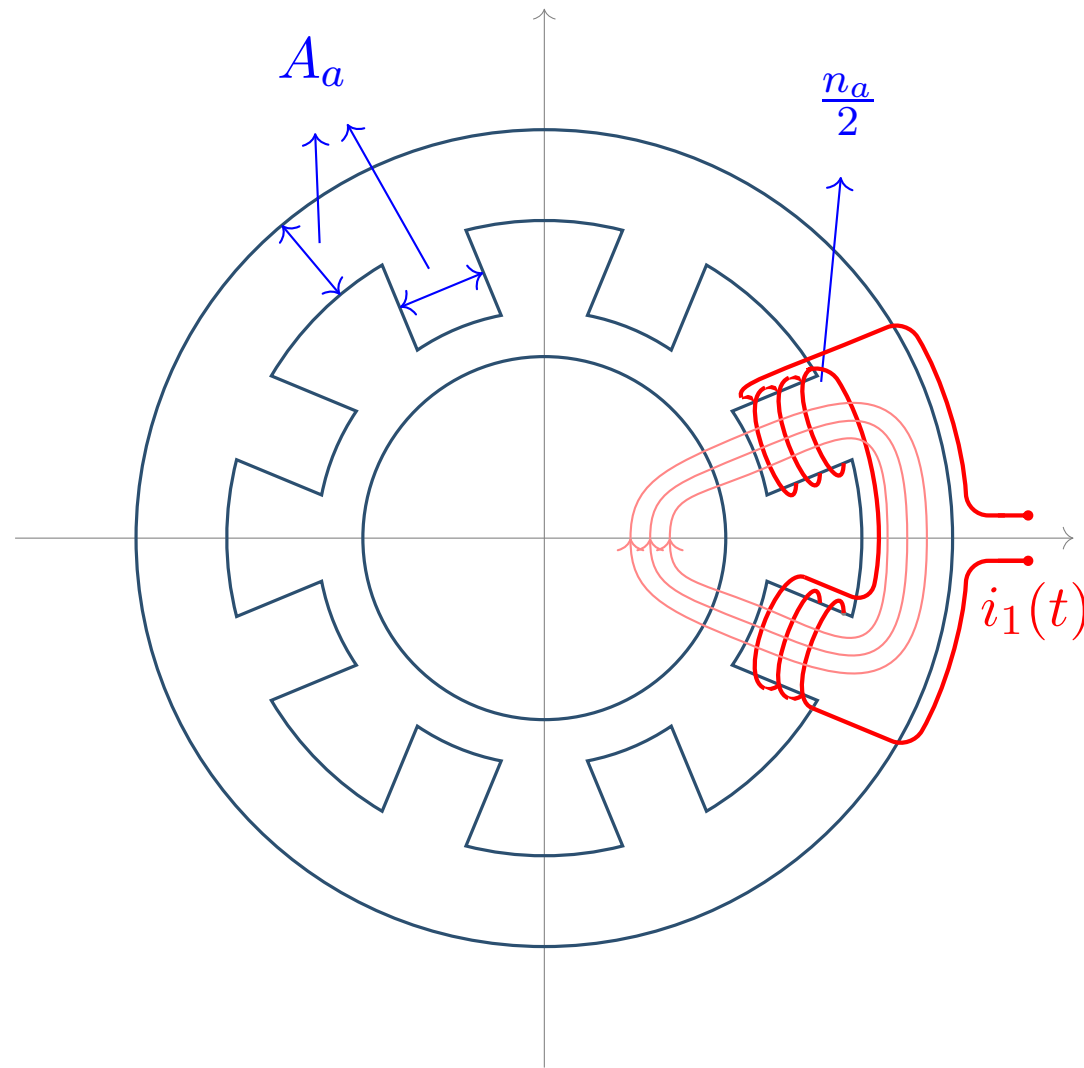
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traditional AMB structure

injecting  
current  $i_1(t)$   
in the right side  
and currents  $i_2, i_3, i_4$   
in the other positions



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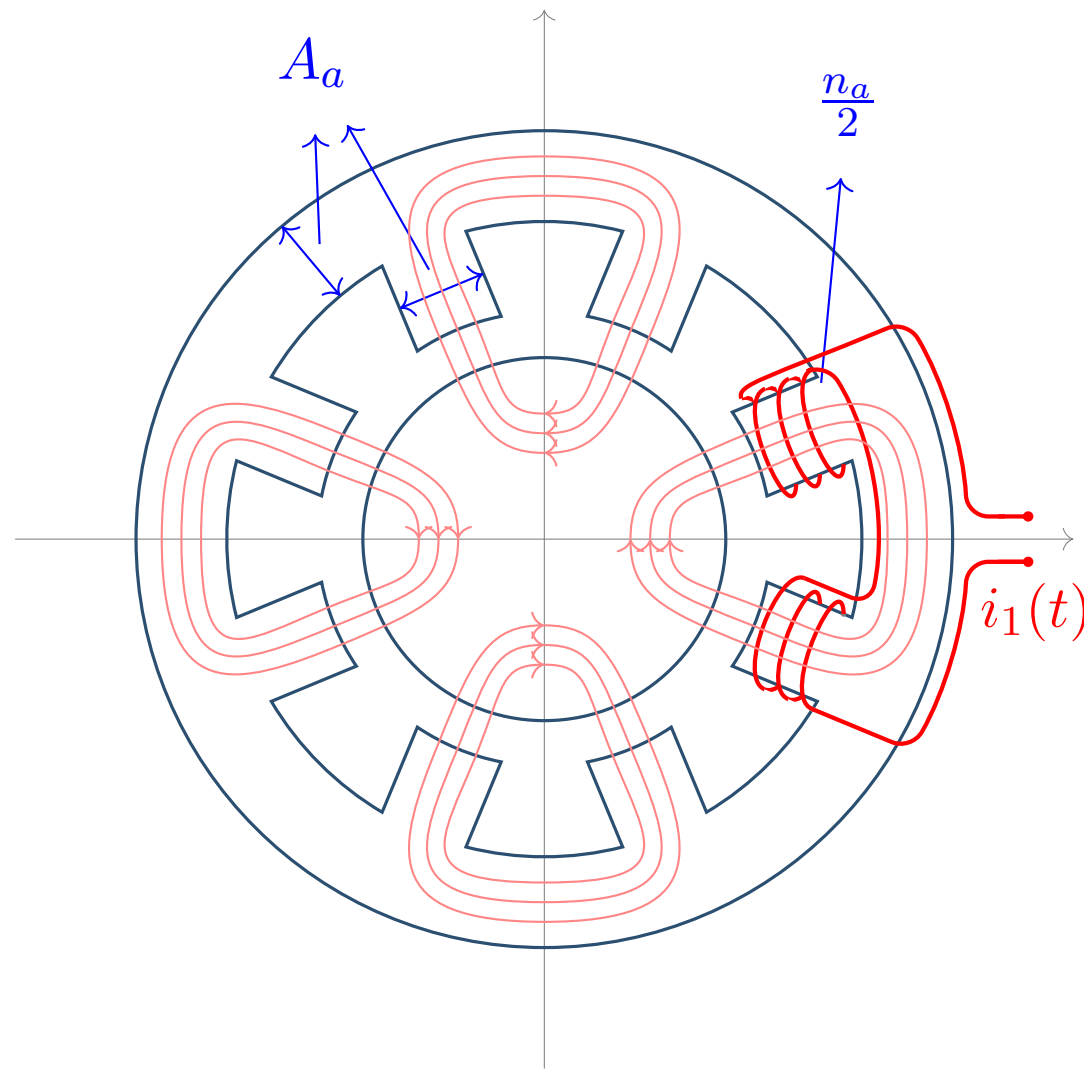
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traditional AMB structure



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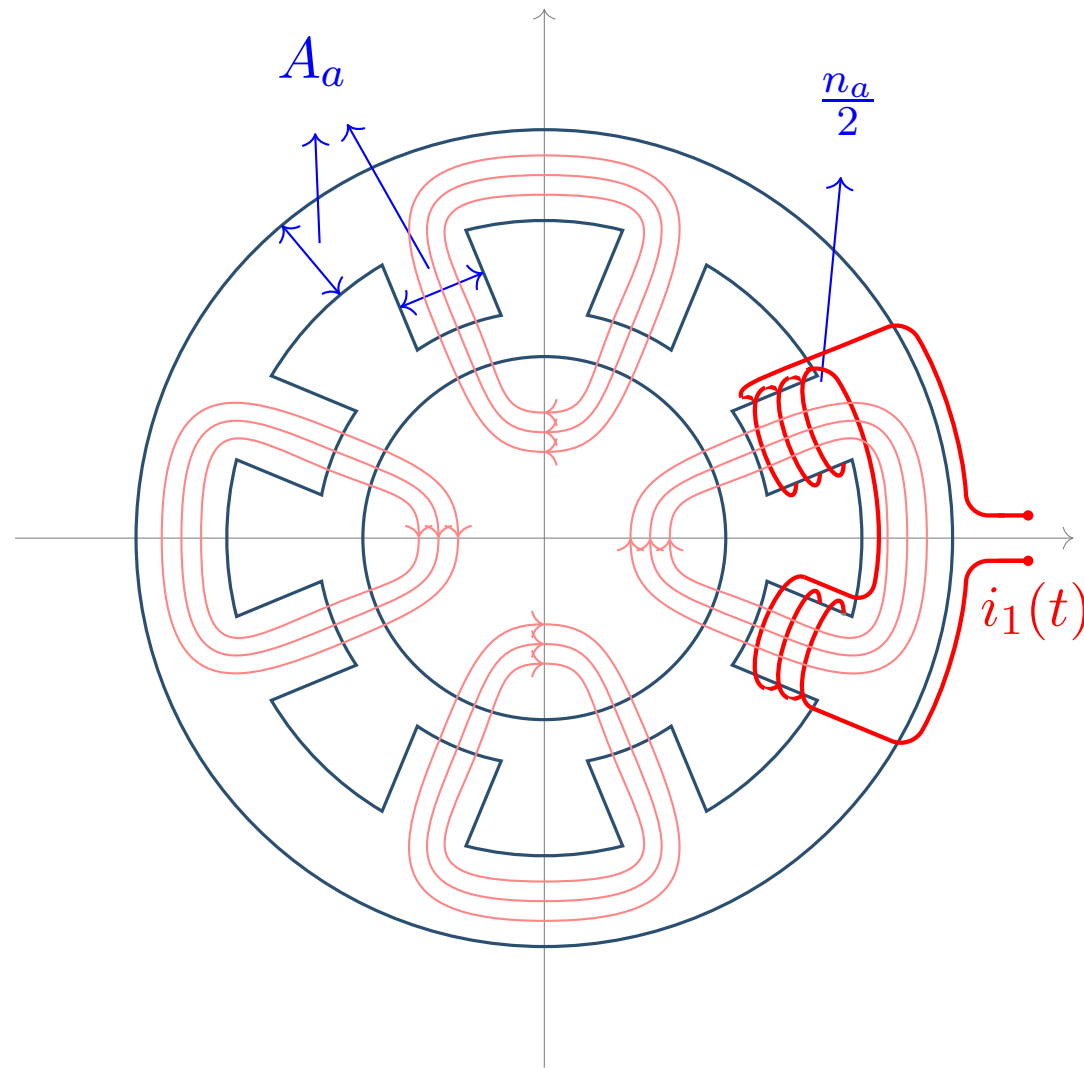
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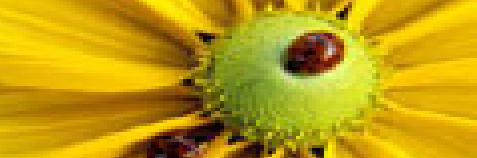
ideas

symm of 3

symm of 3



traditional AMB structure  
can be called



# AMBs: possible types

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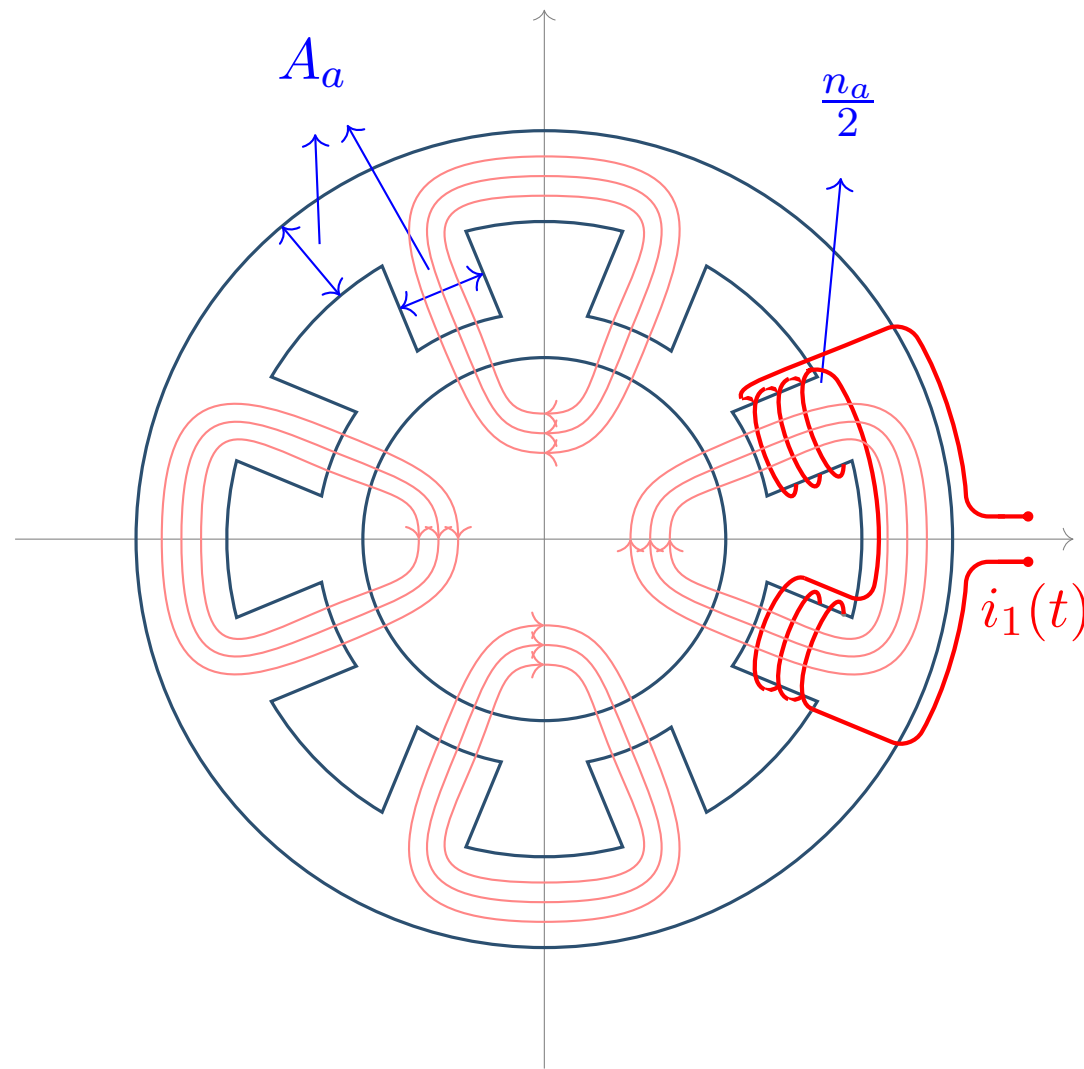
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traditional AMB structure

can be called  
Type A

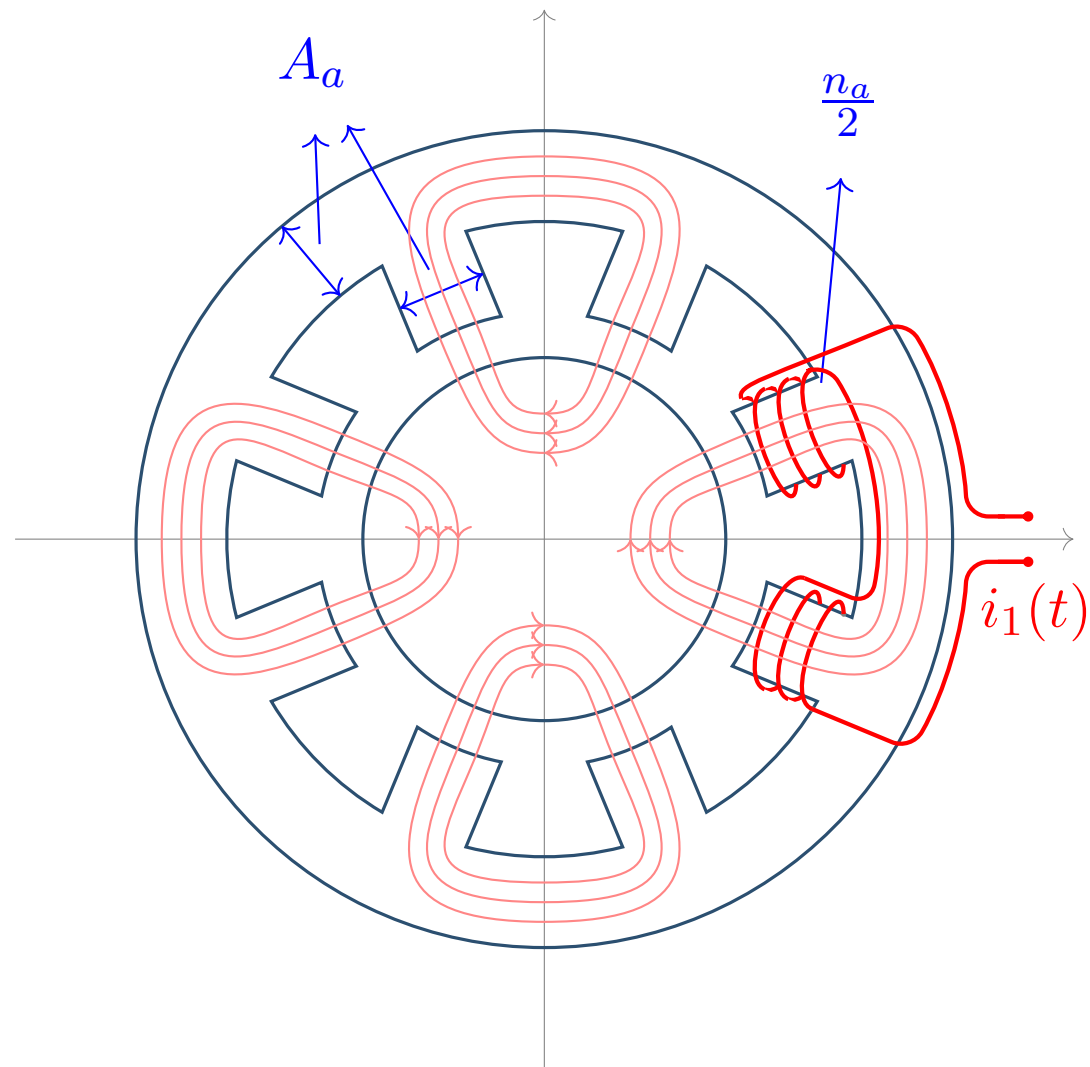




# AMBs: possible types

## types of AMBs

- types of AMBs
- symm of 4
- comparisons
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traditional AMB structure

can be called  
Type A  
"8 poles"



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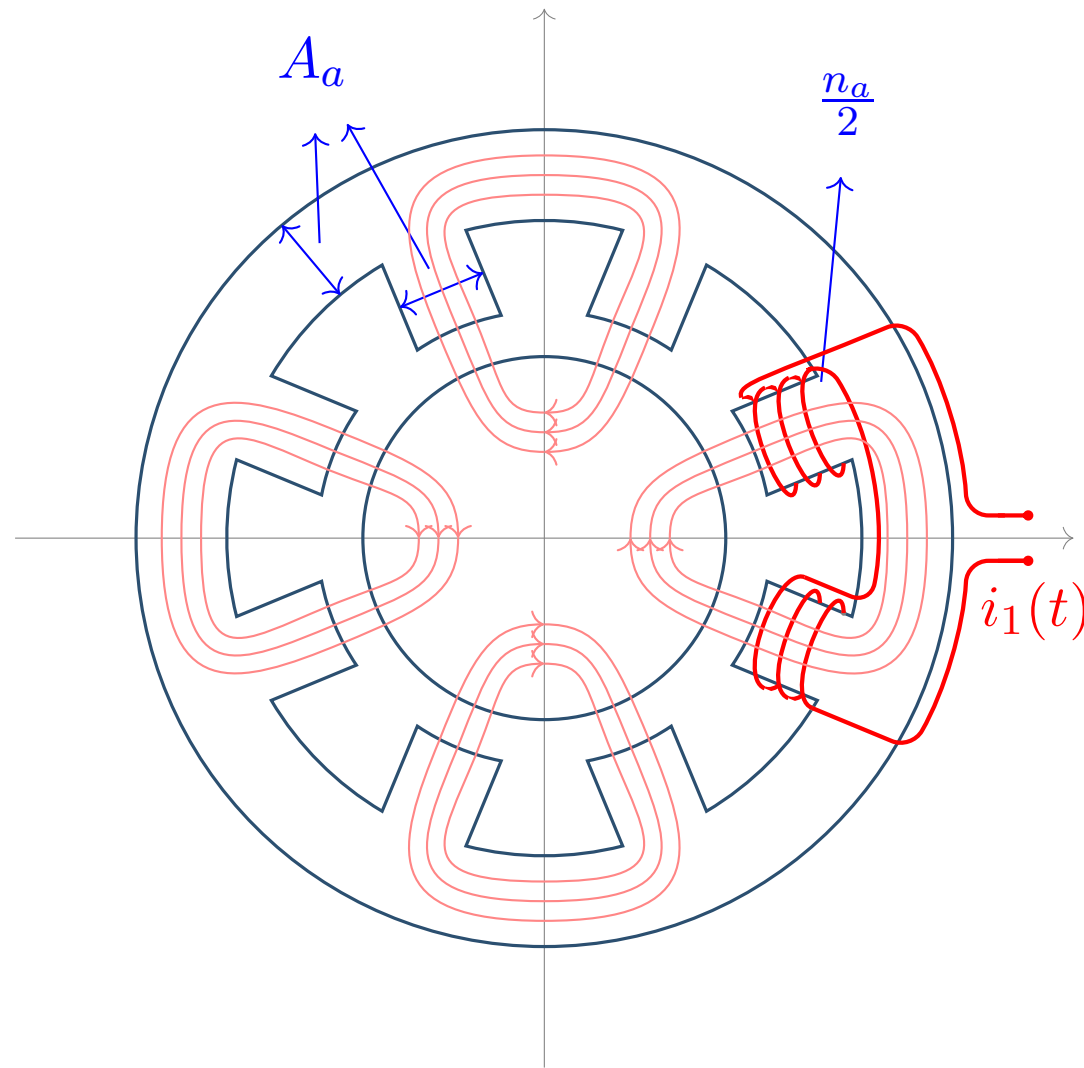
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traditional AMB structure

can be called

Type A

8 gaps



# AMBs: possible types

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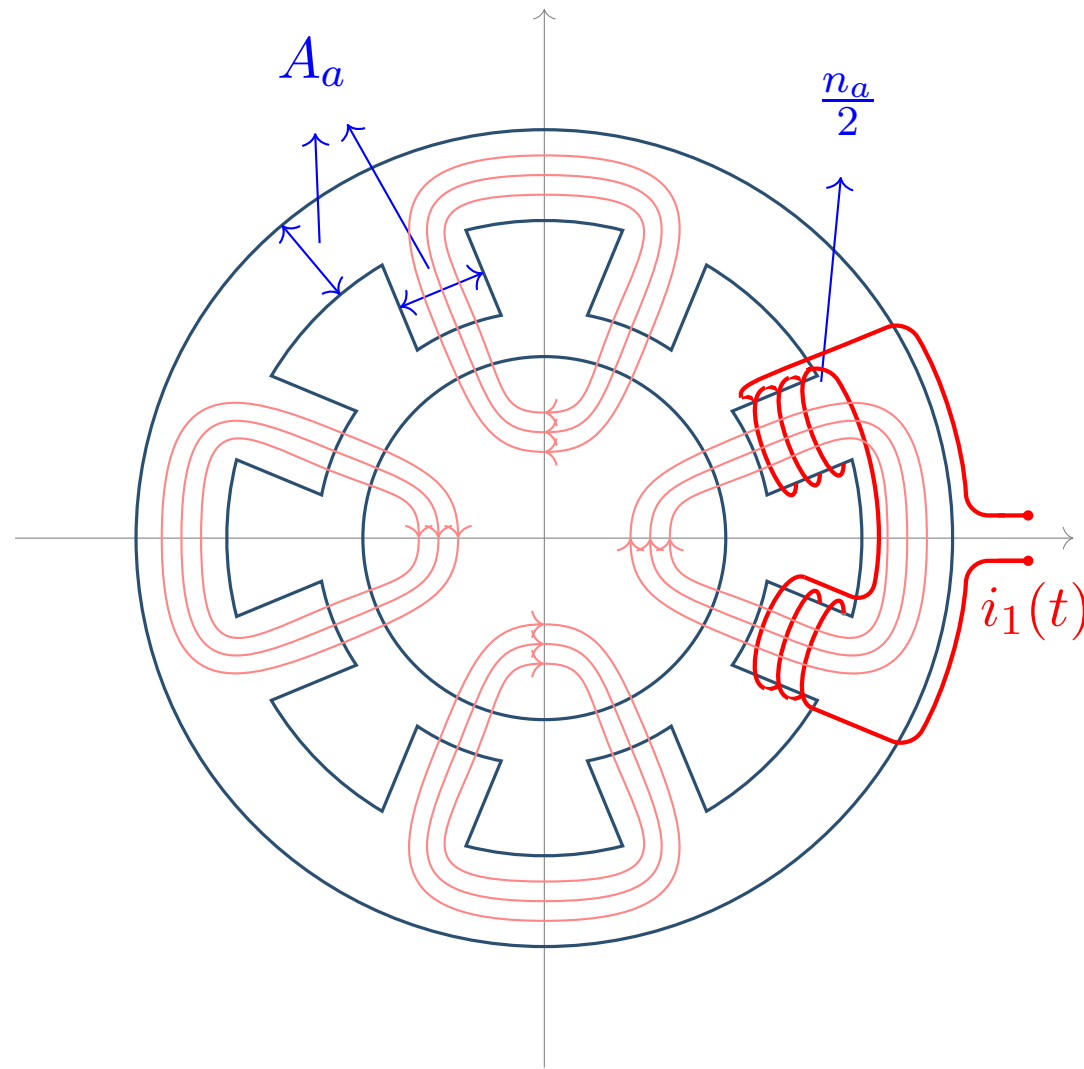
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traditional AMB structure

can be called  
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8 gaps  
uncoupled fluxes

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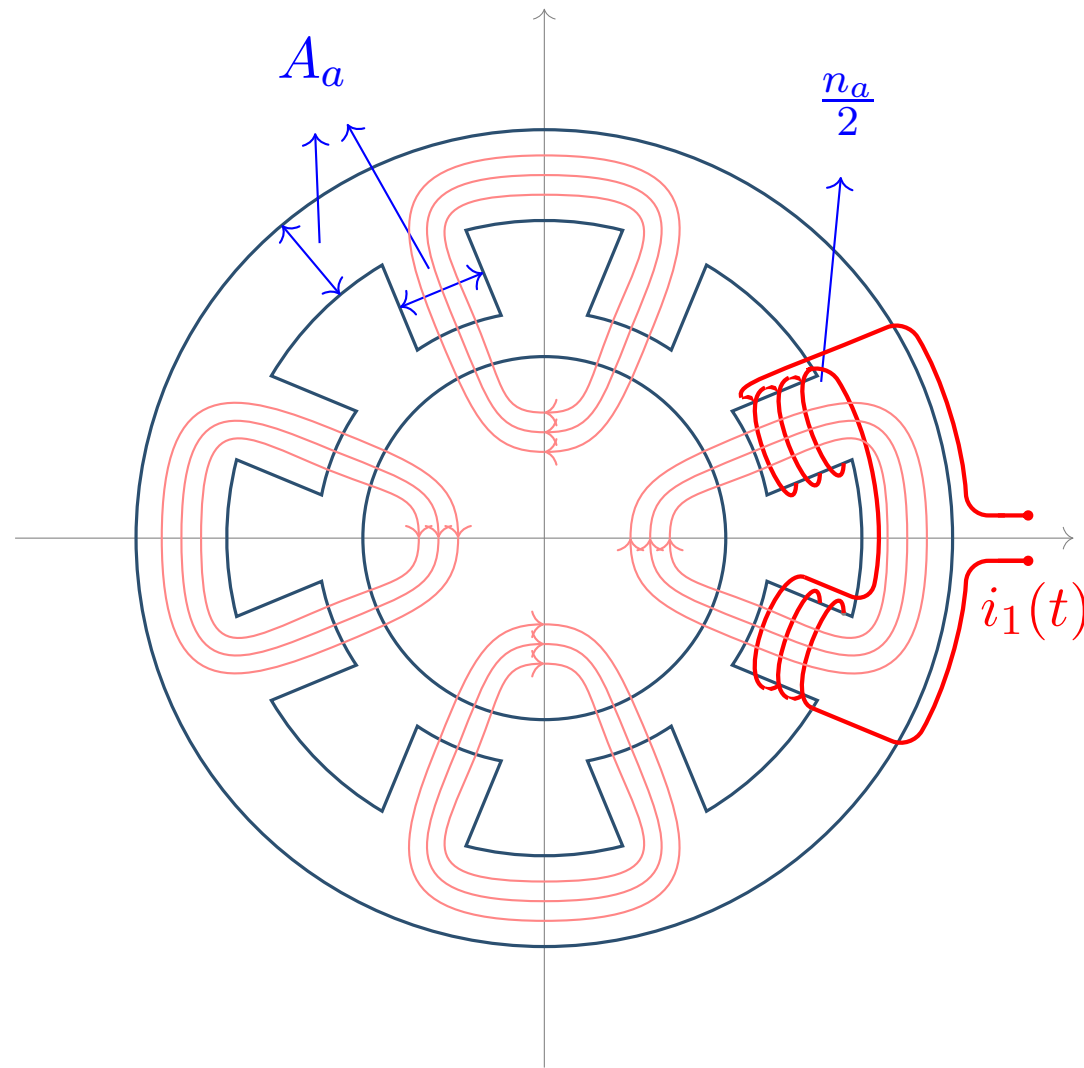
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traditional AMB structure

