```
%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))
end
```

```
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
```

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
```

```
perm = rel_perm * air_perm
```

```
perm = 0.0011
```

Magnetic Top

```
magnetic_top_boss_center_cylnder_r = 0.25 * (magnetic_top_boss_dout + magnetic_top_boss_din)
```

```
magnetic_top_boss_center_cylnder_r = 1.8750
```

```
shell_center_cylinder_r = 0.25 * (shell_dout + shell_din)
```

```
shell_center_cylinder_r = 9.2750
```

```
MR_volume_magnetic_top_hor_l = (shell_center_cylinder_r - magnetic_top_boss_center_cylnder_r) *
```

```
MR_volume_magnetic_top_hor_l = 0.0074
```

```
MR_volume_magnetic_top_hor_A =...
    (pi * (magnetic_top_boss_center_cylnder_r + shell_center_cylinder_r) * ... mean cylnder dia
    (magnetic_top_h - magnetic_top_hole_h)) * 1e-6
```

```
MR_volume_magnetic_top_hor_A = 7.0058e-05
```

```
MR_magnetic_top_hor = MR_volume_magnetic_top_hor_l / ( perm * MR_volume_magnetic_top_hor_A )
```

```
MR_magnetic_top_hor = 9.8889e+04
```

```
MR_volume_magnetic_top_ver_l_out = 0.5 * (magnetic_top_h - magnetic_top_hole_h) * 1e-3
```

```
MR_volume_magnetic_top_ver_l_out = 1.0000e-03
```

```
MR_volume_magnetic_top_ver_A_out = 0.25 * pi * (magnetic_top_dout^2 - shell_din^2) * 1e-6
```

```
MR_volume_magnetic_top_ver_A_out = 8.4501e-05
```

```
MR_magnetic_top_ver_out = MR_volume_magnetic_top_ver_l_out / ( perm * MR_volume_magnetic_top_ve
```

```
MR_magnetic_top_ver_out = 1.1079e+04
```

```
MR_volume_magnetic_top_ver_l_in = (MR_volume_magnetic_top_ver_l_out + magnetic_top_boss_h) * 1e
```

```
MR_volume_magnetic_top_ver_l_in = 0.0165
```

```
MR_volume_magnetic_top_ver_A_in = 0.25 * pi * (magnetic_top_boss_dout^2 - magnetic_top_boss_din
```

```
MR_volume_magnetic_top_ver_A_in = 2.6507e-05
```

```
MR_magnetic_top_ver_in = MR_volume_magnetic_top_ver_l_in / ( perm * MR_volume_magnetic_top_ver_
```

```
MR_magnetic_top_ver_in = 5.8280e+05
```

```
MR_magnetic_top = (MR_magnetic_top_hor + MR_magnetic_top_ver_out + MR_magnetic_top_ver_in)
```

```
MR_magnetic_top = 6.9277e+05
```

```
mmf = (200*0.75)*MR_magnetic_top
```

```
mmf = 1.0391e+08
```

Magnetic Bottom

```
MR_surface_magnetic_bottom_hor_l = 0.5 * (magnetic_bottom_dout - magnetic_bottom_din) * 1e-3
```

```
MR_surface_magnetic_bottom_hor_l = 0.0055
```

```
MR_surface_magnetic_bottom_hor_A = pi * 0.5 * (magnetic_bottom_dout + magnetic_bottom_din) * ma
```

```
MR_surface_magnetic_bottom_hor_A = 1.0838e-04
```

```
MR_magnetic_bottom = MR_surface_magnetic_bottom_hor_l / (perm * MR_surface_magnetic_bottom_hor_
```

```
MR_magnetic_bottom = 4.7508e+04
```

Shell

```
MR_surface_shell_hor_l = 0.5 * (shell_dout - shell_din) * 1e-3
```

```
MR_surface_shell_hor_l = 0.0014
```

```
MR_surface_shell_hor_A = pi * 0.5 * (shell_dout + shell_din) * magnetic_bottom_h * 1e-6
```

