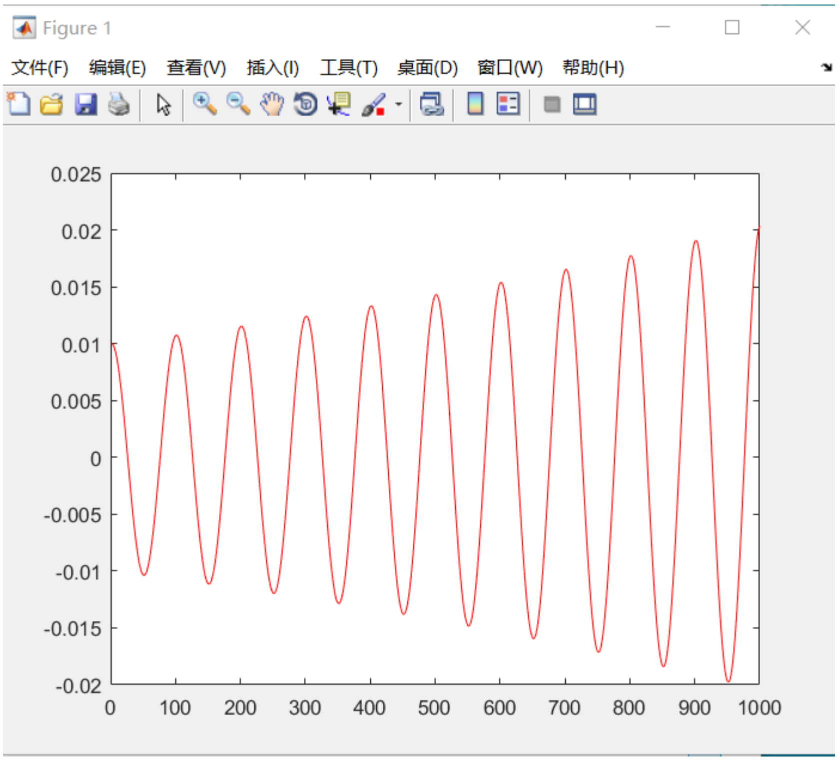
Etude d'un oscillateur linéaire amorti à un degré de liberté

$$\begin{bmatrix} x_{n+1} \\ \dot{x}_{n+1} \end{bmatrix} = \begin{bmatrix} 1 & \Delta t \\ -w_0^2 \Delta t & 1 - 2\Delta t \varepsilon w_0 \end{bmatrix} \begin{bmatrix} x_n \\ \dot{x}_n \end{bmatrix}$$

1.1.a

```
clear all;
w0=2*pi;
x0=0.01;
dx0=0;
T0=1;
n=1000;
dt=10*T0/n;%dt>2*epsilon/2pi=6.4*10^-3,ici,dt=0.01s
epsilon=0.02;
A=[1 dt;-w0^2*dt 1-2*dt*epsilon*w0];
[X1,A1]=eig(A);
U(:,1)=[x0;dx0];
for i=1:n-1
    U(:,i+1)=A*U(:,i);
    E(i)=1/2*((U(2,i))^2+w0^2*(U(1,i))^2);
end
plot(1:n,U(1,:),'r-')
```



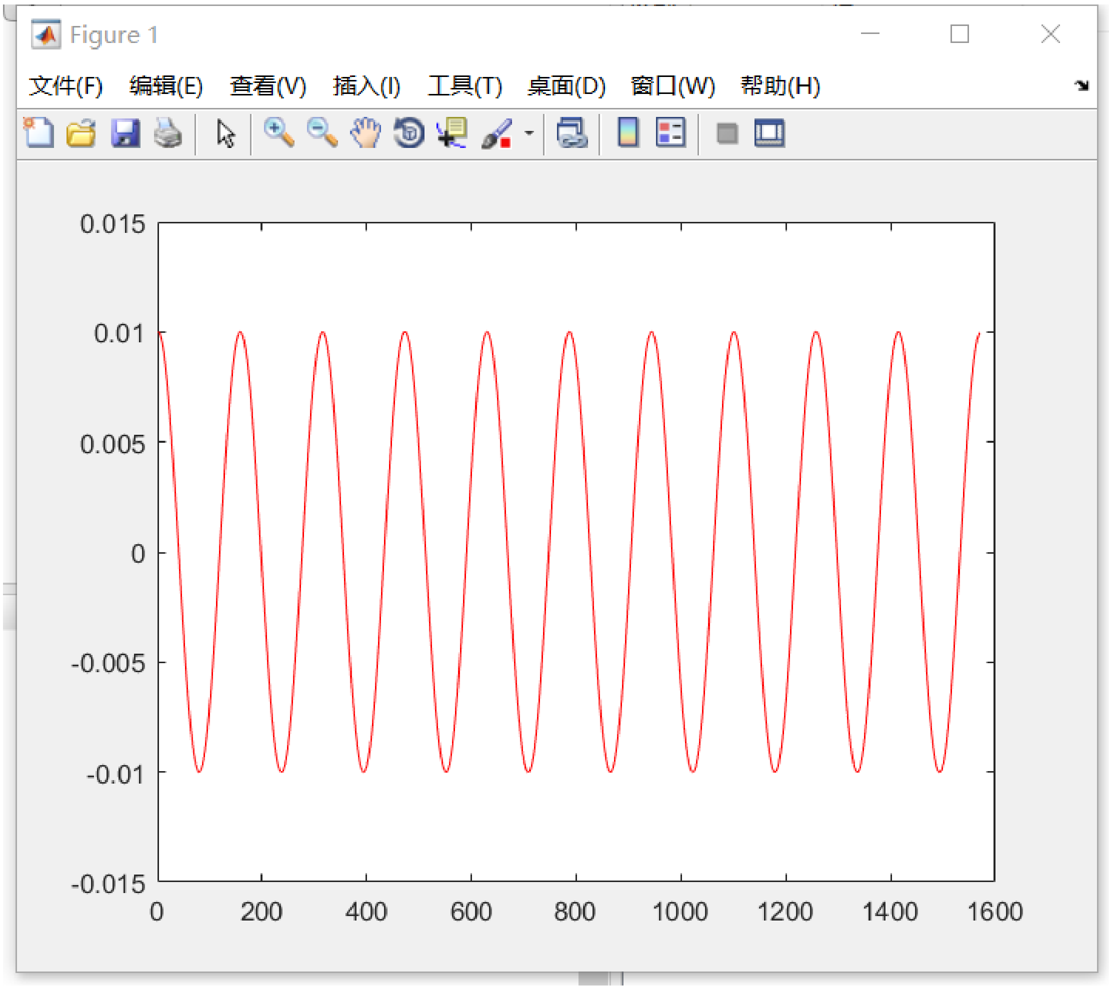
il diverge.

1.1.b

```
w0=2*pi;
x0=0.01;
dx0=0;
```

```
epsilon=0.02;
dt=2*epsilon/w0
n=floor(500*pi)
```

......



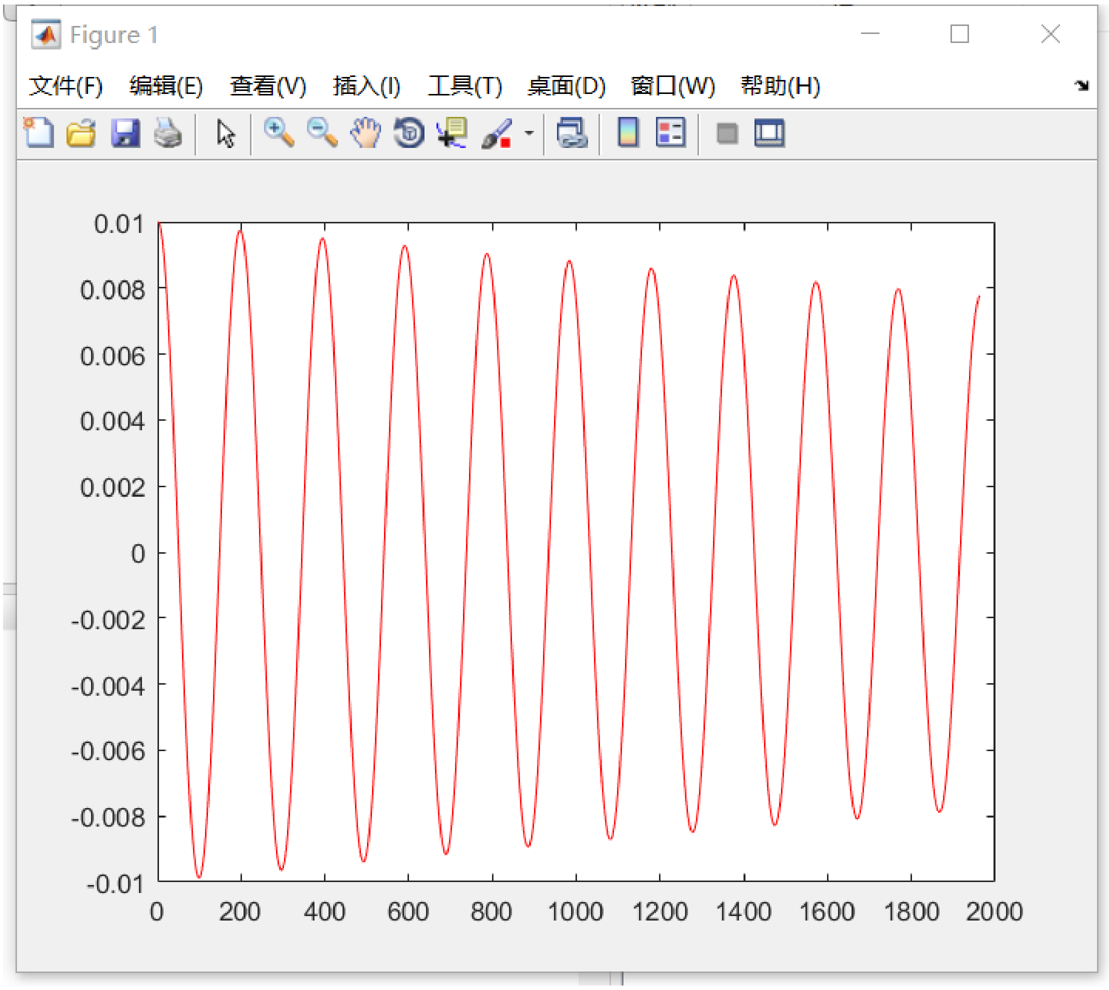
ni diverge ni converge

1.1.c

......

```
dt=0.8*2*epsilon/w0
n=floor(625*pi)
```

......



il converge.

1.1.d

$$|1-\varepsilon w_0\Delta t \pm i w_0 \Delta t(1-\varepsilon^2)^{0.5}| < 1$$

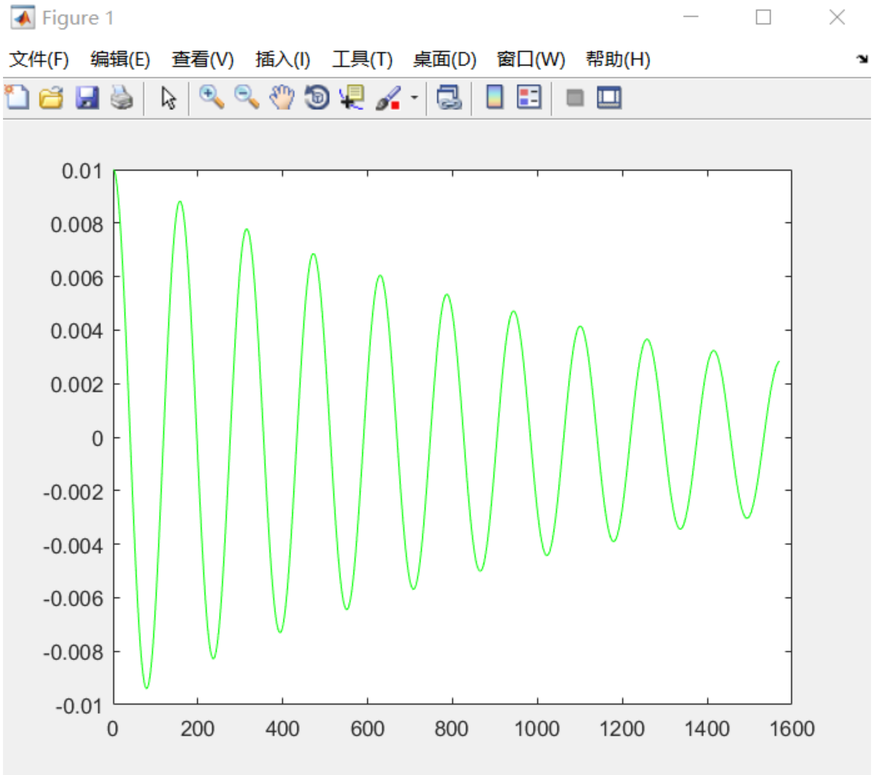
$$\frac{\Delta t}{\frac{2\varepsilon}{w_0}} < 1$$