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uncoupled fluxes

currents at opposite sides

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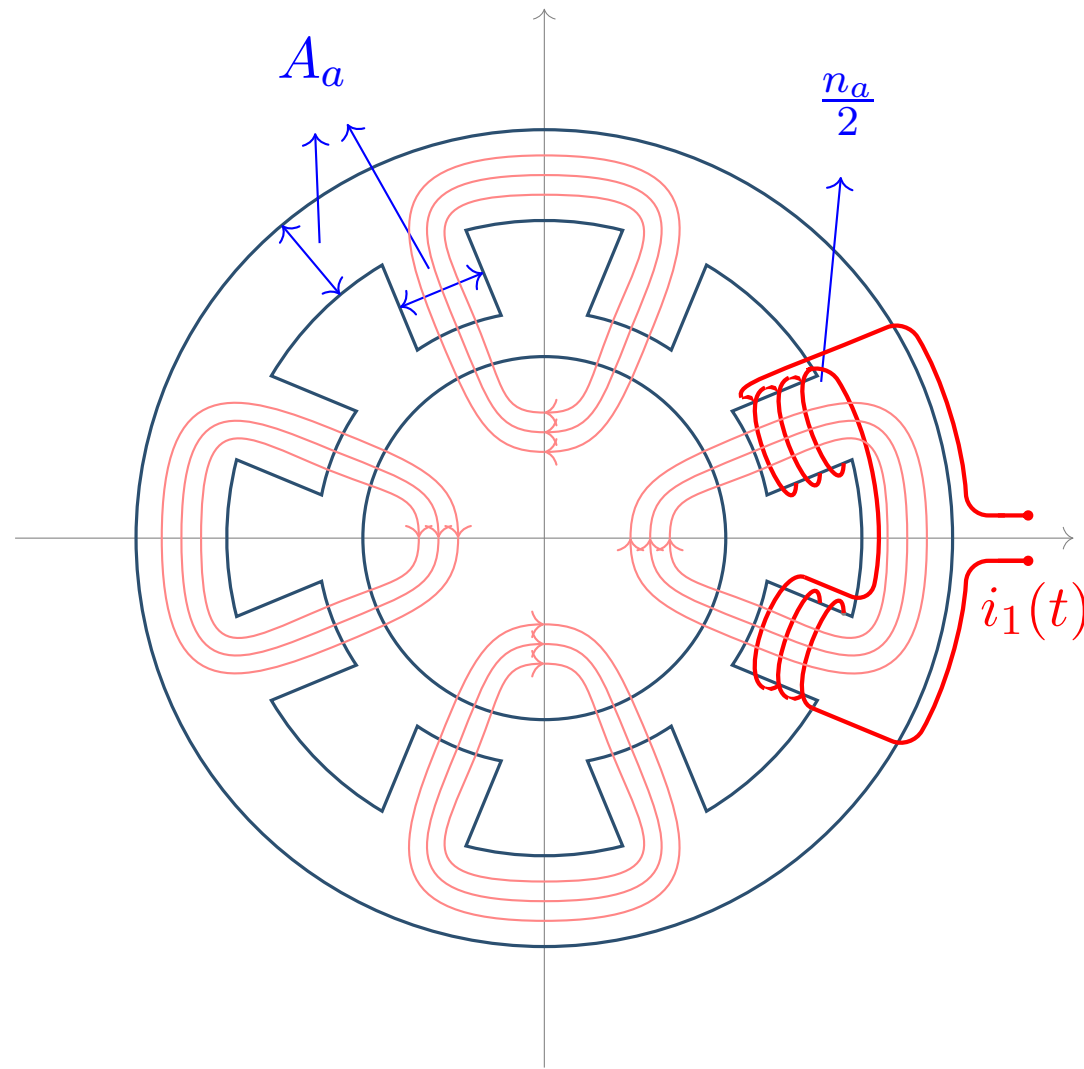
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uncoupled fluxes

$$i_1 = i_0 + i_x \quad i_3 = i_0 - i_x$$

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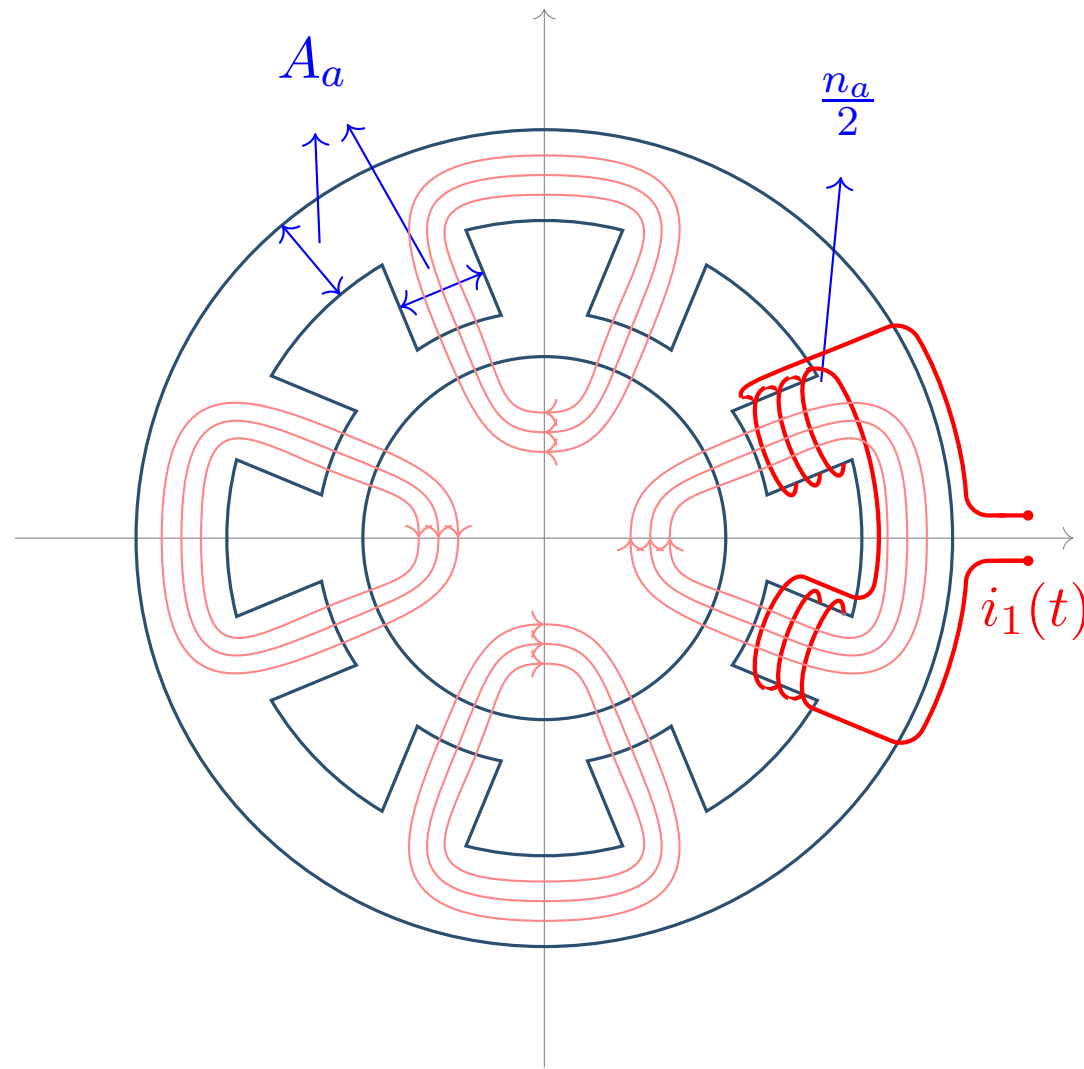
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$$\begin{aligned} i_1 &= i_0 + i_x & i_3 &= i_0 - i_x \\ i_2 &= i_0 + i_y & i_4 &= i_0 - i_y \end{aligned}$$

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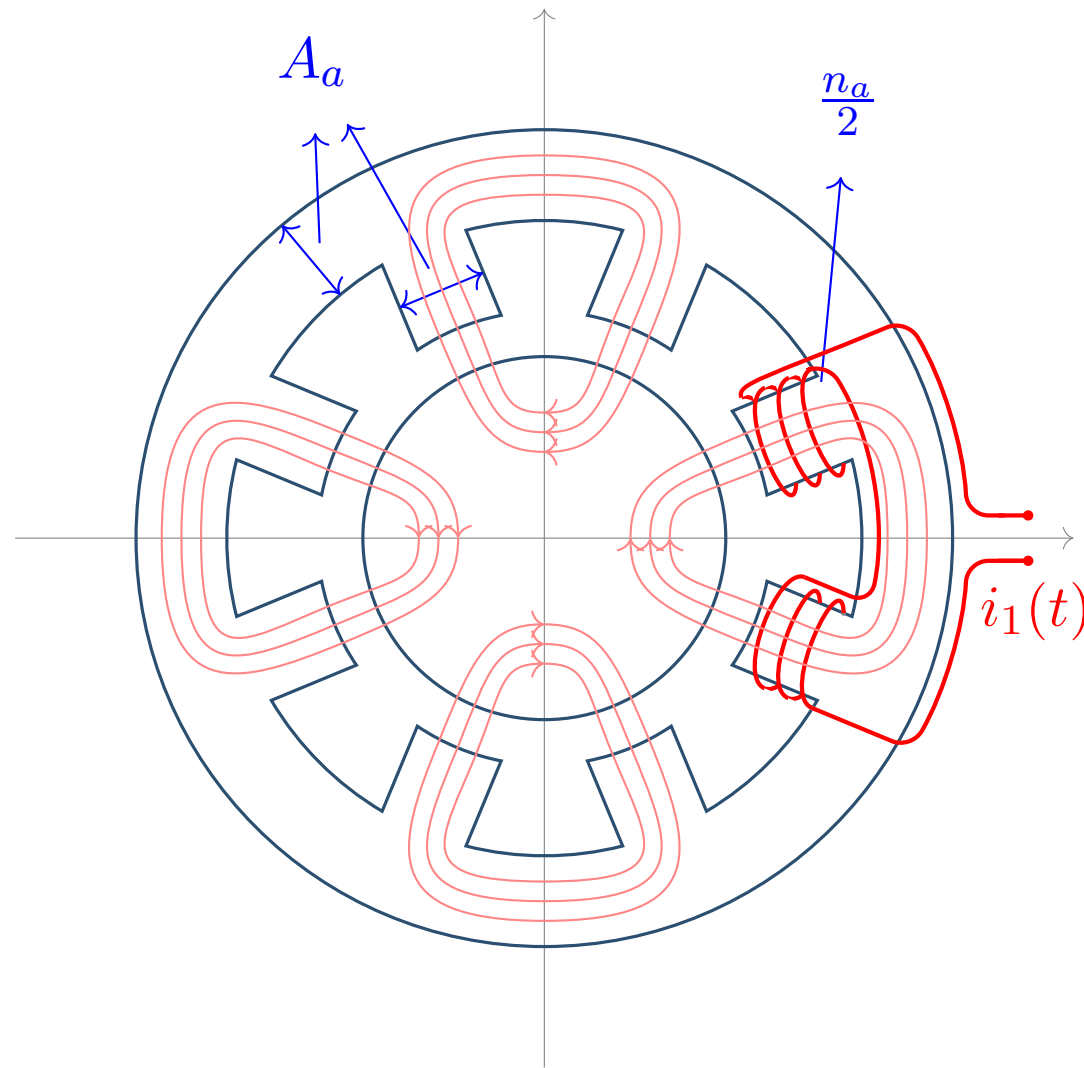
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base and differential currents

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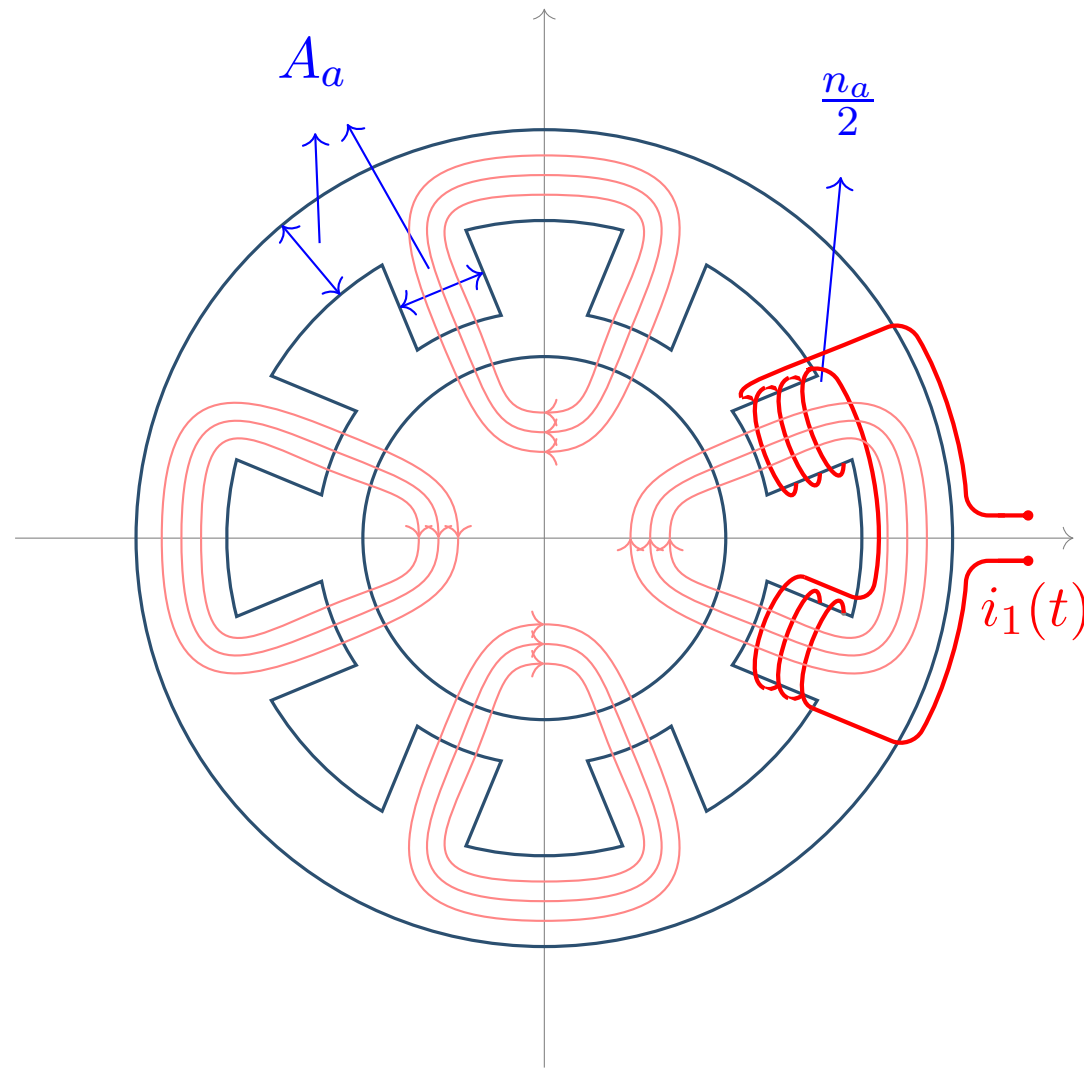
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for small rotor displacements



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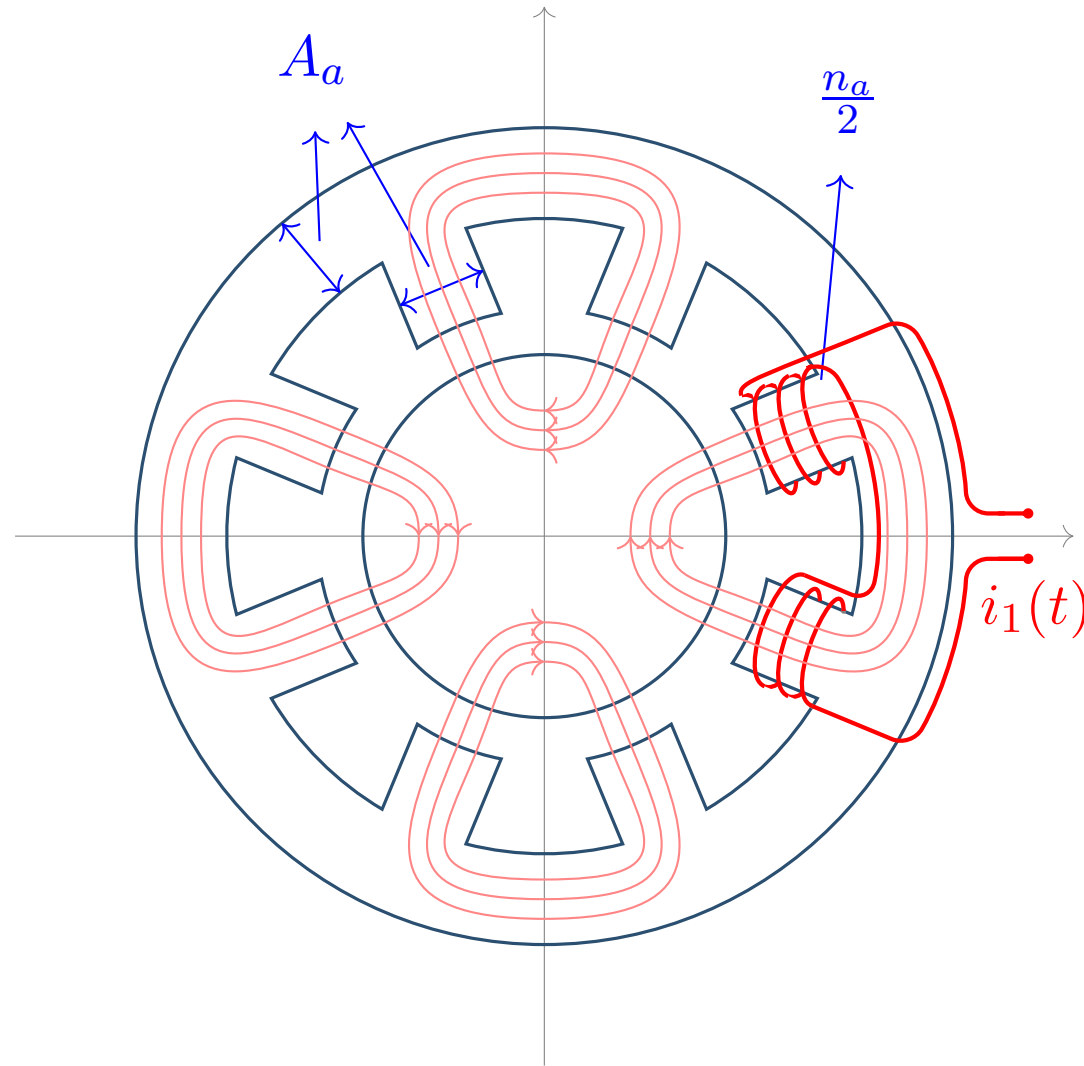
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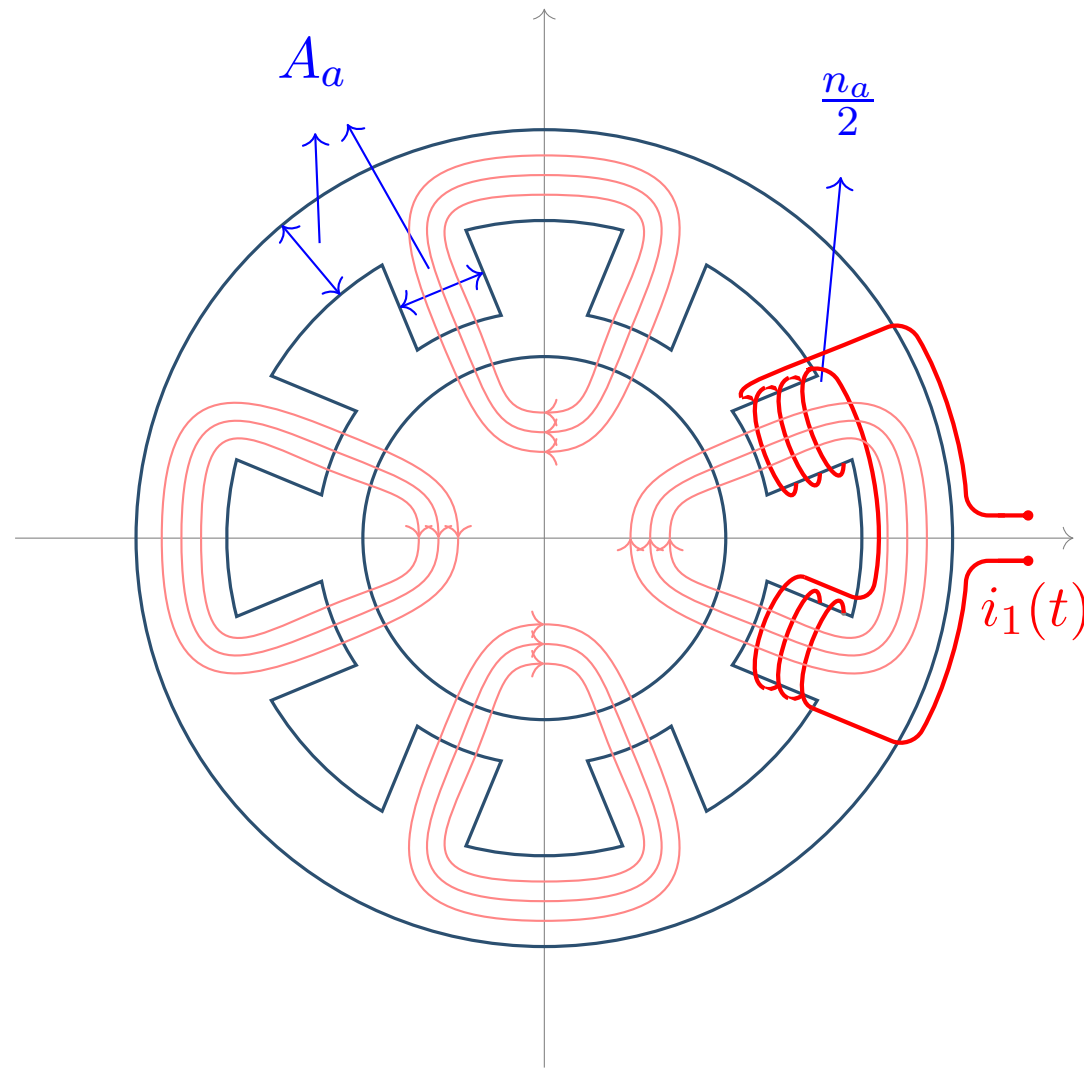
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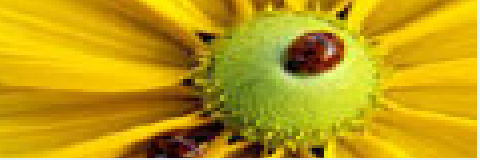
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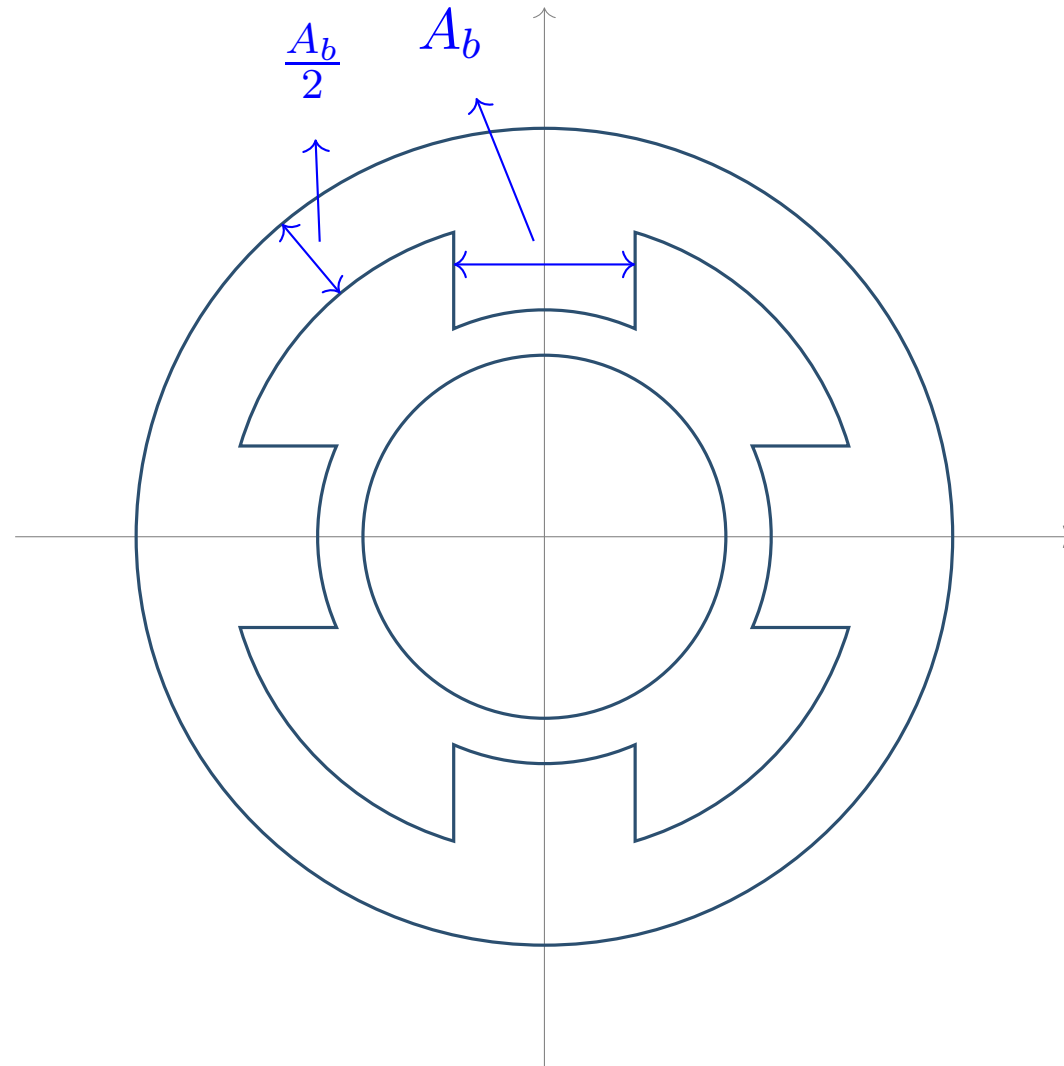
symm of 4

comparisons

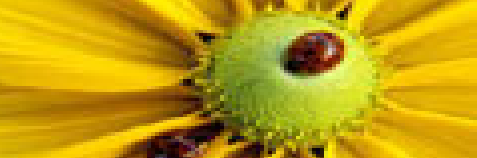
ideas

symm of 3

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not traditional AMB structure



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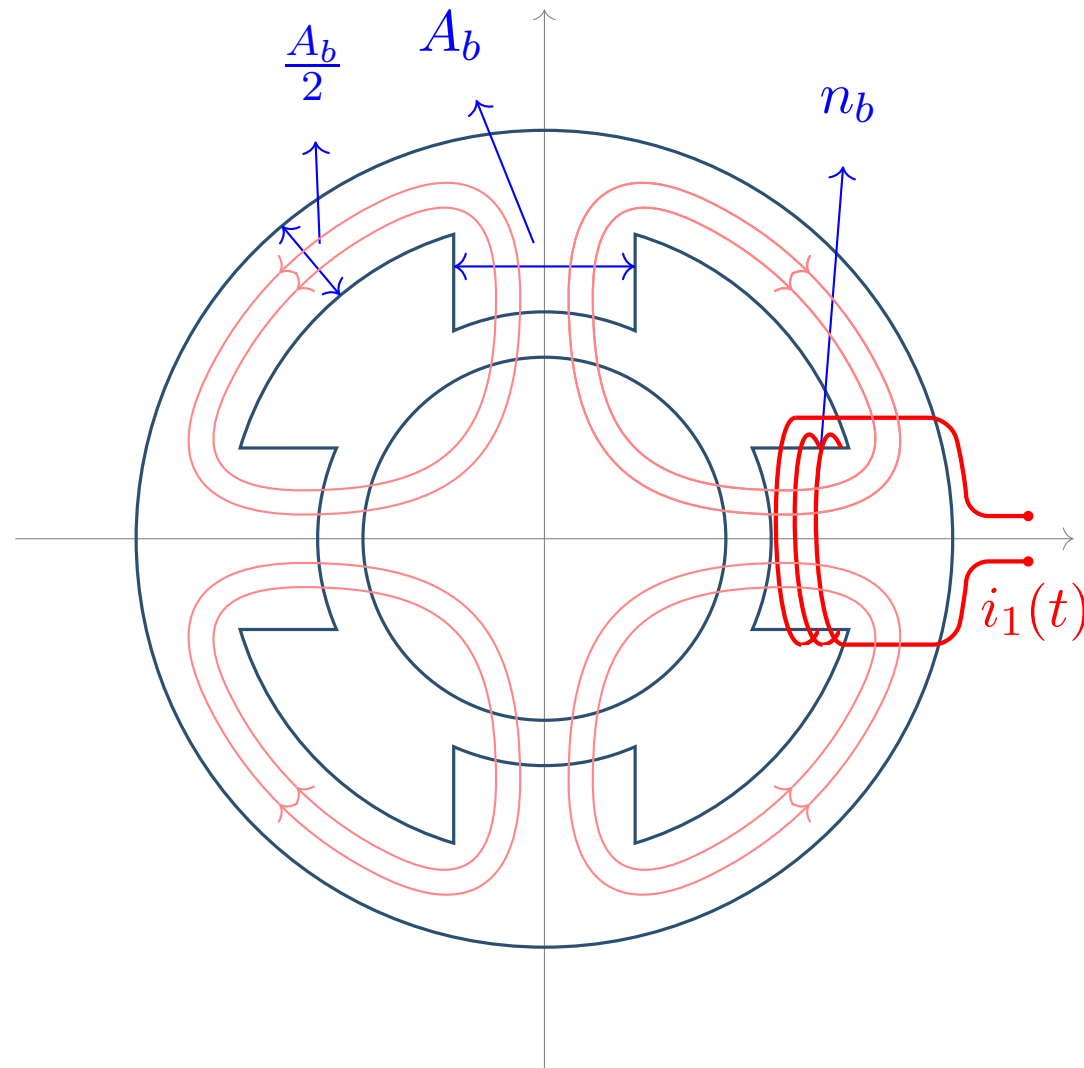
symm of 4

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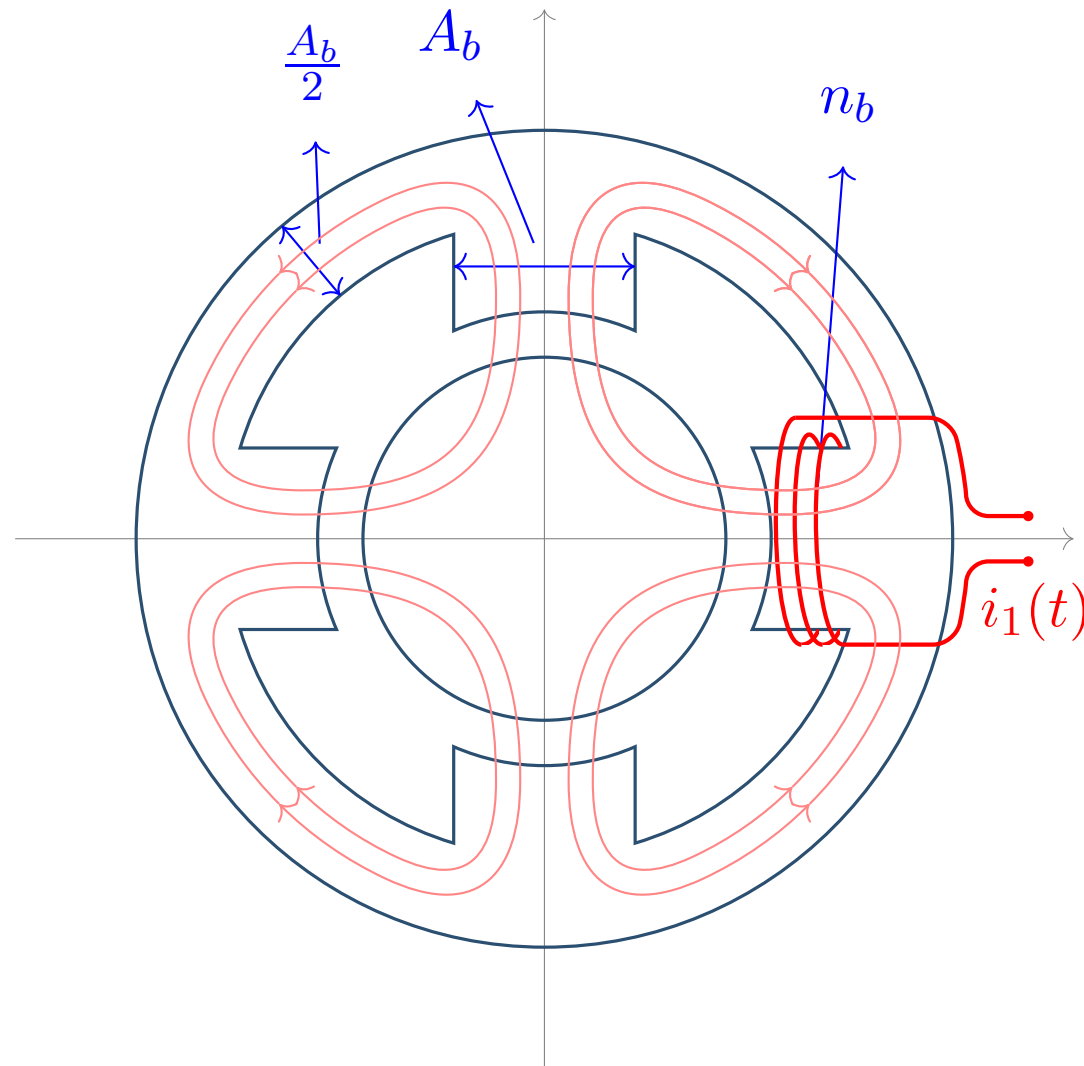
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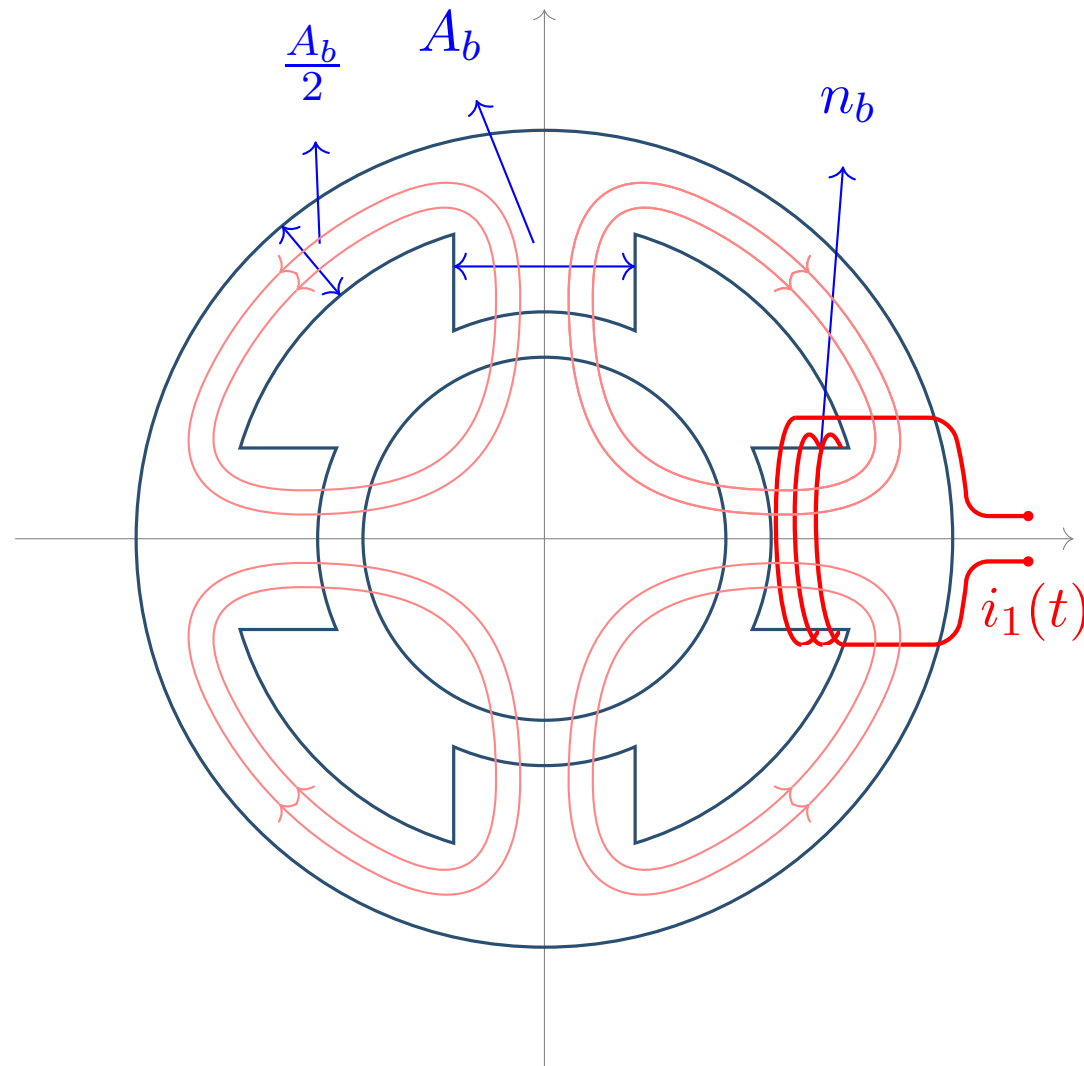
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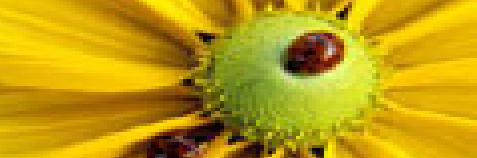
symm of 3

