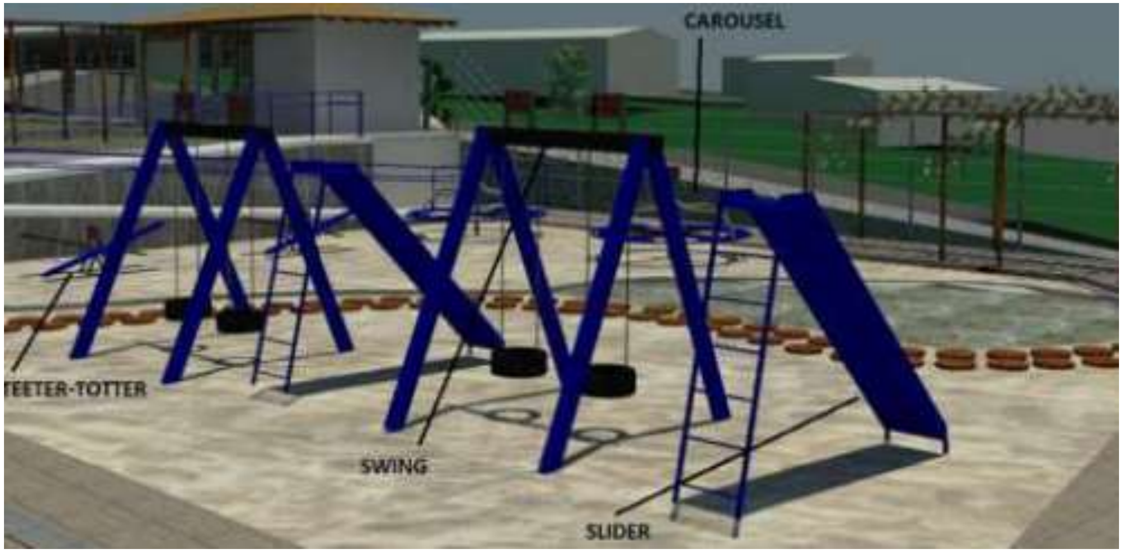
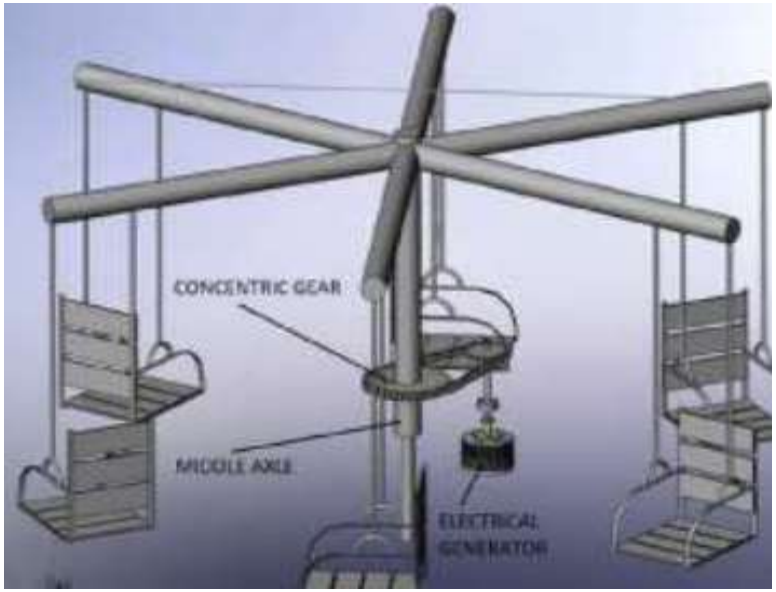
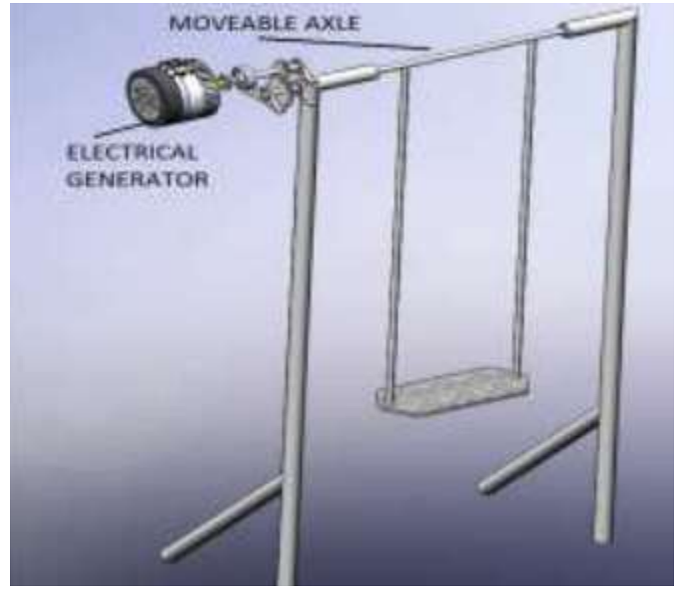
LABESSE Louis
Candidat : 50188

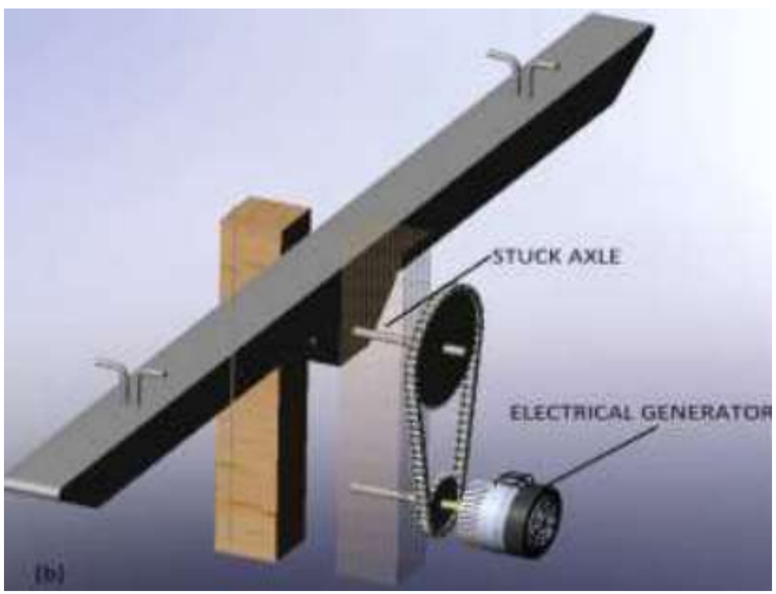
Aires de jeux générant de l’énergie electrique

Contexte







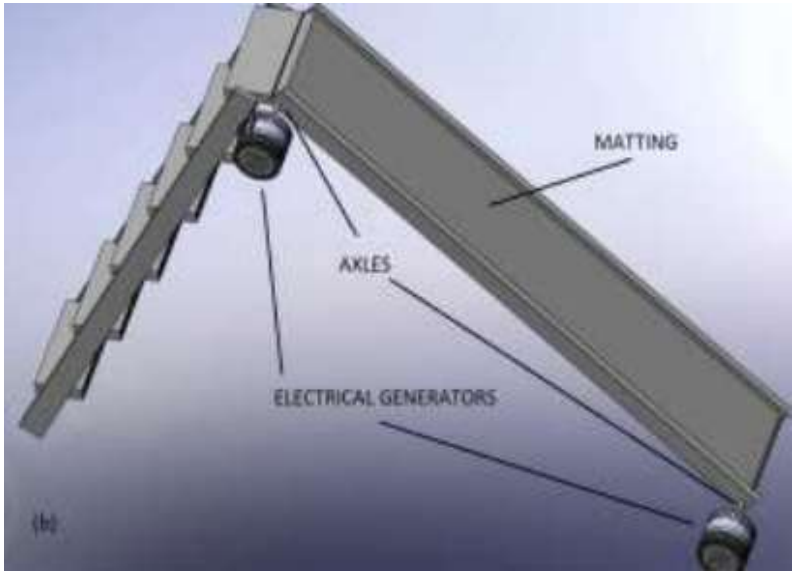


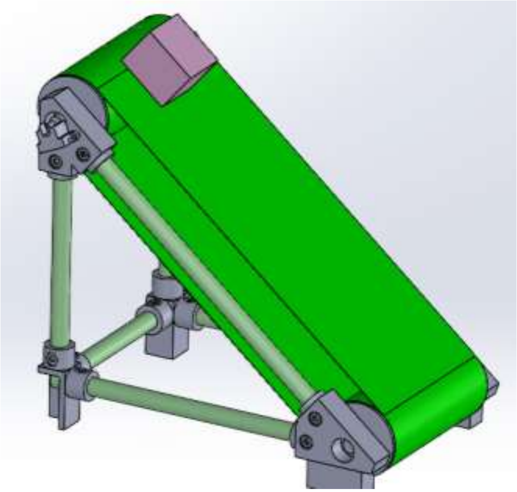
- Jeux couplés avec un générateur et reliés à des batteries

- Energie produite par l'activité physique des enfants

- Nécessité d'une force initiale pour mettre l'utilisateur en mouvement

PRESENTATION DU TOBOGGAN A TAPIS ROULANT





PROBLÉMATIQUE RETENUE

De quelle manière peut-on générer de l’énergie à partir de l’activité physique des enfants dans les terrains de jeux ?

DÉROULEMENT DU PROJET

PARTIE I :

Modélisation : mise en équation sous python

PARTIE II :

Expériences sur la maquette

PARTIE III :

Conclusion et études supplémentaires

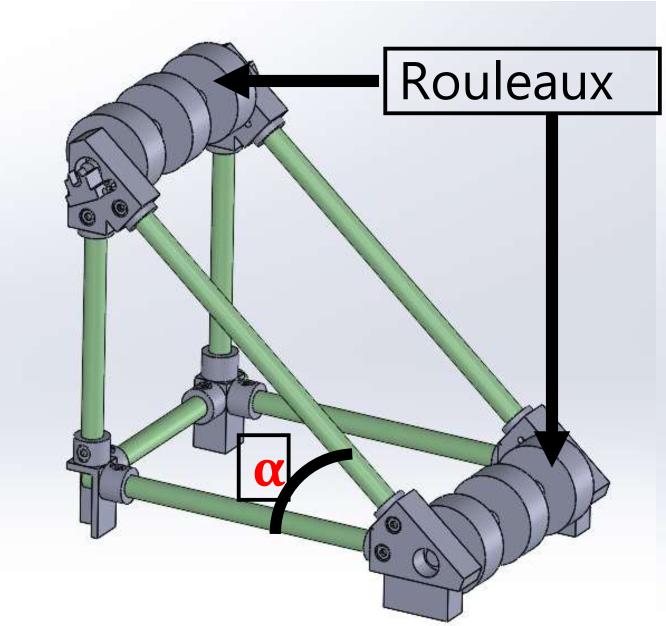
PARTIE I : MODELISATION

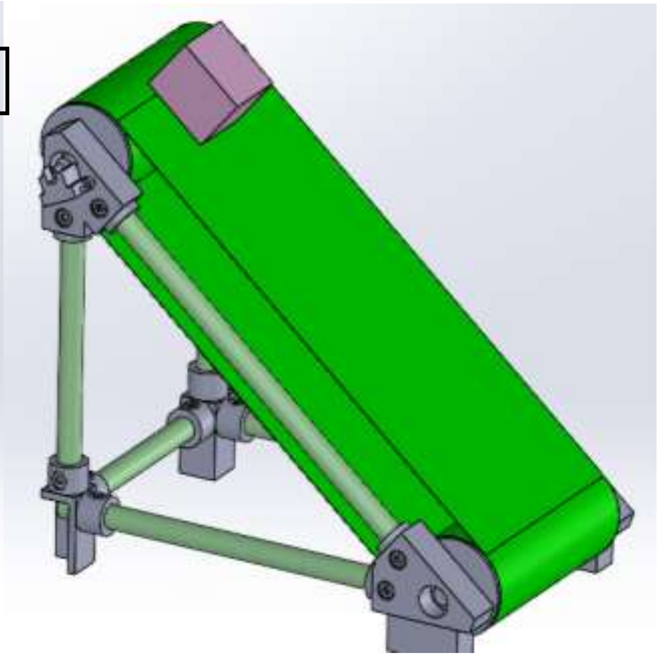
I.a) Présentation de la maquette

I.b) Bilan de Puissances et Mise en équation

I.c) Affichage théorique de la vitesse de descente

I)a) MAQUETTE

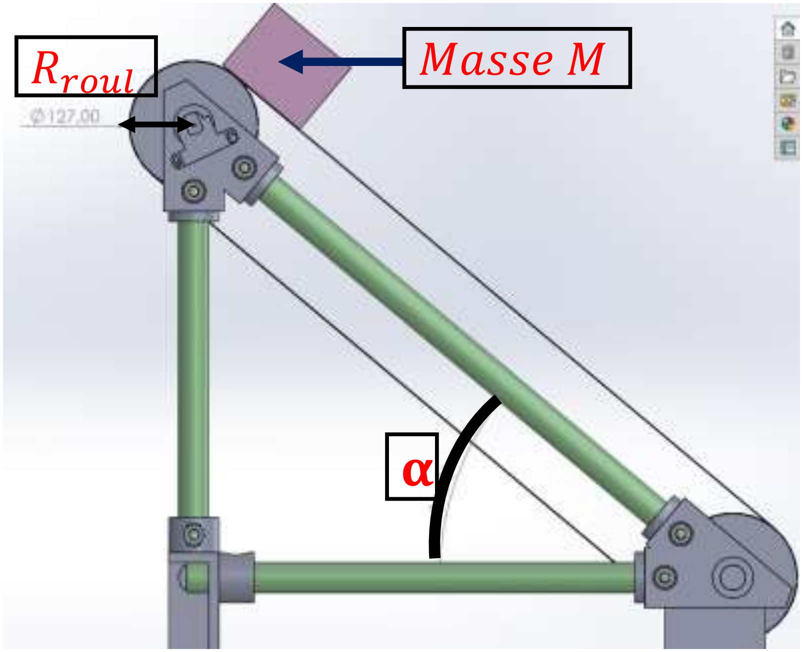




Angle **α** maximal de 50° (imposé par le CDC)

Spécification 5.3.6.3.4 :

Aucune section du toboggan ne doit avoir une pente dépassant 50°



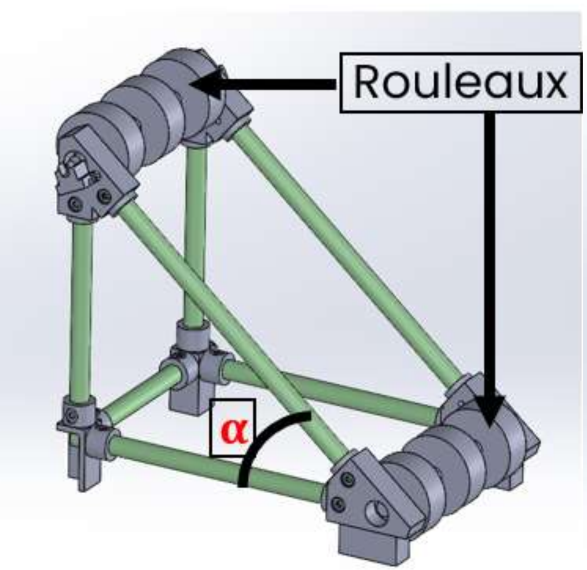
I)b) BILAN DE PUISSANCES

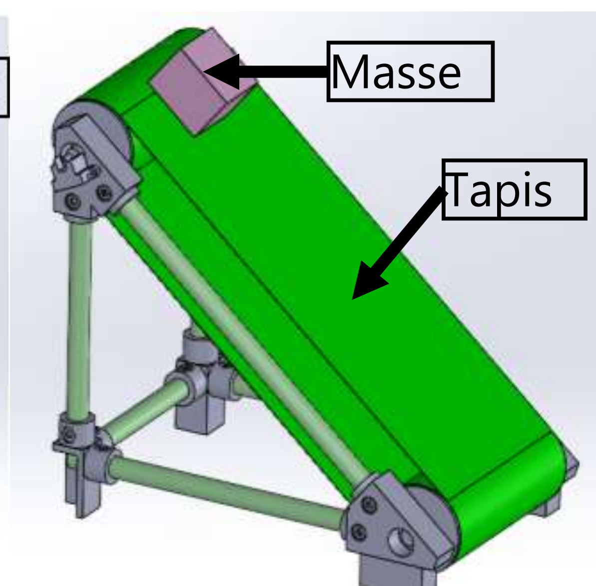
- $P_{res} = C_r\omega = Mg\,sin(\alpha)\,R_{roul}\omega$
- $P_{mot} = C_{\text{mot}} * \omega$
- $P_{\text{f}} = C_f\omega = -f\omega^2$

$Système: \{Tapis + Rouleaux + Masse\}$
$Référentiel\ terrestre\ supposé\ gallil\acute{e}en$

$$\frac{dEc}{dt} = \sum_{i=0}^{n} P_i$$

$$\frac{d}{dt}\left(\frac{1}{2}J_{roul}\omega^2 + \frac{1}{2}J_{tapis}\omega^2 + \frac{1}{2}MR_{roul}{}^2\omega^2\right) = \sum_{i=0}^{n} P_i$$

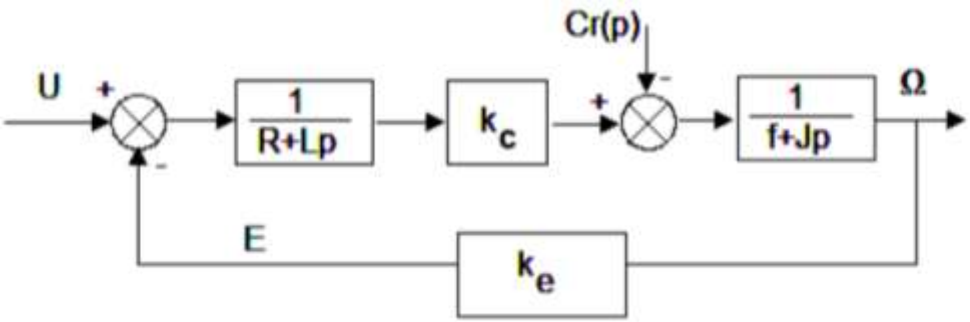




$$\boxed{J_{eq} = J_{\text{roul}} + J_{tapis} + MR_{roul}{}^2}$$

$$J_{tapis} \approx m_t\left(\frac{L}{2\pi}\right)^2$$

I)b) MISE EN EQUATION



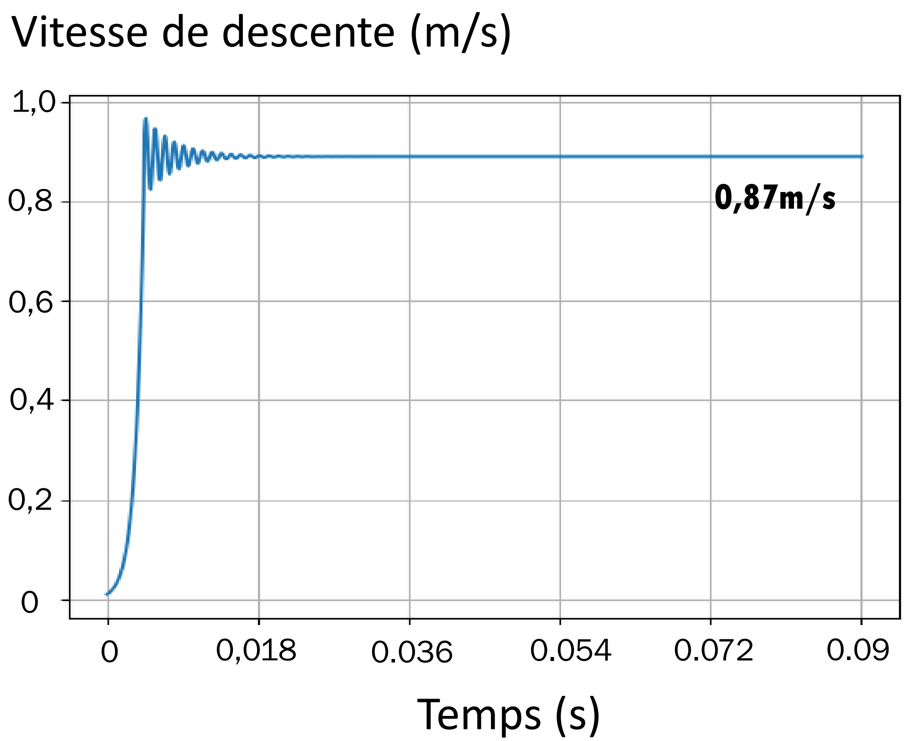
- $C_m - C_r - f\omega = J_{eq}\frac{d\omega}{dt}$
- $C_m = k_c i$ • $\mathrm{E} = k_e\omega$
- $U - E - Ri - L\frac{di}{dt} = 0$
- $C_r(t) = Mg\,sin(\alpha)\,R_{roul}$

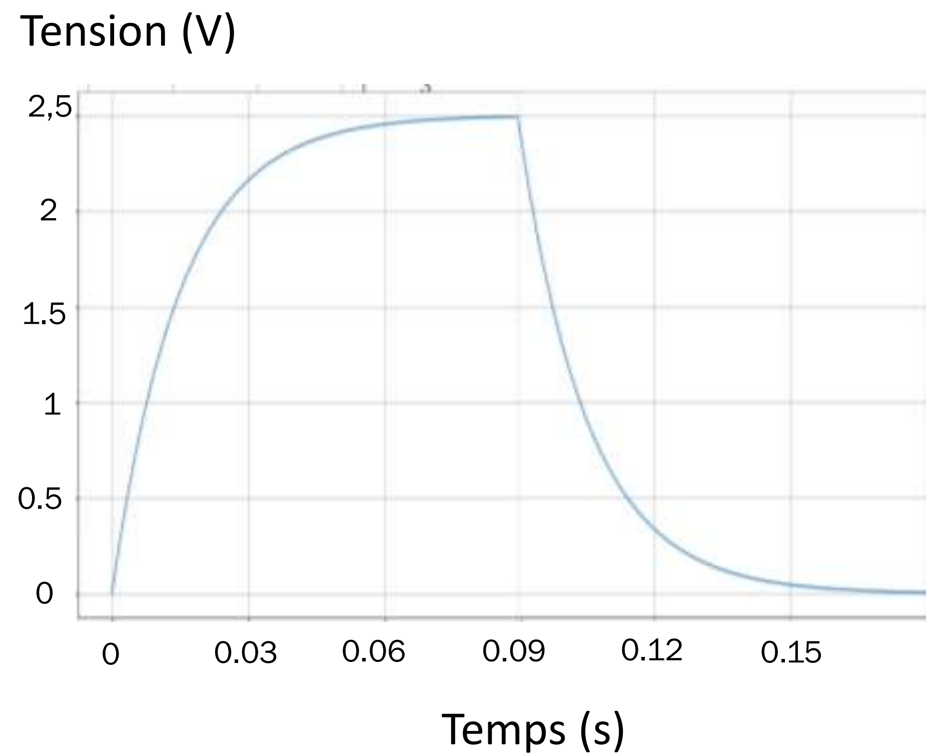
$$\boxed{\omega(t) = e^{-z\omega_0 t}\left(Acos\left(\omega_0\sqrt{1-z^2}t\right) + Bsin\left(\omega_0\sqrt{1-z^2}t\right)\right) + \frac{RMg\,sin(\alpha)\,R_{roul}}{fR + k_e k_c}}$$

$$Conditions\ initiales:\ \omega(0) = 0\ \ ;\ \frac{d\omega(t)}{dt} = 0$$

$$\boxed{U = \frac{d^2\omega}{dt^2}\left(\frac{LJ_{eq}}{k_c}\right) + \frac{d\omega}{dt}\left(\frac{J_{eq}R + fL}{k_c}\right) + \omega\left(k_e + \frac{Rf}{k_c}\right) + \frac{C_r(t)R}{k_c}}$$

