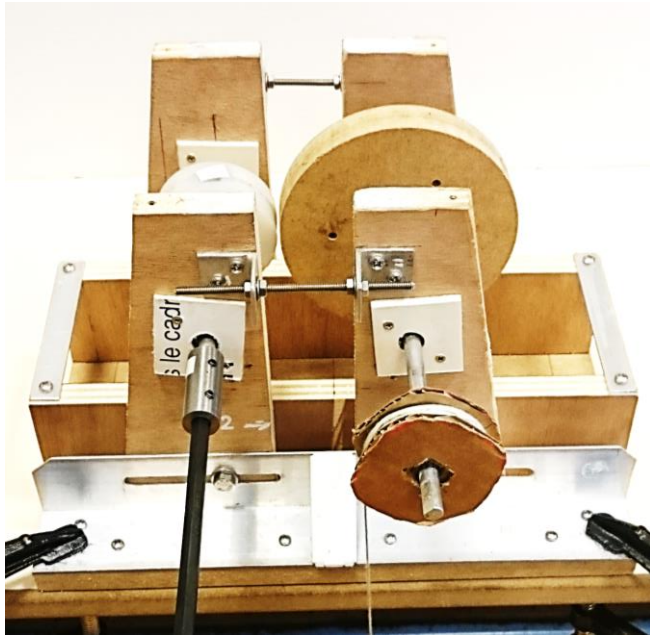
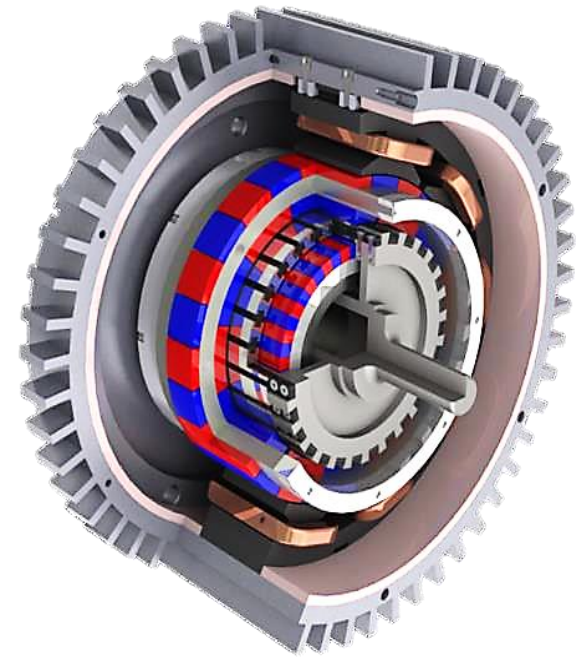


# Engrenage magnétique



*Réalisation d'un  
engrenage magnétique*

*Etude de ses  
performances*

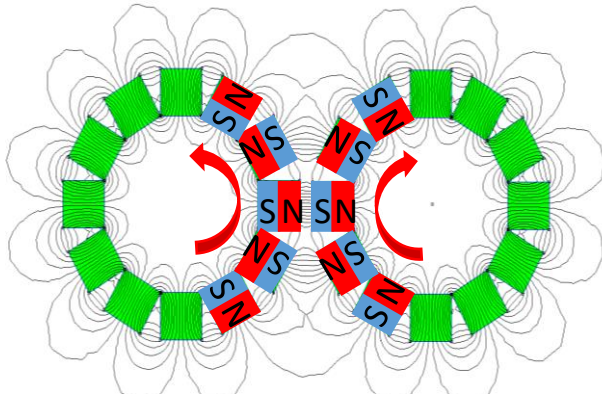


MAGSPLIT, par Magnomatics

# Sommaire

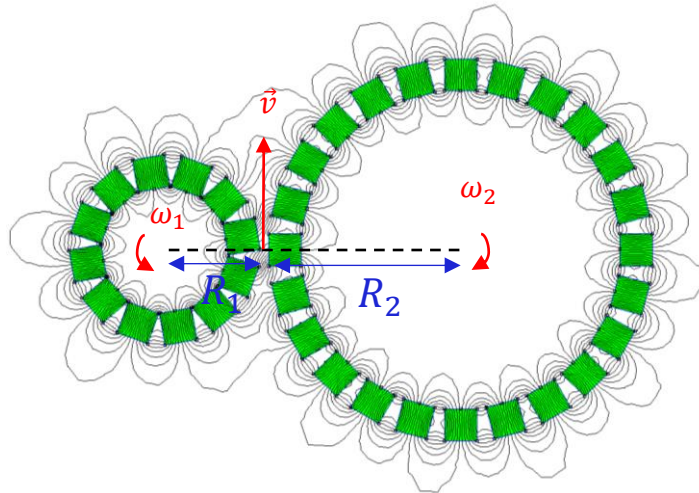
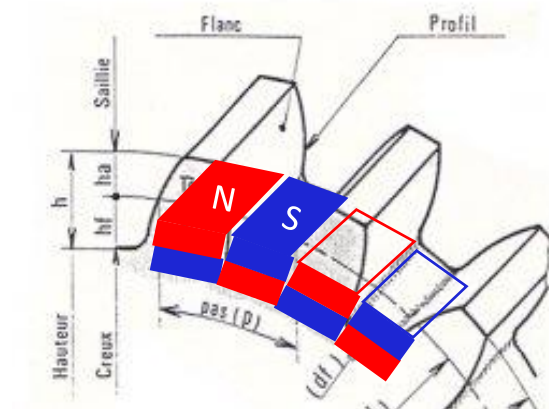
- Réalisation de l'engrenage
  - Principe de fonctionnement et condition d'engrènement
  - Réalisation de la maquette
- Etude théorique du fonctionnement du réducteur
  - Modélisation de la transmission de couple
  - Mesure de la force magnétique
  - Simulations
- Validation expérimentale du modèle théorique
  - Mesure du rapport de réduction
  - Mesures du couple transmissible

# Principe de fonctionnement et condition d'engrènement



- Condition d'engrènement

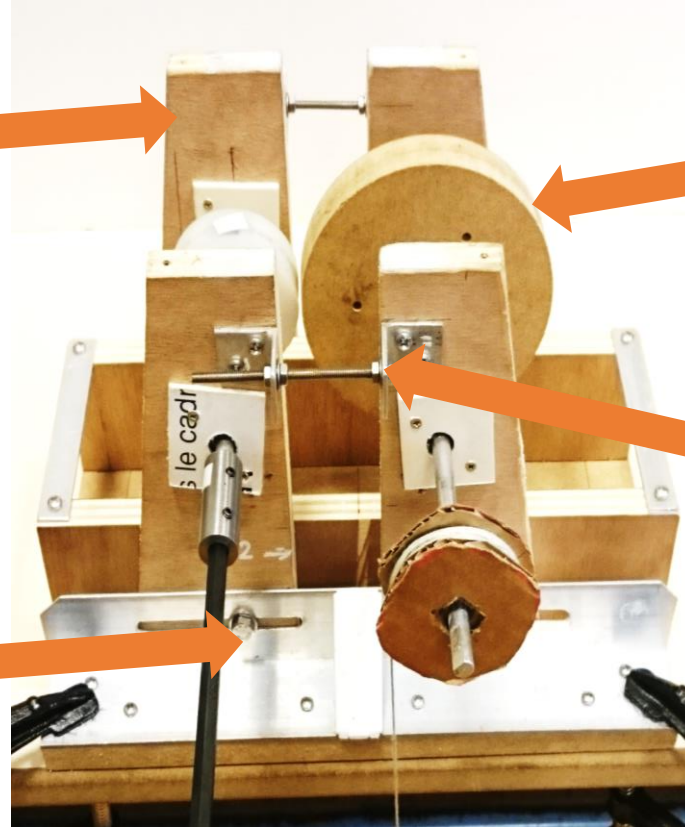
Même module :  $\frac{D_1}{Z_1} = \frac{D_2}{Z_2}$