1.2

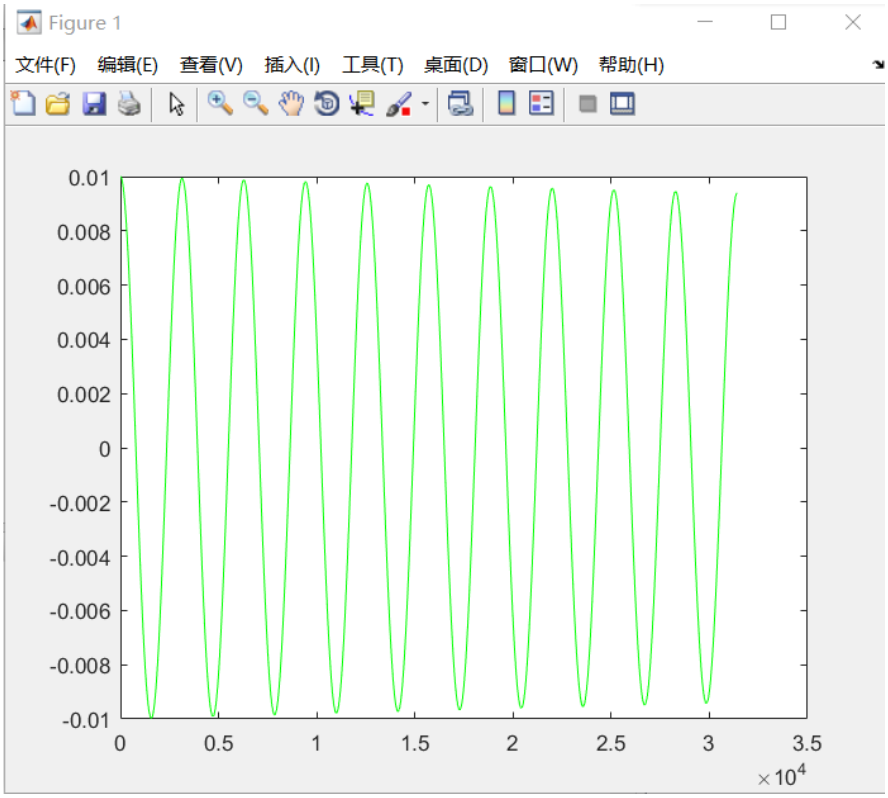
```
clear all
w0=2*pi;
x0=0.01;
dx0=0;
epsilon=0.02;
dt=2*epsilon/w0;
n=10/dt;
A=1/(1+(w0*dt)^2)*[1 dt;-w0^2*dt 1];
[X1,A1]=eig(A);
U(:,1)=[x0;dx0];
for i=1:n-1
    U(:,i+1)=A*U(:,i);
    E2(i)=1/2*((U(2,i))^2+w0^2*(U(1,i))^2);
```

```
end
plot(1:n,U(1,:),'g-')
```

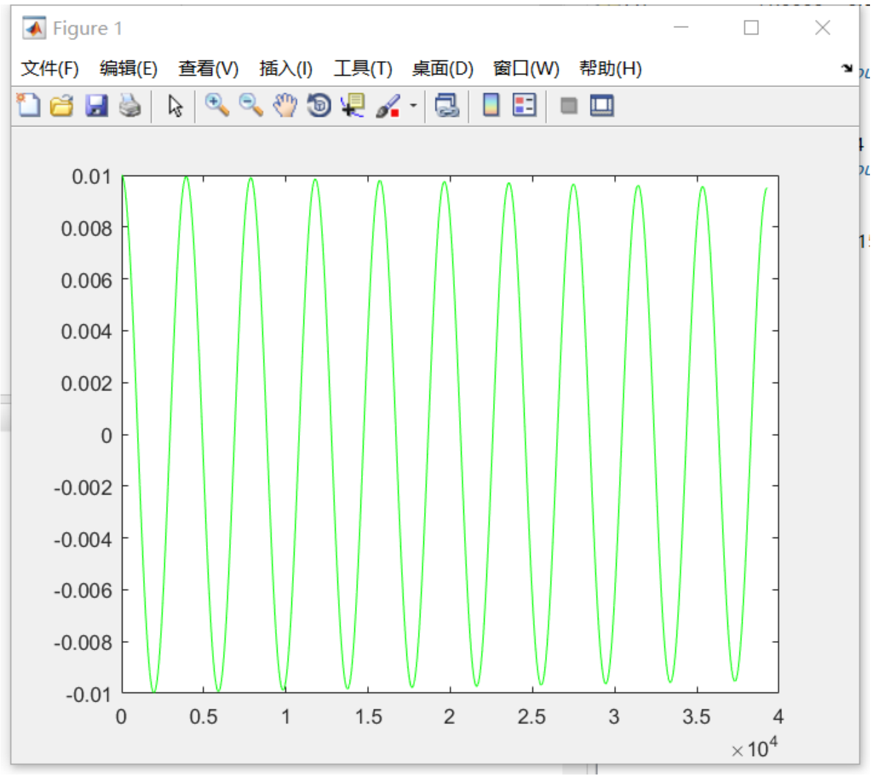
dt=2*epsilon/w0



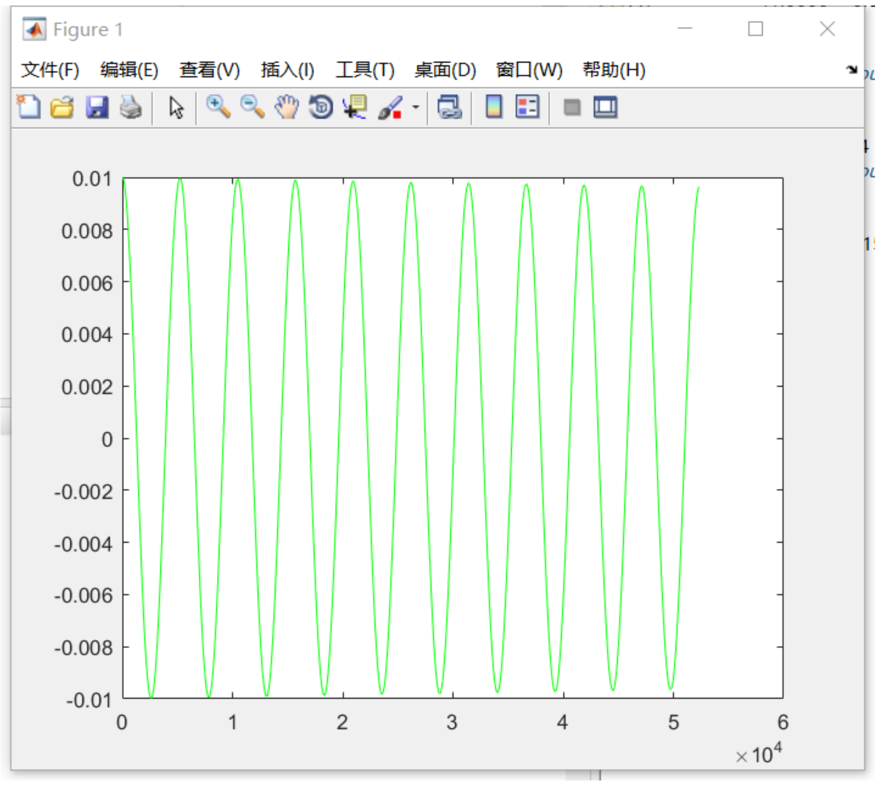
dt=0.05*2*epsilon/w0



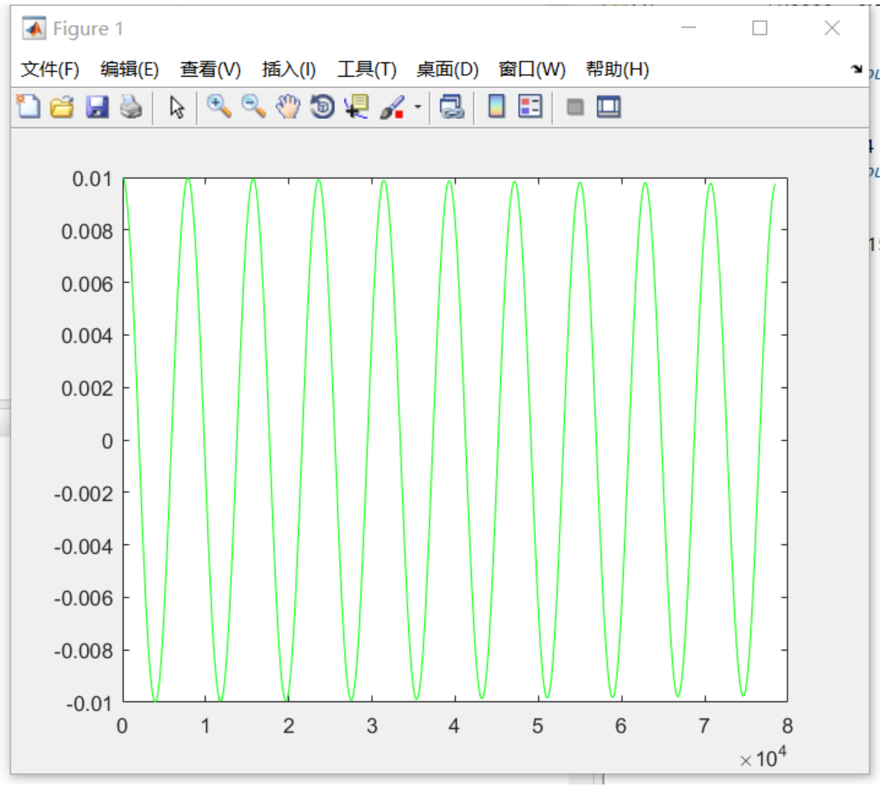
dt=0.04*2*epsilon/w0



dt=0.03*2*epsilon/w0



dt=0.02*2*epsilon/w0



ici, il ne converge pas.

donc, dt=0.02*2*epsilon/w0=1.27*10^-3s

1.3.a

```
clear all
w0=2*pi;
x0=0.01;
dx0=0;
epsilon=0.02;
dt=1.04*2*2^0.5/w0;
n=100/dt;
C=[0 1;-w0^2 -2*epsilon*w0];
U(:,1)=[x0;dx0];
for i=1:n-1
    k1=C*U(:,i);
    k2=C*(U(:,i)+1/2*k1*dt);
    k3=C*(U(:,i)+1/2*k2*dt);
    k4=C*(U(:,i)+k3*dt);
    U(:,i+1)=U(:,i)+(k1+2*k2+2*k3+k4)/6*dt;
end
plot((1:n)*dt,U(1,:),'r-')
```

h=1.04

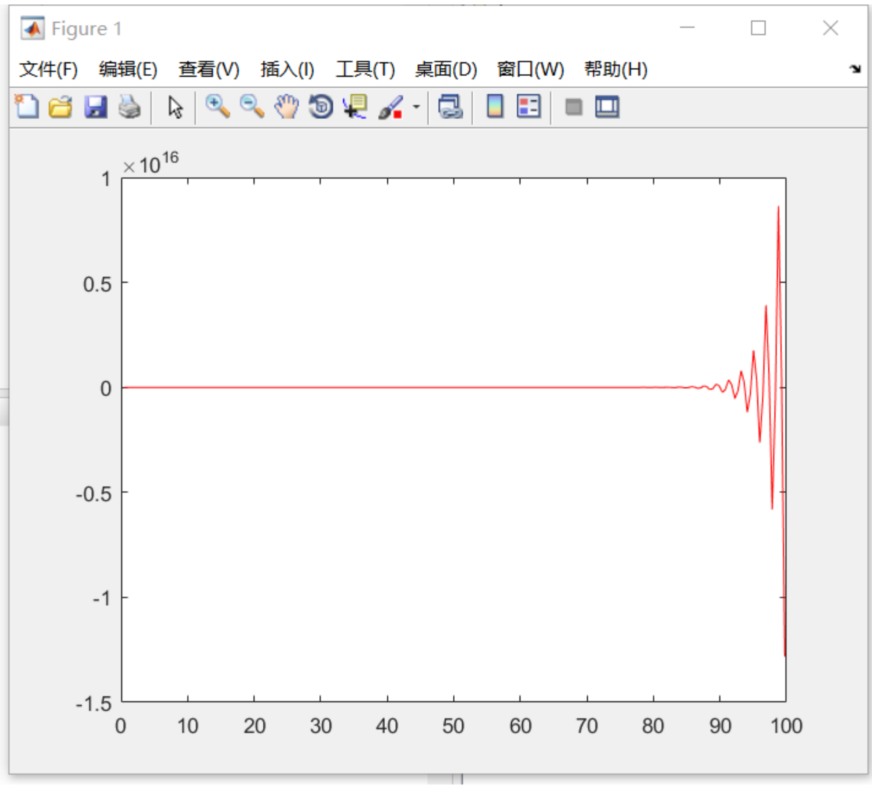


Figure 1
文件(F) 编辑(E) 查看(V) 插入(I) 工具(T) 桌面(D) 窗口(W) 帮助(H)
×10^16
1
0.5
0
-0.5
-1
-1.5
0 10 20 30 40 50 60 70 80 90 100