```
MR_surface_shell_hor_A = 1.7483e-04
```

```
MR_shell_hor = MR_surface_shell_hor_l / (perm * MR_surface_shell_hor_A)
```

```
MR_shell_hor = 7.7647e+03
```

```
MR_surface_shell_ver_l = (shell_h - 0.5 * magnetic_bottom_h) * 1e-3
```

```
MR_surface_shell_ver_l = 0.0345
```

```
MR_surface_shell_ver_A = pi * 0.25 * (shell_dout^2 -shell_din^2) * 1e-6
```

```
MR_surface_shell_ver_A = 8.4501e-05
```

```
MR_shell_ver = MR_surface_shell_ver_l / (perm * MR_surface_shell_ver_A)
```

```
MR_shell_ver = 3.8223e+05
```

```
MR_shell = MR_shell_ver + MR_shell_hor
```

```
MR_shell = 3.9000e+05
```

Shell - Magnetic Bottom Clearance

```
MR_surface_shell_mag_bot_hor_l = 0.5 * clearance * 1e-3
```

```
MR_surface_shell_mag_bot_hor_l = 5.0000e-05
```

```
MR_surface_shell_mag_bot_hor_A = pi * 0.5 * (shell_din + magnetic_bottom_dout) * magnetic_botto
```

```
MR_surface_shell_mag_bot_hor_A = 1.6069e-04
```

```
MR_shell_mag_bot_hor = MR_surface_shell_mag_bot_hor_l / (perm * MR_surface_shell_mag_bot_hor_A)
```

```
MR_shell_mag_bot_hor = 291.3034
```

Shell - Magnetic Top Clearance

```
%MR_surface_shell_mag_top_hor_l = 0.5 * clearance * 1e-3
%MR_surface_shell_mag_top_hor_A = pi * 0.5 * (shell_din + magnetic_top_dout)...
%    * (magnetic_top_h - magnetic_top_hole_h) * 1e-6
MR_shell_mag_top_hor = 0; %MR_surface_shell_mag_top_hor_l / (perm * MR_surface_shell_mag_top_ho
```

Gap

```
gap = rom
```

```
gap = 0.2500
```

```
MR_gap_hor_l = gap * 1e-3
```

```
MR_gap_hor_l = 2.5000e-04
```

```
MR_gap_hor_A = 0.25 * pi * (valve_spool_d^2 - magnetic_top_boss_din^2) * 1e-6
```

```
MR_gap_hor_A = 2.5573e-05
```

```
MR_gap = MR_gap_hor_l / (air_perm * MR_gap_hor_A)
```

```
MR_gap = 7.7796e+06
```

Valve Spool

```
MR_surface_valve_spool_hor_l = 0.5 * (valve_spool_d - valve_spool_hole_d) * 1e-3
```

```
MR_surface_valve_spool_hor_l = 0.0025
```

```
MR_surface_valve_spool_hor_A = pi * 0.5 * (valve_spool_d + valve_spool_hole_d) * magnetic_botto
```

```
MR_surface_valve_spool_hor_A = 3.2515e-05
```

```
MR_valve_spool_hor = MR_surface_valve_spool_hor_l / (perm * MR_surface_valve_spool_hor_A)
```

```
MR_valve_spool_hor = 7.0542e+04
```

```
MR_surface_valve_spool_ver_l = (0.5 * shell_h - gap) * 1e-3
```

```
MR_surface_valve_spool_ver_l = 0.0178
```

```
MR_surface_valve_spool_ver_A = pi * 0.25 * (valve_spool_d^2 - valve_spool_hole_d^2) * 1e-6
```

```
MR_surface_valve_spool_ver_A = 2.6554e-05
```

```
MR_valve_spool_ver = MR_surface_valve_spool_ver_l / (perm * MR_surface_valve_spool_ver_A)
```

```
MR_valve_spool_ver = 6.2580e+05
```

```
MR_valve_spool = MR_valve_spool_ver + MR_valve_spool_hor
```

```
MR_valve_spool = 6.9634e+05
```

Valve Spool - Magnetic Bottom clearance

```
MR_surface_valve_spool_magnetic_bottom_hor_l = 0.5 * clearance * 1e-3
```

```
MR_surface_valve_spool_magnetic_bottom_hor_l = 5.0000e-05
```

```
MR_surface_valve_spool_magnetic_bottom_hor_A = pi * 0.5 * (valve_spool_d + magnetic_bottom_din
```