I)c) AFFICHAGE THEORIQUE DES GRANDEURS EN SORTIE





Hypothèse :

Domaine transitoire négligeable

$$T_{5\%} \approx 0{,}17s$$

Hypothèse :

Domaine stationnaire négligeable

$$T_{5\%} \approx 0{,}86s$$

PARTIE II : EXPERIENCES

II.a) Mesure de la masse minimale pour mettre en mouvement le système

II.b) Mesure des grandeurs caractéristiques du moteur

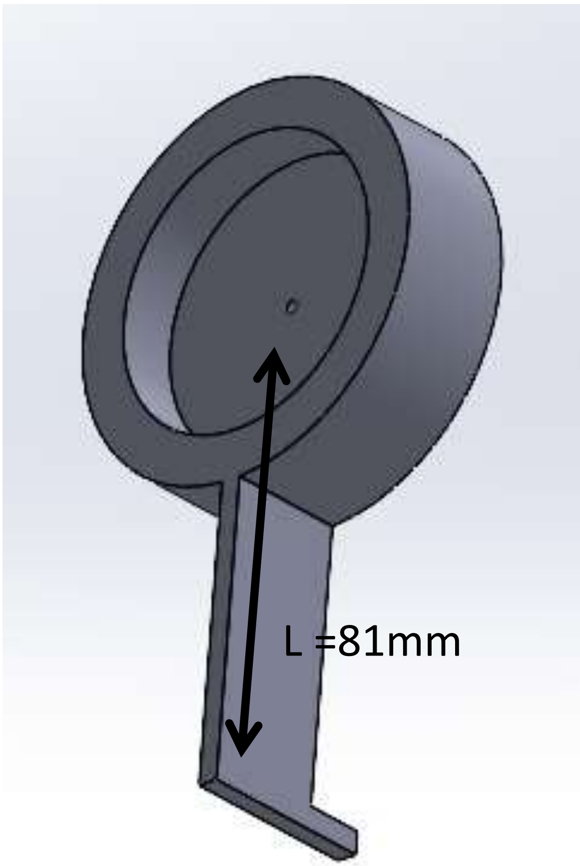
II.c) Expérience des frottements de coulomb

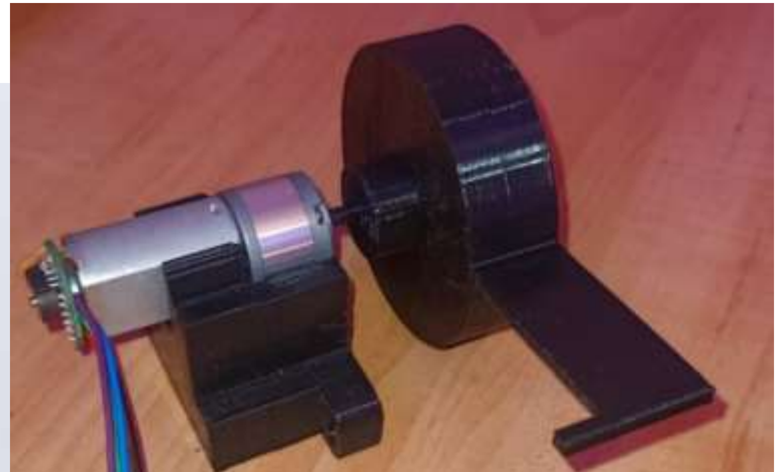
II.d) Etude de la vitesse de descente et de la tension en sortie

MOTEUR ET ROULEMENTS

Moteur :	Roulements:
Motoréducteur 12V (1:19) Référence : TRENZ - 24142	XiKe 4 pièces 6005-2RS 25x47x12mm,
	

II)a) MESURE DE LA MASSE MINIMALE POUR METTRE EN MOUVEMENT LE SYSTEME





MASSE OBTENUE

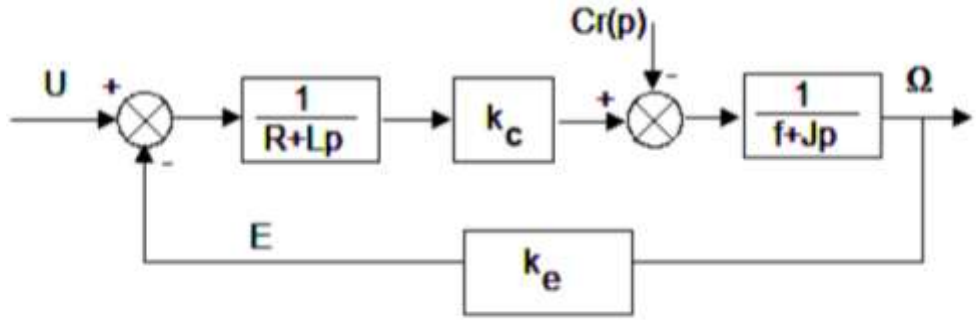
Masses utilisées (g)	Mouvement observé
64,65	Oui
49,53	Oui
49,24	Oui
48,32	Oui
48,04	Oui
47,69	Non
46,96	Non
39,88	Non
29,84	Non

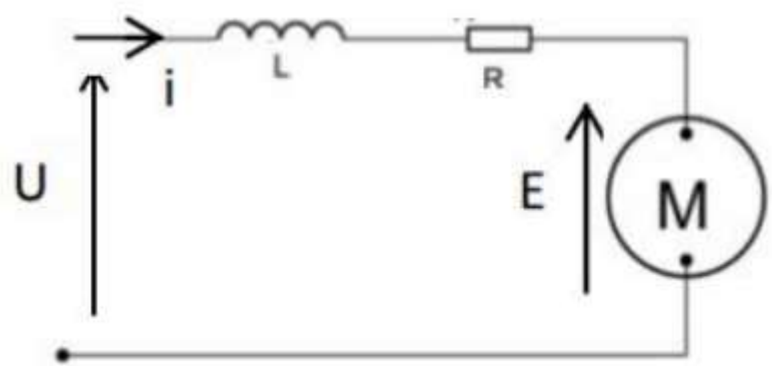
$$\boxed{\begin{gathered}\bar{m} = 47{,}85g \\ u(m) = 0{,}09\ g\end{gathered}}$$

$$Couple\ obtenu : C = \bar{m}gL$$

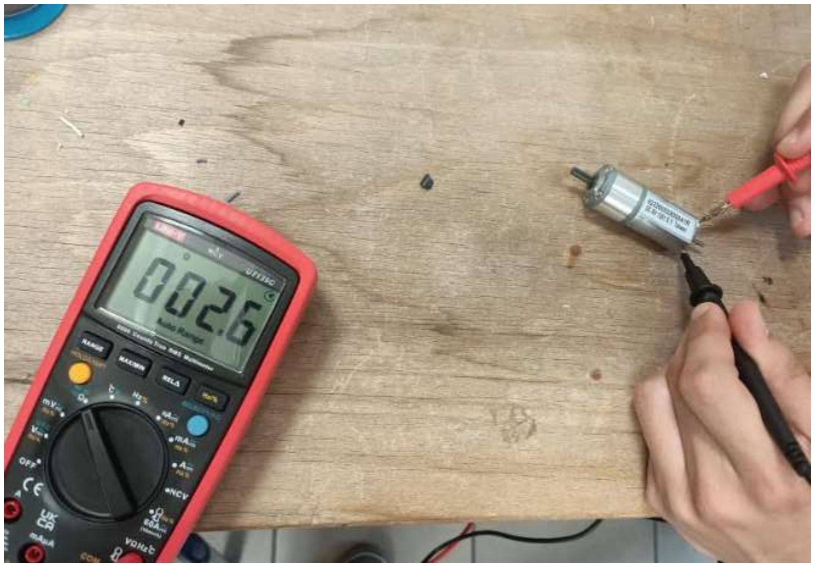
$$\boxed{A.N: \quad C = 0{,}04\ Nm}$$

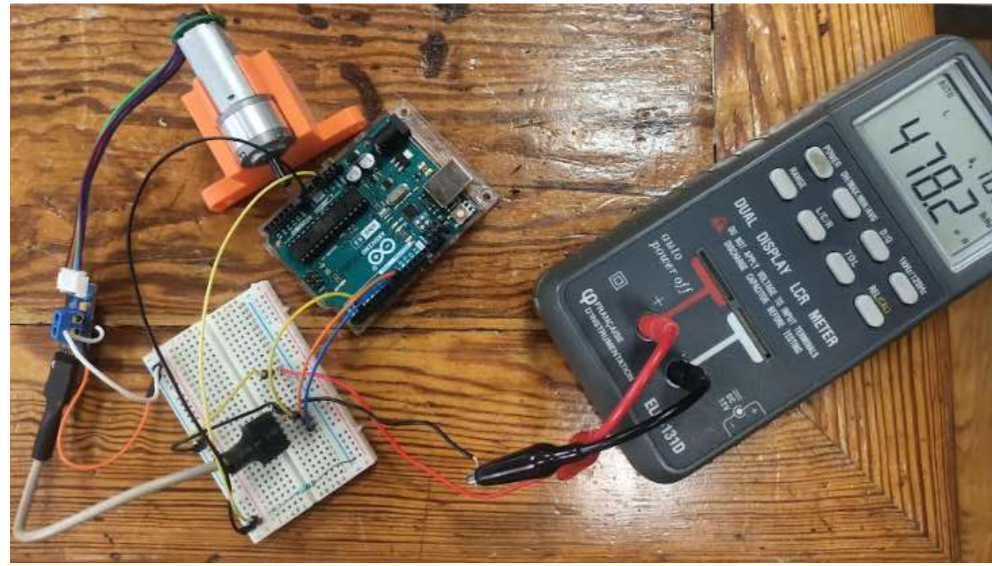
II)b) MESURE DES GRANDEURS CARACTERISTIQUES DU MOTEUR





MESURE DE LA RESISTANCE INTERNE ET DE L'INDUCTANCE





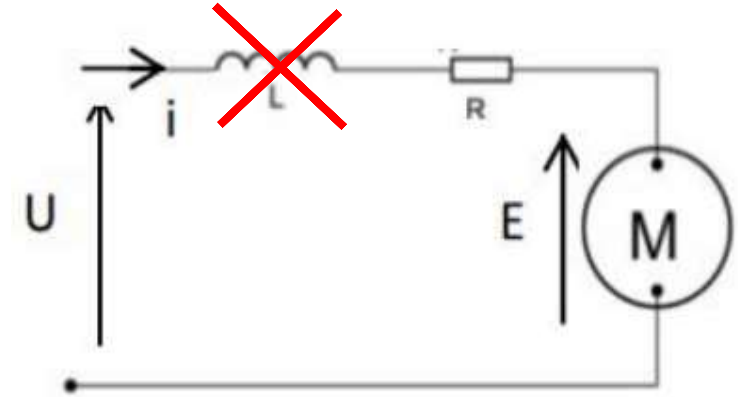
$$R_{min} = 2{,}5\,\Omega$$
$$R_{max} = 2{,}9\,\Omega$$

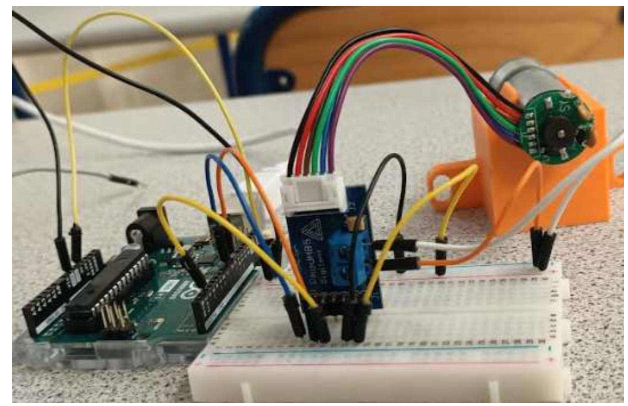
$$\boxed{\begin{array}{c}\bar{R} = 2{,}7\,\Omega \\ u(R) = 0{,}1\,\Omega\end{array}}$$

$$L_{min} = 477{,}9\ \mu H$$
$$L_{max} = 478{,}3\ \mu H$$

$$\boxed{\begin{array}{c}\bar{L} = 477{,}1\,\mu H \\ u(L) = 1\,\mu H\end{array}}$$

MESURE DES CONSTANTES DE FEM ET DE COUPLE





$$\overline{k_c} = 0{,}11\ Nm/A$$

$$u(k_c) = 0{,}006\ Nm/A$$

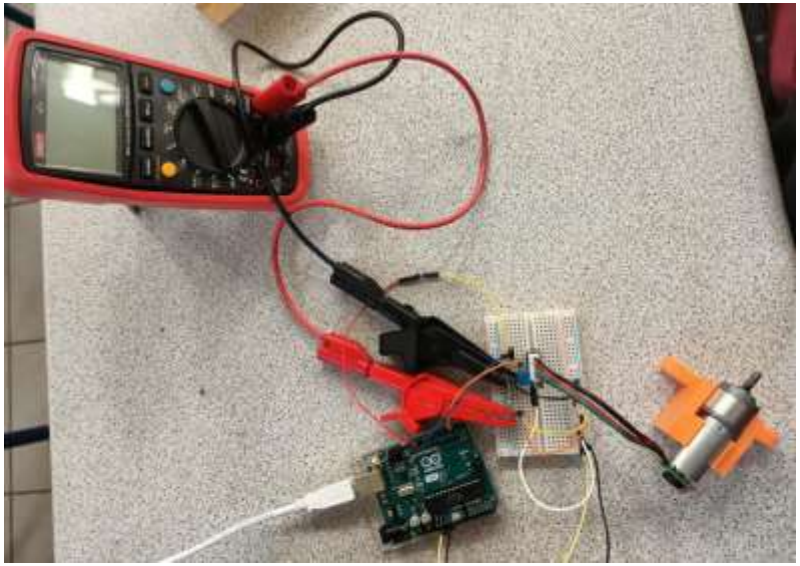
$$Z\left(\overline{k_c}, k_{c_{ref}}\right) = 3{,}64$$

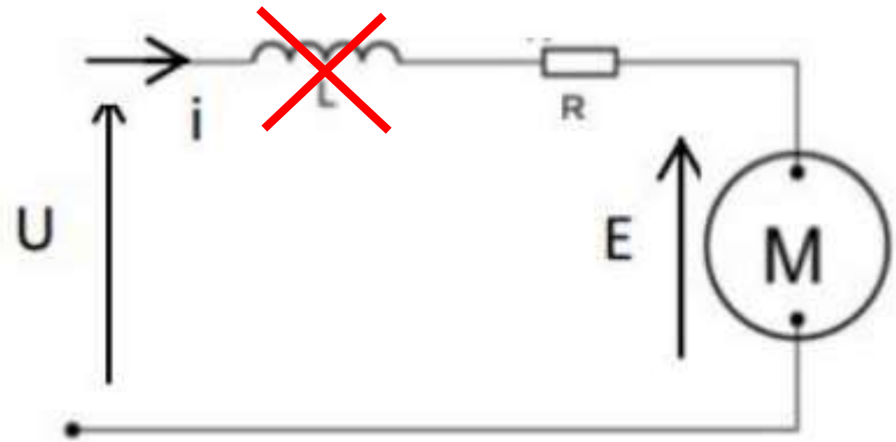
$$\overline{k_e} = 0{,}091\ V/rad/s$$

$$u(k_e) = 0{,}004\ V/rad/s$$

$$Z\left(\overline{k_e}, k_{e_{ref}}\right) = 2{,}51$$

MESURE DU COEFFICIENT DE FROTTEMENTS



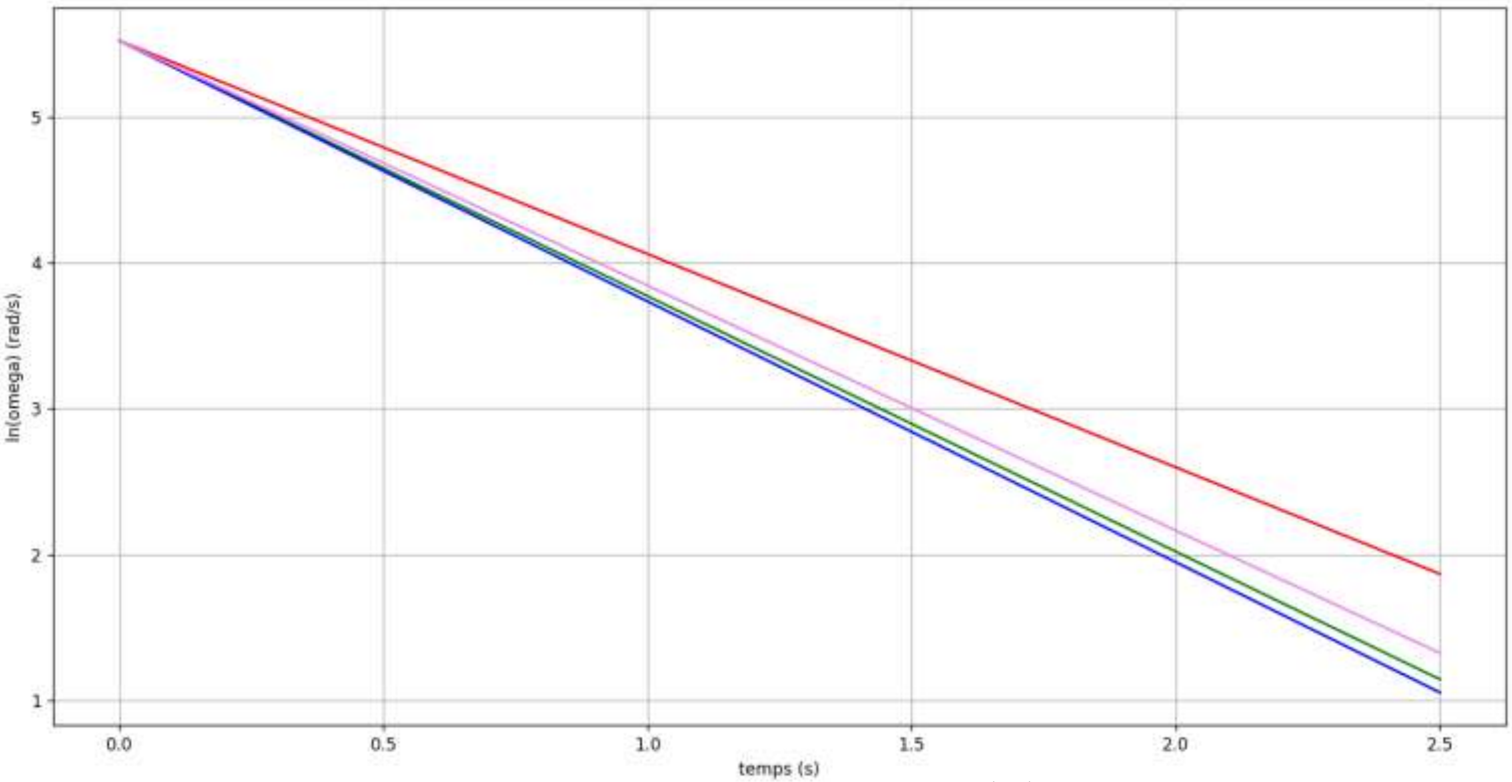


$$\bar{f} = \frac{ki}{\omega} \approx 3{,}85 \times 10^{-5} Nm/s$$

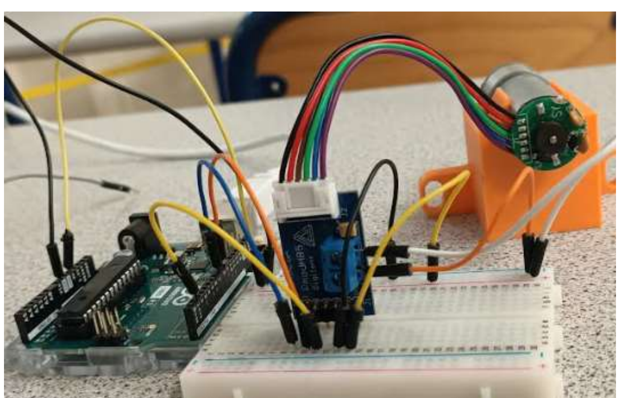
$$u(f) = 0{,}00217 \times 10^{-5} Nm/s$$

MESURE DE L'INERTIE EQUIVALENTE

$\ln(\omega)$ (rad/s)

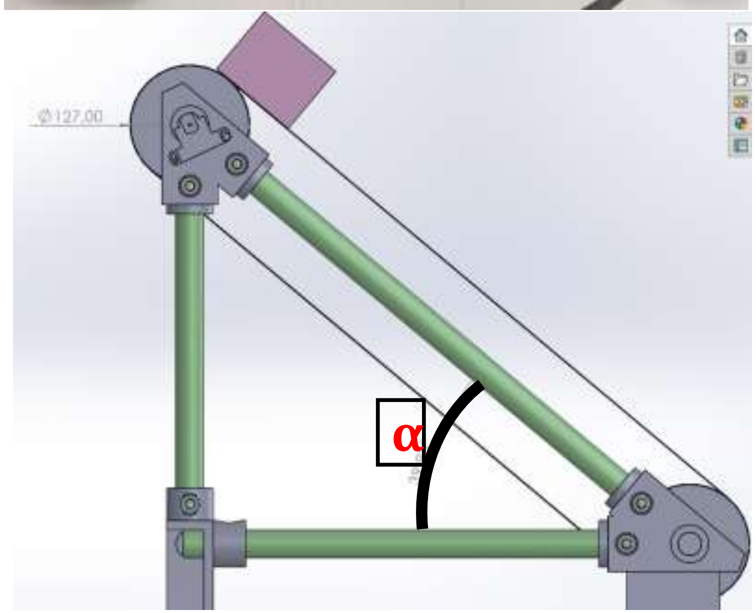


$\mathrm{temps}(s)$



$$\bar{J} = 3{,}13 \times 10^{-5}\ kgm^2$$
$$u(J) = 0{,}0291 \times 10^{-5}\ kgm^2$$