# Réalisation de la maquette

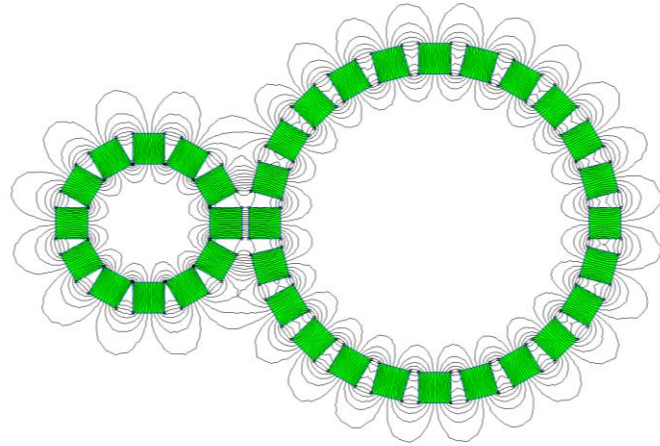


# Réalisation de la maquette



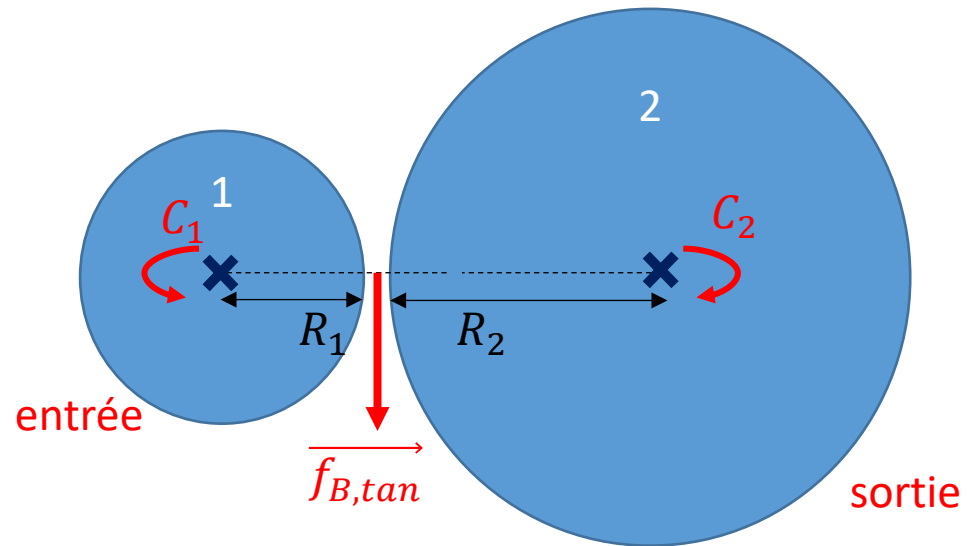
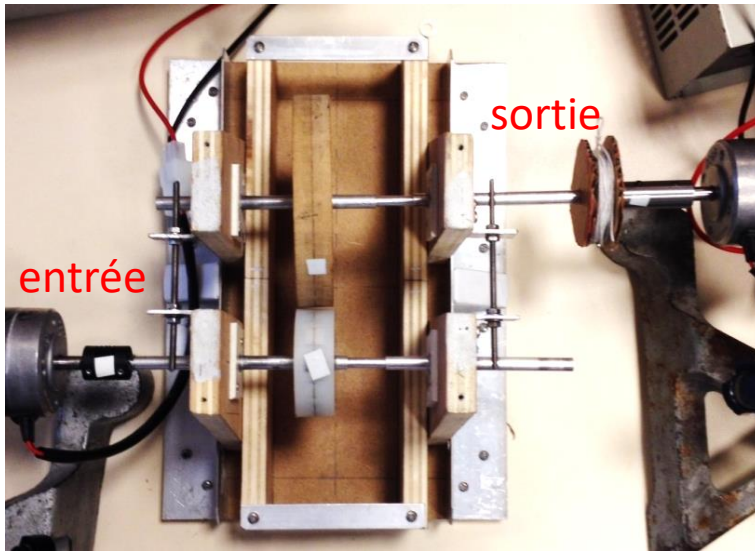
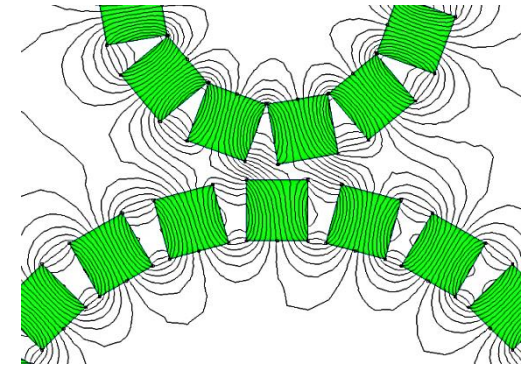


# Transmission du couple



En régime permanent :

- TMC sur {1} :  $f_{B,tan} = \frac{C_1}{R_1}$
- TMC sur {2} :  $C_2 = R_2 * f_{B,tan}$

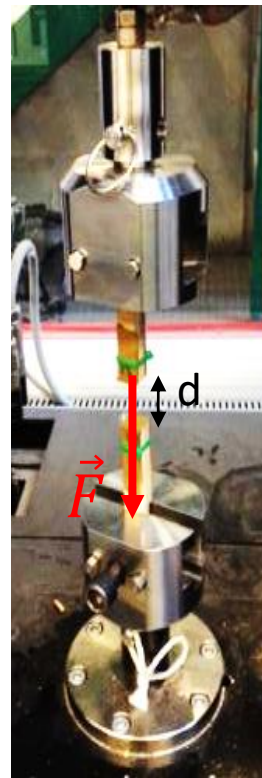
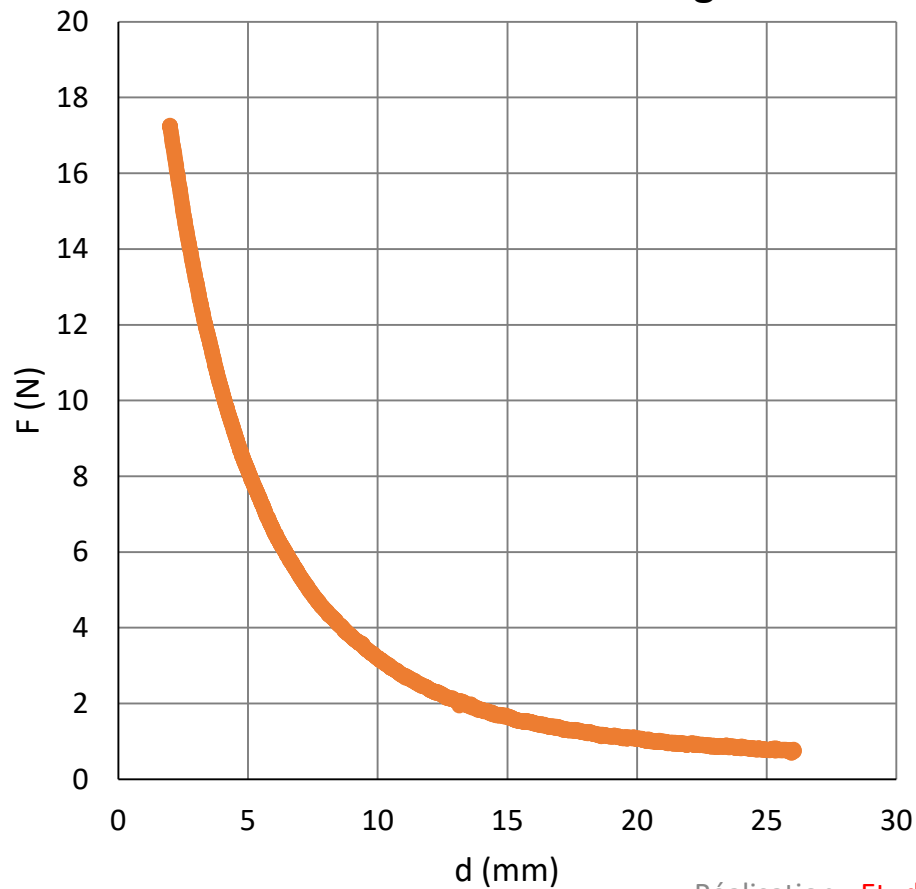


