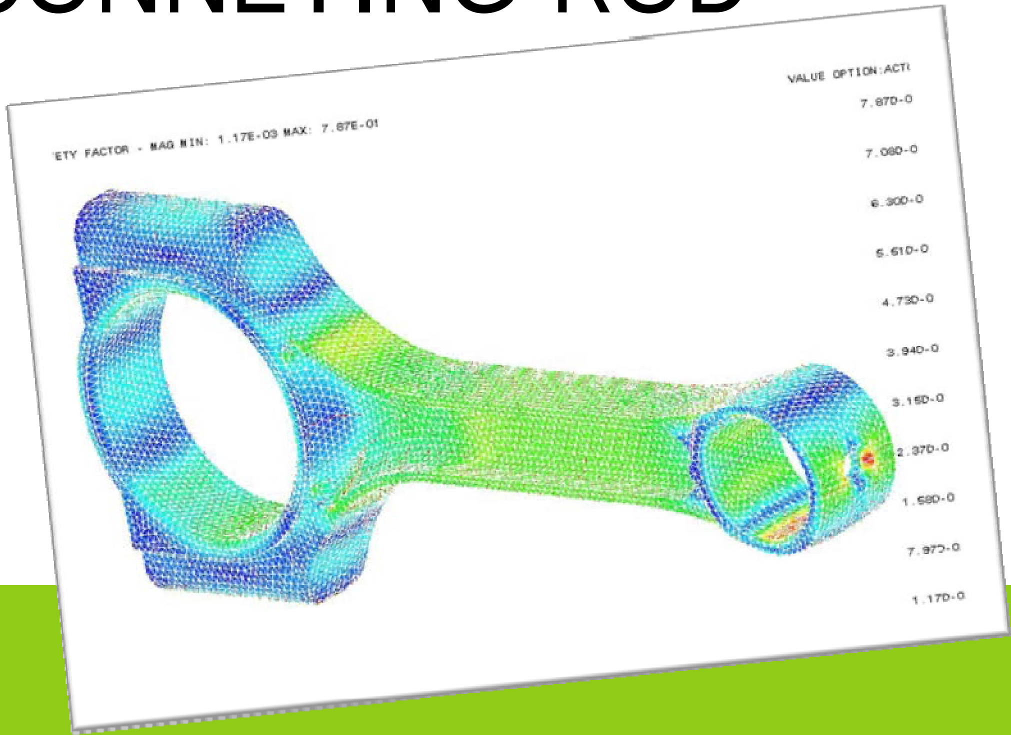
최적설계

OPTIMUM DESIGN OF CONNETING ROD



Op-Rod

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2009-08-27

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PROBLEM STATEMENT

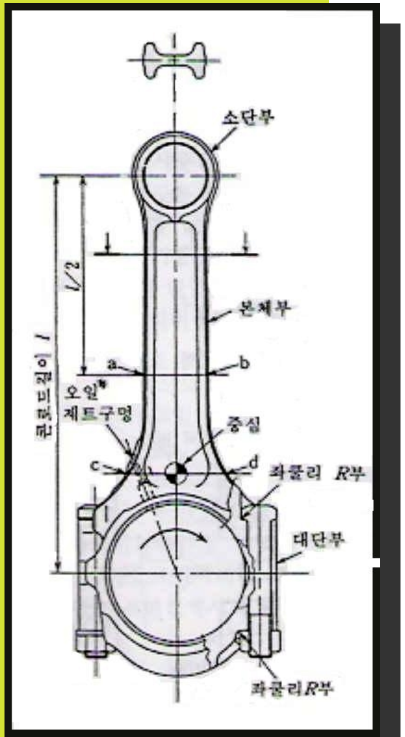
- 기존의 커넥팅 로드는 450g~500g
- The material is a Ti75a
- For low Weight
- 허용응력에 만족하고 좌굴이 생기지 않으며 일반적인 성능(토크)을 발휘하도록 설계
- 기존의 I-beam 형태와 비교하여 hollow shaft형태의 가능성을 판단