h=0.96

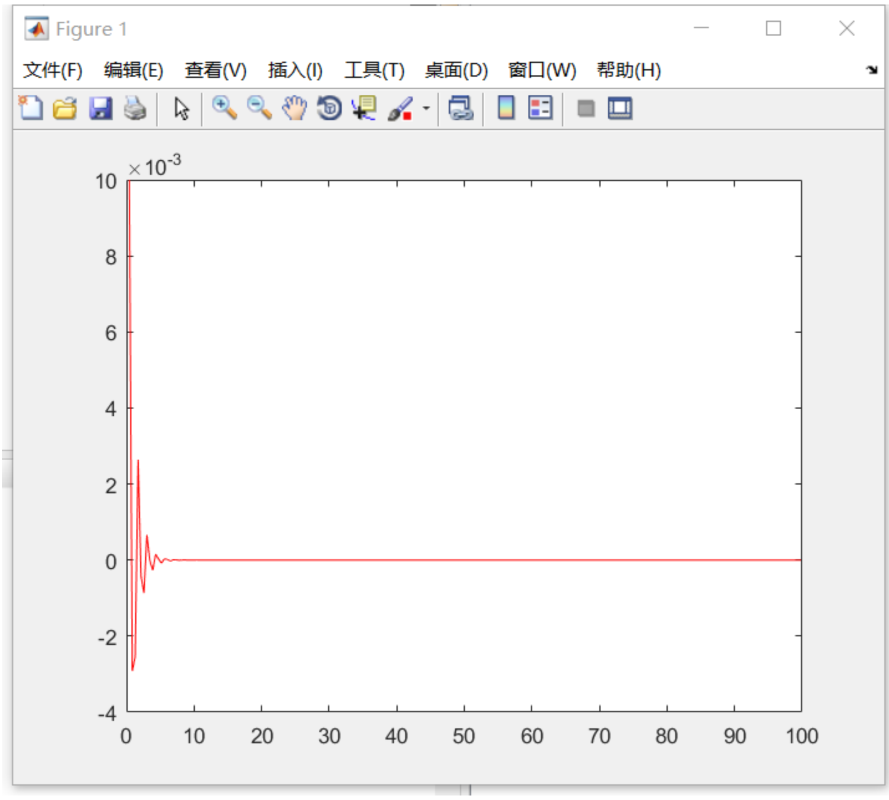
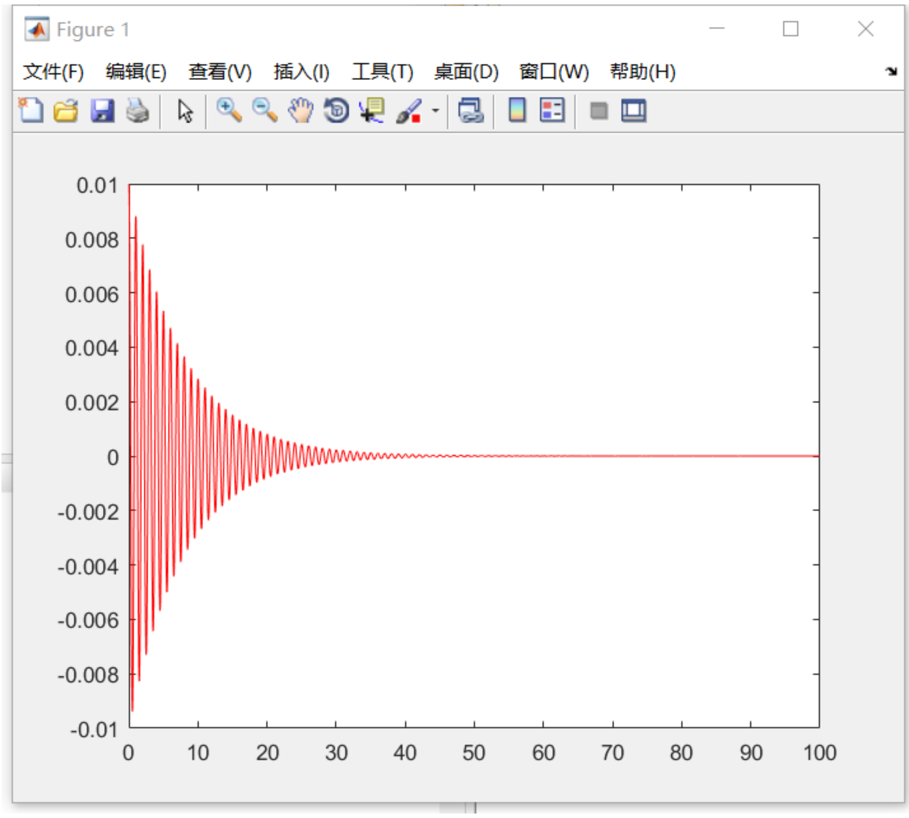


Figure 1
文件(F) 编辑(E) 查看(V) 插入(I) 工具(T) 桌面(D) 窗口(W) 帮助(H)
×10^-3
10
8
6
4
2
0
-2
-4
0 10 20 30 40 50 60 70 80 90 100

h=0.04

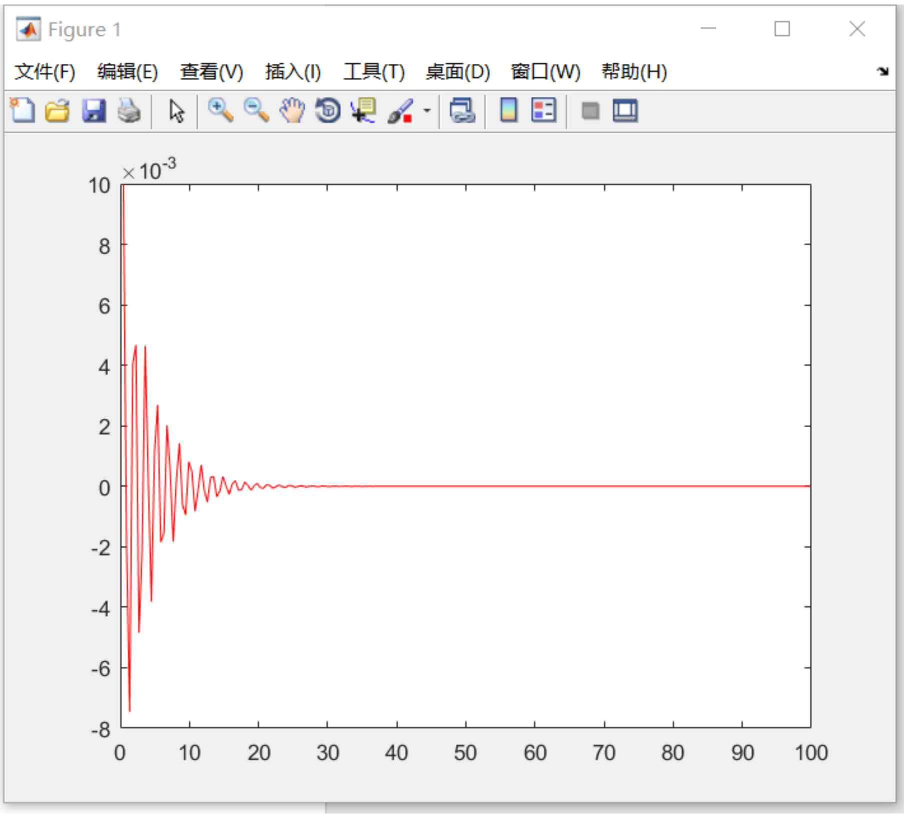


pour h=1.04, il diverge en fin,et pour h=0.04 et pour h=0.96 il converge.

quand h=0.96,il converge plus rapide, il est donc plus stable et précis.

1.3.b

h=1



h=0.98

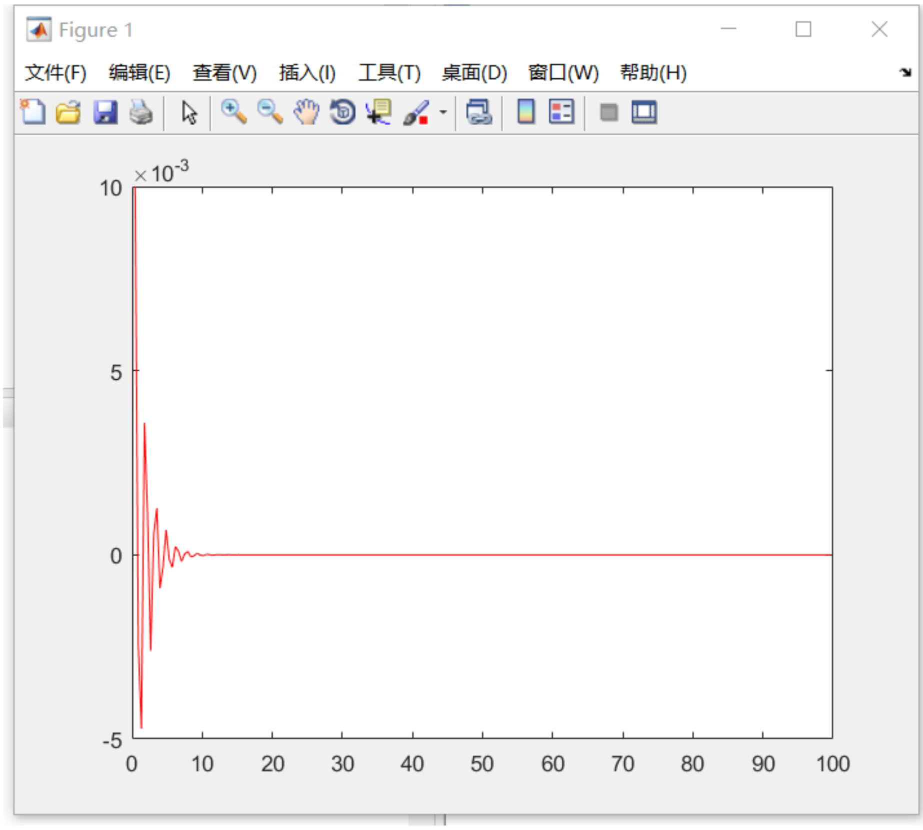


Figure 1
文件(F) 编辑(E) 查看(V) 插入(I) 工具(T) 桌面(D) 窗口(W) 帮助(H)
×10^-3
10
5
0
-5
0 10 20 30 40 50 60 70 80 90 100