Pour notre système,  $Z_1 = 6$ ,  $Z_2 = 12$  donc  $\rho = \frac{1}{2}$

# Mesure de la force magnétique

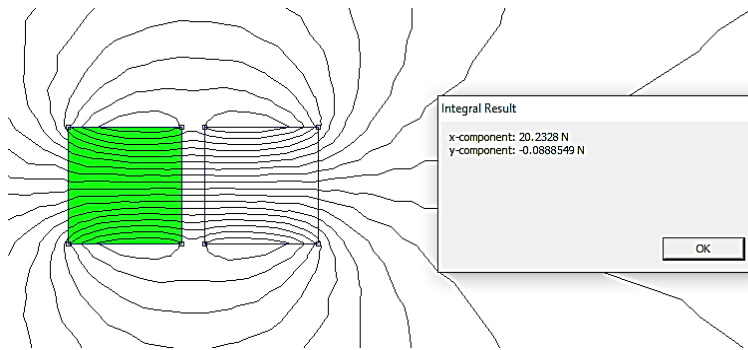
- Avec une machine de traction

Force en fonction de l'allongement



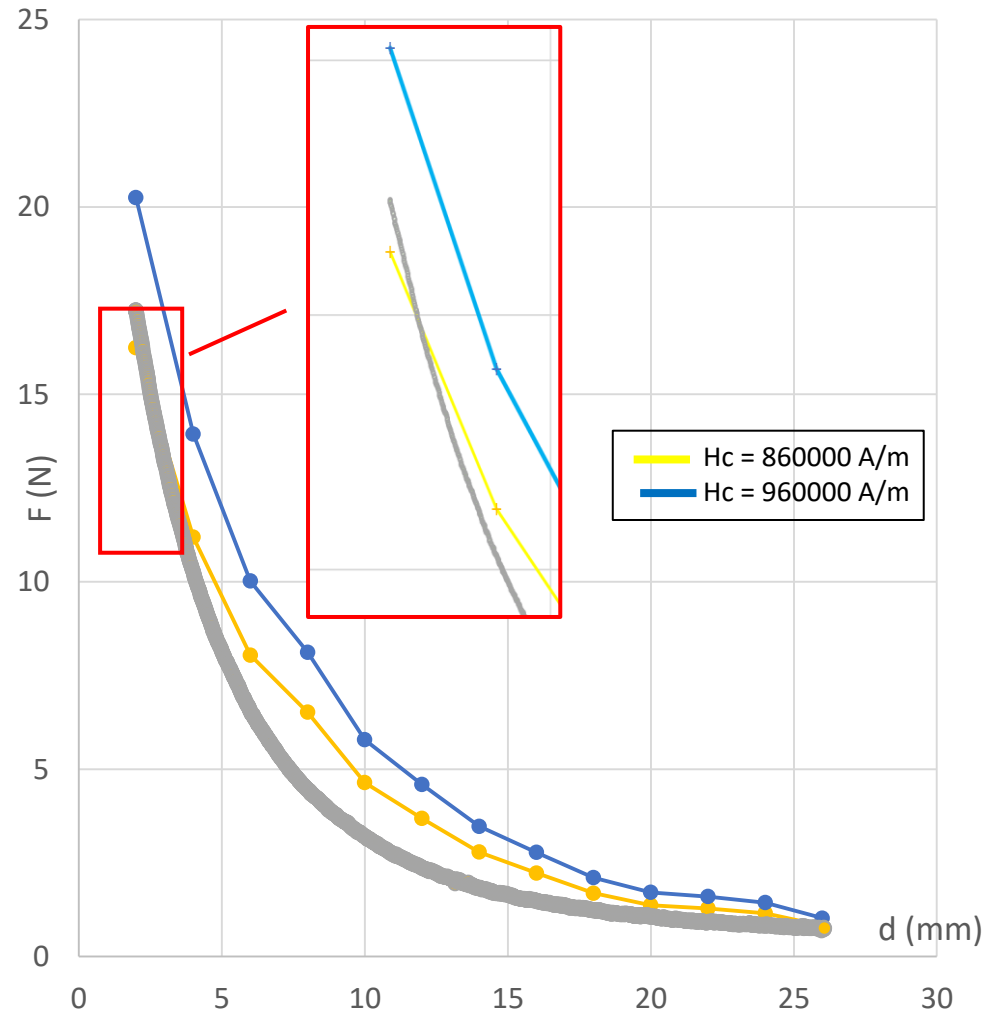
# Caractérisation de $H_c$ de l'aimant

- Simulation FEMM



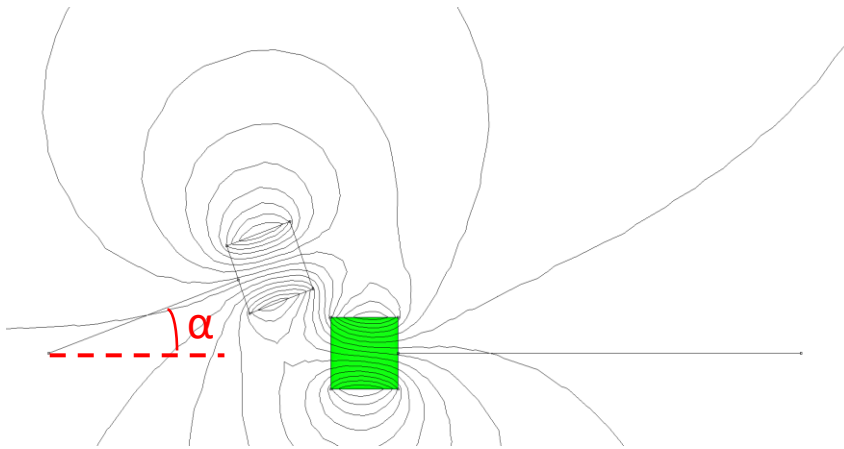
Dans l'intervalle de  $d$  correspondant au système, on a