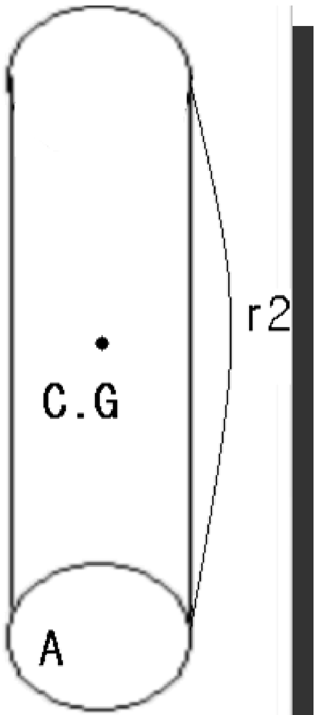
DATA AND INFORMATION

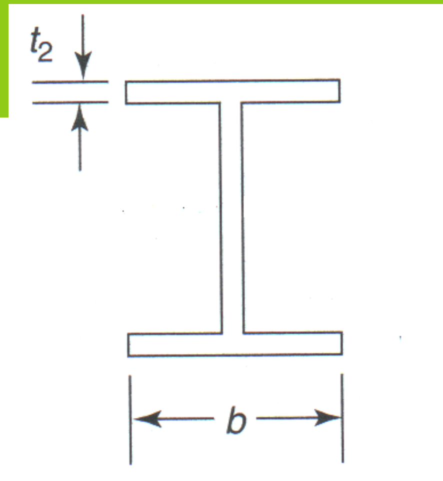
상수명	상수값	설명
D	0.079(m)	피스톤 내경
Izz	Izz(Ro,Ri,l)	회전관성모멘트
M_p	0.439(Kg)	피스톤질량
r_1	0.0485(m)	크랭크반지름
theta	385(Deg)	최대힘크랭크각
theta2	175(Deg)	최소힘크랭크각
N	3600(RPM)	엔진회전수

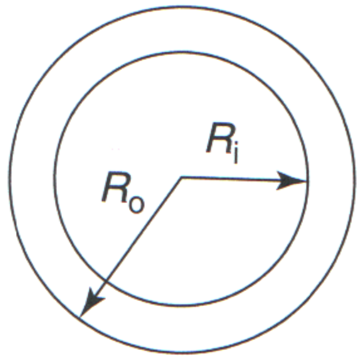
재 료 물 성 치**(TI-75A)**		
피로강도	139(Mpa)	피로해석
극한강도	586(Mpa)	.
밀 도	4400(Kg/m^3)	.

DESIGN VARIABLES









OBJECTIVE FUNCTION

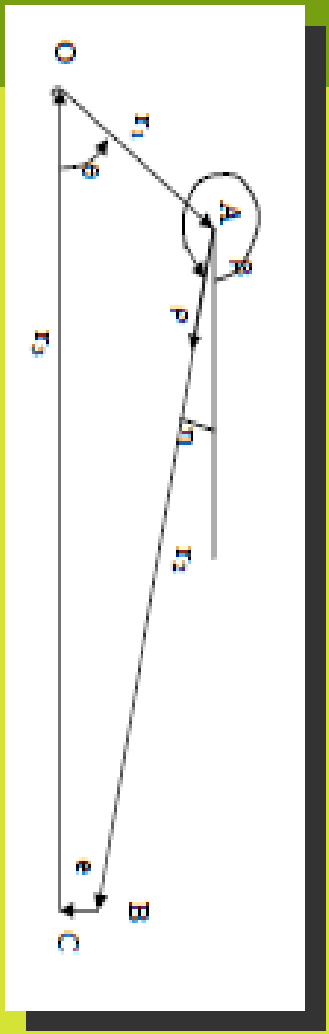
- Mass of the Connecting rod

$$f(l, A) = \rho l A$$

⇓

$$f(R_o, R_i, l) = \rho l \pi (R_o^2 - R_i^2)$$

CONSTRAINTS IN DVS



- Constraints in DVs

$$\sin\beta = -\frac{r_1 \sin\theta}{l} \qquad \cos\beta = \frac{r_1}{l}\sqrt{\left(\frac{l}{r_1}\right)^2 - \sin^2\theta} \qquad \omega = \frac{N r_1 \cos\theta}{l\cos\beta}$$

$$\alpha = \frac{1}{l\cos\beta}\left(\omega_1^2 r_1 \sin\theta - \omega_2^2 l \sin\beta\right)$$

$$m_c(R_o, R_i, l) = \rho l \pi (R_o^2 - R_i^2)$$

$$a = (-r_1\omega_1^2\cos\theta - \frac{l}{2}\omega_2^2\cos\theta - \alpha\frac{l}{2}\sin\beta)\hat{i} + (-r_1\omega_1^2\sin\theta - \frac{l}{2}\omega_2^2\sin\beta - \alpha\frac{l}{2}\cos\beta)\hat{j}$$

