Tuning the magnetic orientation of ferrite segments for cogging torque optimization in small PM DC motors.

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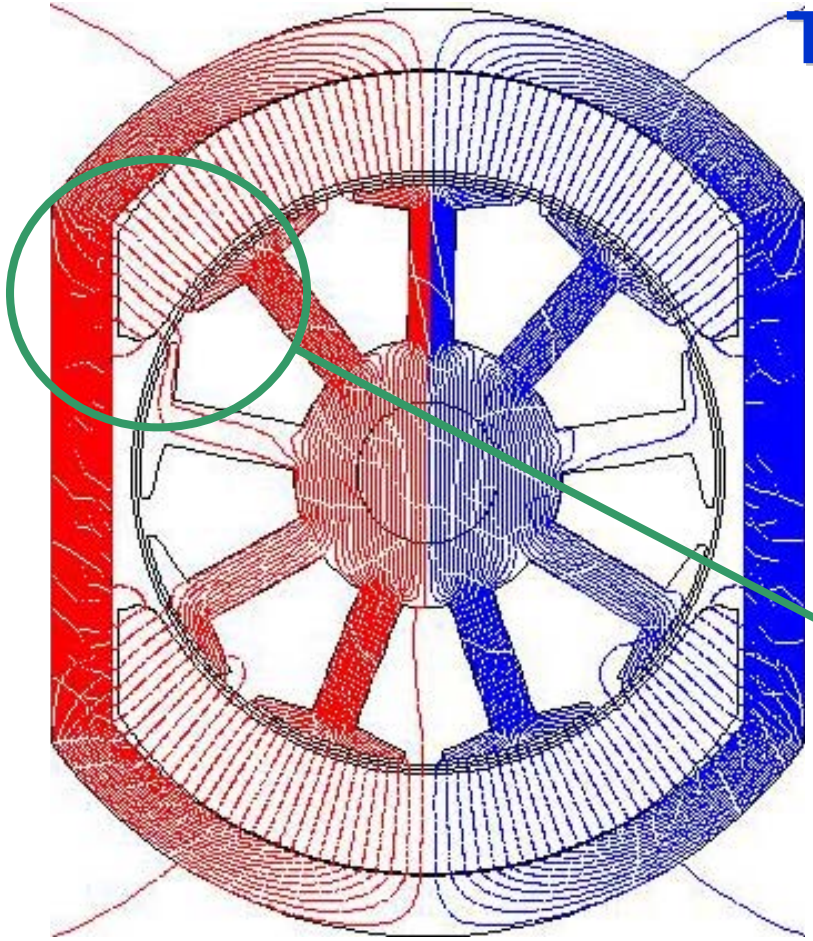
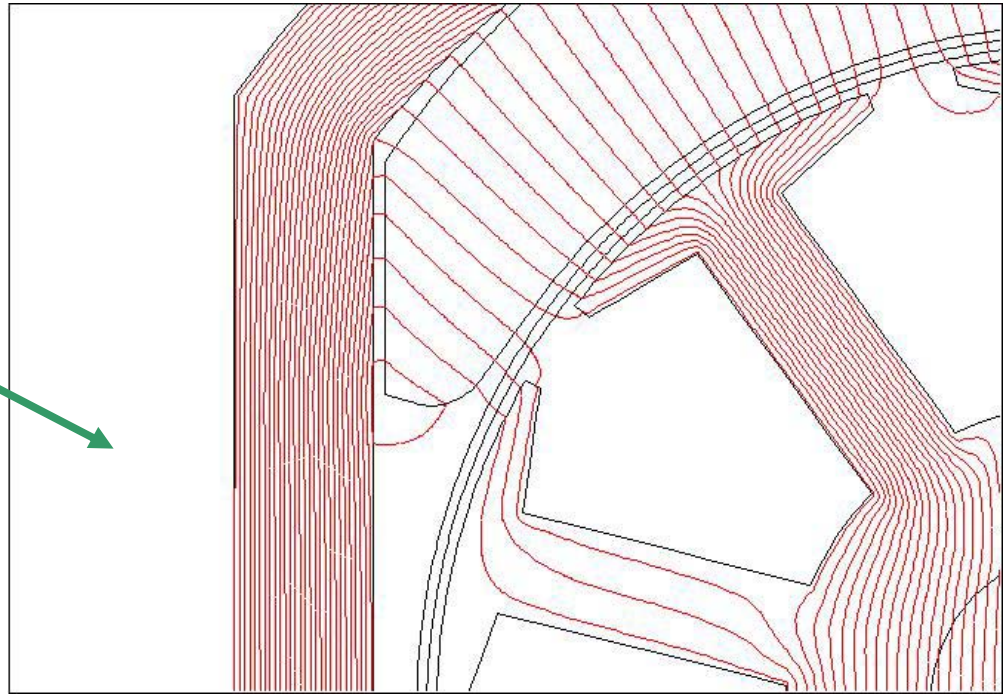
Outlines.

- ✓ Origins and basic phenomenon.
- ✓ Cogging torque minimizing methods.
- ✓ Measuring the magnetic orientation.
- ✓ Tuning the magnetic orientation.
- ✓ Conclusions

Introduction.



The cogging torque is due to a variation of the magnetic energy in the air-gap



each time a slot passes in front of one magnet end

Cogging torque concerns NOISE and VIBRATIONS

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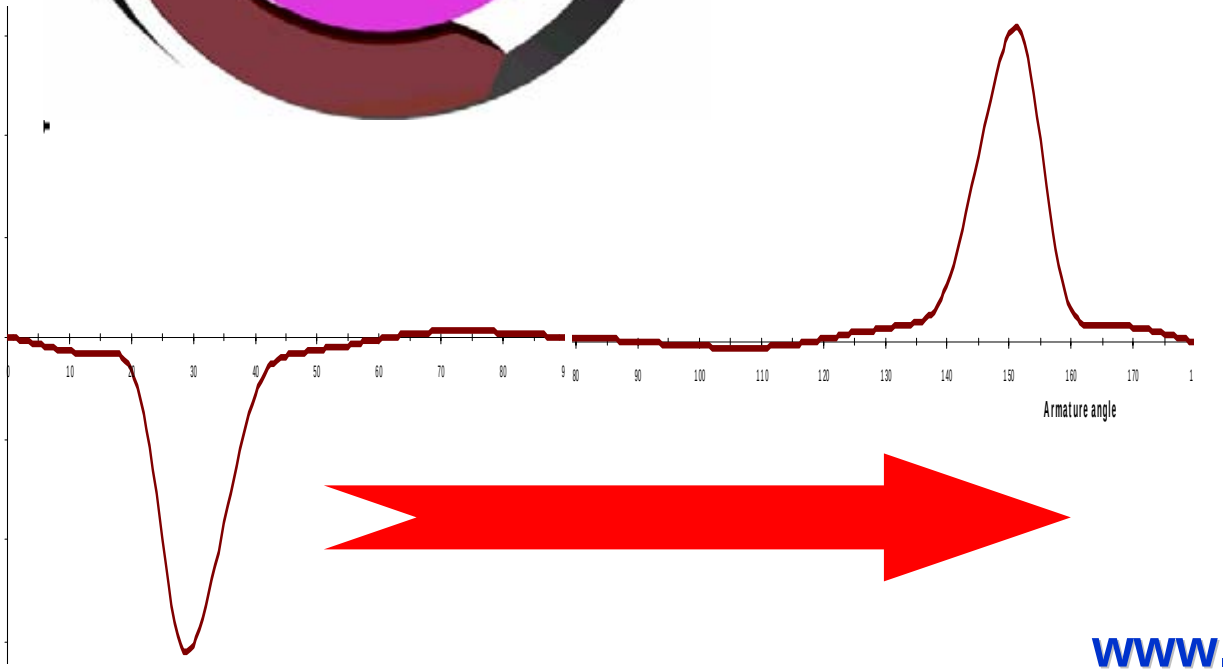
Torque pulses.

2 poles

2 teeth

Each time a single slot passes in front of a magnet end



Torque pulses

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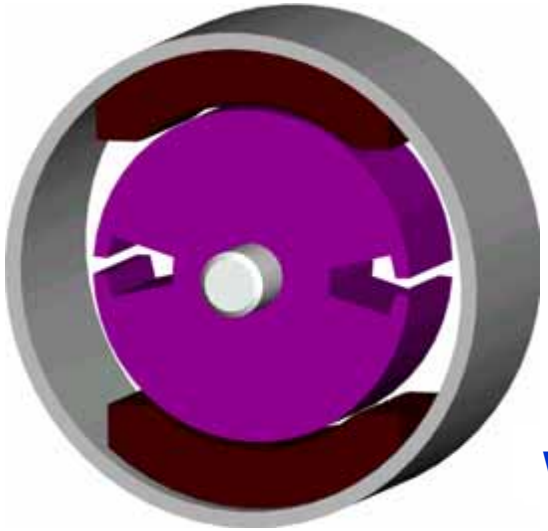
Pulses combination (X teeth, 2 poles).

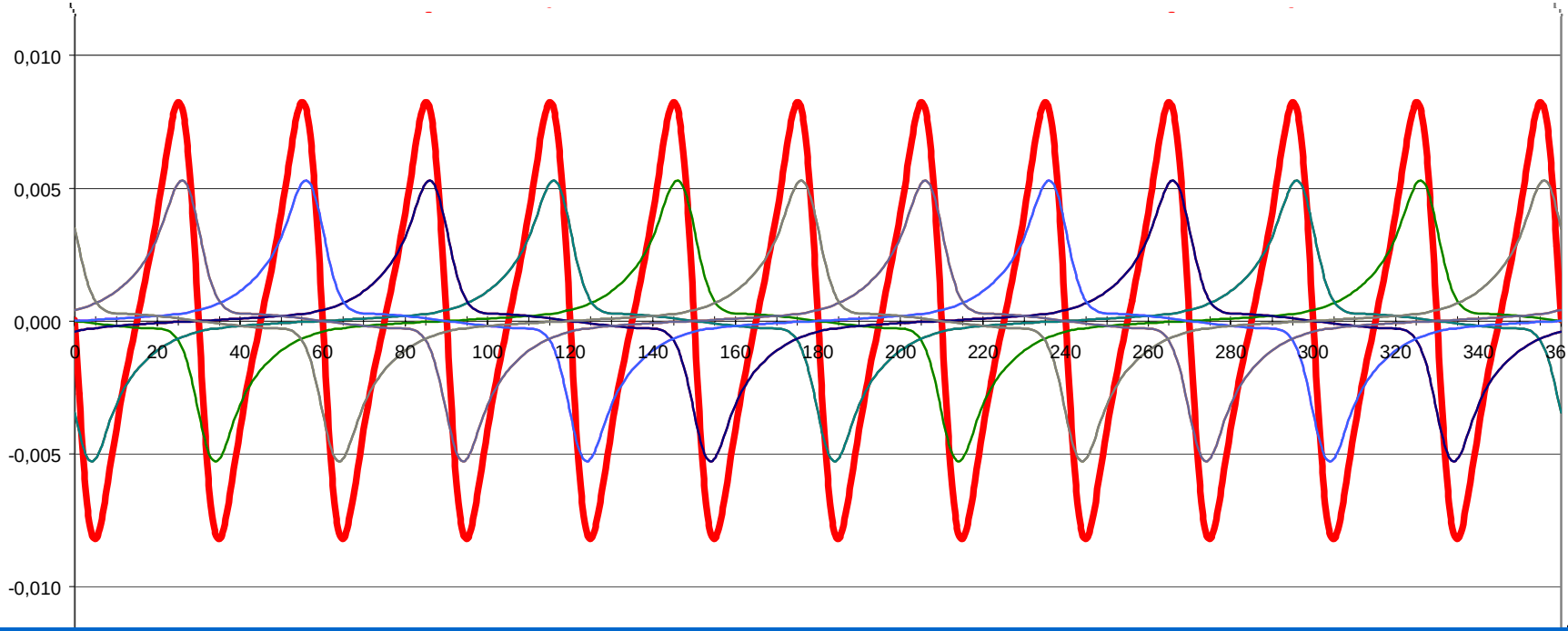


With 12 slots

Cogging torque

=

addition of the torque pulses generated by all the slots moving under all the magnets ends



3 complementary ways to minimize the cogging torque

- ✓ ① By smoothing the variation of the magnetic energy when each slot passes in front of a magnet end
- ✓ ② By compensating two torque pulses generated at the two ends of each magnet
- ✓ ③ By compensating the torque pulses generated by all the magnets.

