Autodesk Inventor Engineer s Handbook

هندبوک مهندسی نرم افزار Autodesk Inventor

انجمن اینونتور ایران

www.irinventor.com

Email: irinventor@chmail.ir irinventor@hotmail.com

Tel: 09352191813 &

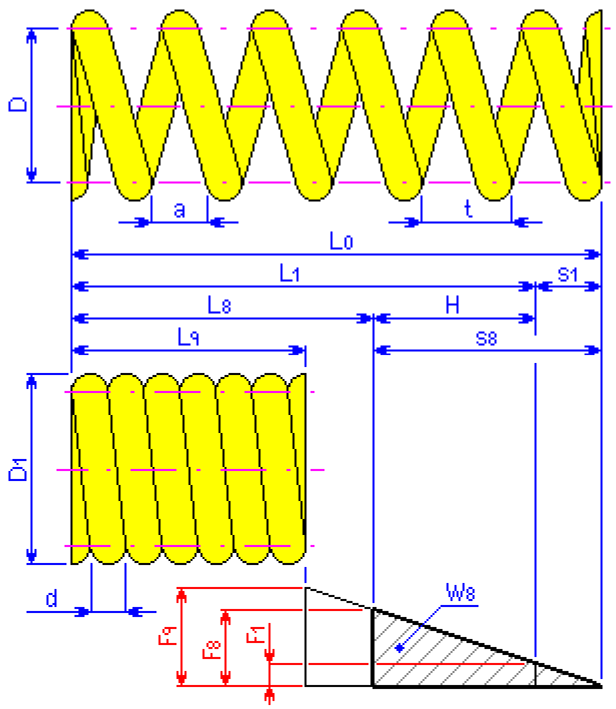
021-46088862

Spring Generator

Compression Spring Generator

Basic concepts

The compression spring is a helical spring with permanent clearance between active coils capable of carrying the outer opposing forces actuating in its axis.



Dimensions

d wire diameter [mm, in]
D mean spring diameter [mm, in]
D_1 outside spring diameter [mm, in]
D_2 inside spring diameter [mm, in]
H working deflection [mm, in]
t pitch of active coils in free state [mm, in]
a space between active coils in free state [mm, in]
s_x spring deflection [mm, in]
L_x spring length [mm, in]
F_x working force exerted by the spring [N, lb]
W_8 deformation energy [J, ft lb]
x index responding with the spring state

Coiling

1. Right (usually)
2. Left (must be notified in words)

States

1. Free: the spring is not loaded (index 0)
2. Pre loaded: smallest working load is applied to the spring (index 1)
3. Fully loaded: maximum working load is applied to the spring (index 8)
4. Limit: the spring is depressed up to coil touching (index 9)

alculation formulas in metric units

General Calculation Formulas

Utilization factor of material

Safety factor at the fatigue limit

Outside spring diameter

$D_1 = D + d$ [mm]

where:

Dmean spring diameter [mm]

d wire diameter [mm]

Inside spring diameter

$D_2 = D - d$ [mm]

where:

Dmean spring diameter [mm]

d wire diameter [mm]

Working deflection

$H = L_1 - L_8 = s_8 - s_1$ [mm]

where:

L_8length of fully loaded spring [mm]

L_1length of pre loaded spring [mm]

s_8 deflection of fully loaded spring [mm]

s_1 deflection of pre loaded spring [mm]

Spring index

c = D/d [-]

where:

Dmean spring diameter [mm]

d wire diameter [mm]

Wahl correction factor

$$K_w = \frac{4 \cdot c - 1}{4 \cdot c - 4} + \frac{0.615}{c} \quad [-]$$

where:

cspring index [-]

dwire diameter [mm]

General force exerted by the spring

$$F = \frac{\pi \cdot d^3 \cdot \tau}{8 \cdot D \cdot K_w} = \frac{G \cdot s \cdot d^4}{8 \cdot D^3 \cdot n} + F_0 \quad [N]$$

where:

d wire diameter [mm]

τ torsional stress of spring material in general [MPa]

D mean spring diameter [mm]

K_w Wahl correction factor [-]

G modulus of elasticity of spring material [MPa]

s spring deflection in general [mm]

n number of active coils [-]

F_0 spring initial tension [N]

