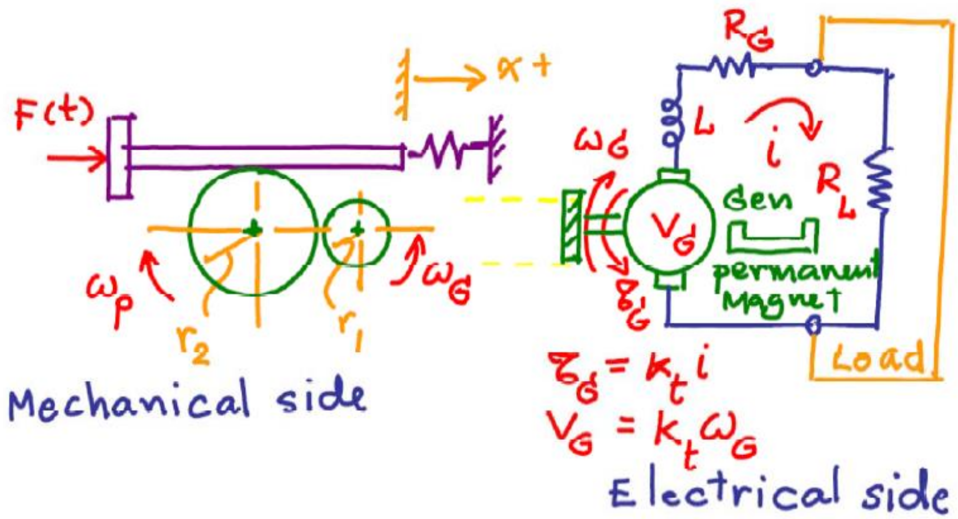
Saeth Wannasuphoprasit 5930504121

Thitiwat Hannarong 5930141021

Project assignment 1 Genpath Simulation

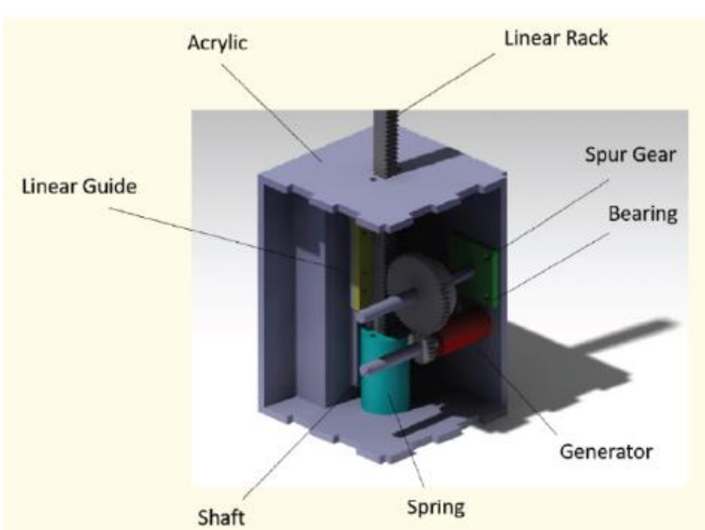


Picture A

Objective: Optimize the energy generation of the system with the maximum RL and study effects of parameters that impact the energy generation

1.Principle

From picture A, when apply F(t), which is the stomp force of the user, the purple rack will rotate the pinion r2. Then the pinion r2 will rotate the pinion r1 resulting in power generation at RL from the DC generator.



1. Basic equations (from picture A)

$x_1 = x$ and $x_2 = \dot{x}$ $\quad M = (m + \frac{J_p}{r_2^2} + \frac{J_G}{r_1^2})$.

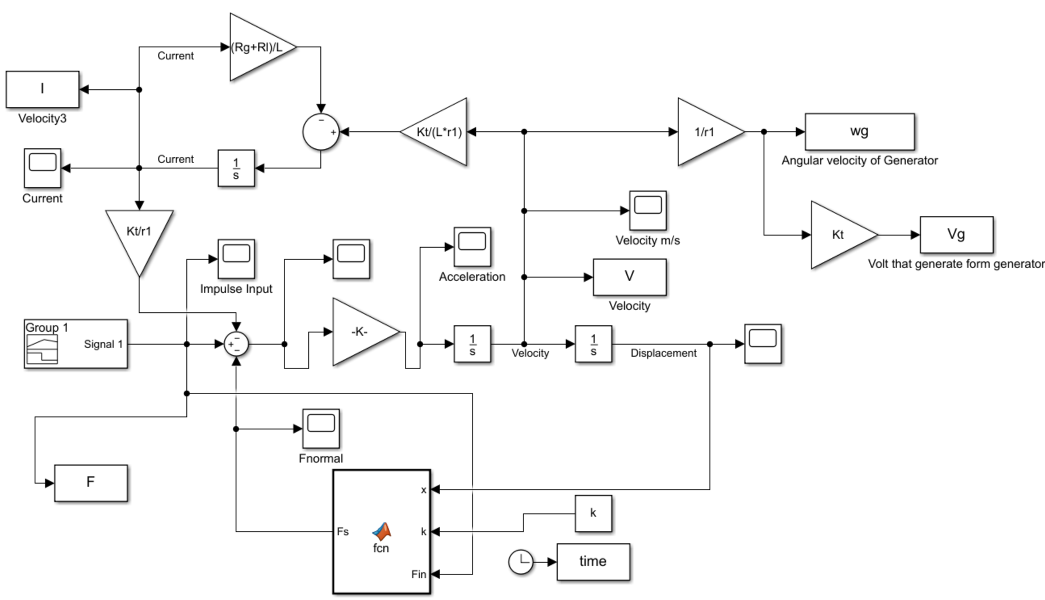
$$\frac{d}{dt}\begin{pmatrix} i \\ x_1 \\ x_2 \end{pmatrix} = \begin{bmatrix} -\left(\frac{R_G + R_L}{L}\right) & 0 & \frac{K_t}{Lr_1} \\ 0 & 0 & 1 \\ \frac{-K_t}{Mr_1} & 0 & 0 \end{bmatrix}\begin{pmatrix} i \\ x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ \frac{-F_s + F(t)}{M} \end{pmatrix}$$