```
MR_surface_valve_spool_magnetic_bottom_hor_A = 5.6077e-05
```

```
MR_valve_spool_magnetic_bottom_hor = MR_surface_valve_spool_magnetic_bottom_hor_l / (air_perm *
```

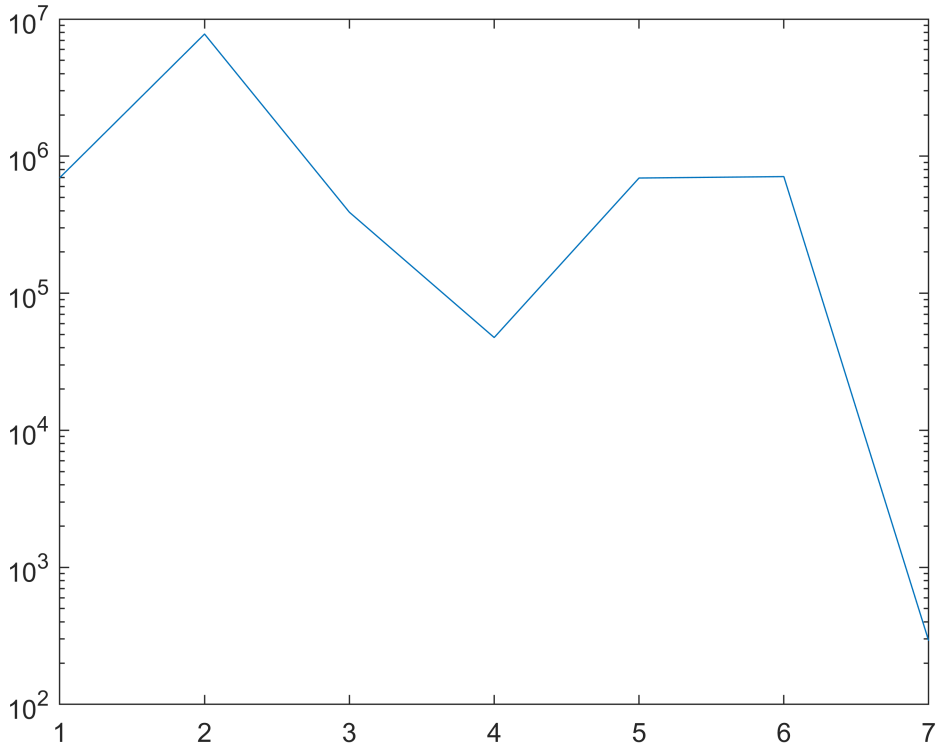
```
MR_valve_spool_magnetic_bottom_hor = 7.0953e+05
```

Total

```
MR_total = MR_valve_spool + MR_gap + MR_shell + MR_magnetic_bottom + MR_magnetic_top +...
    MR_valve_spool_magnetic_bottom_hor + MR_shell_mag_bot_hor + MR_shell_mag_top_hor
```

```
MR_total = 1.0316e+07
```

```
semilogy([MR_valve_spool,MR_gap,MR_shell,MR_magnetic_bottom,MR_magnetic_top,...
    MR_valve_spool_magnetic_bottom_hor,MR_shell_mag_bot_hor,MR_shell_mag_top_hor])
```




```
rec_max_A = 3.5; % A/mm2;
wire_areas = [0.05 0.1 0.2 0.4 0.7 1]; %mm^2
for i=1:length(wire_areas)
    wire_area = wire_areas(i)
    R_per_km = 18.426905*wire_area^-0.997135
    wire_d = 2 * sqrt(wire_area/pi);
    wire_curr_cap = rec_max_A * wire_area;
    coil_cross_section_A = (coil_dout - coil_din) * coil_h; % mm2;
    N(i) = coil_cross_section_A / wire_d^2;
    wire_len(i) = N(i) * pi * (coil_dout + coil_din) * 1e-3;
    wire_R(i) = wire_len(i) * R_per_km * 1e-3;
    sol_V(i) = wire_R(i) * wire_curr_cap;
    sol_P(i) = wire_R(i) * wire_curr_cap^2;


