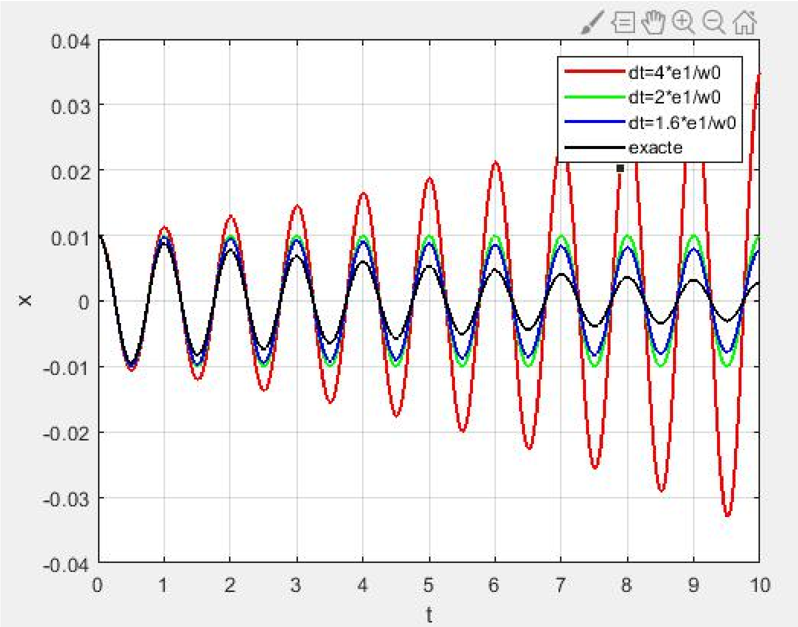
DM4

Oscillateur linéaire amorti à un degré de liberté

1.1.a/b/c

```
T0=10;q0=0.01;dq0=0;w0=2*pi;,e1=0.02;omega=w0*(1-e1^2)^(1/2)
for dt1=[4*e1/w0,2*e1/w0,1.6*e1/w0 ]%pour le cas dt>2*e1/w0, on choisit dt=2*tc
    t1=(0:dt1:T0)';
    np1=size(t1,1);
    q1=zeros(np1,1);
    dq1=zeros(np1,1);
    ddq1=zeros(np1,1);
    q1(1)=q0;
    dq1(1)=dq0;
    ddq1(1)=-2*e1*w0*dq1(1)-w0^2*q1(1);%forme (21)
    for inc=2:np1
        q1(inc)=q1(inc-1)+dt1*dq1(inc-1);
        dq1(inc)=dq1(inc-1)+dt1*ddq1(inc-1);
        ddq1(inc)=-2*e1*w0*dq1(inc)-w0^2*q1(inc)
    end
    if dt1==4*e1/w0
        plot(t1,q1,'r','Linewidth',1.5)
        hold on
    elseif dt1==2*e1/w0
        plot(t1,q1,'g','Linewidth',1.5)
        hold on
    else
        plot(t1,q1,'b','Linewidth',1.5)
        hold on
    end
end;
%calcul de la valeur exacte
dt=e1/w0
t=(0:dt:T0)';
np=size(t,1);
q=zeros(np,1);
dq=zeros(np,1);
ddq=zeros(np,1);
q(1)=q0;
dq(1)=dq0;
ddq(1)=-2*e1*w0*dq(1)-w0^2*q(1);
    for inc=2:np
       t(inc)=(inc-1)*dt
```

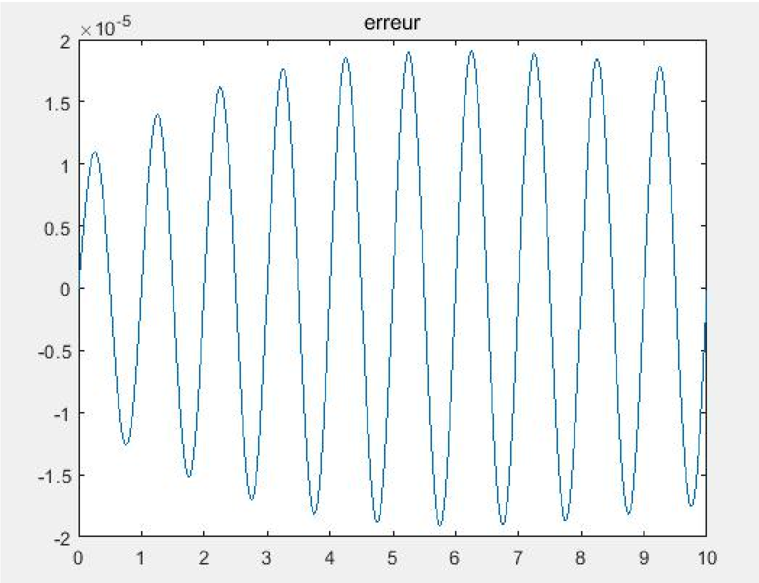
```
        q(inc)=exp(-e1*w0*t(inc))*(q0*cos(omega*t(inc))+(e1*w0*q0+dq0)/omega*s
        in(omega*t(inc)))
    end
plot(t,q,'k','Linewidth',1.5)
grid on;
xlabel('t');
ylabel('x');
legend('dt=4*e1/w0','dt=2*e1/w0','dt=1.6*e1/w0','exacte')
%2*e1/w0 est le temps critique.dt doit inferieur a tc pour que le module absolu
de valeur propre soit inferieur a 1.
%quand dt<tc,x converge selon t;quand dt>tc, x diverge;quand dt=tc, c'est
%une fonction sinusoidale.
```



1.1.d

```
%critere: la valeur de dt par apport a le temps critique
%precision suffisante: le rapport inferieur a 0.05
w0=2*pi;
e1=0.02;
omega=w0*(1-e1^2)^(0.5);
dt=0.05*2*e1/w0;
T0=1;
q0=0.01;
dq0=0;

A=[1,0;dt*(w0^2),1+2*dt*e1*w0];
B=[1,dt;0,1];
C=inv(A)*B
U=[q0;dq0];
```