Assumption: Both pinions are made from the same material.

So, M = `m+(a*r2^2)+(a*r1^2); a = Jp/r2^4`

Lists of parameters/ I : current (Amp) , X : distance (m) , Rg : resistance in DC generator (ohm) , RL : resustance in Load (ohm) , L : inductor (H) , Kt ; DC generator constant (Vs/Rad) , r1 : pinion radius (m) , r2 : DC generator radius (m) , m : mass of rack (kg) , Jp : moment of inertia of pinion (kg m^2) , Jg : moment of inertia of DC generator. Fs : spring force (N) = k*X ; k = spring stiffness (N/m) , F(t) : external force (N)

2. Simulink construction



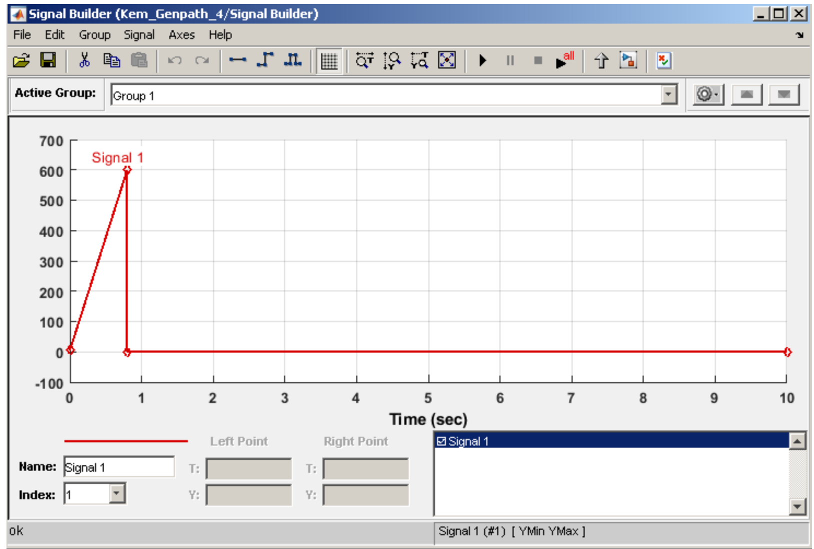
Note that the gain K is 1/(m+(a*r2^2)+(a*r1^2)) and F(s) is k*X when x<20mm, Fs = F when x>=20mm.

Additionally, F is a Ramp function with magnitude of 600 N within 0.8 sec.

```
function Fs = fcn(x,k,Fin)

if (x<0.02)
    Fs = k*x;
else
    Fs = Fin;
end
```

(ฟังชั่น FS)



(Ramp F(t))

3.Matlab program

We vary parameters to see trends of the power at RL as describe below.

3.1 Define initial parameters which are close to the real world situation

```
clear all;
close all;
clc;
```

Set Parameter

```
r1 = 0.75*10^-2 ; % m
r2 = 3*10^-2 ;  % m
k = 350  ; % N/m
Jp = 10^(-5) ; % kg*m^2
m = 0.16 ; % kg
Rg = 50 ; % Ohm
L = 1*10^-3 ;% H
Kt = 0.048 ;% V*s/rad
```

```
%J = 1/8*p*L*D^4 so Jg = Jp*(r1^4/r2^4) , J = a* r^4 ; a = 1/(2^7)*p*L Assume L
% is equivalent
Jg = Jp*(r1^4/r2^4) ; % N/m^2
a = Jp/r2^4 ;

%Assume
Rl = 500 ; % Ohm
% M from paper
M = m+((Jp)/(r2^2))+((Jg)/(r1^2)) ; % kg
M = m+((a*r2^4)/(r2^2))+((a*r1^4)/(r1^2)) ; % kg
M = m+(a*r2^2)+(a*r1^2) ; % kg
```

3.2 Run Simulink to calculate power at RL (I rms ^2 * RL)

Run Simulink

```
t = linspace(0,0.8,1000) ;
sim('Kem_Genpath_4',t);
```

Calculate Power Output

```
%Vg = Kt*wg; % Volt
Irms = rms(I); % Amp
Pavg = Irms^2*Rl; % Watt
fprintf('Power generate = %6.8f Watt\n',Pavg);
```

```
Power generate = 0.16712825 Watt
```