All impact magnetic flux

Flux / cogging torque optimization

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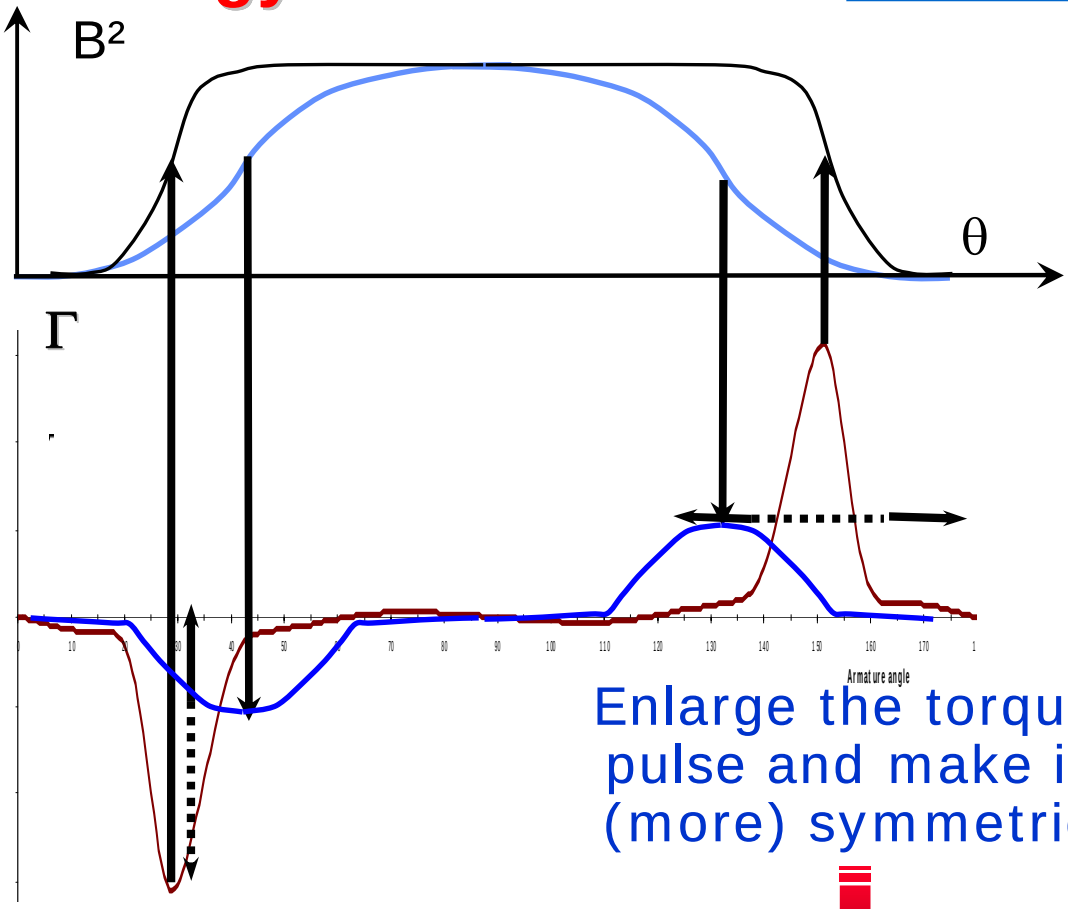
Minimizing the magnetic energy variations.

Torque $\Gamma = \frac{\partial W}{\partial \theta}$

Magnetic energy $W = \iiint_{Vair-gap} \frac{1}{2} \cdot \frac{B^2}{\mu 0} dv$



Minimize the amplitude

Peak to peak torque decrease

Enlarge the torque pulse and make it (more) symmetric

Robustness / variations of dimensions

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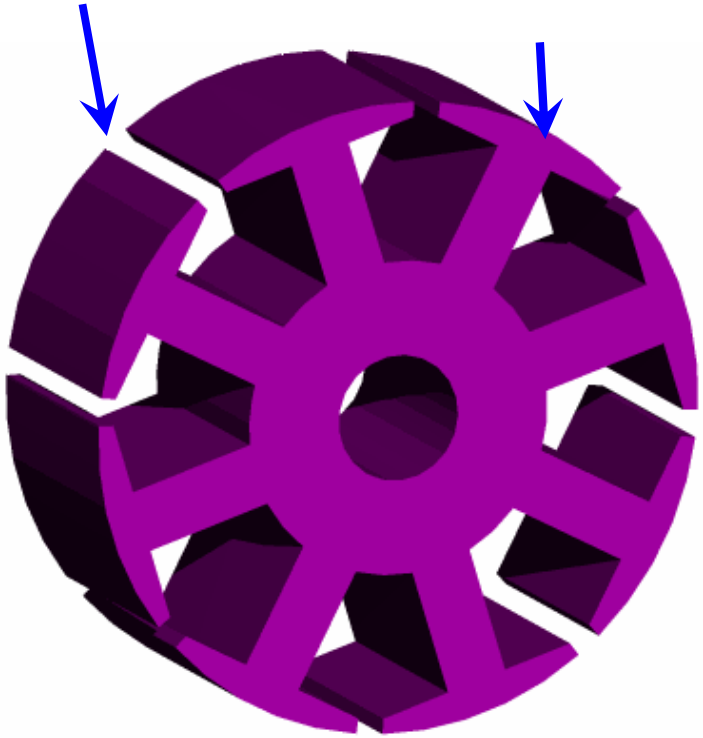
Parameters to minimize the magnetic energy variations.

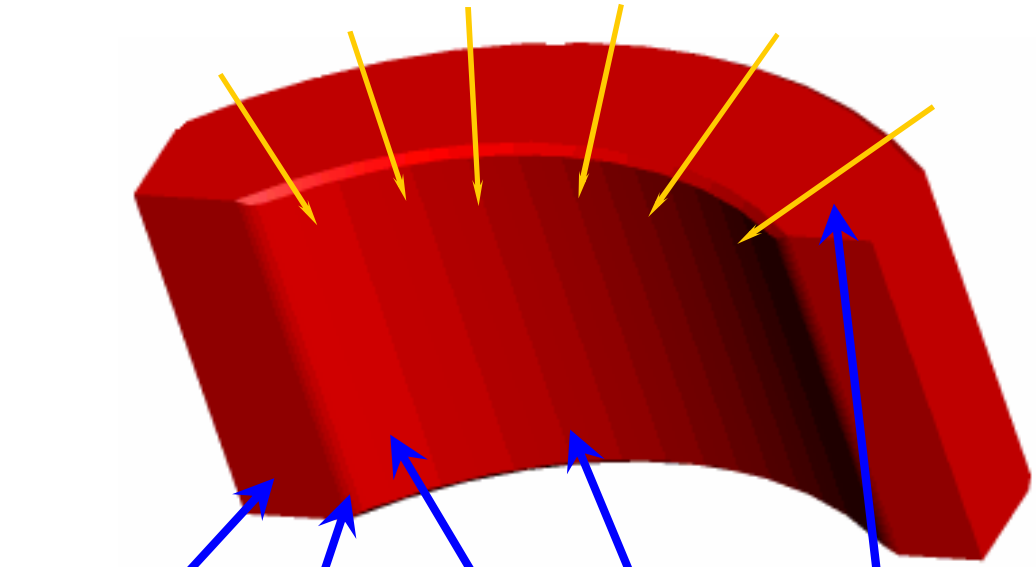
armature

Slot opening

Shape of the teeth



segment



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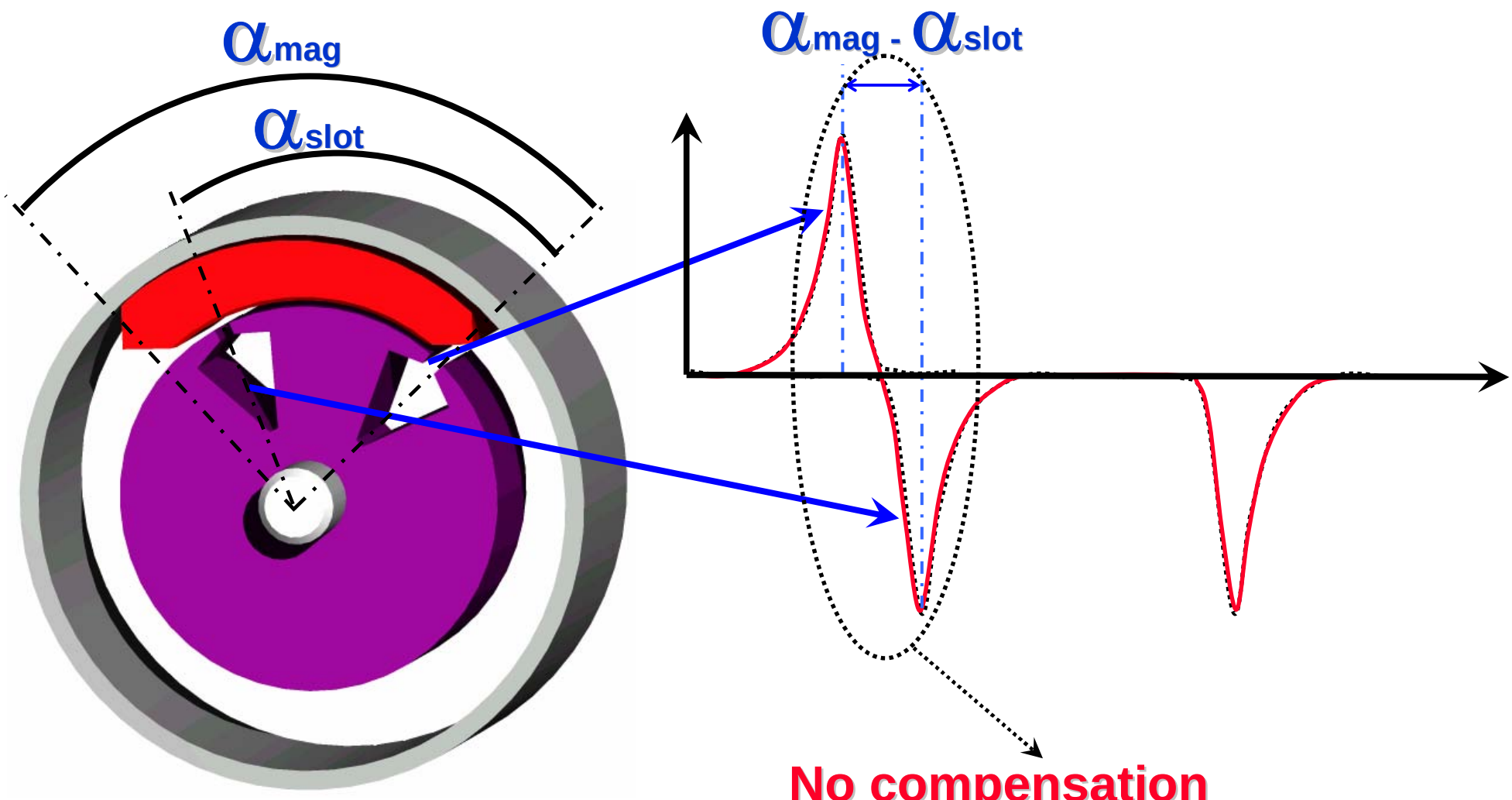
Pulses compensation within a single magnet.



