```
%https://www.electrical4u.com/magnetic-reluctance/
clear
filename = 'design_params_ref.xlsx';
[NUM,TXT,RAW] = xlsread(filename);
PI = pi;
for i=1:size(RAW,1)
    eval(RAW(i,1) + " = " + RAW(i,2) + ";")
    eval("valve." + RAW(i,1) + " = " + RAW(i,1) + ";")
end
clearvars -except valve
```

Modification

Sealin Surface

```
do = 0.5;
r = 0.25;
R = 0.5 * do + r;
fun = @(x) 2*pi*(sqrt(r^2 - x.^2) + R).*sqrt(r^2./(r^2 - x.^2))
```

```
fun = function_handle with value:
    @(x)2*pi*(sqrt(r^2-x.^2)+R).*sqrt(r^2./(r^2-x.^2))
```

```
S = integral(fun,0,r)
```

```
S = 1.6264
```

```
Ao = pi * do^2 / 4
```

```
Ao = 0.1963
```

```
Ap = pi * R^2
```

```
Ap = 0.7854
```

```
20.5*S
```

```
ans = 33.3412
```

```
50*Ap
```

```
ans = 39.2699
```

Magnetic Reluctance

```
rel_perm = 850
```

```
rel_perm = 850
```

```
air_perm = 1.25663753*1e-6
```

```
air_perm = 1.2566e-06
```

```
valve.perm = rel_perm * air_perm
```