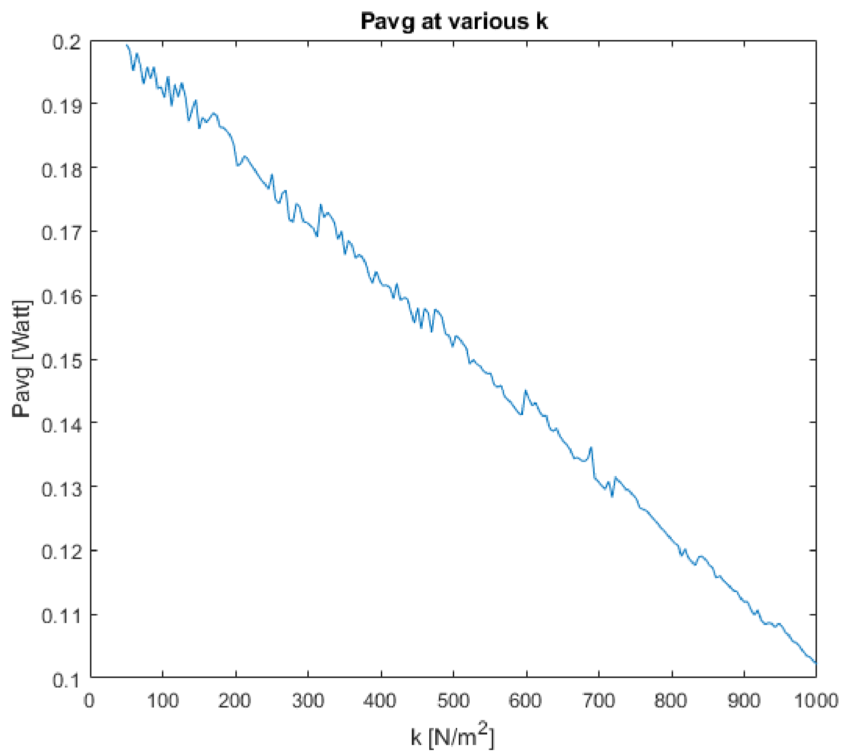
3.3 Vary parameters to see the effect of each one in generating the power at RL (parameters of the DC generator will remain constant)

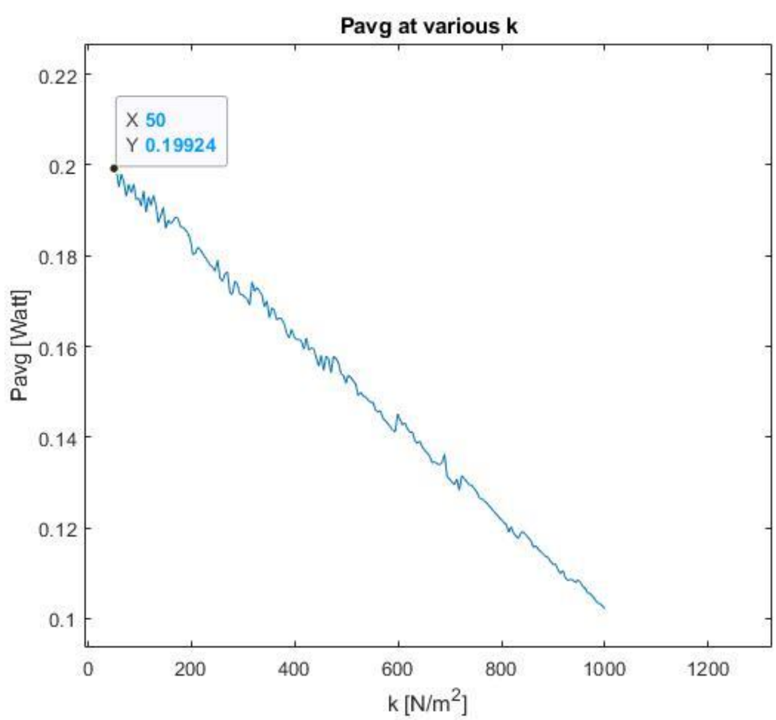
3.3.1 Vary k from 50N/m to 1000N/m m (because it is not common to find springs out of this range)

Loop for various k Assume minimum at 50 N/m

```
Pvar = 0; % For collecting Pavg
kvar = linspace(50,1000,200);
for i = 1:200
    k = kvar(i);
    sim('Kem_Genpath_4',t);
    Pvar(i) = rms(I)^2*Rl;
end
figure() ;
plot(kvar,Pvar);
xlabel('k [N/m^2]');
ylabel('Pavg [Watt]');
title('Pavg at various k');
```

```
yindex = find(Pvar==max(Pvar)) ;
k = kvar(yindex);
```