h=0.97

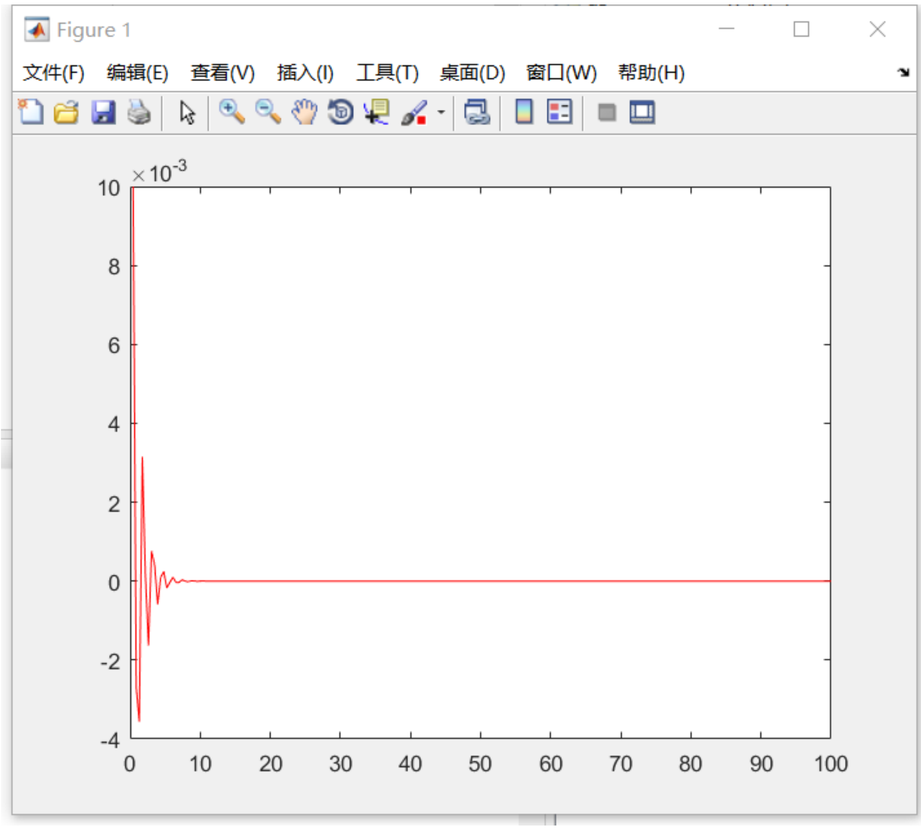
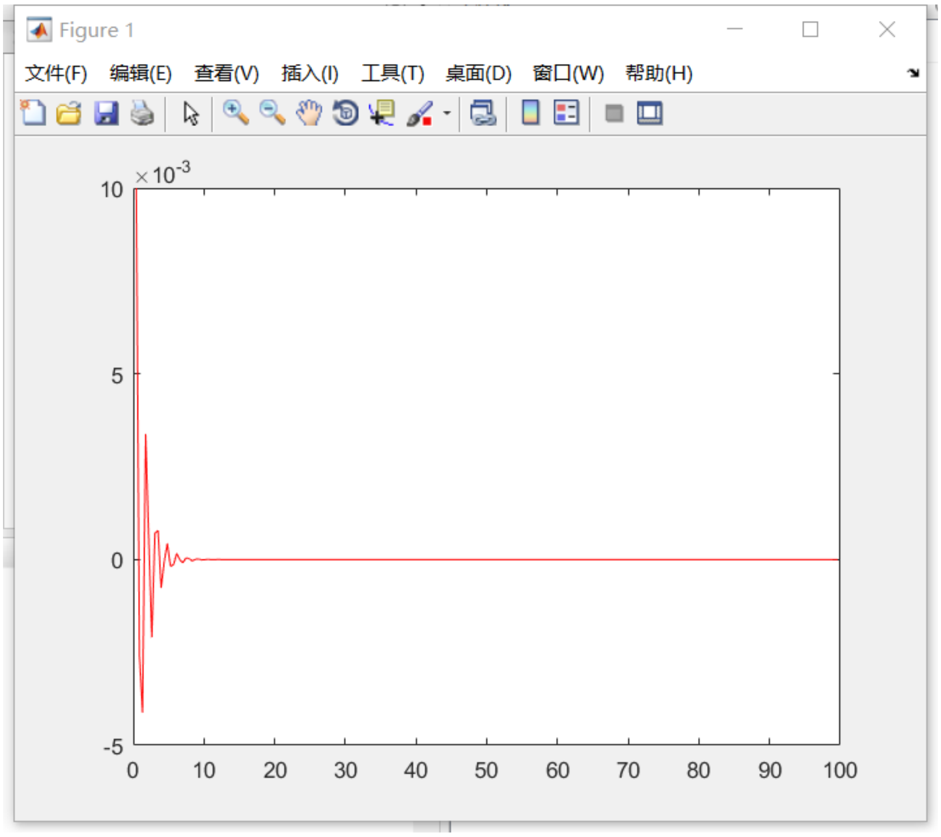
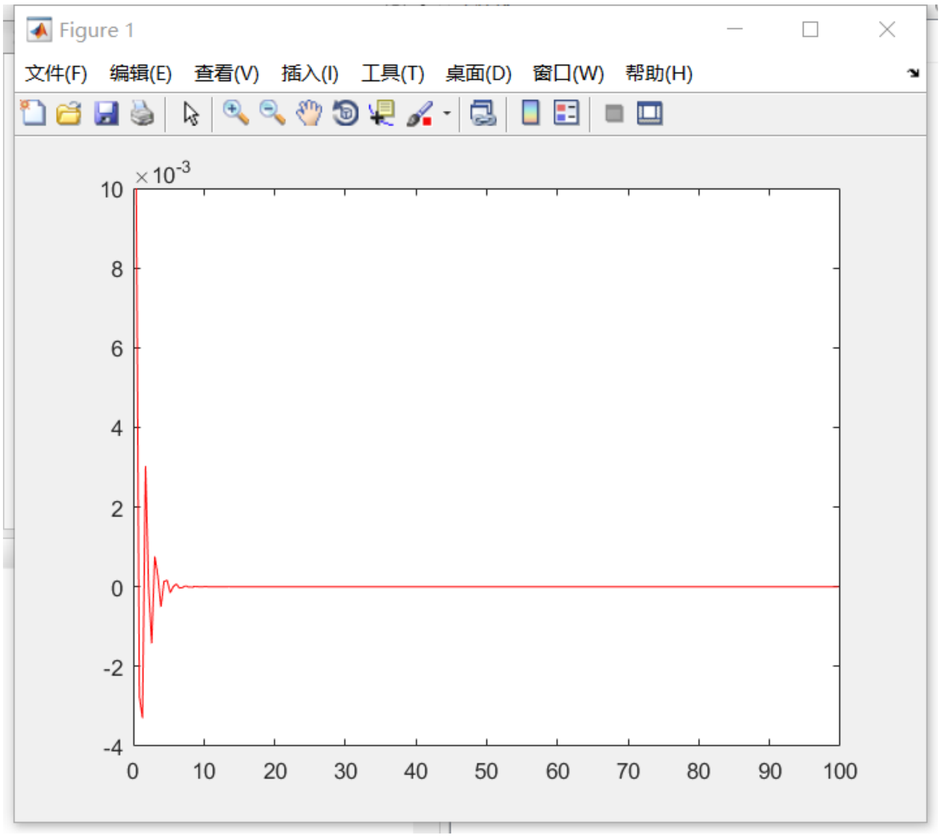


Figure 1
文件(F) 编辑(E) 查看(V) 插入(I) 工具(T) 桌面(D) 窗口(W) 帮助(H)
×10^-3
10
8
6
4
2
0
-2
-4
0 10 20 30 40 50 60 70 80 90 100