$$H_c = 860000 \text{ A/m}$$

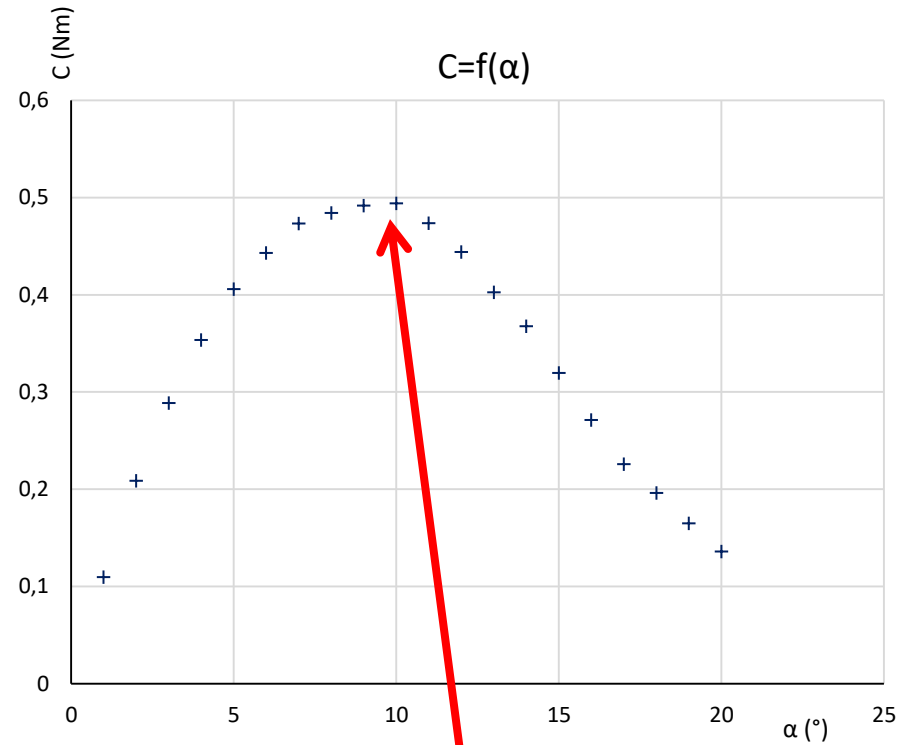




# Simulation : couple pour deux aimants

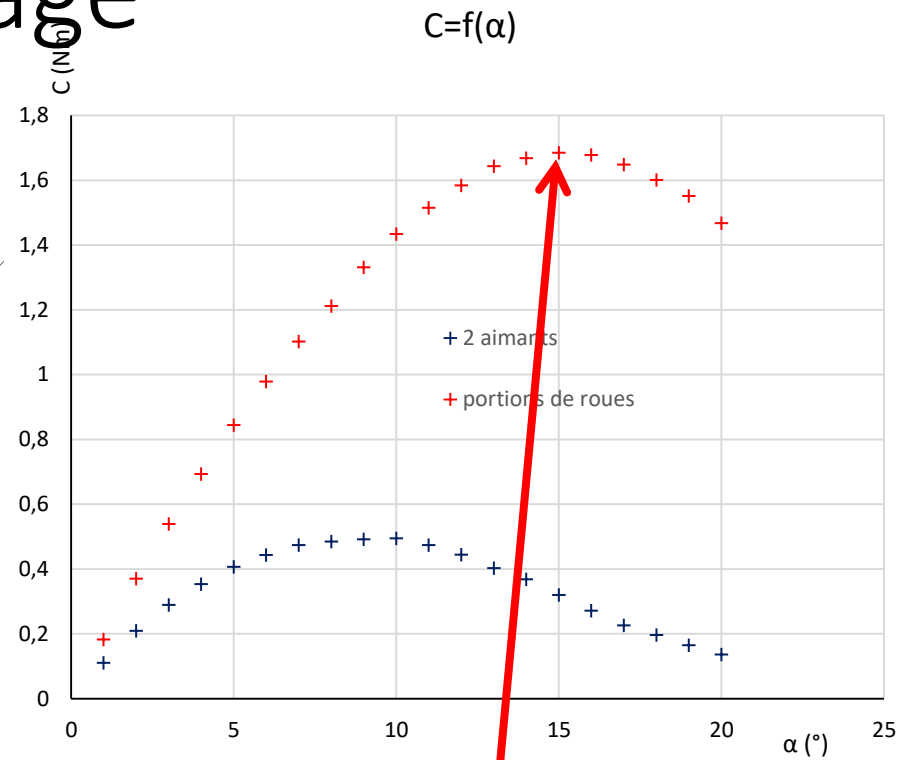
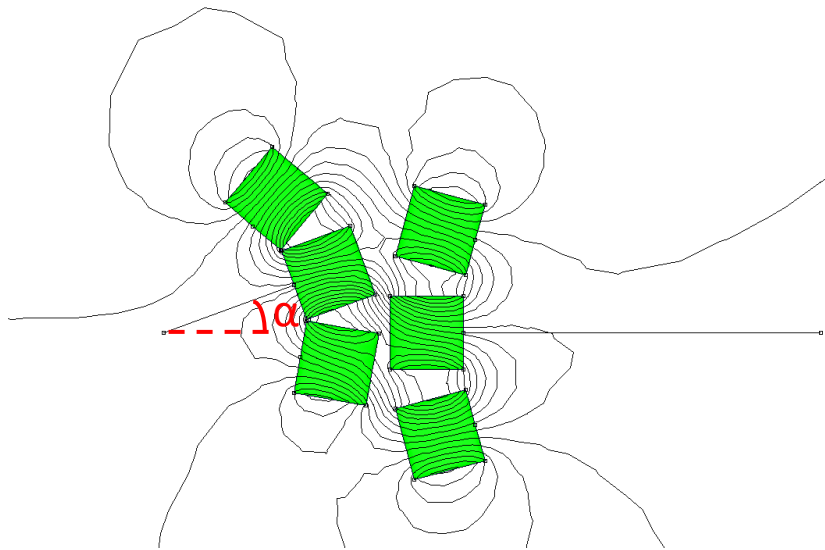


```
for angle=1,20,1 do --> boucle variation angle aimants  
  
mi_selectgroup(3)  
mi_moverotate(0,0,1,4)  
  
mi_analyze(1)  
mi_loadsolution()  
  
mo_selectblock(4.5,0)  
force=mo_blockintegral(21)+mo_blockintegral(19) --> calcul force  
  
couple=r*force
```



Couple maximal  
transmissible puis  
décrochage

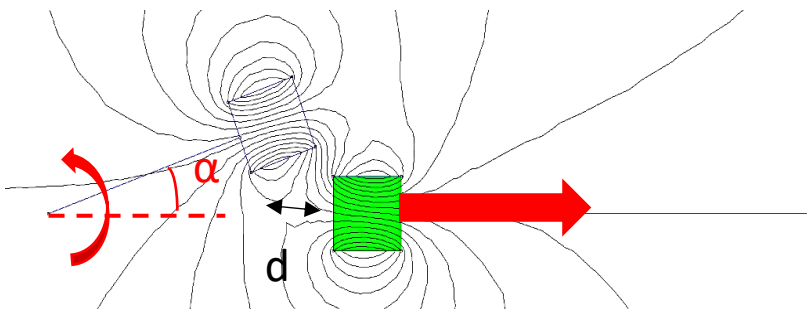
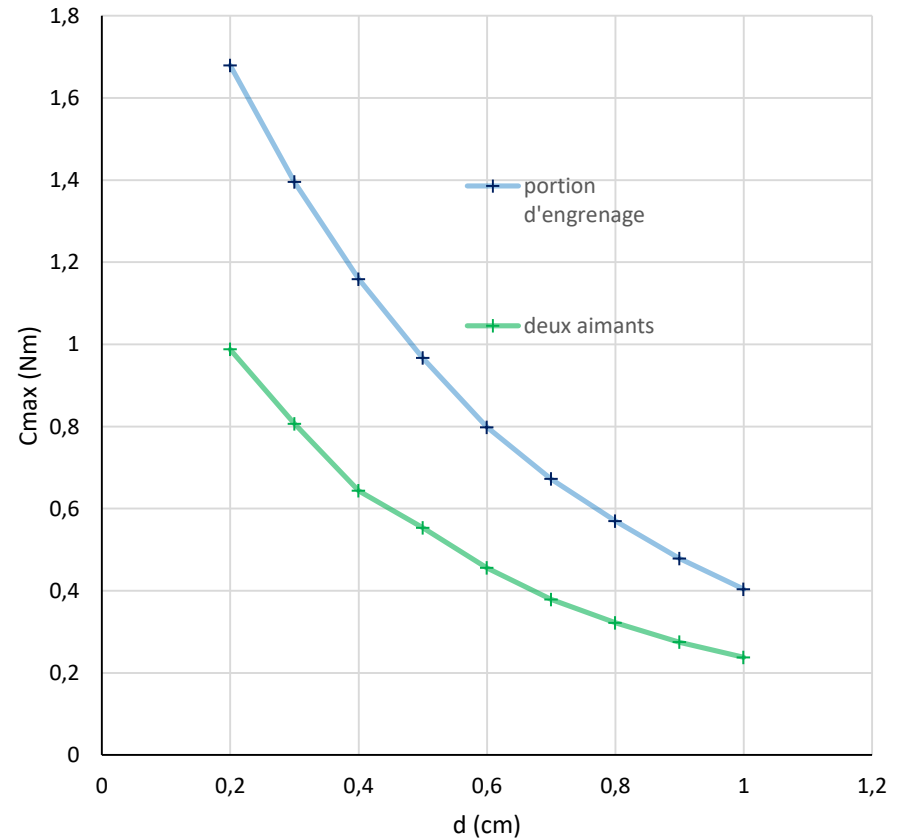
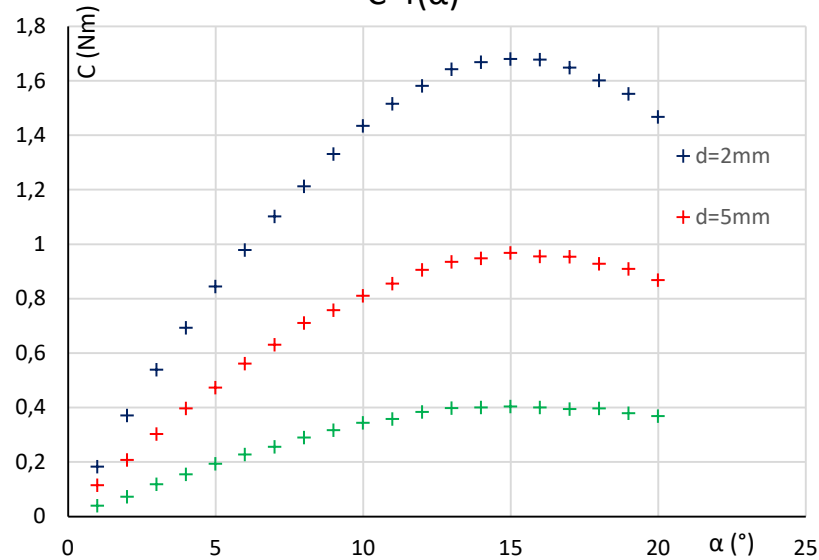
# Simulation : couple pour une portion d'engrenage