II)c) EXPERIENCE DES FROTTEMENTS DE COULOMB



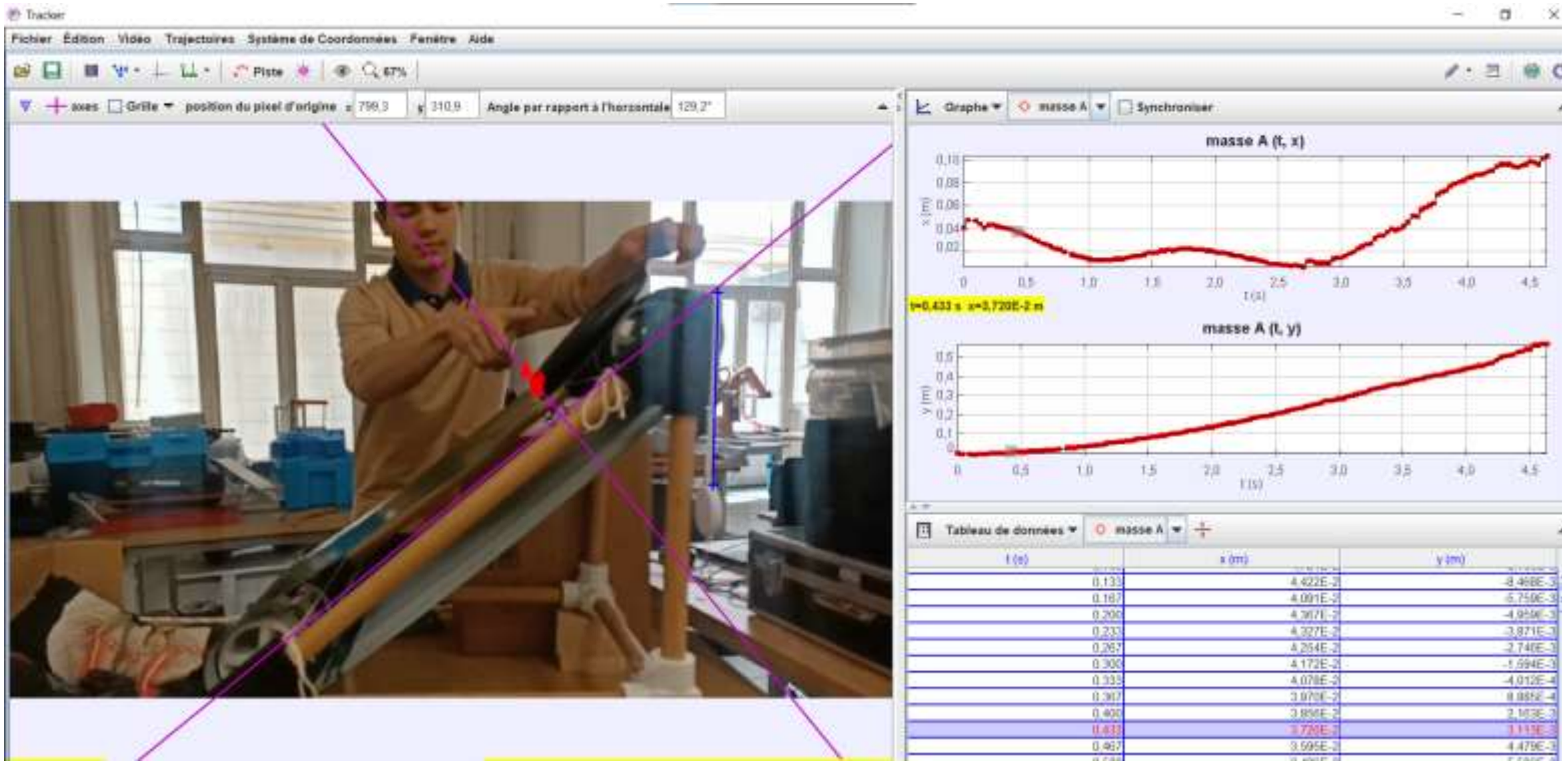
$$\bar{\alpha} = 42°$$
$$u(\alpha) = 0{,}4°$$
$$\mu = 0{,}9$$
$$Z(\mu, \mu_{ref}) = 1{,}8$$

$\mu_{ref} = 0{,}896\ (Caoutchouc/pvc)$

Source: https://dds.univ-lyon1.fr/icap_website/3649/72052

II)d) EXPERIENCES DE LA DESCENTE DE LA MASSE

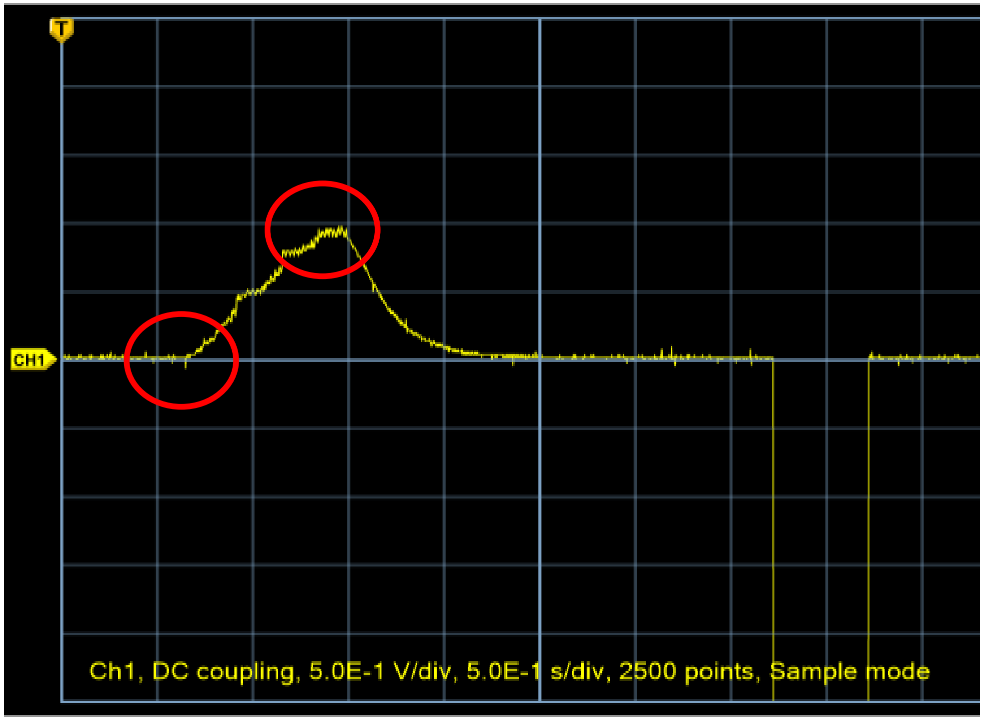
- Masses variant de 100g à 5kg



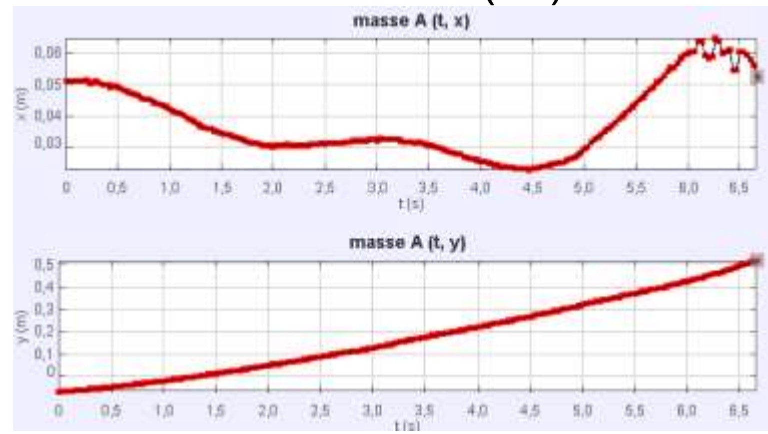
- Acquisition de la tension avec un oscilloscope avec TektronixOpenchoice™
- Acquisition de la vitesse de descente avec Tracker

Masse : 1kg

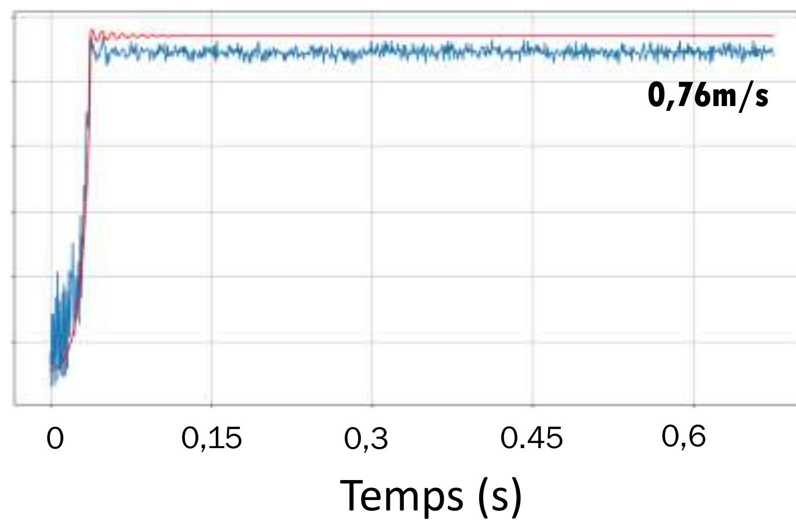
Tension (V)



Position (m)



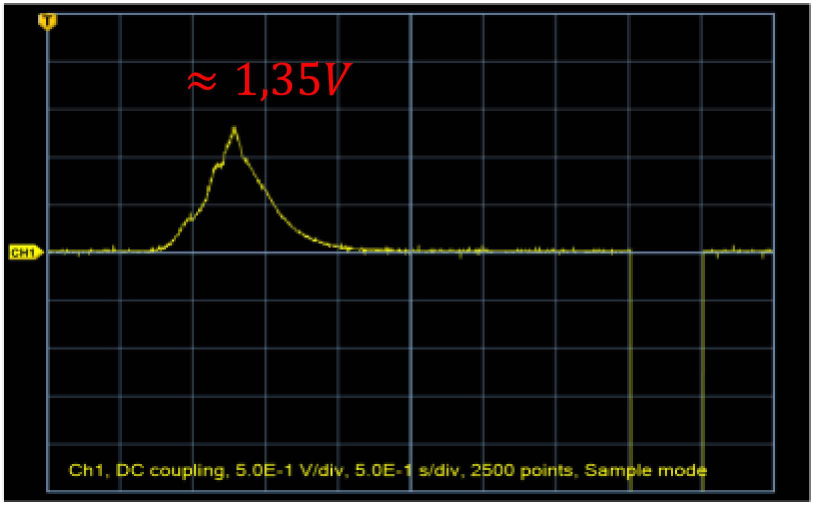
Vitesse (m/s)

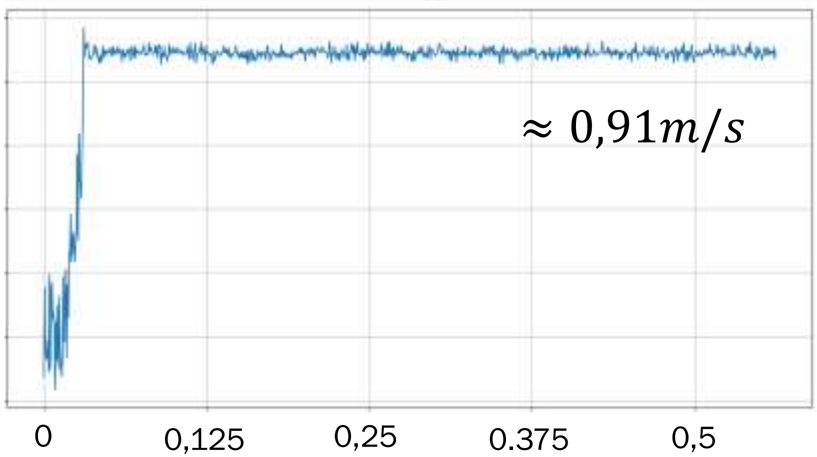


Pic de tension à ≈0,7s
Valeur : ≈0,1V

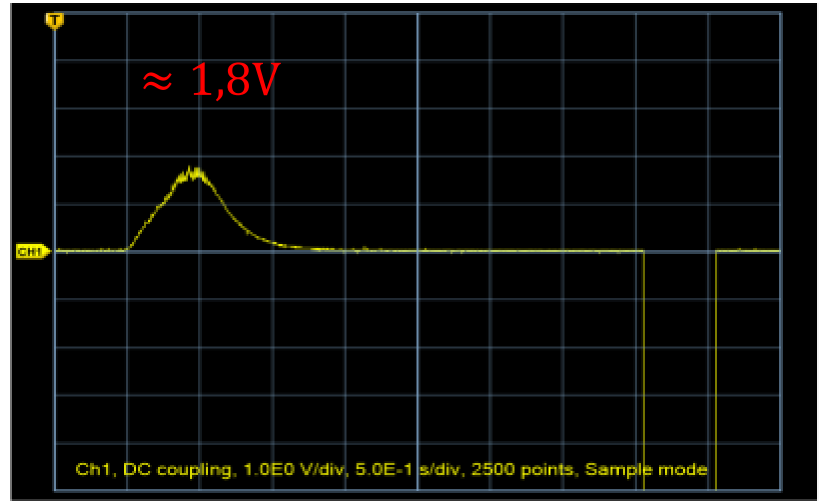
Vitesse en régime stationnaire ≈0,76m/s

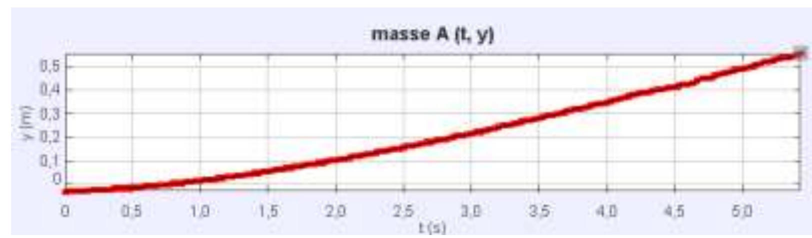
Masse : 1,5kg

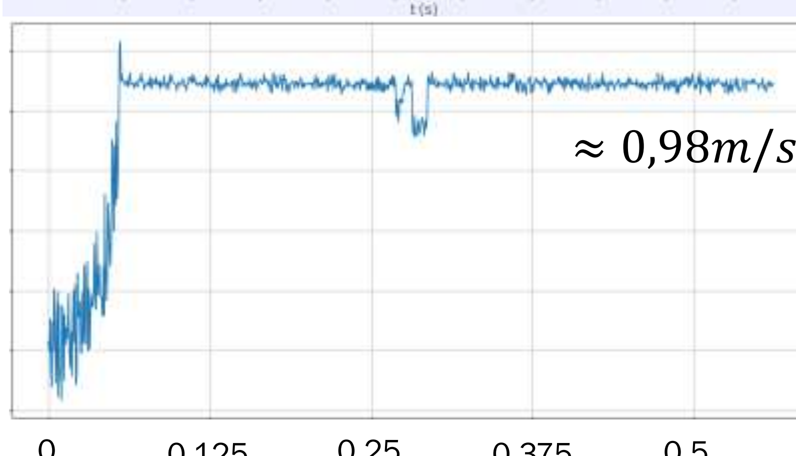




Masse : 2kg

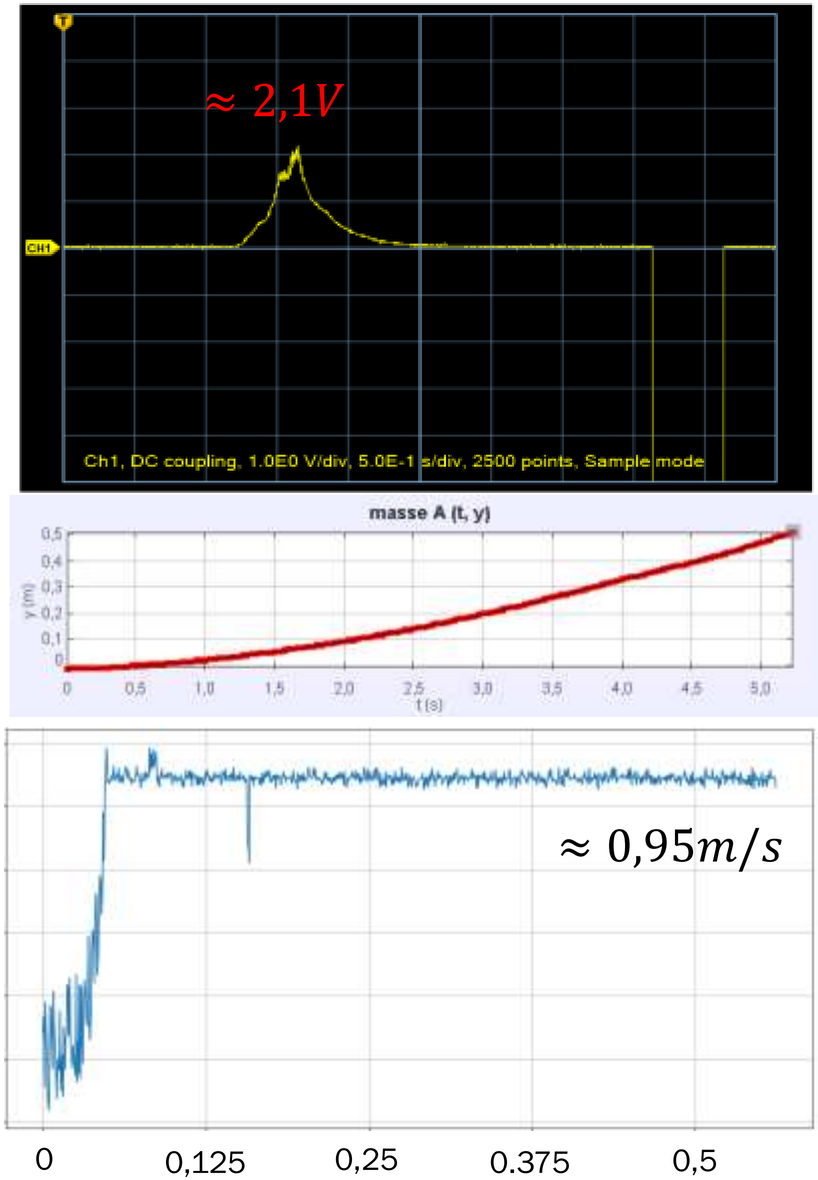




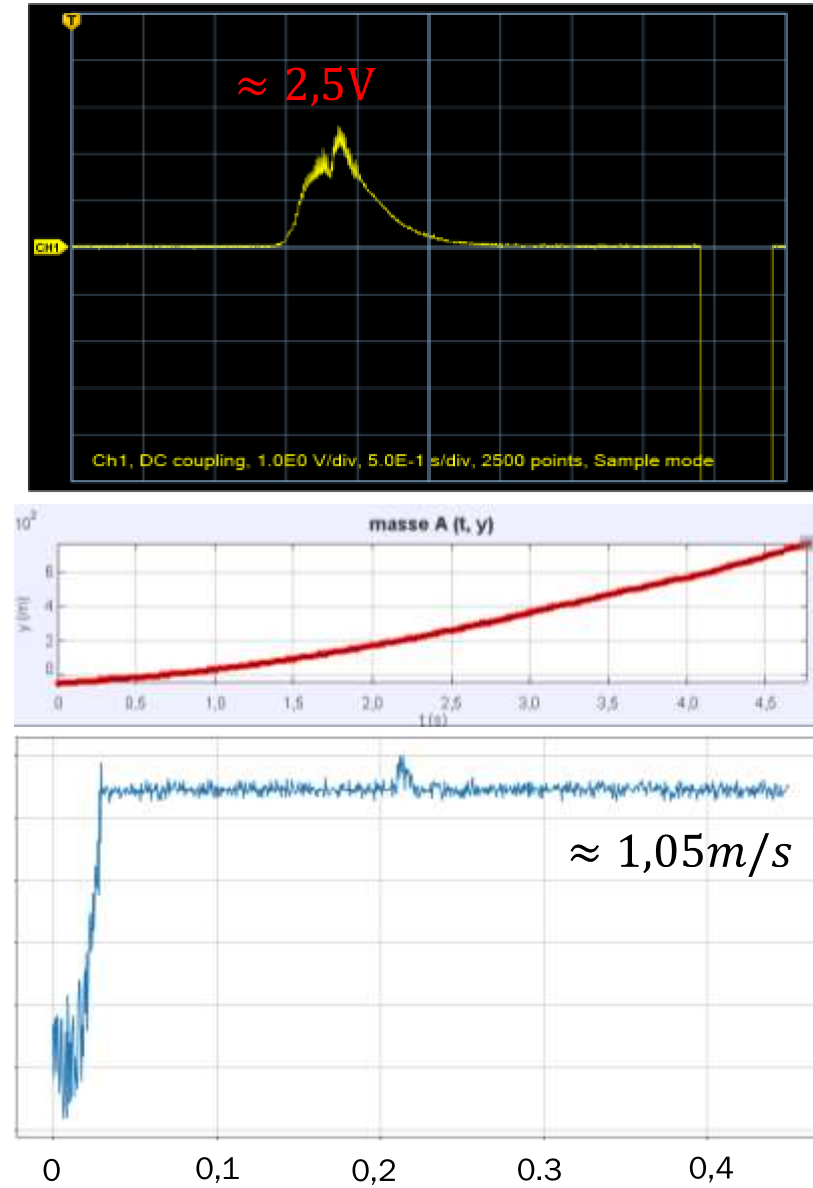


Temps (s)

Masse : 2,5kg

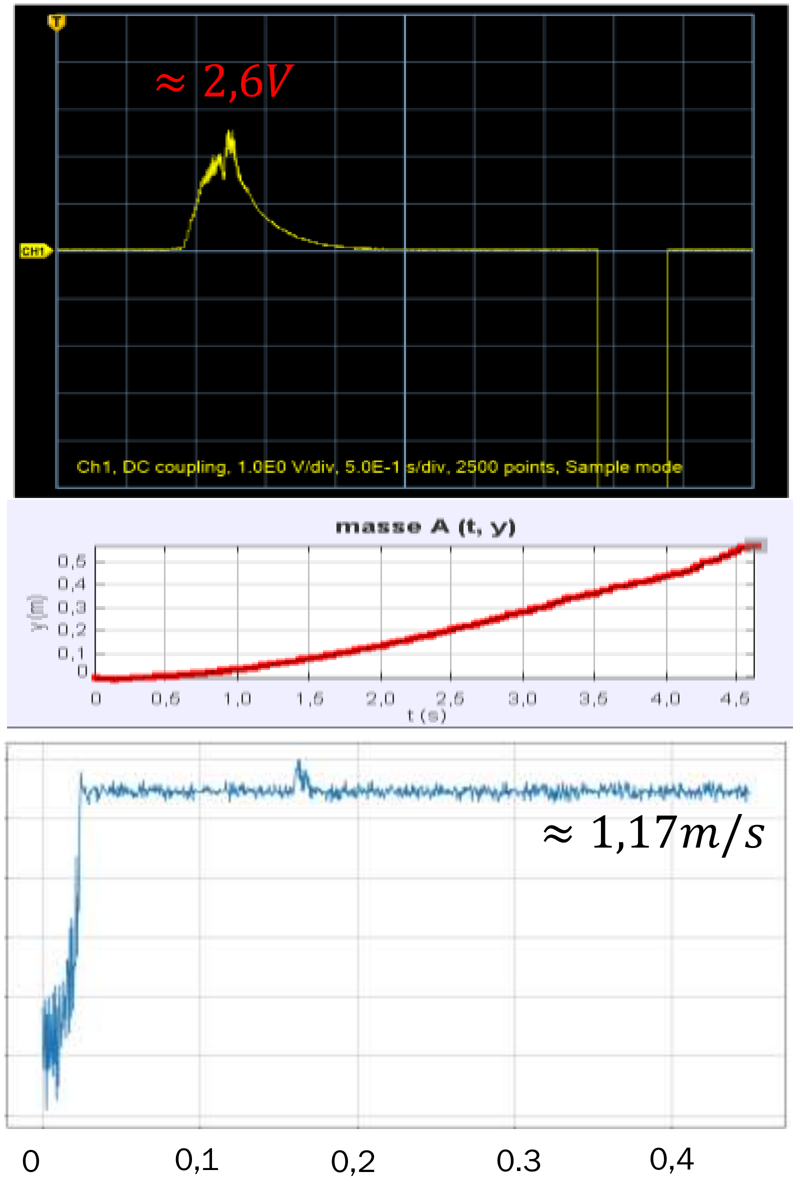


Masse : 3kg

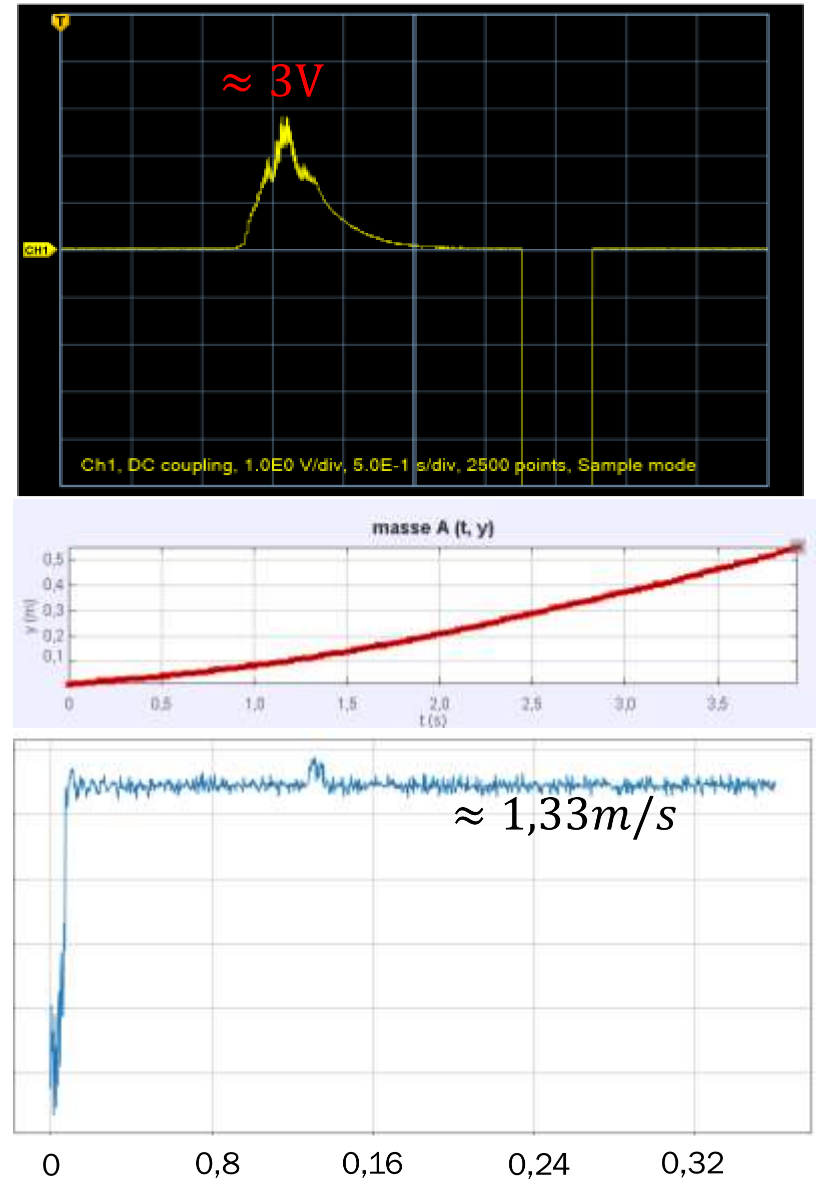


Temps (s)