$$F_{bx} = -(m_p a_p + GasLoad)$$

$$F_{by} = \frac{l}{\cos\beta}\left[m_c a_{c.gX}\frac{l}{2}\cos\beta - m_c a_{c.gX}\frac{l}{2}\sin\beta + I_{zz}\alpha + F_{bx} l \sin\beta\right]$$

$$F_{ax} = m_c a_{c.gX} - F_{bx}$$

$$F_{ay} = m_c a_{c.gY} - F_{by}$$

CONSTRAINTS IN DVS

- Buckling by axial load on Conrod

```
g1=abs((cos((acos((1-((r_1./x3).^2).*(sin(theta).^2)).^(1./2)))).*(-(((pi.*x1.^2-pi.*x2.^2).*x3.*4400).*(((-
(N.*2.*pi./60).^2).*r_1.*cos(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*x3.*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2)))-
((1./(x3.*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-
(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*x3.*(-
(r_1.*sin(theta)./x3))))+(6064925.*D^2.*pi./4)))+cos(pi/2-(acos((1-
((r_1./x3).^2).*(sin(theta).^2)).^(1./2)))).*(((M_c.*((-r_1.*((N.*2.*pi./60).^2).*sin(theta)-((-
(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-sin(theta).^2).^0.5)).^2).*(x3./2).*(-
(r_1.*sin(theta)./x3))+((1./(x3.*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*(x3./2).*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2))))).*(x3./2).*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2)))-M_c.*((-
r_1.*((N.*2.*pi./60).^2).*cos(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*(x3./2).*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2)))-
((1./(x3.*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-
(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*(x3./2).*(-
(r_1.*sin(theta)./x3)))).*(x3./2).*(-(r_1.*sin(theta)./x3))+Izz.*((1./(x3.*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3))))+(-(((pi.*x1.^2-pi.*x2.^2).*x3.*4400).*(((-
(N.*2.*pi./60).^2).*r_1.*cos(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*x3.*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2)))-
((1./(x3.*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-
(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*x3.*(-
(r_1.*sin(theta)./x3))))+(6064925.*D^2.*pi./4))).*x3.*(-(r_1.*sin(theta)./x3)))./(x3.*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2)))))))./(pi.*x1.^2-pi.*x2.^2)-(pi.^2).*113800000000.*(pi/4).*(x1.^4-x2.^4)./(x3.^2);
```

CONSTRAINTS IN DVS

- Minimum Torque

```
g2=150-((cos(pi/2-theta).*((M_c.*((-r_1.*((N.*2.*pi./60).^2).*cos(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*(x3./2).*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2)))-
((1./(x3.*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-
(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*(x3./2).*(-
(r_1.*sin(theta)./x3))))-(-(((pi.*x1.^2-pi.*x2.^2).*x3.*4400).*(((-(N.*2.*pi./60).^2).*r_1.*cos(theta)-((-
(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-sin(theta).^2).^0.5)).^2).*x3.*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2)))-((1./(x3.*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*x3.*(-
(r_1.*sin(theta)./x3))))+(6064925.*D^2.*pi./4)))))+sin(pi/2-theta).*((M_c.*((-
r_1.*((N.*2.*pi./60).^2).*sin(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*(x3./2).*(-(r_1.*sin(theta)./x3))+((1./(x3.*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*(x3./2).*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2)))))-(((M_c.*((-r_1.*((N.*2.*pi./60).^2).*sin(theta)-((-
(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-sin(theta).^2).^0.5)).^2).*(x3./2).*(-
(r_1.*sin(theta)./x3))+((1./(x3.*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*(x3./2).*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2))))).*(x3./2).*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2)))-M_c.*((-
r_1.*((N.*2.*pi./60).^2).*cos(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*(x3./2).*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2)))-
((1./(x3.*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-
(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*(x3./2).*(-
(r_1.*sin(theta)./x3)))).*(x3./2).*(-(r_1.*sin(theta)./x3))+Izz.*((1./(x3.*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3))))+(-(((pi.*x1.^2-pi.*x2.^2).*x3.*4400).*(((-
(N.*2.*pi./60).^2).*r_1.*cos(theta)-((-(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-
sin(theta).^2).^0.5)).^2).*x3.*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2)))-
((1./(x3.*((r_1./x3).*(((x3./r_1).^2-sin(theta).^2).^(1/2))))).*(((N.*2.*pi./60).^2).*r_1.*sin(theta)-((-
(N.*2.*pi./60).*cos(theta)./(((x3./r_1).^2-sin(theta).^2).^0.5)).^2).*x3.*(-(r_1.*sin(theta)./x3)))).*x3.*(-
(r_1.*sin(theta)./x3))))+(6064925.*D^2.*pi./4))).*x3.*(-(r_1.*sin(theta)./x3))))./(x3.*((r_1./x3).*(((x3./r_1).^2-
sin(theta).^2).^(1/2)))))))))).*r_1;
```