    flux = N(i) * wire_curr_cap / MR_total;
    Fmag = flux^2 / (air_perm * MR_gap_hor_A);
end
```

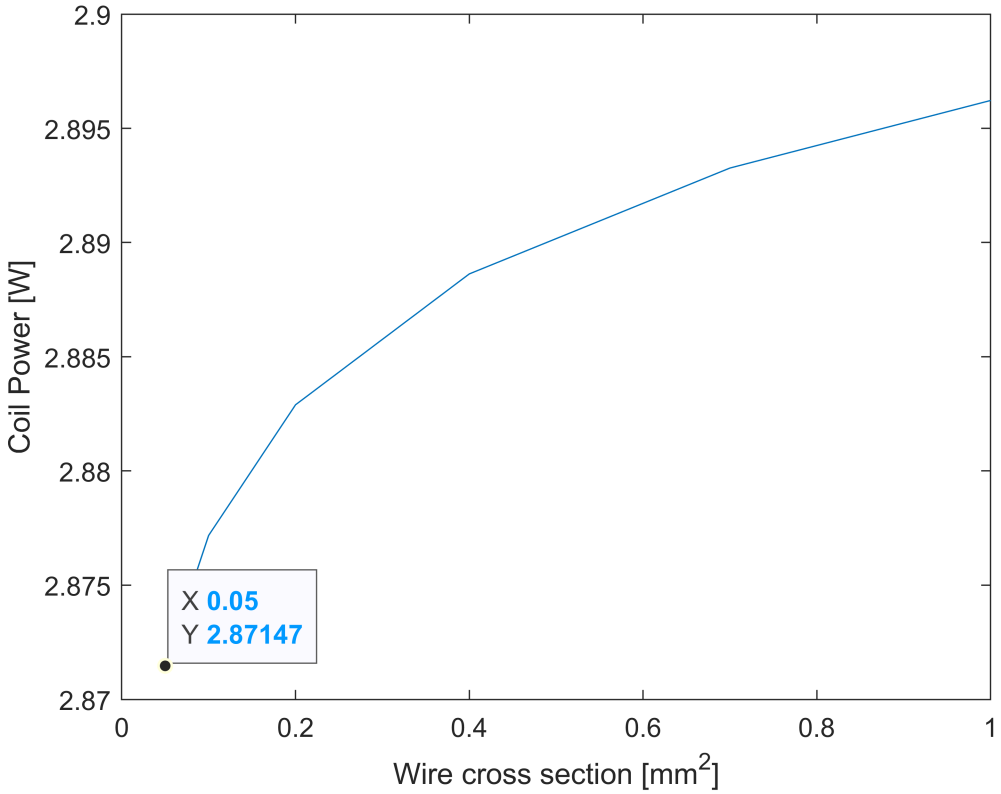
```
wire_area = 0.0500
R_per_km = 365.3886
wire_area = 0.1000
R_per_km = 183.0574
wire_area = 0.2000
R_per_km = 91.7107
wire_area = 0.4000
```