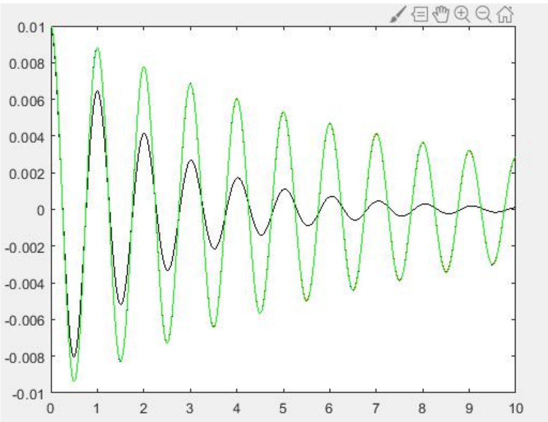
```
Y=[];
for inc=1:(10*T0/dt)
   Y(inc)=U(1);
   U=C*U;
end
L=linspace(0,10*T0,10*T0/dt);
Y0=(exp(-e1*w0*L)).*(q0*cos(omega*L)+(e1*w0*q0+dq0)*(sin(omega*L))/omega);
plot(L,(Y-Y0));
title('erreur');
```

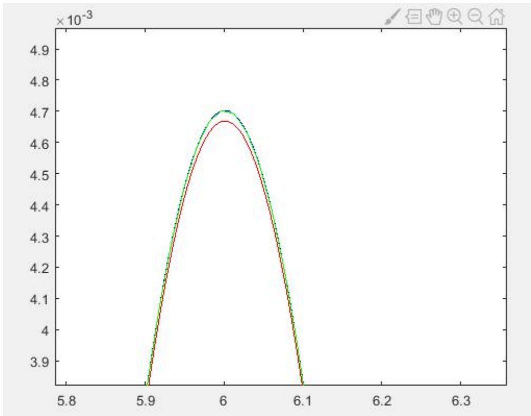


1.2

```
w0=2*pi;
e1=0.02;
omega=w0*(1-e1^2)^(0.5);
T0=1;
q0=0.01;
dq0=0;
for dt2=[0.001*e1/w0,0.02*e1/w0,5*e1/w0]
    A=[1,-dt2;dt2*(w0^2),1+2*e1*w0*dt2];
    A=inv(A);
    U=[q0;dq0];
    Y=[];
    for inc=1:(10*T0/dt2)
        Y(inc)=U(1);
        U=A*U;
    end
    L=linspace(0,10*T0,10*T0/dt2);
    if dt2==0.001*e1/w0
        plot(L,Y,'b')
```

```
        hold on
    elseif dt2==0.02*e1/w0
        plot(L,Y,'r')
        hold on
    else

        plot(L,Y,'k')
        hold on

Y0=(exp(-e1*w0*L)).*(q0*cos(omega*L)+(e1*w0*q0+dq0)*(sin(omega*L))/omega);
        plot(L,Y0,'g')
    end
end
```



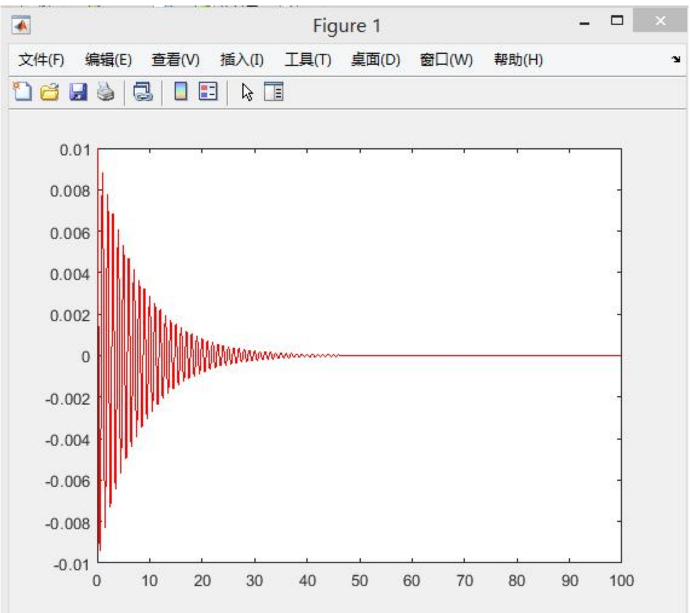


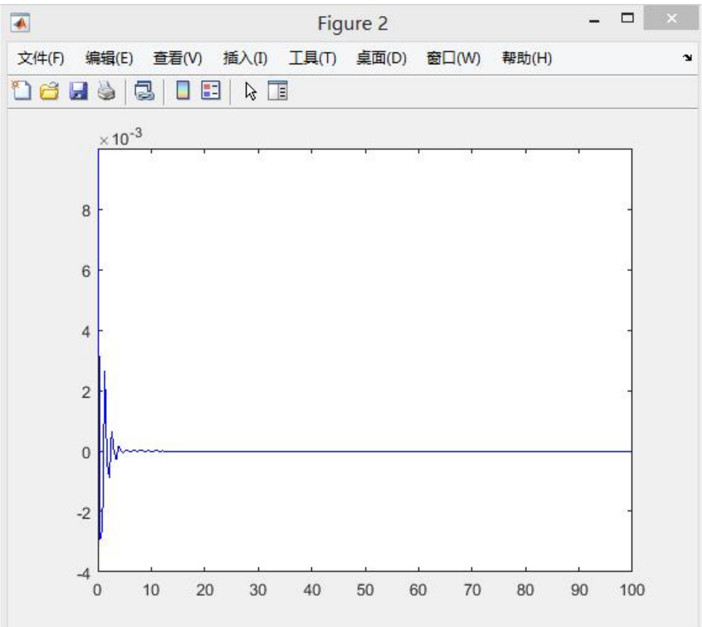
On peut voir que n'import quel dt, la valeur toujours plus petite que la valeur exate, donc pas de temps critique/tc=0.