Spring constant

$$k = \frac{G \cdot d^4}{8 \cdot D^3 \cdot n} = \frac{F_8 - F_1}{H} \quad [N/mm]$$

where:

d wire diameter [mm]

F_8 working force in fully loaded spring [MPa]

D mean spring diameter [mm]

H working deflection [mm]

G modulus of elasticity of spring material [MPa]

n number of active coils [-]

F_1 working force in minimum loaded spring [MPa]

Mean spring diameter

$$D = \sqrt[3]{\frac{G \cdot d^4}{8 \cdot k \cdot n}} \quad [mm]$$

where:

d wire diameter [mm]

k spring constant [N/in]

Gmodulus of elasticity of spring material [MPa]

n number of active coils [-]

Spring deflection in general

s = F / k [mm]

where:

FGeneral force exerted by the spring [N]

kspring constant [N/in]

Loose spring length

$L_0 = L_1 + s_1 = L_8 + s_8$ [mm]

where:

L_8 length of fully loaded spring [mm]

L_1 length of pre loaded spring [mm]

s_8 deflection of fully loaded spring [mm]

s_1 deflection of pre loaded spring [mm]

Spring Design Calculation

Within the spring design, wire diameter, number of coils, and spring free length L0 are designed for a specific load, material and assembly dimensions, or spring diameter. For a spring with recommended wire diameters, the t pitch between spring threads in free state should be within the $0.3\,D \leq t \leq 0.6\,D$ [mm] range.

The spring design is based on the $\tau_8 \leq u_s \tau_A$ strength condition and the recommended ranges of some spring geometric dimensions:

$L_8 \geq L_{minF}$ and $D \leq L_0 \leq 10\,D$ and $L_0 \leq 31.5$ in and $4 \leq D/d \leq 16$ and $n \geq 2$ and $12\,d \leq t < D$

where:

D	mean spring diameter [mm]
d	wire diameter [mm]
pitch of active coils in free state	pitch of active coils in free state [mm]
τ_8	torsional stress of spring material in the fully loaded stress [MPa]
τ_A	allowable torsion stress of spring material [MPa]
u_s	utilization factor of material [-]
L_8	length of fully loaded spring [mm]
L_{minF}	limit test length of spring [mm]
n	number of active coils [-]

If safety conditions for buckling and check conditions for fatigue loading are set in the specification, the spring must comply.

The spring design procedures for the specific design types are listed in the following.

Design Procedures

1. Specified load, material, and spring assembly dimensions

First check and calculate the input values.

Design the wire diameter and number of coils in accordance with the strength and geometric requirements listed in the previous table. Or use spring diameter values in the specification.

During the design the program calculates, step by step from the smallest to the biggest, all the spring wire diameters that conform to the strength and geometric conditions. If all conditions are fulfilled, the design is finished with selected values, irrespective of other conforming spring wire diameters. This means that the program tries to design a spring with the least wire diameter and the least number of coils.

2. Spring design for a specified load, material, and spring diameter

First, check the input values for the calculation.

Design the wire diameter, number of coils, spring free length, and assembly dimensions in accordance with the strength and geometric conditions listed previously, or with any assembly dimension L_1 or L_8 stated in the specification, or any working spring deflection value that is limited.

Use the following formula to design the spring for the specified wire diameter.

$$d = 2 \cdot \sqrt[3]{\frac{F_8 \cdot D \cdot K_w}{\pi \cdot \tau_8}} \quad [mm]$$

where:

$\tau_8 = 0.85\ \tau_A$

F_8 working force in fully loaded spring [MPa]

D mean spring diameter [mm]

K_w Wahl correction factor [-]

τ_8 torsional stress of spring material in the fully loaded stress [MPa]

τ_A allowable torsion stress of spring material [MPa]

If no suitable combination of spring dimensions can be designed for this wire diameter, all the spring wire diameters that conform to the strength and geometric conditions are tested, starting with the smallest, going up to the biggest. The suitable coil numbers are tested, whether the spring design conforms with the conditions. In this case the design is finished with the selected values, irrespective of other suitable spring wire diameters, and the spring is designed with the least wire diameter and the least number of coils.

3. Spring design for the specified maximum working force, determined material, assembly dimensions, and spring diameter

First, check the input values for the calculation.

Then the wire diameter, number of coils, spring free length and the F_1 minimum working force are designed, so that the previously mentioned strength and geometric conditions are fulfilled.