```
R_per_km = 45.9465
wire_area = 0.7000
R_per_km = 26.2973
wire_area = 1
R_per_km = 18.4269
```

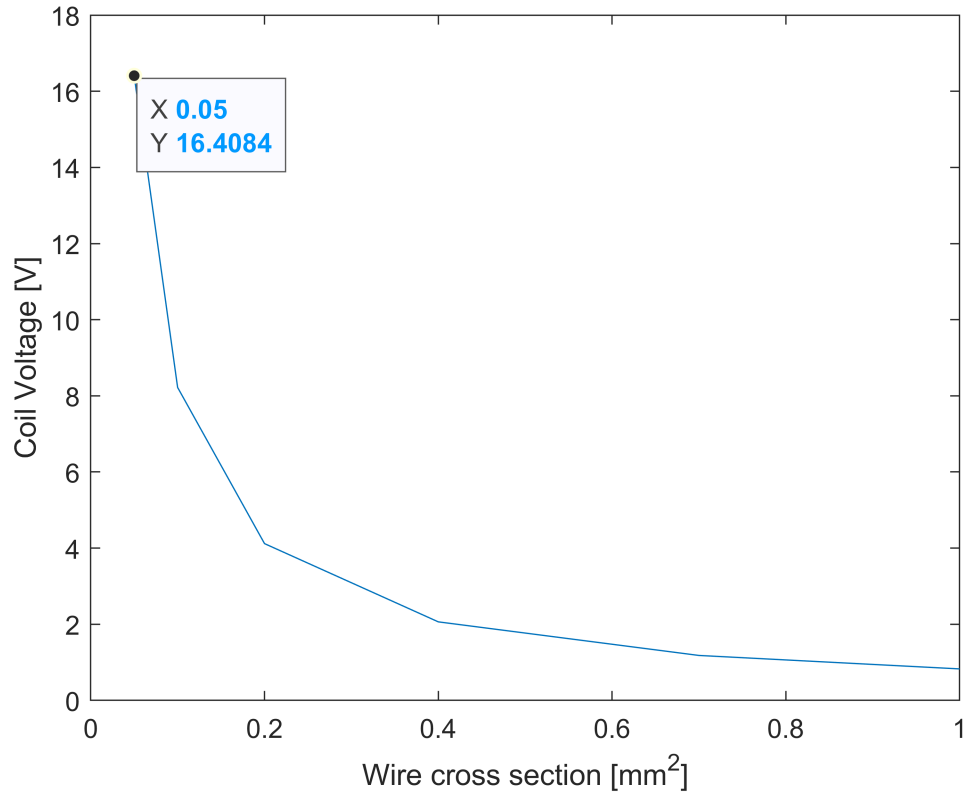
```
Fmag
```