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not traditional AMB structure

can be called  
Type B



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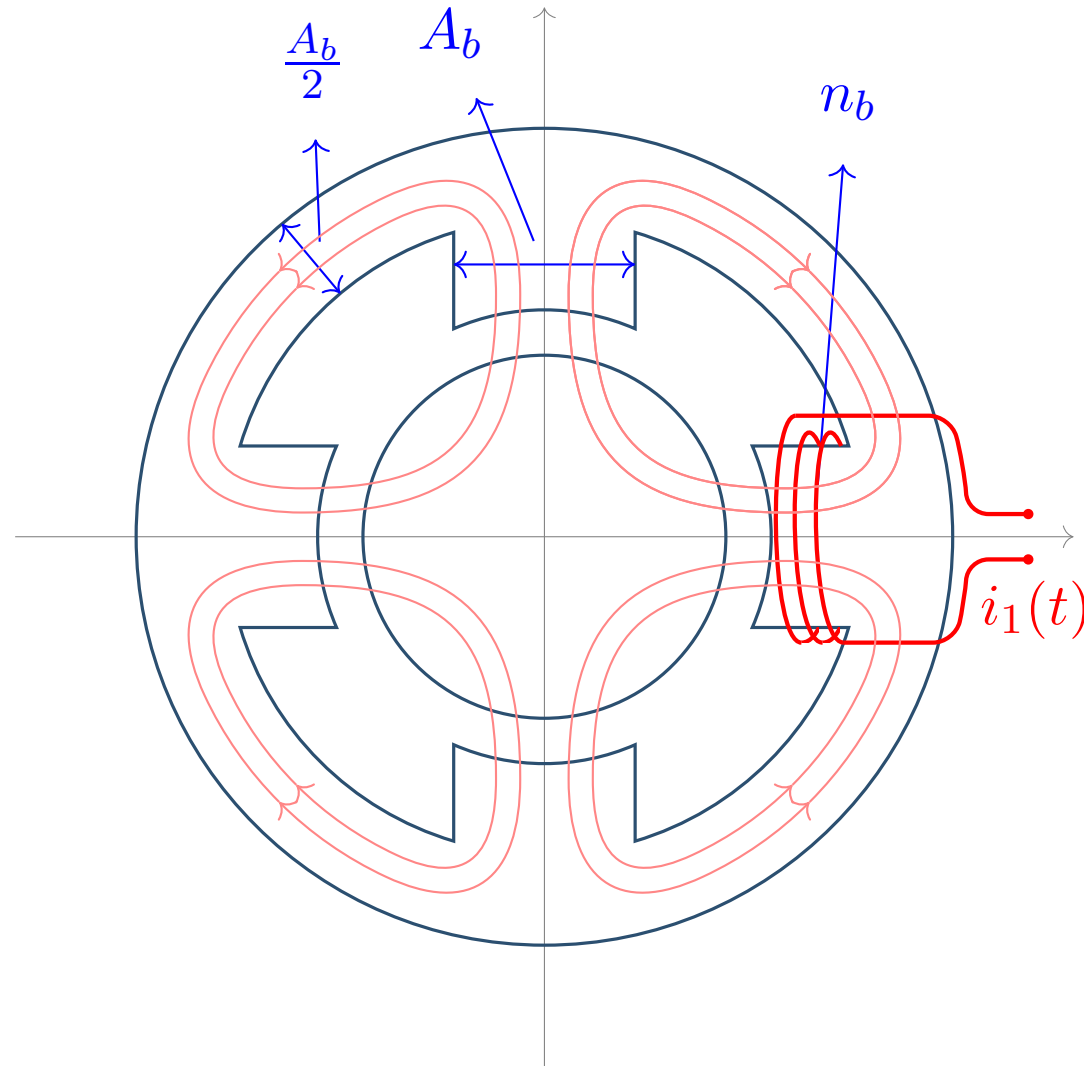
symm of 4

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not traditional AMB structure

can be called  
Type B  
"4 poles"





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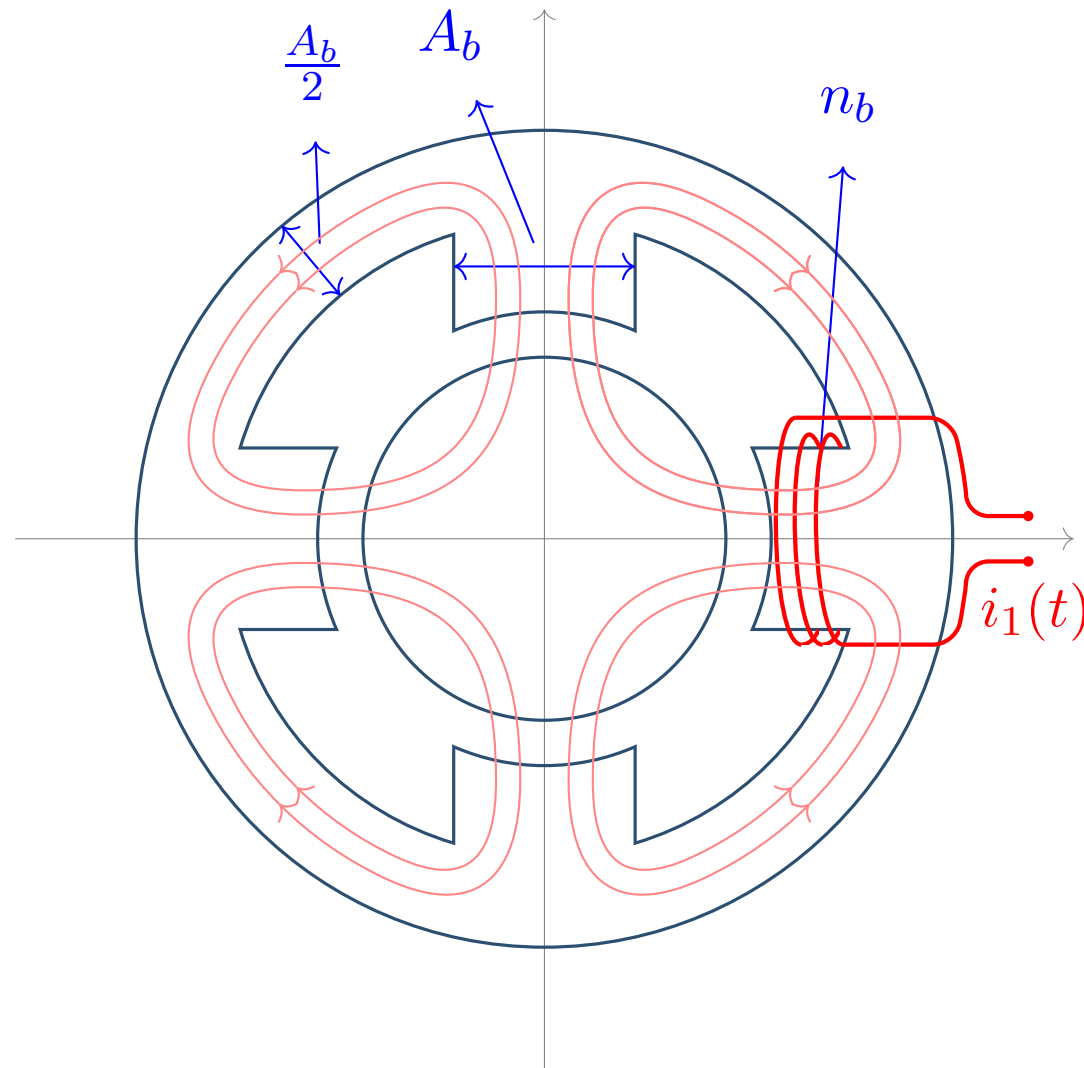
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not traditional AMB structure

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4 gaps



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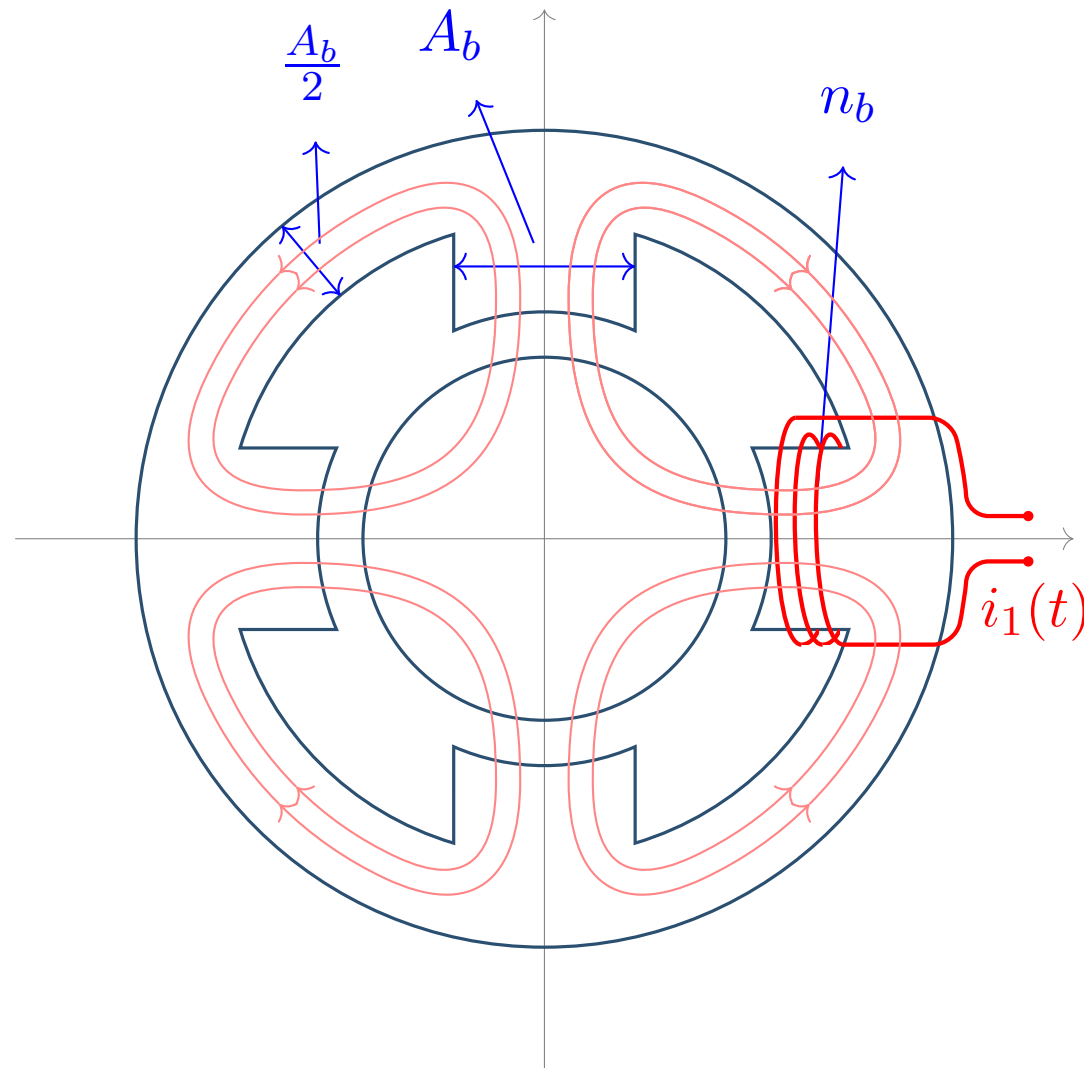
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not traditional AMB structure

can be called  
Type B  
4 gaps  
coupled fluxes



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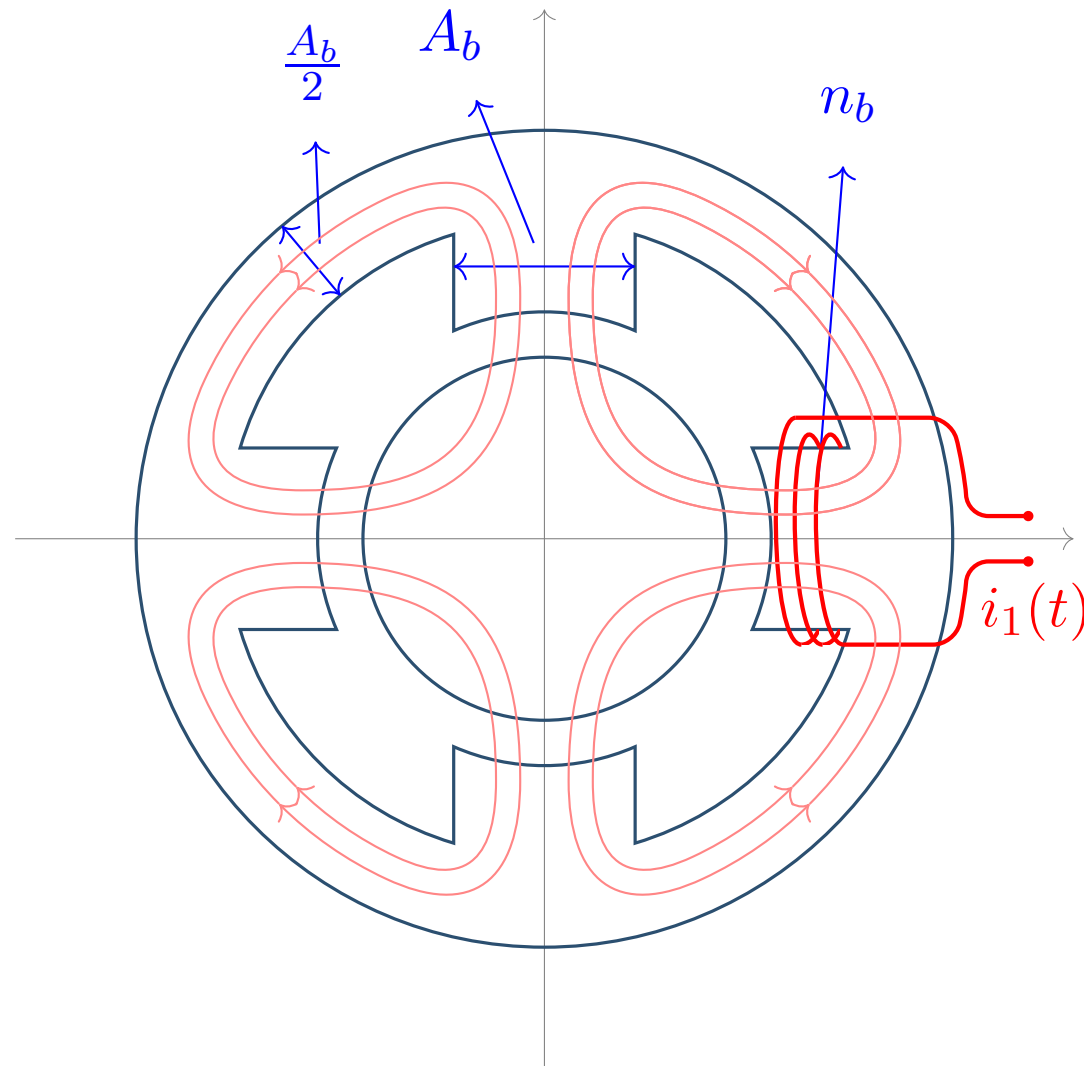
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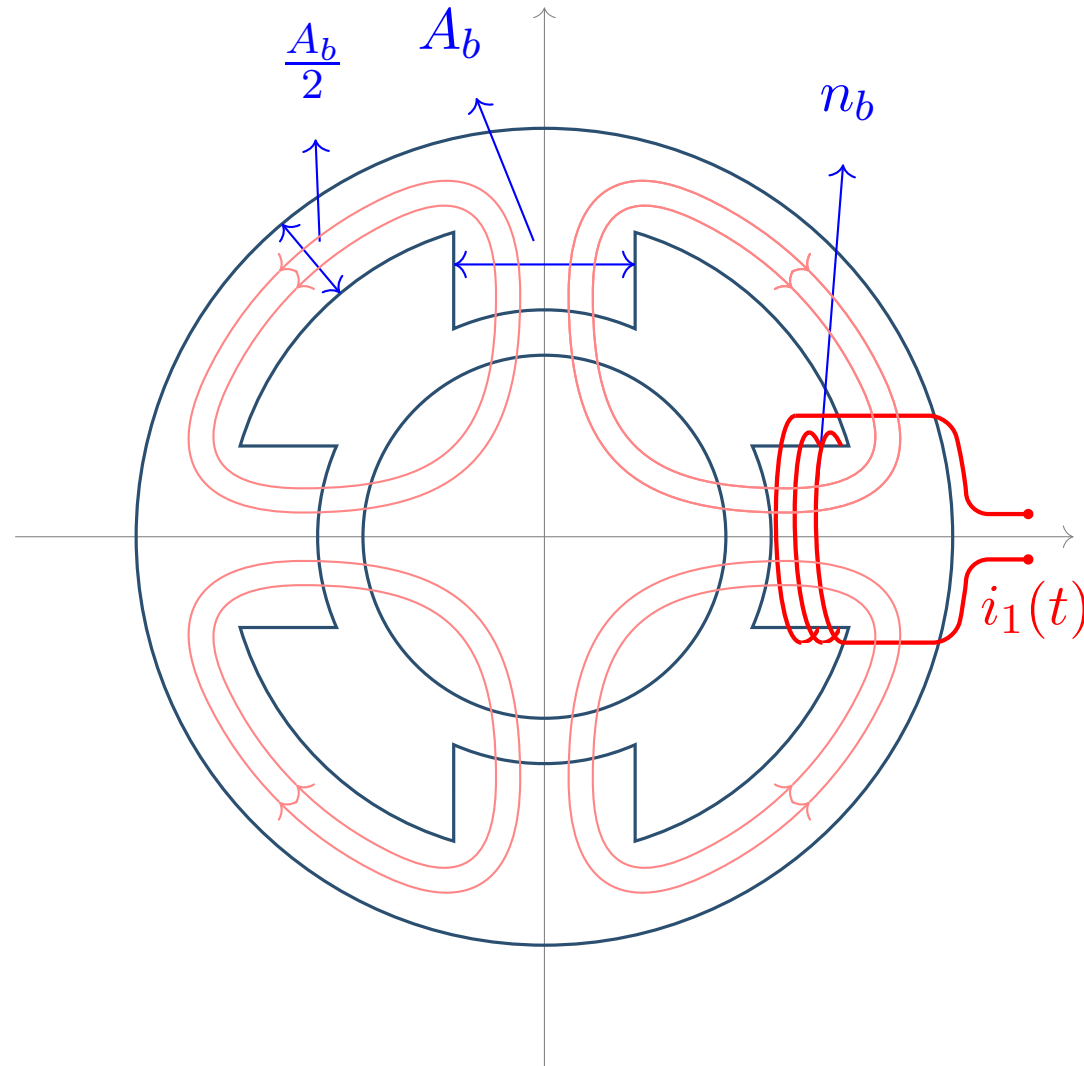
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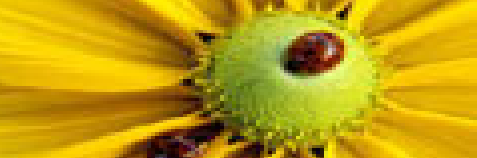
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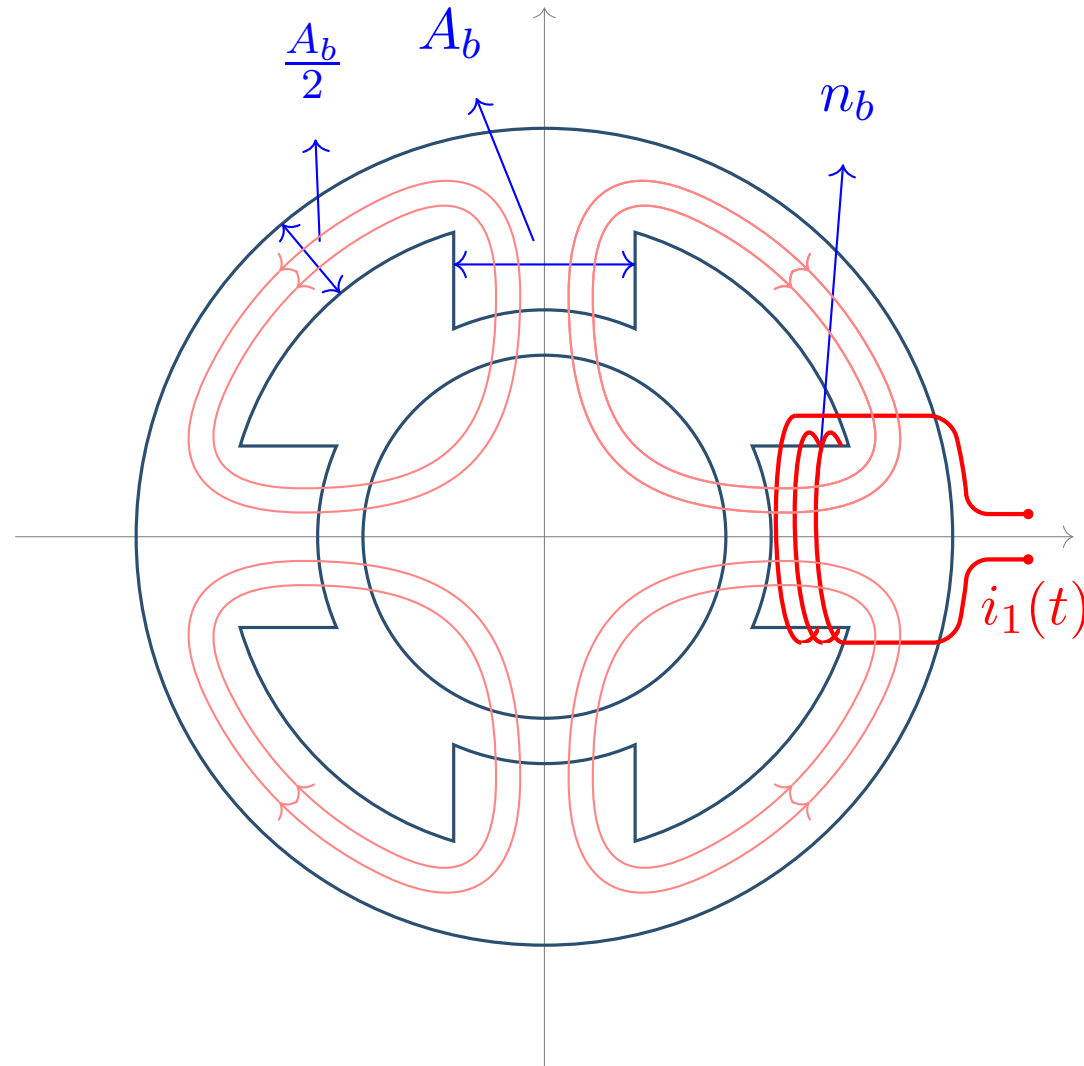
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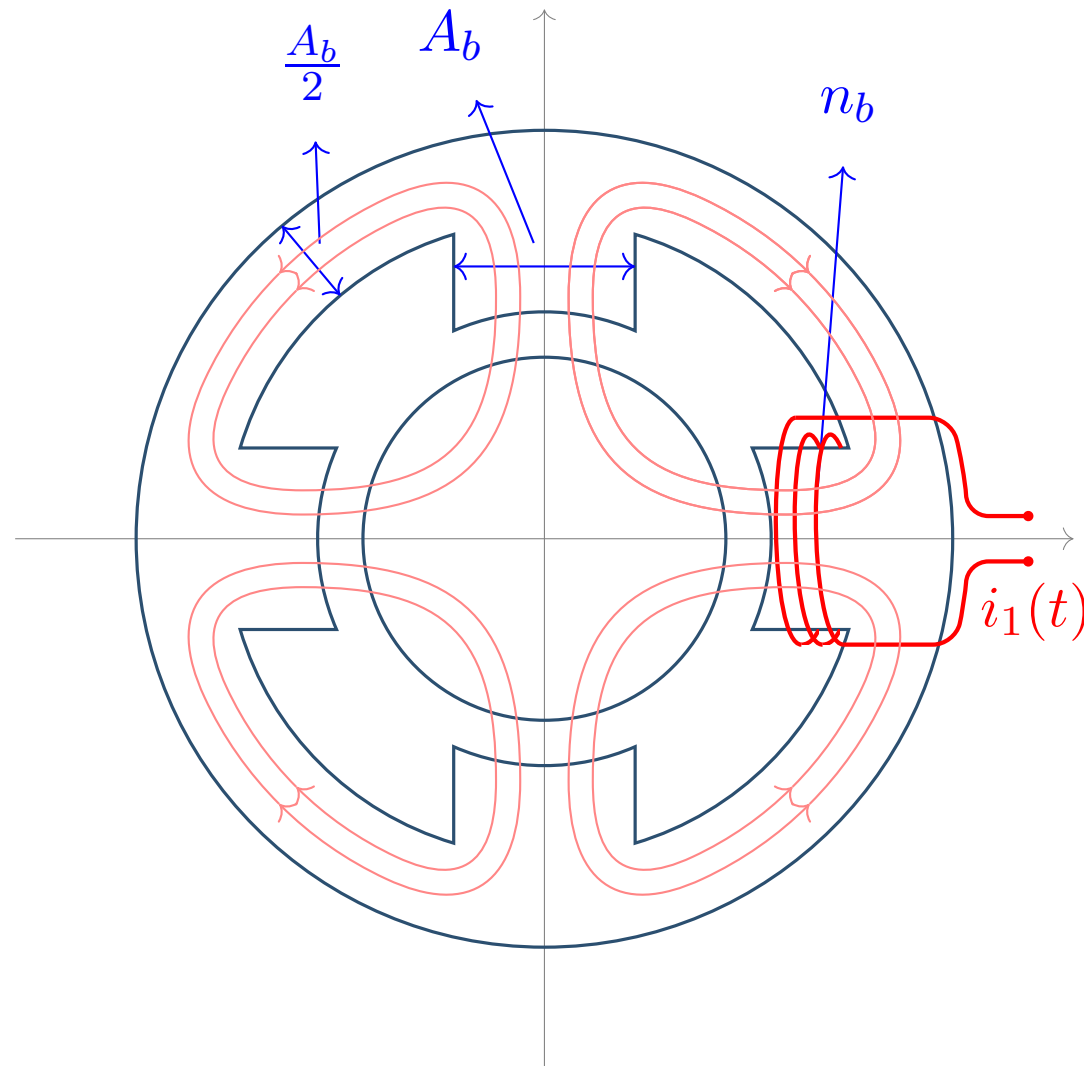
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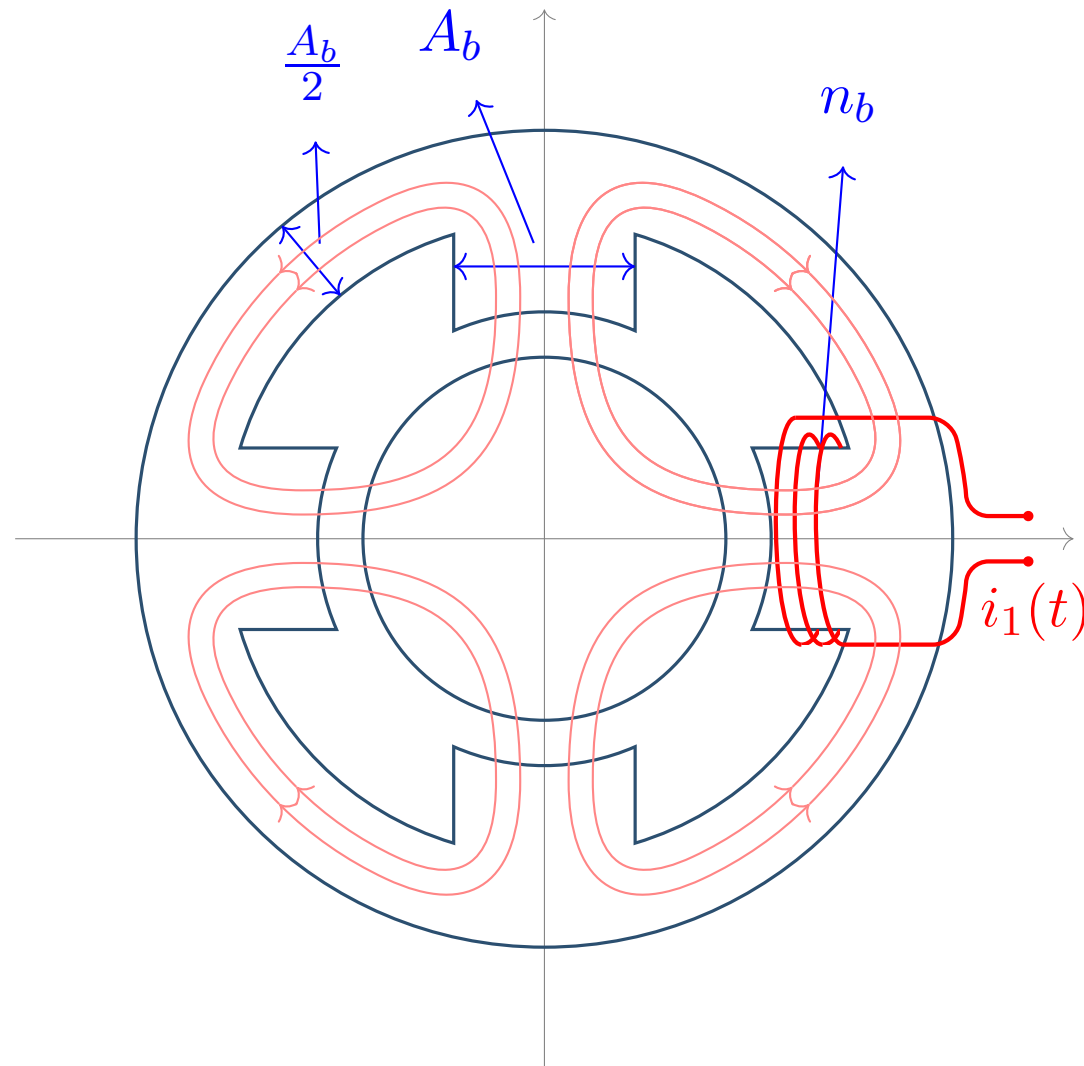
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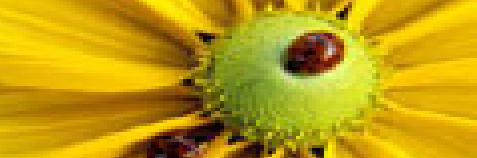
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for small rotor displacements