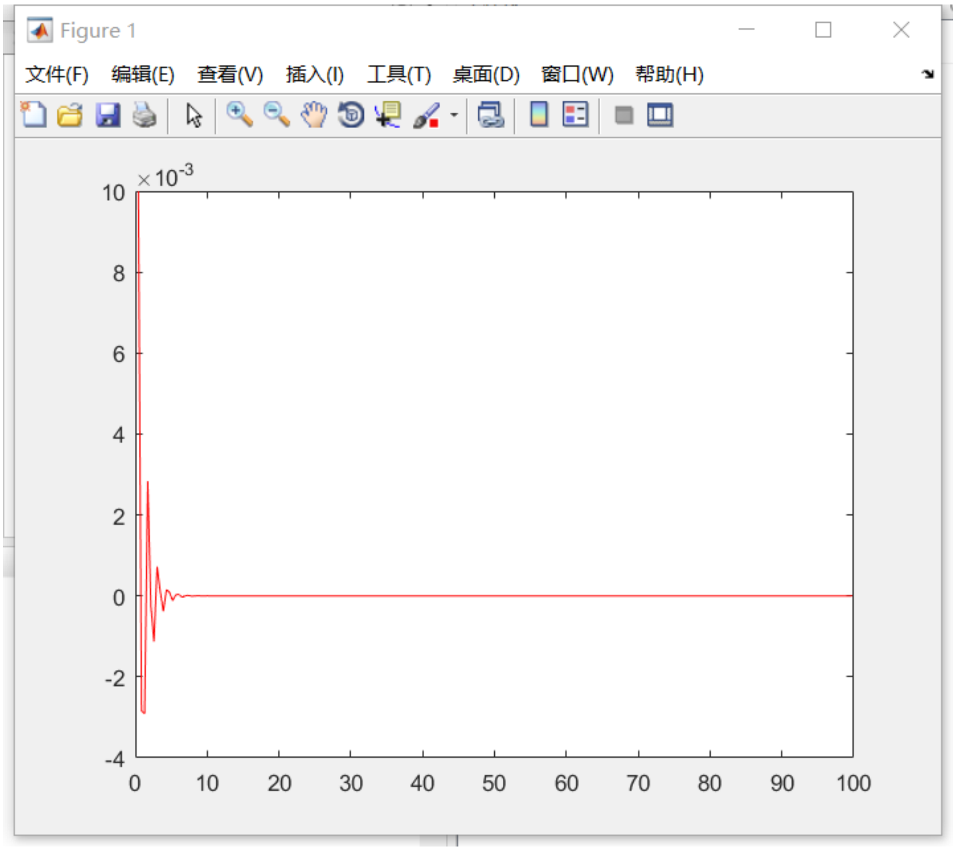
h=0.975



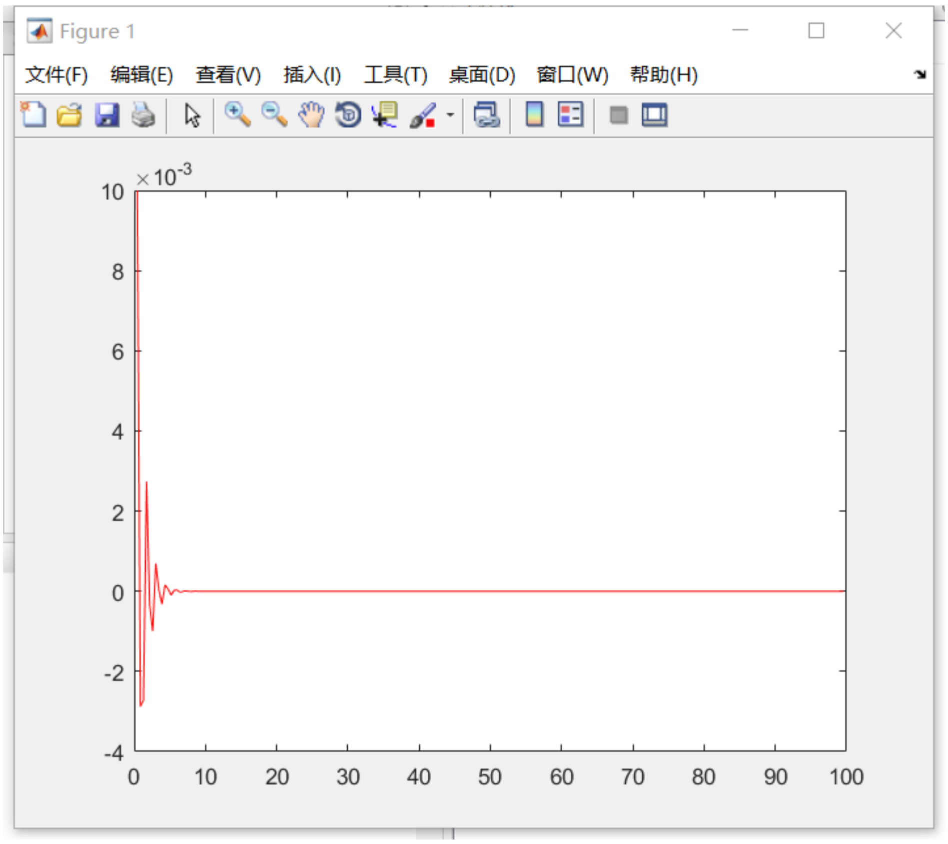
h=0.9675



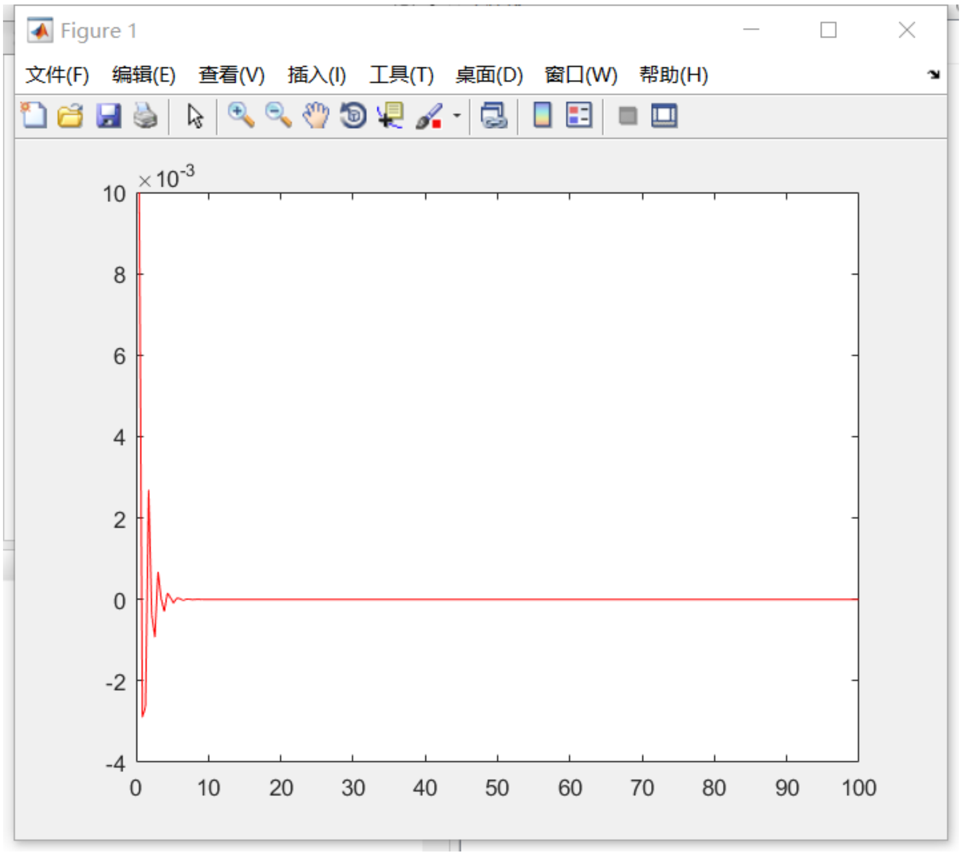
h=0.96375



h=0.961875



h=0.9609375

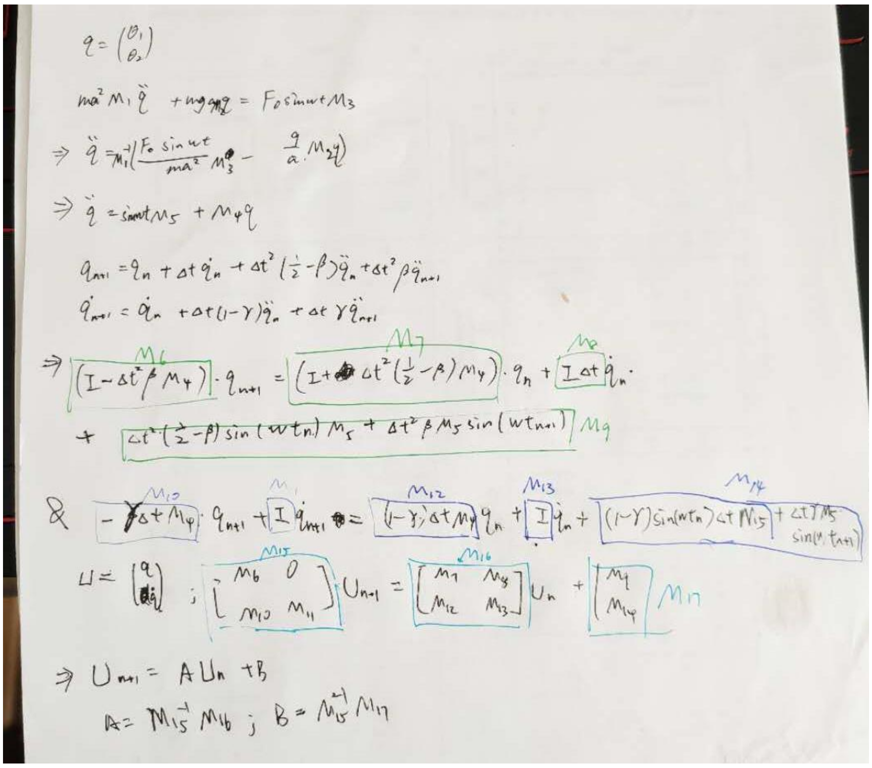


hc=0.9609375

donc, dtc=0.9609375*2*2^0.5/(2*pi)=0.4326s

Etude d'un double pendule avec l'hypothèse des petits mouvements

1.1



```
syms dt n;
eigmax=[];
m = 2;
a = 0.5;
g = 9.81;
F0 = 20;
w = 2 * pi;
beta = 0;
gamma = 0.5;
theta1_0 = 0;
theta2_0 = 0;
dtheta1_0 = - 1.31519275;
dtheta2_0 = - 1.85996342;
I = [1, 0; 0, 1];
M1 = [2, 1; 1, 1];
M2 = [2, 0; 0, 1];
M3 = [a; a / sqrt(2)];
M4 = - inv(M1) * g / a * M2;
M5 = inv(M1) * F0 / m / a / a * M3;
M6 = I - dt * dt * beta * M4;
M7 = I + dt * dt * (0.5 - beta) * M4;
M8 = I * dt;
M9 = dt * dt * (0.5 - beta) * M5 * sin(w * n * dt) +
dt * dt * beta * M5 * sin(w * (n + 1) * dt);
M10 = - dt * gamma * M4;
M11 = I;
M12 = dt * (1 - gamma) * M4;
M13 = I;
M14 = dt * (1 - gamma) * M5 * sin(w * n * dt) + dt *
gamma * M5 * sin(w * (n + 1) * dt);
M15 = [M6, 0; M10, M11];
M16 = [M7, M8; M12, M13];
M17 = [M9; M14];
A = inv(M15) * M16
B = inv(M15) * M17
```

A =

[1 - (981*dt^2)/50, (981*dt^2)/100, dt, 0]
[(981*dt^2)/50, 1 - (981*dt^2)/50, 0, dt]
[(981*dt*((981*dt^2)/50 - 1))/50 - (981*dt)/50 + (962361*dt^3)/5000, (981*dt)/100 - (981*dt*((981*dt^2)/50 - 1))/100 - (962361*dt^3)/5000, 1 - (981*dt^2)/50,

(981*dt^2)/100]
[(981*dt)/50 - (981*dt*((981*dt^2)/50 - 1))/50 - (962361*dt^3)/2500, (981*dt*((981*dt^2)/50 - 1))/50 - (981*dt)/50 + (962361*dt^3)/5000, (981*dt^2)/50, 1 - (981*dt^2)/50]

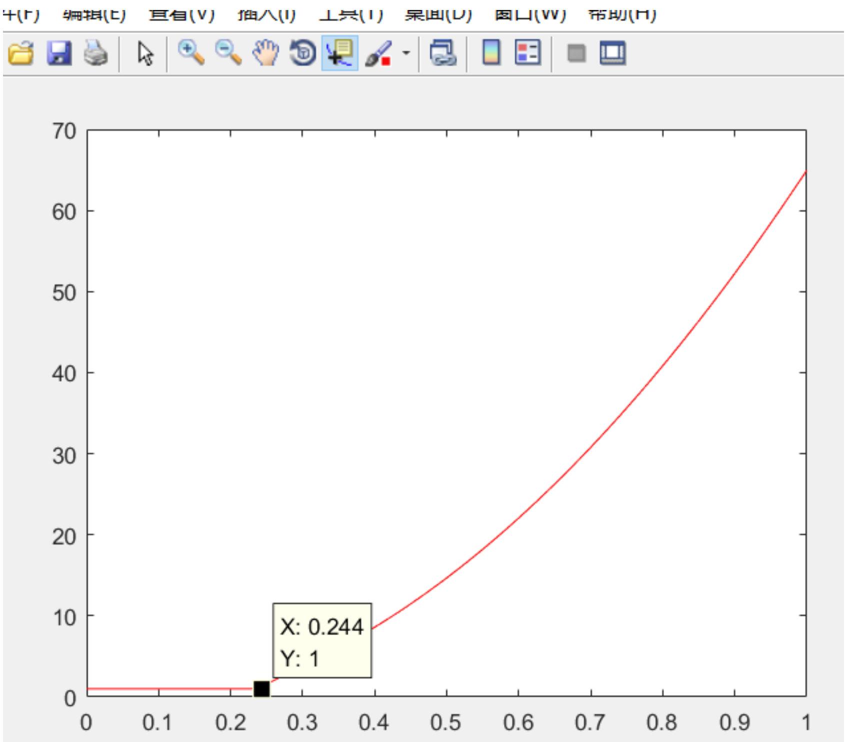
B =

(3297684477769025*dt^2*sin(2*pi*dt*n))/1125899906842624

(2331815056444095*dt^2*sin(2*pi*dt*n))/562949953421312
(3297684477769025*dt*sin(2*pi*dt*(n + 1)))/1125899906842624 - (947517902319756633*dt^3*sin(2*pi*dt*n))/5629499534213120 + (3297684477769025*dt*sin(2*pi*dt*n))/1125899906842624
(2331815056444095*dt*sin(2*pi*dt*(n + 1)))/562949953421312 - (2679985336103801073*dt^3*sin(2*pi*dt*n))/11258999068426240 + (2331815056444095*dt*sin(2*pi*dt*n))/562949953421312

1.2

```
......
for dt=0:0.001:1;
    eigmax=[eigmax,max(abs(eig(eval(A))))];
end
dt=0:0.001:1;
plot(dt, eigmax,'r-')
```



le pas est inférieure à 0.244, tous les modules de valeur propre est presque égale à 1, et quand le pas est supérieure à 0.244, les modules de valeur propre supérieure à 1.

1.3

$$\ddot{q} = M_5 sinwt + M_4 q$$

t=0 ;

$$\ddot{q}_0 = M_4 q_0$$

```
q0 = [theta1_0; theta2_0];
dq0 = [dtheta1_0; dtheta2_0];
d2q0 = M4 * q0;
```

1.4

$$\begin{bmatrix} 1 & 0 & -\beta \Delta t^2 \\ 0 & 1 & -\gamma \Delta t \\ w_0^2 & 0 & 1 \end{bmatrix} \begin{bmatrix} q_j \\ \dot{q}_{j+1} \\ \ddot{q}_{j+1} \end{bmatrix} = \begin{bmatrix} 1 & \Delta t & \Delta t^2(0.5-\beta) \\ 0 & 1 & \Delta t(1-\beta) \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} q_j \\ \dot{q}_j \\ \ddot{q}_j \end{bmatrix}$$

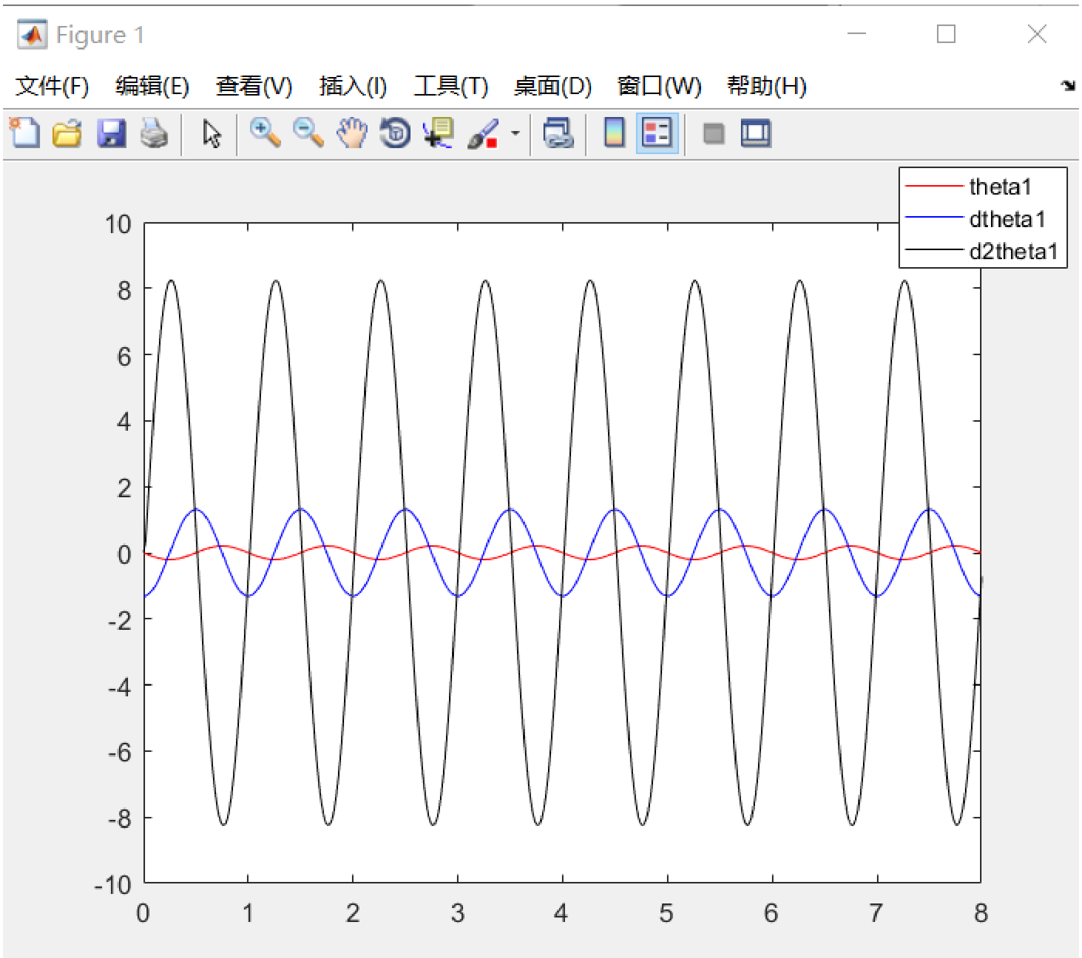
$$\begin{cases} \ddot{q}_j = \sin wt_j \cdot M_5 + M_4 q_j \\ \ddot{q}_{j+1} = \sin wt_{j+1} \cdot M_5 + M_4 q_{j+1} \end{cases}$$