The program preferably tries to design the spring for wire diameter, according to the formula:

$$d = 2 \cdot \sqrt[3]{\frac{F_8 \cdot D \cdot K_w}{\pi \cdot \tau_8}} \quad [mm]$$

where:

$\tau_8 = 0.85\ \tau_A$

F_8 working force in fully loaded spring [MPa]

D mean spring diameter [mm]

K_w Wahl correction factor [-]

τ_8 torsional stress of spring material in the fully loaded stress [MPa]

τ_A allowable torsion stress of spring material [MPa]

If no suitable combination of spring dimensions can be designed for this wire diameter, the program continues, starting with the smallest, going up to the biggest, all the spring wire diameters that conform to the strength and geometric conditions. It tests the suitable coil numbers, whether the designed spring conforms with the all demanded conditions. In this case the design is finished with the selected values, irrespective of other suitable spring wire diameters. Here the program makes an effort to design a spring with the least wire diameter and the least number of coils.

Spring Check Calculation

Calculates corresponding values of assembly dimensions and working deflection for the specified load, material, and spring dimensions.

First, the input values for the calculation are checked. Then the assembly dimensions are calculated using the following formulas.

Length of preloaded spring

$$L_1 = L_0 - \frac{8 \cdot F_1 \cdot n \cdot D^3}{G \cdot d^4} \quad [mm]$$

Length of fully loaded spring

$$L_8 = L_0 - \frac{8 \cdot F_8 \cdot n \cdot D^3}{G \cdot d^4} \quad [mm]$$

where:

L_0 length of free spring [mm]

F_1 working force in minimum loaded spring [mm]

n number of active coils [-]

D mean spring diameter [mm]

G modulus of elasticity of spring material [MPa]

d wire diameter [mm]

F_8 working force in fully loaded spring [MPa]

Working deflection

$H = L_1 - L_8$ [mm]

Calculation of Working Forces

Corresponding forces produced by spring in their working states are calculated in this calculation for the specified material, assembly dimensions, and spring dimensions. First the input data is checked and calculated, then the working forces are calculated according to the following formulas.

Minimum working force

$$F_1 = \frac{(L_0 - L_1) \cdot G \cdot d^4}{8 \cdot n \cdot D^3} \quad [N]$$

Maximum working force

$$F_8 = \frac{(L_0 - L_8) \cdot G \cdot d^4}{8 \cdot n \cdot D^3} \quad [N]$$

Calculation of spring output parameters

Common for all types of spring calculation, and calculated in the following order.

Spring constant

$$k = \frac{G \cdot d^4}{8 \cdot D^3 \cdot n} \quad [N/mm]$$

Theoretic limit length of spring

$L_9 = (n + n_z + 1 - z_0)\ d$ [mm]

Limit test length of spring

$L_{minF} = L_{9max} + S_{amin}$ [mm]

where the upper limit spring length in the limit state L_{9max} :

for non ground ends

$L_{9max} = 1.03\ L_9$ [mm]

for ground ends and (n + nz) <= 10.5

$L_{9max} = (n + n_z)\ d$ [mm]

for ground ends and (n + nz) > 10.5

$L_{9max} = 1.05\ L_9$ [mm]

Sum of the least allowable space between spring active coils in the fully loaded state

$$S_{amin} = \frac{d \cdot c \cdot n}{50} \quad [mm]$$

while the c = 5 value is used for the c < 5 spring index values

Spring deflection in limit state

$s_9 = L_0 - L_9$ [mm]

Limit spring force

$F_9 = k\ S^9$ [N]

Space between coils

$$a = \frac{s_9}{n} \quad [mm]$$

Pitch of active coils

$t = a + d$ [mm]

Pre loaded spring deflection

$s_1 = L_0 - L_1$ [mm]

Total spring deflection

$s_8 = L_0 - L_8$ [mm]

Torsional stress of spring material in the pre loaded state

$$\tau_1 = \frac{8 \cdot F_1 \cdot D \cdot K_w}{\pi \cdot d^3} \quad [\mathrm{MPa}]$$

Torsional stress of spring material in the fully loaded stress

$$\tau_8 = \frac{8 \cdot F_8 \cdot D \cdot K_w}{\pi \cdot d^3} \quad [\mathrm{MPa}]$$