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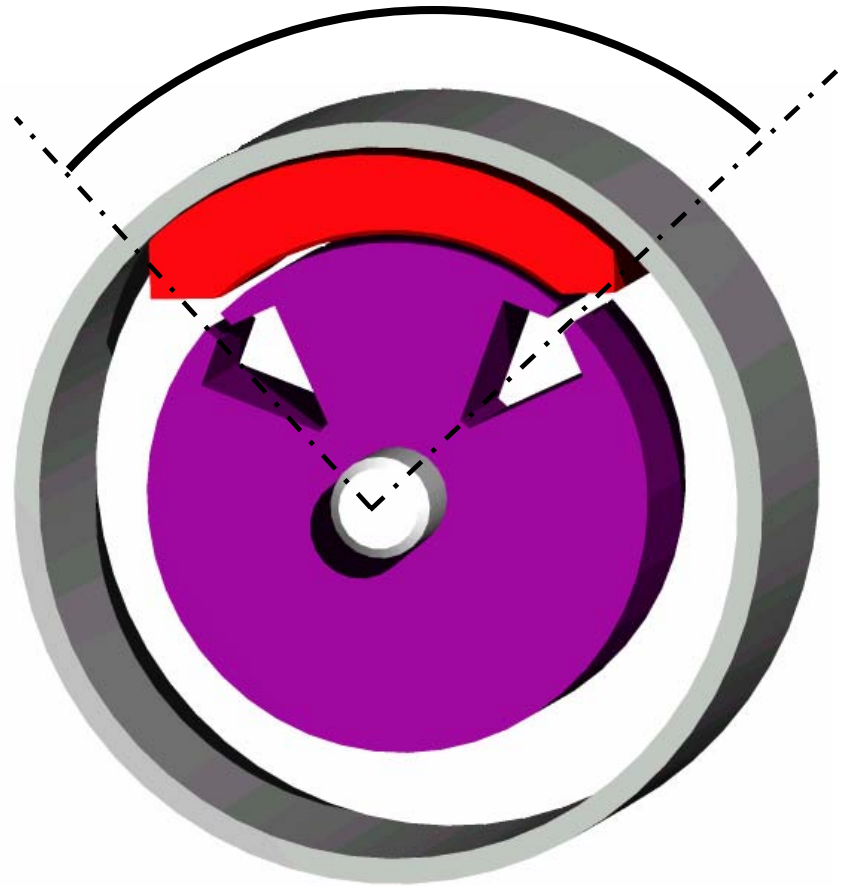
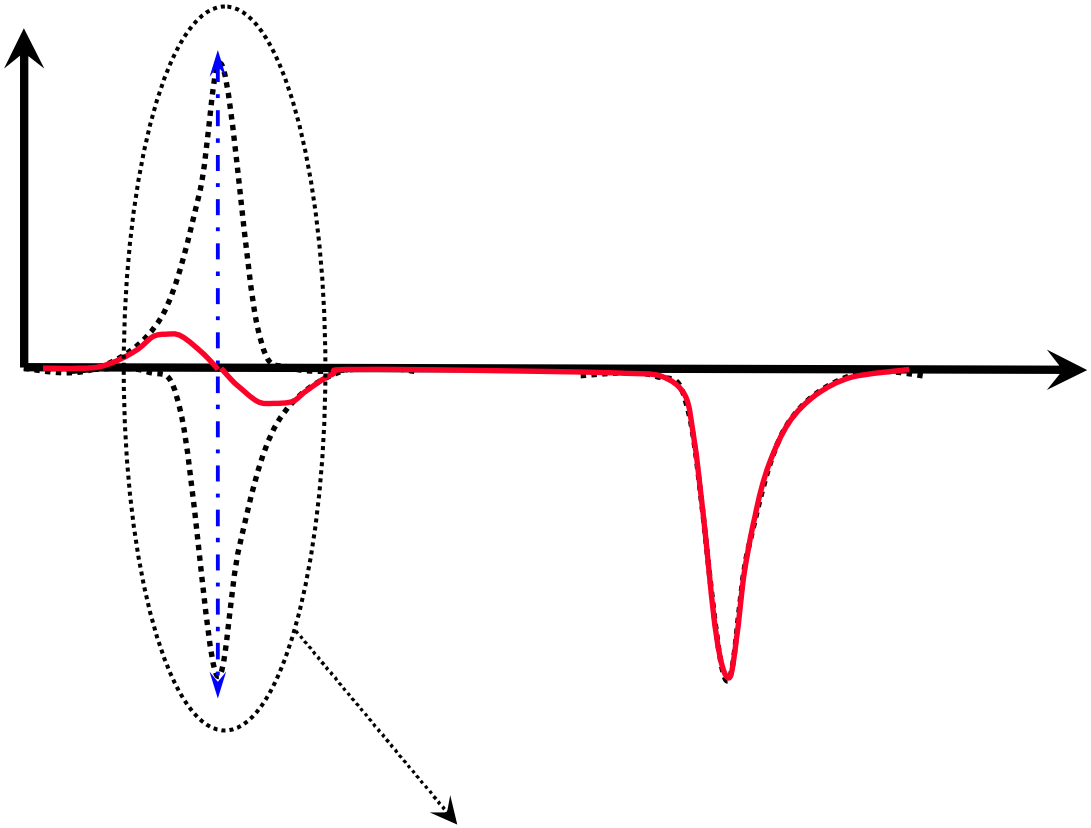
Pulses compensation within a single magnet.

$\alpha_{mag} = \alpha_{slot}$





Good compensation

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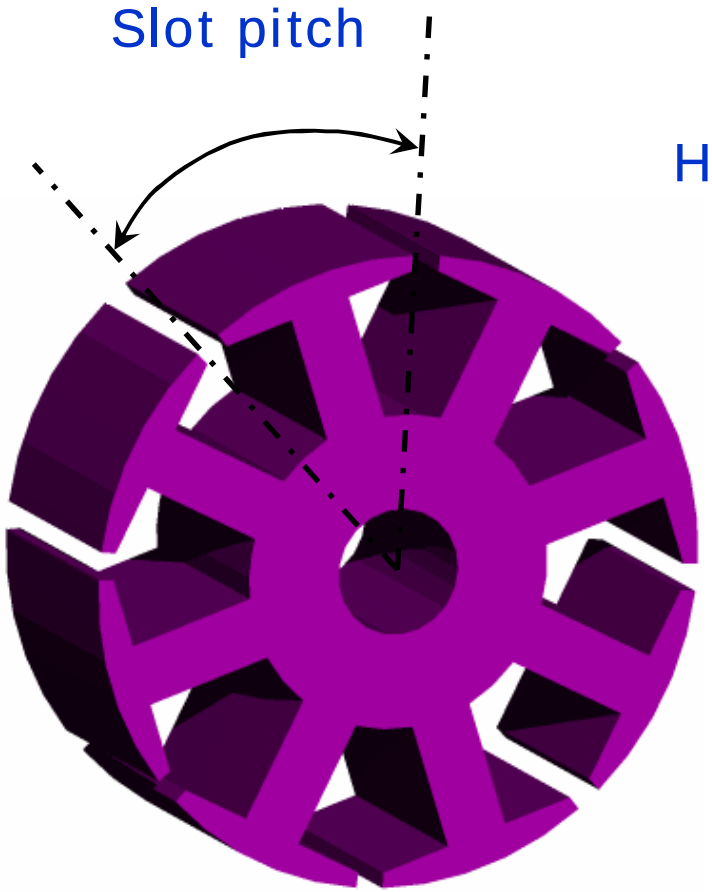
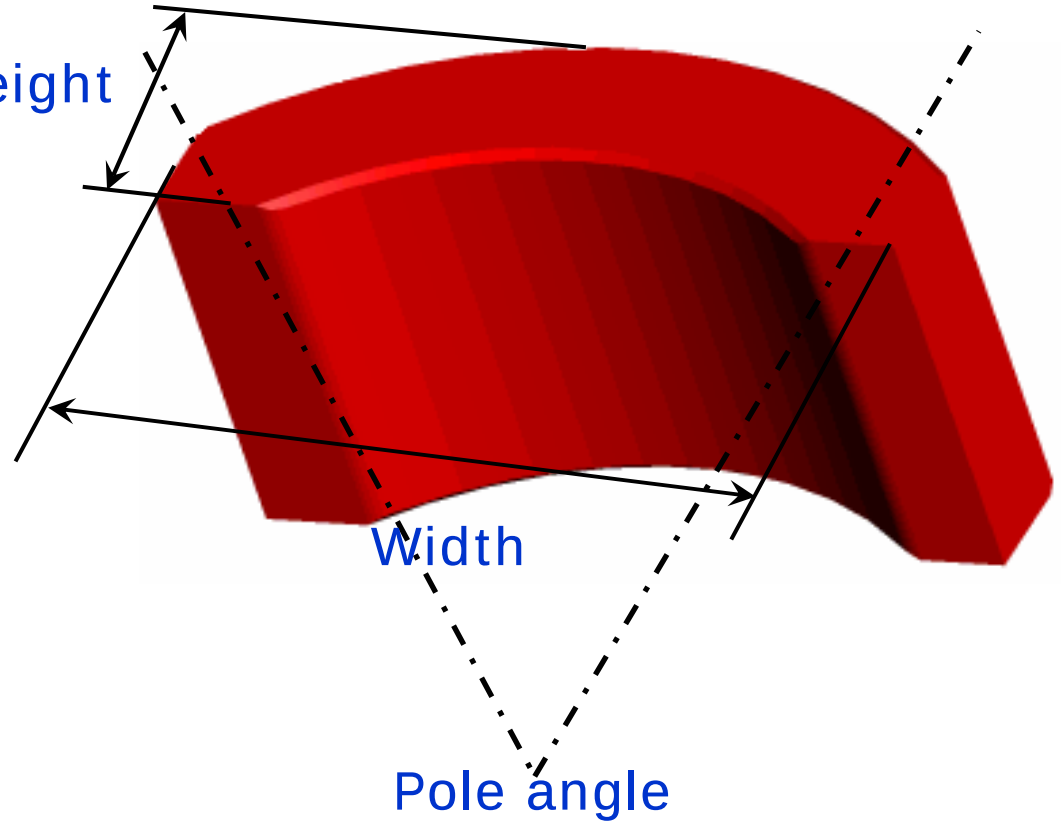
Parameters to adjust pulses compensation within a single magnet.