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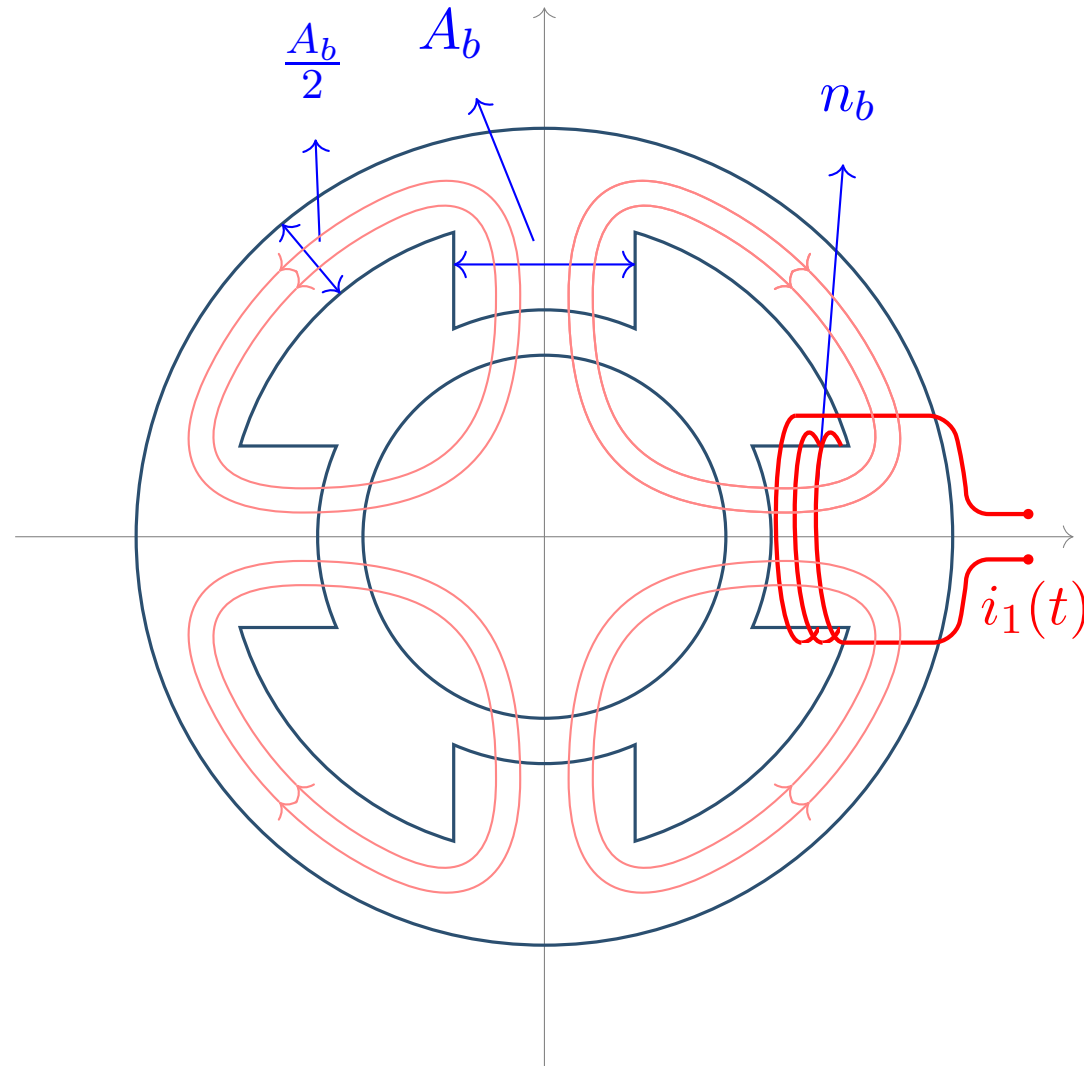
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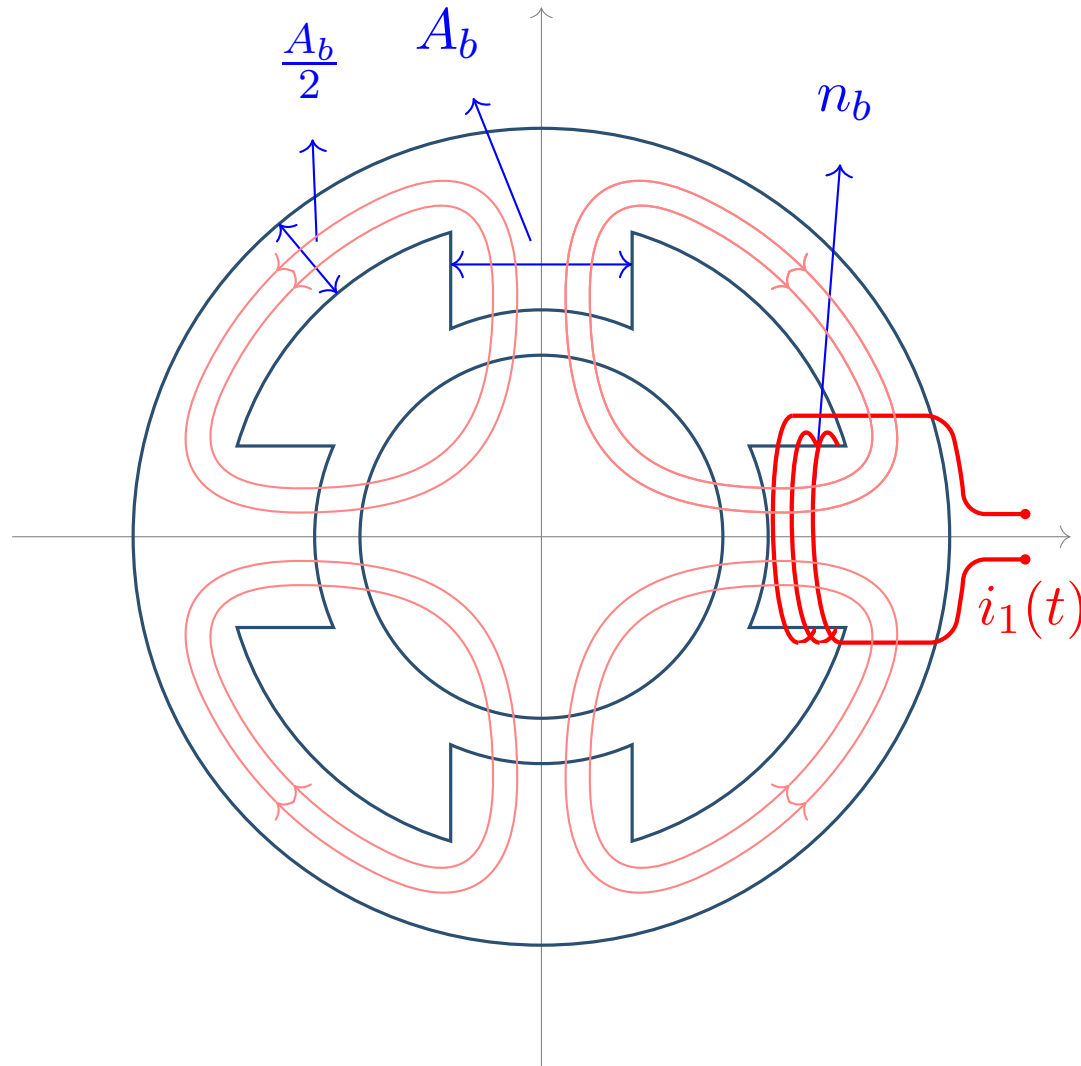
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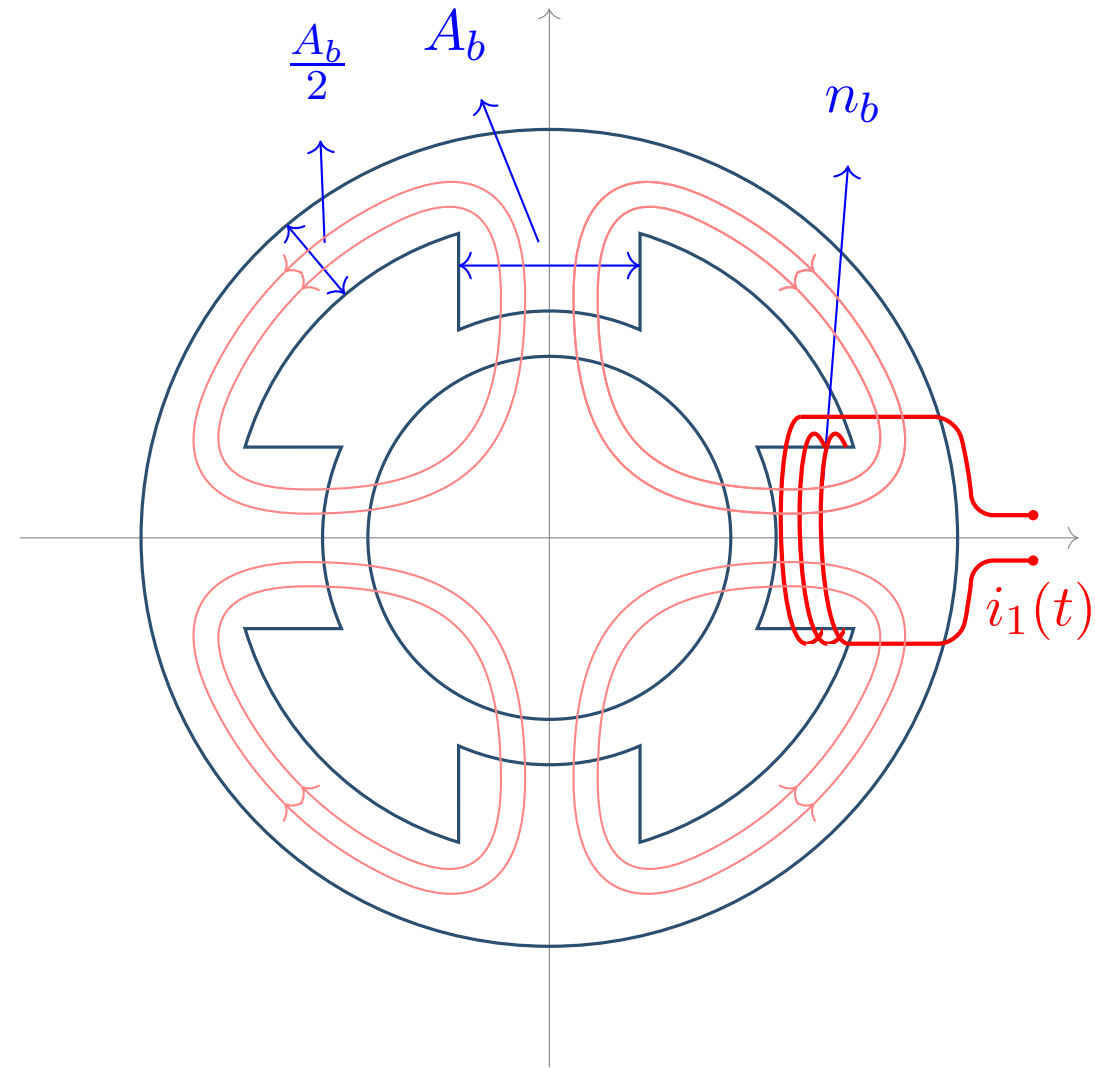
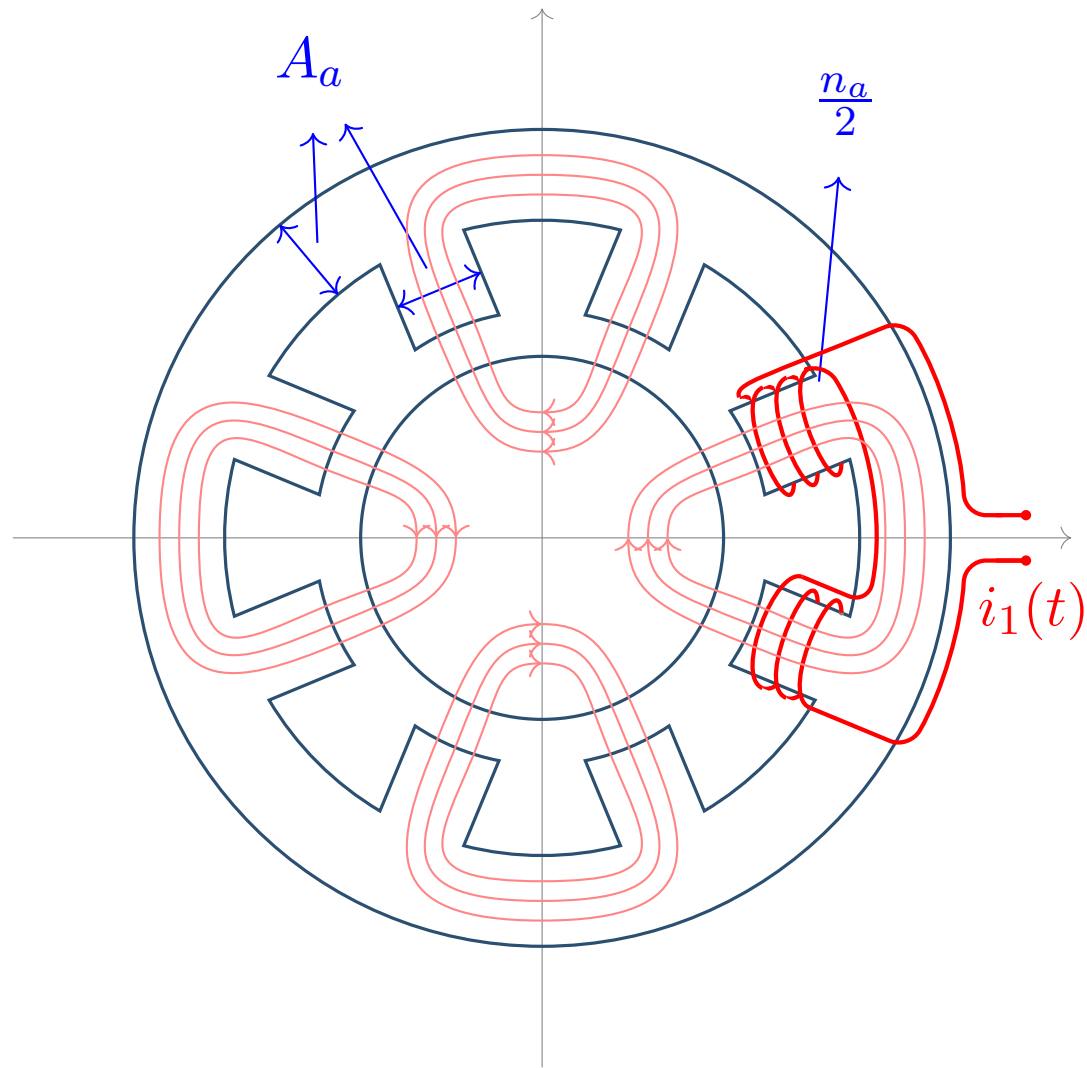
$$k_p^b = 2k_p^a$$

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# symmetry of 4 AMBs

- types of AMBs
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- symm of 4**
- comparisons
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- symm of 3





# symmetry of 4 AMBs: comparisons

types of AMBs

types of AMBs

symm of 4

comparisons

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for type B:



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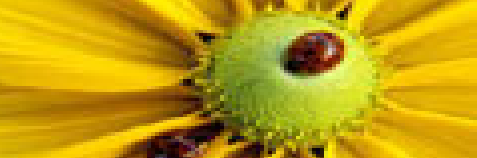
ideas

symm of 3

symm of 3

for type B:

$$\left. \begin{aligned} f_x &= k_p^b x + k_i^b i_x \\ f_y &= k_p^b y + k_i^b i_y \end{aligned} \right\} \text{where } \begin{cases} k_p^b = 2\mu_0 A_b n_b^2 I_0^2 / h^3 \\ k_i^b = 2\mu_0 A_b n_b^2 I_0 / h^2 \end{cases}$$



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- fluxes are **interconnected**, but forces are **decoupled**



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- fluxes are **interconnected**, but forces are **decoupled**
- $k_p^b$  and  $k_i^b$  ..... at least **two times bigger** than  $k_p^a$  and  $k_i^a$



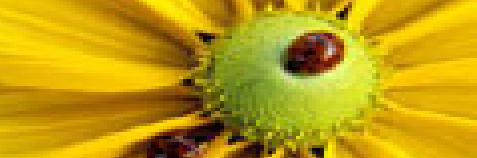
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- $A_b$  can be chosen greater than  $A_a$  .....  $n_b$  can, possibly, be larger than  $n_a$



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- $A_b$  can be chosen greater than  $A_a$  .....  $n_b$  can, possibly, be larger than  $n_a$

depending on  $A_b$  and  $n_b$ , even **higher rates**





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- fluxes are **interconnected**, but forces are **decoupled**
- $k_p^b$  and  $k_i^b$  ..... at least **two times bigger** than  $k_p^a$  and  $k_i^a$
- $A_b$  can be chosen greater than  $A_a$  .....  $n_b$  can, possibly, be larger than  $n_a$

depending on  $A_b$  and  $n_b$ , even **higher rates**

how much?



# symmetry of 4 AMBs: comparisons

- types of AMBs
- types of AMBs
- symm of 4
- comparisons**
- ideas
- symm of 3
- symm of 3

for type B:

$$\left. \begin{aligned} f_x &= k_p^b x + k_i^b i_x \\ f_y &= k_p^b y + k_i^b i_y \end{aligned} \right\} \text{where } \begin{cases} k_p^b = 2\mu_0 A_b n_b^2 I_0^2 / h^3 \\ k_i^b = 2\mu_0 A_b n_b^2 I_0 / h^2 \end{cases}$$

- fluxes are **interconnected**, but forces are **decoupled**
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depending on  $A_b$  and  $n_b$ , even **higher rates**

how much?

magnetic saturation seems to be the limit



## Type B seems...

types of AMBs

types of AMBs

symm of 4

comparisons

ideas

symm of 3

symm of 3

a very promising idea



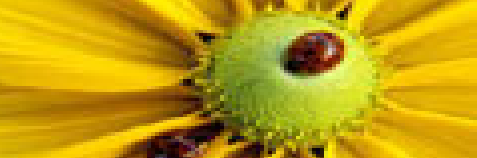
## Type B seems. . .

types of AMBs  
types of AMBs  
symm of 4  
comparisons

ideas

symm of 3  
symm of 3

a **very promising** idea  
stiffer suspension to rotors



## Type B seems. . .

types of AMBs

types of AMBs

symm of 4

comparisons

ideas

symm of 3

symm of 3

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stiffer suspension to rotors

cleaner, more compact design



## Type B seems. . .

types of AMBs

types of AMBs

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symm of 3

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types of AMBs

types of AMBs

symm of 4

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symm of 3

symm of 3

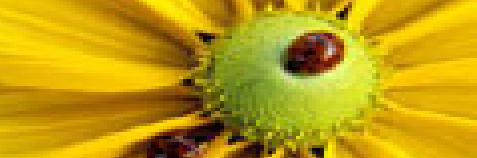
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stiffer suspension to rotors

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easier to manufacture

smaller flux losses



## Type B seems. . .

types of AMBs

types of AMBs

symm of 4

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symm of 3

symm of 3

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## Type B seems. . .

types of AMBs  
types of AMBs  
symm of 4  
comparisons

ideas

symm of 3  
symm of 3

a **very promising** idea  
stiffer suspension to rotors  
cleaner, more compact design  
easier to manufacture  
smaller flux losses

why?

less gaps?



## Type B seems. . .

types of AMBs  
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symm of 3

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**why?**

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connected fluxes?



## Type B seems. . .

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but **real answers** come only from . . .



## Type B seems...

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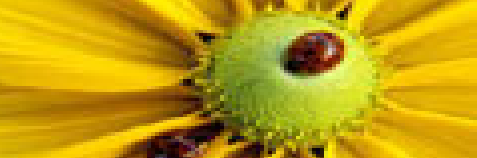
**why?**

less gaps?

connected fluxes?

but **real answers** come only from ...

**building**



## Type B seems...

types of AMBs  
types of AMBs  
symm of 4  
comparisons

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symm of 3  
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stiffer suspension to rotors  
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types of AMBs  
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connected fluxes?

but **real answers** come only from ...

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and

**testing**



## Type B seems...

types of AMBs  
types of AMBs  
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symm of 3  
symm of 3

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stiffer suspension to rotors

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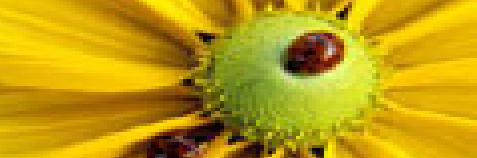
but **real answers** come only from ...

**building**

and

**testing**

prototypes



## Type B seems...

types of AMBs  
types of AMBs  
symm of 4  
comparisons

ideas

symm of 3  
symm of 3

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stiffer suspension to rotors

cleaner, more compact design

easier to manufacture

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prototypes

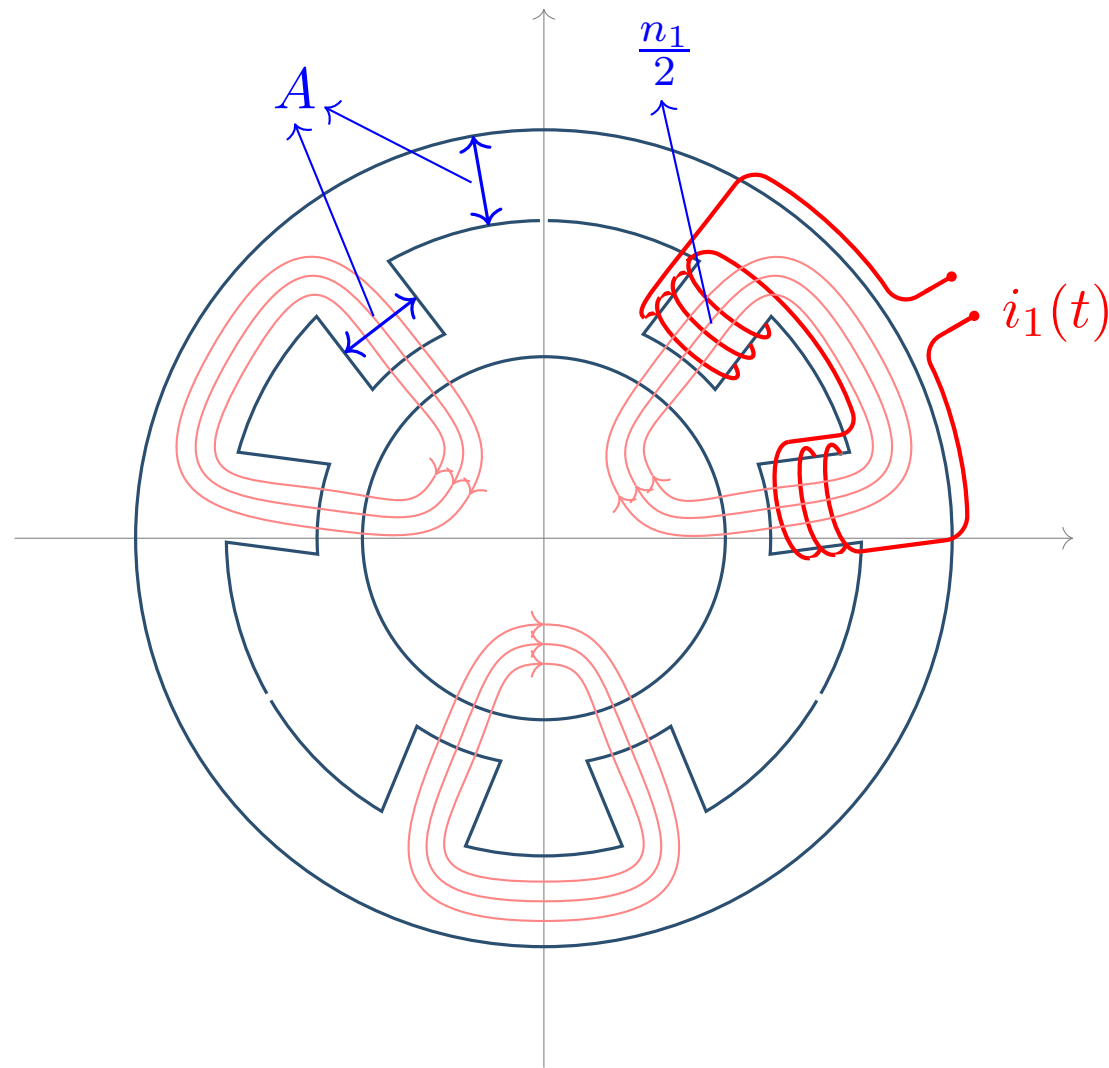
before this is complete...





# symmetry of 3 AMBs

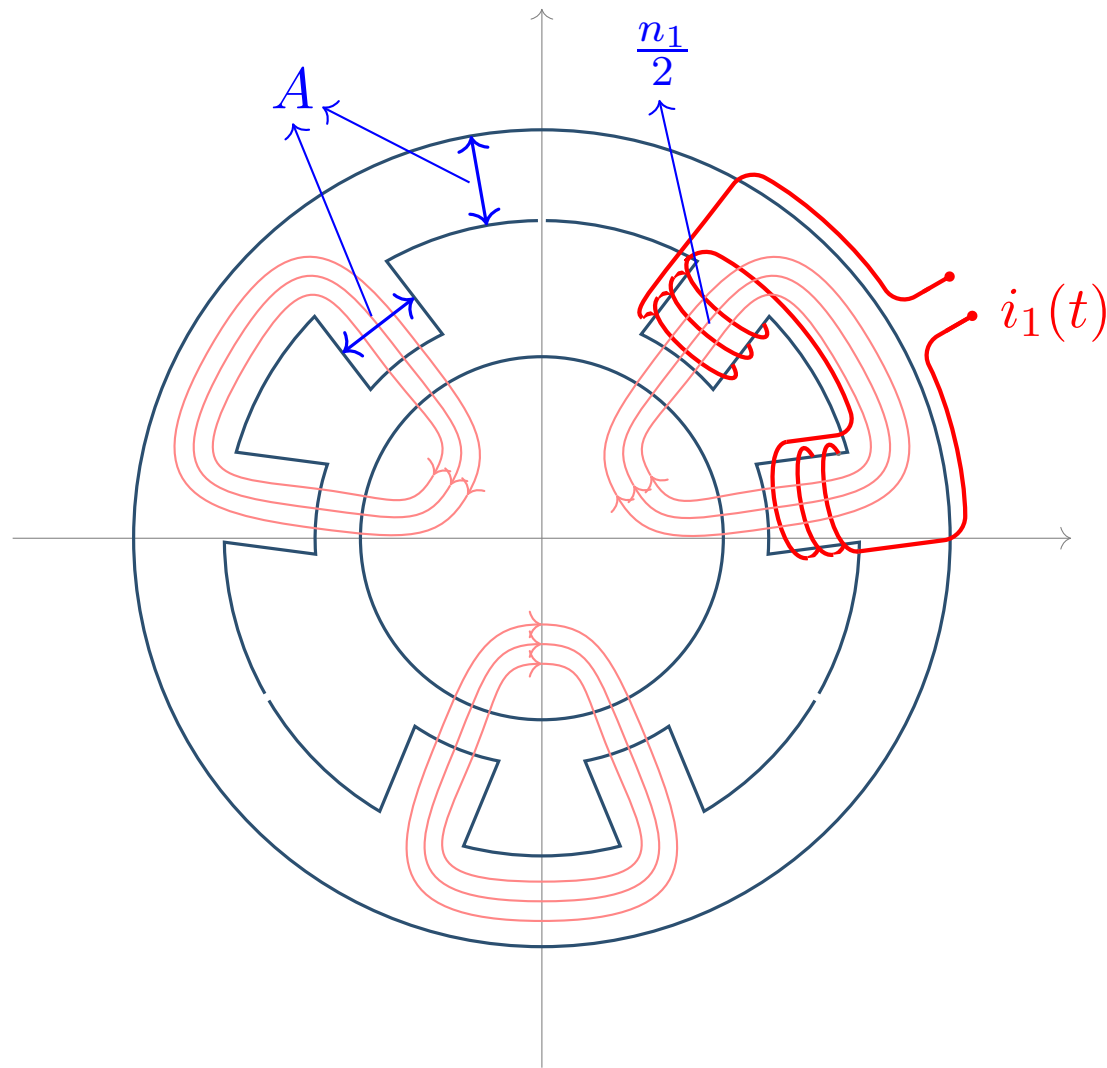
- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3**
- symm of 3





# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
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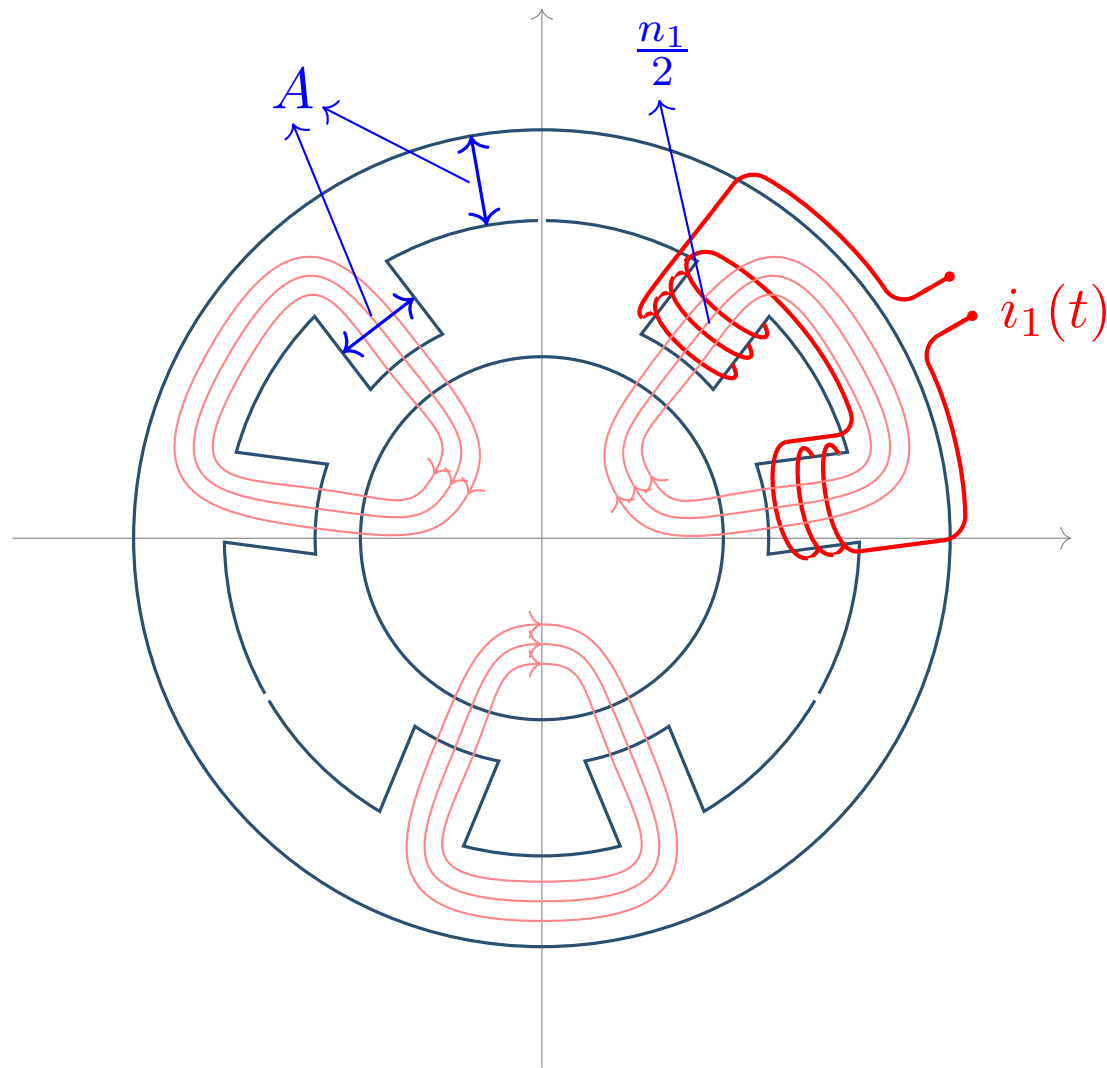


not traditional AMB structure



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
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- symm of 3