```
Fmag = 88.3829
```

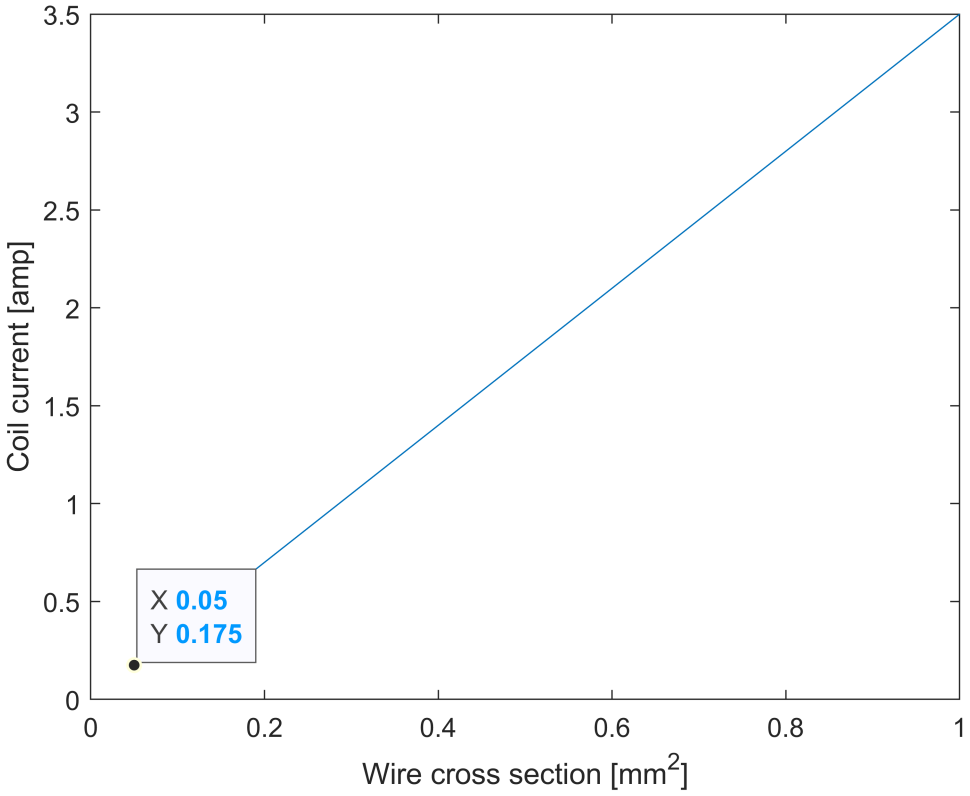
```
plot(wire_areas,sol_P), xlabel('Wire cross section [mm^2]'), ylabel('Coil Power [W]')
```



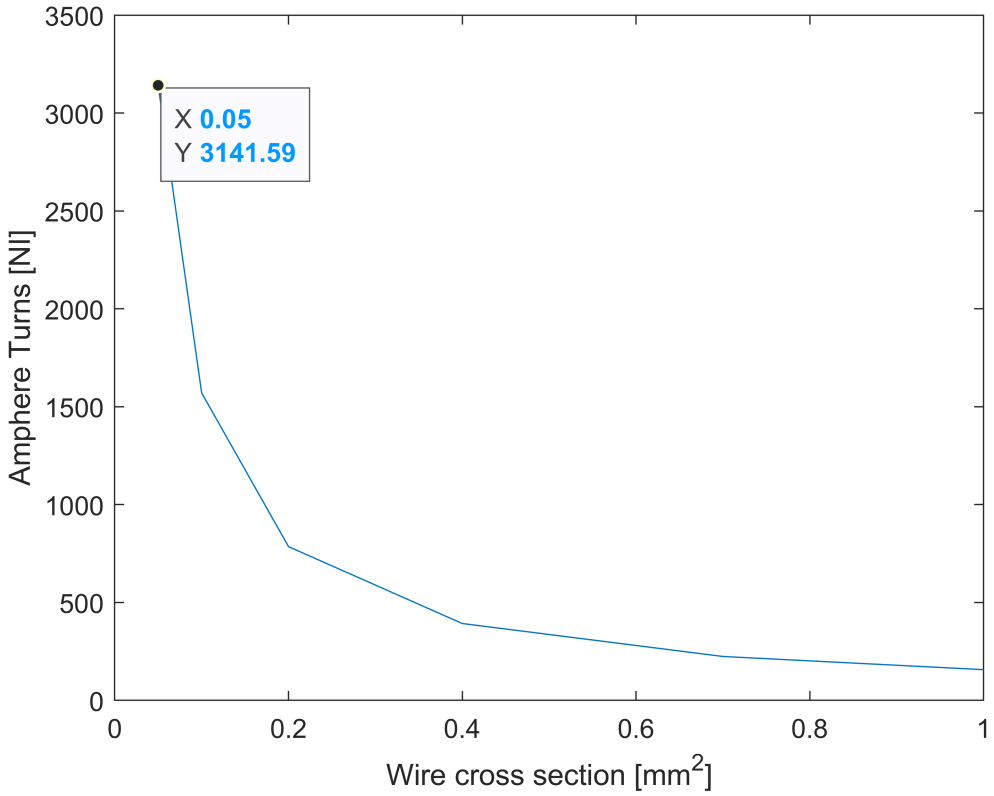

```
plot(wire_areas,sol_V), xlabel('Wire cross section [mm^2]'), ylabel('Coil Voltage [V]')
```



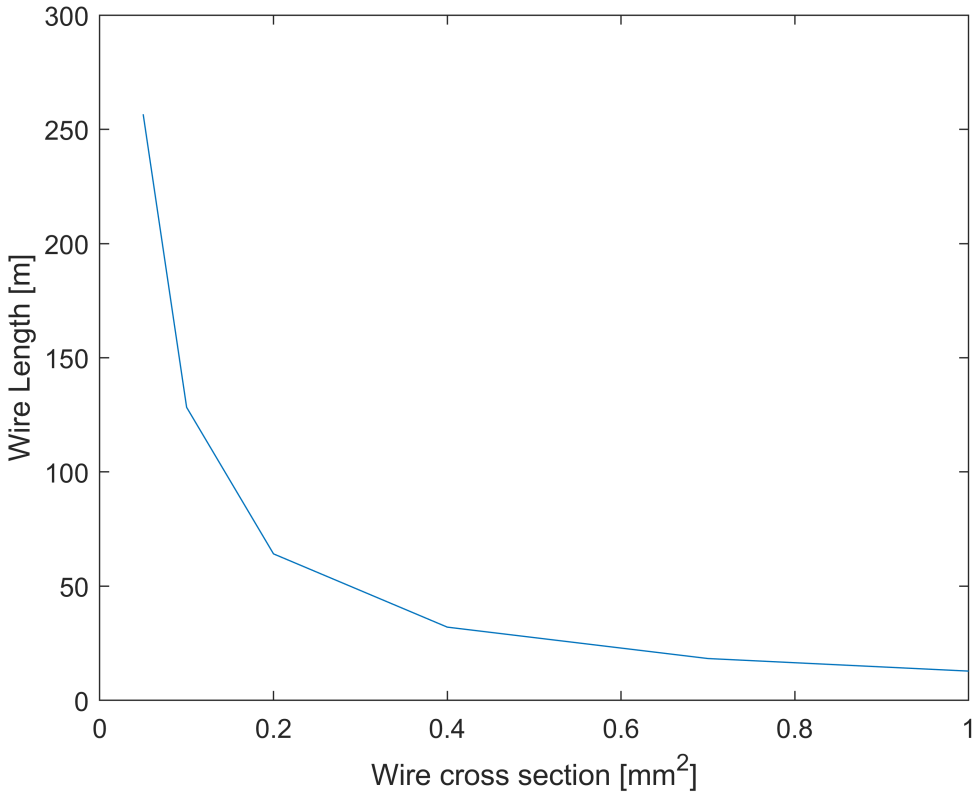