Masse : 4kg



Masse : 5kg



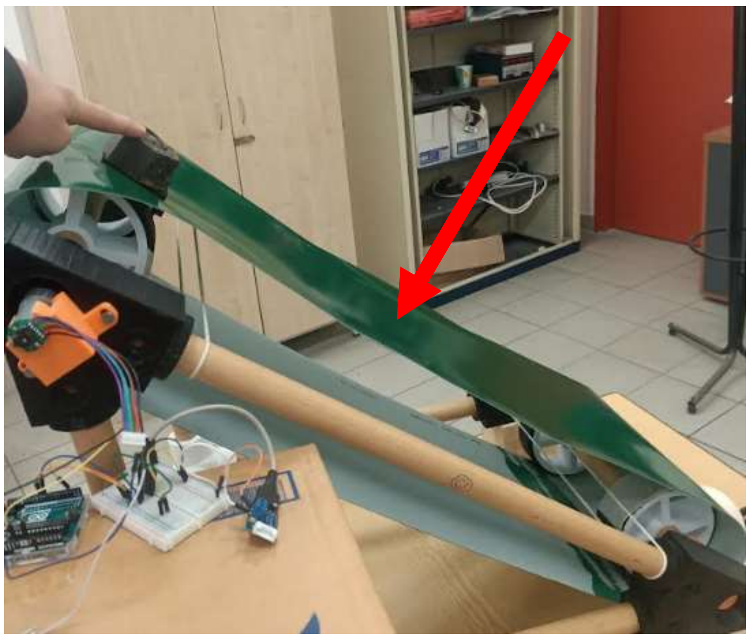
Temps (s)

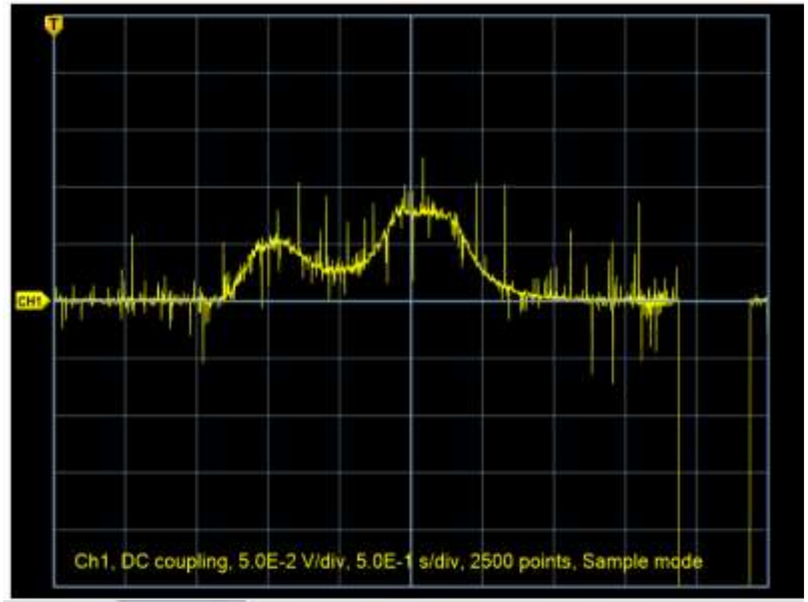
PARTIE III : CONCLUSION

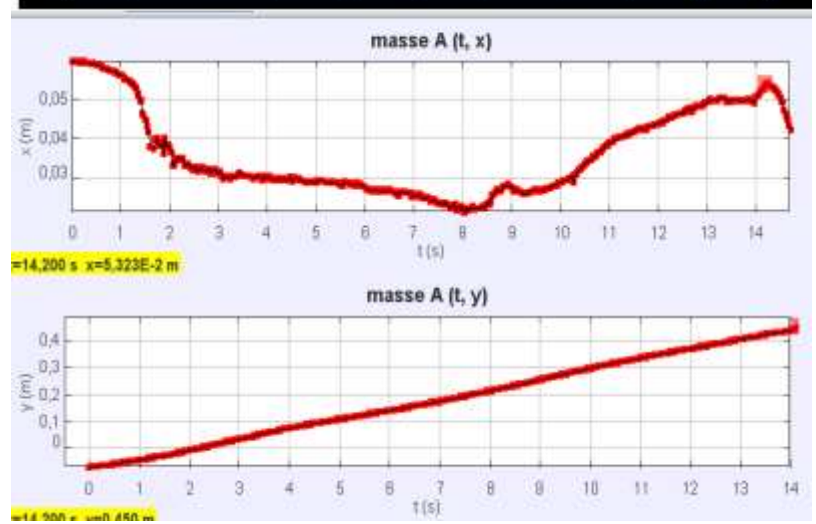
III.a) Courbes atypiques et explications

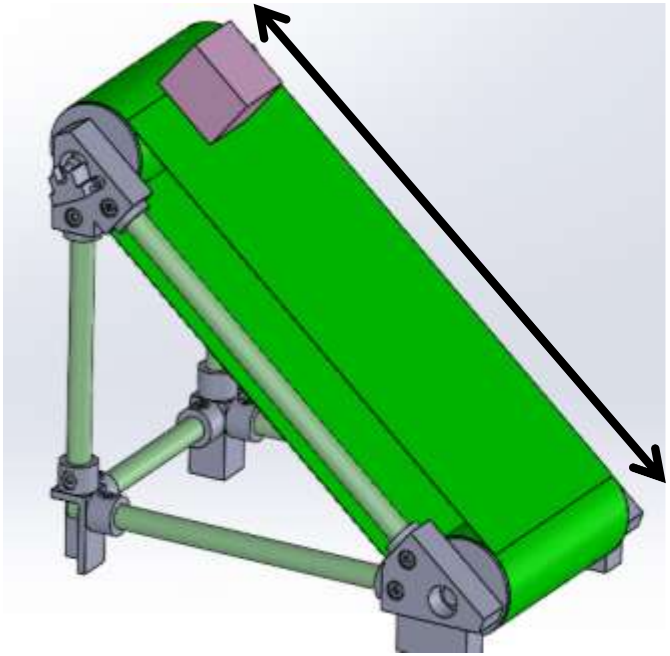
III.b) Limites et autres expériences

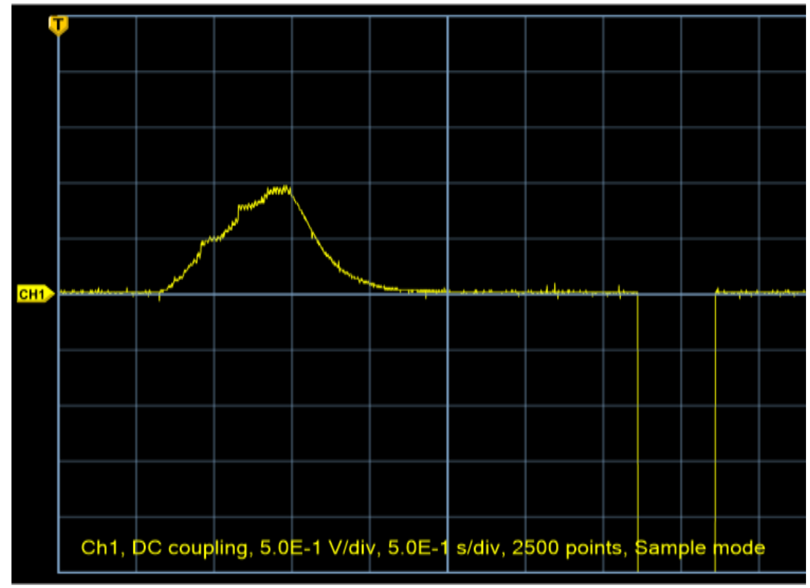
Masse : 0,5kg




CH1
Ch1, DC coupling, 5.0E-2 V/div, 5.0E-1 s/div, 2500 points, Sample mode


masse A (t, x)
x (m)
0,05
0,04
0,03
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
t (s)
=14,200 s x=5,323E-2 m
masse A (t, y)
y (m)
0,4
0,3
0,2
0,1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
t (s)





Longueur de descente trop petite

Aucun régime stationnaire observable

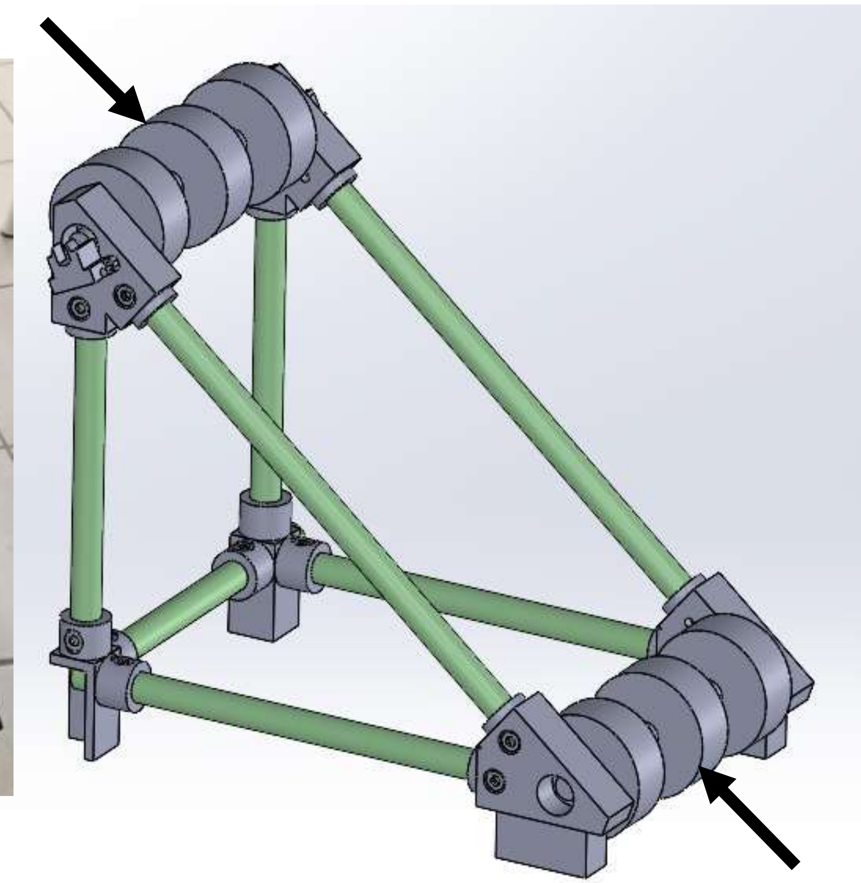
Conséquence:

Sortie en tension peu exploitable

Solutions:

Toboggans en série/parallèle?