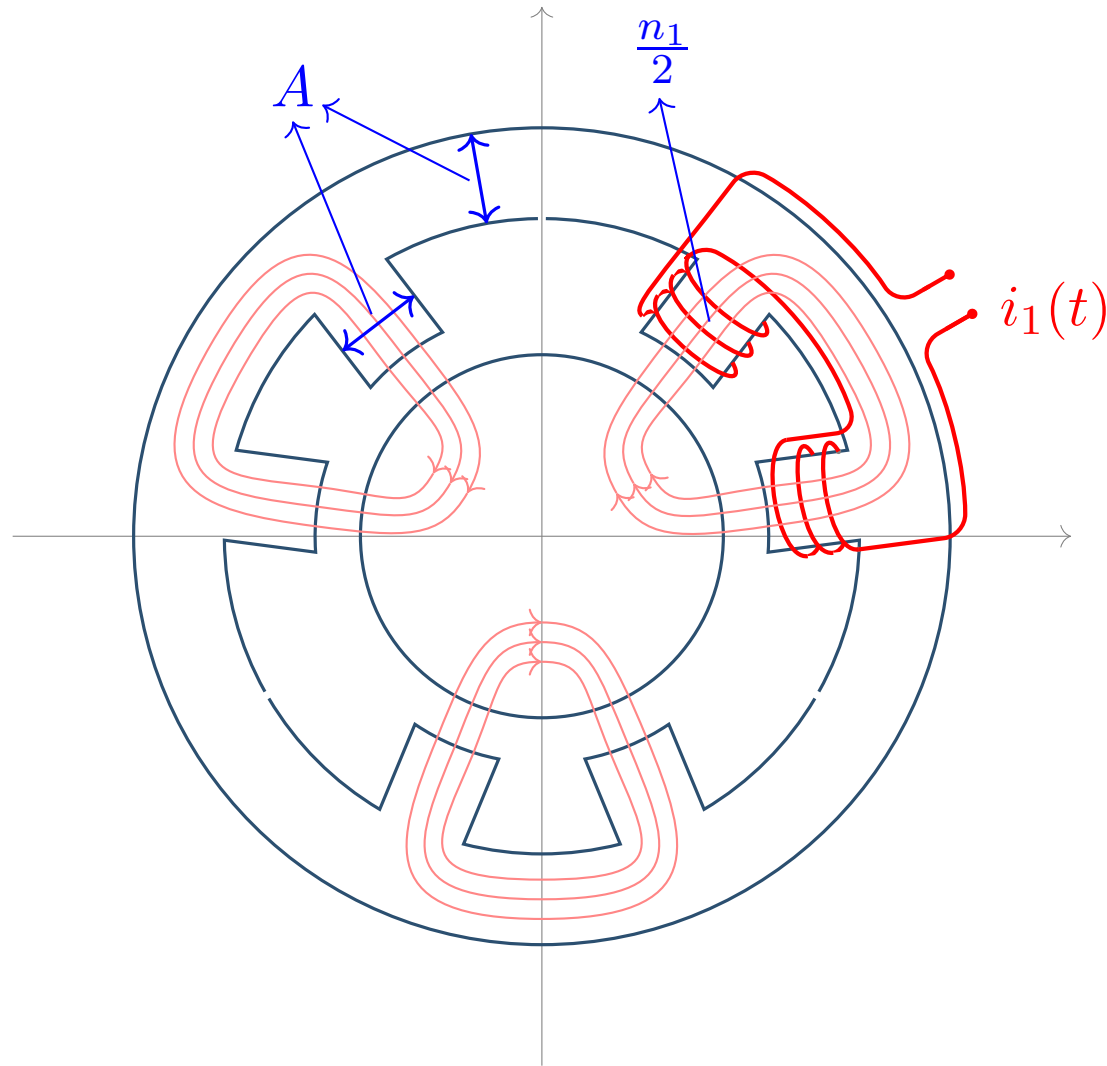


not traditional AMB structure  
can be called



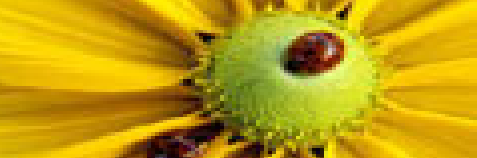
# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3**
- symm of 3



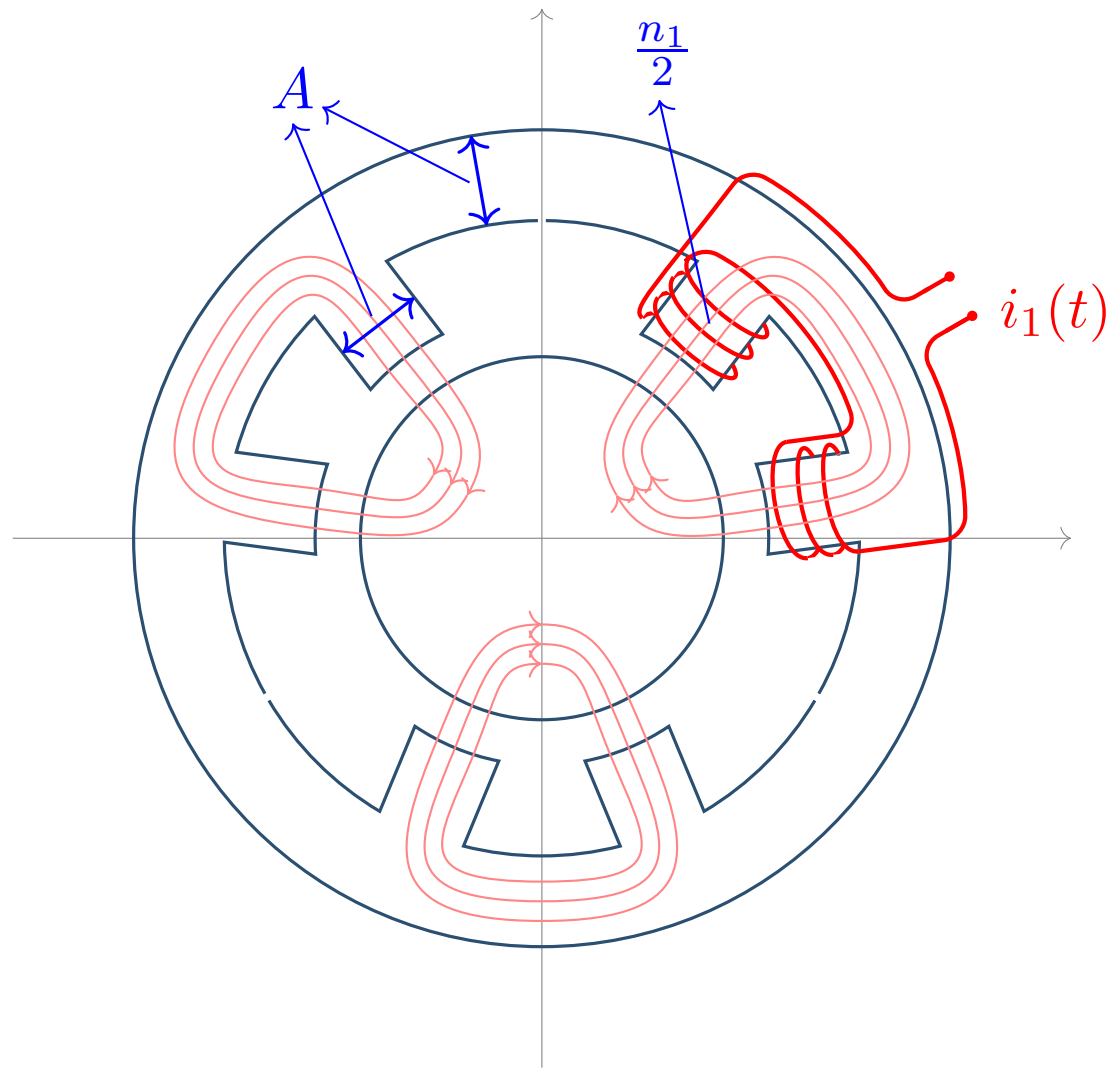
not traditional AMB structure

can be called  
Type A



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3**
- symm of 3



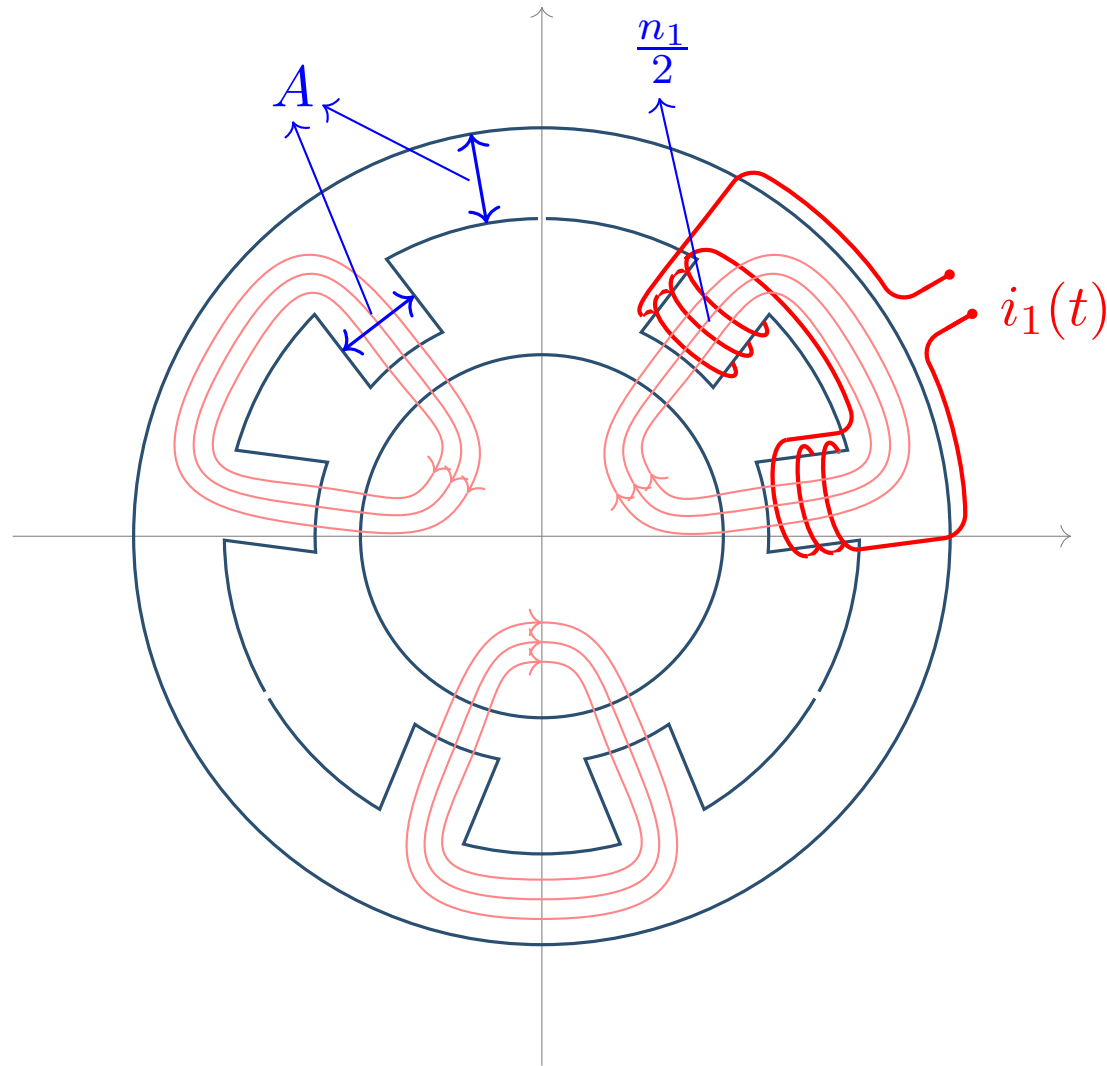
not traditional AMB structure

can be called  
Type A  
"6 poles"



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3**
- symm of 3



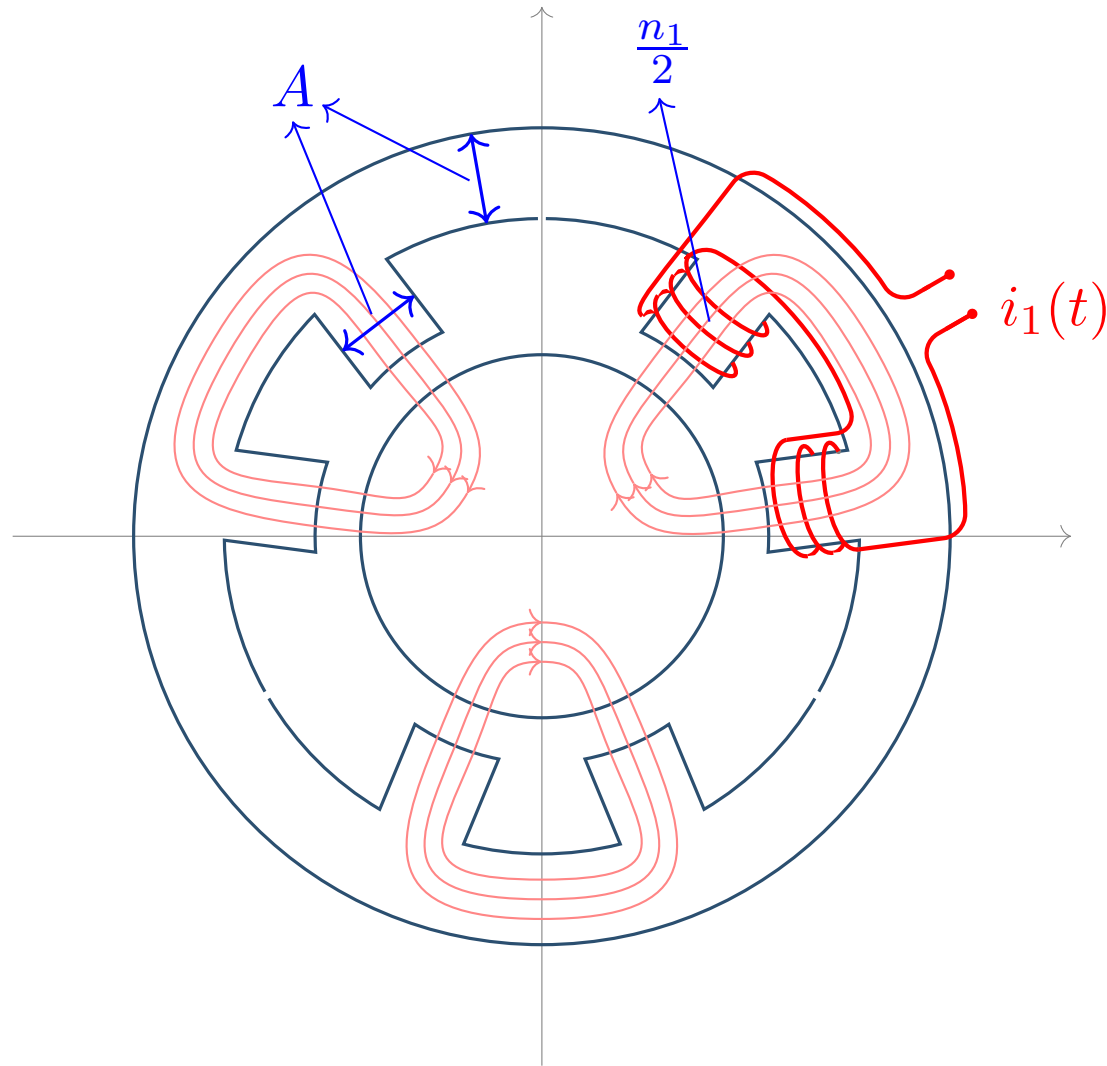
not traditional AMB structure

can be called  
Type A  
6 gaps



# symmetry of 3 AMBs

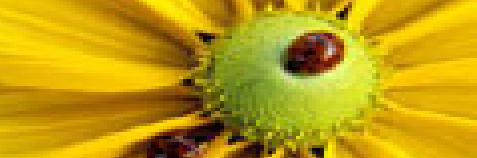
- types of AMBs
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not traditional AMB structure

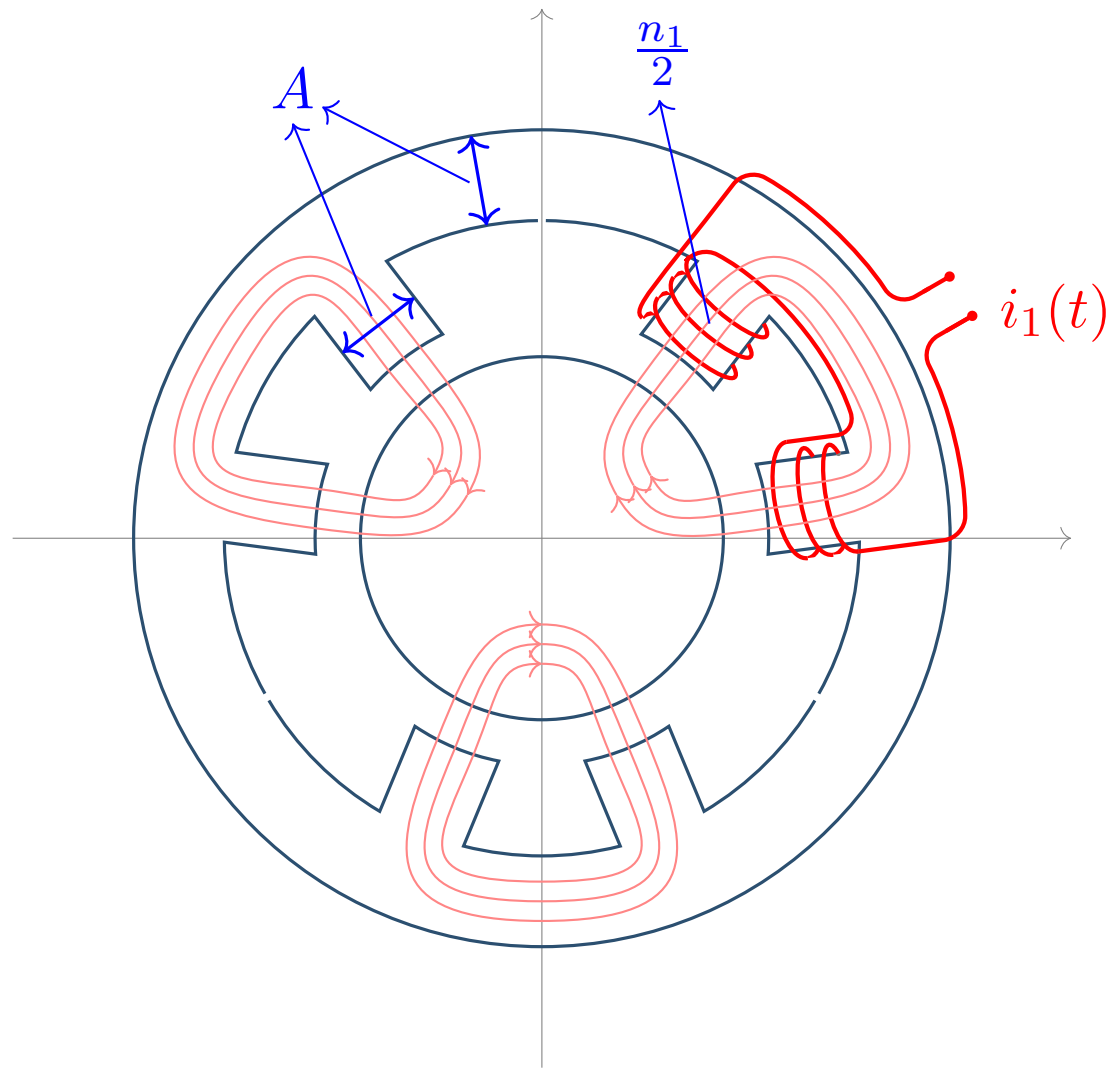
can be called  
Type A

6 gaps  
uncoupled fluxes



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3**
- symm of 3



not traditional AMB structure

can be called  
Type A

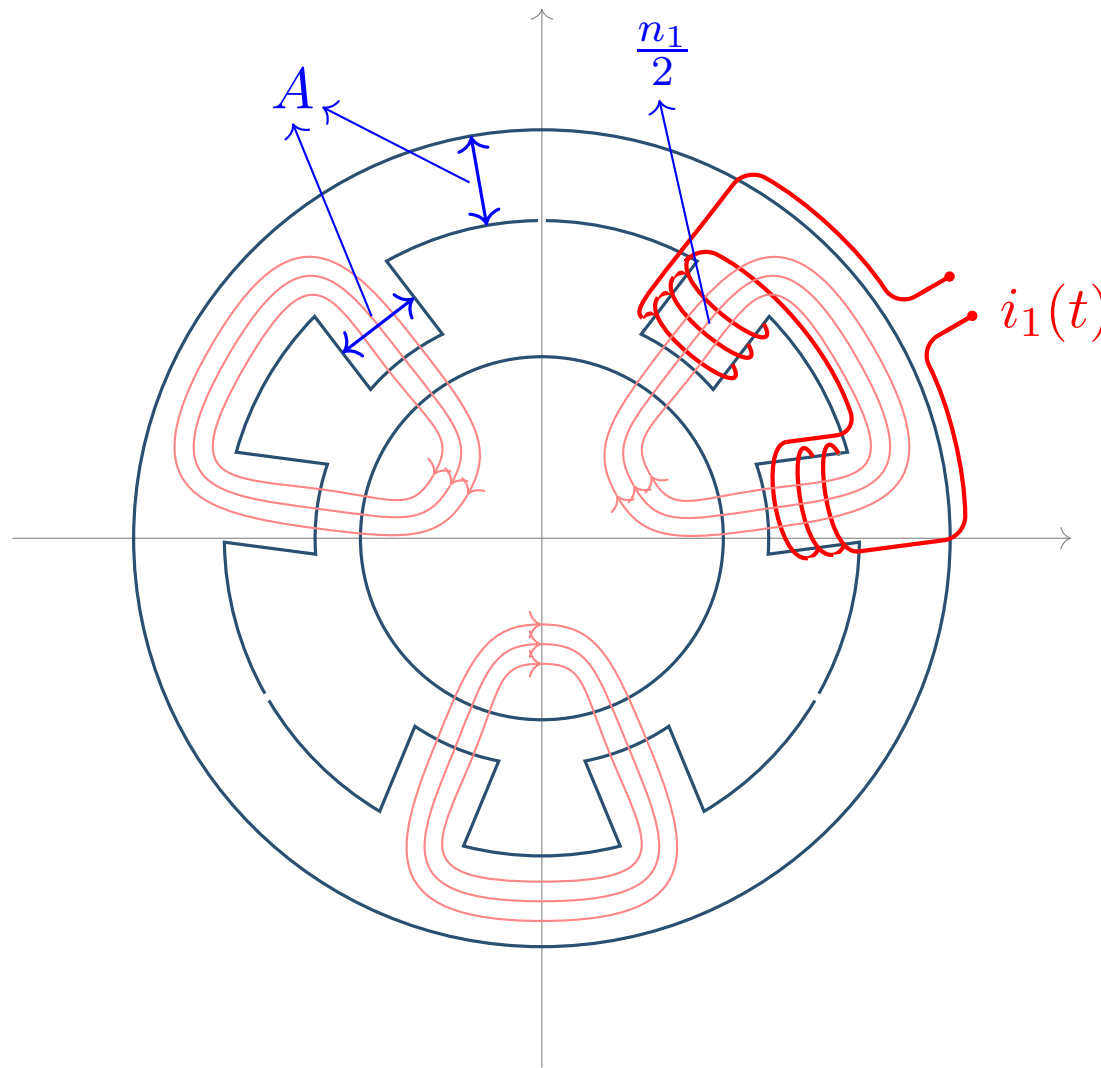
6 gaps  
uncoupled fluxes  
3 injected currents





# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3**
- symm of 3



not traditional AMB structure

can be called  
Type A

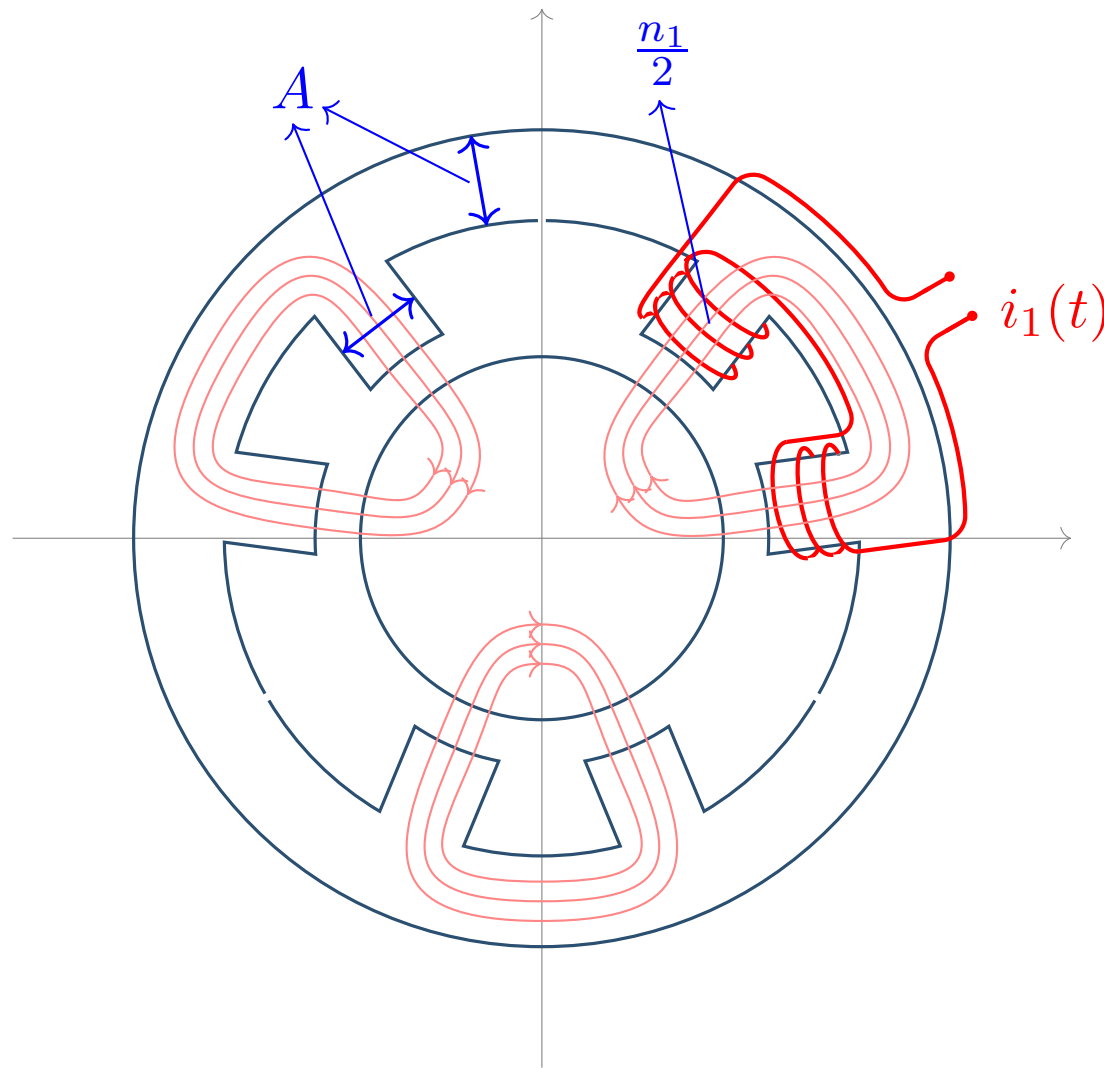
6 gaps  
uncoupled fluxes

$$i_1 = i_0 + i_x + i_y \quad i_2 = i_0 - i_x + i_y$$



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
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- ideas
- symm of 3**
- symm of 3



not traditional AMB structure

can be called  
Type A

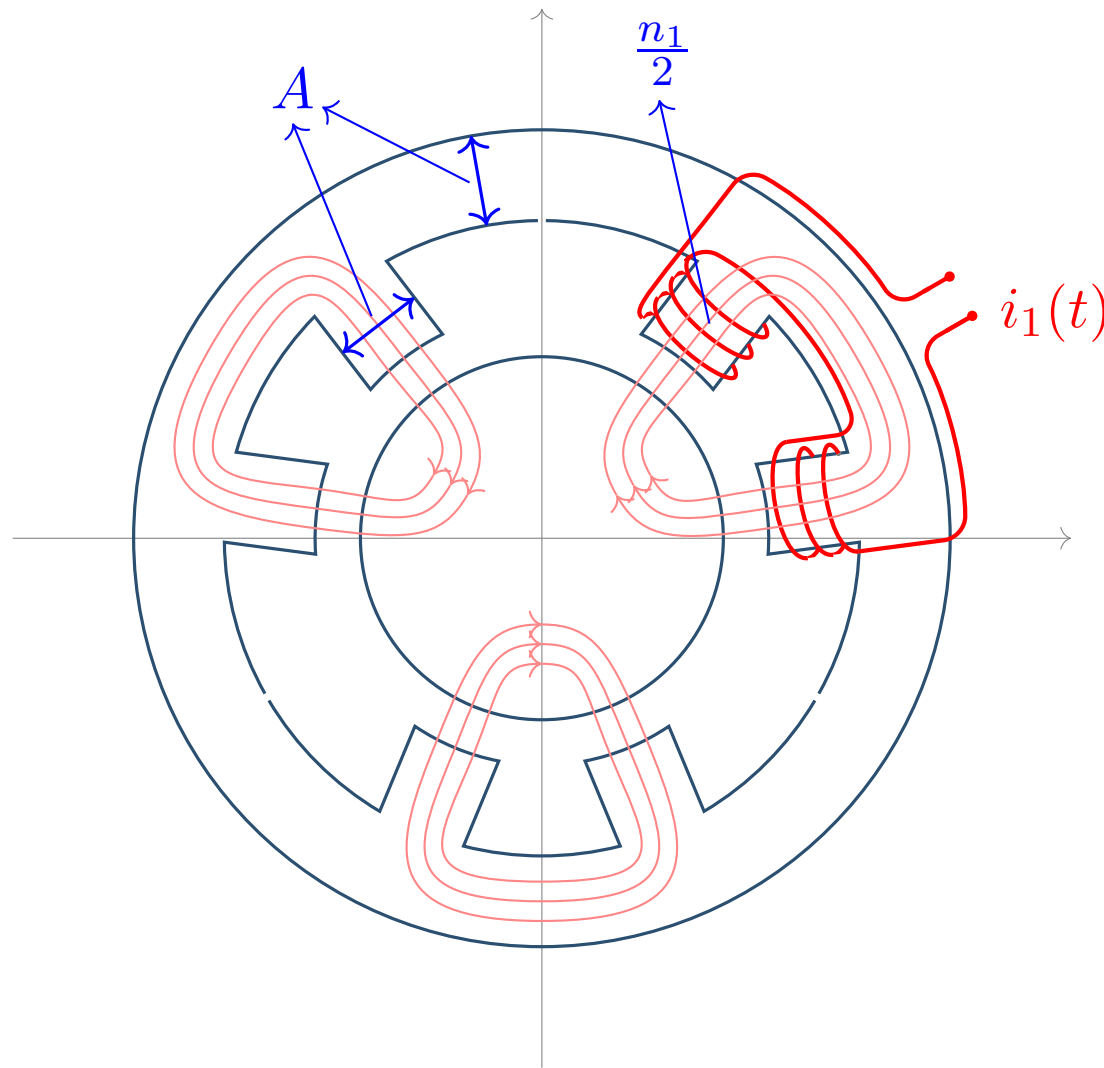
6 gaps  
uncoupled fluxes

$$i_1 = i_0 + i_x + i_y \quad i_2 = i_0 - i_x + i_y$$
$$i_3 = i_0 - i_y$$



# symmetry of 3 AMBs

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uncoupled fluxes

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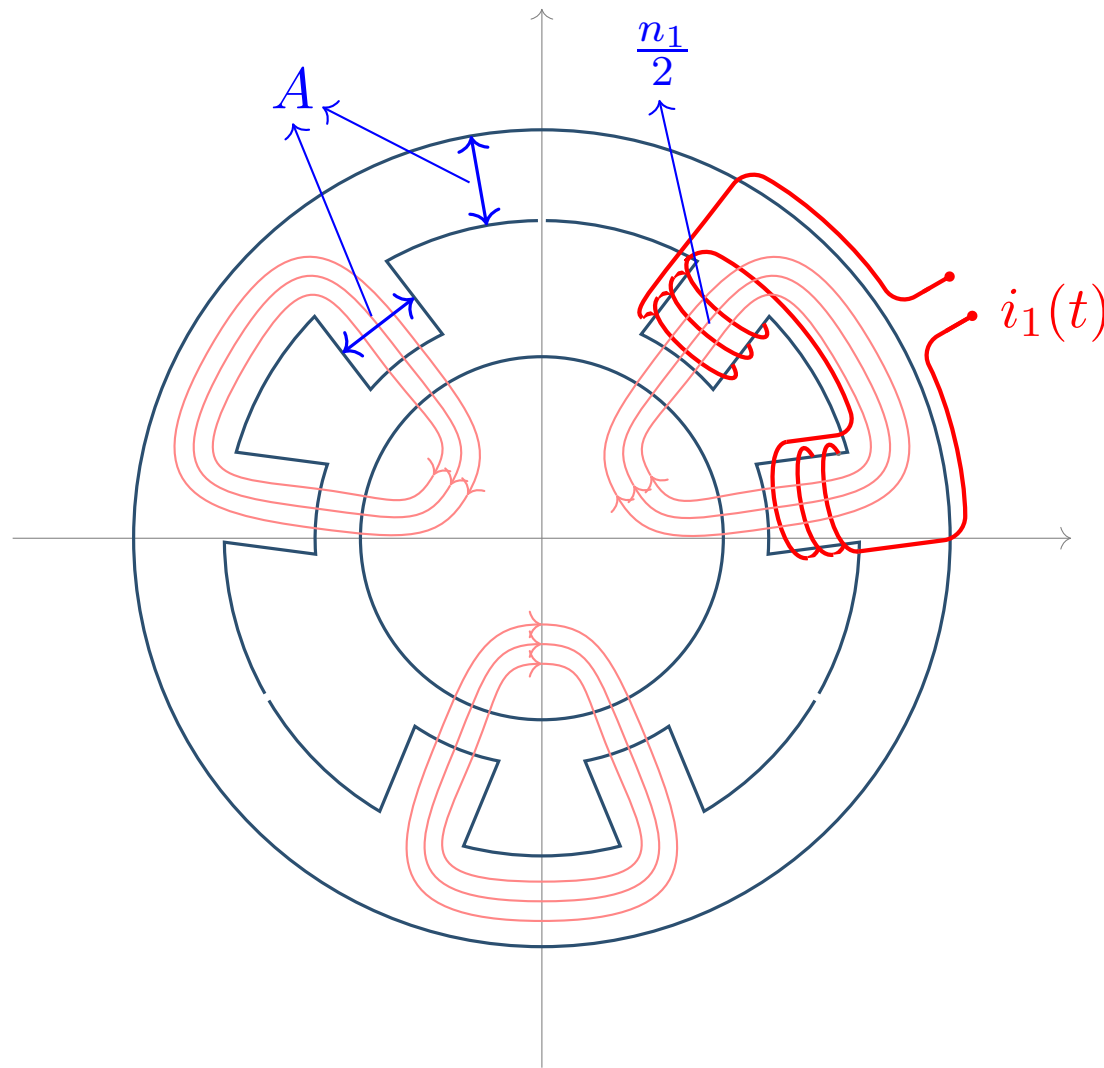
$$i_3 = i_0 - i_y$$

base and differential currents



# symmetry of 3 AMBs

- types of AMBs
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not traditional AMB structure