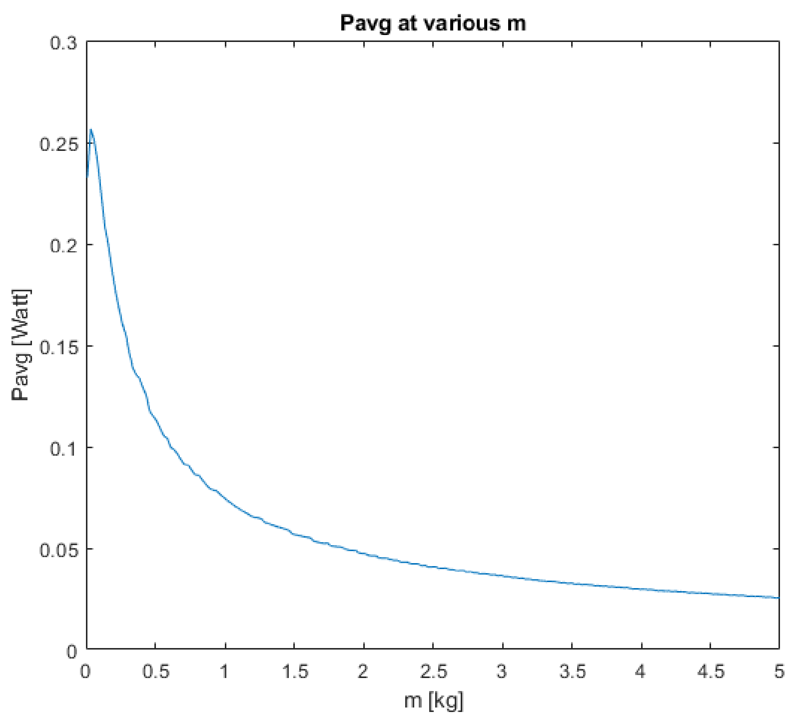


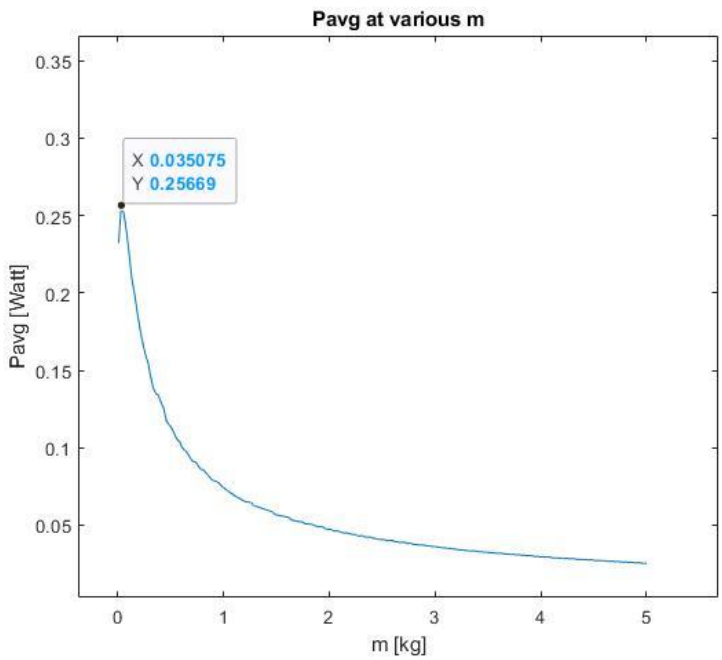
It can be seen that lower k results in more power at RL.

3.3.2 Vary m from 0.01 kg to 5 kg because racks are not that heavy (less than 5kg).

Loop for various m

```
Pvar = 0; % For collecting Pavg
mvar = linspace(0.01,5,200);
for i = 1:200
    m = mvar(i);
    sim('Kem_Genpath_4',t);
    Pvar(i) = rms(I)^2*Rl;
end
figure() ;
plot(mvar,Pvar);
xlabel('m [kg]');
ylabel('Pavg [Watt]');
title('Pavg at various m');
yindex = find(Pvar==max(Pvar)) ;
m = mvar(yindex);
```



