Design JK 조

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JK와 함께 트램펄린운동으로 아름다운 몸매를!

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1. Statement

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1. Statement

몸무게가 100kg 나가는 한 여자가 있다. 그녀의 목표는 바로 김아중! 다이어트를 위한 운동으로 트램펄린을 선택하였다.

트램펄린에 달린 용수철은 N개이고, 용수철 하나 당 길이 L cm라고 한다.

이 여성이 사용했을 때, 늘어나는 길이가 10cm이하가 되도록 하는 용수철의 최소 size를 결정하라.

용수철은 Helical Spring, 재질은 ASTM 229 wire 이다. (단, 용수철에는 축 방향의 힘만 작용하고 각 용수철에는 같은 하중이 걸린다.)

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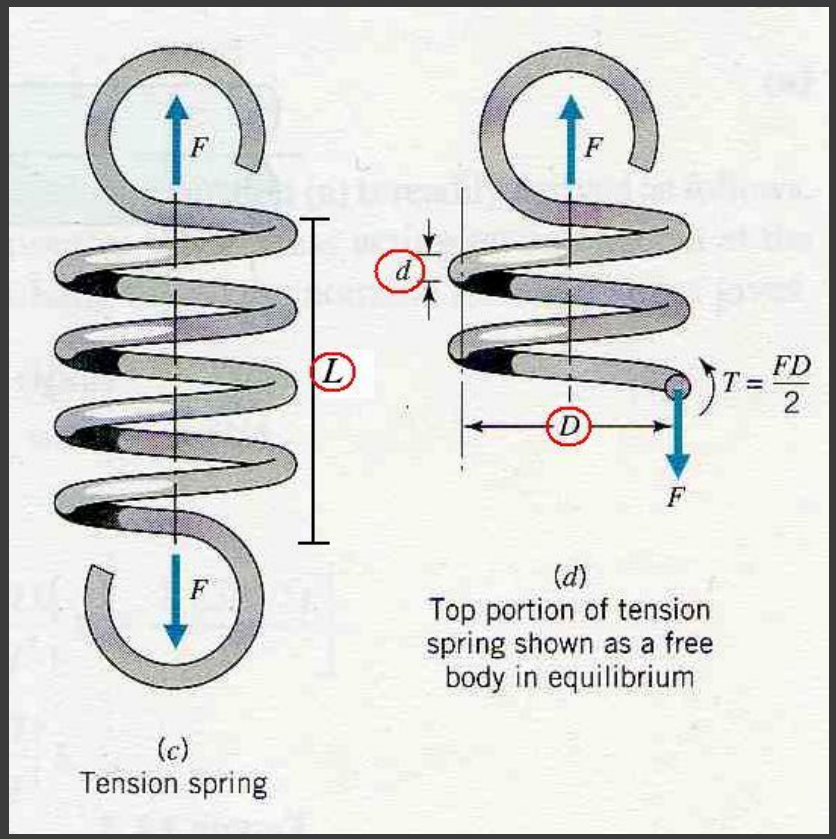
2. Data and Information Collection