armature



segment



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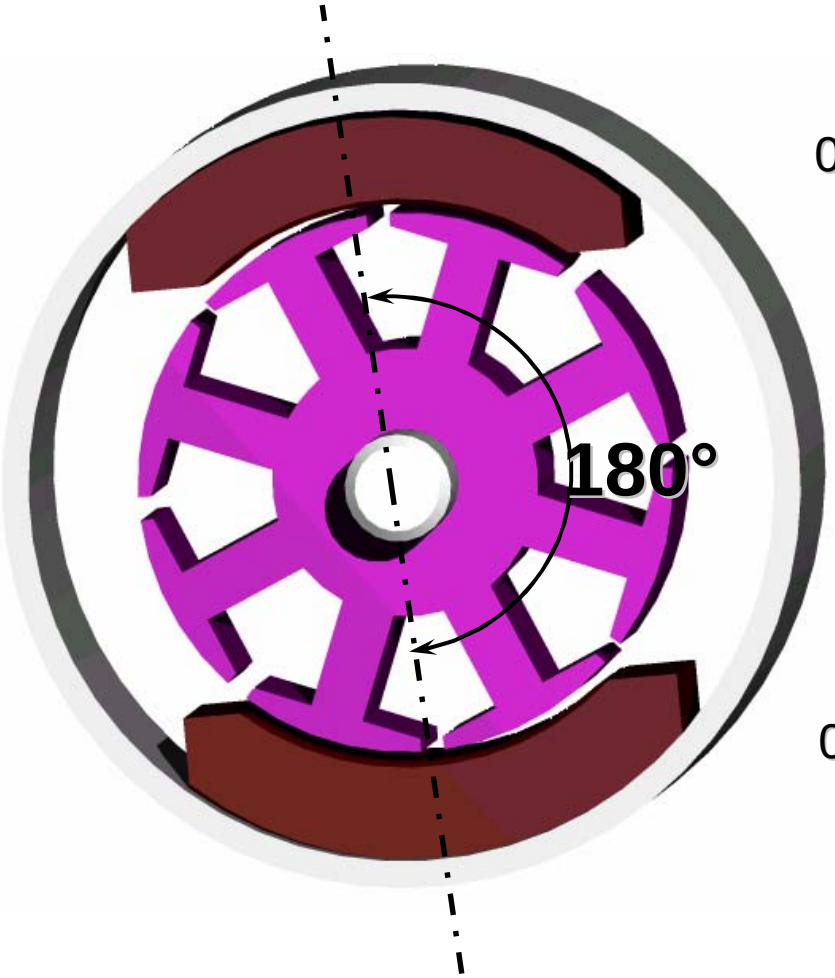
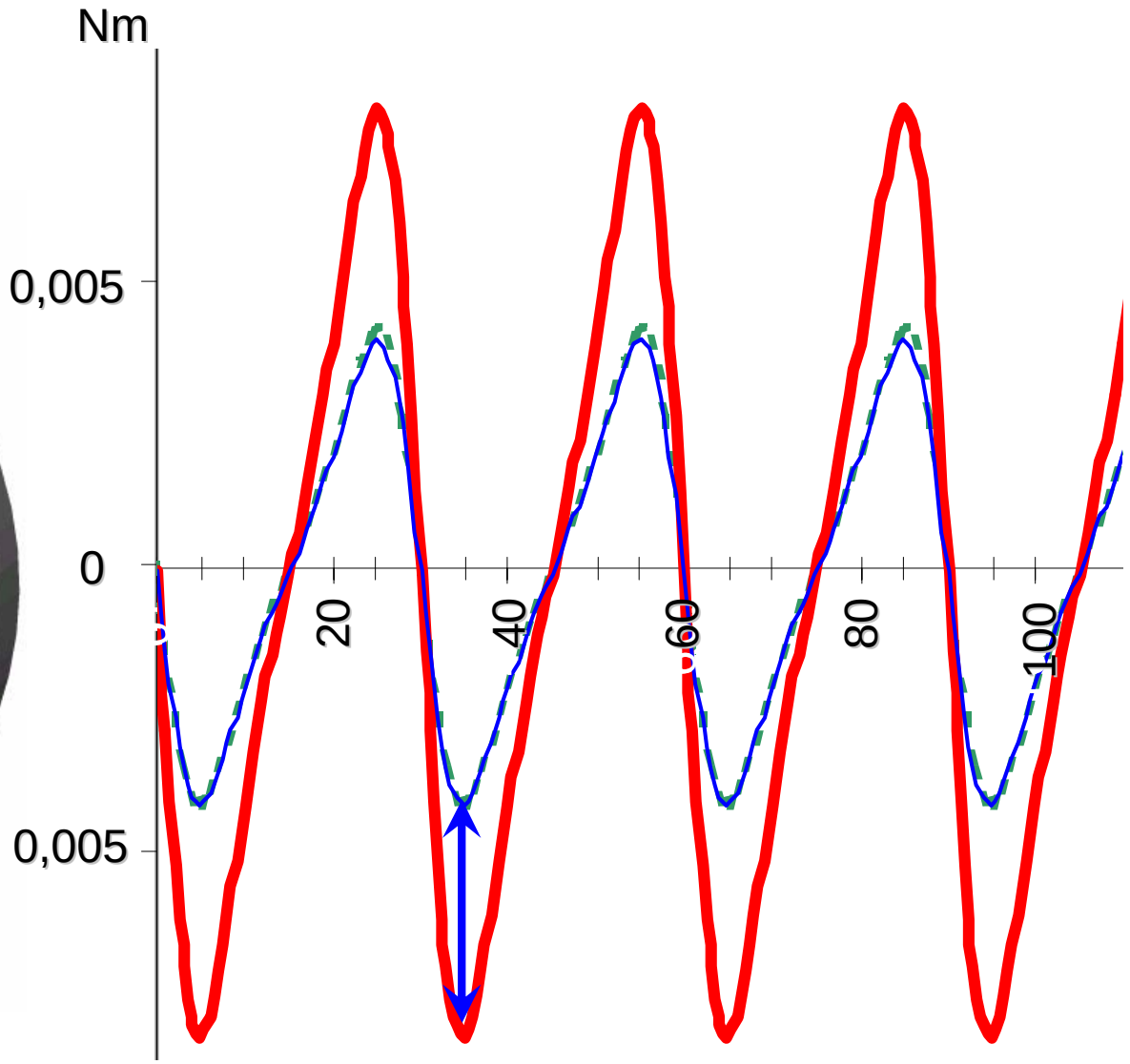
Pulses compensation over several magnets.