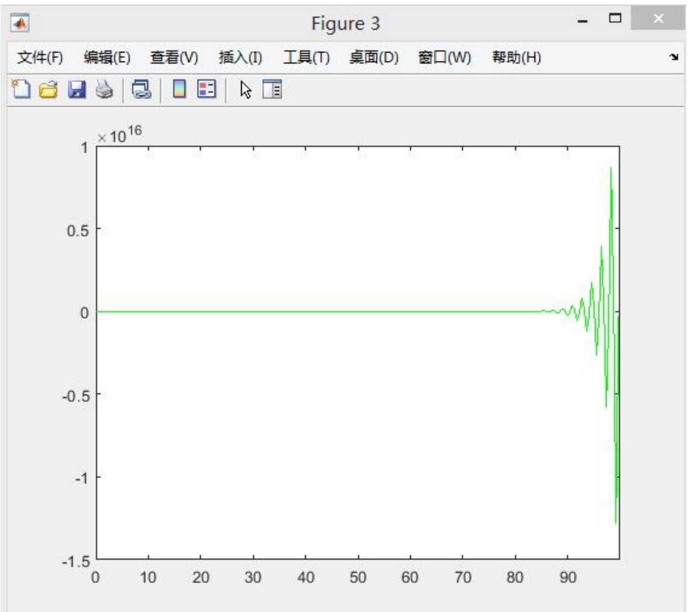
1.3

```
for h=[0.04,0.96,1.04]
    e1=0.02;
    T0=1;
    dt3=h*2*2^(0.5)/w0;
    t3=(0:dt3:100*T0)';
    np3=size(t3,1)
    q0=0.01;
    dq0=0;
    q3=zeros(np3,1);
    dq3=zeros(np3,1);
    q3(1)=q0;
    dq3(1)=dq0;
    qj=[q0;dq0];
    for inc=2:np3
        tc=t3(inc-1);
        xc=qj;
```

```
        k1=cal_f(xc,tc,e1,2*pi);
        xc=qj+k1*dt3/2;
        k2=cal_f(xc,tc+dt3/2,e1,2*pi)
        xc=qj+k2*dt3/2
        k3=cal_f(xc,tc+dt3/2,e1,2*pi);
        xc=qj+k3*dt3;
        k4=cal_f(xc,tc+dt3,e1,2*pi);
        dq=(k1+2*k2+2*k3+k4)/6;
        qj=qj+dq*dt3;
        q3(inc)=qj(1);
        dq3(inc)=qj(2);
    end
    if h==0.04
        figure(1)
        plot(t3,q3,'r')
    elseif h==0.96
        figure(2)
        plot(t3,q3,'b')
    elseif h==1.04
        figure(3)
        plot(t3,q3,'g')
    end
end
%les deux premiers sont precis et stables
```