```
plot(wire_areas,sol_P./sol_V), xlabel('Wire cross section [mm^2]'), ylabel('Coil current [amp]'
```



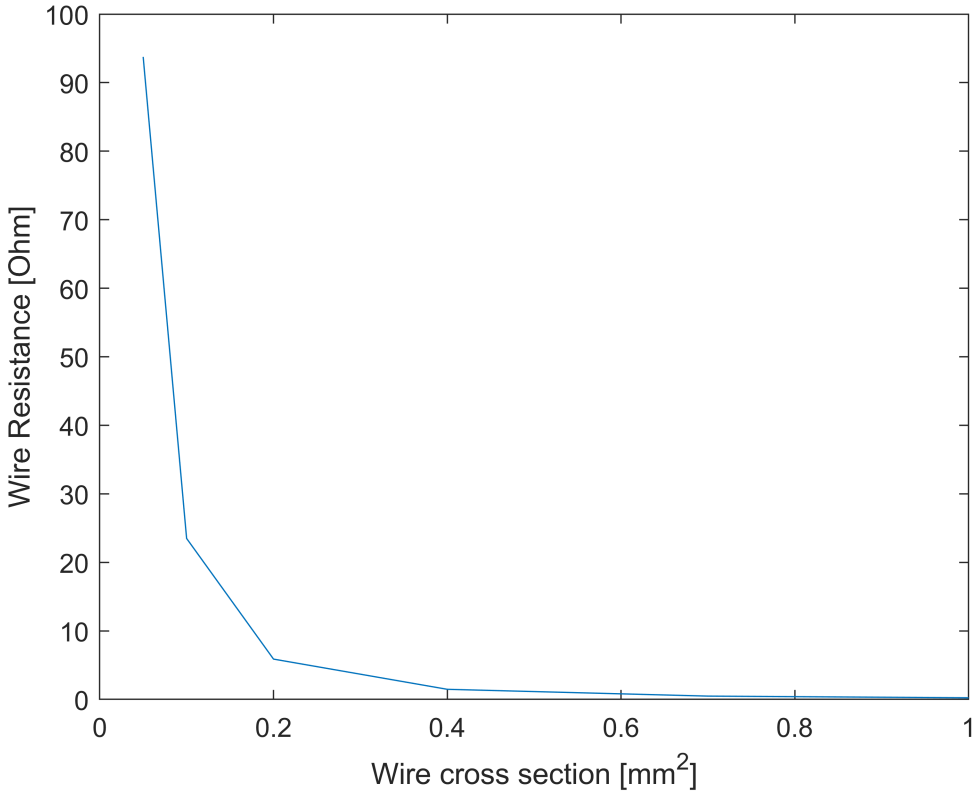
```
plot(wire_areas,N), xlabel('Wire cross section [mm^2]'), ylabel('Amphere Turns [NI]')
```




```
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 [Ohm]')
```



0.05 mm^2 = 30AWG wire.