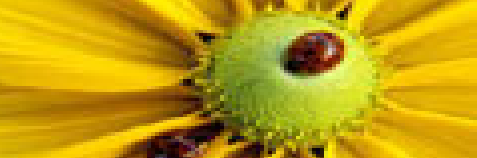
can be called  
Type A

6 gaps  
uncoupled fluxes

$$i_1 = i_0 + i_x + i_y \quad i_2 = i_0 - i_x + i_y$$

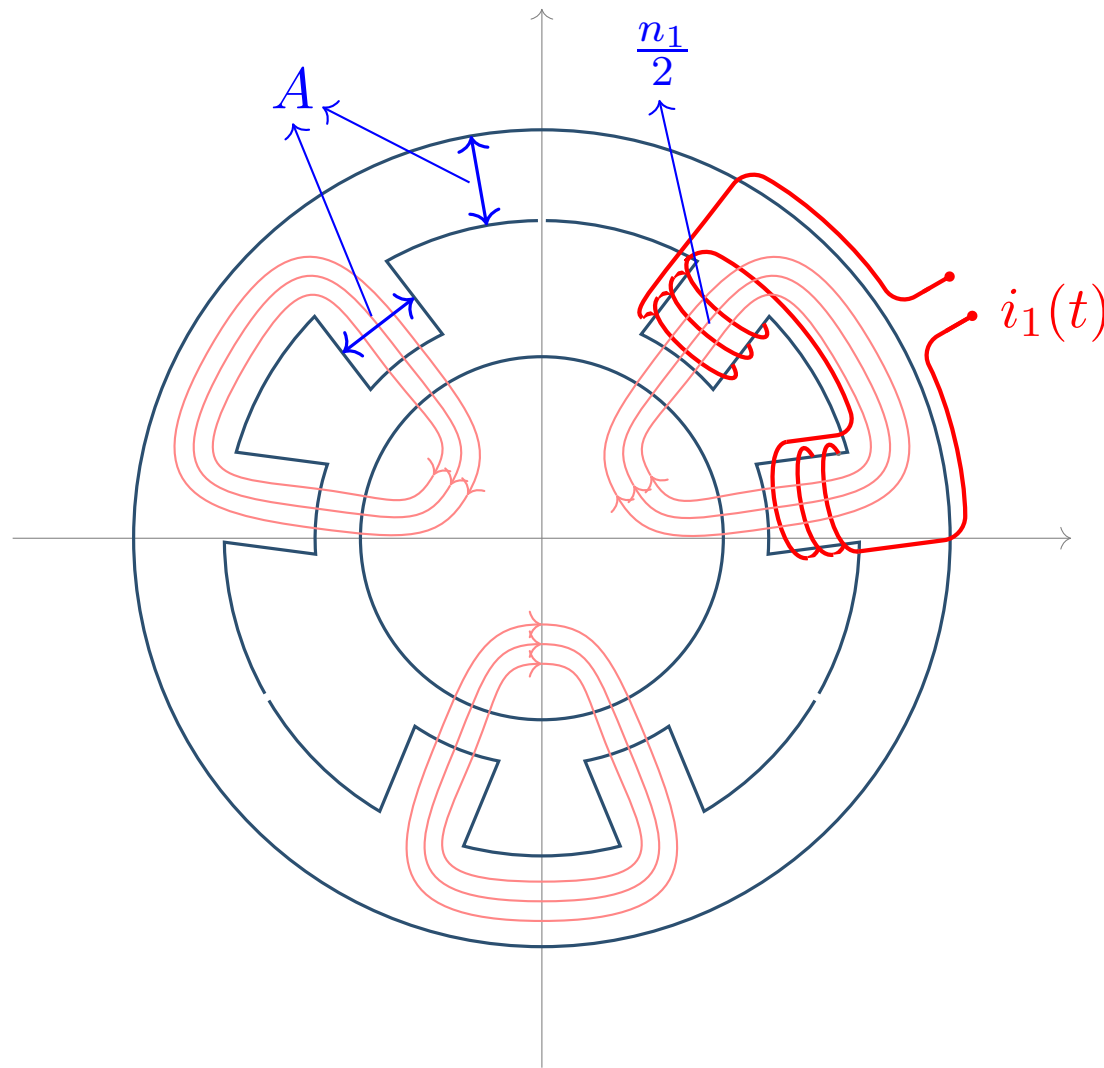
$$i_3 = i_0 - i_y$$

for small rotor displacements



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
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not traditional AMB structure

can be called  
Type A

6 gaps

uncoupled fluxes

$$i_1 = i_0 + i_x + i_y \quad i_2 = i_0 - i_x + i_y$$

$$i_3 = i_0 - i_y$$

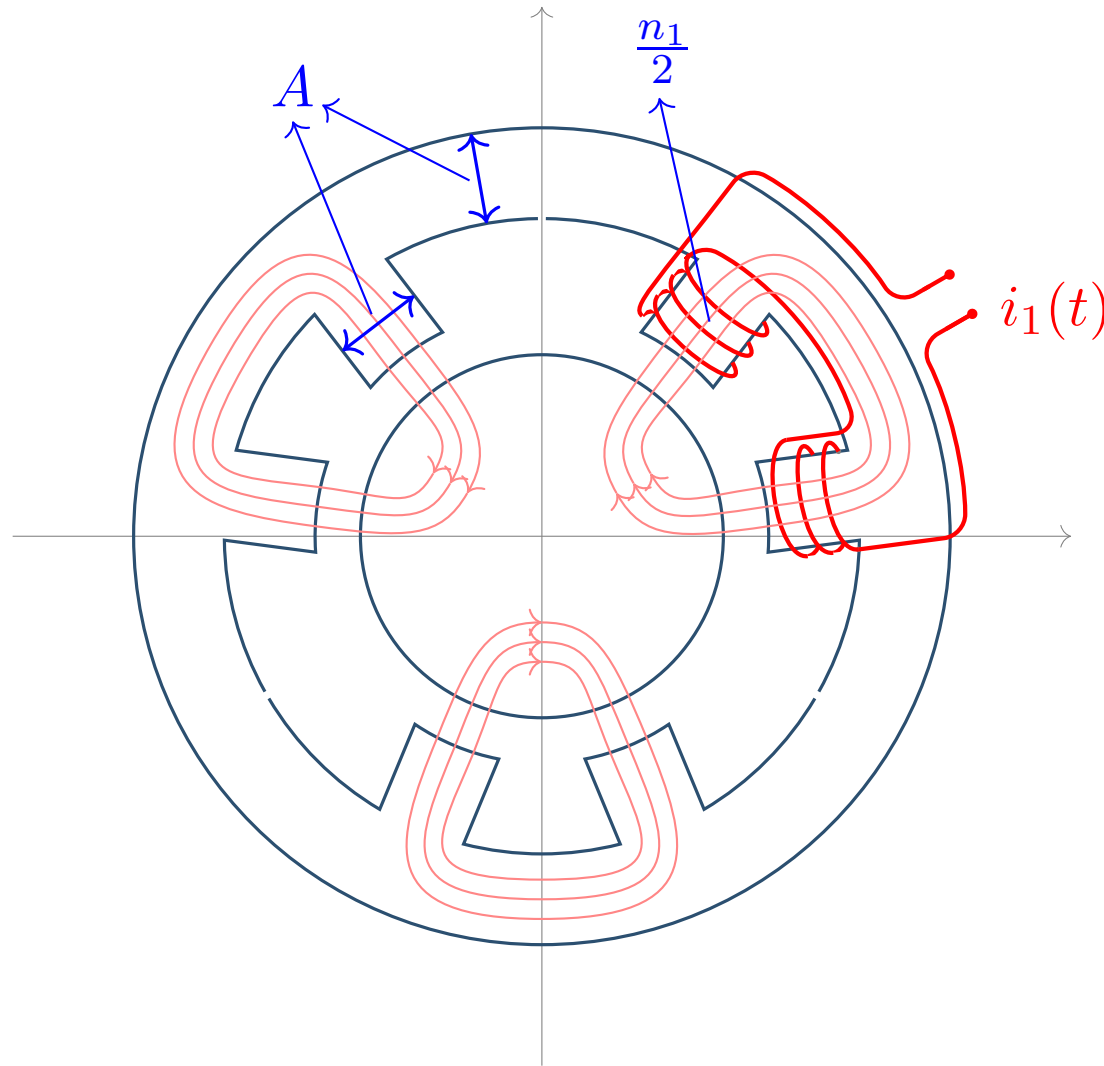
$$f_x = k_p^a x + 2\sqrt{3}k_i^a i_x$$

$$f_y = k_p^a y + 4k_i^a i_y$$



# symmetry of 3 AMBs

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not traditional AMB structure

can be called  
Type A

6 gaps

uncoupled fluxes

$$i_1 = i_0 + i_x + i_y \quad i_2 = i_0 - i_x + i_y$$

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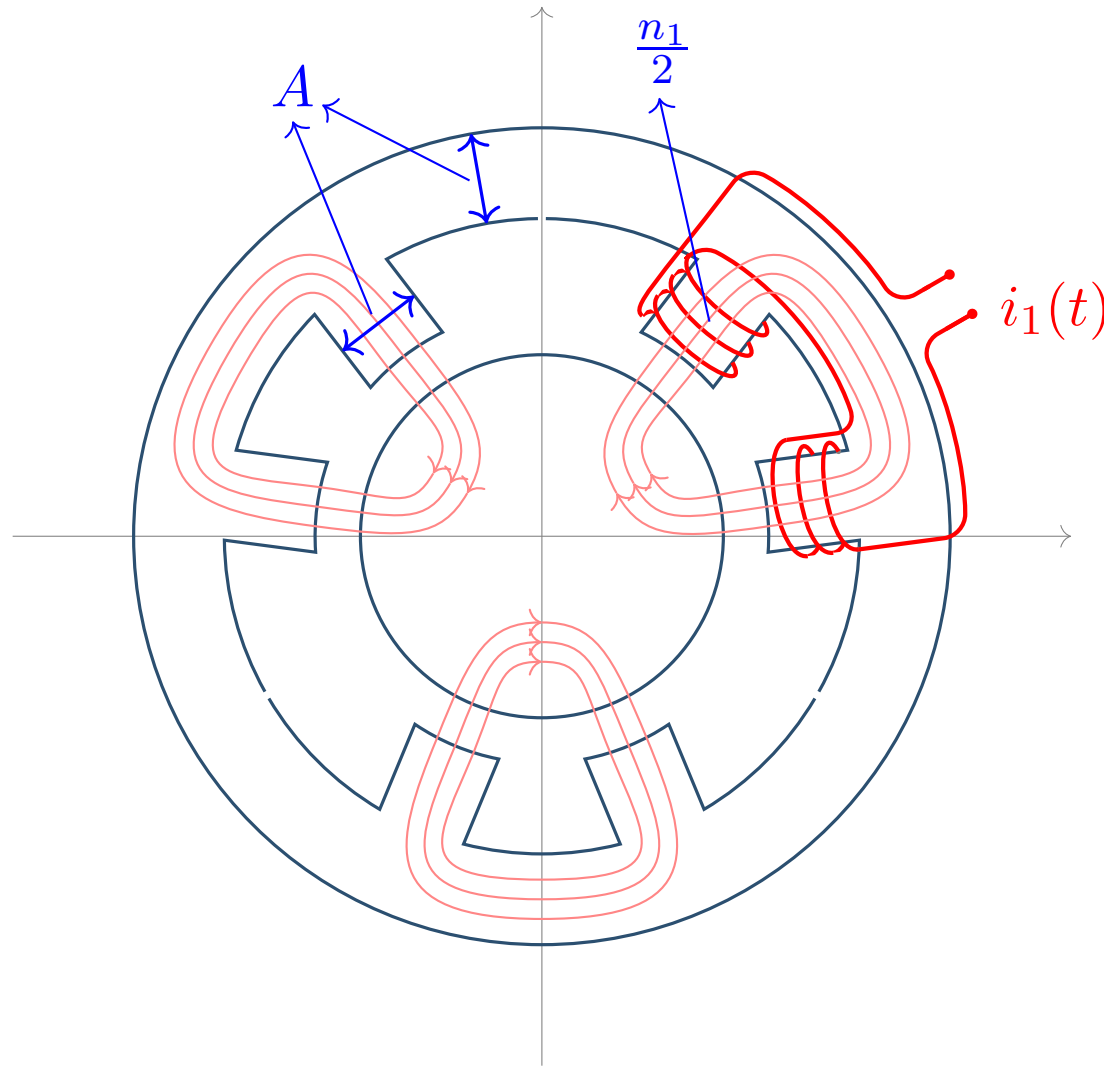
$$k_p^a = 3\mu_0 A n^2 i_0^2 / (4h^3)$$

$$k_i^a = \mu_0 A n^2 i_0 / (4h^2)$$



# symmetry of 3 AMBs

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not traditional AMB structure

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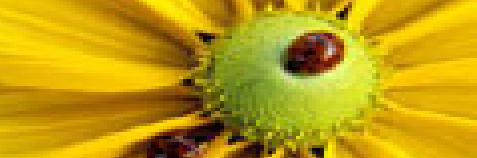
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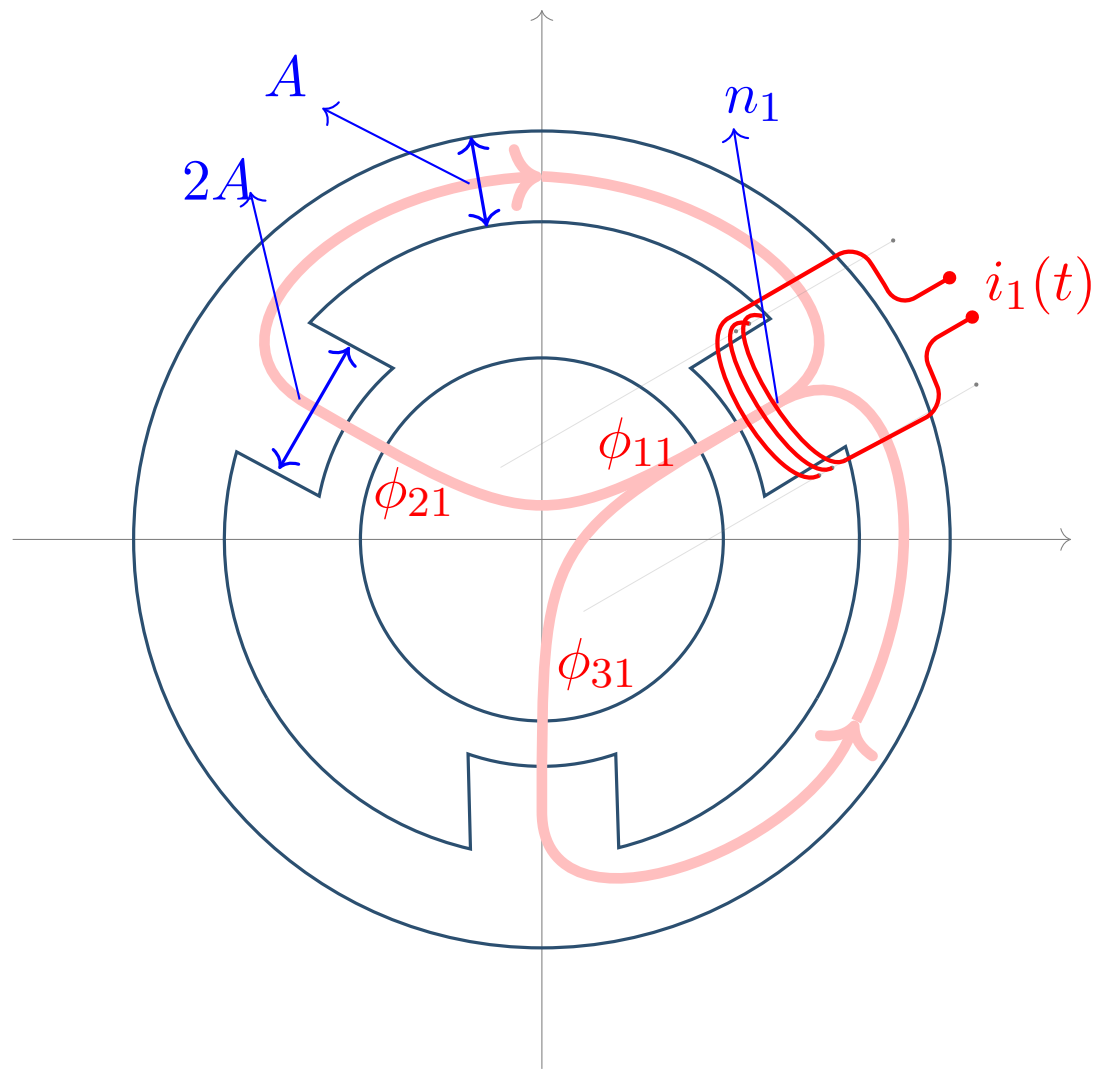
$$k_i^a = \mu_0 A n^2 i_0 / (4h^2)$$

is there a Type B?



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3
- symm of 3

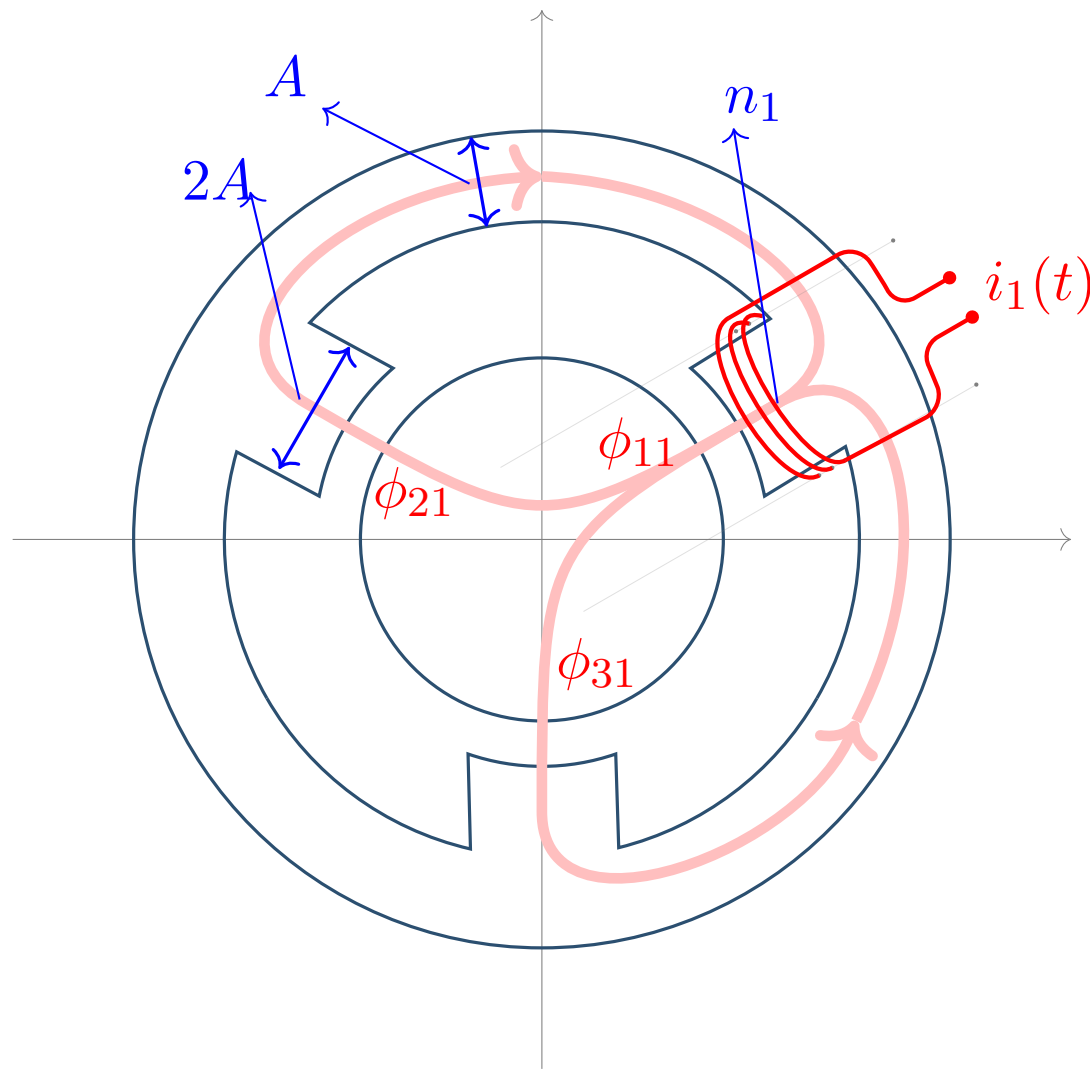






# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
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- symm of 3

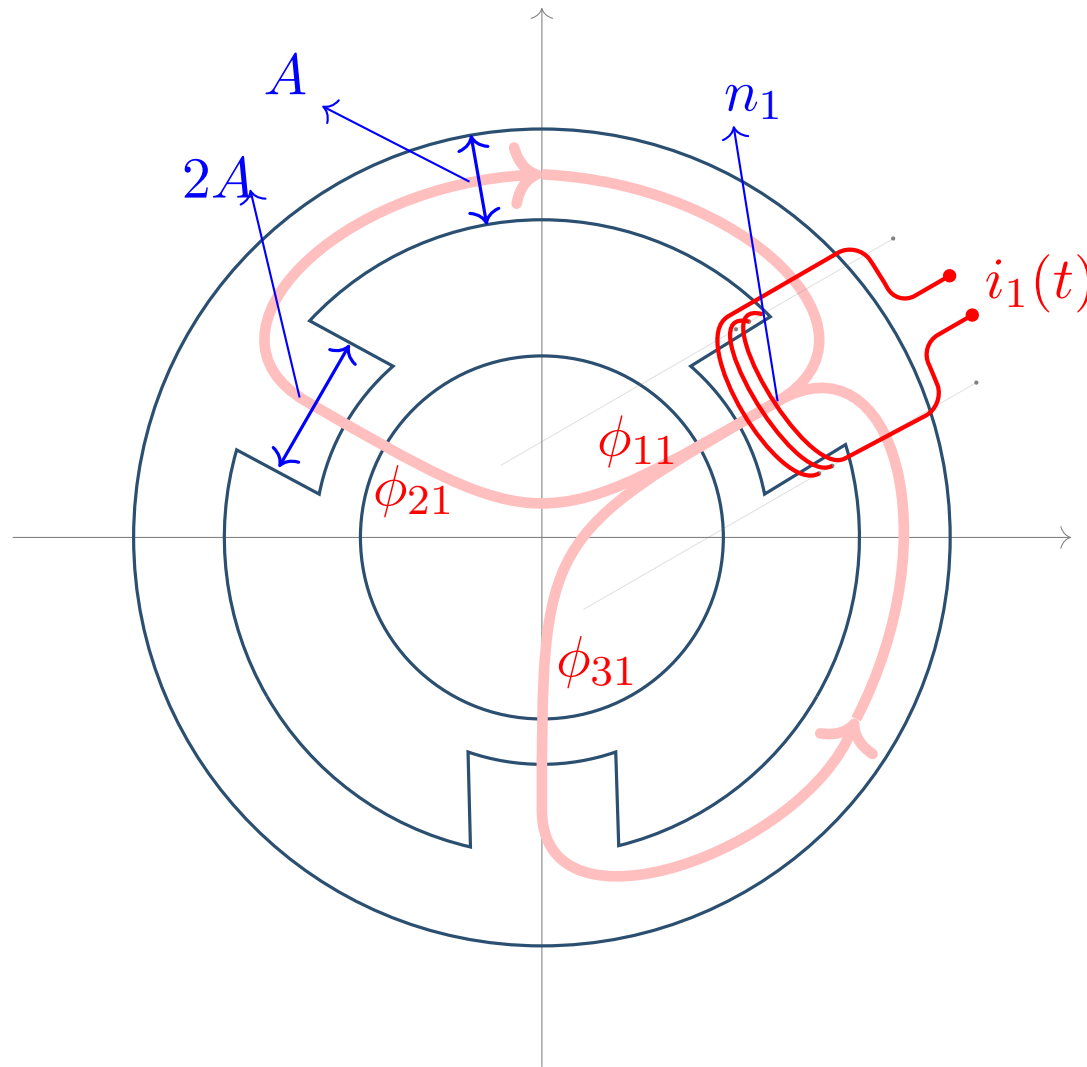


not traditional AMB structure



# symmetry of 3 AMBs

- types of AMBs
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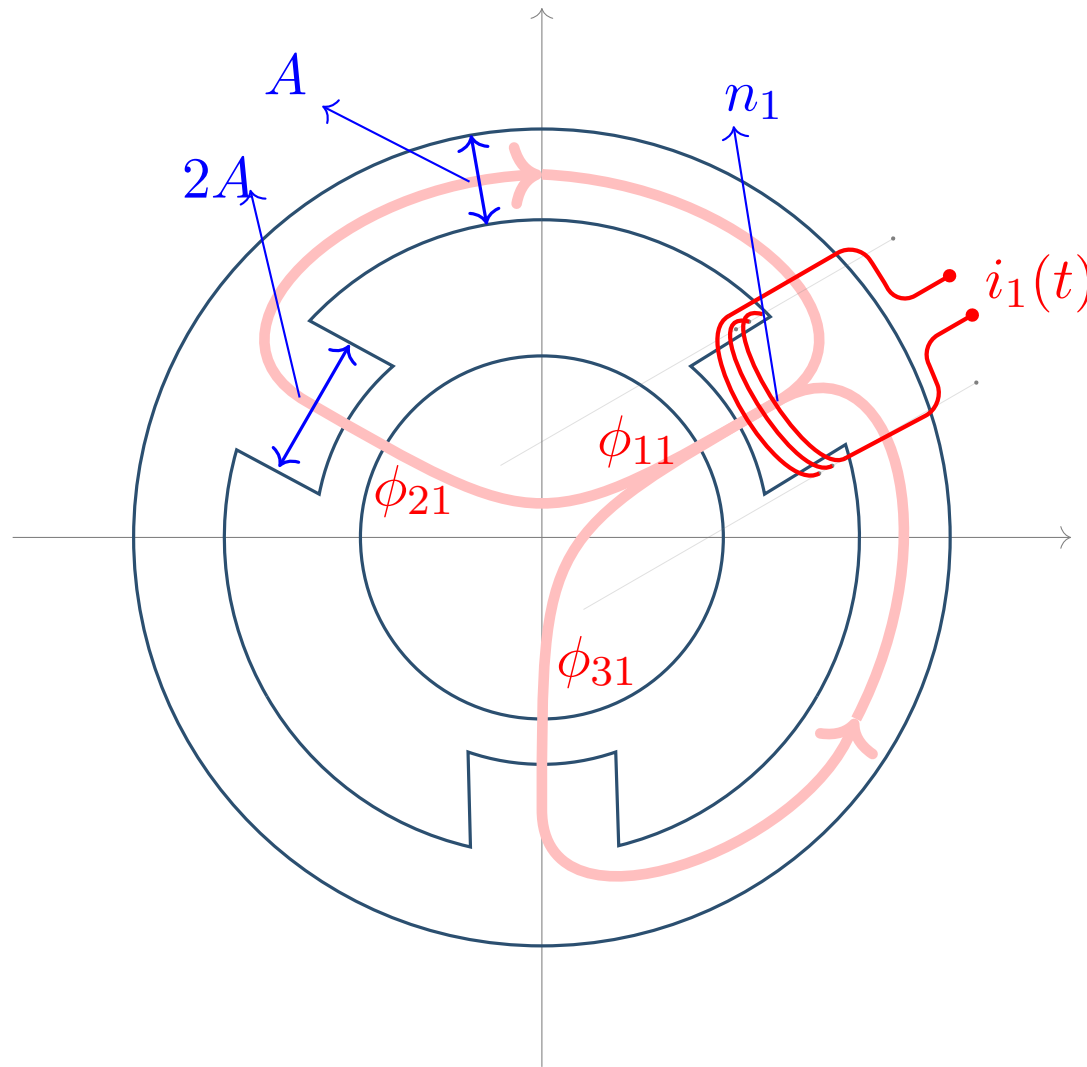


not traditional AMB structure  
can be called



# symmetry of 3 AMBs

- types of AMBs
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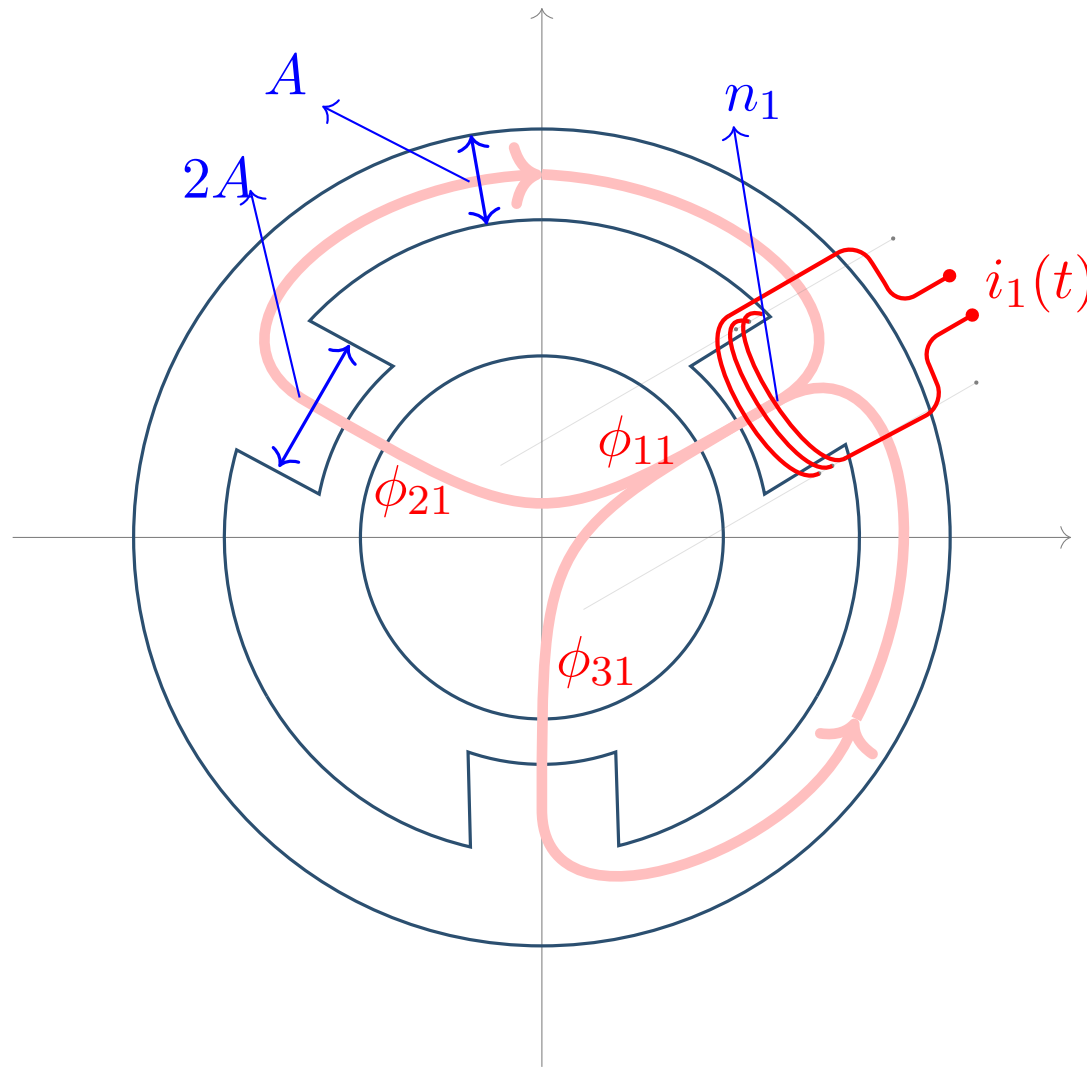
not traditional AMB structure

can be called  
Type B



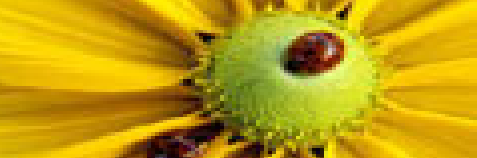
# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
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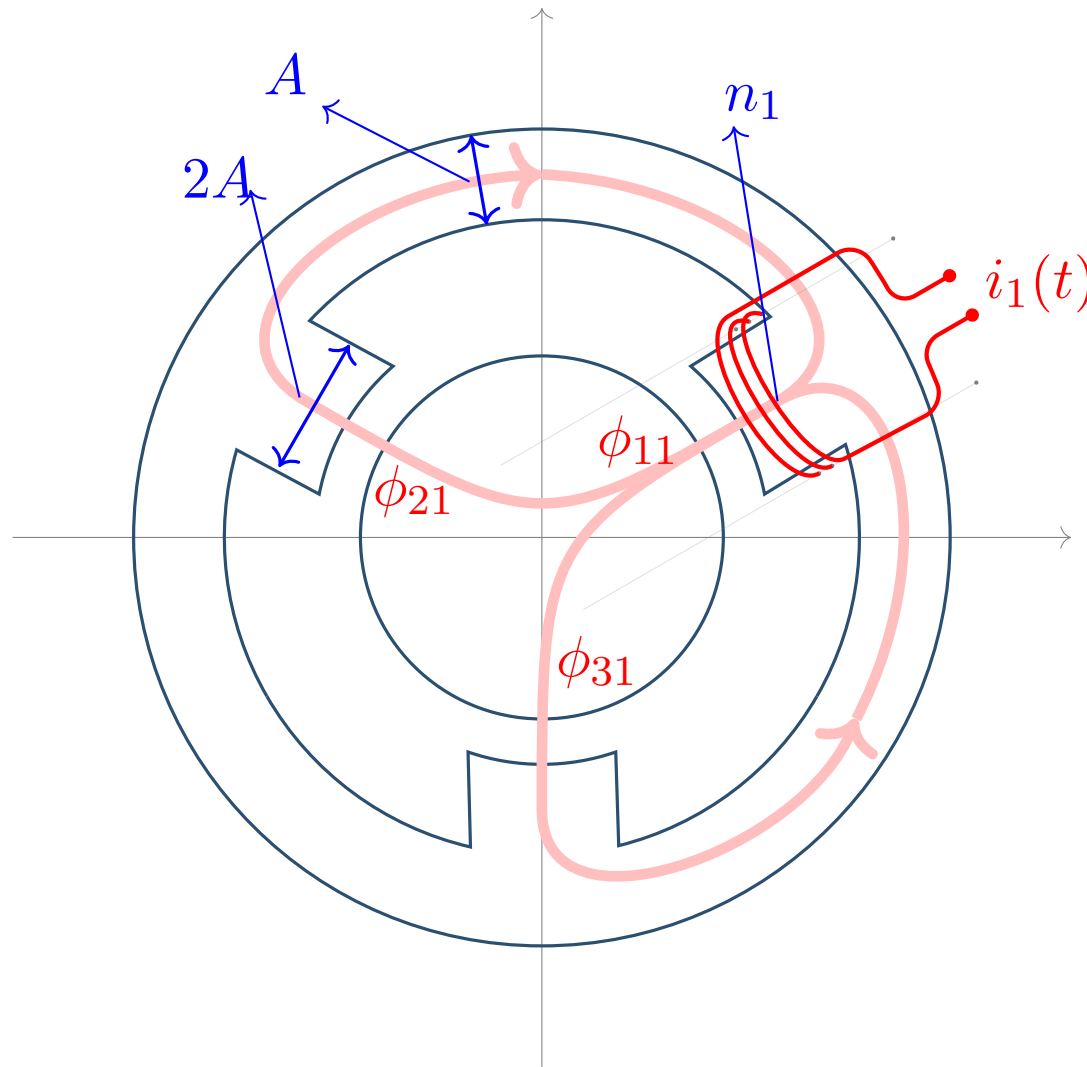
not traditional AMB structure

can be called  
Type B  
"3 poles"