$$U_{n+1} = A \cdot U_n + B.$$

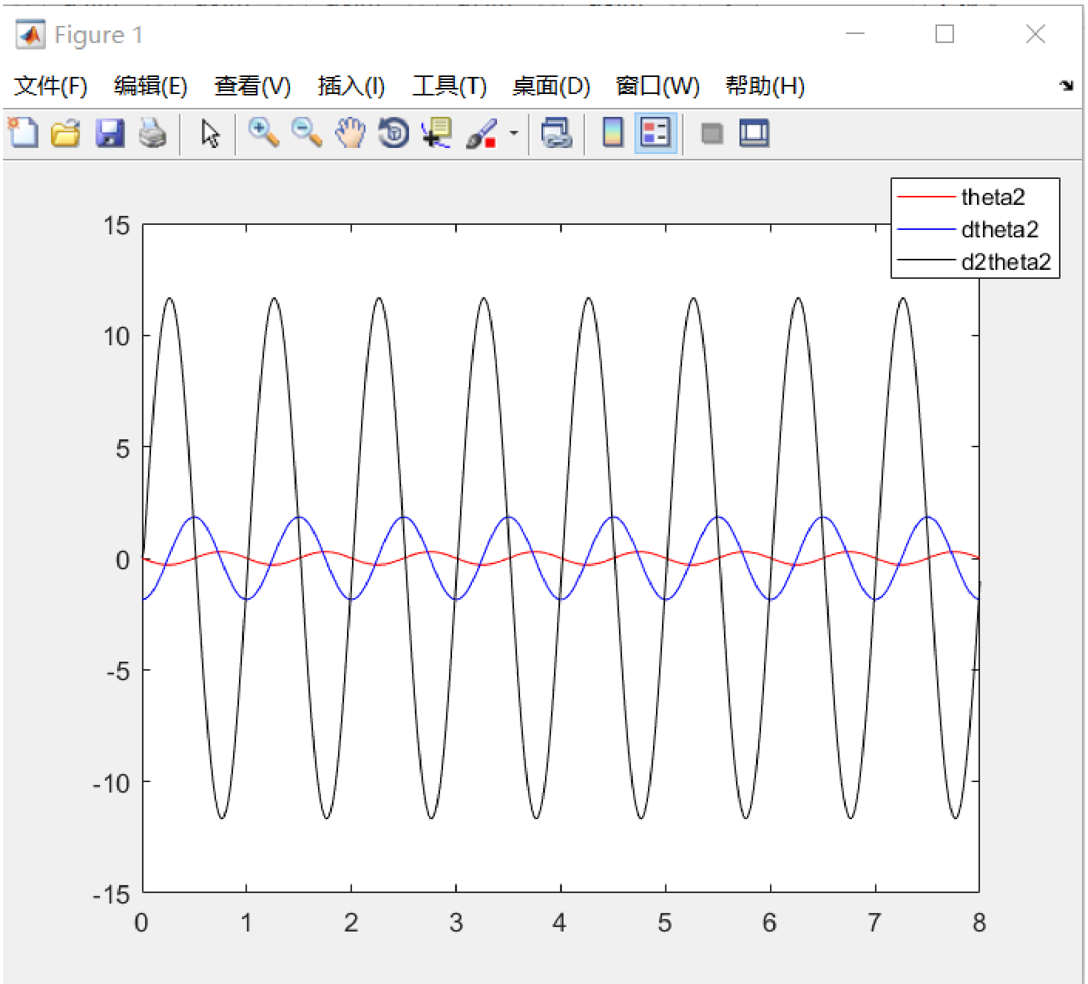
1.5

```
T0 = 8;
dt = 0.02;
m=T0 / dt - 1;
q = [q0];
dq = [dq0];
d2q = [d2q0];
U = [q0; dq0];
for n = 0 : m
    U = eval(A) * U + eval(B);
    q = [q, U(1:2)];
    dq = [dq, U(3:4)];
    d2q = [d2q, M4 * U(1:2) + M5 * sin(w * n * dt)];
end
t = (0 : (m+1)) * dt;
plot(t, q(1, :),'r-');
```

```
hold on;
plot(t, dq(1, :),'b-');
hold on;
plot(t, d2q(1, :),'k-');
```



```
plot(t, q(2, :),'r-');
hold on;
plot(t, dq(2, :),'b-');
hold on;
plot(t, d2q(2, :),'k-');
```



1.6

pour t=0, dt et 2dt

```
q(:, 1 : 3)
```

ans =

0	-0.0263	-0.0522
0	-0.0372	-0.0738

pour t=0.5s

```
q(:, 0.5 / dt + 1)
```

ans =

1.0e-03 *

-0.2988

-0.4226

de même

```
dq(:, 1 : 3)
```

ans =

```
   -1.3152   -1.3048   -1.2739
   -1.8600   -1.8453   -1.8016
```

```
dq(:, 0.5 / dt + 1)
```

ans =

```
    1.3143
    1.8587
```

```
d2q(:, 1 : 3)
```

ans =

```
         0    0.3023    1.3340
         0    0.4275    1.8866
```

```
d2q(:, 0.5 / dt + 1)
```

ans =

```
    0.7376
    1.0432
```

2.1.

......

```
beta = 0.25;
gamma = 0.5;
```

.....

A =

[(962361*dt^4)/(962361*dt^4 + 392400*dt^2 + 20000) - (200*(981*dt^2 + 100)*((981*dt^2)/100 - 1))/(962361*dt^4 + 392400*dt^2 + 20000), (981*dt^2*(981*dt^2 + 100))/(962361*dt^4 + 392400*dt^2 + 20000) - (98100*dt^2*((981*dt^2)/100 - 1))/(962361*dt^4 + 392400*dt^2 + 20000), (200*dt*(981*dt^2 + 100))/(962361*dt^4 + 392400*dt^2 + 20000), (98100*dt^3)/(962361*dt^4 + 392400*dt^2 + 20000)]

[(1962*dt^2*(981*dt^2 + 100))/(962361*dt^4 + 392400*dt^2 + 20000) - (196200*dt^2*((981*dt^2)/100 - 1))/(962361*dt^4 + 392400*dt^2 + 20000), (962361*dt^4)/(962361*dt^4 + 392400*dt^2 + 20000) - (200*(981*dt^2 + 100)*((981*dt^2)/100 - 1))/(962361*dt^4 + 392400*dt^2 + 20000), (196200*dt^3)/(962361*dt^4 + 392400*dt^2 + 20000), (200*dt*(981*dt^2 + 100))/(962361*dt^4 + 392400*dt^2 + 20000)]

[(1924722*dt^3)/(962361*dt^4 + 392400*dt^2 + 20000) - (981*dt)/50 + (1962*(981*dt^3 + 200*dt)*((981*dt^2)/100 - 1))/(962361*dt^4 + 392400*dt^2 + 20000), (981*dt)/100 - (196200*dt*((981*dt^2)/100 - 1))/(962361*dt^4 + 392400*dt^2 + 20000) -

(962361*dt^2*(981*dt^3 + 200*dt))/(100*(962361*dt^4 + 392400*dt^2 + 20000)), 1 - (1962*dt*(981*dt^3 + 200*dt))/(962361*dt^4 + 392400*dt^2 + 20000), (196200*dt^2)/(962361*dt^4 + 392400*dt^2 + 20000)]
[(981*dt)/50 - (392400*dt*((981*dt^2)/100 - 1))/(962361*dt^4 + 392400*dt^2 + 20000) - (962361*dt^2*(981*dt^3 + 200*dt))/(50*(962361*dt^4 + 392400*dt^2 + 20000)), (1924722*dt^3)/(962361*dt^4 + 392400*dt^2 + 20000) - (981*dt)/50 + (1962*(981*dt^3 + 200*dt)*((981*dt^2)/100 - 1))/(962361*dt^4 + 392400*dt^2 + 20000), (392400*dt^2)/(962361*dt^4 + 392400*dt^2 + 20000), 1 - (1962*dt*(981*dt^3 + 200*dt))/(962361*dt^4 + 392400*dt^2 + 20000)]

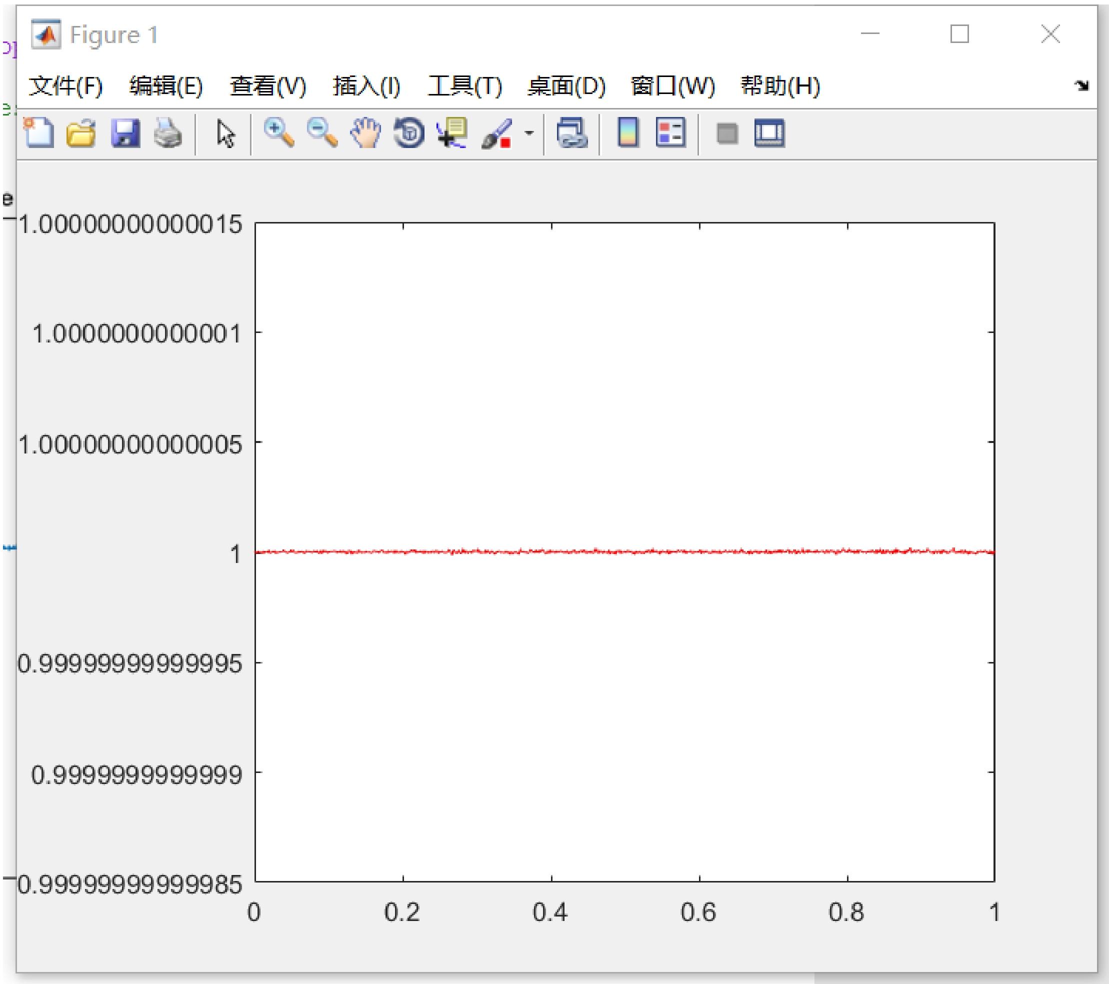
B =

(98100*dt^2*((2331815056444095*dt^2*sin(2*pi*dt*n))/1125899906842624 + (2331815056444095*dt^2*sin(2*pi*dt*(n + 1)))/1125899906842624))/(962361*dt^4 + 392400*dt^2 + 20000) + (200*(981*dt^2 + 100)*((3297684477769025*dt^2*sin(2*pi*dt*n))/2251799813685248 + (3297684477769025*dt^2*sin(2*pi*dt*(n + 1)))/2251799813685248))/(962361*dt^4 + 392400*dt^2 + 20000)

(196200*dt^2*((3297684477769025*dt^2*sin(2*pi*dt*n))/2251799813685248 + (3297684477769025*dt^2*sin(2*pi*dt*(n + 1)))/2251799813685248))/(962361*dt^4 + 392400*dt^2 + 20000) + (200*(981*dt^2 + 100)*((2331815056444095*dt^2*sin(2*pi*dt*n))/1125899906842624 + (2331815056444095*dt^2*sin(2*pi*dt*(n + 1)))/1125899906842624))/(962361*dt^4 + 392400*dt^2 + 20000)
(3297684477769025*dt*sin(2*pi*dt*(n + 1)))/1125899906842624 + (3297684477769025*dt*sin(2*pi*dt*n))/1125899906842624 - (1962*(981*dt^3 + 200*dt)*((3297684477769025*dt^2*sin(2*pi*dt*n))/2251799813685248 + (3297684477769025*dt^2*sin(2*pi*dt*(n + 1)))/2251799813685248))/(962361*dt^4 + 392400*dt^2 + 20000) + (196200*dt*((2331815056444095*dt^2*sin(2*pi*dt*n))/1125899906842624 + (2331815056444095*dt^2*sin(2*pi*dt*(n + 1)))/1125899906842624))/(962361*dt^4 + 392400*dt^2 + 20000)
(2331815056444095*dt*sin(2*pi*dt*(n + 1)))/562949953421312 + (2331815056444095*dt*sin(2*pi*dt*n))/562949953421312 - (1962*(981*dt^3 + 200*dt)*((2331815056444095*dt^2*sin(2*pi*dt*n))/1125899906842624 + (2331815056444095*dt^2*sin(2*pi*dt*(n + 1)))/1125899906842624))/(962361*dt^4 + 392400*dt^2 + 20000) + (392400*dt*((3297684477769025*dt^2*sin(2*pi*dt*n))/2251799813685248 + (3297684477769025*dt^2*sin(2*pi*dt*(n + 1)))/2251799813685248))/(962361*dt^4 + 392400*dt^2 + 20000)

.