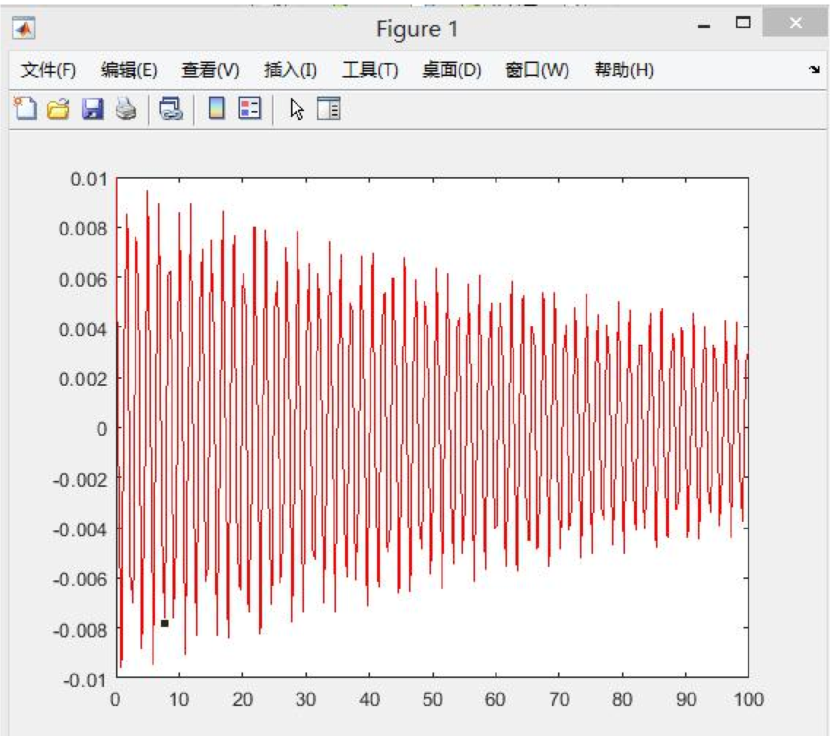


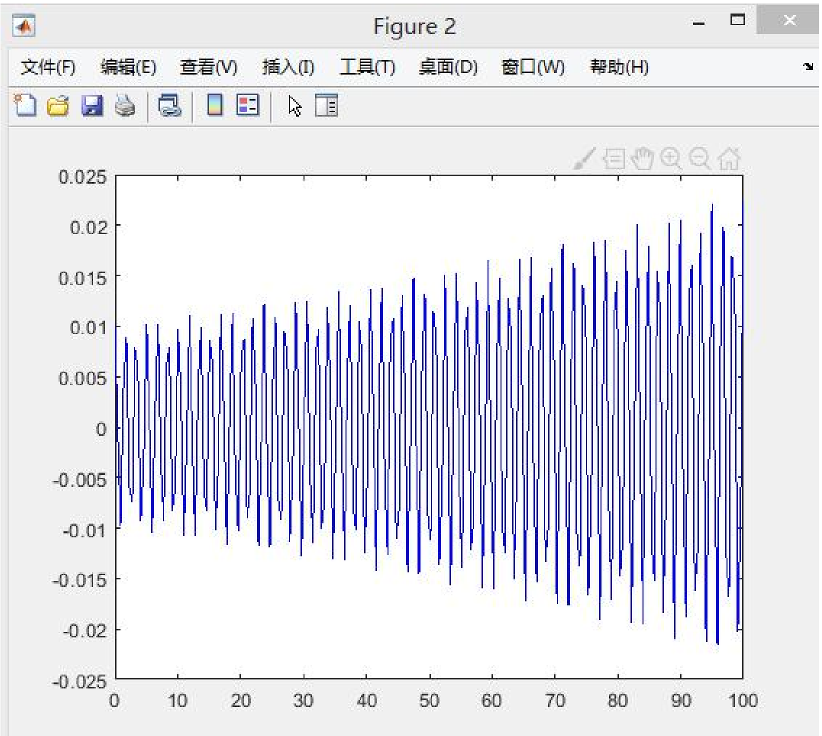


1.3.b

```
for h=[1.013,1.014]
    e1=0.02;
    T0=1;
    dt3=h*2*2^(0.5)/w0;
    t3=(0:dt3:100*T0)';
    np3=size(t3,1)
    q0=0.01;
    dq0=0;
    q3=zeros(np3,1);
    dq3=zeros(np3,1);
```

```
    q3(1)=q0;
    dq3(1)=dq0;
    qj=[q0;dq0];
    for inc=2:np3
        tc=t3(inc-1);
        xc=qj;
        k1=cal_f(xc,tc,e1,2*pi);
        xc=qj+k1*dt3/2;
        k2=cal_f(xc,tc+dt3/2,e1,2*pi)
        xc=qj+k2*dt3/2
        k3=cal_f(xc,tc+dt3/2,e1,2*pi);
        xc=qj+k3*dt3;
        k4=cal_f(xc,tc+dt3,e1,2*pi);
        dq=(k1+2*k2+2*k3+k4)/6;
        qj=qj+dq*dt3;
        q3(inc)=qj(1);
        dq3(inc)=qj(2);
    end
    if h==1.013
        figure(1)
        plot(t3,q3,'r')
    elseif h==1.014
        figure(2)
        plot(t3,q3,'b')

    end
end
%hmax=1.014;hmin=1.013
```





Double pendule

1.1

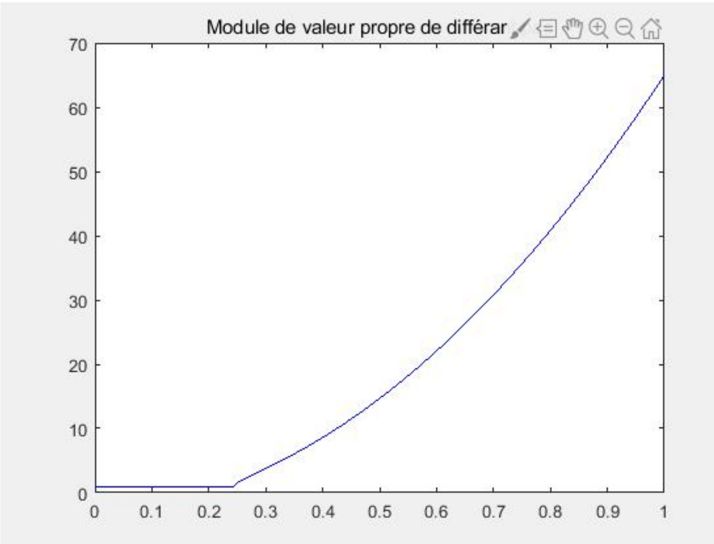
```
syms m;syms a;syms g;syms F0;
syms w;syms b;syms r;syms dt;
syms n;
```

```
A=[2, 1; 1, 1];
B=[2, 0; 0, 1];
C=[a; a / 2^0.5];
% Donc on a m*a^2*A*d2q+m*g*a*B*q=F0*sin(w*t)*C avec
% q = [theta1; theta2] et d2q = [d2theta1; d2theta2]
% donc on peut trouver d2q=D*q+E*sin(w*t) avec
D=-inv(A)*g/a*B;
E=inv(A)*F0/(m*a*a)*C;
% Selon les relation (2) et (3), on a
% F*qn_=G*qn+H*dqn+Iavec
F=eye(2)-dt^2*b*D;
G=eye(2)+dt^2*(0.5-b)*D;
H=eye(2)*dt;
I=dt^2*(0.5-b)*E*sin(w*n*dt)+dt^2*b*E*sin(w*(n+1)*dt);
%J*qn_1+K*dqn_1=L*qn+M*dqn+N avec
J=-dt*r*D;
K=eye(2);
L=dt*(1-r)*D;
M=eye(2);
N=dt*(1-r)*E*sin(w*n*dt)+dt*r*E*sin(w*(n+1)*dt);
%supposons que U=[q;dq],on peut trouver que O*Un_1=P*Un+Q avec
O=[F,0*eye(2);J,K];
P=[G,H;L,M];
Q=[I;N];
% Donc,on a Un_1=M1*Un+M2 avec
M1=inv(O)*P
M2=inv(O)*Q
% %M1 =
%
% [                                ((2*g*(b - 1/2)*dt^2)/a + 1)*(a^2 +
2*b*g*a*dt^2))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2) - (2*b*dt^4*g^2*(b -
1/2))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2),
(a*b*dt^2*g*((2*g*(b - 1/2)*dt^2)/a + 1))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2)
- (dt^2*g*(a^2 + 2*b*g*a*dt^2)*(b - 1/2))/(a*(a^2 + 4*a*b*dt^2*g +
2*b^2*dt^4*g^2)),          (dt*(a^2 + 2*b*g*a*dt^2))/(a^2 + 4*a*b*dt^2*g +
2*b^2*dt^4*g^2),                        (a*b*dt^3*g)/(a^2 + 4*a*b*dt^2*g +
2*b^2*dt^4*g^2)]
% [                     (2*a*b*dt^2*g*((2*g*(b - 1/2)*dt^2)/a + 1))/(a^2 +
4*a*b*dt^2*g + 2*b^2*dt^4*g^2) - (2*dt^2*g*(a^2 + 2*b*g*a*dt^2)*(b -
1/2))/(a*(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2)),
(((2*g*(b - 1/2)*dt^2)/a + 1)*(a^2 + 2*b*g*a*dt^2))/(a^2 + 4*a*b*dt^2*g +
2*b^2*dt^4*g^2) - (2*b*dt^4*g^2*(b - 1/2))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2),
(2*a*b*dt^3*g)/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2),          (dt*(a^2 +
```

```
2*b*g*a*dt^2))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2)]
% [         (2*dt*g*(r - 1))/a - (2*(b*r*dt^3*g^2 + a*r*dt*g)*((2*g*(b -
1/2)*dt^2)/a + 1))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2) - (2*dt^3*g^2*r*(b -
1/2))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2), (2*dt^2*g*(b*r*dt^3*g^2 +
a*r*dt*g)*(b - 1/2))/(a*(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2)) - (dt*g*(r - 1))/a
+ (a*dt*g*r*((2*g*(b - 1/2)*dt^2)/a + 1))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2),
1 - (2*dt*(b*r*dt^3*g^2 + a*r*dt*g))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2),
(a*dt^2*g*r)/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2)]
% [ (4*dt^2*g*(b*r*dt^3*g^2 + a*r*dt*g)*(b - 1/2))/(a*(a^2 + 4*a*b*dt^2*g +
2*b^2*dt^4*g^2)) - (2*dt*g*(r - 1))/a + (2*a*dt*g*r*((2*g*(b - 1/2)*dt^2)/a +
1))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2),      (2*dt*g*(r - 1))/a -
(2*(b*r*dt^3*g^2 + a*r*dt*g)*((2*g*(b - 1/2)*dt^2)/a + 1))/(a^2 + 4*a*b*dt^2*g
+ 2*b^2*dt^4*g^2) - (2*dt^3*g^2*r*(b - 1/2))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2),
(2*a*dt^2*g*r)/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2), 1 - (2*dt*(b*r*dt^3*g^2
+ a*r*dt*g))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2)]

% M2 =
%
%
((a^2 + 2*b*g*a*dt^2)*(b*dt^2*sin(dt*w*(n + 1))*(F0/(a*m) - (2^(1/2)*F0)/(2*a*m))
- dt^2*sin(dt*n*w)*(F0/(a*m) - (2^(1/2)*F0)/(2*a*m))*(b - 1/2)))/(a^2 +
4*a*b*dt^2*g + 2*b^2*dt^4*g^2) - (a*b*dt^2*g*(b*dt^2*sin(dt*w*(n + 1))*(F0/(a*m)
- (2^(1/2)*F0)/(a*m)) - dt^2*sin(dt*n*w)*(F0/(a*m) - (2^(1/2)*F0)/(a*m))*(b -
1/2)))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2)
%
(2*a*b*dt^2*g*(b*dt^2*sin(dt*w*(n + 1))*(F0/(a*m) - (2^(1/2)*F0)/(2*a*m)) -
dt^2*sin(dt*n*w)*(F0/(a*m) - (2^(1/2)*F0)/(2*a*m))*(b - 1/2)))/(a^2 +
4*a*b*dt^2*g + 2*b^2*dt^4*g^2) - ((a^2 + 2*b*g*a*dt^2)*(b*dt^2*sin(dt*w*(n +
1))*(F0/(a*m) - (2^(1/2)*F0)/(a*m)) - dt^2*sin(dt*n*w)*(F0/(a*m) -
(2^(1/2)*F0)/(a*m))*(b - 1/2)))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2)
%  dt*r*sin(dt*w*(n + 1))*(F0/(a*m) - (2^(1/2)*F0)/(2*a*m)) - (2*(b*r*dt^3*g^2
+ a*r*dt*g)*(b*dt^2*sin(dt*w*(n + 1))*(F0/(a*m) - (2^(1/2)*F0)/(2*a*m)) -
dt^2*sin(dt*n*w)*(F0/(a*m) - (2^(1/2)*F0)/(2*a*m))*(b - 1/2)))/(a^2 +
4*a*b*dt^2*g + 2*b^2*dt^4*g^2) - dt*sin(dt*n*w)*(F0/(a*m) -
(2^(1/2)*F0)/(2*a*m))*(r - 1) - (a*dt*g*r*(b*dt^2*sin(dt*w*(n + 1))*(F0/(a*m)
- (2^(1/2)*F0)/(a*m)) - dt^2*sin(dt*n*w)*(F0/(a*m) - (2^(1/2)*F0)/(a*m))*(b -
1/2)))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2)
%    (2*(b*r*dt^3*g^2 + a*r*dt*g)*(b*dt^2*sin(dt*w*(n + 1))*(F0/(a*m) -
(2^(1/2)*F0)/(a*m)) - dt^2*sin(dt*n*w)*(F0/(a*m) - (2^(1/2)*F0)/(a*m))*(b -
1/2)))/(a^2 + 4*a*b*dt^2*g + 2*b^2*dt^4*g^2) - dt*r*sin(dt*w*(n + 1))*(F0/(a*m)
- (2^(1/2)*F0)/(a*m)) + dt*sin(dt*n*w)*(F0/(a*m) - (2^(1/2)*F0)/(a*m))*(r - 1)
+ (2*a*dt*g*r*(b*dt^2*sin(dt*w*(n + 1))*(F0/(a*m) - (2^(1/2)*F0)/(2*a*m)) -
dt^2*sin(dt*n*w)*(F0/(a*m) - (2^(1/2)*F0)/(2*a*m))*(b - 1/2)))/(a^2 +
4*a*b*dt^2*g + 2*b^2*dt^4*g^2)
```