No compensation

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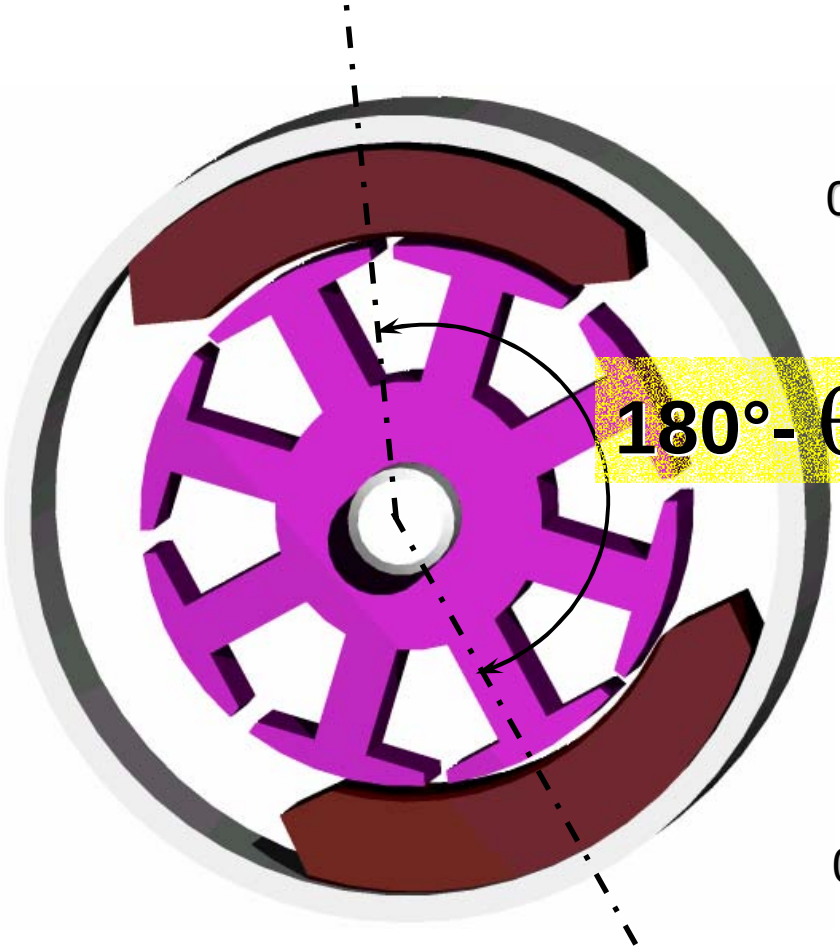
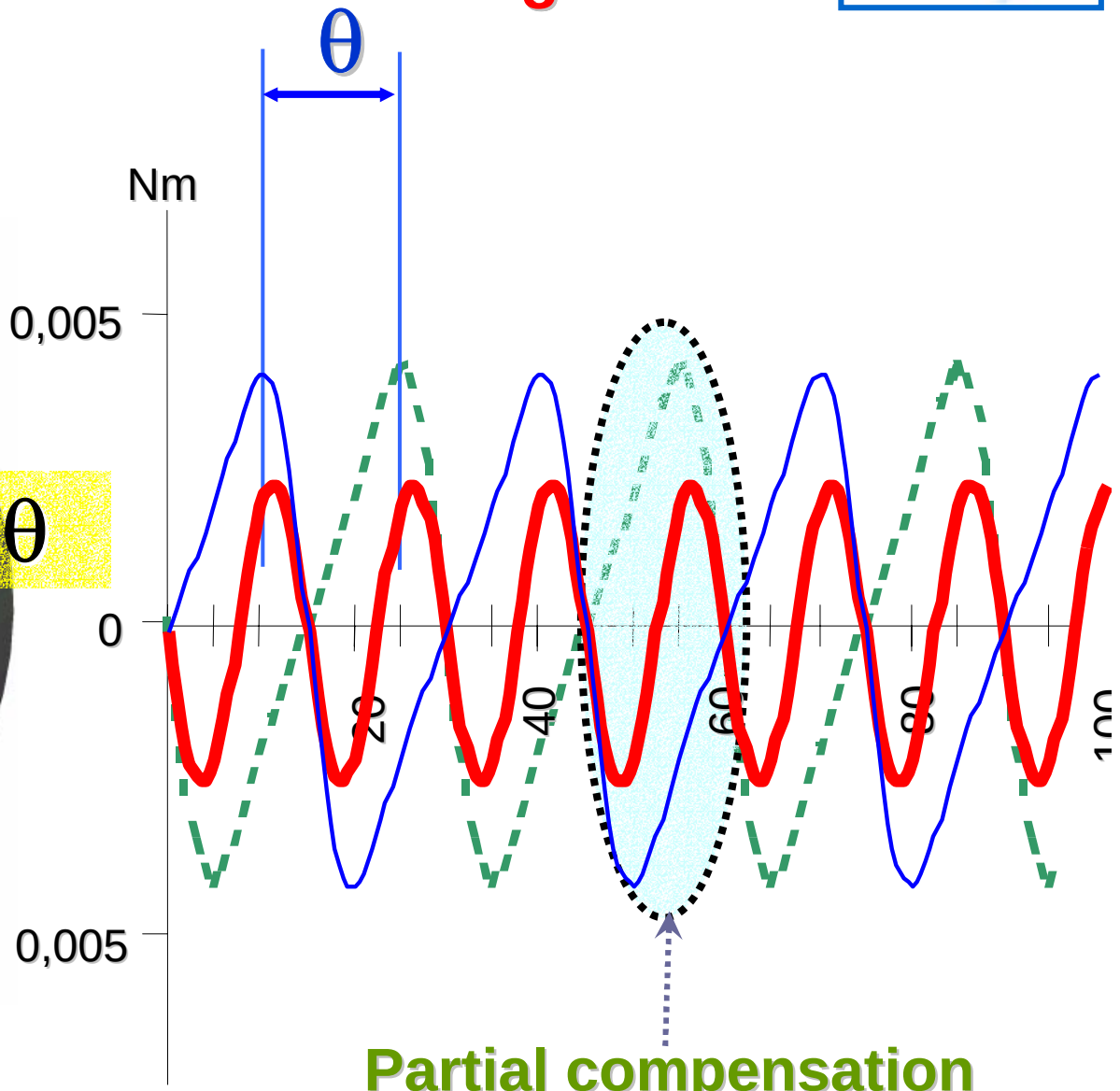
Pulses compensation over several magnets.

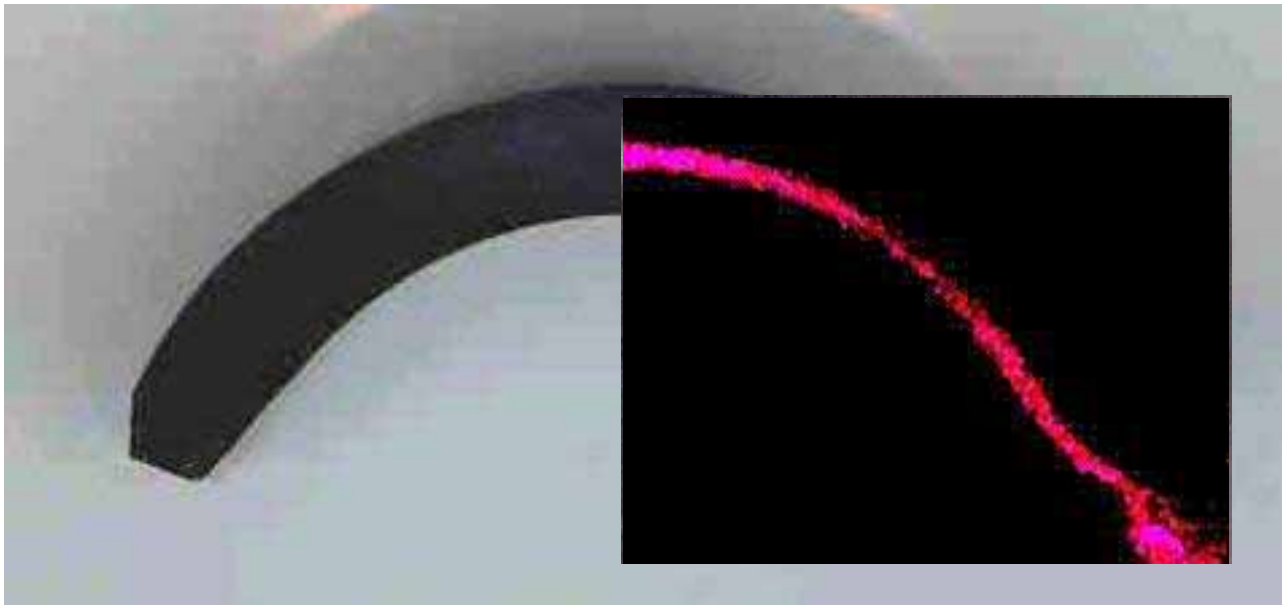




Partial compensation

Full compensation at θ = Slot pitch / 2

Simple and fast method.



Magnet (Preferably cut widthwise)

Magnetic paper (neutral zone visualization)

But depends on both the geometry and the orientation

Digital enhancement

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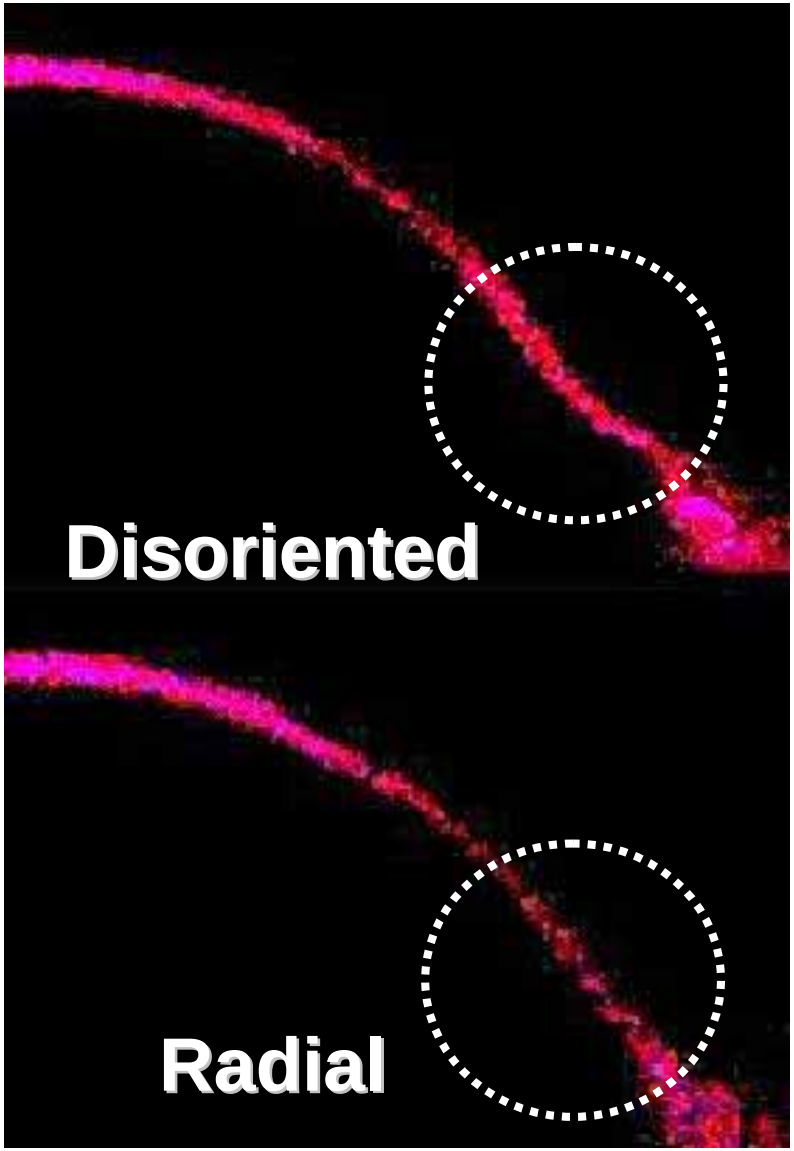
Fast comparison between two similar magnets.



- ✓ Impacted by any surface defect (chips, chamfer…).
- ✓ Only to compare magnets with rigorously the same shape.
- ✓ No quantified data.