- 스프링의 기본 형상



D : mean coil diameter
d : wire diameter
L : length

Spring index $C = \frac{D}{d} \geq 3$

Force $F = \frac{100 \times 9.8}{N}$

2. Data and Information Collection

- ASTM 229 wire

$$G = 79GPa$$

$$\tau_{allow} = 0.45S_u = 0.45 \times 225ksi$$

$$= 0.45 \times 225 \times 6.89MPa$$

$$= \mathbf{697.613MPa}$$

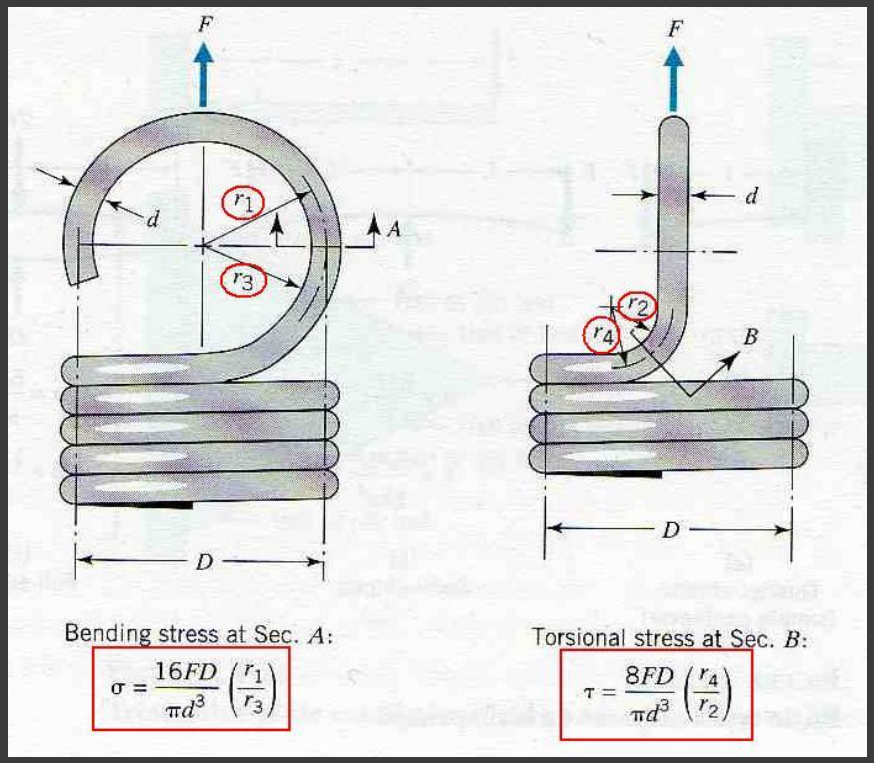
$$\sigma_{allow} = 0.5S_u = 0.5 \times 225ksi$$