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3
- symm of 3



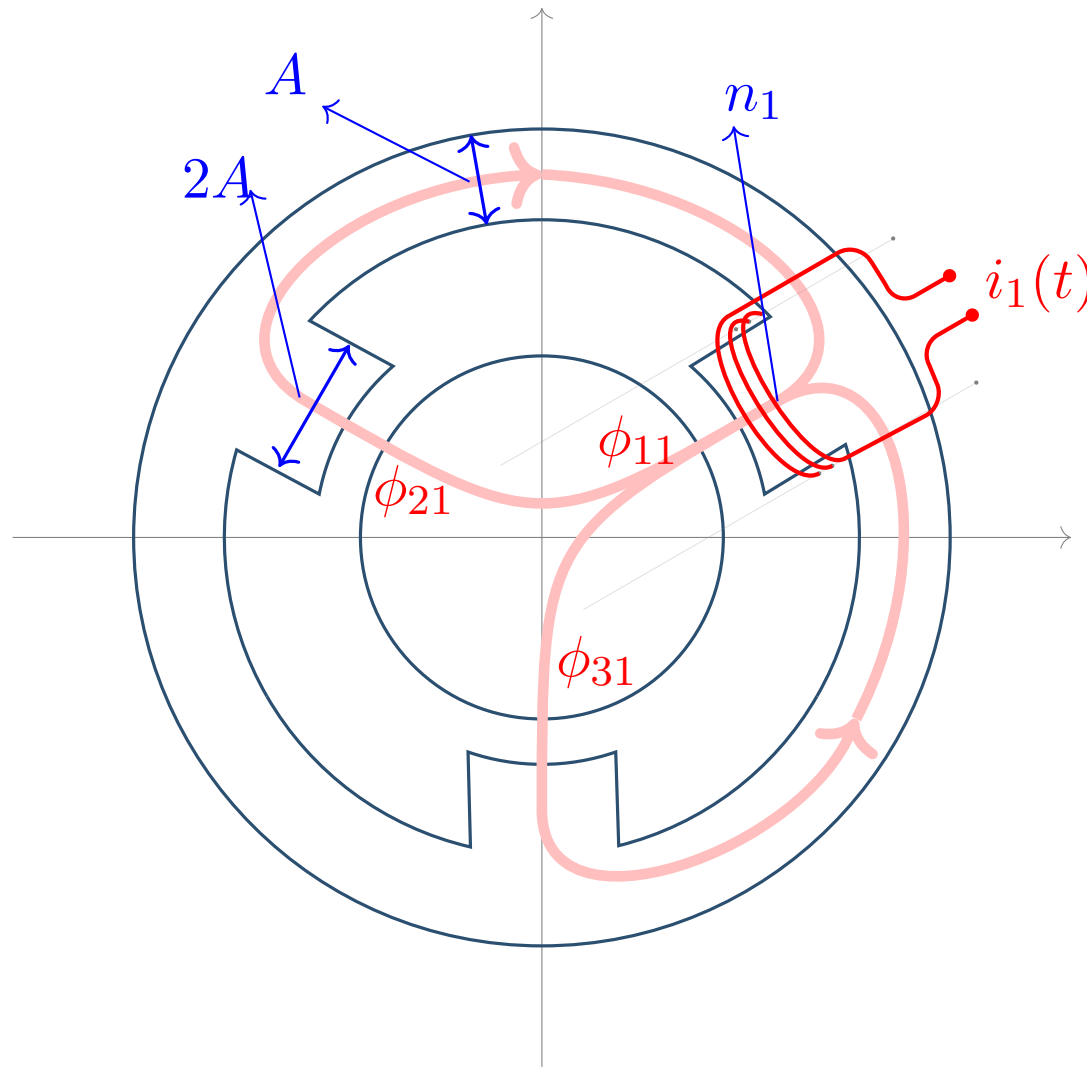
not traditional AMB structure

can be called  
Type B  
3 gaps



# symmetry of 3 AMBs

- types of AMBs
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- symm of 4
- comparisons
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- symm of 3



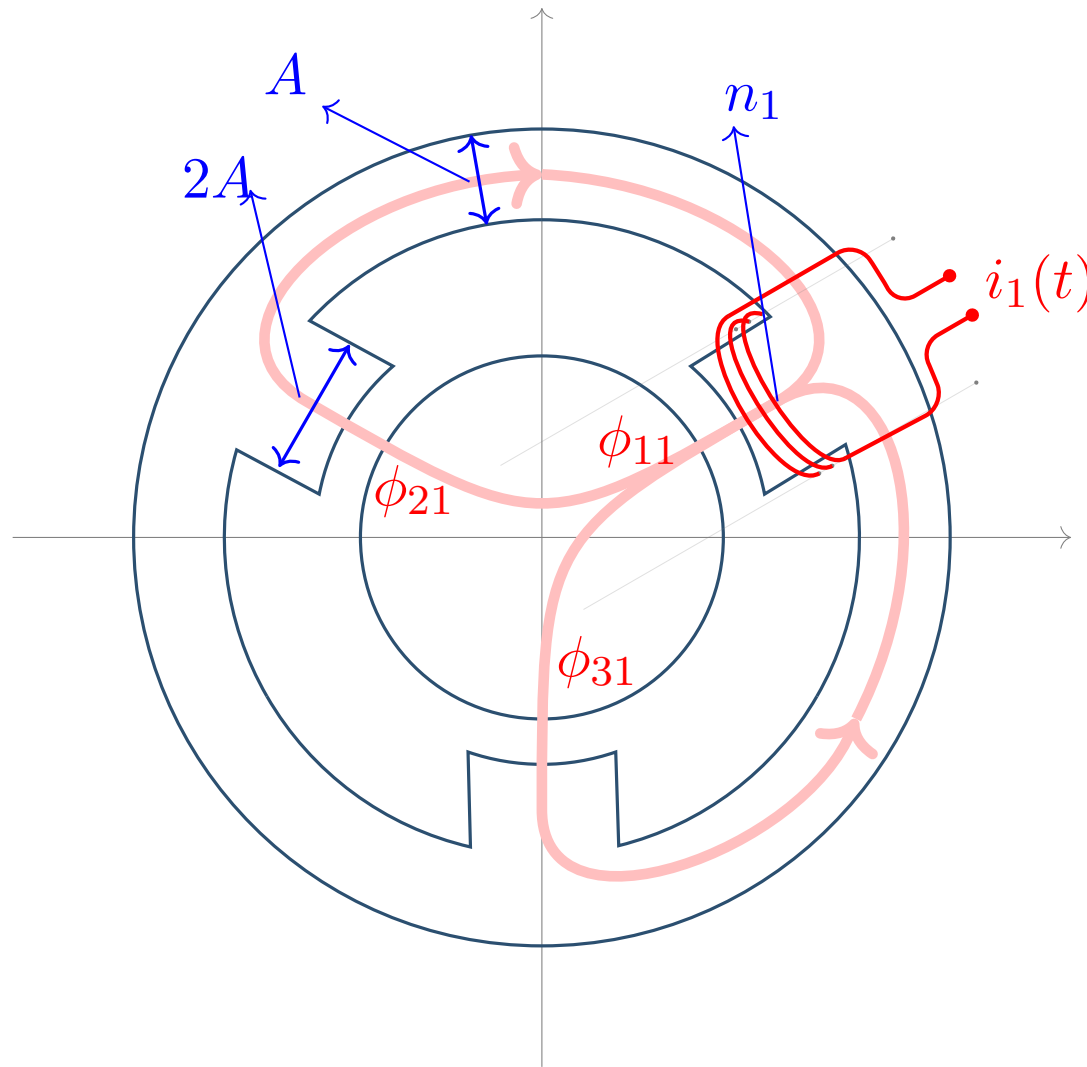
not traditional AMB structure

can be called  
Type B  
3 gaps  
coupled fluxes



# symmetry of 3 AMBs

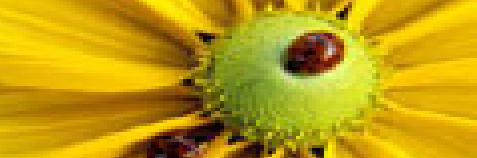
- types of AMBs
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- symm of 4
- comparisons
- ideas
- symm of 3
- symm of 3



not traditional AMB structure

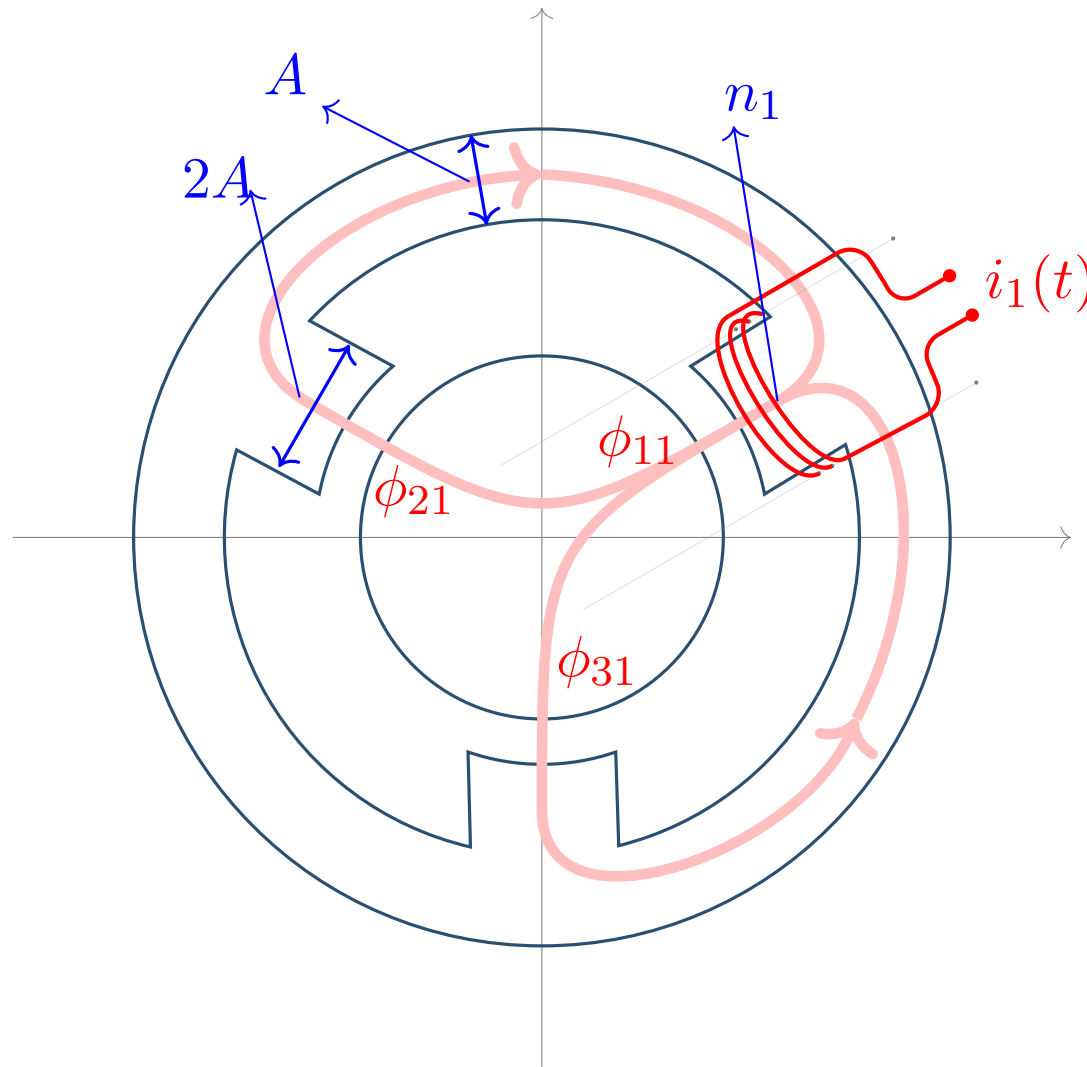
can be called  
Type B

3 gaps  
coupled fluxes  
3 injected currents



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
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- symm of 3



not traditional AMB structure

can be called  
Type B

3 gaps  
coupled fluxes

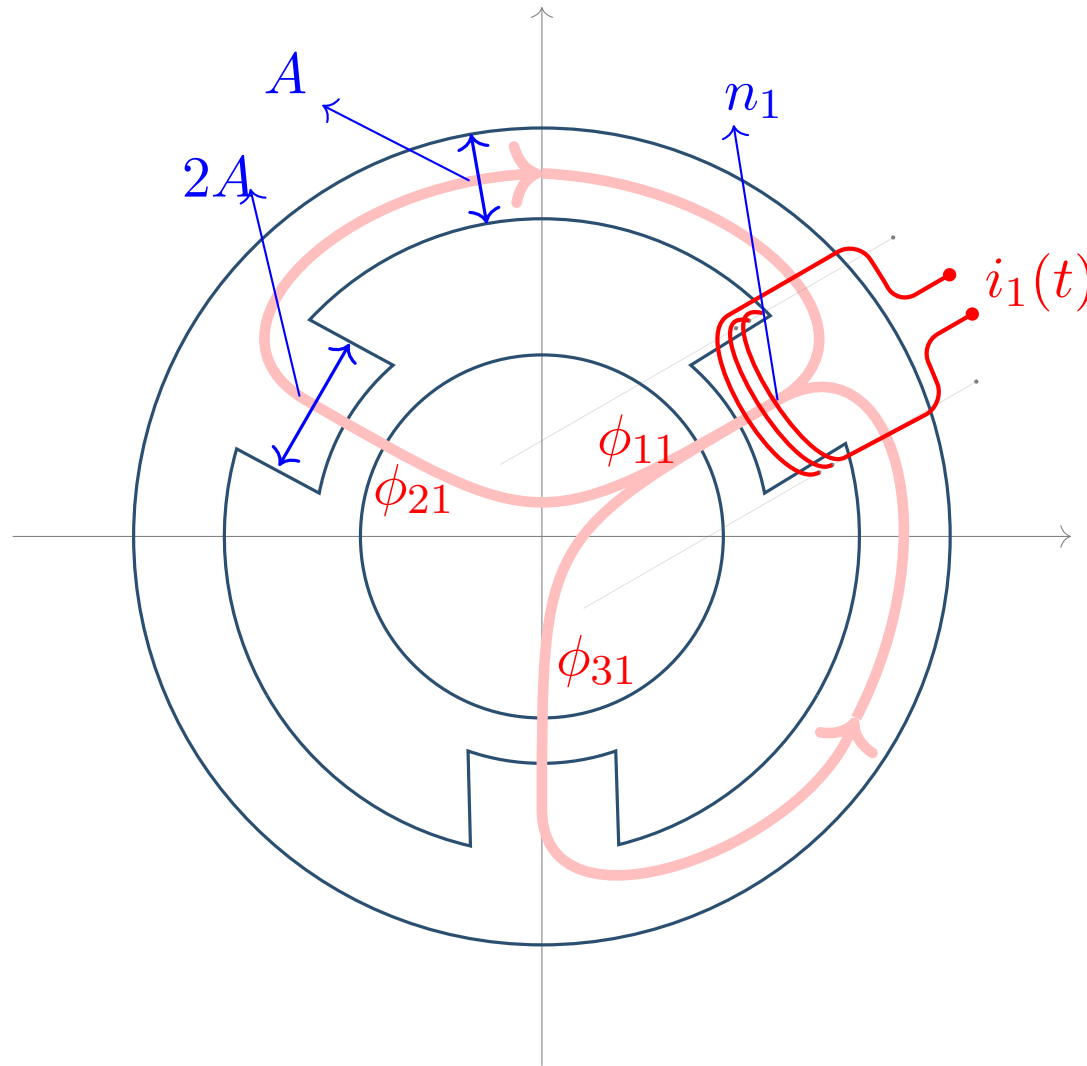
$$i_1(t) = b_1 + v_1(t) \quad i_2(t) = b_2 + v_2(t)$$





# symmetry of 3 AMBs

- types of AMBs
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not traditional AMB structure

can be called  
Type B

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coupled fluxes

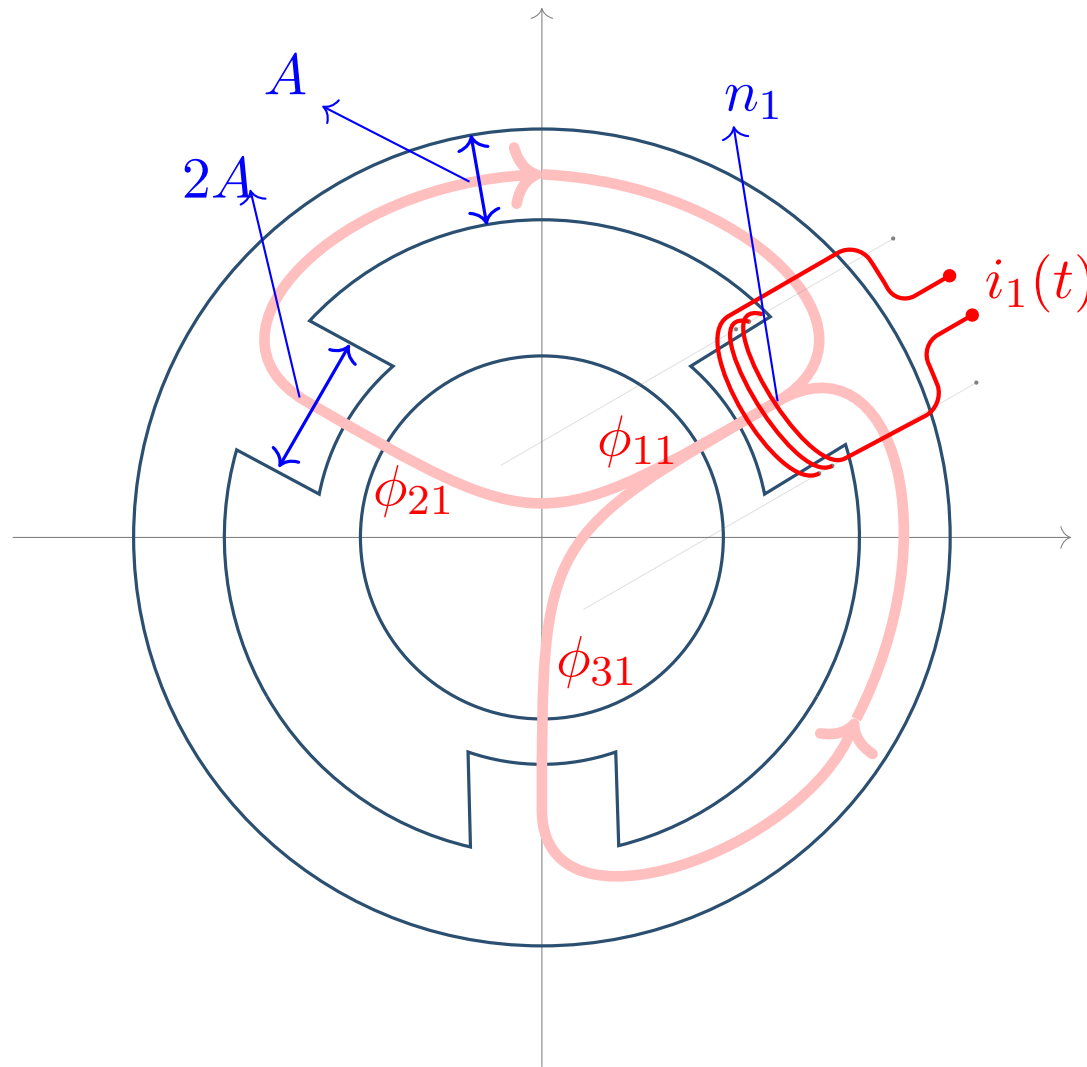
$$i_1(t) = b_1 + v_1(t) \quad i_2(t) = b_2 + v_2(t)$$

$$i_3(t) = b_3 + v_3(t)$$



# symmetry of 3 AMBs

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not traditional AMB structure

can be called  
Type B

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coupled fluxes

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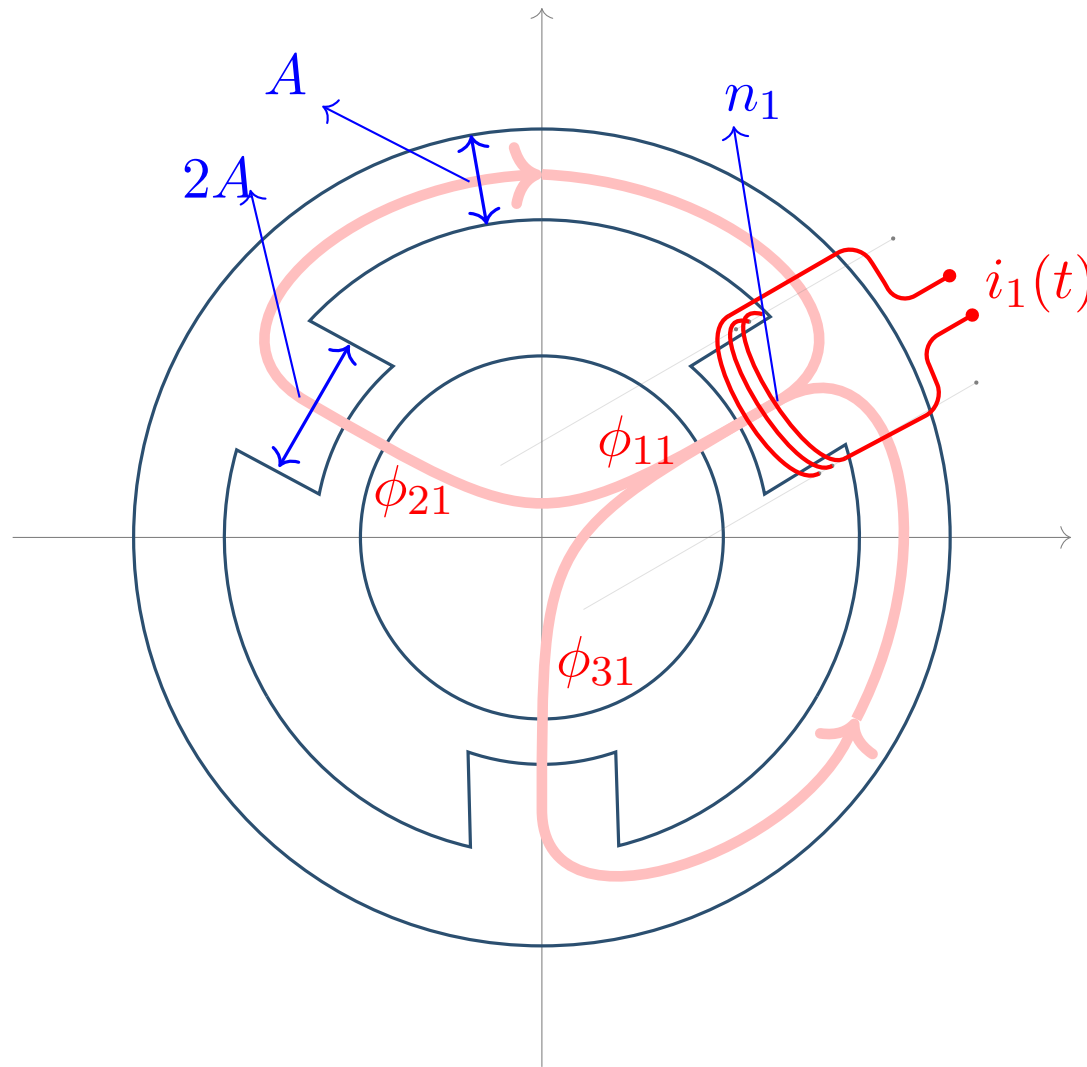
$$i_3(t) = b_3 + v_3(t)$$

base and differential currents



# symmetry of 3 AMBs

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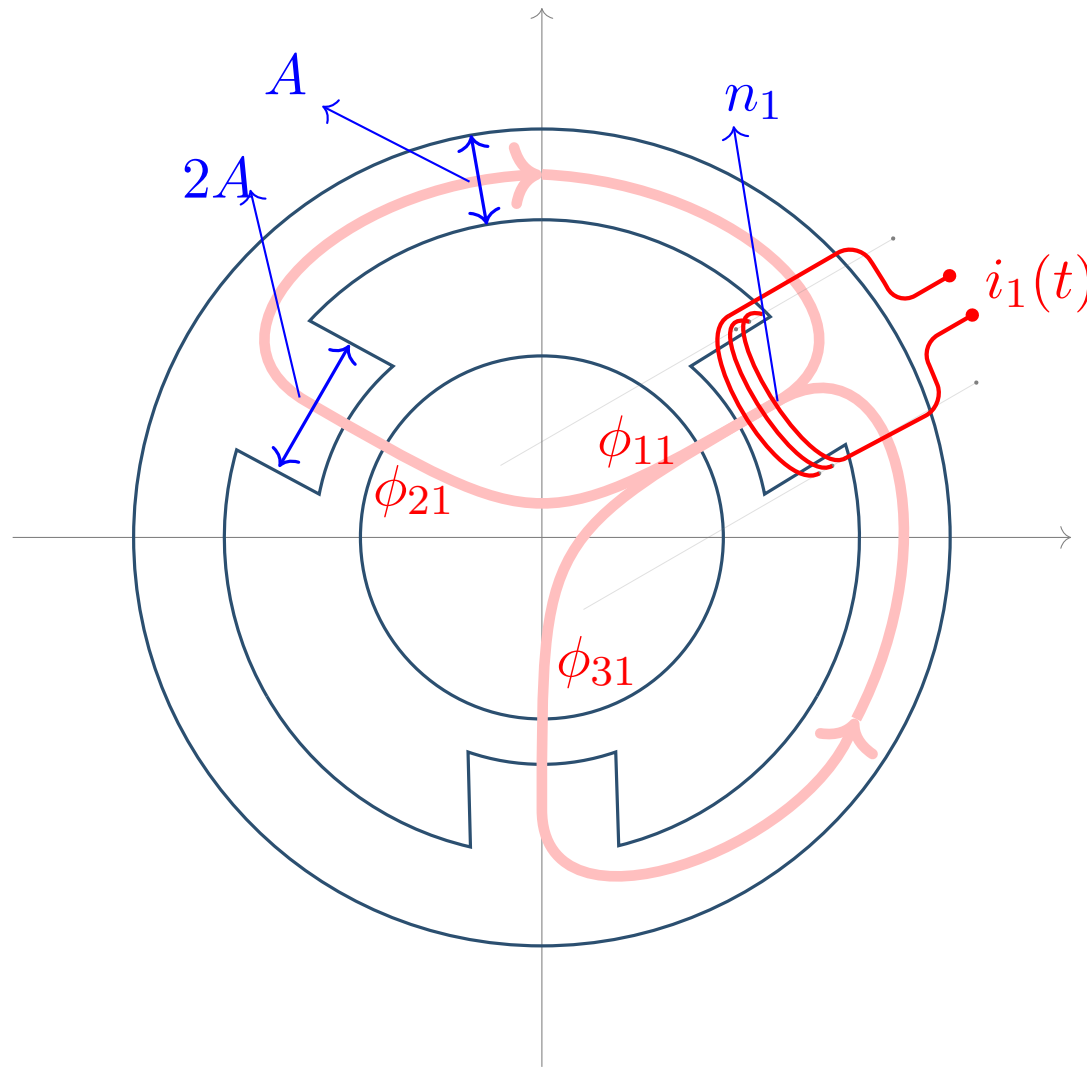
$$i_3(t) = b_3 + v_3(t)$$

for small rotor displacements



# symmetry of 3 AMBs

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- symm of 4
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- symm of 3
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not traditional AMB structure

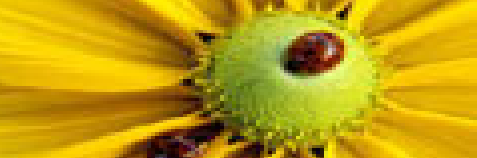
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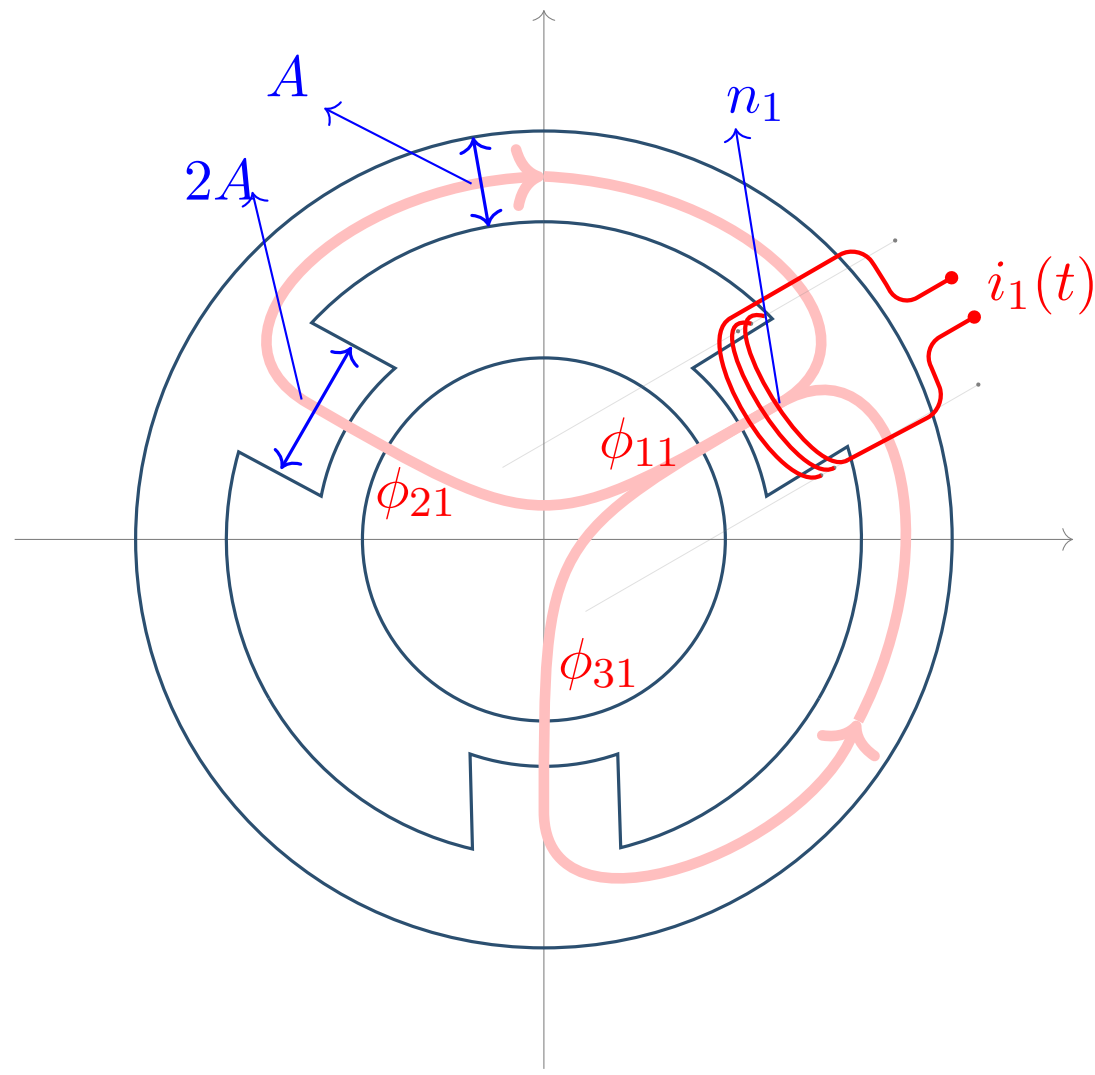
$$i_3(t) = b_3 + v_3(t)$$

careful linearization process ...