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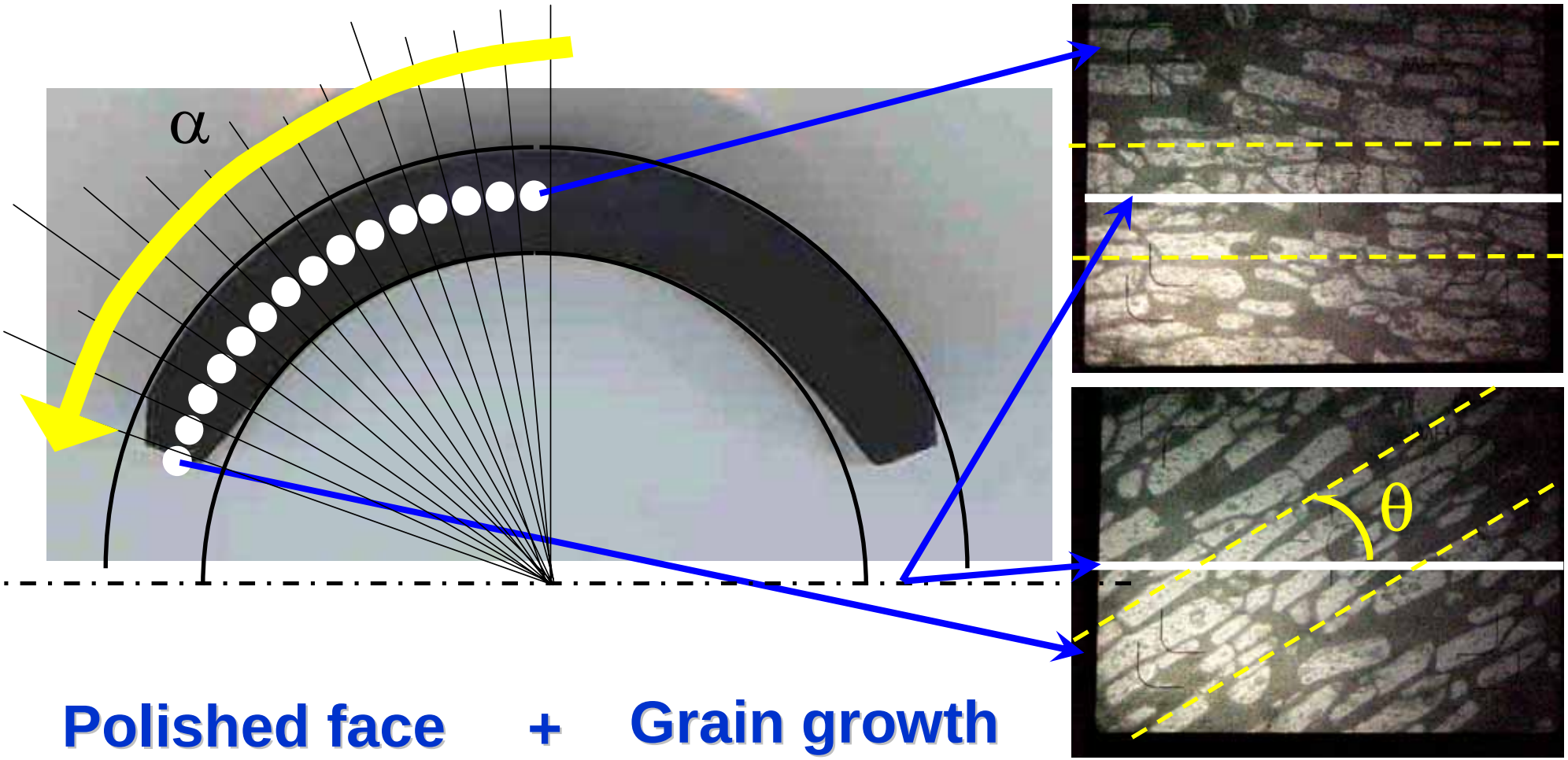
Quantitative method.



Polished face + Grain growth

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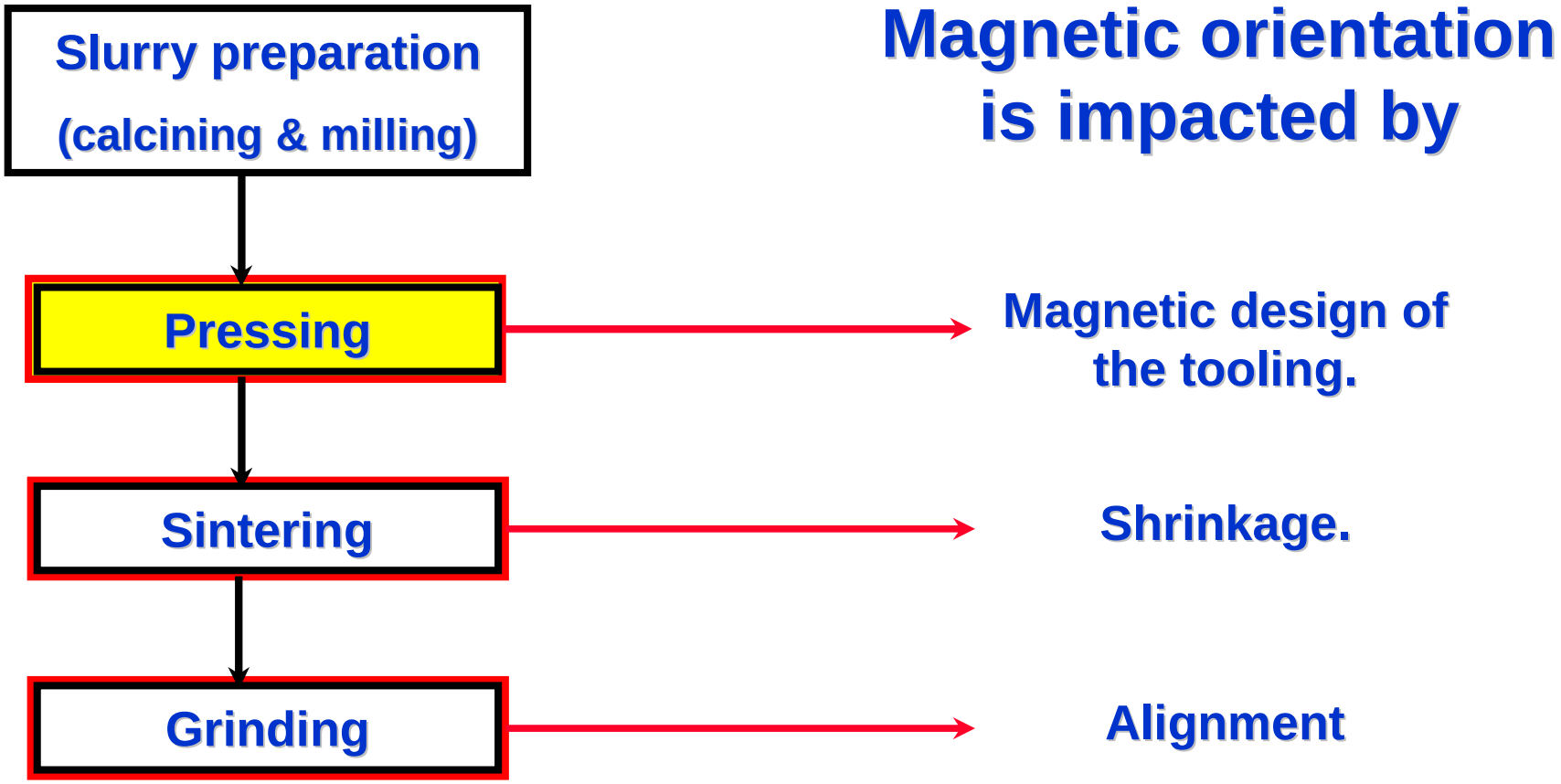
The magnetic orientation in the ferrite manufacturing process.



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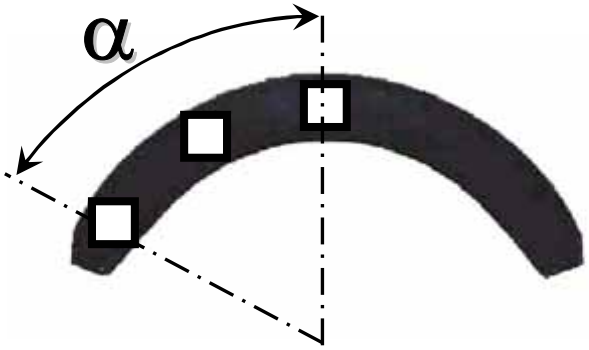
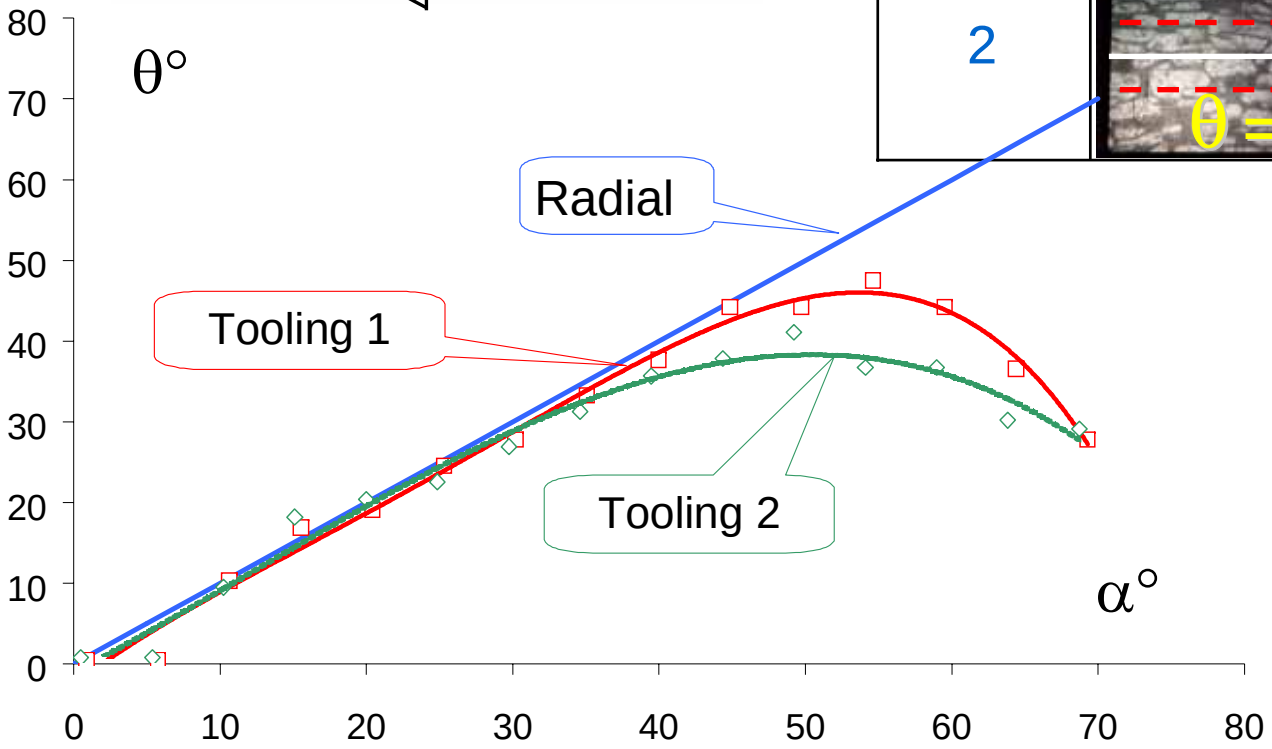
Incidences of different press tooling designs.



Tooling	α = 0°	α = 55°	α = 70°
1	θ = 0°	θ = 33°	θ = 26°
2	θ = 0°	θ = 43°	θ = 25°



Impact the cogging torque

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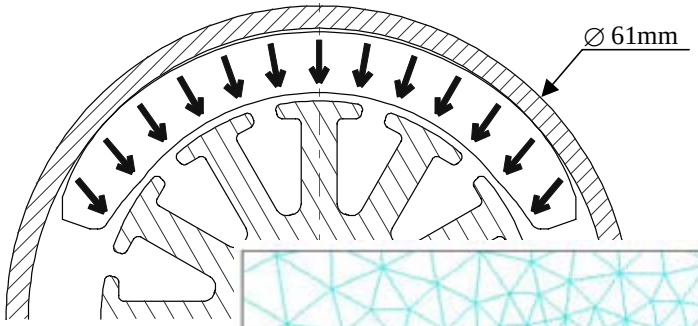
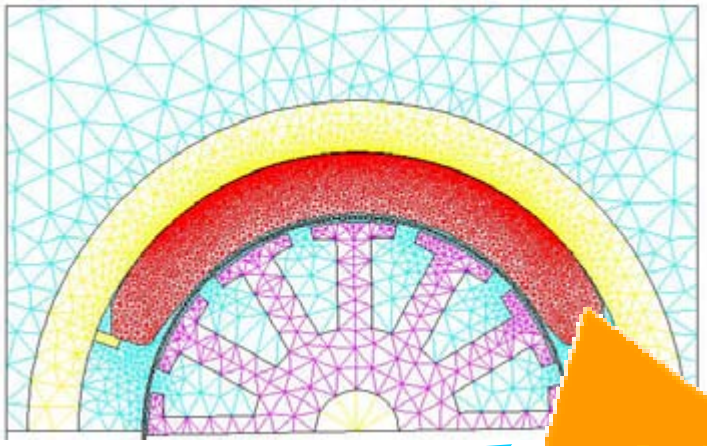
Finite elements modeling.