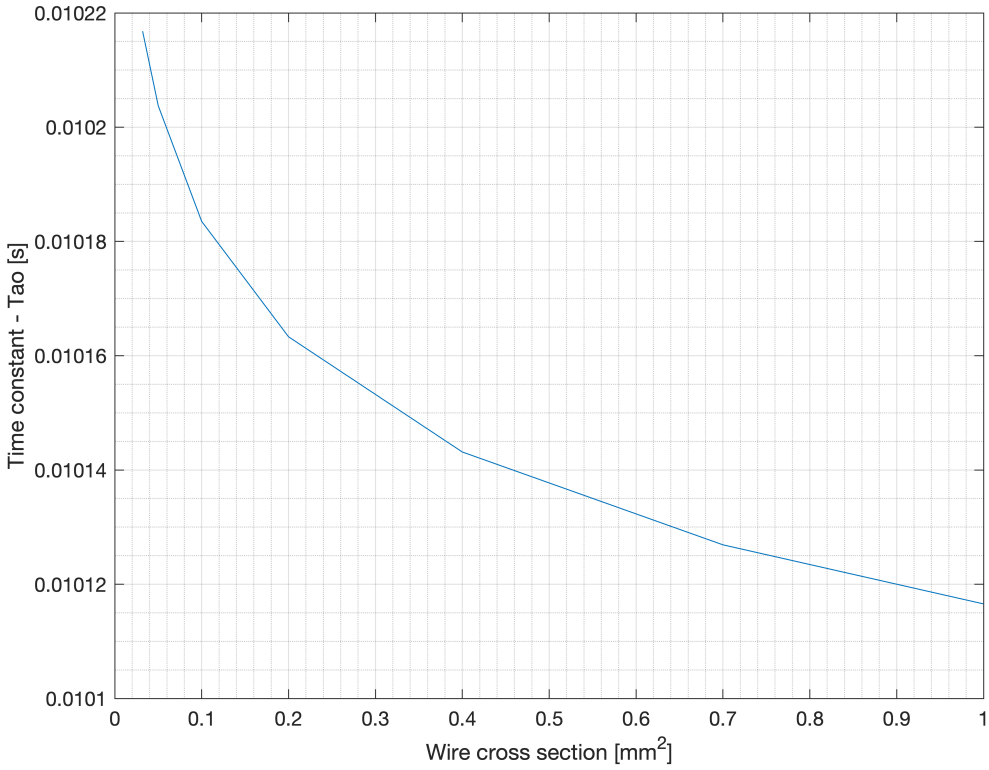
```
valve = struct with fields:
                                    rom: 0.2500
                              clearance: 0.1000
                                oring_d: 1.7800
                  face_oring_gland_depth: 1.3400
                 face_oring_groove_width: 2.1500
                          face_oring_dout: 12.8100
                     oring_groove_radius: 0.2000
                radial_oring_gland_depth: 1.2900
               radial_oring_groove_width: 2.3500
                        radial_oring_dout: 20.7300
            valve_seat_outlet_orifice_d: 0.5000
          valve_seat_outlet_orifice_rad: 0.5000
                    valve_seat_outlet_d: 20
                    valve_seat_outlet_h: 3
      valve_seat_outlet_face_oring_dout: 12.8100
       valve_seat_outlet_face_oring_din: 8.5100
         valve_seat_outlet_face_oring_h: 1.3400
                    valve_seat_inlet_h: 3
                    valve_seat_upper_h: 5
       valve_seat_upper_face_oring_dout: 12.8100
        valve_seat_upper_face_oring_din: 8.5100
          valve_seat_upper_face_oring_t: 1.3400
        valve_seat_upper_rad_oring_dout: 20.7300
         valve_seat_upper_rad_oring_din: 18.1500
           valve_seat_upper_rad_oring_t: 2.3500
                         valve_seat_h: 11
                       valve_seat_din: 6
                    valve_cone_cone_d: 4
                    valve_cone_cone_h: 3
                         valve_cone_h: 3
                    valve_cone_hole_d: 1
                   valve_cone_insert_d: 3
                   valve_cone_insert_h: 3
                         valve_spool_d: 5.9000
                         valve_spool_h: 22
                  valve_spool_insert_d: 3
                  valve_spool_insert_h: 3
                    valve_spool_hole_d: 1
                    valve_spool_hole_h: 17.6000
                  valve_spool_hole_2_d: 1
                  valve_spool_hole_2_h: 14.0800
                           coil_wire_A: 0.0500
                           coil_wire_d: 0.2523
                                coil_h: 25
                              coil_din: 9
                             coil_dout: 17
                        coil_former_din: 9
                       coil_former_dout: 17
                       coil_former_h_in: 25
                      coil_former_h_out: 33
                     coil_former_hole_d: 6
          coil_former_face_oring_dout: 12.8100
           coil_former_face_oring_din: 8.5100
             coil_former_face_oring_t: 1.3400
                 magnetic_bottom_dout: 17
                    magnetic_bottom_h: 3
                  magnetic_bottom_din: 6
        magnetic_bottom_face_oring_din: 0
       magnetic_bottom_face_oring_dout: 0
          magnetic_bottom_face_oring_t: 0
                magnetic_top_boss_dout: 6
```

```
magnetic_top_boss_din: 1.5000
  magnetic_top_boss_h: 16.5000
       magnetic_top_h: 8
    magnetic_top_dout: 20
     magnetic_top_din: 4
  magnetic_top_hole_d: 6
  magnetic_top_hole_h: 6
magnetic_top_face_oring_din: 0
magnetic_top_face_oring_dout: 0
   magnetic_top_face_oring_t: 0
                 shell_din: 17.1000
                shell_dout: 20
                   shell_h: 36
     spring_rod_long_h: 19
     spring_rod_long_d: 1.4000
    spring_rod_thick_d: 5
    spring_rod_thick_h: 1
    spring_rod_short_h: 4.5000
    spring_rod_short_d: 1.4000
         fastener_dout: 24
            fastener_h: 5
 fastener_face_oring_dout: 12.8100
  fastener_face_oring_din: 8.5100
    fastener_face_oring_t: 1.3400
                casing_din: 20.2000
                  casing_h: 60
                  casing_t: 3
          casing_thread_h: 5
                     perm: 0.0011
```