# symmetry of 3 AMBs

- types of AMBs
- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3
- symm of 3



not traditional AMB structure

can be called  
 Type B  
 3 gaps  
 coupled fluxes

$$i_1(t) = b_1 + v_1(t) \quad i_2(t) = b_2 + v_2(t)$$

$$i_3(t) = b_3 + v_3(t)$$

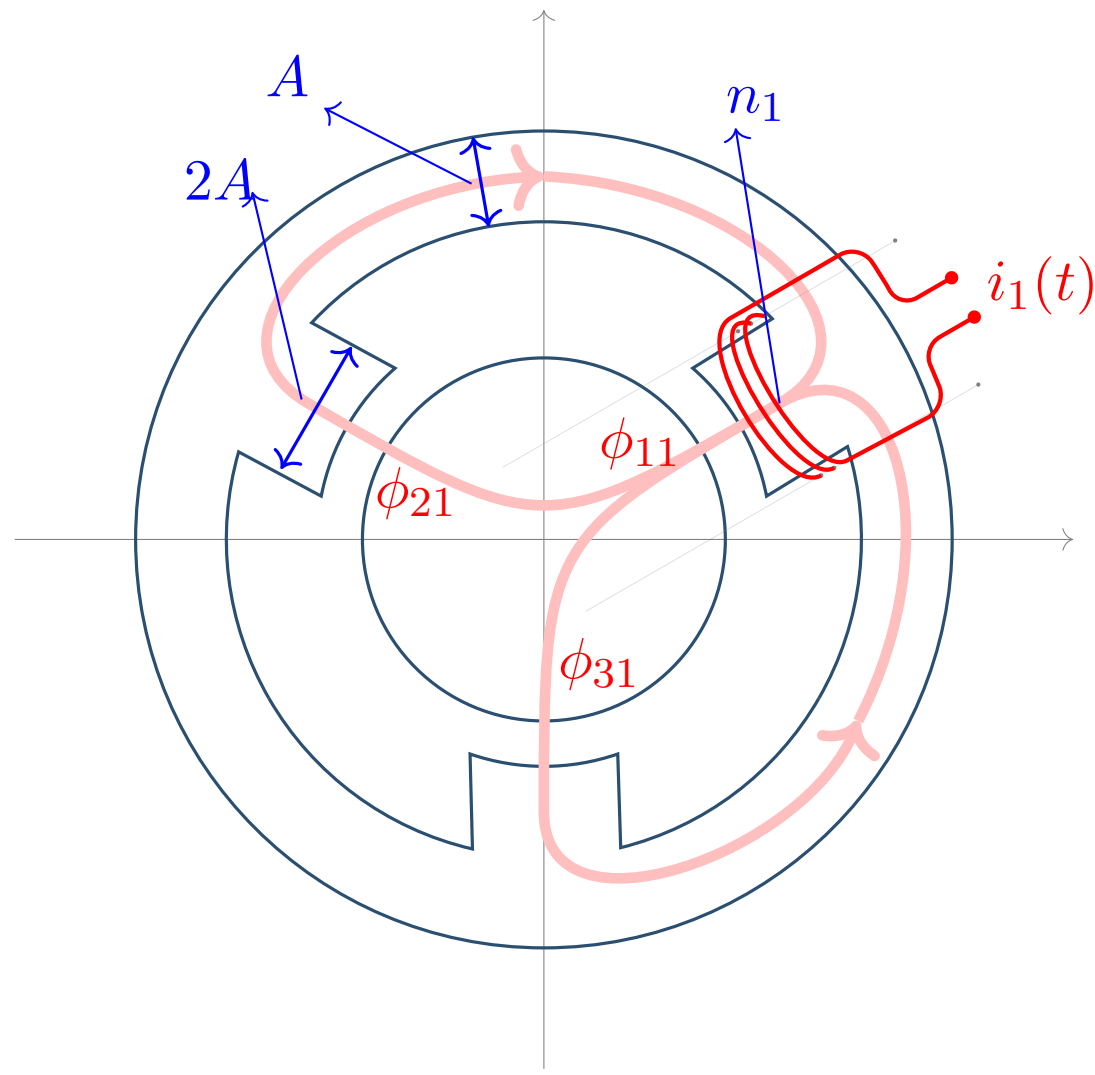
careful linearization process ...

allows to prove that



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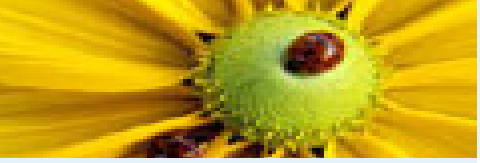
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$$i_3(t) = b_3 + v_3(t)$$

careful linearization process ...

allows to prove that

linearization is impossible!



## comparing symmetries of 3 and 4 AMBs

types of AMBs

types of AMBs

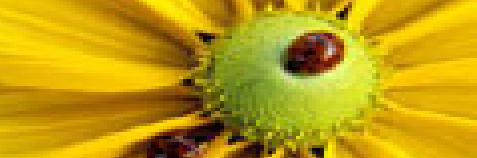
symm of 4

comparisons

ideas

symm of 3

symm of 3



## comparing symmetries of 3 and 4 AMBs

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- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3
- symm of 3

looks like





# comparing symmetries of 3 and 4 AMBs

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- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3
- symm of 3

looks like ..... 3 gaps AMBs **do not exist**



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looks like ..... 3 gaps AMBs **do not exist**

and in the symmetry of 3 world



# comparing symmetries of 3 and 4 AMBs

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looks like ..... 3 gaps AMBs **do not exist**

and in the symmetry of 3 world ..... there are **no better structures**



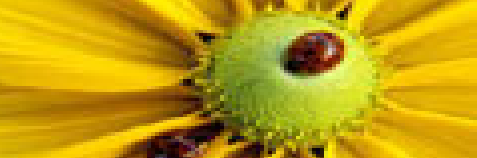
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but



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looks like ..... 3 gaps AMBs **do not exist**

and in the symmetry of 3 world ..... there are **no better structures**

but ..... better structures **may be caused by coupled fluxes**



## comparing symmetries of 3 and 4 AMBs

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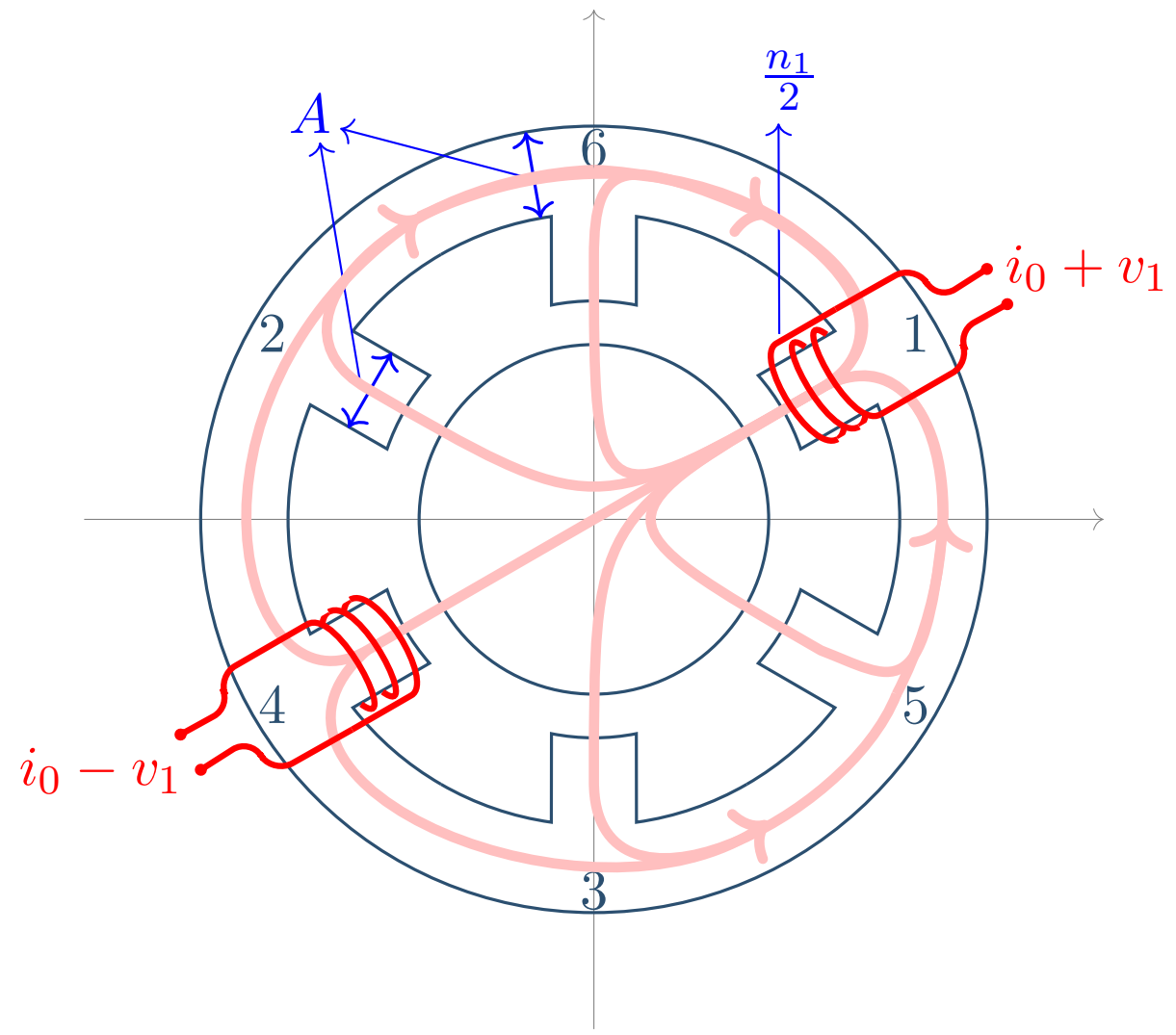
but ..... better structures **may be caused by coupled fluxes**

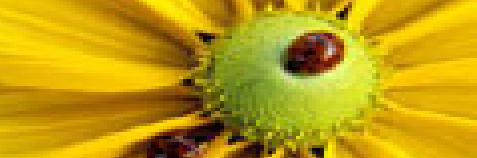
what about



# symmetry of 3 — 6 gaps coupled fluxes

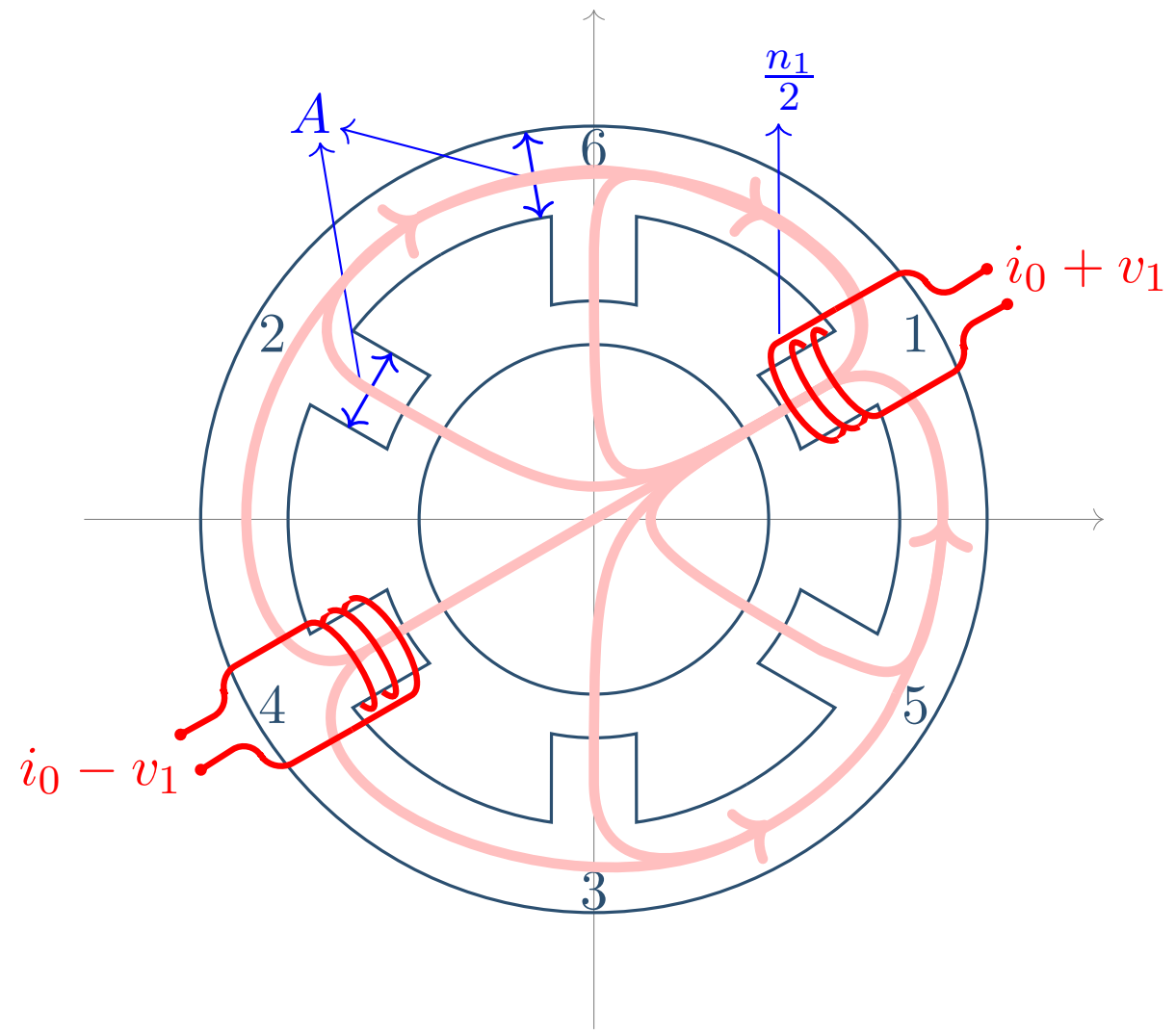
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# symmetry of 3 — 6 gaps coupled fluxes

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- types of AMBs
- symm of 4
- comparisons
- ideas
- symm of 3
- symm of 3



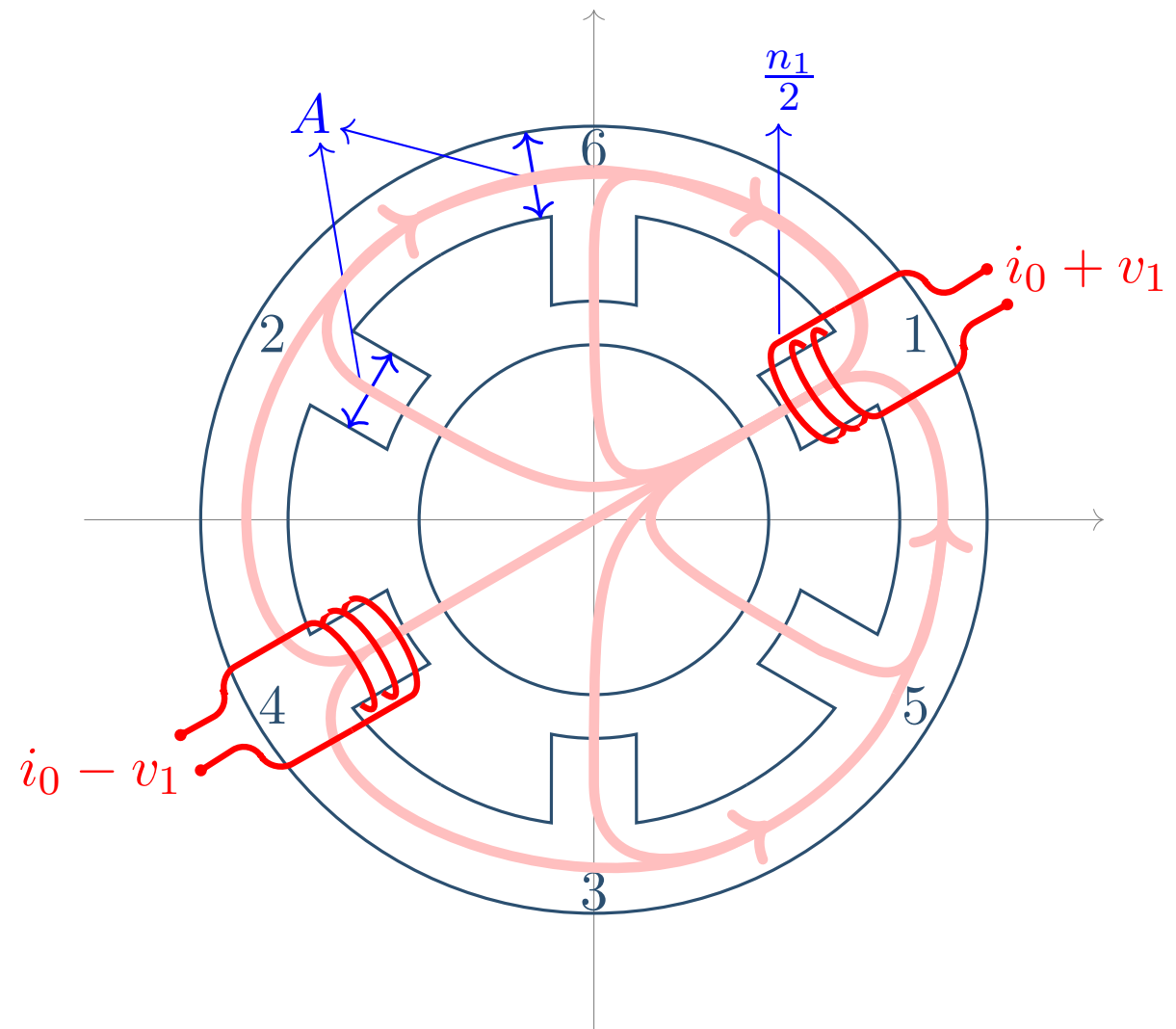
a symmetry of 3 geometry





# symmetry of 3 — 6 gaps coupled fluxes

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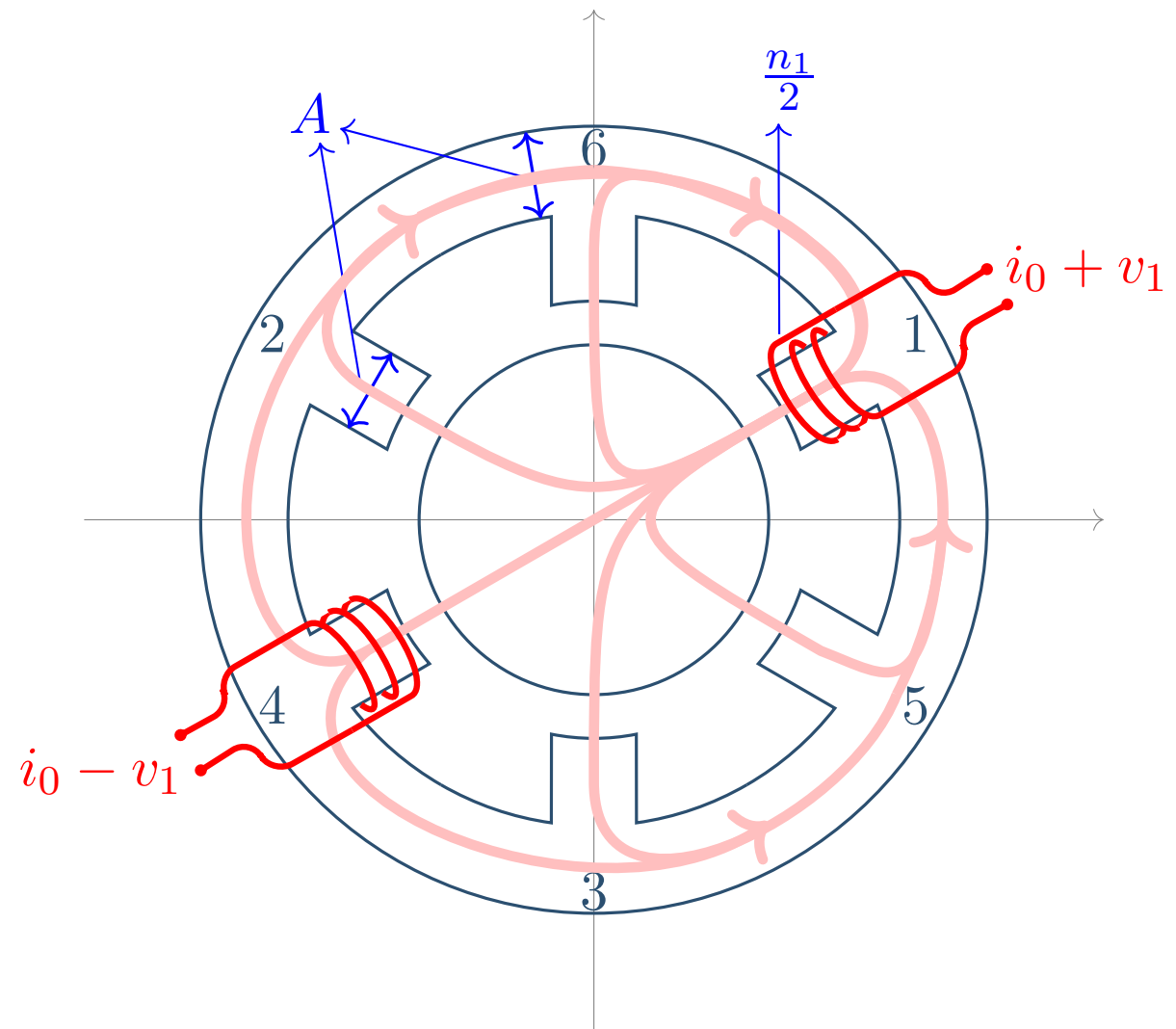


a symmetry of 3 geometry  
with 6 gaps



# symmetry of 3 — 6 gaps coupled fluxes

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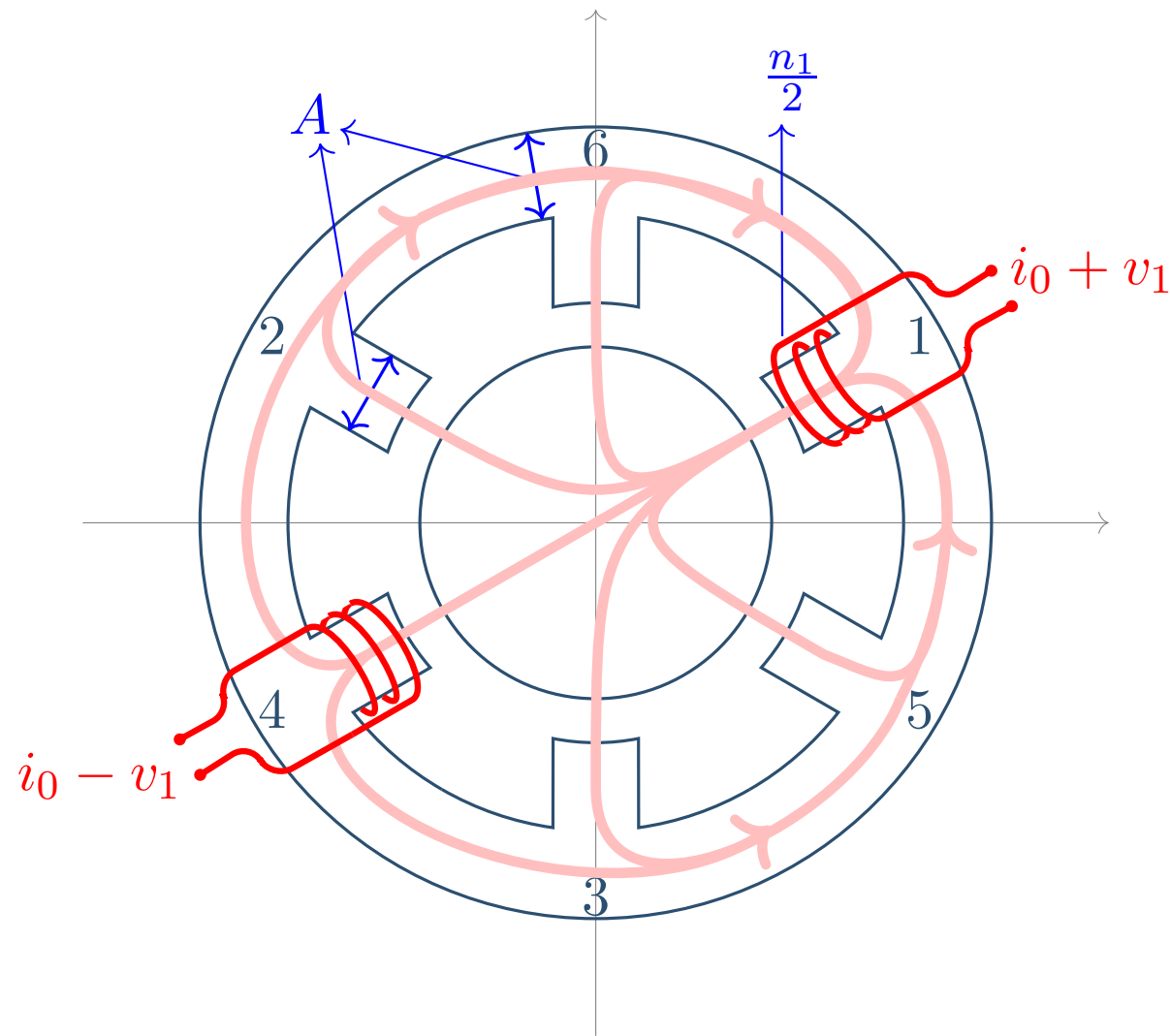


a symmetry of 3 geometry  
with 6 gaps  
and coupled fluxes



# symmetry of 3 — 6 gaps coupled fluxes

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a symmetry of 3 geometry

with 6 gaps

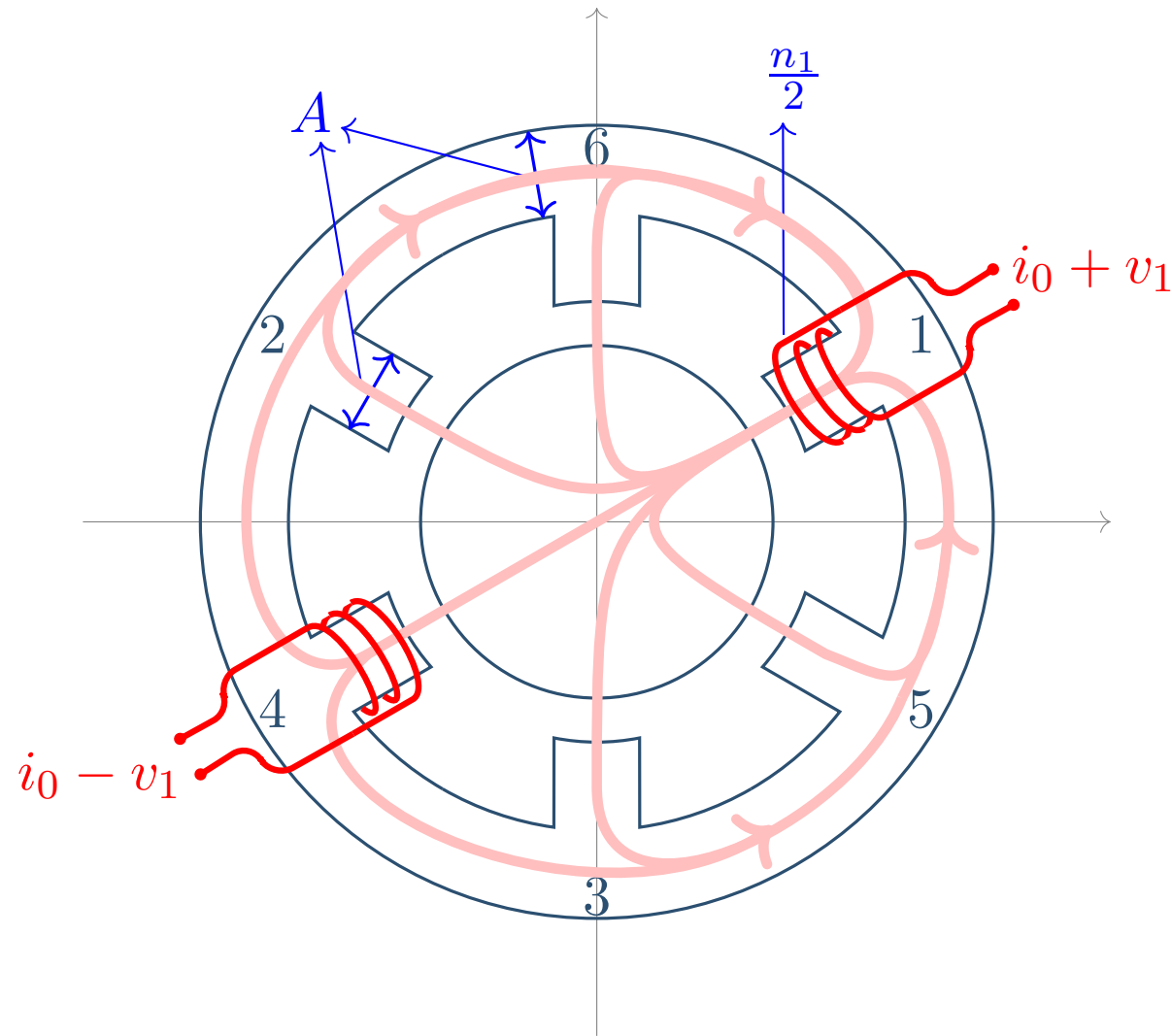
and coupled fluxes

will it work?



# symmetry of 3 — 6 gaps coupled fluxes

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- types of AMBs
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a symmetry of 3 geometry

with 6 gaps

and coupled fluxes

will it work?

will it be a better structure?