2.2



Il est quasiment toujours égale à 1.

2.3

on seulement change le valeur de beta, et il vaut changer quelque valeur lié avec beta dans les matrice, mais la relation ne change pas.

$$\ddot{q} = M_5 sinwt + M_4 q$$

t=0 ;

$$\ddot{q}_0 = M_4 q_0$$

```
q0 = [theta1_0; theta2_0];
dq0 = [dtheta1_0; dtheta2_0];
d2q0 = M4 * q0;
```

2.4

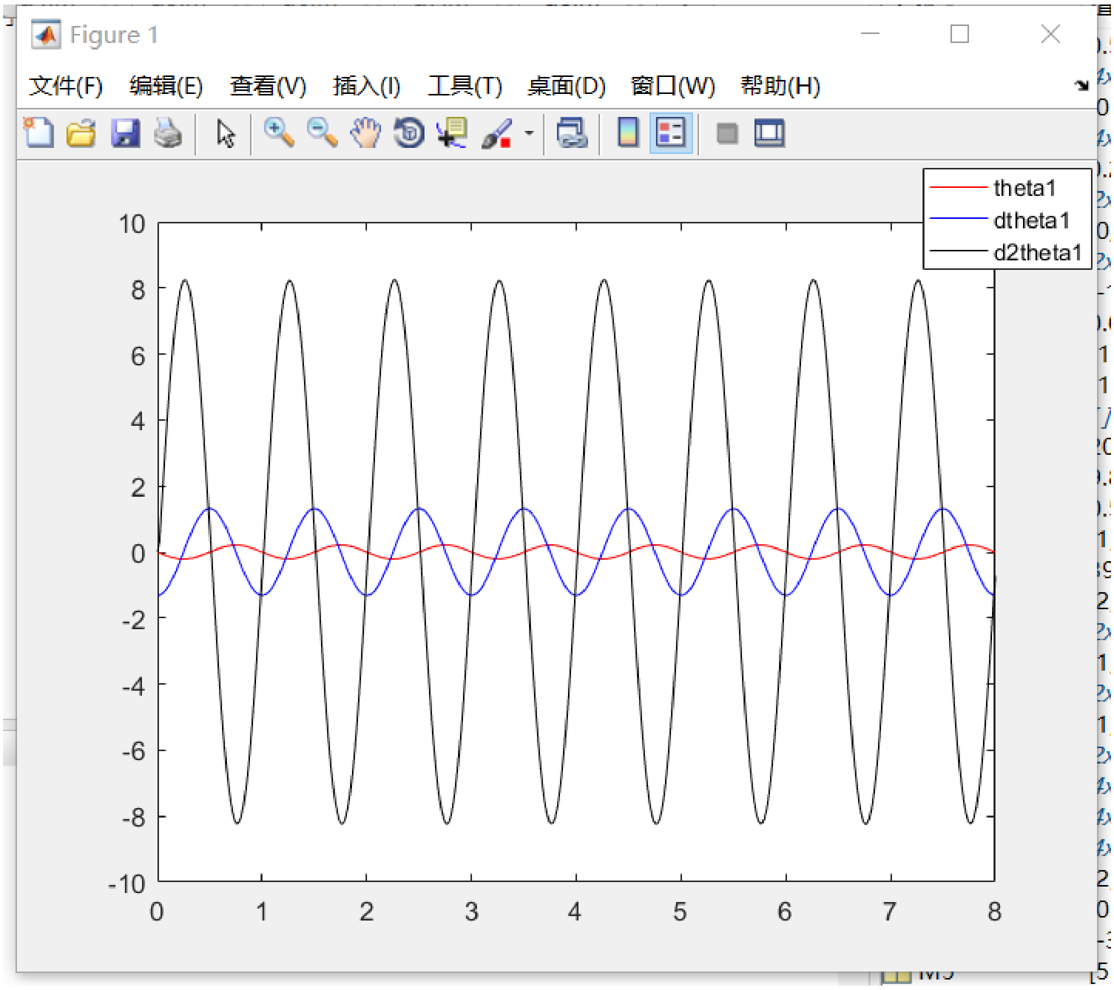
de même, les relation de symbole ne change pas.

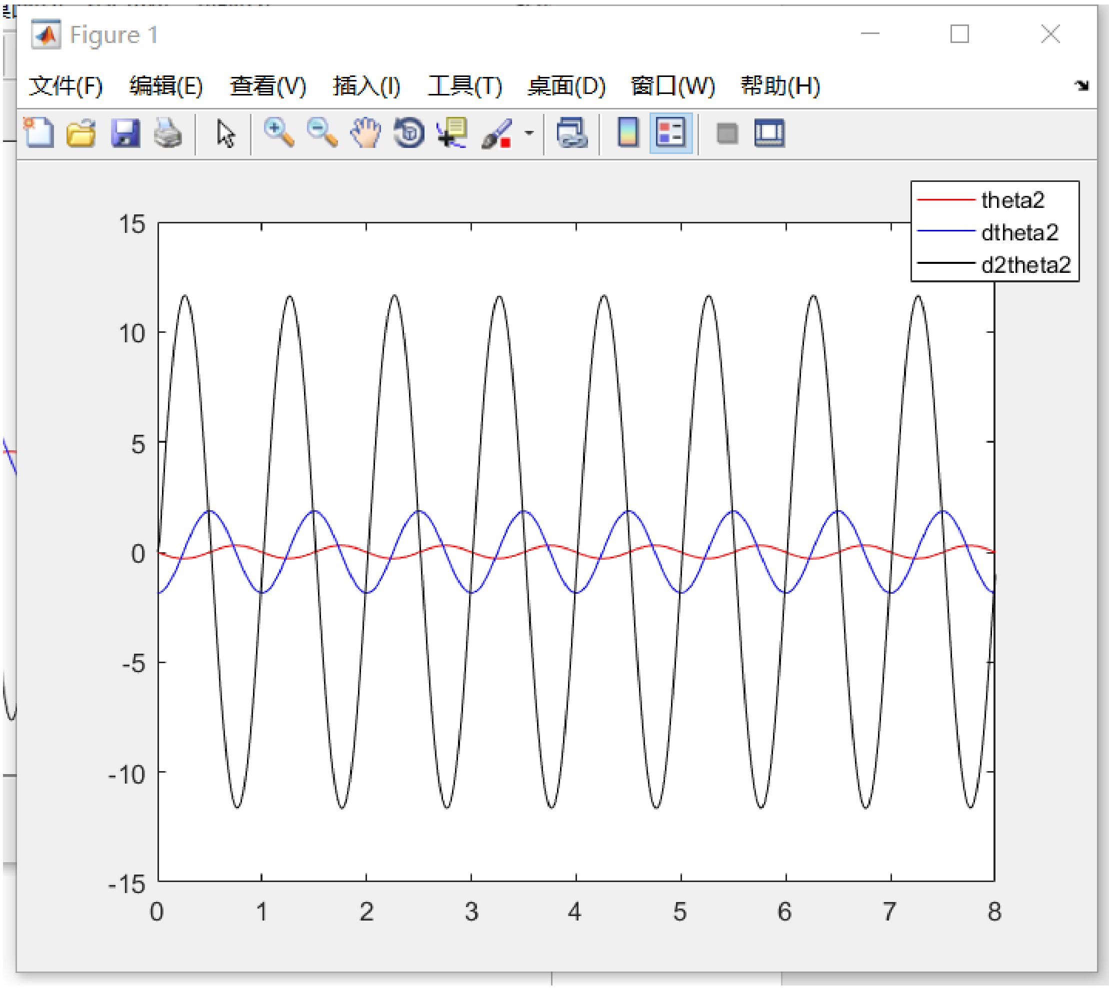
$$\begin{bmatrix} 1 & 0 & -\beta\Delta t^2 \\ 0 & 1 & -\gamma\Delta t \\ \omega_0^2 & 0 & 1 \end{bmatrix} \begin{vmatrix} q_j \\ \dot{q}_{j+1} \\ \ddot{q}_{j+1} \end{vmatrix} = \begin{bmatrix} 1 & \Delta t & \Delta t^2(0.5-\beta) \\ 0 & 1 & \Delta t(1-\beta) \\ 0 & 0 & 0 \end{bmatrix} \begin{vmatrix} q_j \\ \dot{q}_j \\ \ddot{q}_j \end{vmatrix}$$

$$\begin{cases} \ddot{q}_j = \sin \omega t_j \cdot M_5 + M_4 q_j \\ \ddot{q}_{j+1} = \sin \omega t_{j+1} \cdot M_5 + M_4 q_{j+1} \end{cases}$$

$$U_{n+1} = A \cdot U_n + B.$$

2.5





2.6

pour t=0, dt et 2dt

```
q(:, 1 : 3)
```

ans =

```
         0   -0.0262   -0.0520
         0   -0.0371   -0.0735
```

```
dq(:, 1 : 3)
```

ans =

```
   -1.3152   -1.3048   -1.2739
   -1.8600   -1.8453   -1.8016
```

```
d2q(:, 1 : 3)
```

ans =

```
         0    0.3011    1.3317
         0    0.4259    1.8833
```

```
q(:, 0.5 / dt + 1)
```

ans =

-0.0009
-0.0013

```
dq(:, 0.5 / dt + 1)
```

ans =

1.3124
1.8561

```
d2q(:, 0.5 / dt + 1)
```

ans =

0.7448
1.0533

oscillateur non linéaire à un degré de liberté

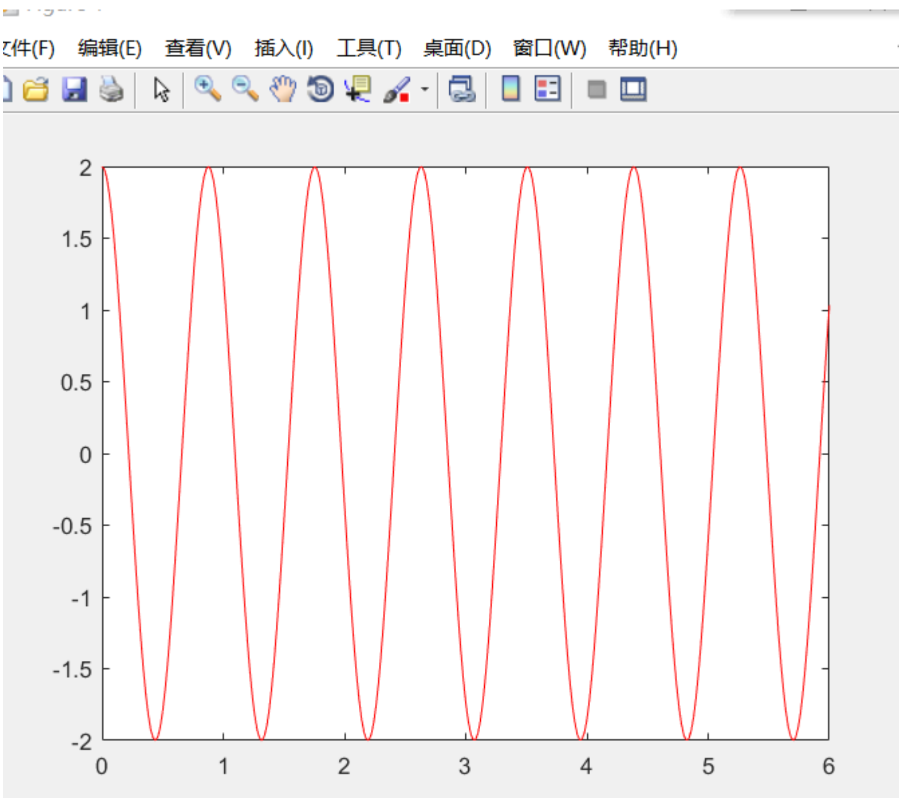
1.1

avec $\beta = 0;\ \gamma = 0.5$

$$q_{j+1} = q_j + \Delta t \dot{q}_j + \frac{\Delta t^2}{2} \ddot{q}_{j+1}$$
$$\ddot{q}_{j+1} = -w_0^2 q_{j+1}\left(1 + a q_{j+1}^2\right)$$
$$\dot{q}_{j+1} = \dot{q}_j + \frac{\Delta t}{2}\left(\ddot{q}_j + \ddot{q}_{j+1}\right)$$