1.2

```
m=2;a=0.5;g=9.81;F0=20;
w=2*pi;b=0;r=0.5;

d=[];
for dt=[0:0.001:1]
d=[d,max(abs(eig(eval(M1))))];
end

dt=[0:0.001:1];
plot(dt, d,'b');
title('Module de valeur propre de différant pas');

% On peut constaterque quand le pas est inférieure a 0.24, tous les modules de valeur propre sont presque égales a 1,
%quand le pas est superieure a 0.24, les modules de valeur propre sont superieure a 1.
```



1.3

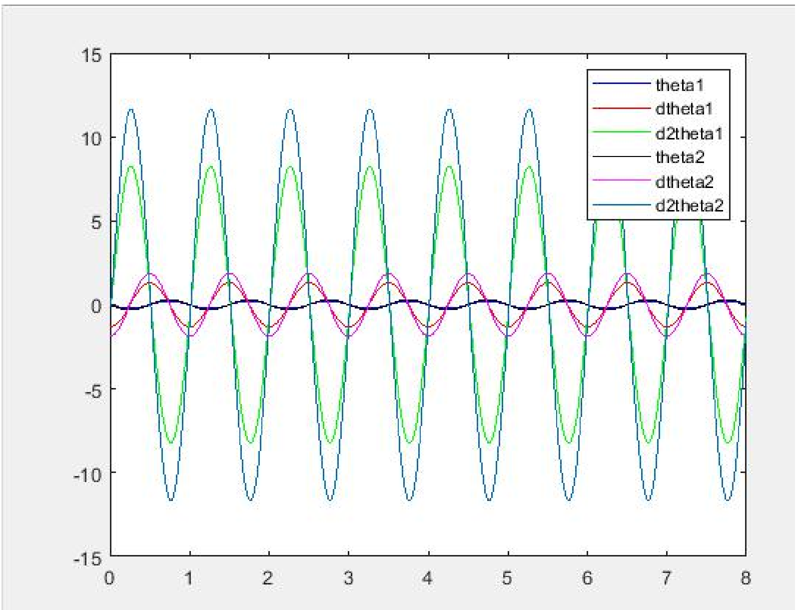
```
theta1_0 = 0;
theta2_0 = 0;
dtheta1_0 = - 1.31519275;
dtheta2_0 = - 1.85996342;

q0 = [theta1_0; theta2_0];
dq0 = [dtheta1_0; dtheta2_0];
d2q0 = eval(D) * q0;
```