RDM sur les poutres en bois et rouleaux

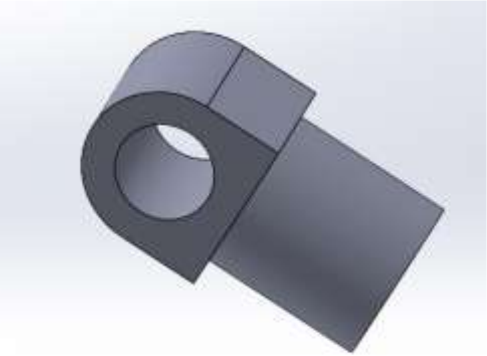


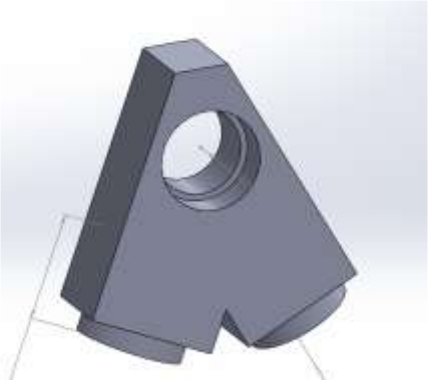
FIN DE LA PRESENTATION

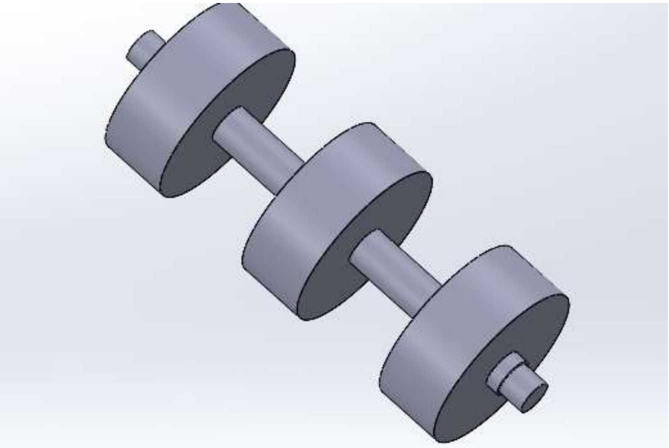
Merci de m’avoir écouté

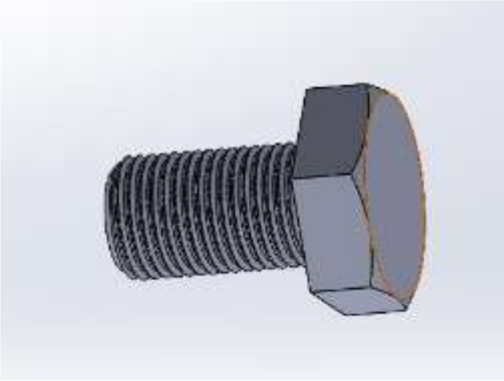
Annexes

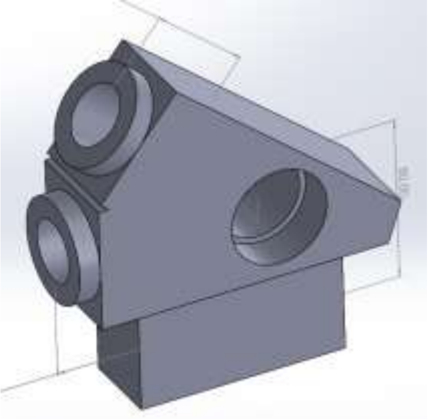
A) Montage du toboggan

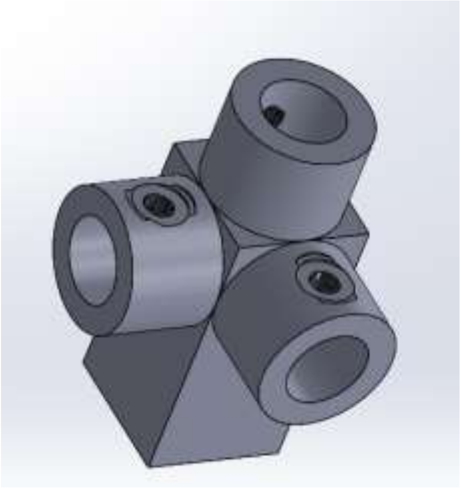


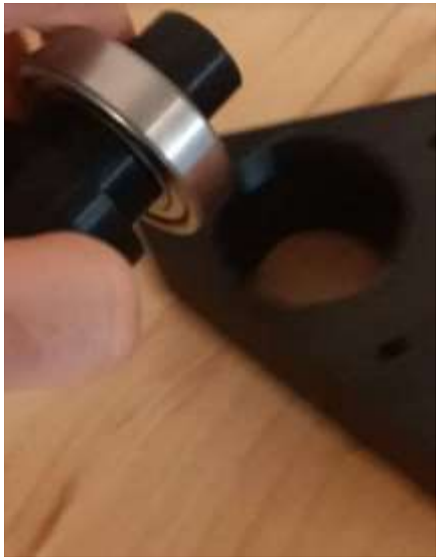


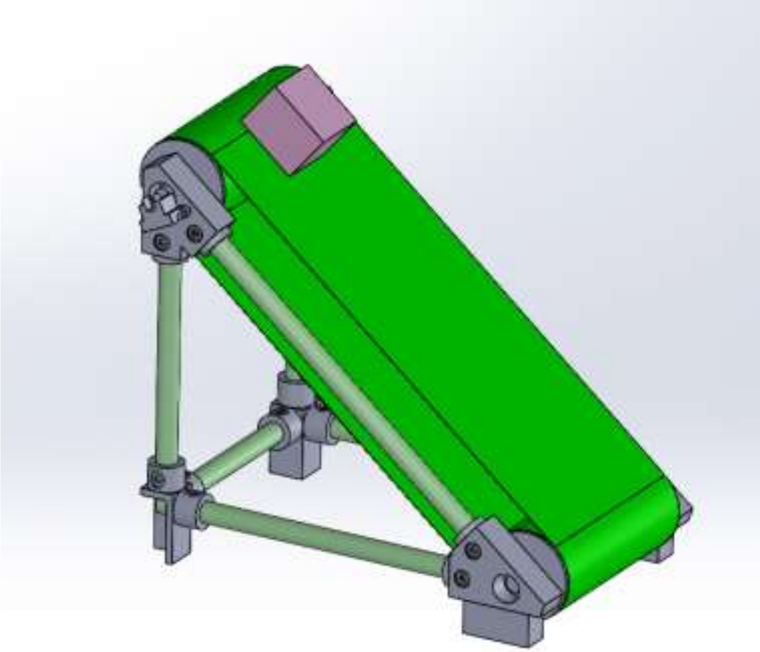


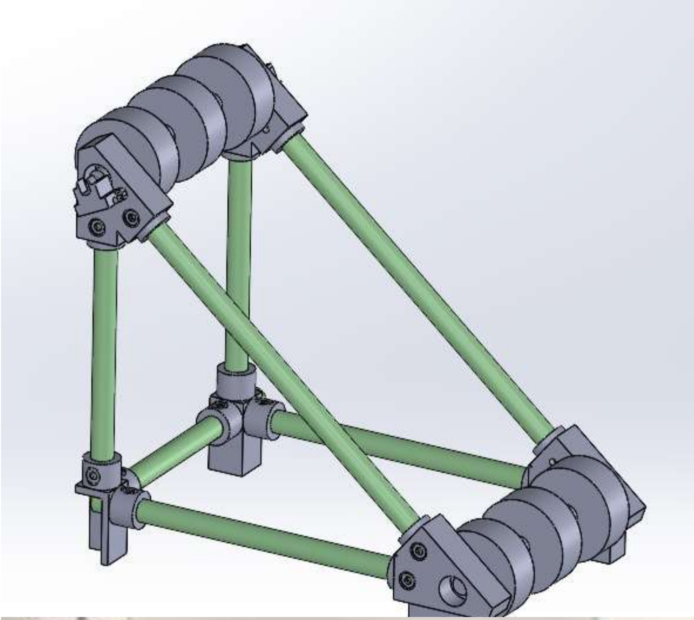


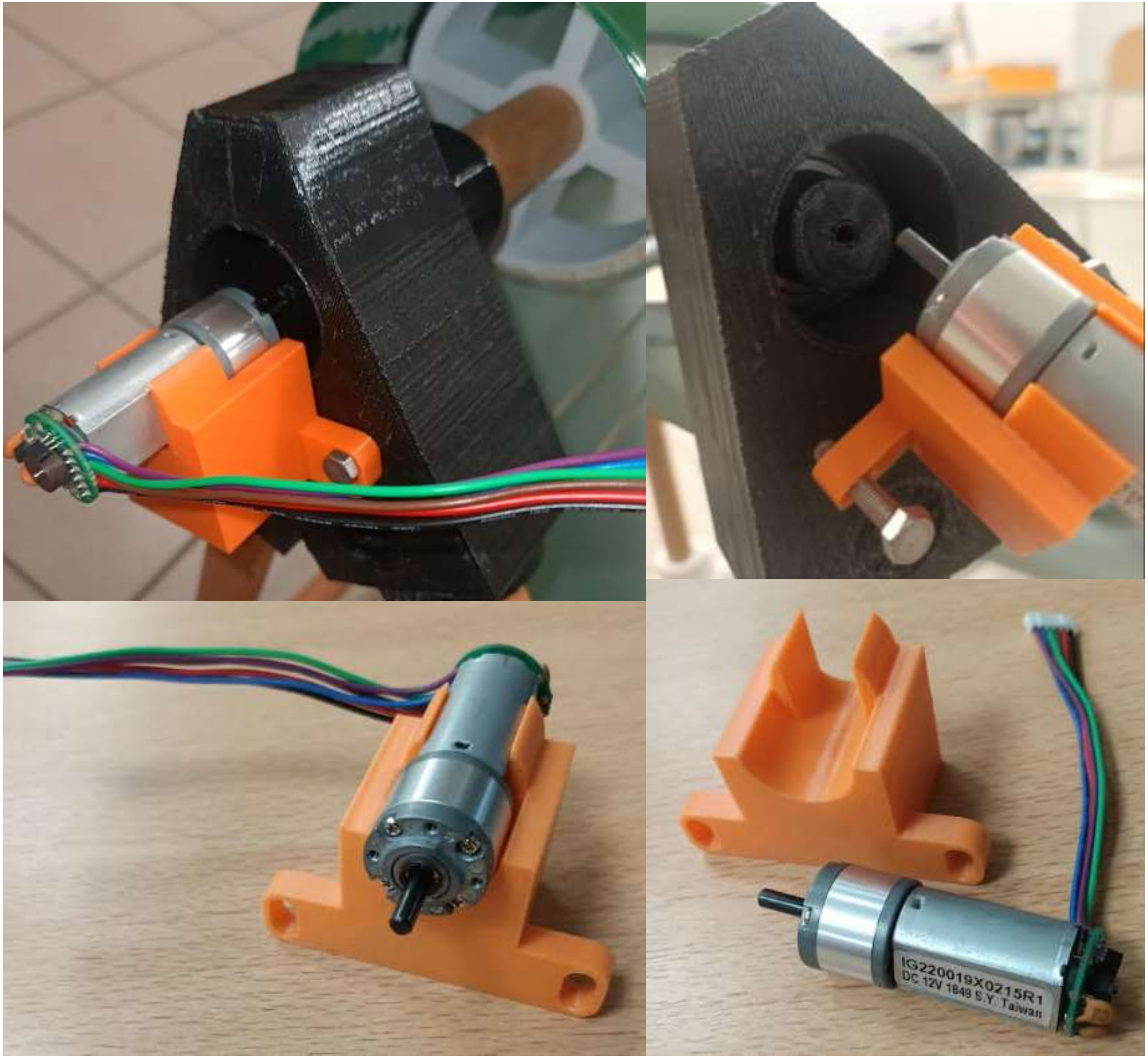


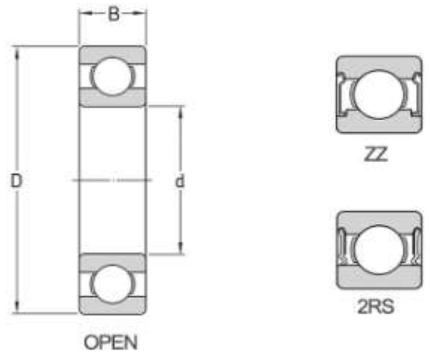






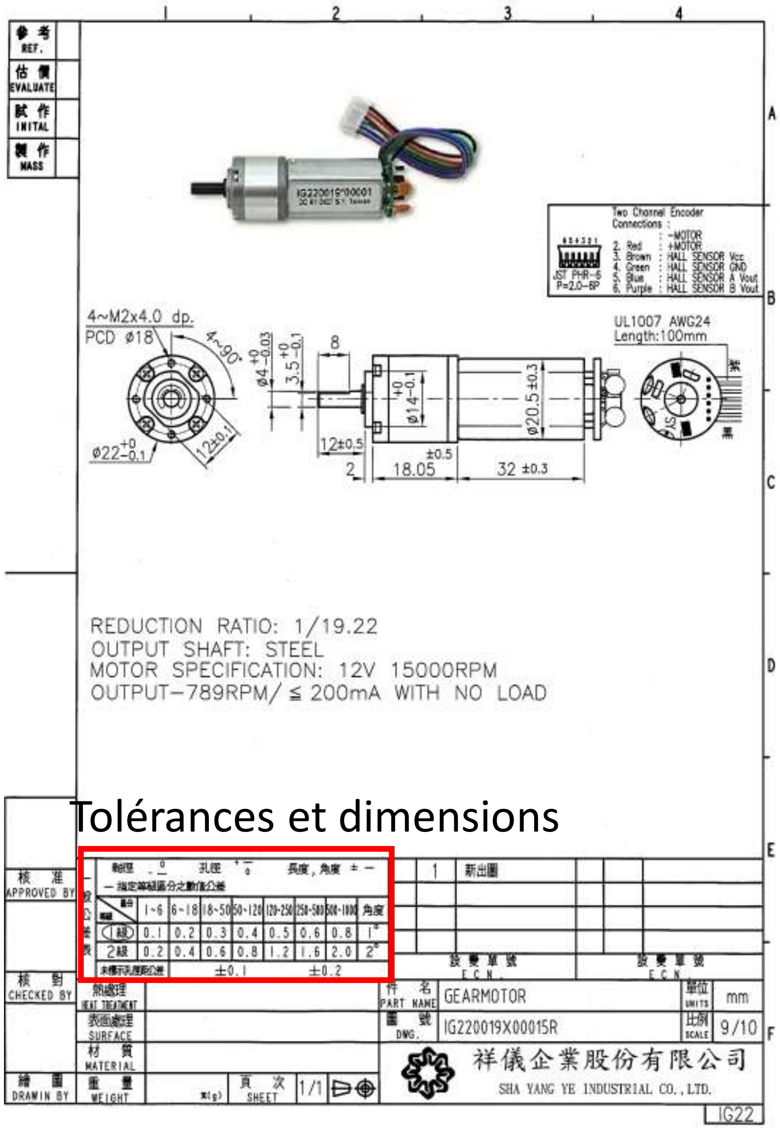



IG220019X0215R1
DC 12V 1849 S.Y. Taiwan



- Material: Chrome steel
- Precision grade: abec-3 or p6
- Grease: Pre-lubricated

↑↓	XIKE MODEL	Main Dimensions			Reference Data				
		d	D	B	Dynamic Loads	Static Loads	Grease Speed	Oil Speed	Weight
		MM			KN	KN	RPM	RPM	KG
	6000-2RS	10	26	8	4.1	1.79	21000	25000	0.018
	6001-2RS	12	28	8	4.8	2.15	22000	27000	0.022
	6002-2RS	15	32	9	5.3	2.57	18000	22000	0.031
	6003-2RS	17	35	10	5.7	2.95	17000	20000	0.041
	6004-2RS	20	42	12	8.9	4.54	14000	17000	0.068
▶	6005-2RS	25	47	12	9.6	5.31	13000	15000	0.079
	6006-2RS	30	55	13	13	7.54	11000	13000	0.116
	6007-2RS	35	62	14	15	9.36	9100	11000	0.151
	6008-2RS	40	68	15	16	10.5	8400	9800	0.195
	6009-2RS	45	75	16	20	13.8	7000	8400	0.241



Tolérances et dimensions

Technical Data

Part Number	IG220019X00015R	
Customer P/N		
ITEM	**Specifications**	**Note**
1. Operation Status		
1.1 Rated Voltage	12V D.C.	Stable power source
1.2 Rated torque	0.3 kgf.cm	6mm from shaft end
1.3 Radial load	8N (0.8kg-f)	
1.4 Axial load	6N (0.6kg-f)	
1.5 Turning direction	Shaft horizontal	
1.6 Reverse direction	CW.CCW	
1.7 Using environment	Temperature -10~60 ℃ Humidity 20~90% RH	
1.8 Preserve environment	Temperature -20~70 ℃ Humidity 20~90% RH	
1.9 Using voltage range	12V (D.C.) ±10%	
2.Electrical Characteristics		
2.1 No Load current	200 mA max.	
2.2 No Load speed	789 rpm ±15%	
2.3 Rated current	620 mA	
2.4 Rated speed	639 rpm ±15%	
2.5 Stall current	2.4 A	
2.6 Stall torque	2.2 kgf.cm	
2.7 Insulation	D.C. 100V meg. 1.0 MΩ min	Motor terminal shell
2.8 Durable voltage	100V (A.C.) 1 minute min	Motor terminal shell
2.9 Coil resistance	5Ω Ω	Reference
2.10 Torque constant	0.91 kgf.cm/A	Reference
2.11 Voltage constant	8.68 mV/r/min	Reference
3.Mechanical characteristic		
3.1 Reduction ratio	1/19.225	
3.2 Thrust play of shaft	0.2 mm max.	
3.3 Radial play of shaft	0.05 mm max.	
3.4 Back lash	3° max.	
3.5 Outside Appearance	No scratch defective....	By visual judgment
2.Life Cycle	72000 cycles min. ccw 5 off 5 5 cw 5 1 cycle	After the rated life cycle test current @ rated load must stay within ±30% of the initial value and r.p.m. @ rated load must stay within ±20% of the initial value. However change of mechanical noise level was not considered as part of the testing

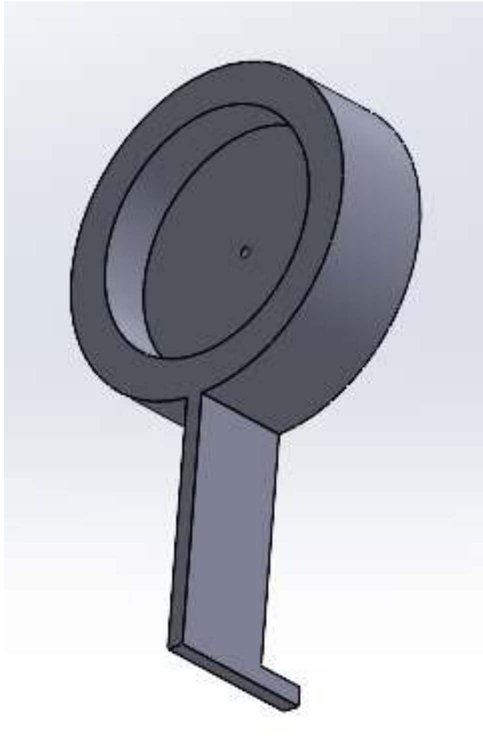
$$k_c = 0{,}089 Nm/A$$
$$k_e = 0{,}083 V/rad/s$$

Source : https://www.farnell.com/datasheets/2022064.pdf

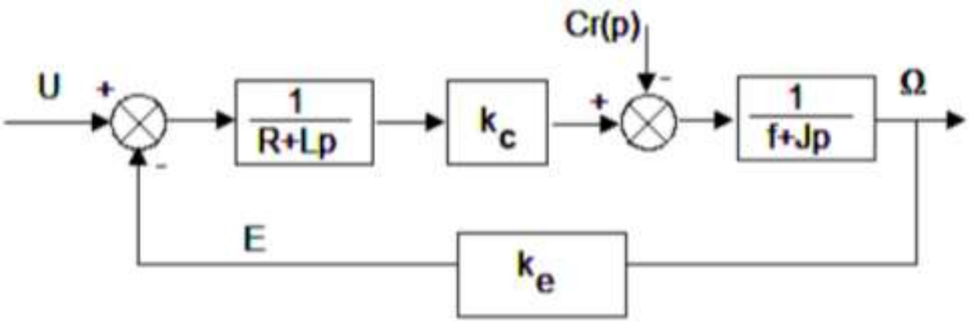
Function	Range	Resolution	Accuracy ± ([% of Reading] + [Counts])
AC Volts (Average responding)	6.000 V 60.00 V 600.0 V 1000 V	0.001 V 0.01 V 0.1 V 1 V	2.0 % + 2 (45 Hz to 1 kHz)
DC mV	600.0 mV	0.1 mV	0.3 % + 1
DC Volts	6.000 V 60.00 V 600.0 V 1000 V	0.001 V 0.01 V 0.1 V 1 V	0.3 % + 1
Continuity	600 Ω	1 Ω	Meter beeps at <25 Ω, beeper turns off at >250 Ω; detects opens or shorts of 250 µs or longer.
Ohms	600.0 Ω 6.000 kΩ 60.00 kΩ 600.0 kΩ 6.000 MΩ 50.00 MΩ	0.1 Ω 0.001 kΩ 0.01 kΩ 0.1 kΩ 0.001 MΩ 0.01 MΩ	0.5 % + 2 0.5 % + 1 0.5 % + 1 0.5 % + 1 0.5 % + 1 2.0 % + 1
Diode test	2.400 V	0.001 V	1 % + 2
Capacitance	1000 nF 10.00 µF 100.0 µF 9999 µF[1]	1 nF 0.01 µF 0.1 µF 1 µF	1.2 % + 2 1.2 % + 2 1.2 % + 2 10 % typical
AC Amps (Average responding)[2]	60.00 mA 400.0 mA[3] 6.000 A 10.00 A[4]	0.01 mA 0.1 mA 0.001 A 0.01 A	2.5 % + 2 (45 Hz to 1 kHz)

[1] In the 9999 µF range for measurements to 1000 µF, the measurement accuracy is 1.2 % + 2.
[2] Amps input burden voltage (typical): 400 mA input 2 mV/mA, 10 A input 37 mV/A.
[3] 400.0 mA accuracy specified up to 600 mA overload.
[4] >10 A unspecified.

100mH	40.00mH~399.99mH	1.5%+5 digits	1.5%+5 digits	En parallèle
40mH	4.000mH~39.999mH	1.5%+2 digits	1.5%+2 digits	En parallèle
4mH	400.0uH~3.9999mH	0.5%+2 digits	0.5%+2 digits	----
400µH	40.00uH~399.99µH	0.5%+2 digits	0.5%+2 digits	En séries
40µH	4.000uH~39.999µH	0.8%+5 digits	0.8%+5 digits	En séries
4µH	0.000uH~3.999µH	2.5%+10 digits	Non spécifié	En séries



B) Mise en équation



- $C_m - C_r - f\omega = J_{eq}\frac{d\omega}{dt}$
- $C_m = k_c i$ • $\mathrm{E} = k_e \omega$
- $U - E - Ri - L\frac{di}{dt} = 0$
- $C_r(t) = Mg\,sin(\alpha)\,R_{roul}$

$$\frac{\Omega(p)}{C_r(p)} = \frac{\frac{R + Lp}{fR + k_e k_c}}{1 + \frac{J_{eq}R + fL}{fR + k_e k_c}p + \frac{J_{eq}L}{fR + k_e k_c}p^2}$$

$$\Omega(p)\left(1 + \frac{J_{eq}R + fL}{fR + k_e k_c}p + \frac{J_{eq}L}{fR + k_e k_c}p^2\right) = \frac{R + Lp}{fR + k_e k_c}C_r(p)$$

$$\omega(t) + \frac{J_{eq}R + fL}{fR + k_e k_c}\frac{d\omega}{dt} + \frac{J_{eq}L}{fR + k_e k_c}\frac{d^2\omega}{dt^2} = \frac{R}{fR + k_e k_c}C_r(t)$$

Résolution de l'équation différentielle

$$\omega(t) + \frac{2z}{{\omega_0}^2}\frac{d\omega}{dt} + \frac{1}{{\omega_0}^2}\frac{d^2\omega}{dt^2} = \frac{R}{fR +\ k_e k_c}C_r(t)$$

$$\omega_0 = \sqrt{\frac{fR +\ k_e k_c}{J_{eq}L}}$$

$$z = \frac{1}{2}\frac{J_{eq}R + fL}{\sqrt{J_{eq}L}\sqrt{fR + k_e k_c}}$$

$$z = \frac{1}{2}\frac{J_{eq}R + fL^2}{\sqrt{J_{eq}L}\sqrt{fR + k_e k_c}}$$

$A.N:\quad z = 0{,}85$

$z < 1$

$$(EC): \frac{1}{{\omega_0}^2}X^2 + \frac{2z}{{\omega_0}^2}X + 1 = 0 \qquad \Delta = \frac{4(z^2 - 1)}{{\omega_0}^2} < 0 \qquad X = \omega_0(-z \ \pm j\sqrt{1 - z^2})$$

$$\omega(t) = e^{-z\omega_0 t}\left(A cos\left(\omega_0\sqrt{1 - z^2}t\right) + B sin\left(\omega_0\sqrt{1 - z^2}t\right)\right) + \frac{R}{fR +\ k_e k_c}C_r(t)$$

$$\omega(t) = e^{-z\omega_0 t}\,(A cos\left(\omega_0\sqrt{1-z^2}t\right) + B sin\left(\omega_0\sqrt{1-z^2}t\right) + \frac{R}{fR + \ k_e k_c} C_r(t)$$

$$Conditions\ initiales\text{: } \omega(0) = 0 \quad ; \quad \frac{d\omega(t)}{dt} = 0$$

$$A = -\frac{RC_r(t)}{fR + k_e k_c} \qquad\qquad B = -\frac{zRC_r(t)}{\sqrt{1-z^2}(fR + k_e k_c)}$$

$$Or : \ C_r(t) = \ Mg\, sin(\alpha)\, R_{roul}$$

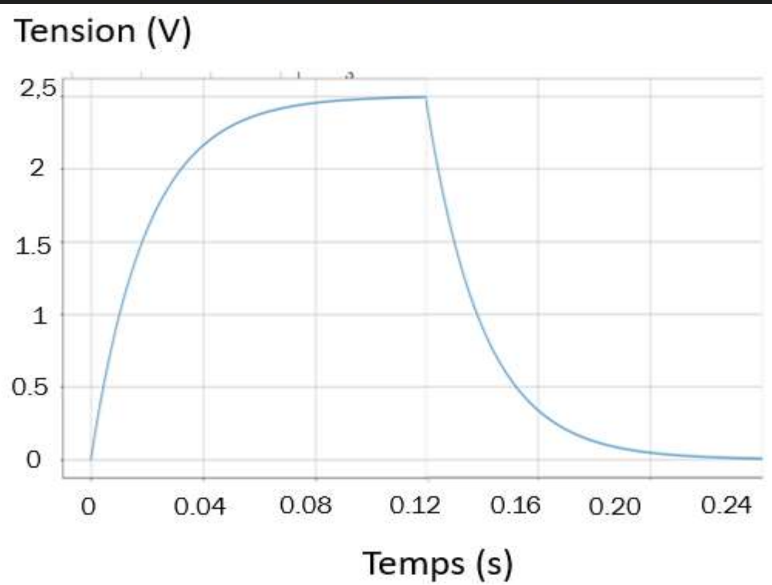
$$\boxed{\omega(t) = e^{-z\omega_0 t}\,\left(A cos\left(\omega_0\sqrt{1-z^2}t\right) + B sin\left(\omega_0\sqrt{1-z^2}t\right)\right) + \frac{RMg\, sin(\alpha)\, R_{roul}}{fR + \ k_e k_c}}$$

Obtention de la courbe de tension

- $C_m + C_r + f\omega = J_{eq}\frac{d\omega}{dt}$
- $C_m = k_c i$
- $U - E - Ri - L\frac{di}{dt} = 0$
- $C_r(t) = Mg\,sin(\alpha)\,R_{roul}$

$$\boxed{U = \frac{d^2\omega}{dt^2}\left(\frac{LJ_{eq}}{k_c}\right) + \frac{d\omega}{dt}\left(\frac{J_{eq}R + fL}{k_c}\right) + \omega\left(k_e + \frac{Rf}{k_c}\right) + \frac{C_r(t)R}{k_c}}$$

```
def fonctionderiv(t,alpha,m):
    -z*w0*np.exp(-z*w0*t)*(A(alpha,m)*np.cos(w0*((1-z**2)**0.5)*t)+B(alpha,m)*np.sin(w0*((1-z**2)**0.5)*t)) + (R*Cr(alpha,m))/(f*R+ke*kc)+-z*w0*np.exp(-z*w0*t)*(A(alpha,m

def fonctionderiv2(t,alpha,m):
    -z*w0**2*np.exp(-z*w0*t)*(A(alpha,m)*np.cos(w0*((1-z**2)**0.5)*t)+B(alpha,m)*np.sin(w0*((1-z**2)**0.5)*t)) + (R*Cr(alpha,m))/(f*R+ke*kc)+-z*w0*np.exp(-z*w0*t)*(A(alph

def Tension(t,alpha,m):
    return fonctionderiv2(t,alpha,m)*(J*L)/(kc) + fonctionderiv(t,alpha,m)*(J*R +f*L)/(kc) + fonction((t,alpha,m))*(ke+R*f)/(kc)
```



Programmes python

Affichage de la vitesse de rotation

```python
J = 2.77 * 10**-6
R = 0.5
f = 10**-5
L = 10**-3
ke = 2.510**-2
kc = 2.510**-2
Rroul = 0.0635
alpha0 = np.pi/4
M0 = 5
g = 9.81
Cr0 = M0*g*np.sin(alpha0)*Rroul
z = 0.5 * (J*R + f*L)/(((J*L)**0.5)*(f*R + ke*kc)**0.5)
w0 = ((f*R + ke*kc)/(J*L))**0.5
A0 = -(R*Cr0)/(f*R + ke*kc)
B0 = -((z*R*Cr0)/((f*R + ke*kc)*np.sqrt(1-z**2)**0.5))



def Cr(alpha,m):
    return m*g*np.sin(alpha)*Rroul

def A(alpha,m):
    return -(R*Cr(alpha,m))/(f*R + ke*kc)

def B(alpha,m):
    return -(R*Cr(alpha,m))/(f*R + ke*kc)



T = np.linspace(0,300,100)

def fonction(t,alpha,m):
    return np.exp(-z*t)*(A(alpha,m)*np.cos(w0*((1-z**2)**0.5)*t)+B(alpha,m)*np.sin(w0*((1-z**2)**0.5)*t)) + (R*Cr(alpha,m))/(f*R+ke*kc)

# omega = fonction(T,alpha0,M0)

plt.grid()

ALPHA = np.linspace(0,np.pi/4,100)
MASSE = np.linspace(0.05,5,100)
# plt.subplot(2,2,1)
plt.plot(T,fonction(T,alpha0,M0 ),"r")
```

Affichage de la vitesse de descente

```python
V = []
L = fonction(T,alpha0,M0 )
for k in L:
    V.append(k*0.0635)


plt.plot(T,V,"b")
plt.show()
```

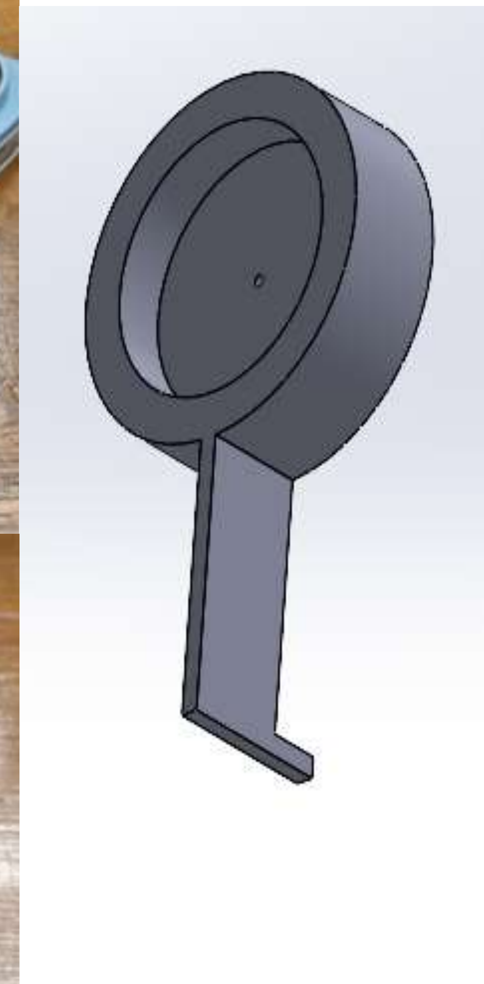
Affichage de la vitesse maximale en fonction des paramètres

```python
V = []
L = fonction(T,alpha0,M0 )
for k in L:
    V.append(k*0.0635)
# plt.plot(T,V,"b")

# plt.subplot(2,2,2)
plt.plot(ALPHA,V,"g")
# plt.subplot(2,2,3)
plt.plot(MASSE, V,"b")


plt.show()
```

C) Détails des expériences







Couple de démarrage obtenu

Masses utilisées (g)	Mouvement observé
64,65	Oui
49,53	Oui
49,24	Oui
48,32	Oui
48,04	Oui
47,69	Non
46,96	Non
39,88	Non
29,84	Non

Estimateur : $\bar{m} = \frac{m_{max} + m_{min}}{2} = 47{,}86g$

Incertitude due à la variabilité du système

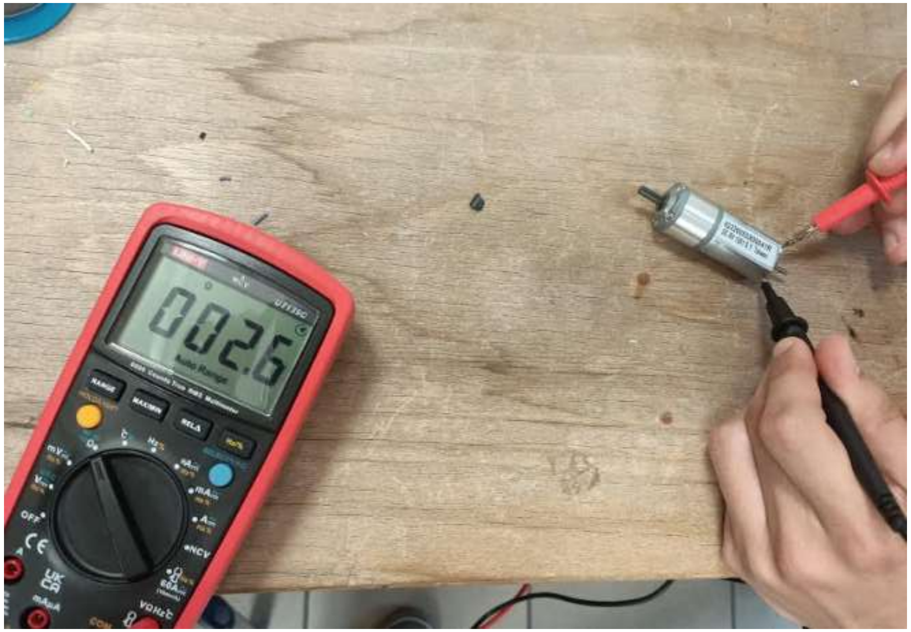
$$u_1(m) = \frac{m_{max} - m_{min}}{2\sqrt{3}} = 0{,}09\ g$$