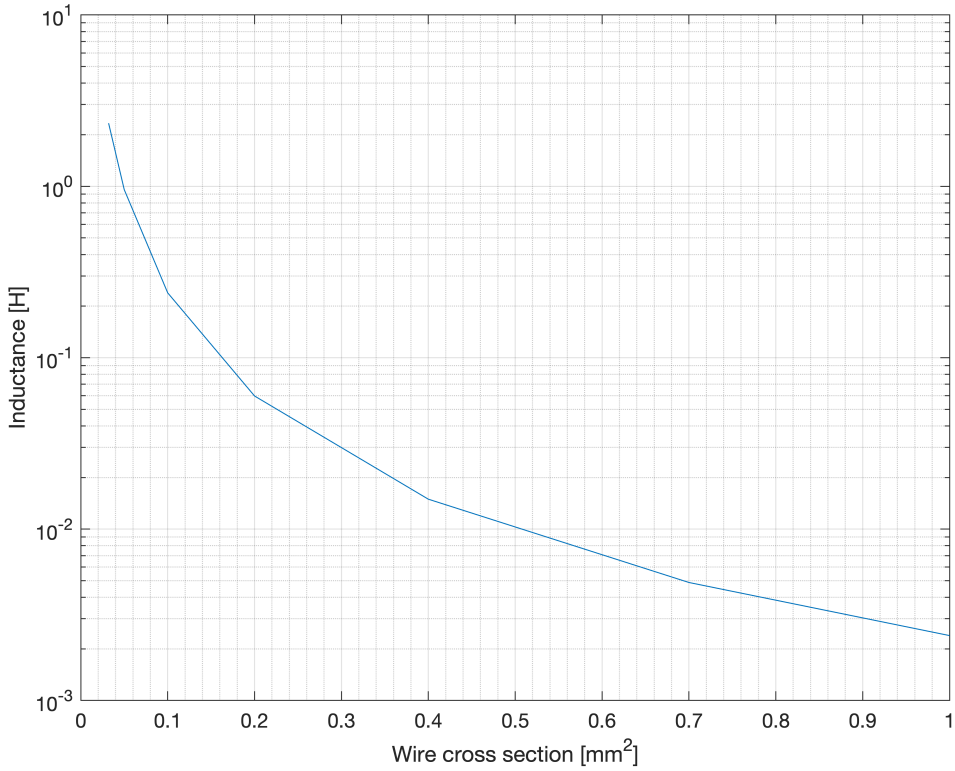
```
wire_areas = [0.032 0.05 0.1 0.2 0.4 0.7 1]; %mm^2
rec_max_A = 3.5; % A/mm2;
for i=1:length(wire_areas)
    valve.wire_area = wire_areas(i);
    [Fmag(i),N(i),wire_len(i),wire_R(i),sol_V(i),sol_P(i),L(i)] = valve_magnetic_force
end
Fmag
```

```
Fmag = 1×7
   44.1915   44.1915   44.1915   44.1915   44.1915   44.1915   44.1915
```

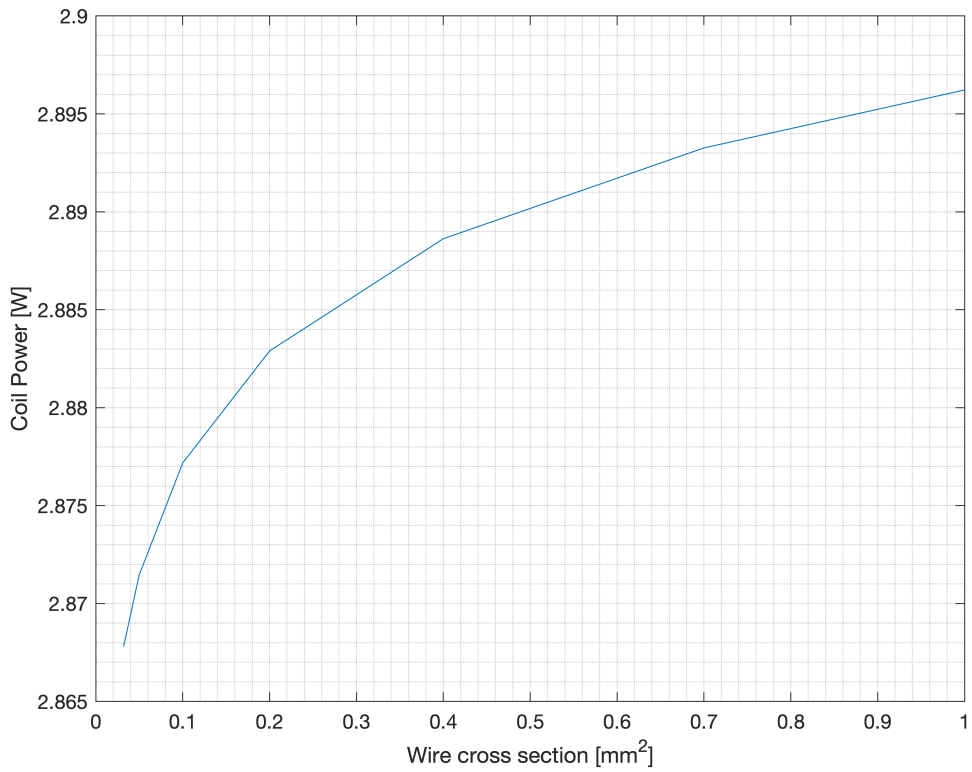
```
plot(wire_areas,L./wire_R), xlabel('Wire cross section [mm^2]'), ylabel('Time constant
```