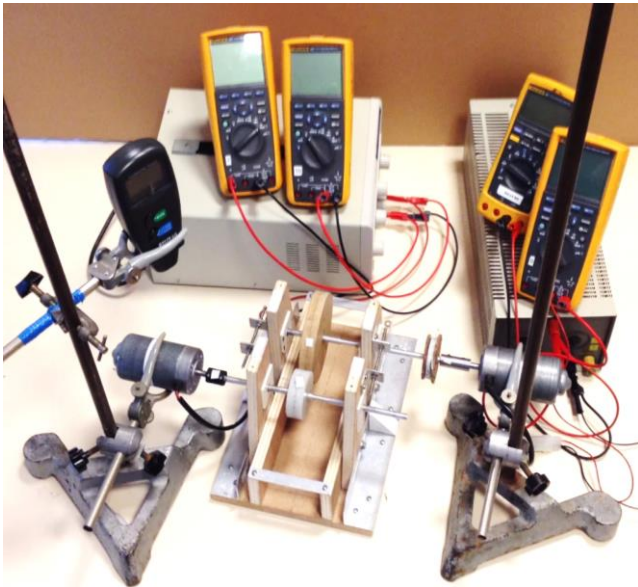
Couple maximal transmissible puis saut d'une dent

# Simulation : influence de la distance sur le couple transmissible $C_{\max}=f(d)$

$$C=f(\alpha)$$

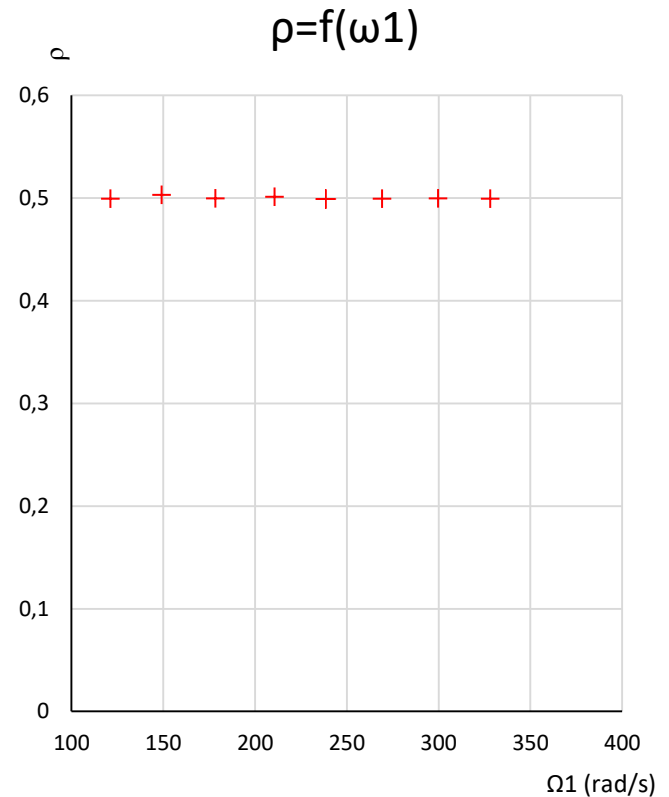
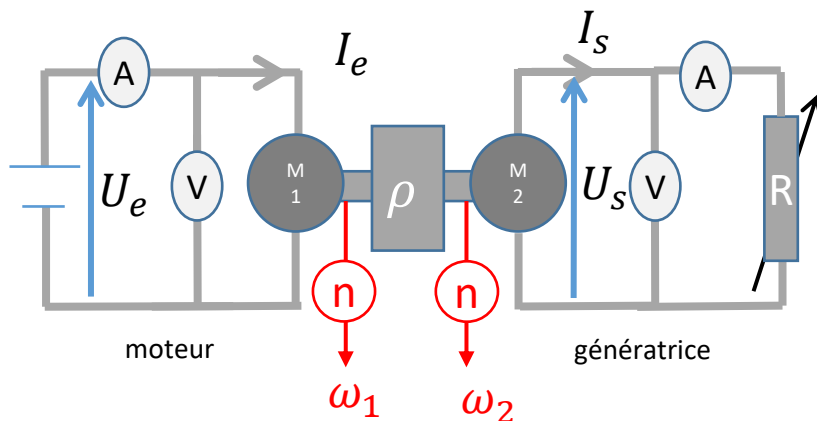