Incertitude type de résolution:

$$u_2(m) = \frac{0{,}01}{\sqrt{3}} = 0{,}006\ g$$

$$\boxed{\mathrm{u}(m) = \sqrt{u_1(m)^2 + u_2(m)^2} = 0{,}09g}$$

Mesure de la résistance interne



$$\boxed{\begin{gathered}\bar{R} = \frac{R_{max} + R_{min}}{2} = 2{,}7\Omega \\ u(R) = 0{,}2\Omega\end{gathered}}$$

$$R_{min} = 2{,}6\,\Omega$$
$$R_{max} = 2{,}8\Omega$$

Mesure de la résistance interne (incertitudes)

Incertitude due à la variabilité du système

$$u_1(R) = \frac{R_{max} - R_{min}}{2\sqrt{3}} = 0,1\Omega$$

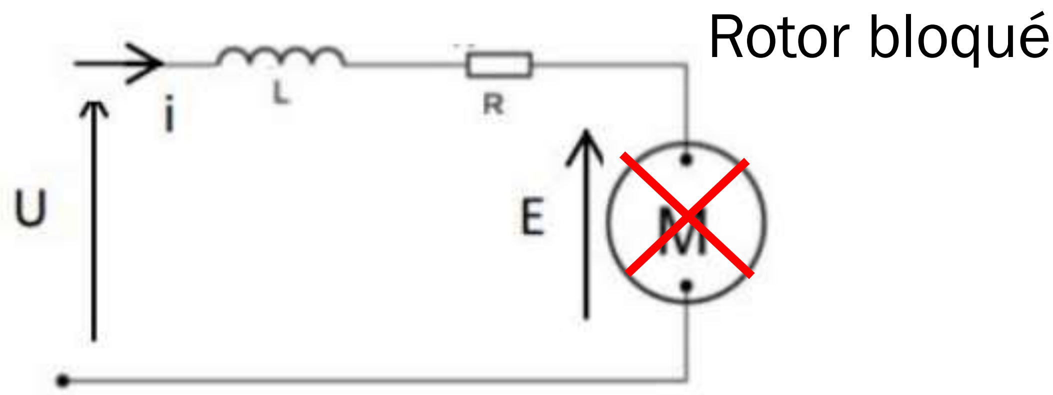
Incertitude type due à l'instrument de mesure

$$u_2(R) = \frac{2,7 \times \frac{0,5}{100} + 2 \times 0,1}{\sqrt{3}} = 0,1\Omega$$

Incertitude composée

$$\boxed{\mathrm{u}(R) = \sqrt{u_1(R)^2 + u_2(R)^2} = 0,1\Omega}$$

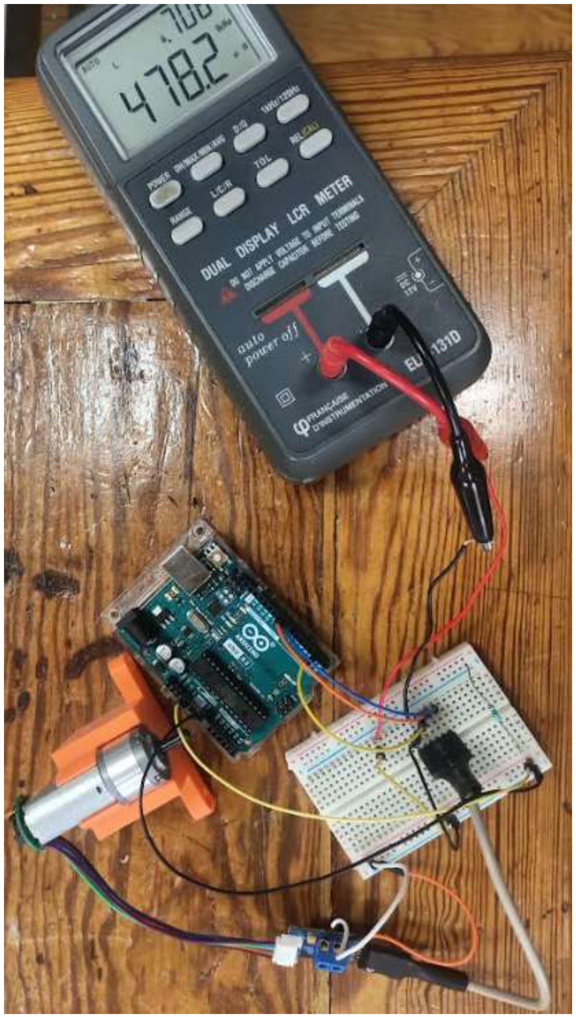
Mesure de l’inductance



Autre Protocole:

- On bloque le rotor
- On alimente de moteur à l’aide de l’arduino
- On mesure sa tension à ses bornes à l’aide d’un oscillo
- On trace l’évolution temporelle de i
- On identifie $3\tau = 3\frac{L}{R}$
- On calcule $L = \frac{3\tau R}{3}$

Mesure de l’inductance



$$L_{min} = 477{,}9\ \mu H$$
$$L_{max} = 478{,}3\ \mu H$$

$$\boxed{\begin{gathered}\bar{L} = \frac{L_{max} + L_{min}}{2} = 477{,}1 \mu H \\ u(L) = 1 \mu H\end{gathered}}$$

Incertitude due à la variabilité du système

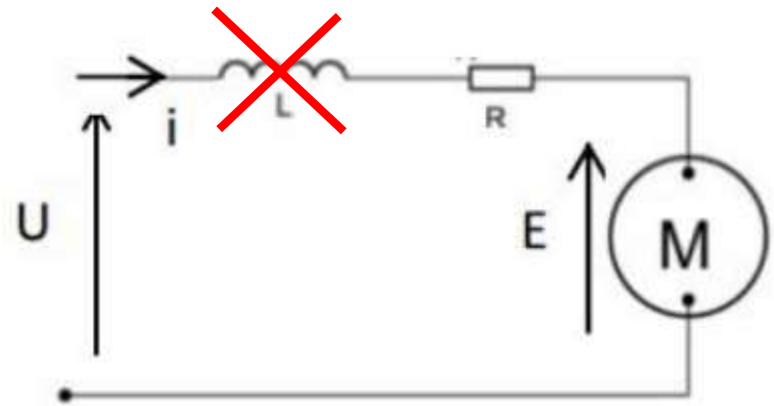
$$u_1(L) = 0{,}1 \mu H$$

Incertitude type due à l’instrument de mesure

$$u_2(L) = 1 \mu H$$

$$\mathrm{u}(L) = \sqrt{u_1(R)^2 + u_2(R)^2} = 1 \mu H$$

Mesure de la constante de FEM (incertitudes)



$$\overline{k_e} = \frac{U\ - Ri}{\omega} = 0{,}091\, V/rad/s$$

$$\bar{\imath} = \frac{i_{max} + i_{min}}{2} = 0{,}045\ A$$

$i_{min} = 0{,}044\ A$
$i_{max} = 0{,}046\ A$

$\omega_{min} = 17{,}9\, rad/s$
$\omega_{max} = 18{,}1\, rad/s$

$U_{min} = 1{,}78\ V$
$U_{max} = 1{,}82\ V$

$$u_1(i) = \frac{i_{max} - i_{min}}{2\sqrt{3}} = 0{,}00058\ A$$

$$u_2(i) = \frac{0{,}045 \times \frac{2{,}5}{100} + 2 \times 0{,}001}{\sqrt{3}} = 0{,}001A$$

Mesure de la constante de FEM (incertitudes)

$$u_1(\omega) = \frac{\omega_{max} - \omega_{min}}{2\sqrt{3}} = 0{,}058\, rad/s$$

$$u_2(\omega) = \frac{1}{\sqrt{3}} = 0{,}58\, rad/s$$

$$\bar{\omega} = \frac{\omega_{max} + \omega_{min}}{2} = 18,0\, rad/s$$

$$u_1(U) = \frac{U_{max} - U_{min}}{2\sqrt{3}} = 0{,}01\, V$$

$$\bar{U} = \frac{U_{max} + U_{min}}{2} = 1{,}80\, V$$

$$u_2(U) = \frac{1{,}80 \times \frac{3}{100} + 1 \times 0{,}001}{\sqrt{3}} = 0{,}03 V$$

Mesure de la constante de FEM (incertitudes)

$$u(i) = \sqrt{u_1(i)^2 + u_2(i)^2} = 0{,}001A$$

$$u(U) = \sqrt{u_1(U)^2 + u_2(U)^2} = 0{,}03V$$

$$u(\omega) = \sqrt{u_1(\omega)^2 + u_2(\omega)^2} = 0{,}58 rad/s$$

$$u(k_e) = k_e \sqrt{\left(\frac{u(\omega)}{\bar{\omega}}\right)^2 + \left(\frac{u(i)}{\bar{\imath}}\right)^2 + \left(\frac{u(U)}{\bar{U}}\right)^2 + \left(\frac{u(R)}{\bar{R}}\right)^2}$$
$$= 0{,}004\, V/rad/s$$

$$\boxed{Z\left(\overline{k_e}, k_{e_{ref}}\right) = \frac{\left|\overline{k_e} - k_{e_{ref}}\right|}{|u(k_e)|} = 2{,}5}$$

Mesure de la constante de couple

$$k_c = \frac{C_m}{i} = \frac{R_{Poulie} \times m \times g}{i}$$

$i \in [0{,}083A ; 0{,}085A]$ $\quad \bar{\imath} = 0{,}084\ A$

$\bar{m} = 60\ g$ $\quad \overline{R_{Poulie}} = 20mm$

$$\overline{k_c} = \frac{\overline{R_{Poulie}} \times \bar{m} \times g}{\bar{\imath}} = 0{,}11\ Nm/A$$

Mesure de la constante de couple (incertitudes)

$$u(i) = \sqrt{u_1(i)^2 + u_2(i)^2} = 0{,}001A$$

$$u(R_{Poulie}) = 0{,}5\ mm$$

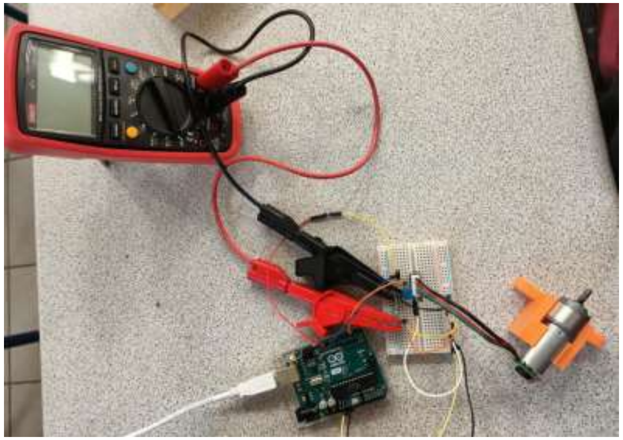
$$u(m) = \sqrt{u_1(m)^2 + u_2(m)^2} = 0{,}1g$$

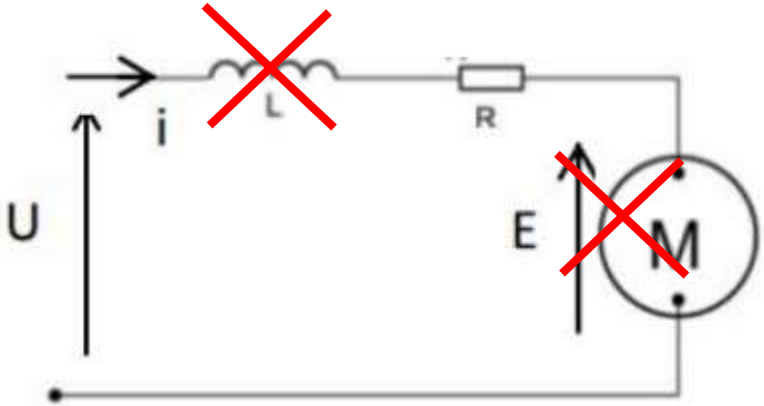
$$u(k_c) = \overline{k_c}\sqrt{\left(\frac{u(\omega)}{\overline{\omega}}\right)^2 + \left(\frac{u(i)}{\overline{\imath}}\right)^2 + \left(\frac{u(U)}{\overline{U}}\right)^2} = 0{,}006\ Nm/A$$

$$\boxed{Z\left(\overline{k_c}, k_{c_{ref}}\right) = 3{,}64}$$

Mesure du coefficient de frottements

Protocole:
- On alimente le moteur et on suppose le être en régime permanent
- Le moteur tourne à vide donc $C_r = 0Nm$
- D’après les lois du moteur : $k_c i - f\omega = 0$
- On mesure ω avec le capteur à effet hall du moteur
- On mesure i avec un ampèremètre et k_c est connu
- On calcule $f = \frac{k_c i}{\omega}$





Mesure du coefficient de frottements

$$i_{min} = 8{,}31\,mA$$
$$i_{max} = 8{,}25mA$$

$$\bar{\imath} = \frac{i_{max} + i_{min}}{2} = 8{,}28\,mA$$
$$u(i) = \frac{i_{max} - i_{min}}{2\sqrt{3}} = 0{,}0173\,mA$$

$$\omega_{min} = 18{,}9\,rad/s$$
$$\omega_{max} = 19{,}3\,rad/s$$

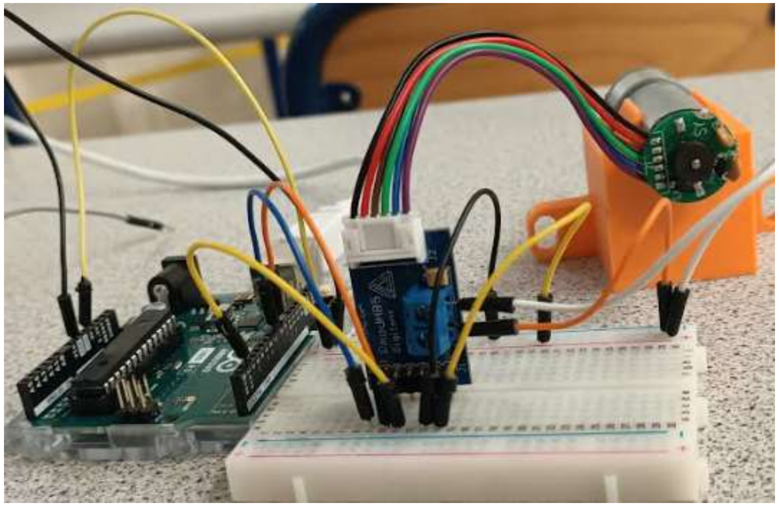
$$\bar{\omega} = \frac{\omega_{max} + \omega_{min}}{2} = 19{,}1\,rad/s$$
$$u(\omega) = \frac{\omega_{max} - \omega_{min}}{2\sqrt{3}} = 0{,}0115\,rad/s$$

$$\boxed{\bar{f} = \frac{k_c \bar{\imath}}{\bar{\omega}} \approx 3{,}85 \times 10^{-5} Nm/s}$$

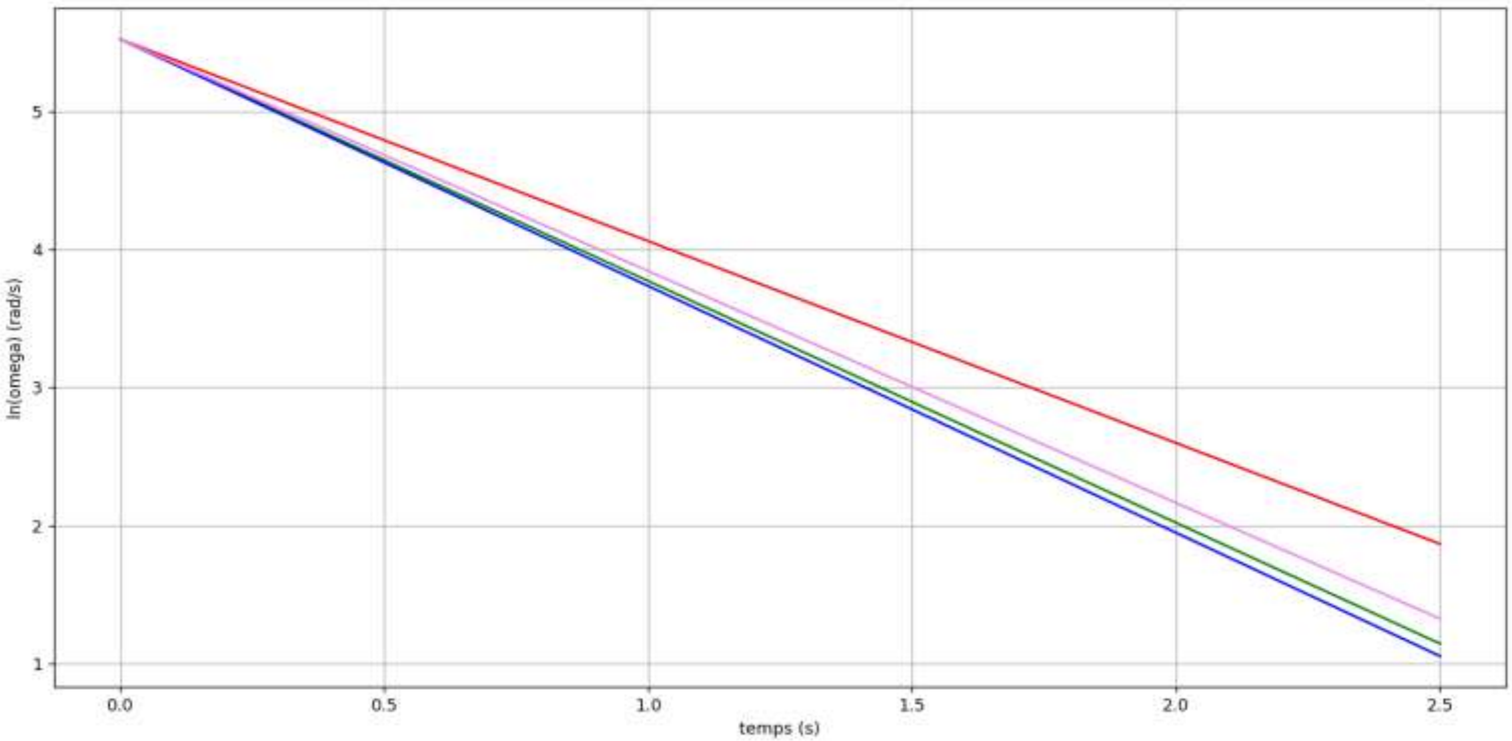
$$\boxed{u(f) = \bar{f}\sqrt{\left(\frac{u(\omega)}{\bar{\omega}}\right)^2 + \left(\frac{u(i)}{\bar{\imath}}\right)^2 + \left(\frac{u(k_c)}{k_c}\right)^2} = 0{,}00217 \times 10^{-5}\ Nm/s}$$

Mesure de l'inertie équivalente

Protocole:
- On fait tourner le moteur à vide à une vitesse angulaire ω_0
- On coupe l'alimentation à $t = 0s$ donc $i = 0V$ et $C_m = 0Nm$
- D'après les lois du moteur: $J\frac{d\omega}{dt} = -f\omega$
- L'équation différentielle donne : $\ln(\omega) = \ln(\omega_0) - \frac{f}{J}t$
- On mesure ω
- On trace ln(ω) en fonction de t
- La pente de cette droite donne directement $-\frac{f}{J}$, avec f connu



Mesure de l'inertie équivalente

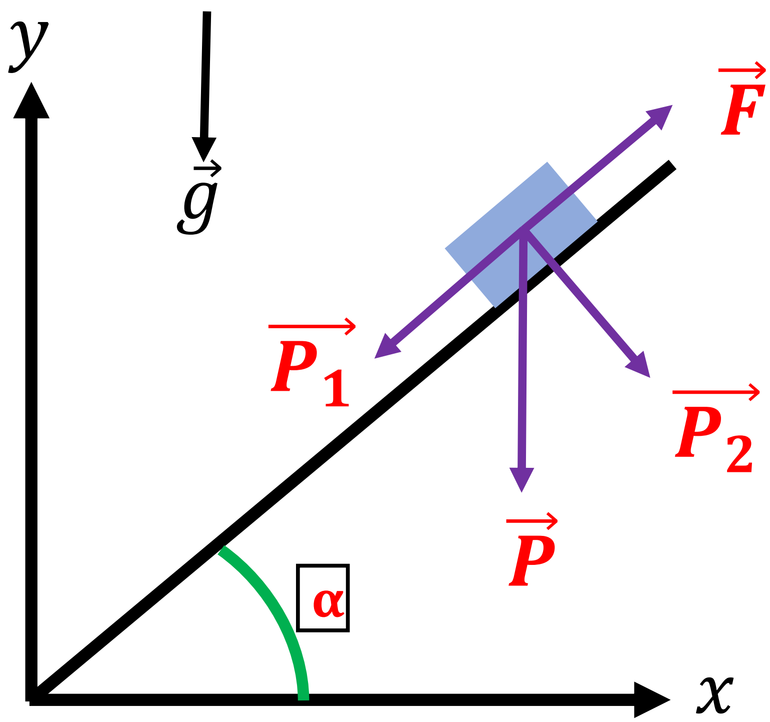


$$u(f) = \bar{f}\sqrt{\left(\frac{u(\omega)}{\bar{\omega}}\right)^2 + \left(\frac{u(f)}{\bar{f}}\right)^2 + \left(\frac{u(p)}{\bar{p}}\right)^2} = 0{,}0291 \times 10^{-5}\ kgm^2$$

$$\bar{J} = 3{,}13 \times 10^{-5}\ kgm^2$$
$$u(J) = 0{,}0291 \times 10^{-5}\ kgm^2$$

$$p_{min} = -1{,}21\ rad/s^2 \quad J_{max} = 3{,}18 \times 10^{-5}\ kgm^2$$
$$p_{max} = -1{,}25\ rad/s^2 \quad J_{min} = 3{,}08 \times 10^{-5}\ kgm^2$$

Expérience des frottements de coulomb



$$\|\overrightarrow{P_1}\| = \|\vec{P}\|\sin(\alpha)$$

$$\|\overrightarrow{P_2}\| = \|\vec{P}\|\cos(\alpha)$$

$$\|\vec{F}\| = \mu\|\overrightarrow{P_2}\|$$

$$A\ l'\acute{e}quilibre$$

$$\|\vec{F}\| = \|\overrightarrow{P_1}\| = \mu\|\overrightarrow{P_2}\|$$

$$\mu = \frac{\|\overrightarrow{P_1}\|}{\|\overrightarrow{P_2}\|} = \tan(\alpha)$$