$$= 0.5 \times 225 \times 6.89MPa$$

$$= \mathbf{775.125MPa}$$

Safety Factor
1.3

2. Data and Information Collection



$$r_1 = \frac{D}{2}, \quad r_3 = \frac{1}{2}(D-d)$$

$$r_4 = 2.5d\,(recommended), \quad r_2 = 2.5d - \frac{d}{2} = 2d$$

변형되는 길이

$$\delta = \frac{8FD^3N}{d^4G} = \frac{8FD^3L}{d^5G} \le 0.1(m)$$

Spring 끝 쪽에서 발생하는 응력

$$\sigma = \frac{16FD}{\pi d^3}\left(\frac{r_1}{r_3}\right)$$

$$\tau = \frac{8FD}{\pi d^3}\left(\frac{r_4}{r_2}\right)$$

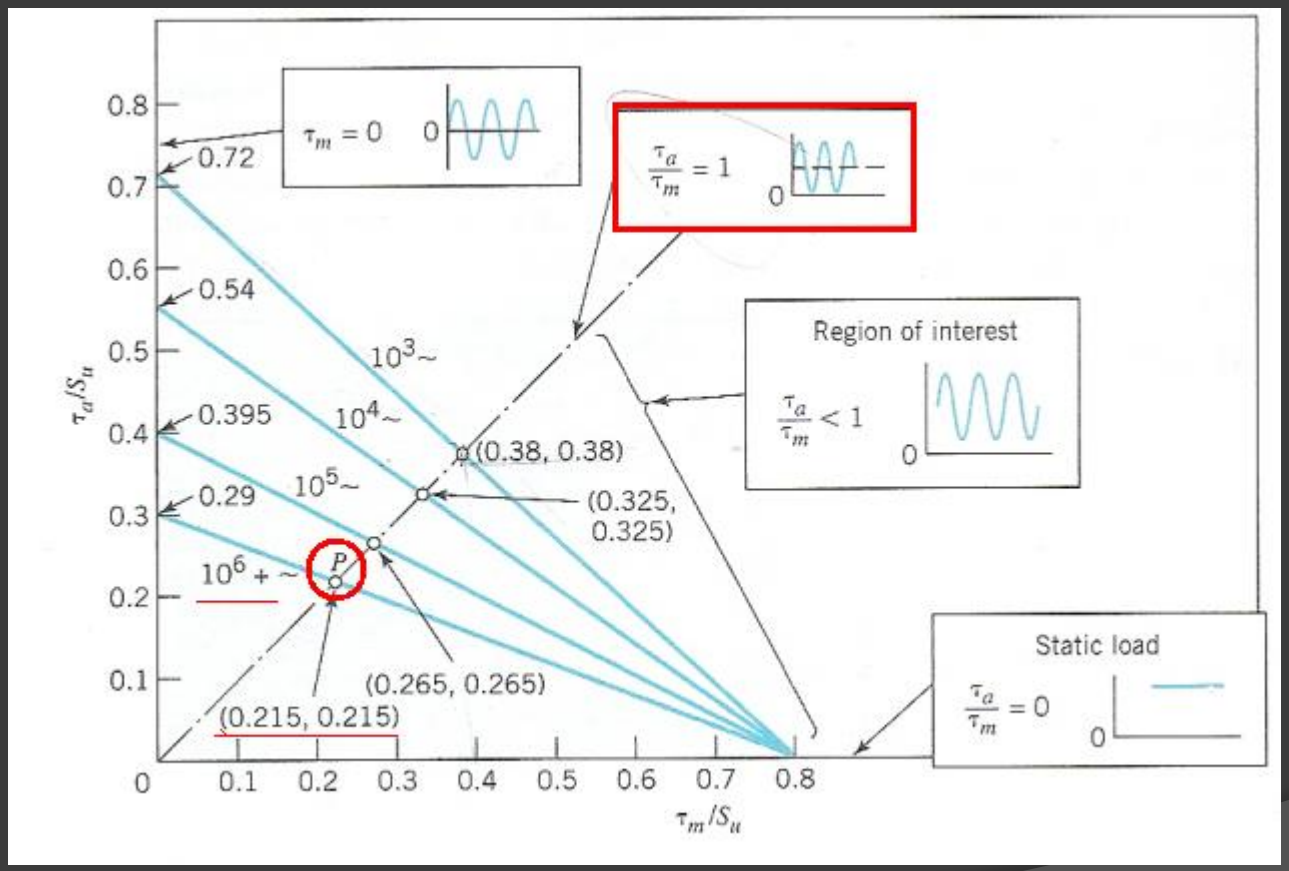
Coil 내에서 발생하는 응력

$$\tau = \frac{8FD}{\pi d^3}\left(1+\frac{0.5}{C}\right) \le \tau_{initial}$$

$$\tau_{initial} = 0.4\frac{S_u}{C}$$

2. Data and Information Collection

- 무한 반복하중



$$\tau_m \le 0.215Su$$

$$\tau_m = \tau_a = \frac{\tau}{2}$$

$$\tau \le 0.43Su$$

$$\frac{8FD}{\pi d^3} \le 0.43Su$$

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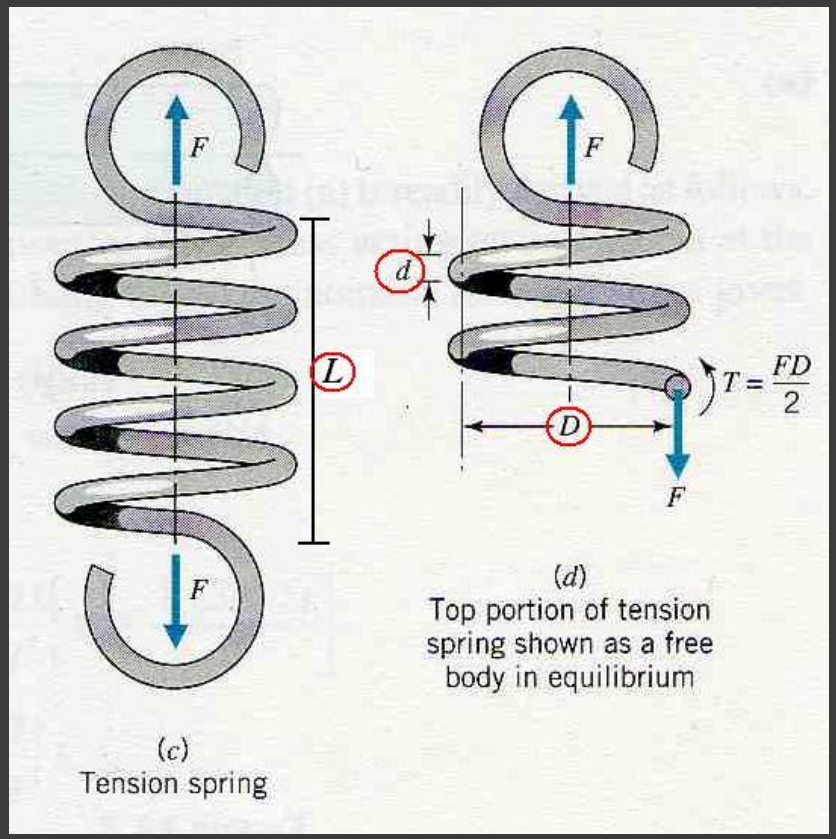
3. Identification of Design Variables