CONSTRAINTS IN DVS

- Fatigue strength by Fluctuaing Stress

$$g3=S_f S_{ut}-2\left[\left(\frac{F_{max}-F_{min}}{2a}\right)S_{ut}+\left(\frac{F_{max}+F_{min}}{2a}\right)S_f\right]\leq 0$$

- Conrod length/Crank radius Recommendation 1

$$g4=r_2-5r_1\leq 0$$

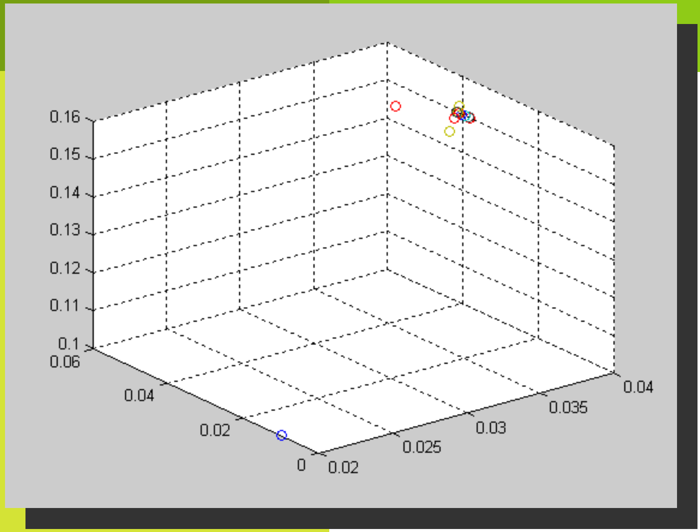
- Conrod length/Crank radius Recommendation 2

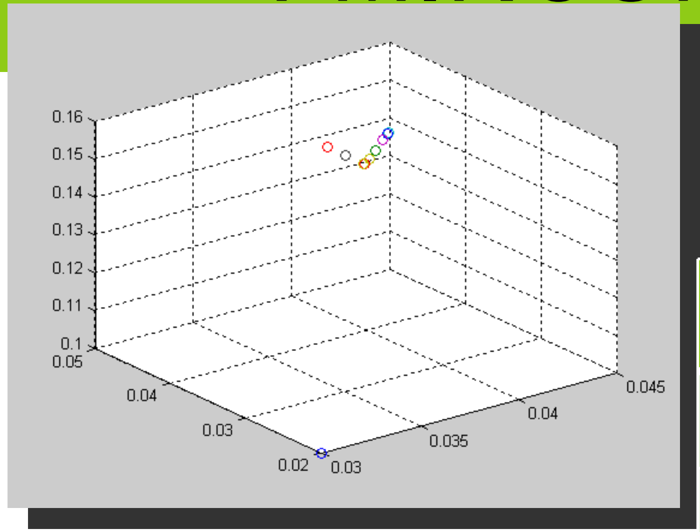
$$g_5=3r_1-r_2\leq 0$$

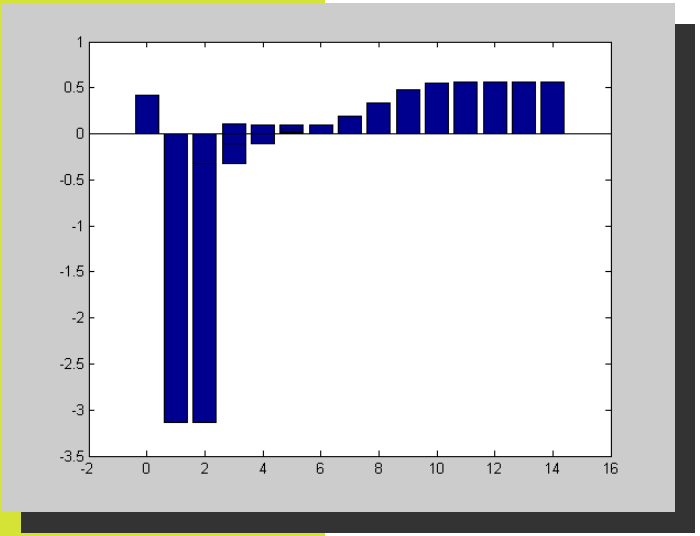
- Cross section restriction by Piston diameter(추가)