Expérience des frottements de coulomb

Expérience	Angle de glissement
1	38°
2	40°
3	39°
4	46°
5	41°
6	43°
7	40°
8	45°
9	39°
10	42°

$$u_1(\alpha) = \frac{\alpha_{max} - \alpha_{min}}{2\sqrt{3}} = 0{,}1°$$

$$u_2(\alpha) = \frac{1°}{\sqrt{3}} = 0{,}2°$$

$$u(\alpha) = \sqrt{u_1(\alpha)^2 + u_2(\alpha)^2} = 0{,}4°$$

$$\boxed{\begin{gathered}\bar{\alpha} = 42° \\ u(\alpha) = 0{,}4° \\ \mu = \tan(\bar{\alpha}) = 0{,}9 \\ Z\left(\mu, \mu_{ref}\right) = 1{,}8\end{gathered}}$$

$$\mu_{ref} = 0{,}896 \ \ (Caoutchouc/pvc)$$

Source: https://dds.univ-lyon1.fr/icap_website/3649/72052

Affichage de la vitesse de rotation sur arduino

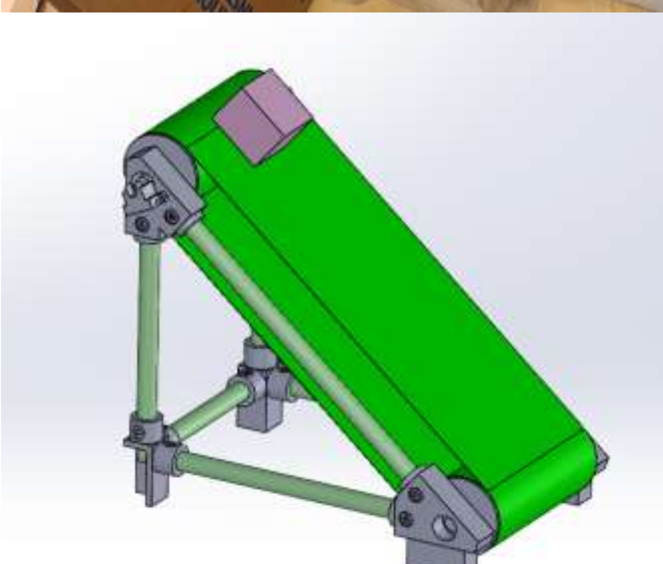
```
#define HALL_SENSOR_PIN 2
#define MOTOR_PWM_PIN 9
#define MOTOR_DIR_PIN 8
volatile unsigned long pulseCount = 0;

void setup() {
  Serial.begin(9600);

  // Configure the motor control pins
  pinMode(MOTOR_PWM_PIN, OUTPUT);
  pinMode(MOTOR_DIR_PIN, OUTPUT);

  // Configure the hall sensor pin
  pinMode(HALL_SENSOR_PIN, INPUT_PULLUP);

  // Attach interrupt to hall sensor pin
  attachInterrupt(digitalPinToInterrupt(HALL_SENSOR_PIN), countPulses, FALLING);

  // Initialize motor
  digitalWrite(MOTOR_DIR_PIN, HIGH);  // Set motor direction
  analogWrite(MOTOR_PWM_PIN, 128);    // Set motor speed (0-255)
}

void loop() {
  // Print pulse count every second
  static unsigned long lastPrintTime = 0;
  if (millis() - lastPrintTime > 1000) {
    lastPrintTime = millis();
    Serial.print("Pulse Count: ");
    Serial.println(pulseCount);
    pulseCount = 0;  // Reset pulse count for the next interval
  }
}
void countPulses() {
  pulseCount++;
}
```

Mesure de l’inertie équivalente sur arduino

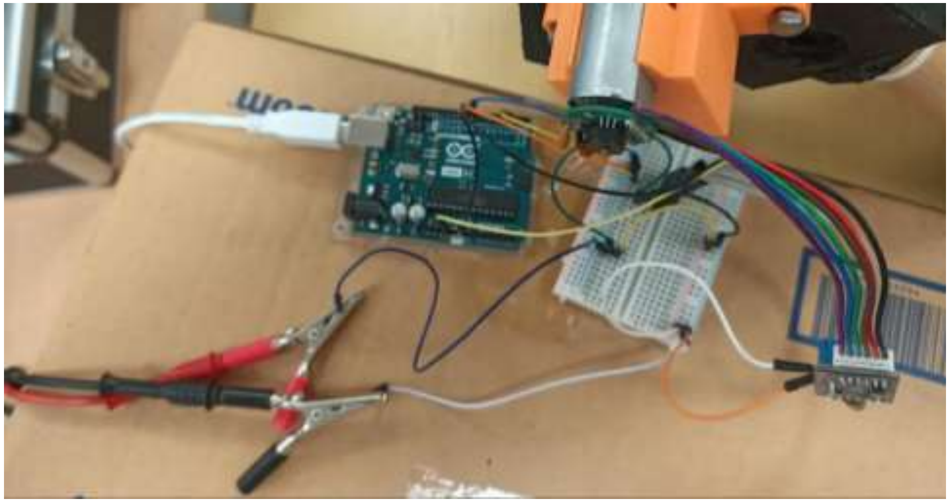
```python
temps = np.linspace(0,2.5,200)
omega1 = [250.0, 244.56097270918136, 239.2402774898438, 234.03533989652266, 228.94364149366987, 223.962718637096, 219.0901612819236, 214.3236118
omega2 = [250.0, 244.450081827391, 239.0233700216726, 233.71712944182647, 228.52868566606966, 223.45542364390735, 218.49478637810986, 213.64427
omega3 = [250.0, 245.44991262134386, 240.98263842330135, 236.5966701770409, 232.2905280858224, 228.06275928572373, 223.91193735545386, 219.8366
87.74932384100022, 86.15225547742205, 84.58425431625975, 83.04479132426992, 81.53334709679916, 80.04941168254022, 78.59248441147793, 77.1620737
9.506298141560924, 9.33328019279429, 9.16341123116751, 8.99663394401403, 8.832892061777837, 8.67213033902853, 8.514294535821827, 8.359331399399
omega4 = [250.0, 244.7829054072227, 239.6746831184053, 234.6730611451147, 229.775814911632, 224.9807662655260, 220.285782508875, 215.688775449
31.649402415071, 30.988930710253793, 30.342241978876128, 29.709048592633202, 29.08906892555646, 28.482027228754667, 27.887653507768782, 27.30568
22.585137543556087, 22.113822347733613, 21.65234273574962, 21.200493454919055, 20.75807353584758, 20.3248862030462, 19.900738787411303, 19.48544
9.715514478153237, 9.512767445953145, 9.314251415534622, 9.11987809275161, 8.92956102601368, 8.743215567834914, 8.56075883718516, 8.3821096826

ln_de_omega1 = []
ln_de_omega2 = []
ln_de_omega3 = []
ln_de_omega4 = []
for i in omega1:
    ln_de_omega1.append(np.log(i))
for i in omega2:
    ln_de_omega2.append(np.log(i))
for i in omega3:
    ln_de_omega3.append(np.log(i))
for i in omega4:
    ln_de_omega4.append(np.log(i))
plt.grid()
plt.xlabel('temps (s)')
plt.ylabel('ln(omega) (rad/s)')
plt.plot(temps,ln_de_omega1,'green')
plt.plot(temps,ln_de_omega2,'blue')
plt.plot(temps,ln_de_omega3,'red')
plt.plot(temps,ln_de_omega4,'violet')
plt.show()
```

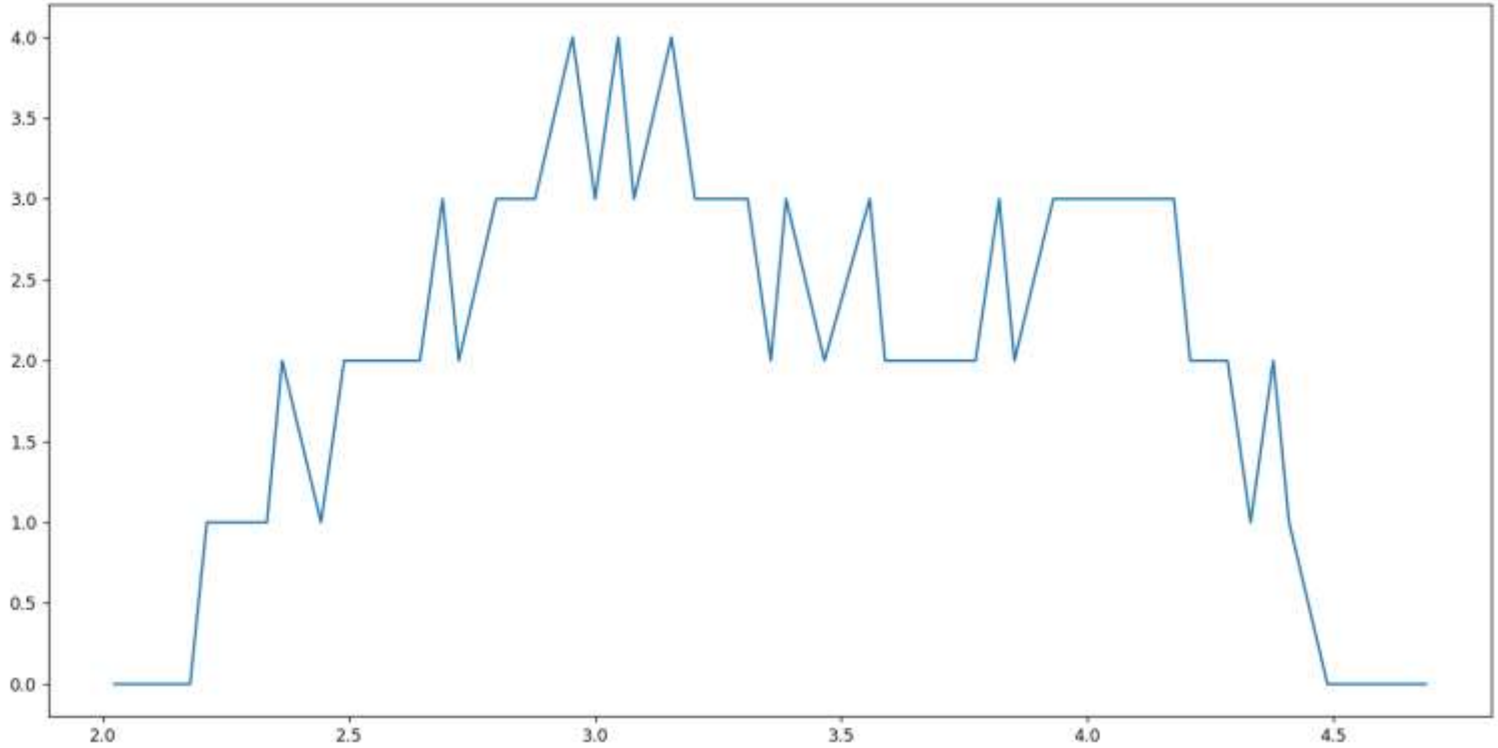
Expérience de la descente de la masse

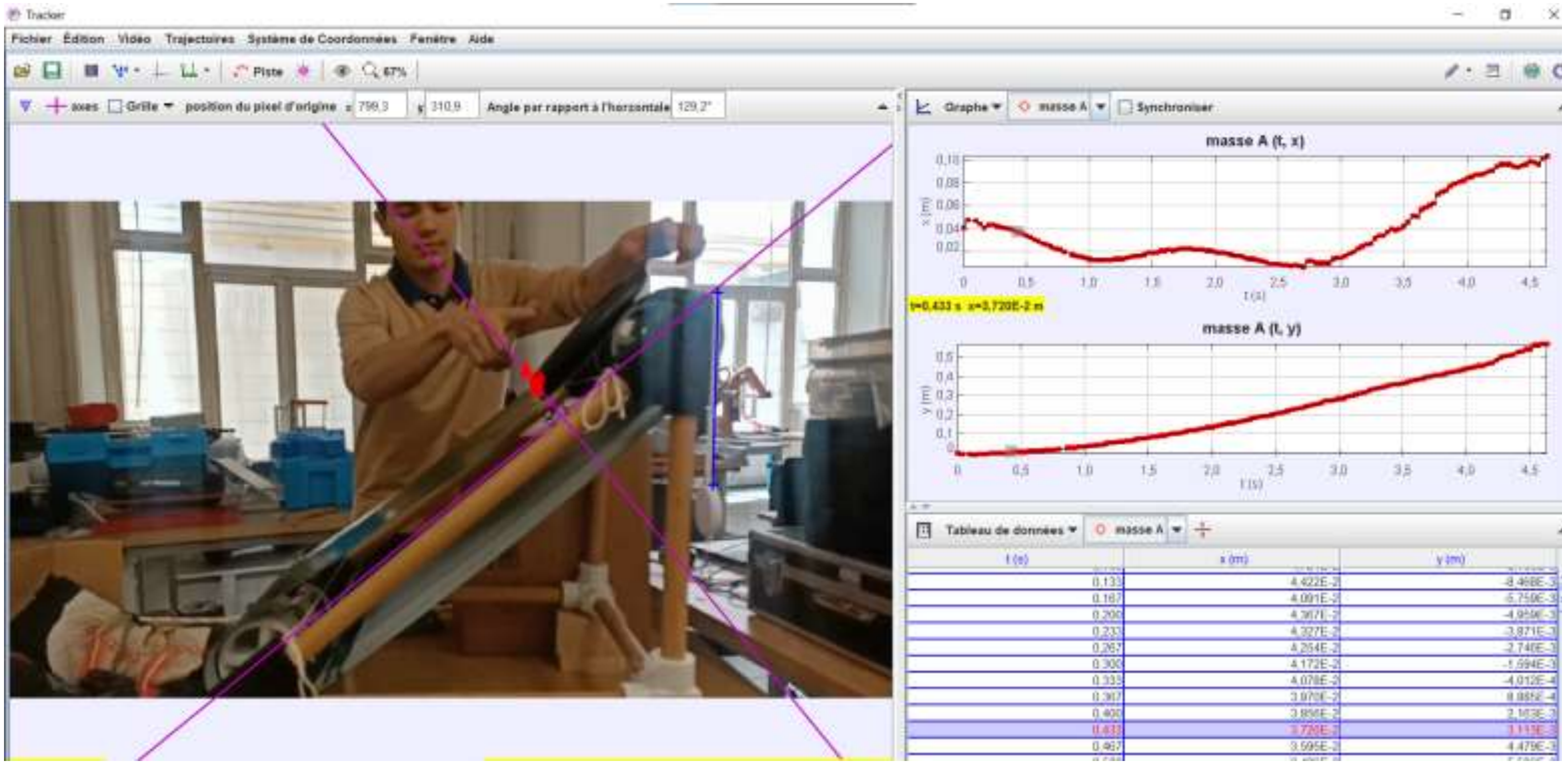
Affichage de la tension



Affichage de la vitesse:
Données peu exploitables





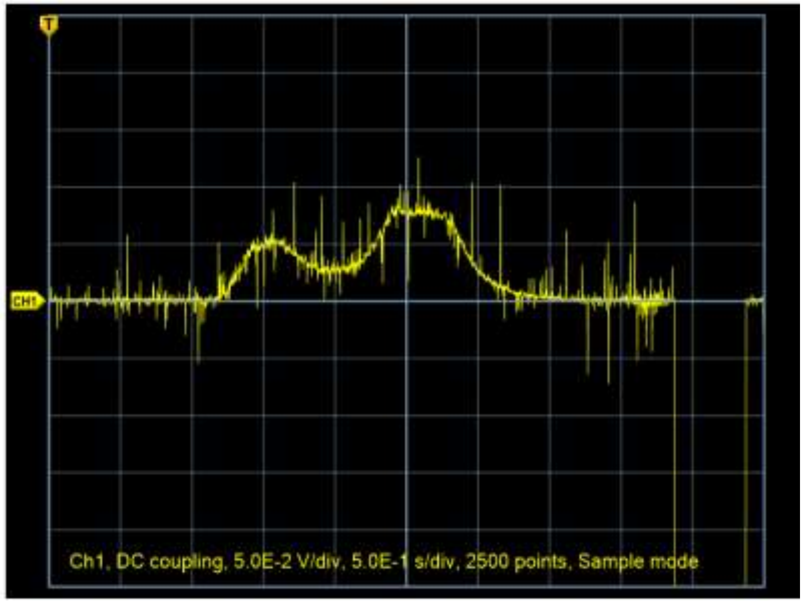


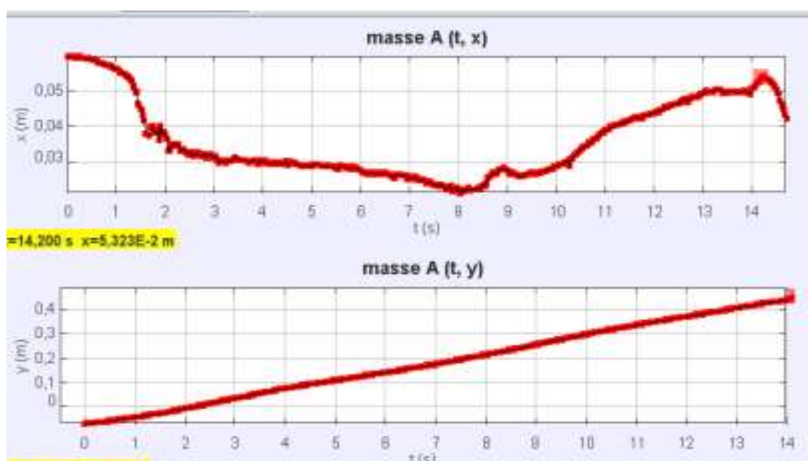
- Acquisition de la tension avec un oscilloscope avec TektronixOpenchoice

- Acquisition de la vitesse de descente avec Tracker

RESULTATS

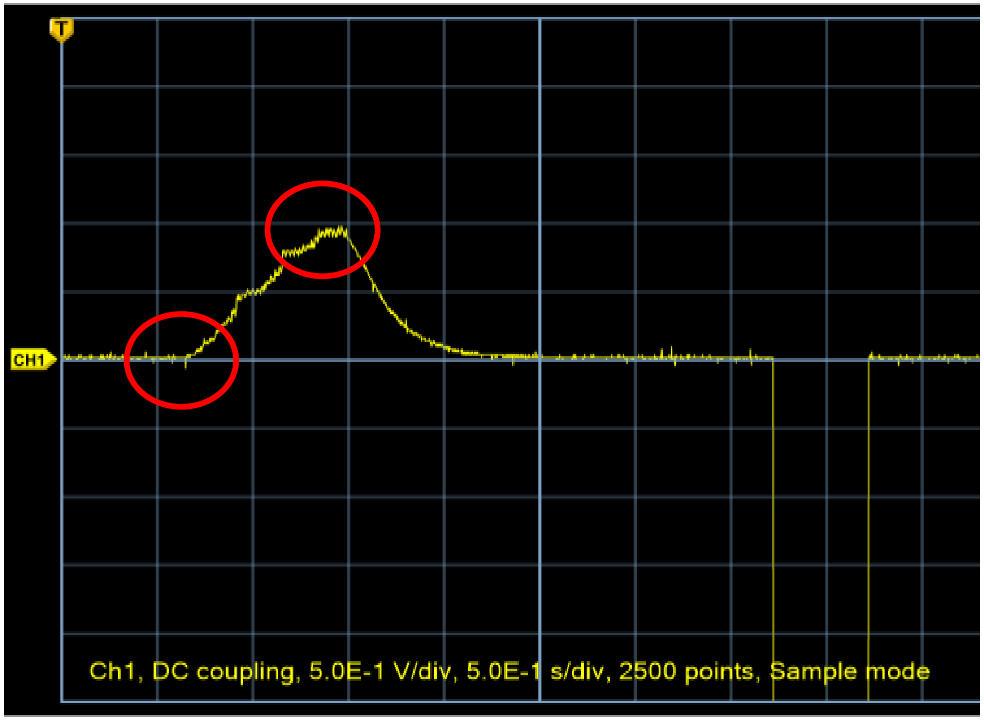
Masse : 500g



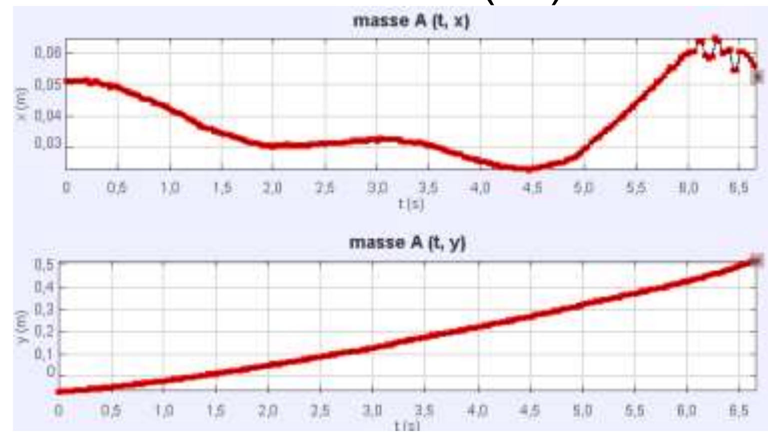


Masse : 1Kg

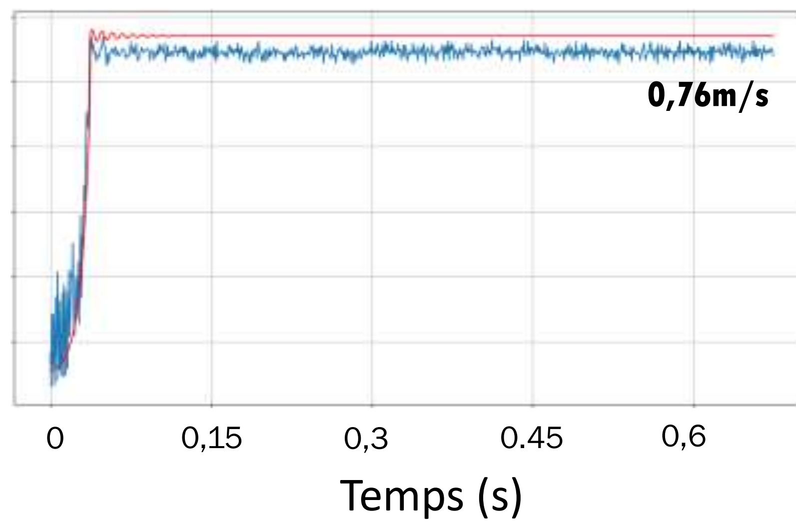
Tension (V)



Position (m)



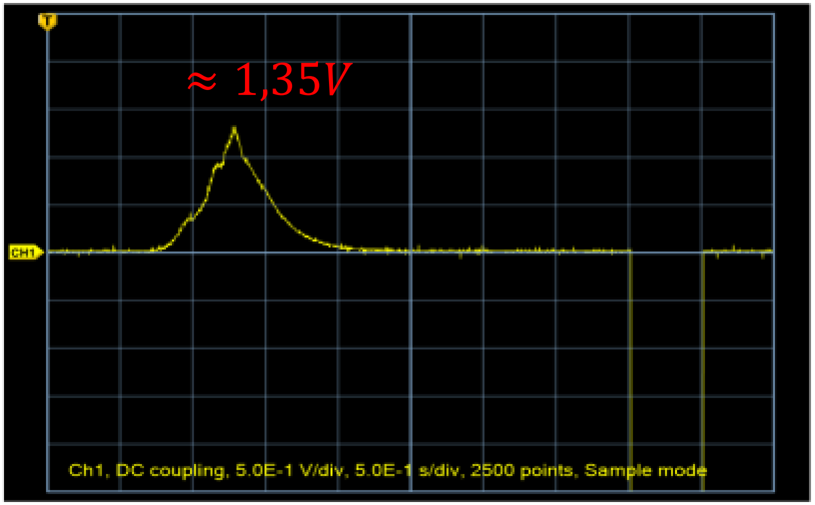
Vitesse (m/s)