- 스프링의 기본 형상



D : mean coil diameter

d : wire diameter

L : Length of spring (단위: m)

N : Number of spring (개)

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4. Identification of a Criterion to be Optimized

- Cost function

  용수철 부피 최소화(재료의 양 최소화)

$$f(D,d) = \frac{\pi}{4} d^2 \times \pi D \frac{L}{d} \times N = \frac{\pi^2}{4} DdLN$$

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5. Identification of Constraints

$$C = \frac{D}{d} \geq 3$$

$$\delta = \frac{8FD^3L}{d^5G} \leq 0.1$$

$$\sigma = \frac{16FD}{\pi d^3}\left(\frac{D}{D-d}\right) \leq \sigma_{allow}/SF$$

$$\tau = \frac{8FD}{\pi d^3}\left(\frac{2.5d}{2d}\right) \leq \tau_{allow}/SF$$

$$\tau = \frac{8FD}{\pi d^3}\left(1+\frac{0.5}{C}\right) \leq \tau_{initial}/SF$$

$$0.1 \leq L \leq 0.3$$

$$\tau = \frac{8FD}{\pi d^3} \leq 0.43Su$$

$$D - d > 0$$

$$g_1 : 3d - D \leq 0$$

$$g_2 : \frac{8FD^3L}{d^5G} - 0.1 \leq 0$$

$$g_3 : \frac{16FD}{\pi d^3}\left(\frac{D}{D-d}\right) - \sigma_{allow}/1.3 \leq 0$$

$$g_4 : \frac{10FD}{\pi d^3} - \tau_{allow}/1.3 \leq 0$$

$$g_5 : \frac{8FD}{\pi d^3}\left(1+\frac{0.5}{C}\right) - \tau_{initial}/1.3 \leq 0$$

$$g_6 : 0.1 \leq L \leq 0.3$$

$$g_7 : \frac{8FD}{\pi d^3} - 0.43Su/1.3 \leq 0$$

$$g_8 : D - d > 0$$

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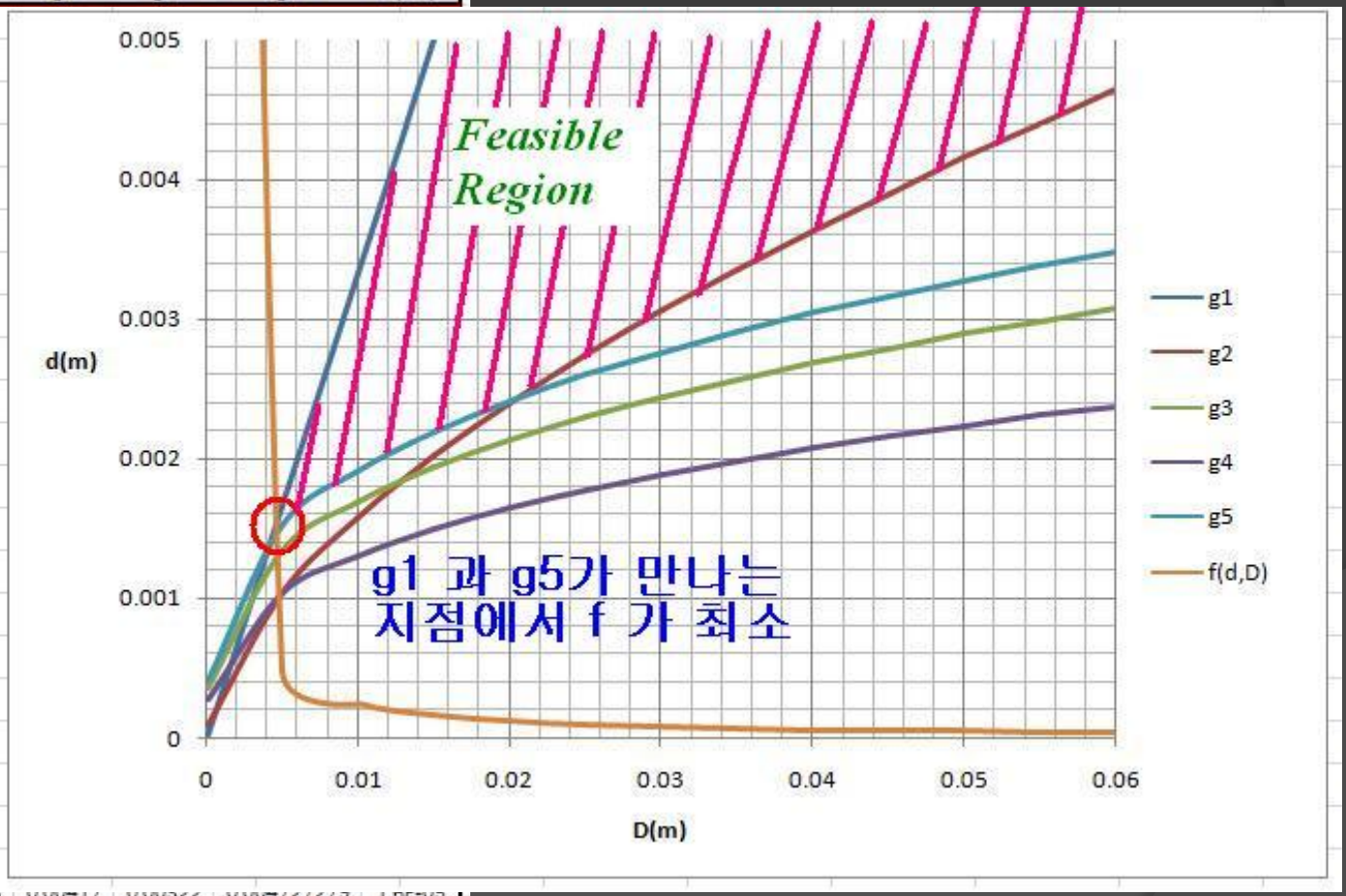
6. Simplified Solution