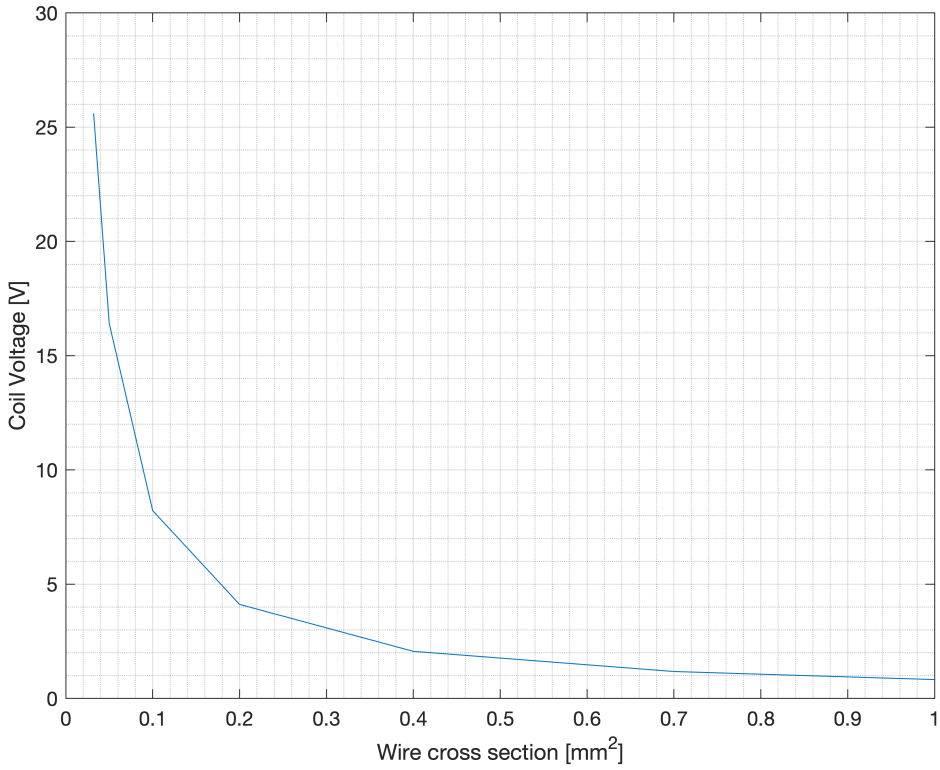

```
semilogy(wire_areas,L), xlabel('Wire cross section [mm^2]'), ylabel('Inductance [H]'),
```



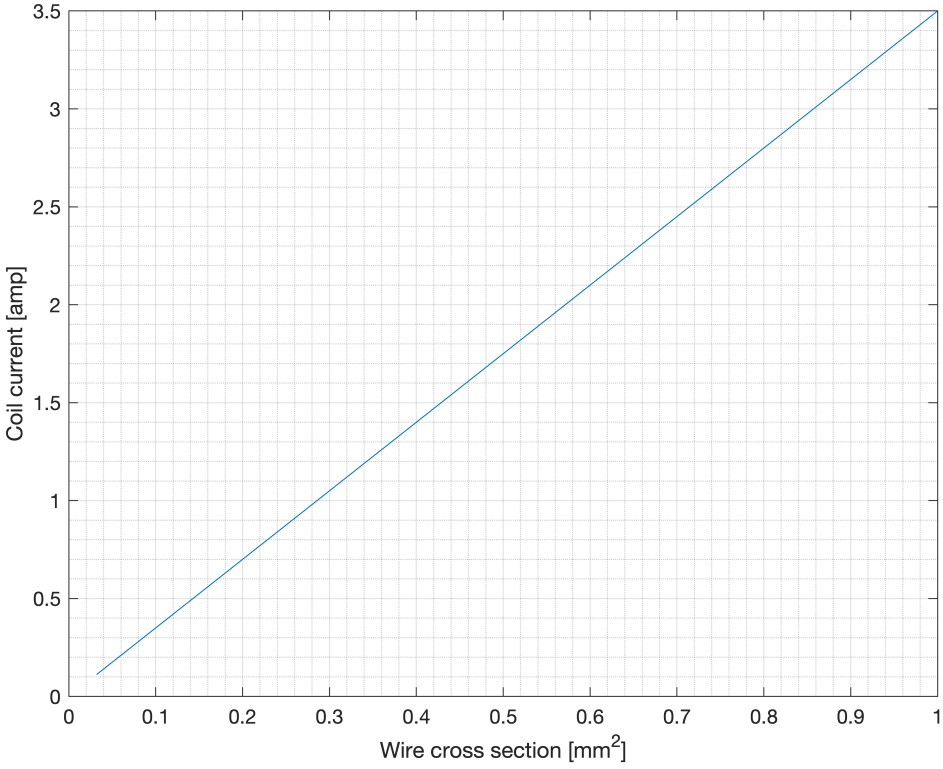
```
plot(wire_areas,sol_P), xlabel('Wire cross section [mm^2]'), ylabel('Coil Power [W]'),
```