1.4

```
%U=[q;dq]
%Un_1=M1*Un+M2,
%d2q=D*q+E*sin(w*t).
```

1.5

```
T0=8;dt=0.02;U=[q0;dq0];
q=[q0];
dq=[dq0];
d2q=[d2q0];
for n=0:(T0/dt-1)
U=eval(M1)*U+eval(M2);
q=[q,U(1:2)];
dq=[dq,U(3:4)];
d2q=[d2q,eval(D*U(1:2)+E*sin(w*n*dt))];
end
t=(0:(T0/dt))*dt;
plot(t,q(1,:),'b');
hold on
plot(t,dq(1,:),'r');
hold on
plot(t,d2q(1,:),'g');
hold on
plot(t,q(2,:),'k');
hold on
plot(t,dq(2,:),'m');
hold on
plot(t,d2q(2,:));
legend('theta1','dtheta1','d2theta1','theta2','dtheta2','d2theta2')
```

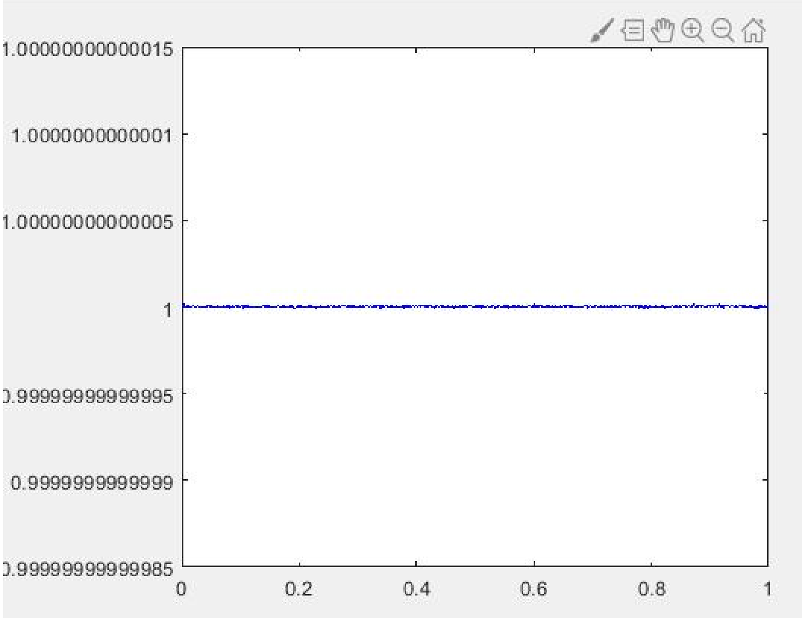


1.6

```
q(:,1:3);%les valeurs de q a 0s , dt , 2dt sont respectivement
       % 0   -0.0263   -0.0522
       % 0   -0.0372   -0.0738
q(:,0.5/dt+1);%le valeur de q a 0.5s est
           % 1.0e-03 *

            %-0.2988
            %-0.4226
dq(:,1:3);%les valeurs de dq a 0s , dt , 2dt sont respectivement
        %-1.3152   -1.3048   -1.2739
        %-1.8600   -1.8453   -1.8016

dq(:,0.5/dt+1);%le valeur de dq a 0.5s est
            %1.3143
            %1.8587
d2q(:,1:3);%les valeurs de d2q a 0s , dt , 2dt sont respectivement
        %0    0.3023    1.3340
        %0    0.4275    1.8866
d2q(:,0.5/dt+1)%le valeur de d2q a 0.5s est
             %0.7376
             %1.0432
```

2.1 et 2.2

```
%% 2.1
% c'est la même matrice que l'exercice 1.1
%% 2.2
b=0.25;
d=[];
for dt=[0:0.001:1]
    d=[d,max(abs(eig(eval(M1))))];
end

dt=[0:0.001:1];
plot(dt,d,'b');
%title('Le module de valeur propre de différant pas');

% On peut conclure que le module de valeur propre presque toujours egale a 1.
```



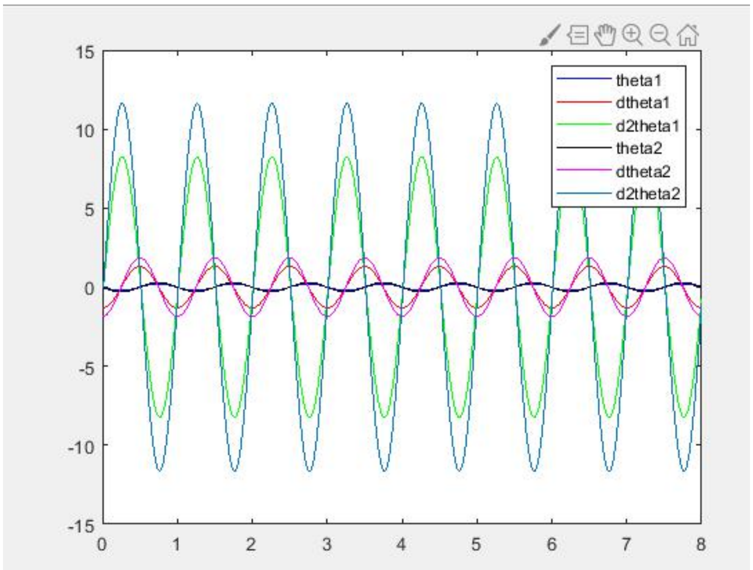
2.3 et 2.4

```
%% 2.3
% U=[q;dq]
% Un_1=M1*Un+M2,d2q=D*q+E*sin(w*t).
%% 2.4
% Un1 = A * Un + B
```