- 결과 표 & 그래프

D	g1	g2	g3	g4	g5	f(d,D)
0.0001	3.3E-05	9.98476E-05				
0.005	0.00167	0.00104404				
0.01	0.00333	0.00158247				
0.015	0.005	0.00201833				
0.02	0.00667	0.00239858				
0.025	0.00833	0.00274221				
0.03	0.01	0.00305921				
0.035	0.01167	0.00335566				
0.04	0.01333	0.00363558				
0.045	0.015	0.00390180				
0.05	0.01667	0.00415642				
0.055	0.01833	0.00440104				
0.06	0.02	0.00463690				
0.065	0.02167	0.00486503				
0.07	0.02333	0.00508623				
0.075	0.025	0.00530120				
0.08	0.02667	0.00551051				
0.085	0.02833	0.00571464				
0.09	0.03	0.00591402				
0.095	0.03167	0.00610902				
0.1	0.03333	0.00629996				
0.105	0.035	0.00648711				
0.11	0.03667	0.00667073				
0.115	0.03833	0.00685104				
0.12	0.04	0.00702823				
0.125	0.04167	0.00720250				
0.13	0.04333	0.00737401				
0.135	0.045	0.00754289				
0.14	0.04667	0.00770929				
0.145	0.04833	0.00787333				
0.15	0.05	0.00803512				



6. Simplified Solution

- Matlab Solver

```
1   %메틀랩 solve를 이용해서 g1과 g5 의 교점을 찾는다.
2 - [D] = solve('D/3 = (8*(100*9.8/20)*D*(1+0.5/3)/(0.4*225*pi*6.89*(10^6)/3))^(1/3)')
3   %D = .43606691333724466263061411286085e-2;
4   %d = .14535563777908155421020470428695e-2;
5   % D와 d 값을 위의 값으로 선택한 다음 목적함수값을 구한다.
6 - f= ((pi^2)/4)*D*d*0.2
7   %f = 3.1279e-006
```