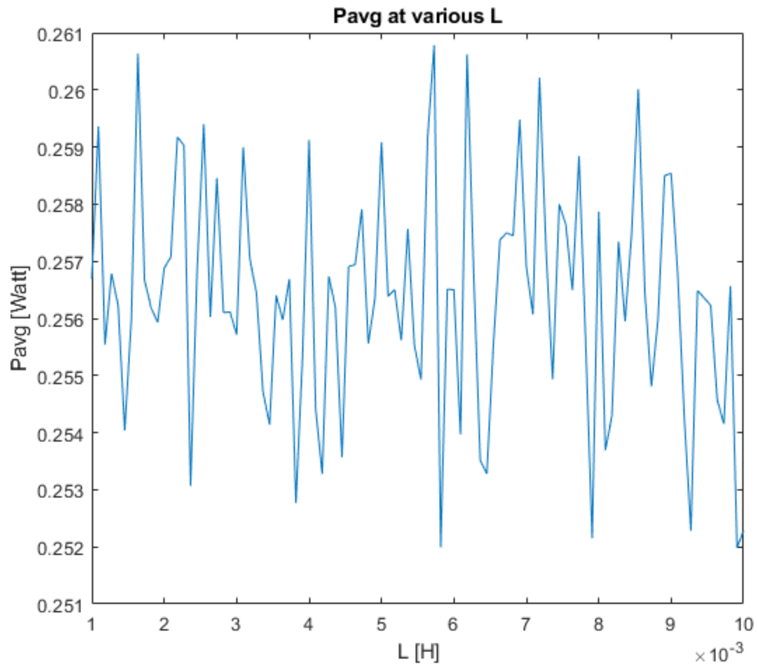


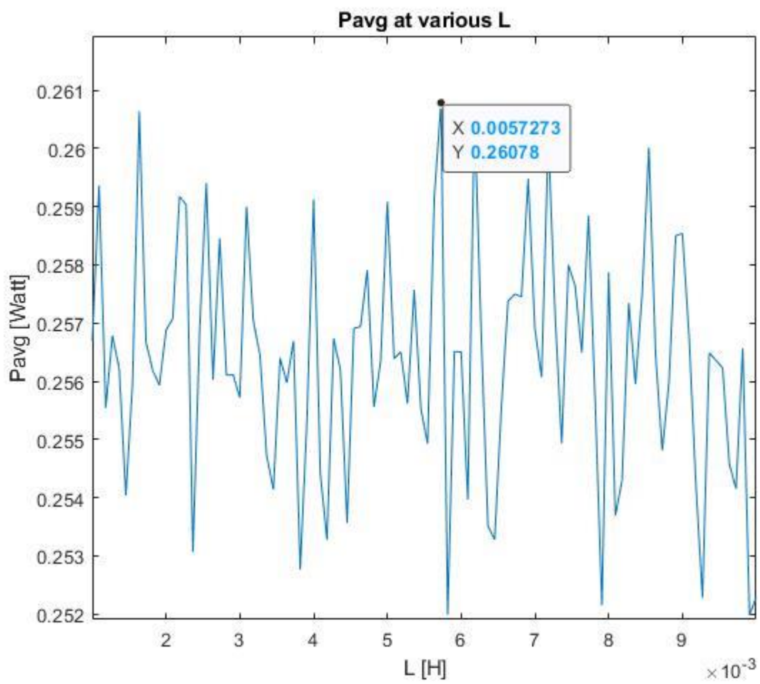
It can be seen that lower m results in more power at RL.

3.3.3 Vary L

Loop for various L

```
Pvar = 0; % For collecting Pavg
Lvar = linspace(0.001,0.01,100);
for i = 1:100
    L = Lvar(i);
    sim('Kem_Genpath_4',t);
    Pvar(i) = rms(I)^2*Rl;
end
figure() ;
plot(Lvar,Pvar);
xlabel('L [H]');
ylabel('Pavg [Watt]');
title('Pavg at various L');
yindex = find(Pvar==max(Pvar)) ;
L = Lvar(yindex);
```