Solid length stress

$$\tau_9 = \frac{8 \cdot F_9 \cdot D \cdot K_w}{\pi \cdot d^3} \quad [\mathrm{MPa}]$$

Developed wire length

$l = 3.2\, D\, (n + n_z)$ [mm]

Spring mass

$$m = \frac{\pi \cdot l \cdot d^2 \cdot \rho}{4 \cdot 10^9} \quad [\mathrm{kg}]$$

Spring deformation energy

$$W_8 = \frac{F_8 \cdot s_8}{2000} \quad [\mathrm{J}]$$

Natural frequency of spring surge

$$f = \frac{d}{2 \cdot \pi \cdot n \cdot D^2} \cdot \sqrt{\frac{G}{2 \cdot \rho}} \cdot 10^6 \quad [Hz]$$

Critical (limit) spring speed concerning the arousal of mutual coil impacts from inertia

$$v = \frac{\tau_9 - \tau_8}{\sqrt{2 \cdot \rho \cdot G}} \cdot 10^3 \quad [m s^{-1}]$$

Check of spring load

$\tau_8 \le u_s \tau_A$ and $L_{minF} \le L_8$

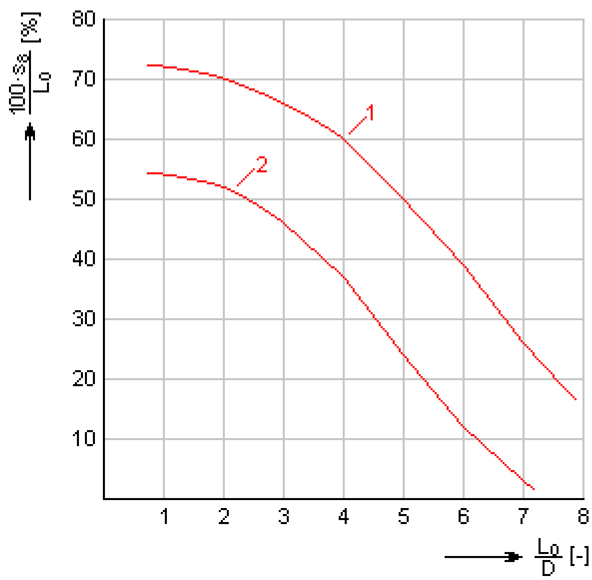
Meaning of used variables:

a space between active coils in the free state [mm]
k spring constant [N/mm]
d wire diameter [mm]
D mean spring diameter [mm]
D_1 spring outside diameter [mm]
D_2 spring inside diameter [mm]
F general force exerted by the spring [N]
G shear modulus of elasticity of spring material [MPa]
c spring index [-]
H working deflection [mm]
K_w Wahl correction factor [-]
k_f safety factor at the fatigue limit [-]
l developed wire length [mm]
L spring length in general [mm]
L_{9max} upper limit length of spring in the limit state [mm]
L_{minF} limit test length of spring [mm]
m spring mass [kg]
N life of fatigue loaded spring in thousands of deflections [-]
n number of active coils [-]
n_z number of end coils [mm]
t pitch of active coils in free state [mm]
s spring deflection (elongation) in general [mm]
s_{amin} sum of the least allowable space between spring active coils [mm]
u_s utilization factor of material [-]
z_0 number of ground coils [-]
ρ density of spring material [kg/m ^{3}]
σ_{ult} ultimate tensile stress of spring material [MPa]
τ torsional stress of spring material in general [MPa]
τ_e endurance limit in shear of fatigue loaded spring [MPa]
τ_{A8} allowable torsion stress of spring material [MPa]

Check of compression spring buckling

Check compression springs for safety against buckling. The required working deflection (given as the percentage ratio of the spring free length L_0) must be lower than the limit deflection determined for specified slenderness ratio L_0/D given by the respective curve, as shown in the image.

For a spring that cannot be designed buckling-safe, use a pin or housing as a guide, or divide it into several short springs.