D = 0.0043m = 4.3 mm

d =0.0014m = 1.4 mm

f= 3.128*10^(-6) m^3

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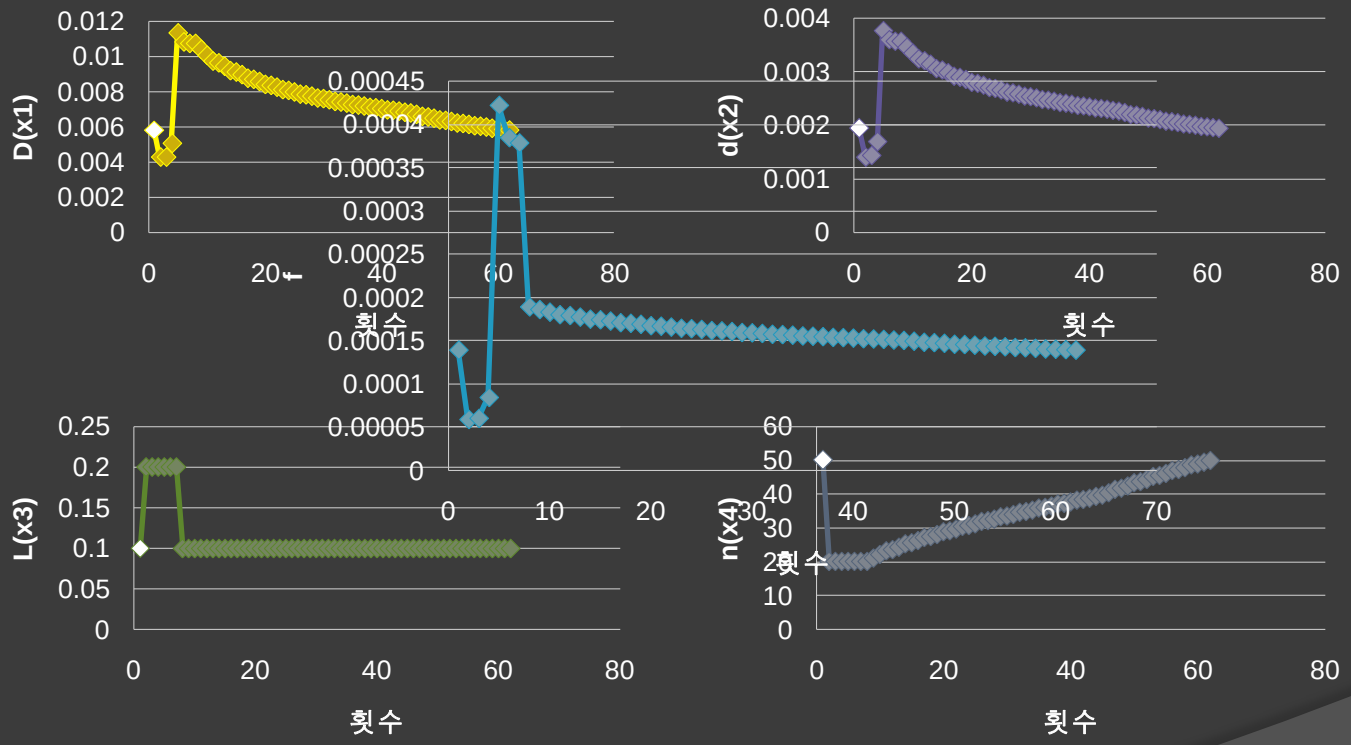
- Excel

변수선언	x1(D)	0.005826126 (m)	
	x2(d)	0.001942042 (m)	
	x3(L)	0.1 (m)	<= 새로 설정된 변수들
	x4(n)	50 (개)	
목적함수	f(x1,x2,x3,x4)	0.000139588 (m^3)	
제한조건갯수	8개		
제한조건	g1	0 >=0	
	g2	-0.07550217 <=0	
	g3	-477147339.2 <=0	
	g4	-486999275.9 <=0	
	g5	-7.07805E-07 <=0	
	g6	0.1 0.1<=,<=0.3	
	g7	-473074113.1 <=0	<= 새로 설정된 제약조건들
	g8	0.003884084	

7. Solve by Excel & Matlab

- Excel



7. Solve by Excel & Matlab

- Matlab

fmincon

x1(D)	0.0107 (m)
x2(d)	0.0036 (m)
x3(L)	0.1 (m)
x4(n)	20 (개)
f(x1,x2,x3,x4)	**1.89E-04** (m^3)

fminimax

x1(D)	0.0107 (m)
x2(d)	0.0036 (m)
x3(L)	0.1661 (m)
x4(n)	20 (개)
f(x1,x2,x3,x4)	**3.15E-04** (m^3)

fmincon

```
object functi function [fun,Grad] = obj_fun(X)
                x1=X(1);
                x2=X(2);
                x3=X(3);
                x4=X(4);

                fun = ((pi^2)/4)*x1*x2*x3*x4;

                if nargout > 1
                    Grad(1,1) = ((pi^2)/4)*x2*x3*x4;
                    Grad(2,1) = ((pi^2)/4)*x1*x3*x4;
                    Grad(3,1) = ((pi^2)/4)*x1*x2*x4;
                    Grad(4,1) = ((pi^2)/4)*x1*x2*x3;
                end
```

```
constraints function [Ineq_cons, Eq_cons, (
                x1=x(1);
                x2=x(2);
                x3=x(3);
                x4=x(4);

                D = 775.125*10^6;
                T = 697.613*10^6;
                Su = 225*6.89*10^6;
                G = 79*10^9;
```