Motor geometry

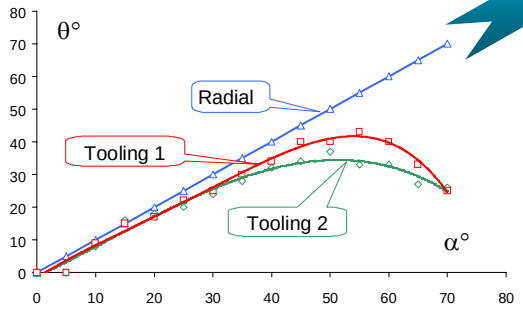


2D geometry:

- ✓Geometric parameters;
- ✓Standard components;
- ✓Rotating bandwidth.

Solving process:

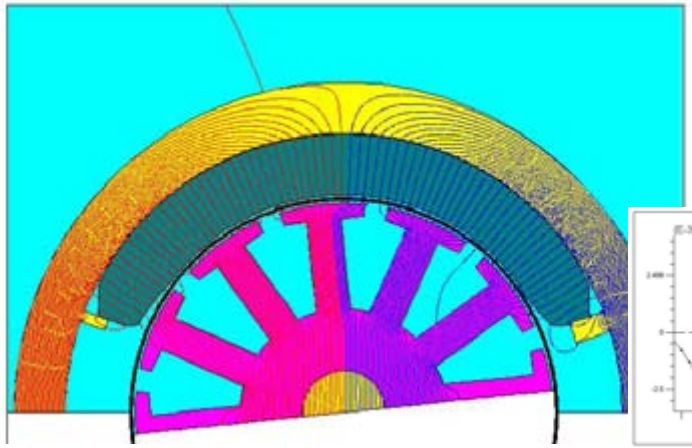
- ✓Non linear ;
- ✓Parametric;
- ✓Along one tooth pitch.

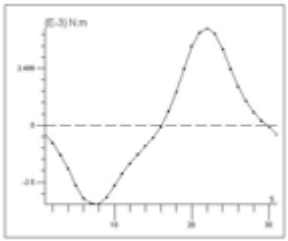


USRMAG routine

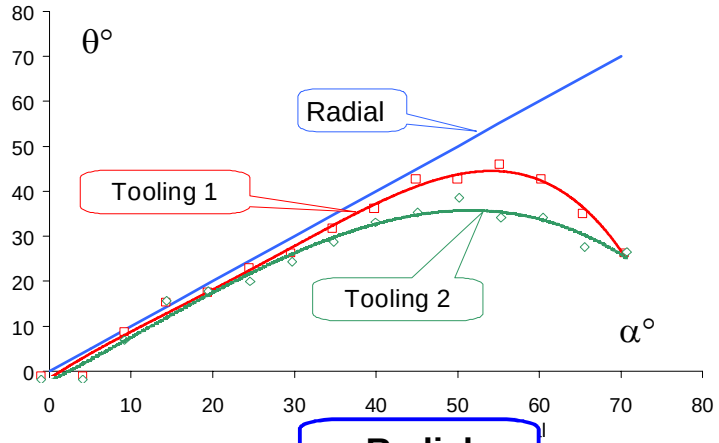
Results analysis:

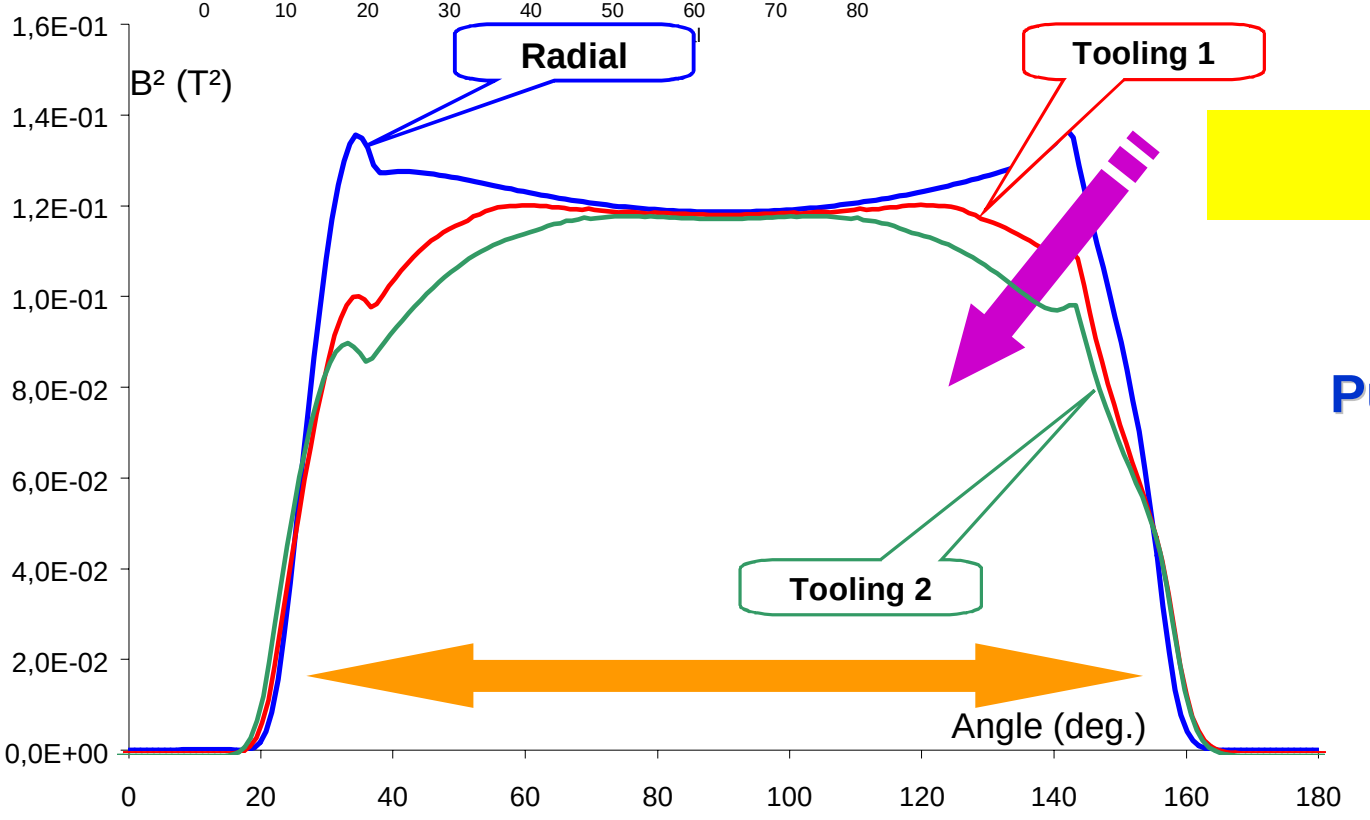
- ✓Cogging torque;
- ✓Flux.





Effect on the B² distribution.





Smoothed B² variations

Magnetic energy variations decrease

OPTIMUM

Pulses compensation impacted

Pole angle change

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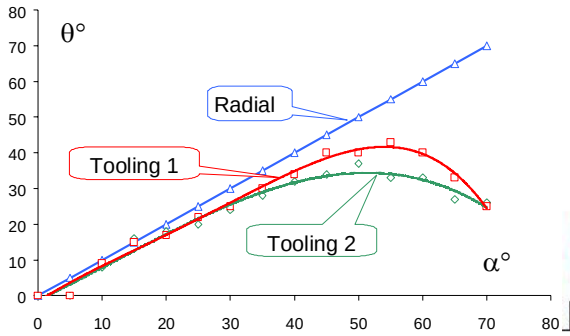
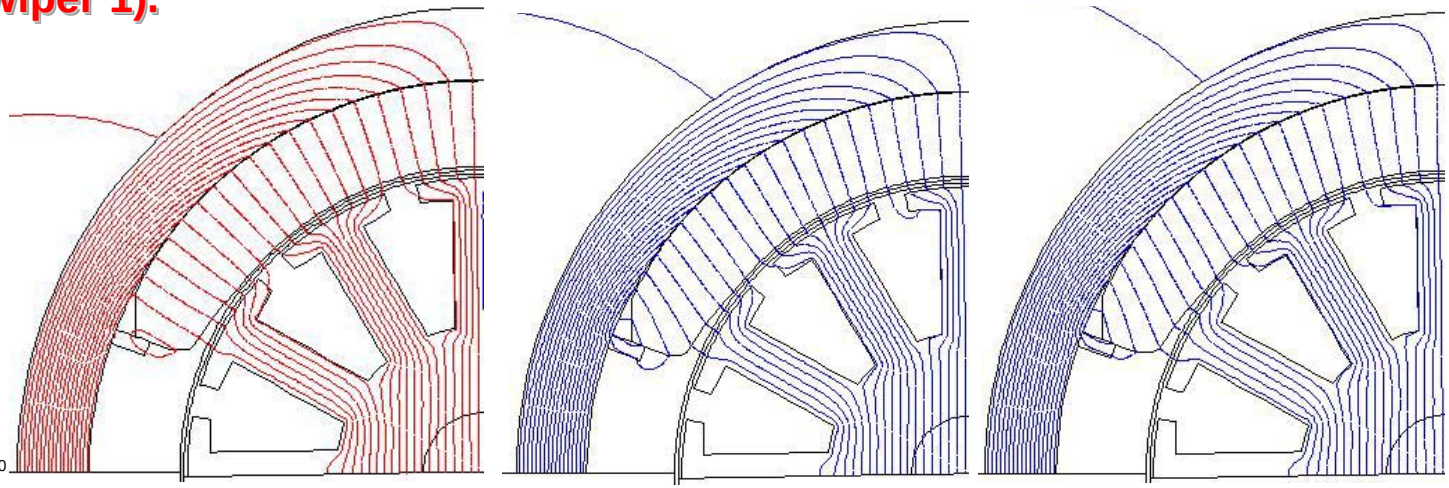
Results (front wiper 1).