# Mesure du rapport de réduction

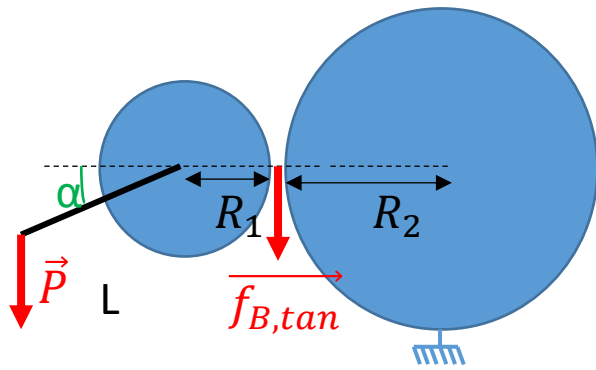


$$\rho = \frac{\omega_2}{\omega_1}$$

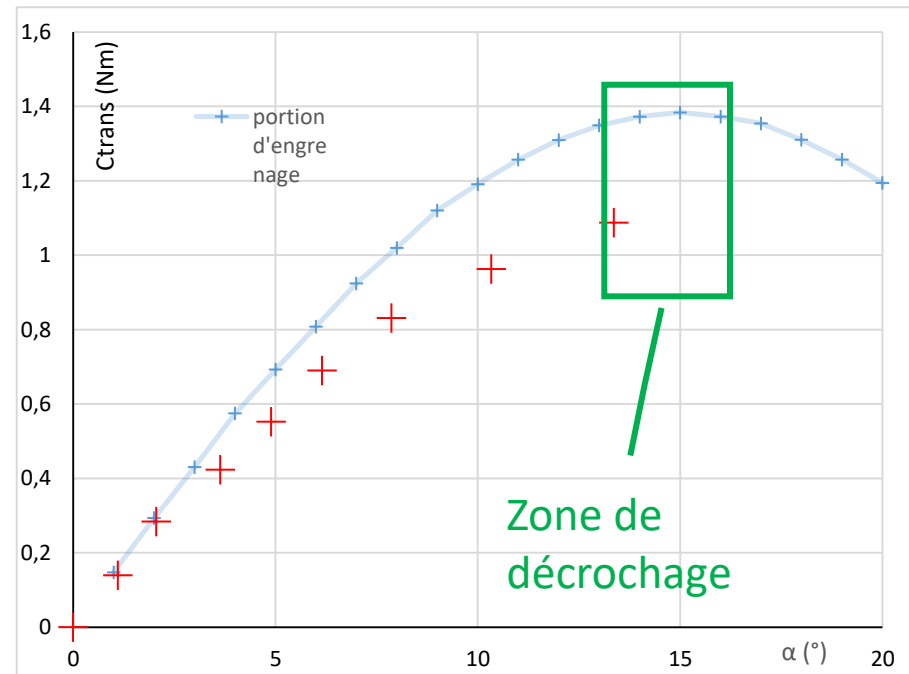
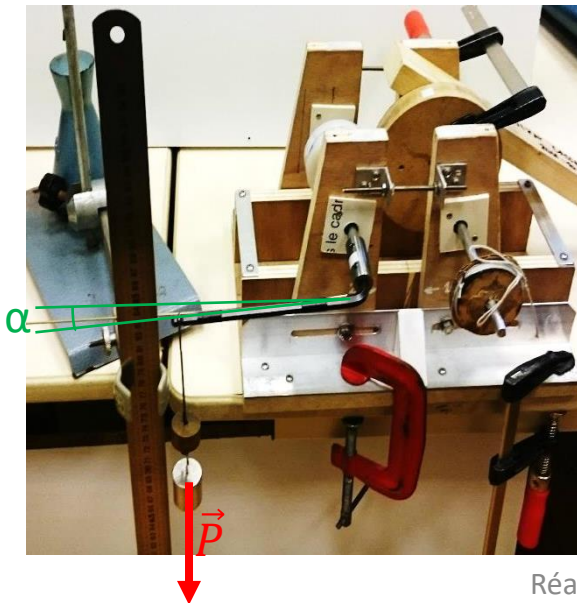
$$\rho \approx 0,5$$



# Mesure du couple en fonction de l'angle

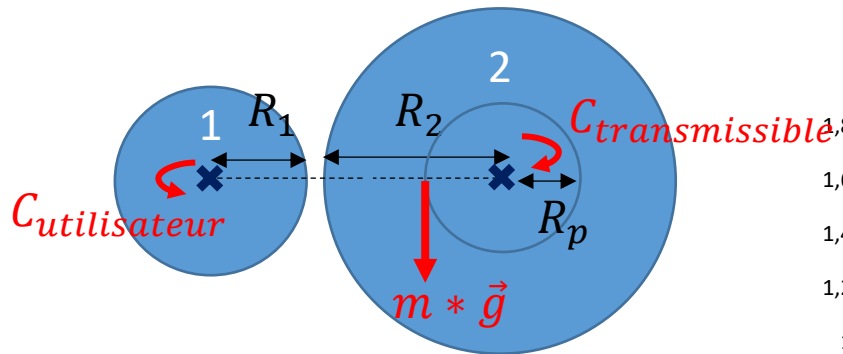


$$C_{trans}(\alpha) = \frac{R_2}{R_1} LP \cos(\alpha)$$

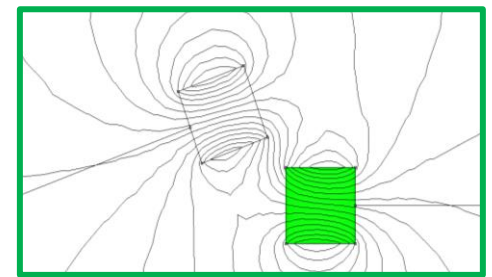
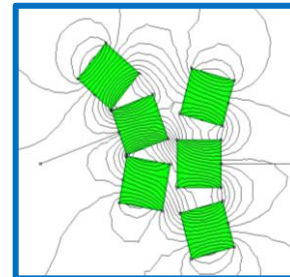
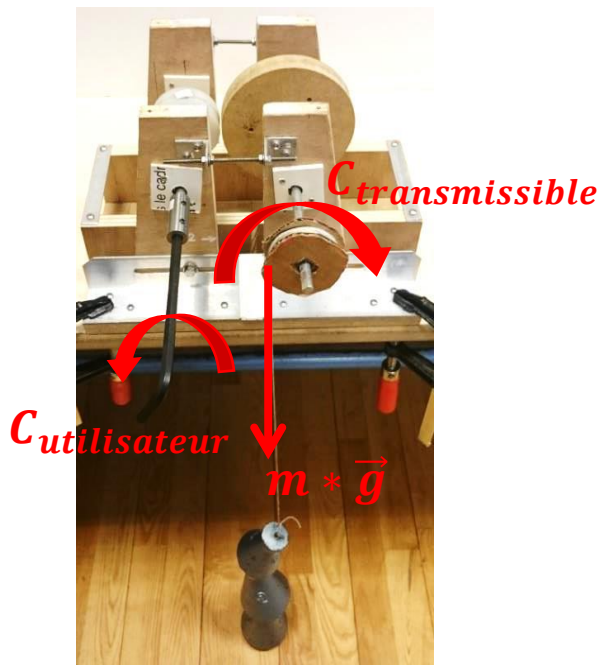
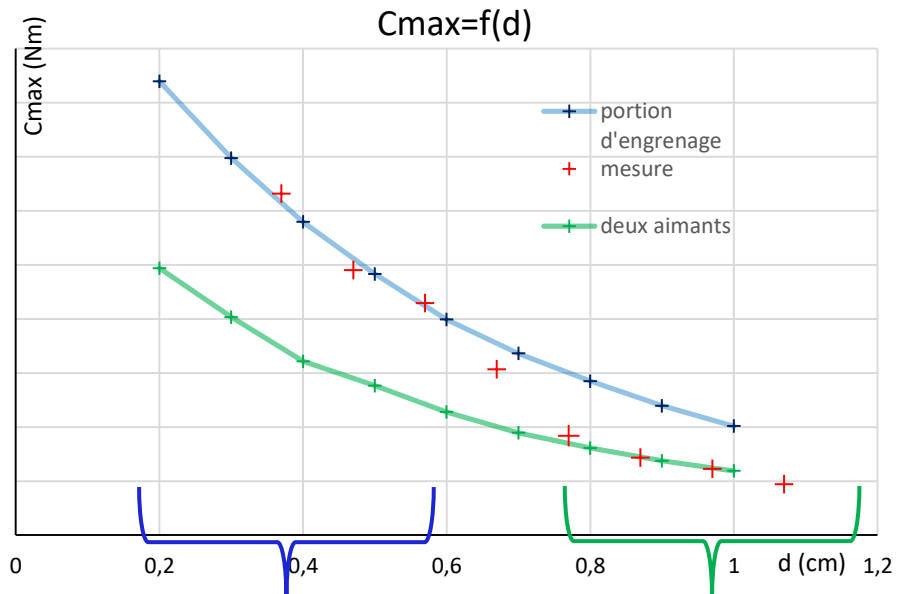