1.89E-04

fminimax

```
object functi function f = obj_fun2(x)
                x1=x(1);
                x2=x(2);
                x3=x(3);
                x4=x(4);

                f = ((pi^2)/4)*x1*x2*x3*x4 ;
```

```
constraints function [Ineq_cons, Eq_cons, Grad_ineq, Grad_eq]=con_fun2(x);
                x1=x(1);
                x2=x(2);
                x3=x(3);
                x4=x(4);

                D = 775.125*10^6;
                T = 697.613*10^6;
                Su = 225*6.89*10^6;
                G = 79*10^9;

                Ineq_cons(1) = 3-x1/x2;
                Ineq_cons(2) = 8*980*(x1^3)*x3/(x4*x2^5*G) - 0.1/1.3;
                Ineq_cons(3) = (16*980*x1/(x4*x2^3*pi))*(x1/(x1-x2)) - D/1.3;
                Ineq_cons(4) = 10*980*x1/(x4*pi*x2^3) - T/1.3;
                Ineq_cons(5) = (8*980*x1/(x4*pi*x2^3))*(1+0.5*x2/x1) - (0.4*x2*x4/1.3)*Su;
                Ineq_cons(6) = 0.1 - x3;
                Ineq_cons(7) = x3 - 0.3;
                Ineq_cons(8) = (8*980*x1/(x4*pi*x2^3)) - 0.43*Su/1.3;
                Ineq_cons(9) = x2 - x1;

                Eq_cons = [];

                if nargout > 2
                    Grad_ineq(1,1) = -1/x2;
                    Grad_ineq(2,1) = x1/(x2^2);
                    Grad_ineq(3,1) = 0;
                    Grad_ineq(4,1) = 0;
```

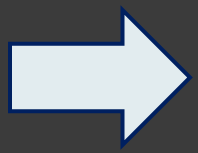
```
output X =
    0.0107
    0.0036
    0.1661
   20.0004

fval =
    3.15E-04
```

7. Solve by Excel & Matlab

- 결과 비교

변수선언	x1(D)	0.005826126 (m)
	x2(d)	0.001942042 (m)
	x3(L)	0.1 (m)
	x4(n)	50 (개)
목적함수	f(x1,x2,x3,x4)	0.000139588 (m^3)



D : 5.82mm
d : 1.94mm
L: 10 cm
N : 50 개
f : 1.396*10^-4

fmincon

x1(D)	0.0107 (m)
x2(d)	0.0036 (m)
x3(L)	0.1 (m)
x4(n)	20 (개)
f(x1,x2,x3,x4)	**1.89E-04** (m^3)

fminimax

x1(D)	0.0107 (m)
x2(d)	0.0036 (m)
x3(L)	0.1661 (m)
x4(n)	20 (개)
f(x1,x2,x3,x4)	**3.15E-04** (m^3)

Comments

- 중간보고 때 구한 결과보다, 최종적으로 구한 결과가 더 안 좋은 결과가 나와서 이유를 파악

변수선언	x1(D)	0.00436067	(m)		
	x2(d)	0.001453556	(m)		
	x3(L)	0.2	(m)		
	x4(n)	20	(개)		
목적함수	f(x1,x2,x3,x4)	3.12791E-06	(m^3)		
제한조건갯수	8개				
제한조건	g1	1.37594E-06	>=0		
	g2	-0.08731794	<=0		
	g3	-243610316.1	<=0		
	g4	-476148497.6	<=0		
	g5	188673187.2	<=0	<=	우리가 예전에 잘못한것
	g6	0.2	0.1<=,<=0.3		
	g7	-489435898.1	<=0		
	g8	0.002907114			

- 트램펄린에 대한 제원이나 기존 설계자료가 없어서 비교하지 못해 아쉬움이 많이 남음

Reference

- Robert C. Juvinall and Kurt M. Marshek , WILEY, “Fundamentals of Machine Component Design 4th Edition” - Ch12

- Jasbir S. Arora, Elsevier, “ Introduction to Optimum Design”

- 질문 있으세요?