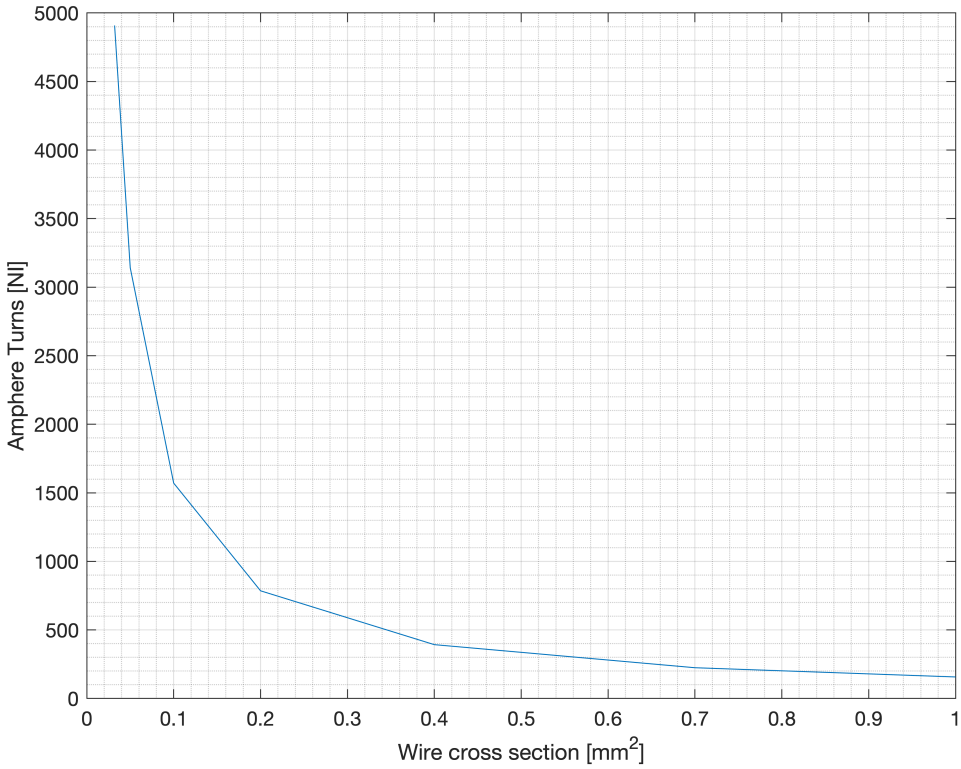

```
plot(wire_areas,sol_V), xlabel('Wire cross section [mm^2]'), ylabel('Coil Voltage [V]'
```