# Mesure du couple maximal en fonction de la distance

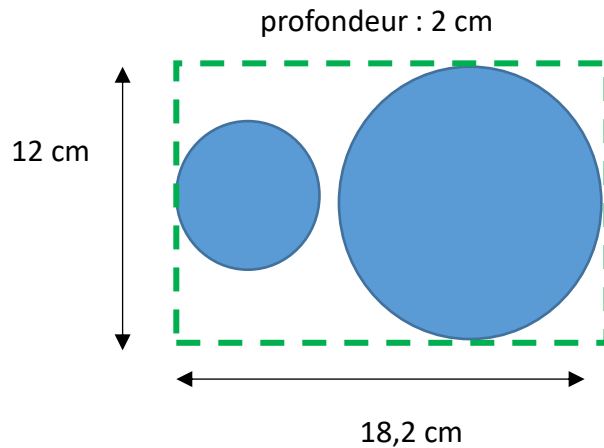


$$\text{TMS : } C_{transmissible,max} = R_p \cdot m_{max} \cdot g$$



Réalisation - Etude théorique - Validation  
expérimentale

# Comparaison avec les engrenages mécaniques



Calcul de la densité de couple transmissible :

$$TORQUE DENSITY = \frac{\text{couple maximal}}{\text{volume}}$$

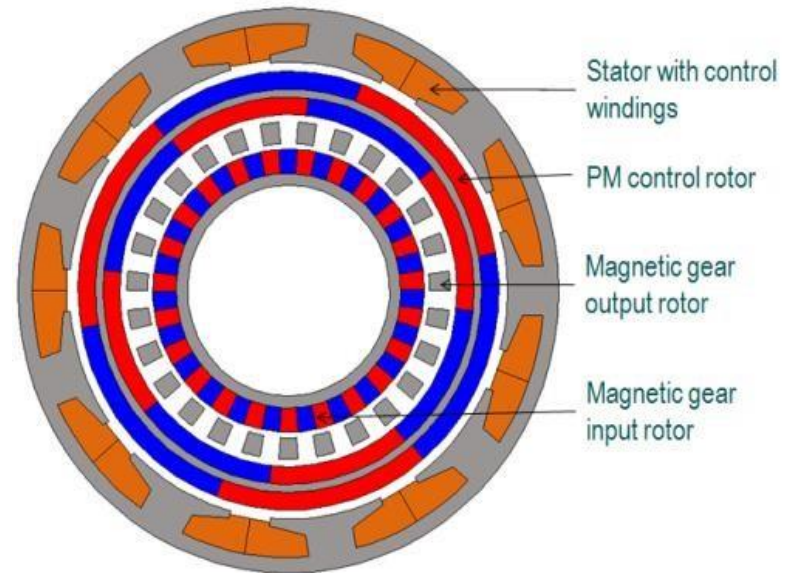
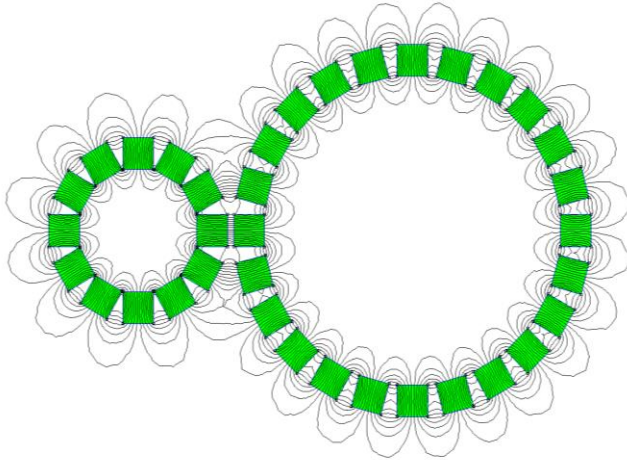
Gear Type	Torque density (kNm/m <sup>3</sup> )
Mechanical spur gear [30]	100-200
Mechanical helical gear(3G)	50-150
Magnetic worm gear [9]	<2
Magnetic bevel gear	<5
Magnetic spur gear	10-20
Magnetic harmonic gear(1G)	140-180
Magnetic harmonic gear(2G)	75
Magnetic planetary gear [26]	≈100
Concentric magnetic gear	70-150

$$TORQUE DENSITY \approx 3 \text{ kNm/m}^3$$

Magnetic gear technologies : a review

Réalisation - Etude théorique - Validation  
expérimentale

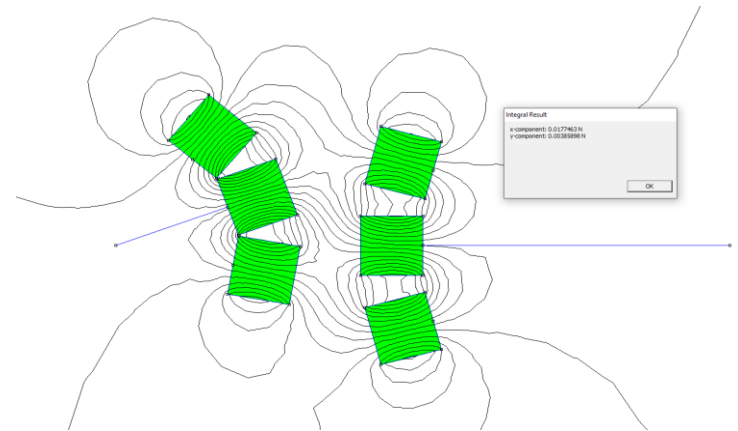
# Conclusion



- Comportement similaire aux engrenages classiques
- Transmission de couple efficace mais limitée

# FEMM

```
pydir="C:\\Users\\Victor\\Desktop\\IIT\\simu_couple")  
open(mydir .. "test_couple_angle_reel.fem")  
  
fichier=writeinto(mydir .. "couples_distance_reel.txt")  
  
r=0.056  
  
ligne="angle".."\t".."\t".."\t".."\t".."\t".."\t".."\t".."  
write(ligne)  
n=0  
  
for dist=0.2,1,0.1 do  
  
  
for angle=1,20,1 do --> boucle variation distance aimant  
  
mi_selectgroup(3)  
mi_moverotate(0,0,1,4)  
  
mi_analyze(1)  
mi_loadsolution()  
  
  
mo_selectblock(3.5+dist,1.4)  
force1=0.96*(mo_blockintegral(21)+mo_blockintegral(19))  
mo_clearblock()  
  
mo_selectblock(3.3+dist,0)  
force2=mo_blockintegral(21)+mo_blockintegral(19)  
mo_clearblock()  
  
mo_selectblock(3.5+dist,-1.4)  
force3=0.96*(mo_blockintegral(21)+mo_blockintegral(19))  
mo_clearblock()  
  
force=force1+force2+force3  
  
couple=r*force  
  
ligne=angle.."\t"..dist.."\t".."\t".."\t".."\t".."  
write(ligne)  
  
end  
  
n=n+1  
print(n)  
  
mi_selectgroup(3)  
mi_moverotate(0,0,-20,4)
```