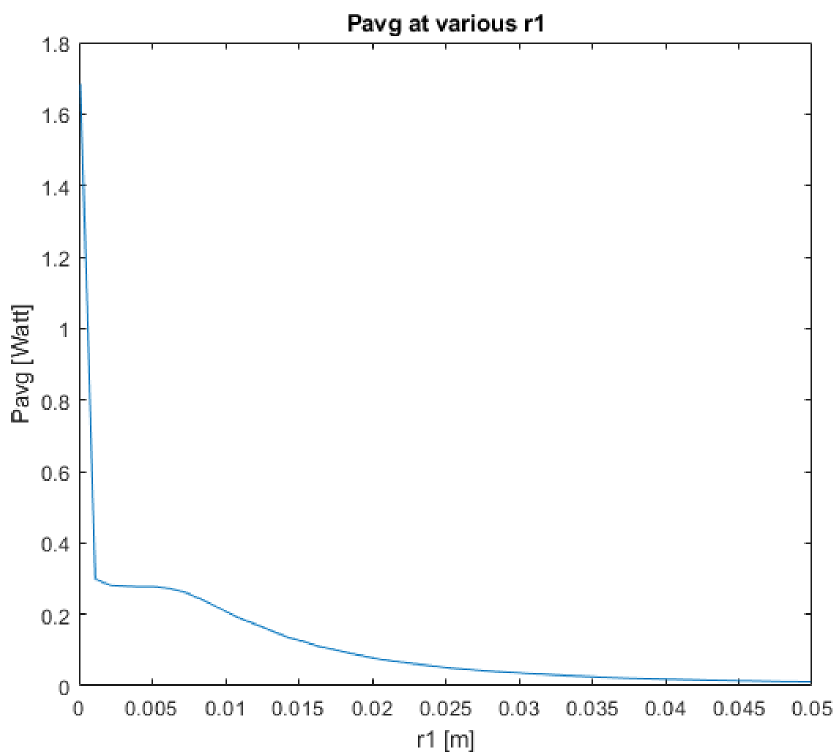


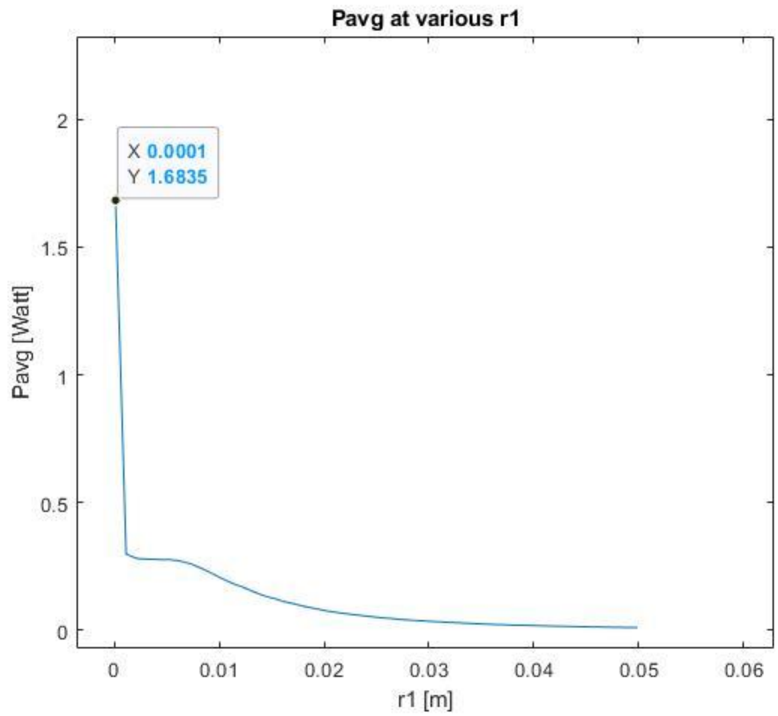
It can be concluded that there is a fluctuation in the trend of L that affects the power generation at RL. The maximum and minimum power slightly differ around 3.5% (0.26078 and 0.25211). So, we can infer that the effect of L to power generation at RL is negligible.

3.3.4 Vary r1 from 0.0001 m to 0.0499 m (this parameter is limited because of the system size: 20*10*10 cm^3)

Loop for various r1

```
Pvar = 0; % For collecting Pavg
r1var = linspace(0.0001,0.0499,50);
for i = 1:50
    r1 = r1var(i);
    sim('Kem_Genpath_4',t);
    Pvar(i) = rms(I)^2*Rl;
end
figure() ;
plot(r1var,Pvar);
xlabel('r1 [m]');
ylabel('Pavg [Watt]');
title('Pavg at various r1');
yindex = find(Pvar==max(Pvar)) ;
r1 = r1var(yindex);
```



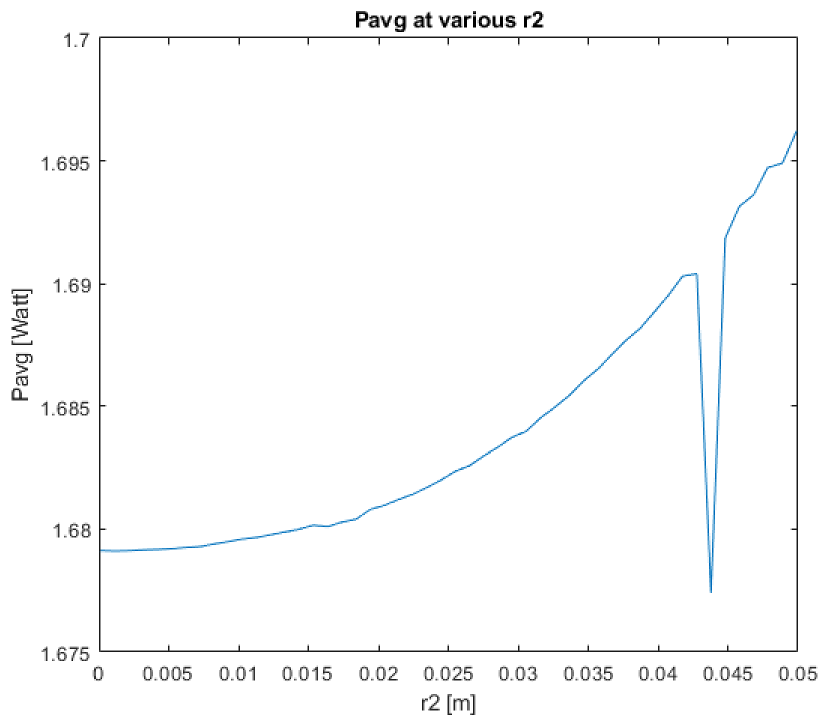


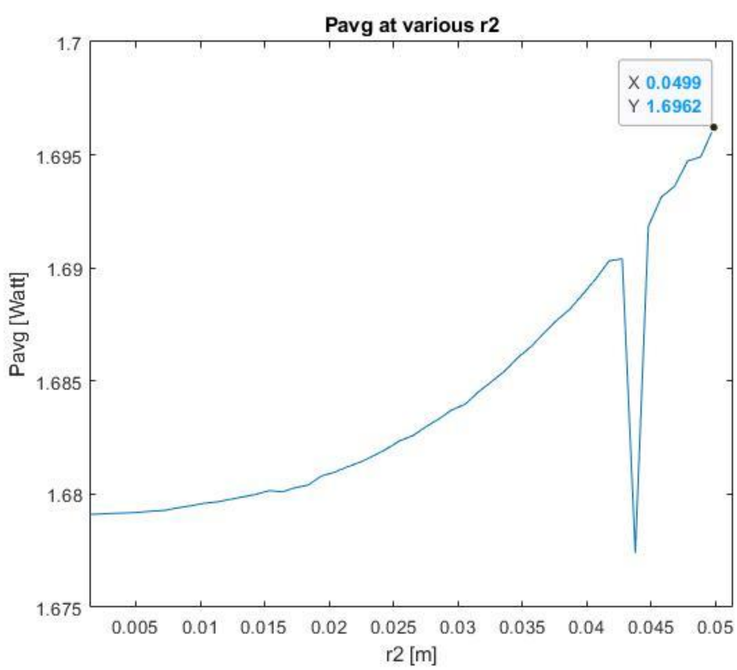
It can be seen that lower r1 results in more power at RL.