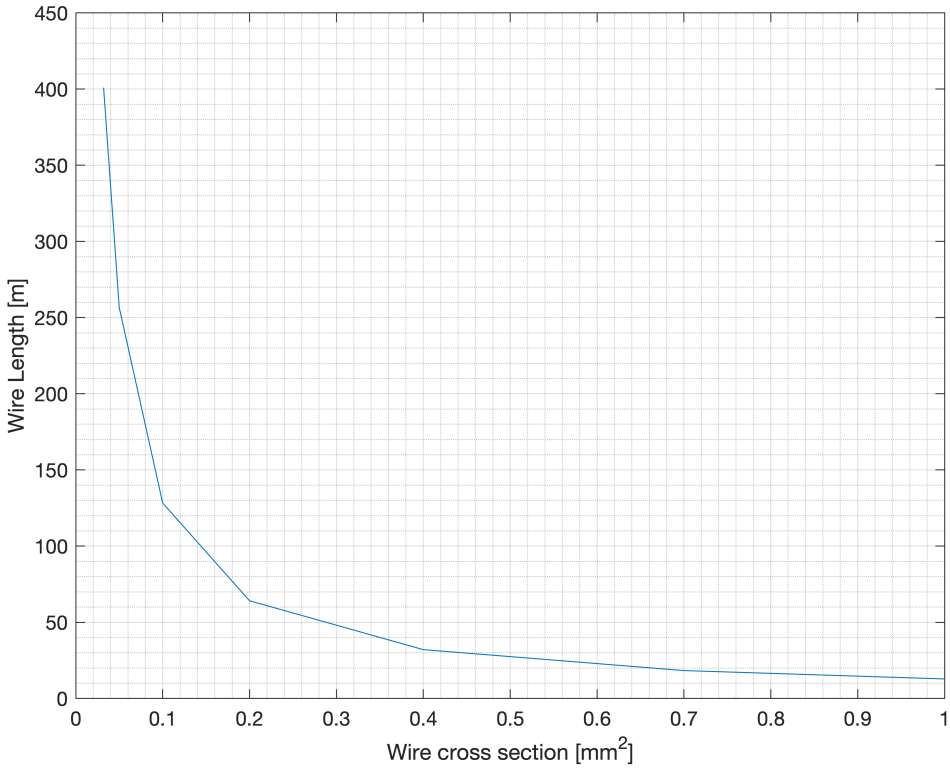

```
plot(wire_areas,sol_P./sol_V), xlabel('Wire cross section [mm^2]'), ylabel('Coil curre
```



```
plot(wire_areas,N), xlabel('Wire cross section [mm^2]'), ylabel('Amphere Turns [NI]'),
```




```
plot(wire_areas,wire_len), xlabel('Wire cross section [mm^2]'), ylabel('Wire Length [m
```




```
%plot(wire_areas,wire_R), xlabel('Wire cross section [mm^2]'), ylabel('Wire Resistance
```

0.032 mm^2 = 32AWG wire.

Dynamic model

```
% F = 0.5 * flux^2 / (Area * perm_air)
% N * i = R * flux
% L = N * flux / i
% V = L * di/dt + R * i
% tao = L / R
% V_L(t) = V * e ^ - t / tao
% I(t) = V / R * (1 - e ^ -t / tao)
wire_index = 2;
V = sol_V(wire_index) % source Voltage
```

```
V = 16.4084
```

```
R = wire_R(wire_index)
```

```
R = 93.7623
```

```
dt = 1e-6
```

```
dt = 1.0000e-06
```

```
tao = L(wire_index) / wire_R(wire_index)
```

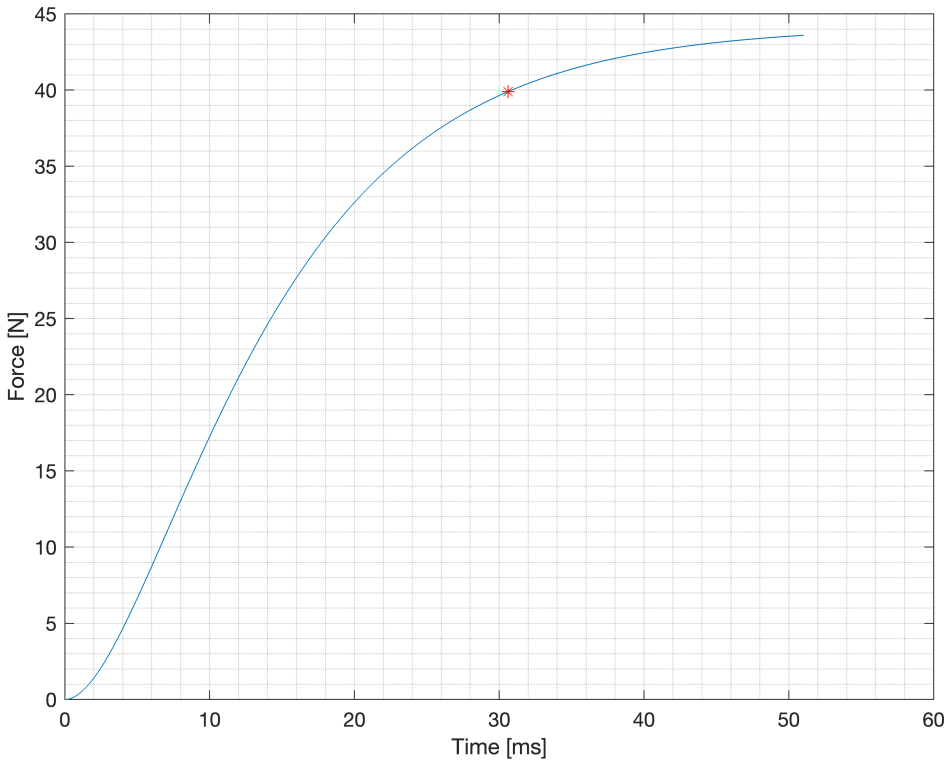
```
tao = 0.0102
```

```
valve.wire_area = wire_areas(wire_index);
```