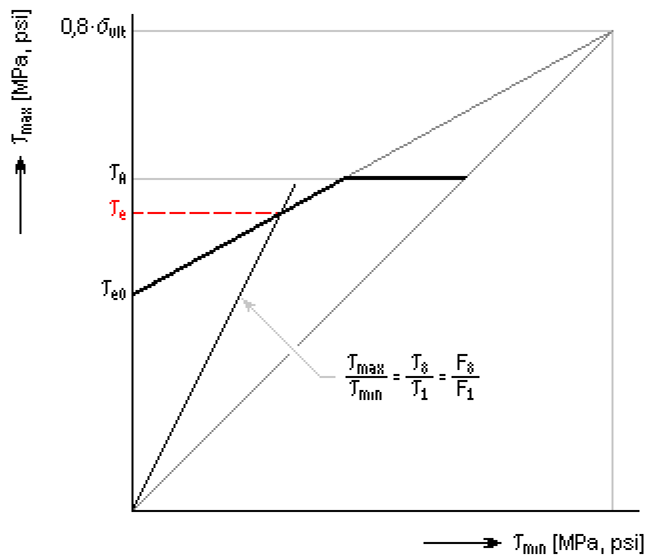
where:

- curve 1 - Parallel ground ends and guided mounting
- curve 2 - Without guided mounting or without parallel ground ends

Check of dynamically (fatigue) loaded spring

For dynamically loaded springs, that is, springs exposed to cyclic load changes and with the required life of more than 10^5 working strokes, the general static stress check according to the $\tau_8 \leq u_s \tau_A$ formula is not enough. Such spring must be checked for fatigue load of the spring material.

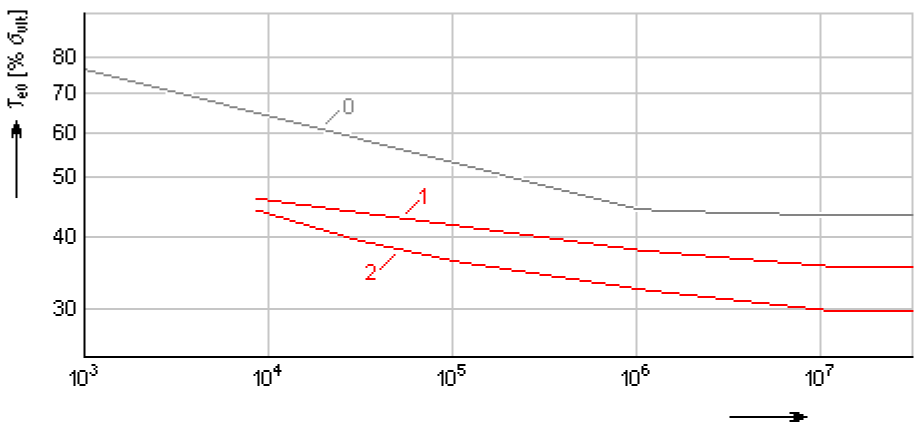
If such spring with expected dynamic load is to be satisfactory, the condition in the $\tau_8 \leq \tau_e / k_f$ formula must be true in addition to the previously mentioned static check. The endurance te limit can be found in the respective "Smith's fatigue graph" according to the specific wire diameter, material, life requirements, and spring load.



where:

F_1 minimum working force [N, lb]
F_8 maximum working force [N, lb]
k_f safety factor at the fatigue limit [-]
N spring life in thousands of deflections [-]
σ_{ult} ultimate tensile stress of spring material [MPa, psi]
τ_1 torsional stress of spring material in the preloaded state [MPa, psi]
τ_8 torsional stress of spring material in the fully loaded state [MPa, psi]
τ_e endurance limit in shear of fatigue loaded spring [MPa, psi]
τ_{e0} basic endurance limit in shear for zero mean stress [MPa, psi]
τ_A allowable torsion stress of spring material [MPa, psi]

Data on basic endurance limit of materials for zero mean stress τ_{e0} are displayed in the experimental data diagram (see the following picture). Validity of these data is given by the specific material, surface finish, and spring life.



where:

curve 0	theoretically calculated curve of basic endurance limit te0 for steel springs with respect to required life
curve 1	maximum recommended values of basic endurance limit for shot-peened springs
curve 8	maximum recommended values of basic endurance limit for non shot-peened springs