3.3.5 Vary r2 from 0.0001 m to 0.0499 m (this parameter is limited because of the system size: 20*10*10 cm^3)

Loop for various r2

```
Pvar = 0; % For collecting Pavg
r2var = linspace(0.0001,0.0499,50);
for i = 1:50
    r2 = r2var(i);
    sim('Kem_Genpath_4',t);
    Pvar(i) = rms(I)^2*Rl;
end
figure() ;
plot(r2var,Pvar);
xlabel('r2 [m]');
ylabel('Pavg [Watt]');
title('Pavg at various r2');
yindex = find(Pvar==max(Pvar)) ;
r2 = r2var(yindex);
```





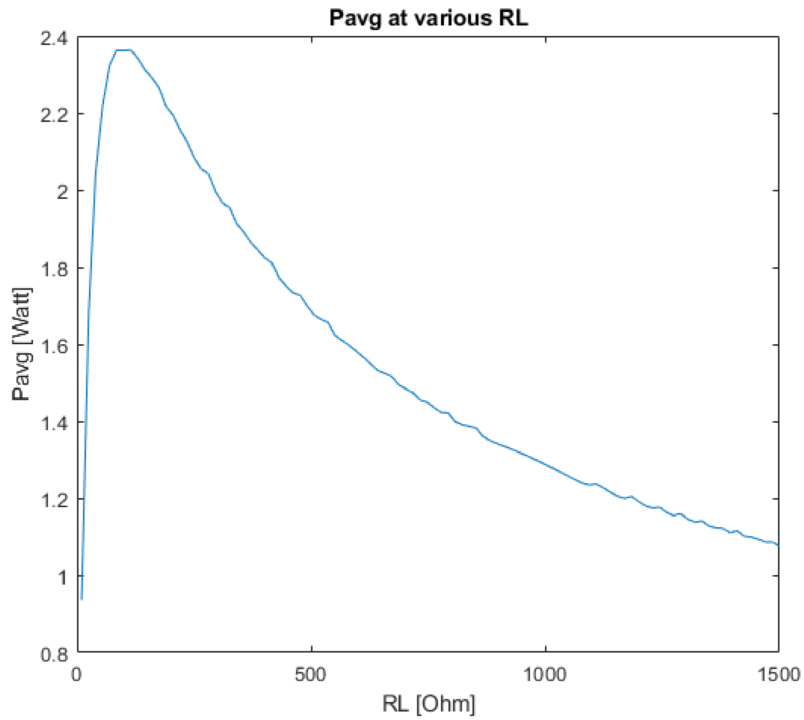
It can be seen that the more r2, the more power generation at RL.

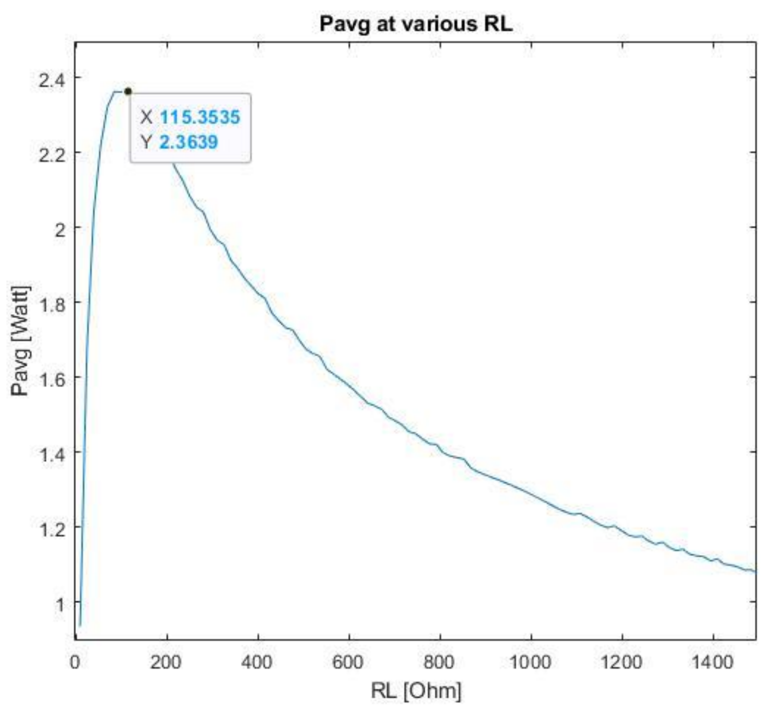
3.3.6 Vary RL from10 ohm to 1500 ohm (this range is the most common in general electric devices) with the remaining parameters equal to the values that lead to the maximum power generation at RL