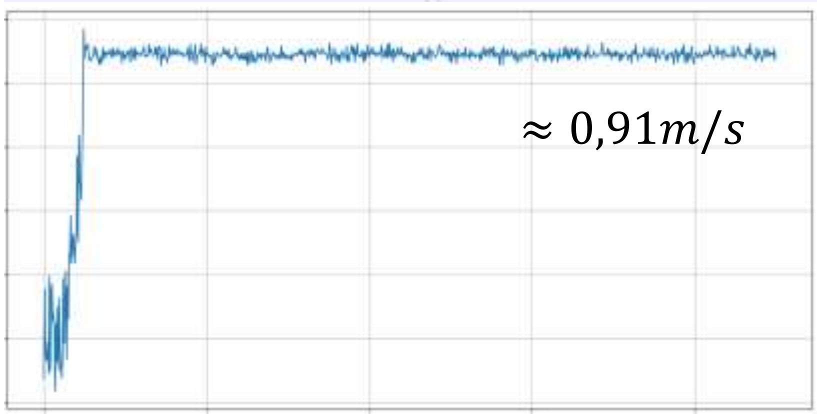


Pic de tension à ≈0,7s
Valeur : ≈0,1V

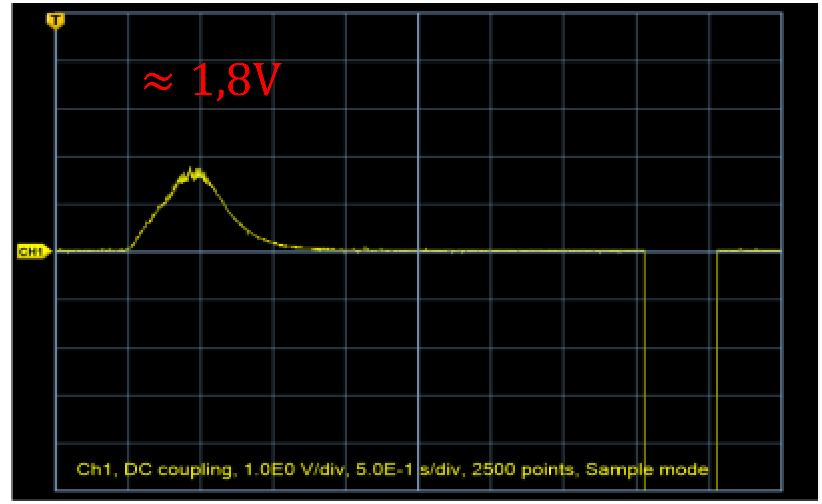
Vitesse en régime permanent ≈0,76m/s

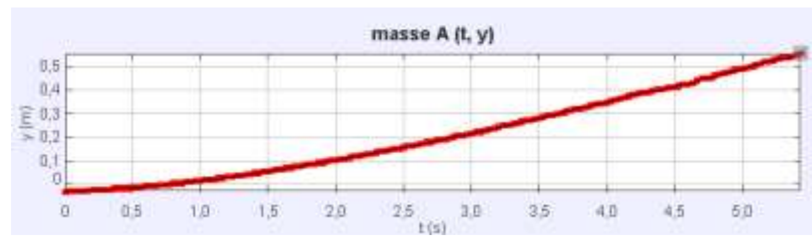
Masse : 1,5Kg



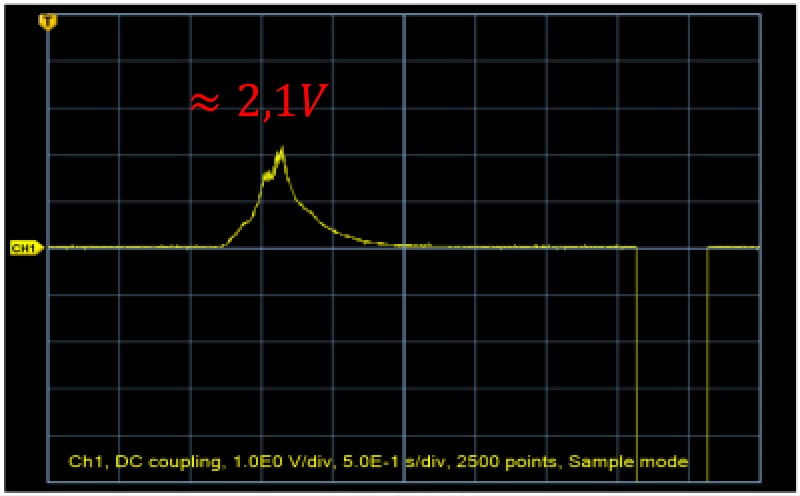


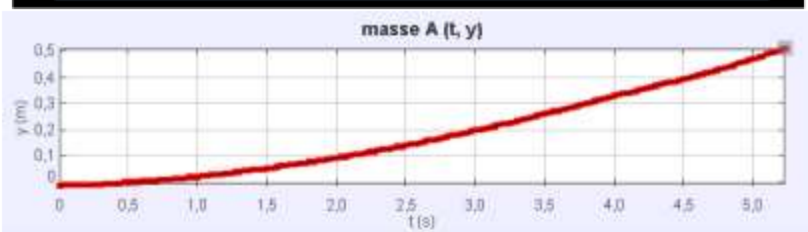
Masse : 2Kg

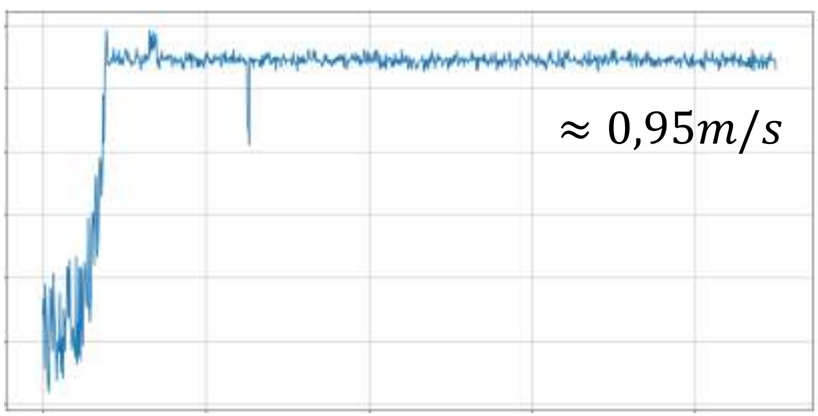




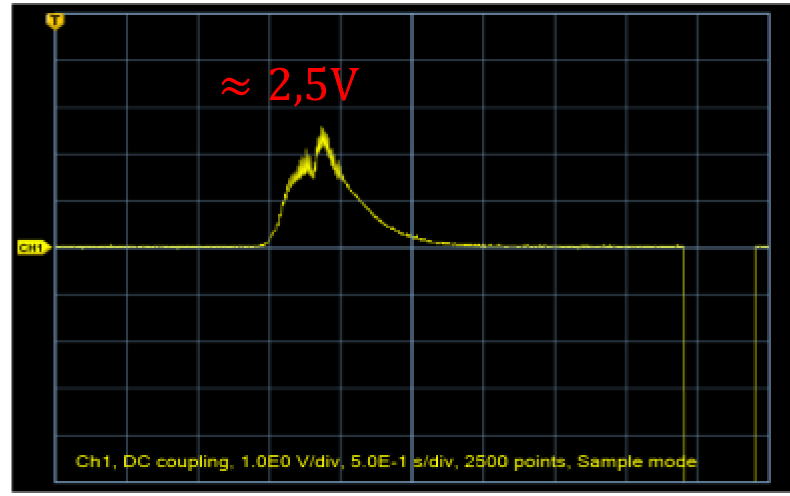
Masse : 2,5Kg

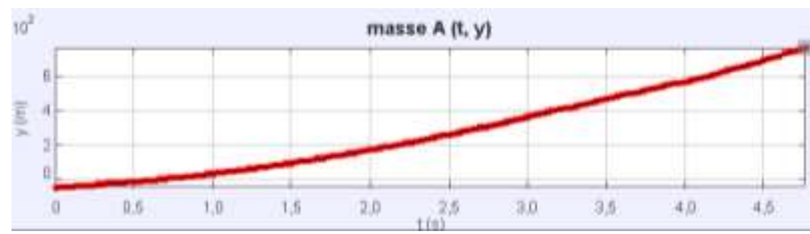


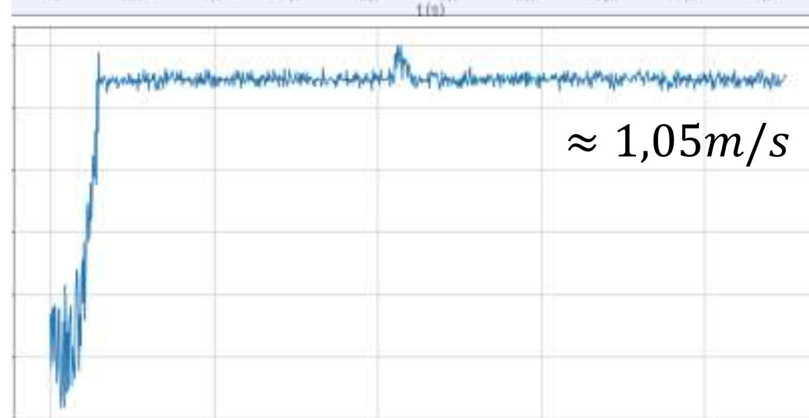




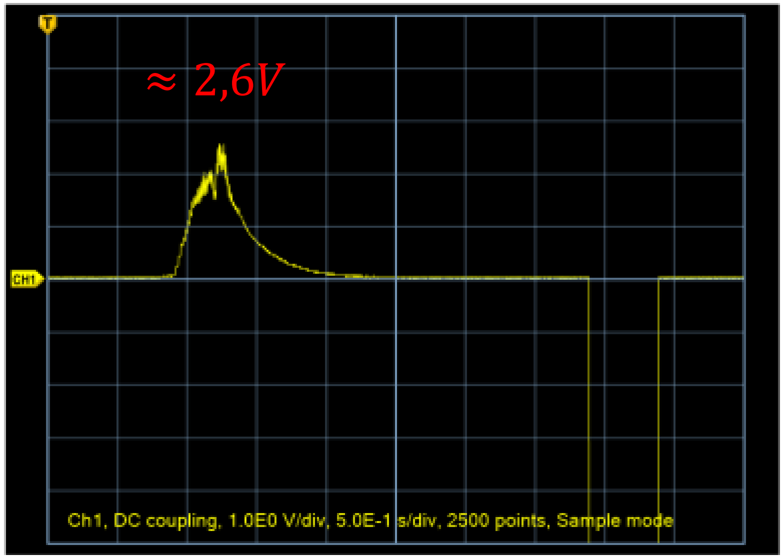
Masse : 3Kg

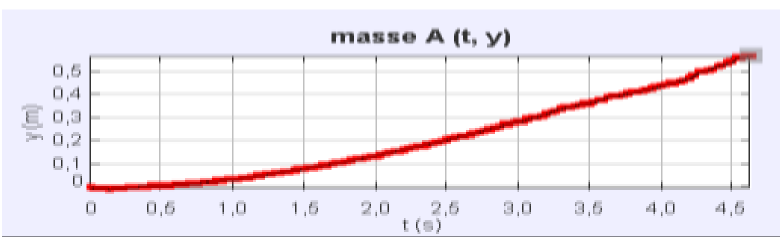


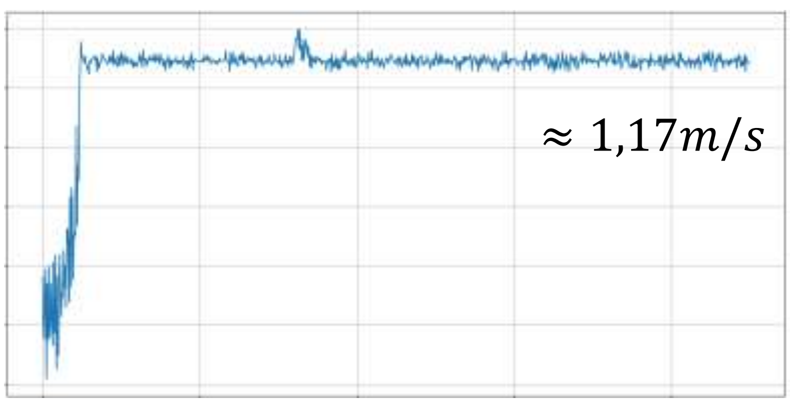




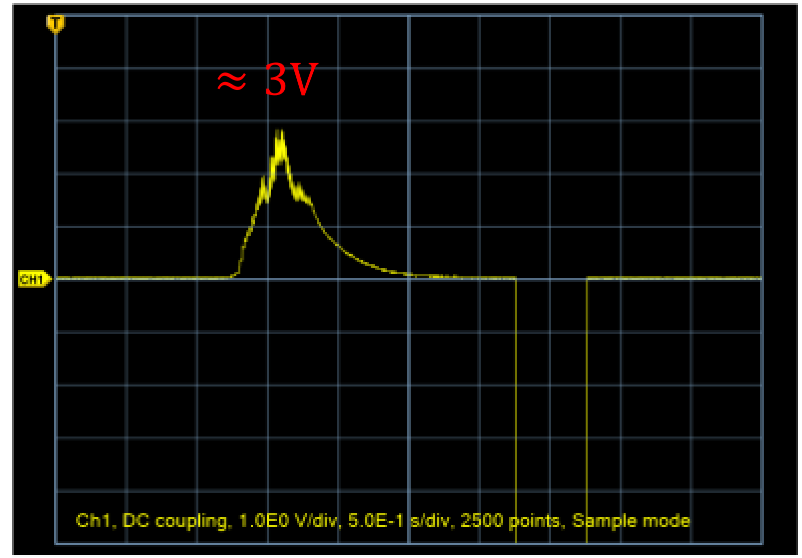
Masse : 4Kg

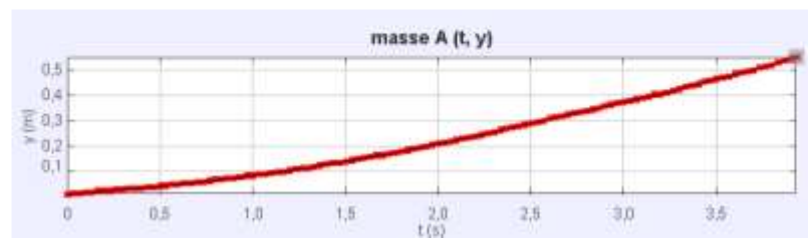


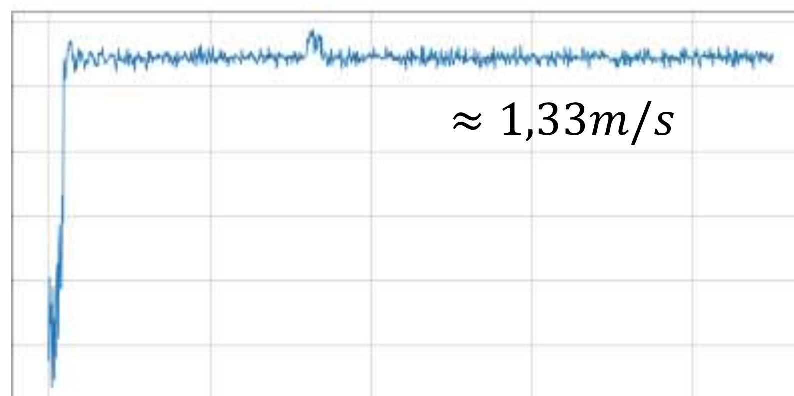




Masse : 5Kg

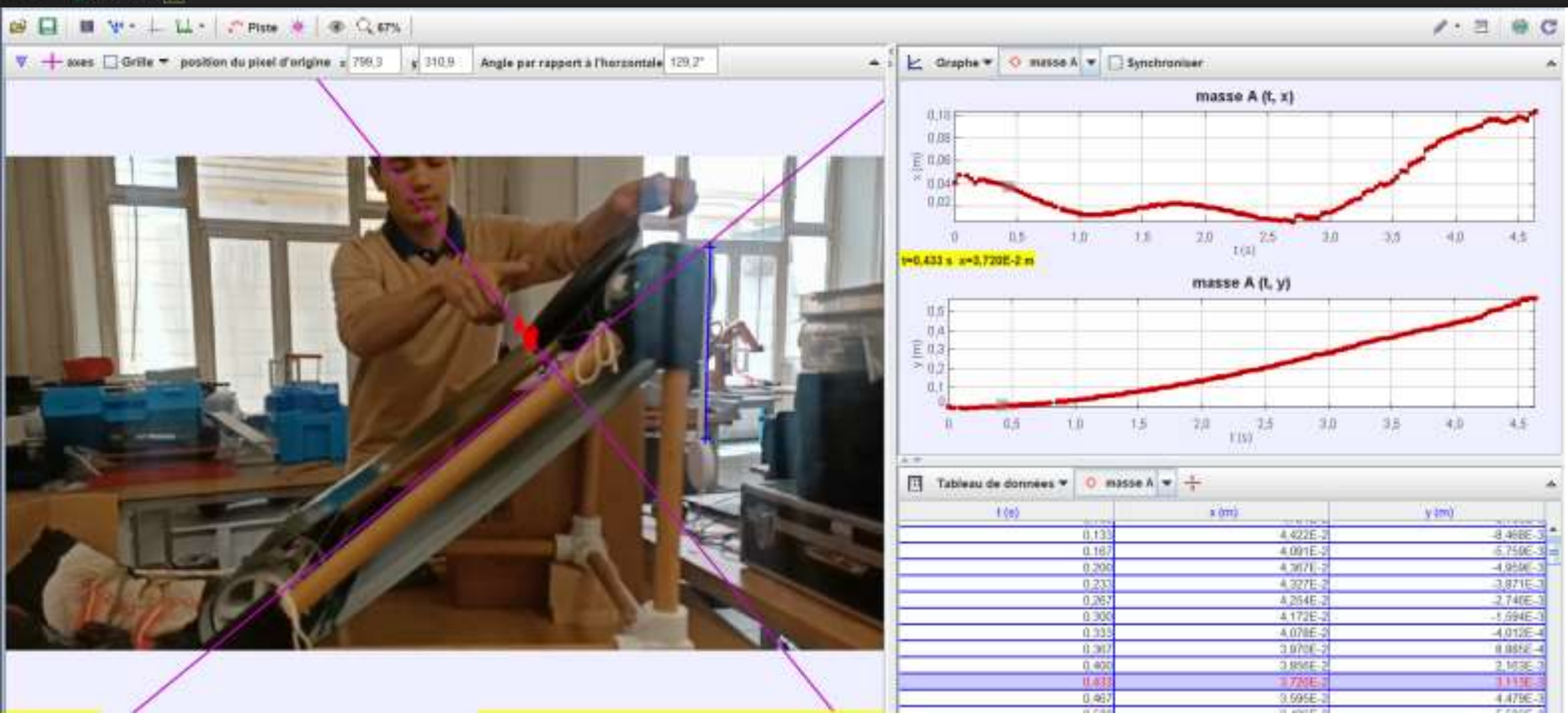


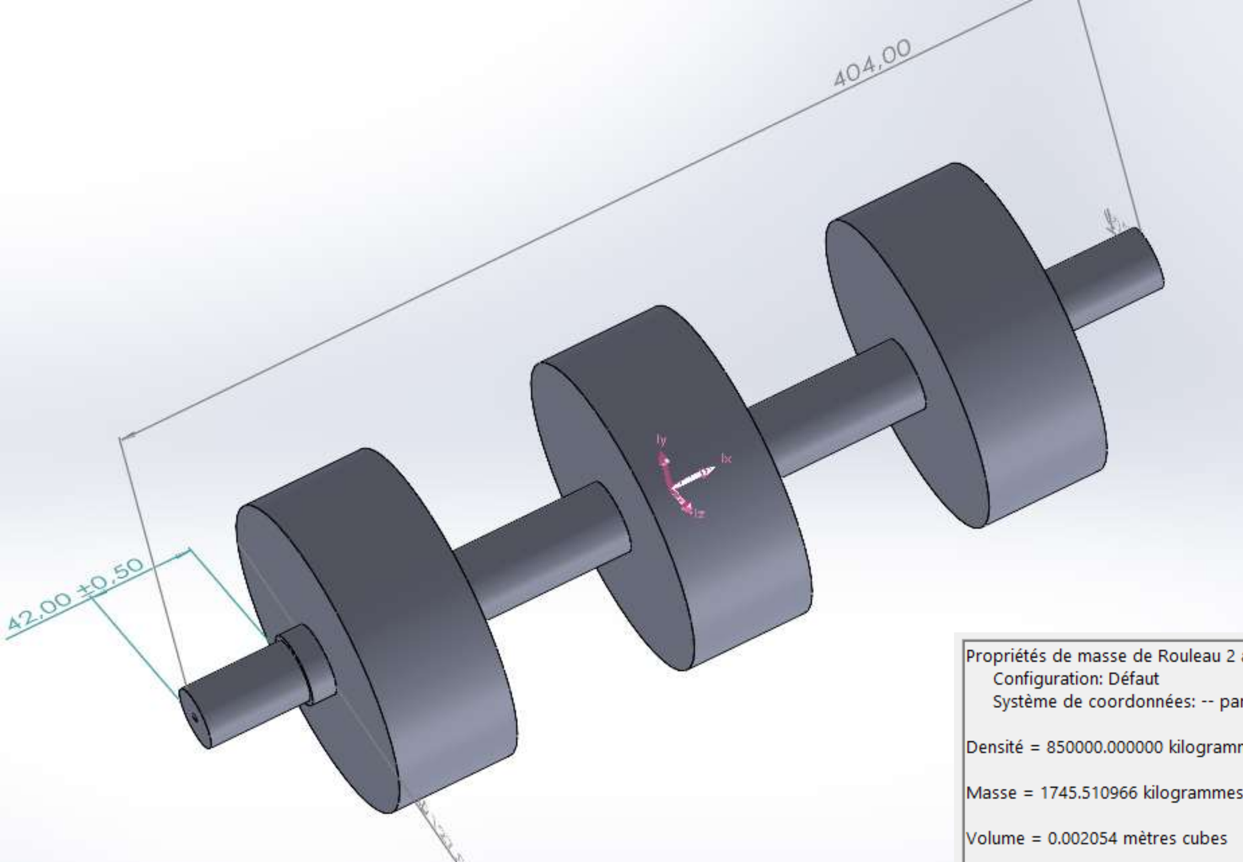




Programmes de traçage des courbes de vitesse

```python
f = open("données.txt")
texte = f.read()
lignes = f.readlines()
f.close()

Vitesse = [0]
temps = []
for i in range(1,len(lignes)):
    Vitesse.append(lignes[i-1][0]-lignes[i][0])
    temps.append(lignes[i][1])

plt.plot(temps,Vitesse)
plt.grid()
plt.show()
```





Propriétés de masse de Rouleau 2 avec moteur
Configuration: Défaut
Système de coordonnées: -- par défaut --

Densité = 850000.000000 kilogrammes par mètre cube

Masse = 1745.510966 kilogrammes

Volume = 0.002054 mètres cubes

Superficie = 0.155478 mètres carrés

$$\boxed{J_{roul} = 3{,}27\ kg/m^2}$$

Centre de gravité: (mètres)
X = 0.000000
Y = 0.000000
Z = -0.149993

Principaux axes et moments d'inertie: (kilogrammes * mètres carrés)
Pris au centre de gravité.

Ix = (0.000000, 0.000000, 1.000000)	Px = 3.269076
Iy = (0.000000, -1.000000, 0.000000)	Py = 20.582608
Iz = (1.000000, 0.000000, 0.000000)	Pz = 20.582608

Moments d'inertie: (kilogrammes * mètres carrés)
Pris au centre de gravité et aligné avec le système de coordonnées de sortie. (En utilisant la notation de tenseur positive.)

Lxx = 20.582608	Lxy = 0.000000	Lxz = 0.000000
Lyx = 0.000000	Lyy = 20.582608	[illegible] -0.00000[illegible]
Lzx = 0.000000	Lzy = -0.000006	Lzz = 3.269076

Moments d'inertie: (kilogrammes * mètres carrés)
Pris au système de coordonnées de sortie. (En utilisant la notation de tenseur positive.)

Ixx = 59.853104	Ixy = 0.000000	Ixz = 0.000000
Iyx = 0.000000	Iyy = 59.853104	Iyz = -0.000010
Izx = 0.000000	Izy = -0.000010	Izz = 3.269076

CONSIGNES DU CDC

5.3.6.3.4 Straight Slides

• *For preschool- and school-age children:*

– The average incline of a slide chute should be no more than 30° (that is, the height to horizontal length ratio shown in Figure 20 does not exceed 0.577).

– No section of the slide chute should have a slope greater than 50°.