2.5

```
T0=8;dt=0.02;U=[q0;dq0];
q=[q0];dq=[dq0];d2q=[d2q0];
for n=0:(T0/dt-1)
    U=eval(M1)*U+eval(M2);
    q=[q,U(1:2)];
    dq=[dq,U(3:4)];
```

```
    d2q=[d2q,eval(D*U(1:2)+E*sin(w*n*dt))];
end
t=(0:(T0/dt))*dt;
plot(t,q(1,:),'b');
hold on
plot(t,dq(1,:),'r');
hold on
plot(t,d2q(1,:),'g');
hold on
plot(t,q(2,:),'k');
hold on
plot(t,dq(2,:),'m');
hold on
plot(t,d2q(2,:));
legend('theta1','dtheta1','d2theta1','theta2','dtheta2','d2theta2')
```



2.6

```
q(:,1:3); %les valeurs de q a 0s , dt , 2dt sont respectivement
        %0   -0.0262   -0.0520
        %0   -0.0371   -0.0735
q(:,0.5/dt+1);%le valeur de q a 0.5s est
            %-0.0009
            %-0.0013
dq(:,1:3);%les valeurs de dq a 0s , dt , 2dt sont respectivement
        %-1.3152   -1.3048   -1.2739
        %-1.8600   -1.8453   -1.8016
dq(:,0.5/dt+1) %le valeur de dq a 0.5s est
             %1.3124
             %1.8561
```

Oscillateur non lineaire a un degre de liberte

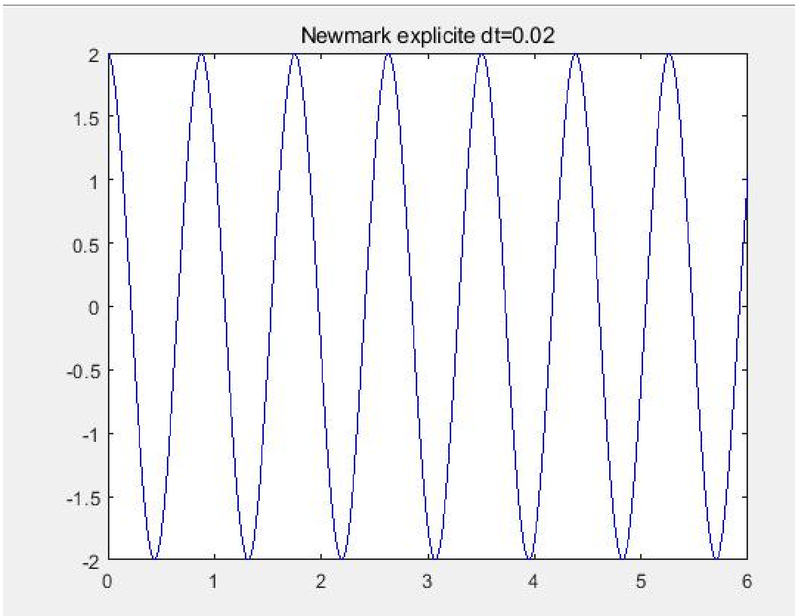
1.1

```
q0=2;
dq0=0;
w0=2*pi;
a=0.1;
ddq0=-w0^2*q0*(1+a*q0^2);
T0=6;
r1=0.5;b1=0;
%selon les relations (2),(4),(5),on a:
% q1(inc+1) = q1(inc) + dt1 * dq1(inc)+ dt1*dt1*0.5*ddq1(inc)
% ddq1(inc+1)=- w0^2*q1(inc+1)*(1+a*q1(inc+1)^2)
% dq1(inc+1) = dq1(inc) +0.5*dt1 * (ddq1(inc) + ddq1(inc+1))
```

1.2 et 1.3

```
dt1 =0.02;
t1 =(0:dt1:T0)';
np1=size(t1,1);
q1=zeros(np1,1);
dq1=zeros(np1,1);
ddq1=zeros(np1,1);
energ1=zeros(np1,1);

q1(1)=q0;
dq1(1)=dq0;
ddq0c=ddq0;
energ1(1)=0.5*dq1(1)^2 + 0.5*w0*w0*q1(1)*q1(1)+0.25*a*w0*w0*q1(1)^4;

for inc =2:np1
    q1(inc)=q1(inc-1)+dt1*dq1(inc-1)+dt1*dt1*0.5*ddq0c;
    ddqc=-w0^2*q1(inc)*(1+a*q1(inc)^2);
    dq1(inc)=dq1(inc-1)+0.5*dt1*(ddq0c+ddqc);
    ddq0c=ddqc;

energ1(inc)=0.5*dq1(inc)^2+0.5*w0*w0*q1(inc)*q1(inc)+0.25*a*w0*w0*q1(inc)^4;
end
%plot(t1,q1,'b')
plot(t1,energ1,'r')
title('Newmark explicite dt=0.02')
q1(1)%=2
q1(2)%=1.9779
q1(3)%=1.9123
```

```
q1(np1)%=1.0329
```



2.1

```
%on cherche a minimiser le residu, ce qui egal a
%abs(ddq+w0^2*q*(1+a*q^2))
```

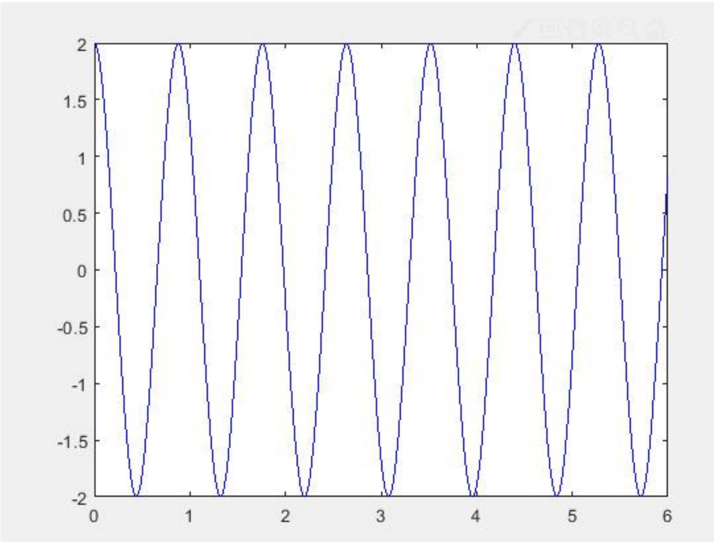
2.2

```
ddq*(j+1)=ddq*(j+1)+deltaddq(j+1);
f(ddq*(j+1),q*(j+1))=ddq*+w0^2*(q*)*(1+a*(q*)^2);
deltaddq(j+1)=-f(ddq*(j+1),q*(j+1))/(df/d(ddq*(j+1))+df/dq*(j+1)*b*dt^2);
```