Loop for various RL and optimize

```
Pvar = 0; % For collecting Pavg
Rvar = linspace(10,1500,100);
for i = 1:100
    Rl = Rvar(i);
    sim('Kem_Genpath_4',t);
    Pvar(i) = rms(I)^2*Rl;
end
figure() ;
plot(Rvar,Pvar);
xlabel('RL [Ohm]');
ylabel('Pavg [Watt]');
title('Pavg at various RL');
yindex = find(Pvar==max(Pvar)) ;
Rl = Rvar(yindex);
fprintf('Maximum Power generate = %6.8f Watt\n',max(Pvar));
fprintf('It is optimize at\n');
fprintf('Load Resistance = %6.8f Ohm\n',Rl);
fprintf('Pinion Radius = %6.8f m\n',r2);
fprintf('Pinion of Generator Radius = %6.8f m\n',r1);
fprintf('Inductance = %6.8f H\n',L);
fprintf('Mass = %6.8f kg\n',m);
fprintf('Stiffness of spring = %6.8f N/m\n',k);
```

```
Maximum Power generate = 2.36391741 Watt
It is optimize at
Load Resistance = 115.35353535 Ohm
Pinion Radius = 0.04990000 m
Pinion of Generator Radius = 0.00010000 m
Inductance = 0.00572727 H
Mass = 0.03507538 kg
Stiffness of spring = 50.00000000 N/m
```





It can be seen that the maximum power happens at the specific value of the RL which in this case is 2.3639 W when RL = 115.3535 Ohm.

4. Find RL and L by setting m = 0.01 kg , varying RL and L , others = peak

```
clear all;
close all;
clc;
```

Set Parameter

```
r1 = 0.0001 ; % m
r2 = 0.0499;  % m
r2in = 3*10^-2 ;  % m
k = 50 ; % N/m
Jpin = 10^(-5) ; % kg*m^2
m = 0.01 ; % kg
Rg = 50 ; % Ohm
L = 0.0057273;% H
Kt = 0.048 ;% V*s/rad
Rl = 115.3535; % Ohm
%J = 1/8*p*L*D^4 so Jg = Jp*(r1^4/r2^4) , J = a* r^4 ; a = 1/(2^7)*p*L Assume L
% is equivalent
a = Jpin/r2in^4;
a = 12.345679012345680;
Jp = a*r2^4 ;
Jg = Jp*(r1^4/r2^4) ; % N/m^2
% M
M = m+((Jp)/(r2^2))+((Jg)/(r1^2)) ; % kg
```

Run Simulink

```
t = linspace(0,0.8,1000) ;
sim('Kem_Genpath_4',t);
```

Calculate Power Output

```
Irms = rms(I); % Amp
Pmax = Irms^2*Rl; % Watt
```

Loop for various RL and L and optimize

```
Pvar = 0; % For collecting Pavg
Rlvar = linspace(100,150,25);
Lvar = linspace(0.001,0.01,100);
for j = 1:25
    Rl = Rlvar(j);
   for ki = 1:100
    L = Lvar(ki);
    sim('Kem_Genpath_4',t);
    Pvar(ki) = rms(I)^2*Rl;
```

```
    if Pvar(ki)> Pmax
        Pmax = Pvar(ki) ;
        Lmax = Lvar(ki) ;
        Rlmax = Rlvar(j);
    end
   end
end

fprintf('Max Power generate = %6.8f Watt\n',Pmax);
fprintf('It is optimize from Trend and Assumption  at\n');
fprintf('Load Resistance = %6.8f Ohm\n',Rlmax);
fprintf('Pinion Radius = %6.8f m\n',r2);
fprintf('Pinion of Generator Radius = %6.8f m\n',r1);
fprintf('Inductance = %6.8f H\n',Lmax);
fprintf('Mass = %6.8f kg\n',m);
fprintf('Stiffness of spring = %6.8f N/m\n',k);
```

```
Max Power generate = 2.37492664 Watt
It is optimize from Trend and Assumption  at
Load Resistance = 100.00000000 Ohm
Pinion Radius = 0.04990000 m
Pinion of Generator Radius = 0.00010000 m
Inductance = 0.00100000 H
Mass = 0.01000000 kg
Stiffness of spring = 50.00000000 N/m
```

Conclusion:

To maximize the power at RL (2.3749 W), we should tune parameters as follow: high r2 (0.0499 m), low r1 (0.0001 m), low mass of racks (0.01 kg), low k (50N/m), RL = 100 Ohm and L = 0.001 H.

Suggestions:

1. We can utilize AC generator instead of the DC one for double the power gain because of back emf from the spring force.

2. We should use light weight pinions and a generator with as low density as possible for minimizing its inertia resulting in lower rotation resistance.

3. We can parallel a capacitor in the power generation circuit for better power factor (adjust it = 1 resulting in reducing lost in L).

4. The internal resistance in the generator (Rg) should be as low as possible to increase the current in the circuit.

5. We should use a generator with Kt as high as possible for the maximum Vg.

6. The power generated per operation (2.37 W) may sound tiny. But if we install the great number of it and many people step on it regularly, we will get great amount of energy for general and emergency usages such as lighting along footpath when it is dark at night.