1.2

```
q0=2;
d1q0=0;
d2q0=-11.2*pi^2;
A=[q0,d1q0,d2q0];
dt=0.02;
w0=2*pi;
a=0.1;
I=1;
t=0:0.02:6;
for j=2:301
    A(j,1)=A(j-1,1)+dt*A(j-1,2)+dt^2/2*A(j-1,3);
    A(j,3)=-w0^2*A(j,1)*(I+a*A(j,1)'*A(j,1));
    A(j,2)=A(j-1,2)+dt/2*(A(j-1,3)+A(j,3));
end;
plot(t,A(:,1),'r-')
```



1.3

pour t=0,dt et 2dt

```
q=[A(:,1)];
q(1:3)
```

ans =

```
    2.0000
    1.9779
    1.9123
```

pour t=T0

```
q(301,1)
```

ans =

```
    1.0329
```

2.1

On doit minimiser la valeur de $\omega_0^{\ 2} q_{j+1}^{*}(1 + a q_{j+1}^{*\ 2})$

2.2

$$\Delta q_{j+1}^{*} = \beta \Delta t^2 \Delta \ddot{q}_{j+1}$$

$$\Delta \dot{q}_{j+1}^{*} = \gamma \Delta t \Delta \ddot{q}_{j+1}$$

en utilisant la correction

$$\ddot{q}_{j+1}^{*} + \Delta \ddot{q}_{j+1} + \omega_0^{\ 2}(q_{j+1}^{*} + \Delta q_{j+1})(1 + a(q_{j+1}^{*} + \Delta q_{j+1})^2) = 0$$

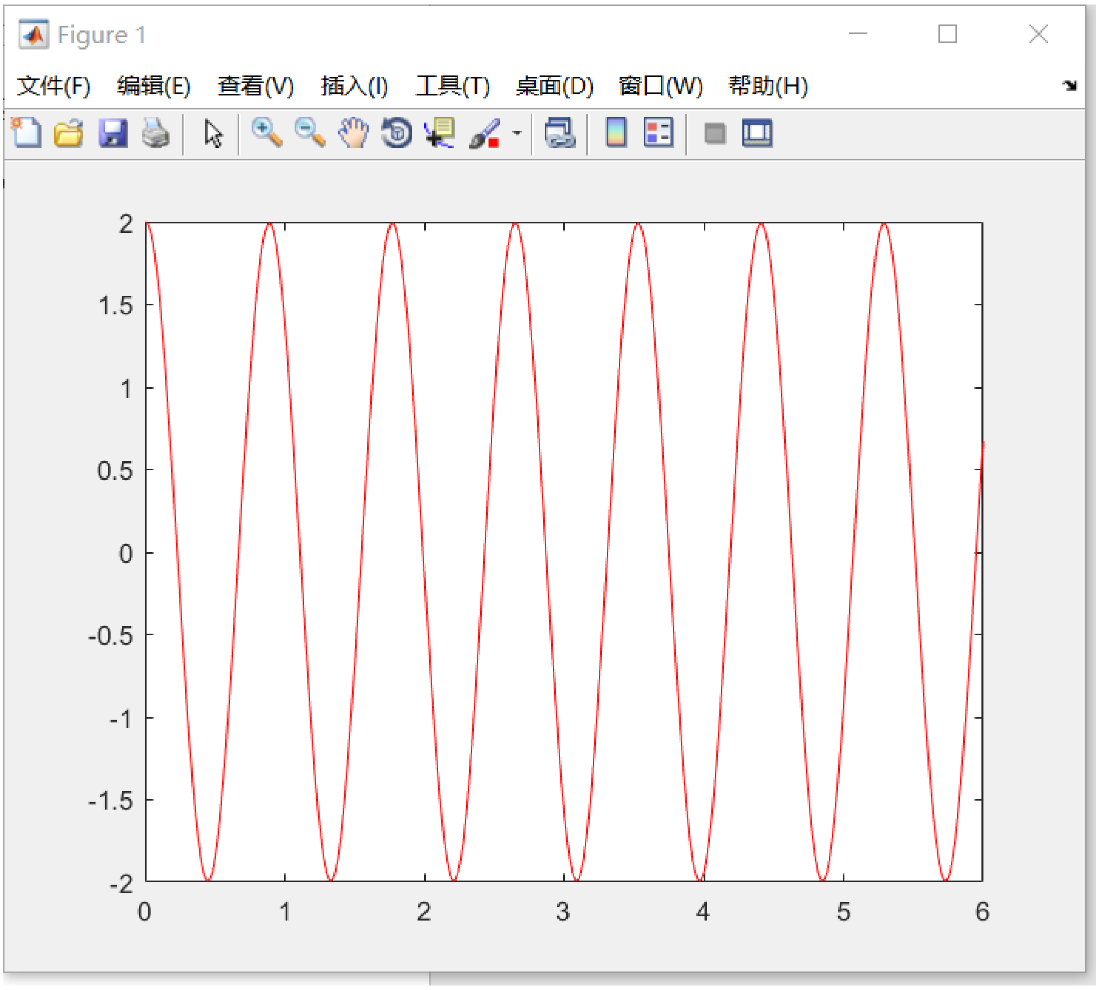
2.3

$$f = \omega_0{}^2 q^*_{j+1}(1+aq^*_{j+1}{}^2)$$

$$\Delta\ddot{q}_{j+1} = -\frac{f}{\dfrac{\partial f}{\partial \ddot{q}^*_{j+1}} + \dfrac{\partial f}{\partial q^*_{j+1}}\beta\Delta t^2} = \frac{-\ddot{q}^*_{j+1} - w_0 q^*_{j+1}(1+aq^*_{j+1}{}^2)}{1+w_0^2\beta\Delta t^2(1+3aq^*_{j+1}{}^2)}$$

```
q1=2;
d1q1=0;
d2q1=0;
B=[q1,d1q1,d2q1];
dt=0.02;
w0=2*pi;
a=0.1;
I=1;
t=0:0.02:6;
delta_q1=0;
d1delta_q1=0;
d2delta_q1=0;
C=[delta_q1,d1delta_q1,d2delta_q1];
for j=2:301
    B(j,3)=0;
    B(j,2)=B(j-1,2)+0.5*dt*B(j-1,3);
    B(j,1)=B(j-1,1)+dt*B(j-1,2)+dt^2*0.25*B(j-1,3);

while(abs(B(j,3)+(w0^2)*B(j,1)*(1+a*B(j,1)^2))>0.01)
      C(j,3)=(-B(j,3)-
(w0^2)*B(j,1)*(1+a*B(j,1)^2)/(1+(w0^2)*(1+3*a*B(j,1)^
2)*0.25*dt^2));
      C(j,2)=0.5*dt*C(j,3);
      C(j,1)=0.25*dt^2*C(j,3);
      B(j,3)=B(j,3)+C(j,3);
      B(j,2)=B(j,2)+C(j,2);
      B(j,1)=B(j,1)+C(j,1);
    end
end
plot(t,B(:,1),'r-')
q1=[B(:,1)]
q1(1:3)
q1(301,1)
```



2.4

pour t=0,dt et 2dt

ans =

    2.0000
    1.9890
    1.9456

pour t=6s

ans =

    0.6694

3.1

$$E=\frac{1}{2}m\ddot{q}^2+\frac{1}{2}mkq^2+\frac{1}{4}amkq^4$$

3.2

soit m=1kg,

$$e=\frac{1}{2}\ddot{q}^2+\frac{1}{2}kq^2+\frac{1}{4}akq^4$$

NM-EX :

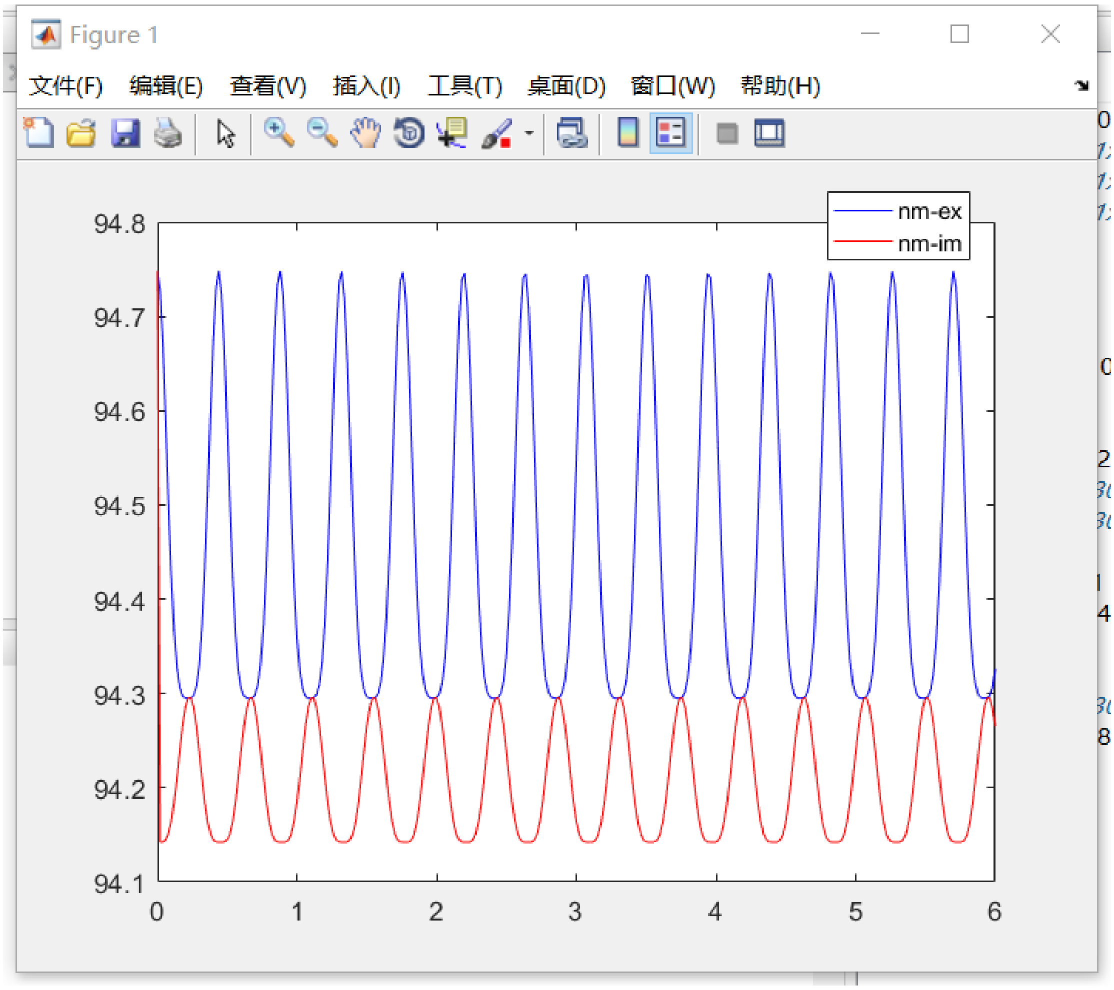
```
q0=2;
d1q0=0;
d2q0=-11.2*pi^2;
A=[q0,d1q0,d2q0];
dt=0.02;
w0=2*pi;
k=w0^2;
a=0.1;
I=1;
t=0:0.02:6;
e=[k*2+a*k*4];
for j=2:301
    A(j,1)=A(j-1,1)+dt*A(j-1,2)+dt^2/2*A(j-1,3);
    A(j,3)=-w0^2*A(j,1)*(I+a*A(j,1)^2);
    A(j,2)=A(j-1,2)+dt/2*(A(j-1,3)+A(j,3));
    e(j)=0.5*A(j,2)^2;
end;
plot(t,e,'b-')
```

NM-IM:

```
q1=2;
d1q1=0;
d2q1=0;
B=[q1,d1q1,d2q1];
dt=0.02;
w0=2*pi;
k=w0^2;
a=0.1;
I=1;
t=0:0.02:6;
delta_q1=0;
d1delta_q1=0;
d2delta_q1=0;
C=[delta_q1,d1delta_q1,d2delta_q1];
e1=[k*2+a*k*4];
for j=2:301
    B(j,3)=0;
    B(j,2)=B(j-1,2)+0.5*dt*B(j-1,3);
    B(j,1)=B(j-1,1)+dt*B(j-1,2)+dt^2*0.25*B(j-1,3);

while(abs(B(j,3)+(w0^2)*B(j,1)*(1+a*B(j,1)^2))>0.01)
     C(j,3)=(-B(j,3)-
(w0^2)*B(j,1)*(1+a*B(j,1)^2)/(1+(w0^2)*(1+3*a*B(j,1)^
2)*0.25*dt^2));
     C(j,2)=0.5*dt*C(j,3);
```

```
        C(j,1)=0.25*dt^2*C(j,3);
        B(j,3)=B(j,3)+C(j,3);
        B(j,2)=B(j,2)+C(j,2);
        B(j,1)=B(j,1)+C(j,1);
    end
    e1(j)=0.5*B(j,2)^2+k/2*B(j,1)^2+a*k/4*B(j,1)^4;
end
plot(t,e1(1,:),'r-')
```



3.3

Energie de NM-EX est toujours grande que celle de NM-IM.