2.3 et 2.4

```
r2=0.5;b2=0.25;
q2=zeros(np1,1);
dq2=zeros(np1,1);
ddq2=zeros(np1,1);
energ2=zeros(np1,1);
q2(1)=q0;
dq2(1)=dq0;
ddq2(1)=ddq0;
energ2(1)= 0.5*dq2(1)^2 + 0.5*w0*w0*q2(1)*q2(1)+0.25*a*w0*w0*q2(1)^4;
for inc=2:np1
    q2(inc)=q2(inc-1)+dt1*dq2(inc-1)+dt1*dt1*(0.5-b2)*ddq2(inc-1);
    dq2(inc)=dq2(inc-1)+dt1*(1-r2)*ddq2(inc-1);
    ddq2(inc)=0;

ddq2c=(-(ddq2(inc)+w0*w0*q2(inc)*(1+a*q2(inc)*q2(inc))))/(1+b2*dt1*dt1*(w0*w
0+3*w0*w0*a*q2(inc)*q2(inc)));
    dq2c=r2*dt1*ddq2c;
```

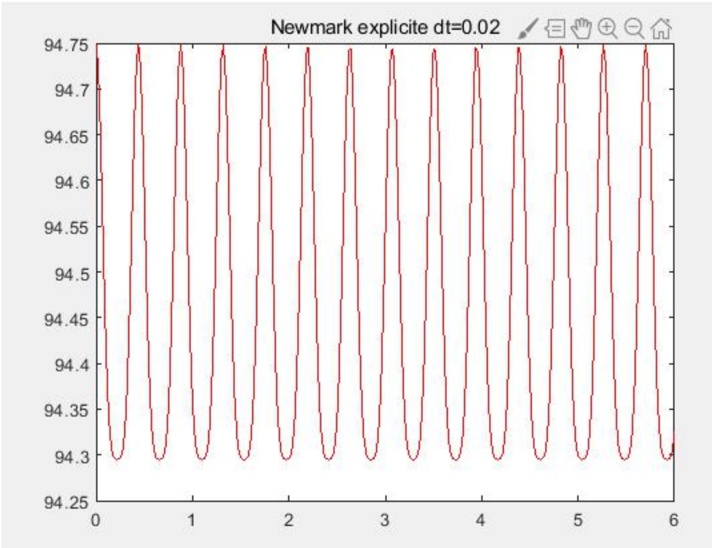
```
    q2c=b2*dt1*dt1*ddq2c;
    q2(inc)=q2(inc)+q2c;
    dq2(inc)=dq2(inc)+dq2c;
    ddq2(inc)=ddq2(inc)+ddq2c;
    energ2(inc)= 0.5*dq2(inc)^2 +
0.5*w0*w0*q2(inc)*q2(inc)+0.25*a*w0*w0*q2(inc)^4;
end
% figure(1)
% plot(t1,q2,'b')
% figure(2)
% plot(t1,dq2,'r')
% figure(3)
% plot(t1,ddq2,'g')
plot(t1,energ2,'r')
q2(1)%=2
q2(2)%=1.9781
q2(3)%=1.9131
q2(np1)%=0.8478
```



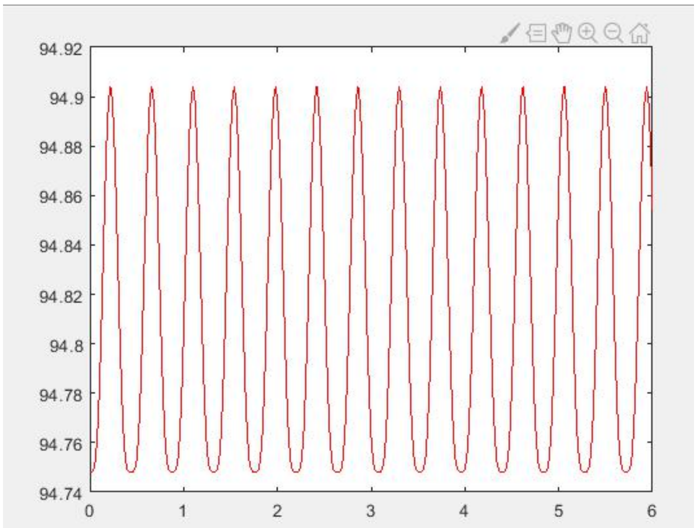
3.1(a la fin des pages)

3.2

Les programme sont comme indiques le 1.2 et 2.3



Newmark explicite dt=0.02
94.75
94.7
94.65
94.6
94.55
94.5
94.45
94.4
94.35
94.3
94.25
0
1
2
3
4
5
6



94.92
94.9
94.88
94.86
94.84
94.82
94.8
94.78
94.76
94.74
0
1
2
3
4
5
6

3.1

$$E_c = \frac{1}{2} m \dot{q}^2$$

$$E_p = \left|\int F\, dq\right|$$

avec $F = -kq(1 + aq^2) = -kq - akq^3$

donc $E_p = \left|-\frac{k}{2}q^2 - \frac{ak}{4}q^4\right| + cte$

$$= \frac{k}{2}q^2 + \frac{ak}{4}q^4 + cte$$

donc $E = E_c + E_p = \frac{1}{2}m\dot{q}^2 + \frac{1}{2}kq^2 + \frac{1}{4}kaq^4 + cte$

$\Rightarrow \frac{E}{m} = \frac{1}{2}\dot{q}^2 + \frac{1}{2}\frac{k}{m}q^2 + \frac{1}{4}\frac{k}{m}aq^4 + cte$

$$= \frac{1}{2}\dot{q}^2 + \frac{1}{2}w_0^2 q^2 + \frac{1}{4}w_0^2 a q^4 + cte$$