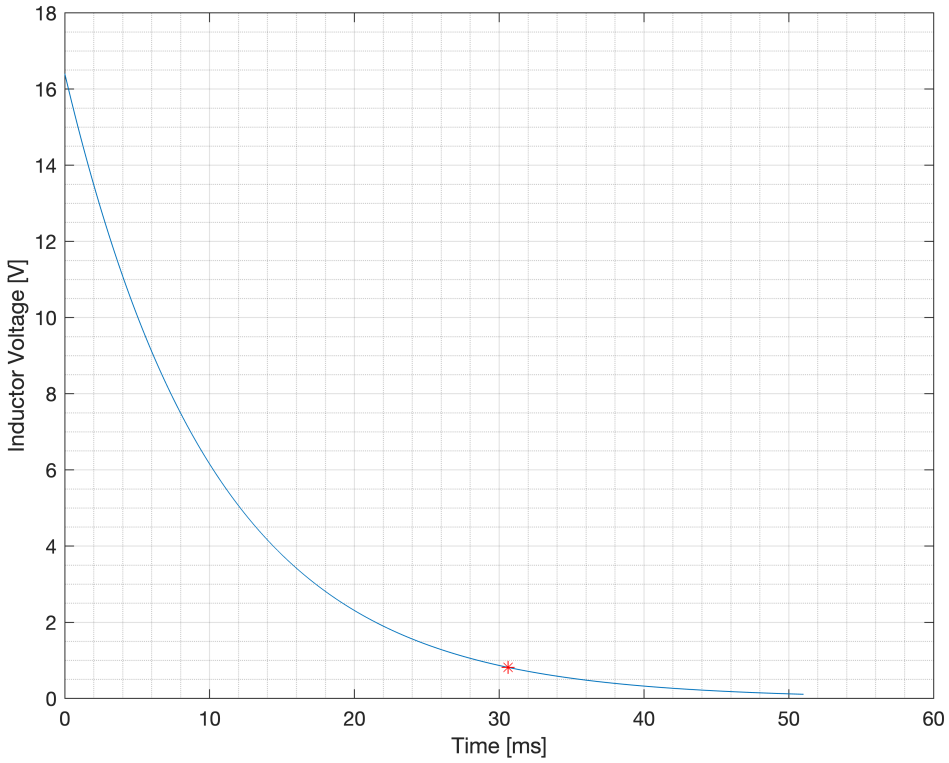
```
clearvars t V_L I Fmag sol_V sol_P L
for i=1:ceil(5*tao/dt)
    t(i) = dt * (i-1) * 1e3;
    V_L(i) = V * exp(-i*dt/tao);
    I(i) = V/R *(1 - exp(-i*dt/tao)) * 1e3;
    [Fmag(i),N,wire_len,wire_R,sol_V(i),sol_P(i),L(i)] = valve_magnetic_force(valve,va
end
tao3index = ceil(3*tao/dt);
t(tao3index)
```

```
ans = 30.6110
```

```
plot(t,Fmag,t(tao3index),Fmag(tao3index),'r*'), xlabel('Time [ms]'), ylabel('Force [N]
```




```
plot(t,V_L,t(tao3index),V_L(tao3index),'r*'), xlabel('Time [ms]'), ylabel('Inductor Vo
```




```
plot(t,I,t(tao3index),I(tao3index),'r*'), xlabel('Time [ms]'), ylabel('Current [mA]'),
```