Tooling		Radial	1	2
Peak to peak cogging torque (mNm)	Calc.	21.7	13 (-40%)	15.6 (-28%)
	Meas.	21.6	10.2 (-53%)	17.4 (-20%)
Flux (mVs)	Calc.	0.552	0.545 (-1.3%)	0.532 (-3.6%)
	Meas.	0.65	0.638 (-1.8%)	0.622 (-4.2%)

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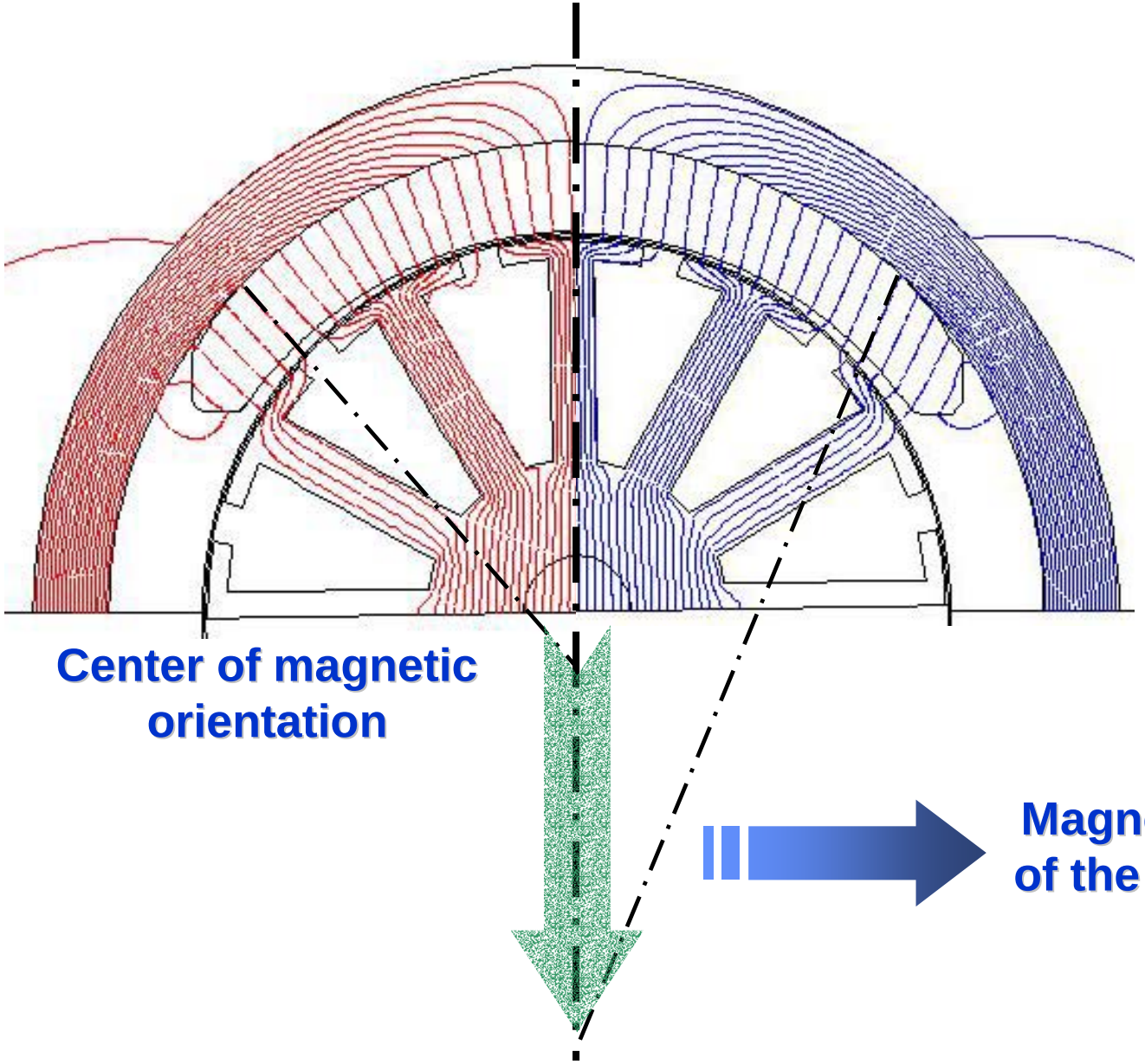
Optimizing the press tooling structure.



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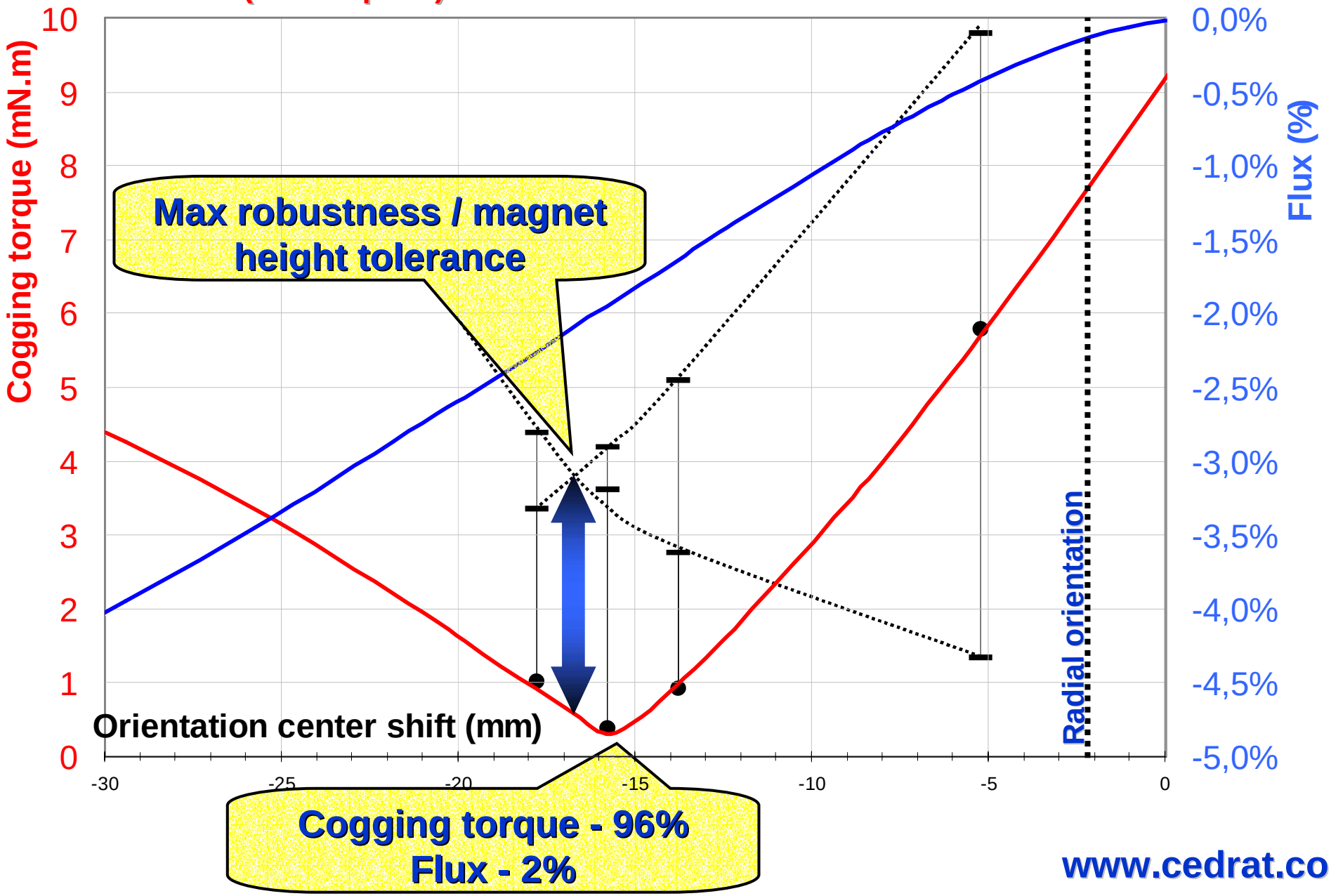
Results (front wiper 2).



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Results and economical aspects (front wiper 2).

Tooling parameter (mm)		0 (radial)	-5	-10
Peak to peak cogging torque (mNm)	Calc.	7.7	5.9 (-23%)	2.8 (-64%)
	Meas.	7	6.2 (-11%)	4 (-43%)

Not radial !

Require to manufacture different tooling.

COST!

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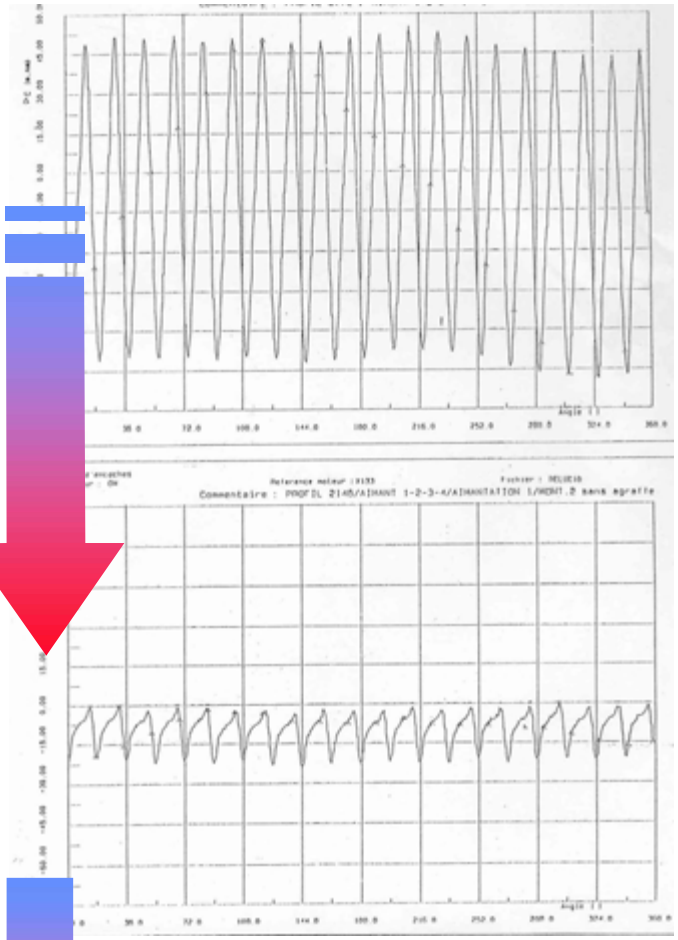
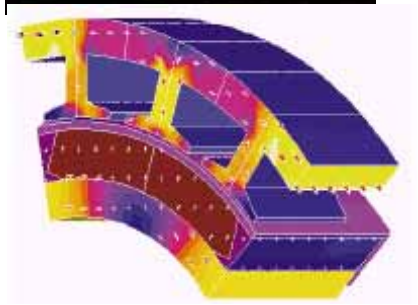
a multi parameters solving procedure involving …





Material tuning and characterization techniques

Magnetic modeling (pressing & motors)

Motor measurement capabilities

… that requires a multi expertise know how.

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