Block Property

Name

ndfeb40

B-H Curve

Linear B-H Relationship

Linear Material Properties

Relative  $\mu_x$

1.049

Relative  $\mu_y$

1.049

$\phi_{hx}$ , deg

0

$\phi_{hy}$ , deg

0

Nonlinear Material Properties

Edit B-H Curve

$\phi_{hmax}$ , deg

0

Coercivity

$H_c$ , A/m

860000

Electrical Conductivity

$\sigma$ , MS/m

0.667

Source Current Density

$J$ , MA/m<sup>2</sup>

0

Special Attributes: Lamination & Wire Type

Not laminated or stranded

Lam thickness, mm

0

Lam fill factor

1

Number of strands

0

Strand dia, mm

0

OK

Cancel

# Annexe 2 : étude dynamique (binôme)

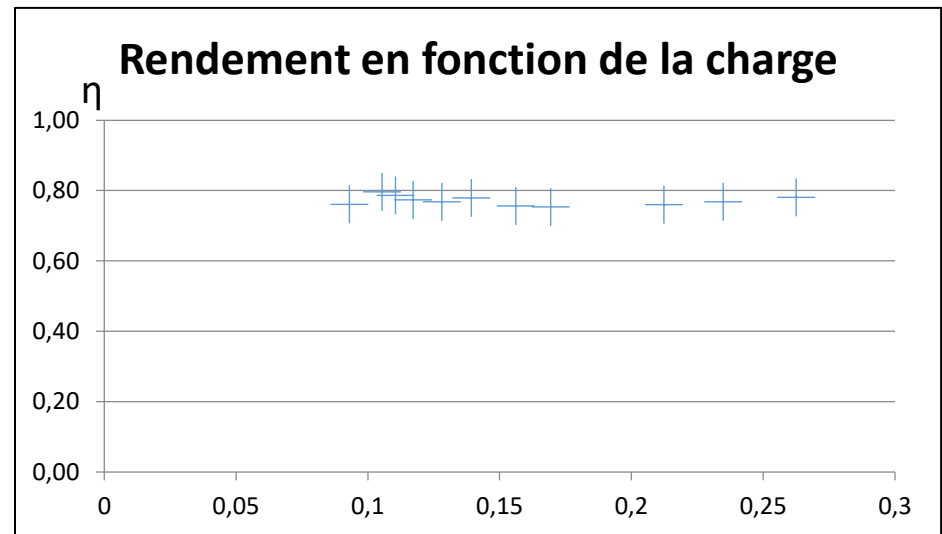
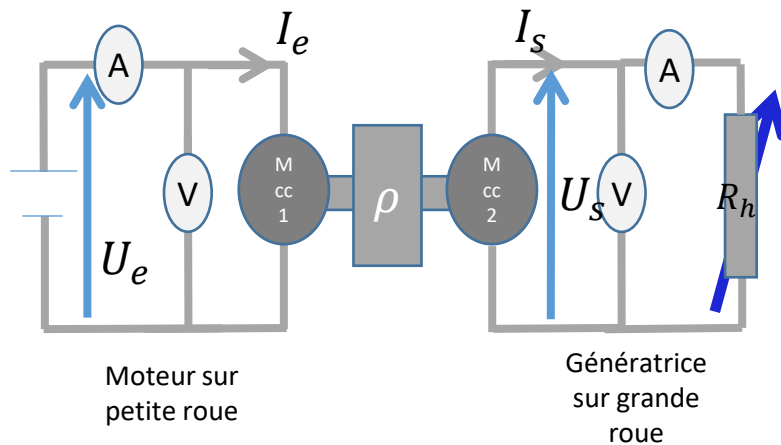
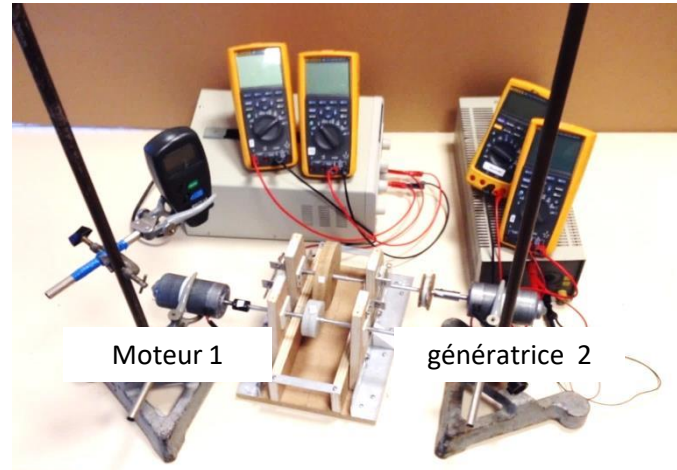
Constantes moteur :

$$k_{mot} = 0,03 \text{ V.s/rad}$$

$$R = 0.375 \Omega$$

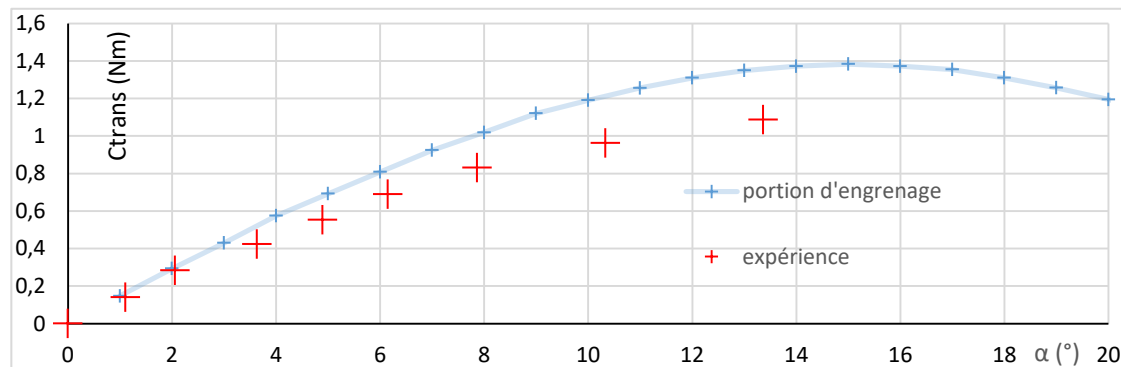
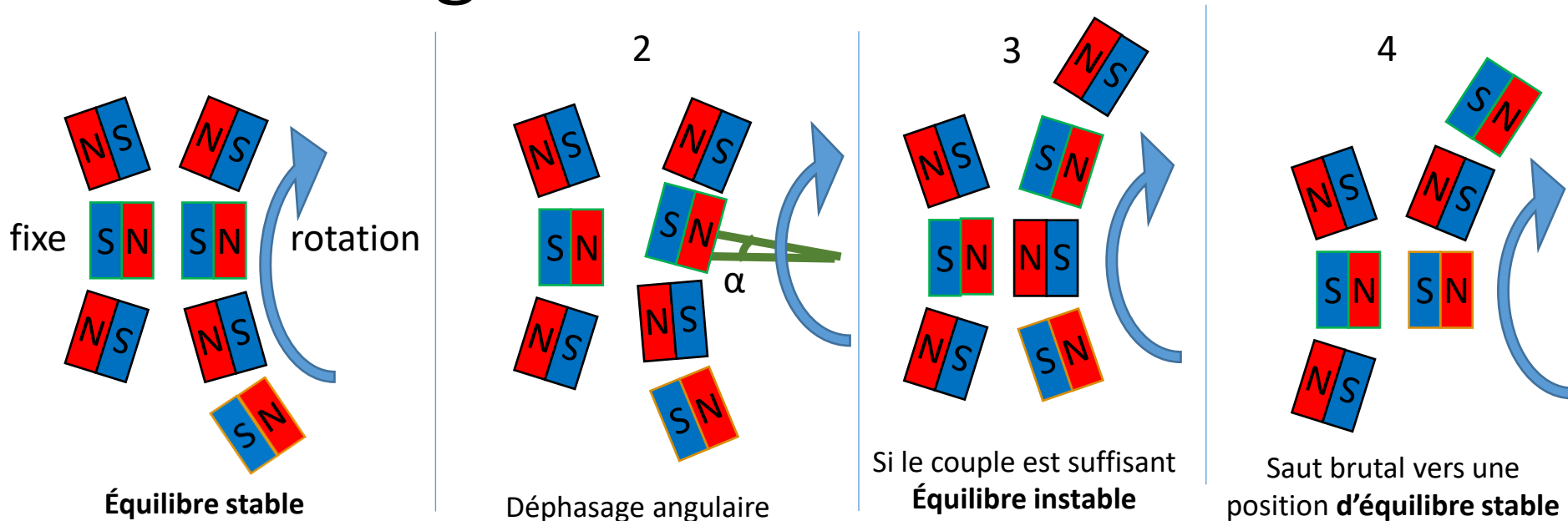
$$C_{frot sec} = 0,0314 \text{ N.m}$$

$$f = 3.10^{-5} \text{ N.m.s/rad}$$





# Annexe 3 : phénomène de dérochage



## Annexe 4 : incertitudes

- $U(\rho) = \rho * \sqrt{\left(\frac{U(\omega_1)}{\omega_1}\right)^2 + \left(\frac{U(\omega_2)}{\omega_2}\right)^2} \approx 2 * 10^{-4}$
- $U(C_t)/C_t = \sqrt{\left(\frac{grad}{\sqrt{12}*mes}\right)^2 + \left(\frac{digit}{\sqrt{3}*mes}\right)^2 + \left(\frac{1}{\sqrt{1+U(\alpha)^2*\cos(\alpha)}}\right)^2}$   
 $\approx 5 * 10^{-3} N, m$
- $U(C_{t,m})/C_{t,m} = \sqrt{\left(\frac{grad}{\sqrt{12}*mes}\right)^2 + \left(\frac{digit}{\sqrt{3}*mes}\right)^2} \approx 3 * 10^{-2} N.m$