Material

Material of spring wire for metric

Wire type	*G [MPA]*	*Allowable limit torsion stress τ A*	*Density ρ* [kg.m ^{3}]
Draw patented from carbon steel	80 500	0.5 σ_{ult}	
Heat treated from carbon steel	78 500	0.6 σ_{ult}	
Heat treated or annealed from alloy steel (Si-Cr, Mn-Cr-V) 14260 and 15260	78 500	0.6 σ_{ult}	7.85 10^{3}
Hardened by drawing from chrome-nickel stainless austenitic steel 17242	68 500	0.5 σ_{ult}	
Hardened by drawing from tin-bronze 423016 and 423018	41 500	0.45 σ_{ult}	8.8 10^{3}
Hardened by drawing from brass 423210 and 423213	34 500	0.45 σ_{ult}	8.43 10^{3}

Material of spring wire for English

Wire type	*Modulus of Elasticity in Shear [psi]*
Hard drawn steel wire QQ-W-428	11 200000
Music wire QQ-W-470	11 200000
Oil-tempered steel wire QQ-W-428	11 200000
Chrome-silicon alloy wire QQ-W-412	11 200000
Corrosion-resisting steel wire QQ-W-423	11 200000
Chrome-vanadium alloy steel wire	11 200000
Silicon-manganese steel wire	11 200000
Valve-spring quality wire	11 200000
Stainless steel 304 and 420	11 600000
Stainless steel 316	11 600000
Stainless steel 431 and 17-7 PH	11 600000

Allowable limit torsion stress τ_A [10^{3} psi]

Wire diameter [in]	*Hard drawn steel wire QQ-*	*Music wire QQ-W470*	*Oil-tempered steel wire QQ-W-428*	*Chrome-silicon alloy wire QQ-W-412*	*Corrosion-resisting steel wire QQ-W-423*	*Chrome-vanadium alloy steel wire*	*Silicon-manganese steel wire*	*Valve-spring quality wire*	*Stainless steel 304 and 420*	*Stainless steel 316*	*Stainless steel 431 and 17-7 PH*

	W-428										
0.010	150	176	157	176	145	175	158	175	138	131	158
0.012	149	171	154	175	143	174	157	174	129	154	158
0.014	148	167	152	174	141	173	156	173	134	127	150
0.016	147	164	150	174	139	172	155	172	132	125	148
0.018	146	161	148	173	137	171	154	171	130	123	145
0.02	145	159	146	173	135	170	153	170	128	121	143
0.024	143	155	142	172	131	168	151	168	124	118	140
0.026	142	153	141	171	129	167	150	167	123	116	138
0.028	141	151	140	171	128	166	149	166	122	115	136
0.030	140	149	139	170	127	165	148	165	121	114	134
0.032	139	147	138	170	126	164	147	164	120	113	132
0.034	138	145	137	169	125	163	146	163	119	112	130
0.036	137	143	136	169	124	162	145	162	118	112	129
0.038	136	142	135	168	123	161	144	161	117	111	128
0.041	135	141	133	167	122	160	144	160	116	110	127
0.0475	132	138	130	166	119	156	140	156	113	107	124
0.054	138	136	128	165	117	152	137	152	111	105	122
0.0625	123	132	125	162	115	149	134	152	109	104	119

Utilization factor of material uS

The factor gives the relation between the torsion stress of a spring in the fully loaded state and the allowable torsion stress, such as $u_S \approx \tau_8 / \tau_A$. If a greater value is selected, less material is needed for spring production, the spring dimensions, and the space for mounting are less, but the securing of spring stability during its function is lower, and vice versa. Therefore this factor is a reciprocal value of the safety rate. For common operational conditions, the value recommended for the utilization factor of the material is in the range of u_S = 0.75 ... 0.95. You can use lower values for springs working in aggressive surroundings, at high temperatures, or loaded with impacts.

Safety factor at the fatigue limit kf

The factor is used when calculating dynamically loaded springs (cyclic fatigue load for life N > 10^5 working strokes). It is given by a ratio between the endurance limit of spring and the torsional stress of spring material exposed to full load, that is, $k_f \approx \tau_e / \tau_8$. For standard operating conditions, the recommended value of safety factor at fatigue limit k_f is recommended to be in the range of 1.1 ... 1.5. In general, higher kf values must be used for springs working in corrosive environment, at high temperatures or under impact loads. The effect of a corrosive environment has a serious influence on the spring fatigue strength, since it can reduce the spring loading capacity down to one fifth, depending on the material and type of corrosive environment.

Web: www.irinventor.ir
Email: irinventor@chmail.ir
& irinventor@hotmail.com

Tel: 09352191813 & 021-46088862