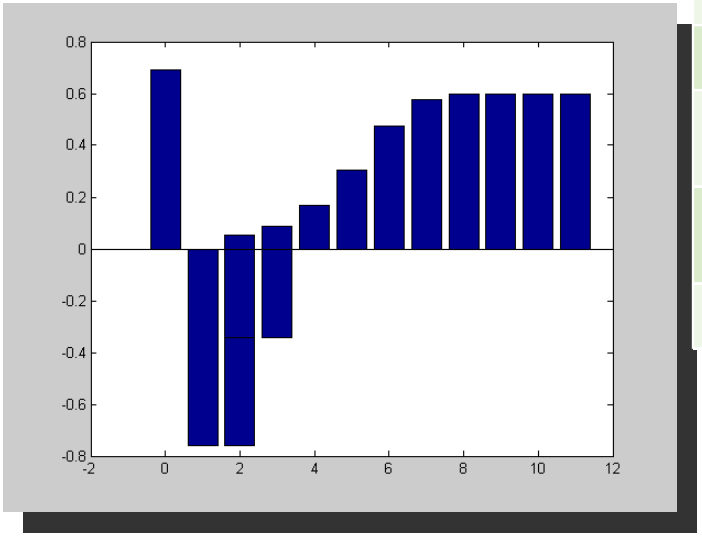
$$g_6=R_o-0.5Bore$$

MATLAB : FMINCON(SQP)









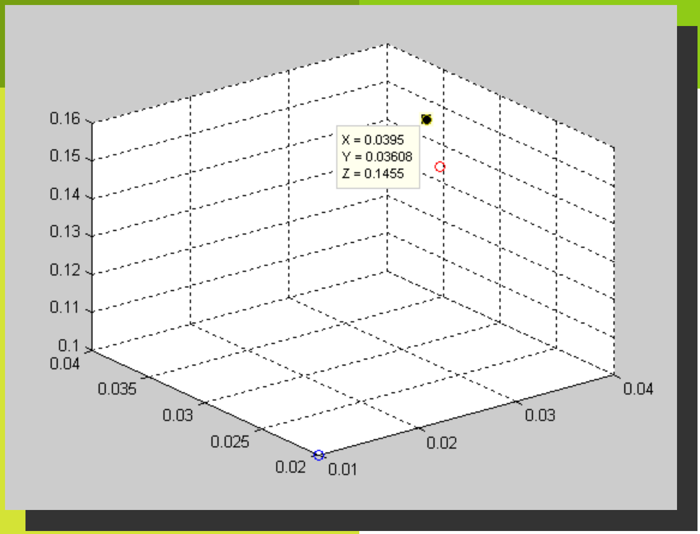
초기값	최적해	Mass
X1=0.02	0.0395	0.559
X2=0.01	0.03595	
X3=0.1	0.1513	
X1=0.03	0.0395	0.597
X2=0.02	0.03583	
X3=0.1	0.1567	

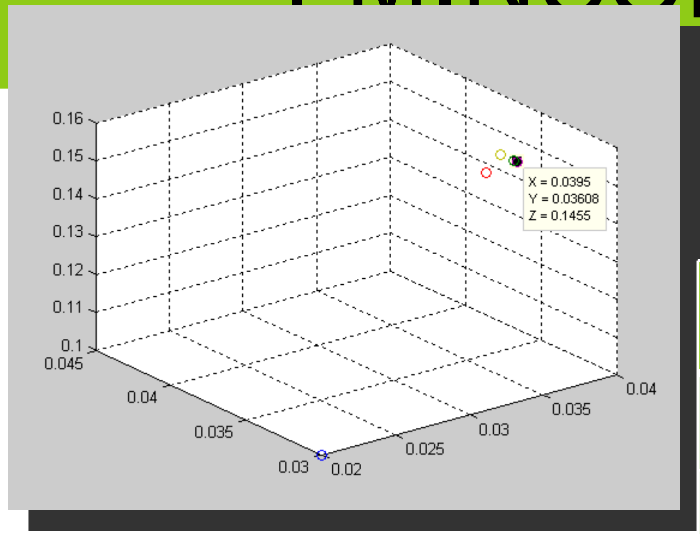
MATLAB : FMINCON(SQP)

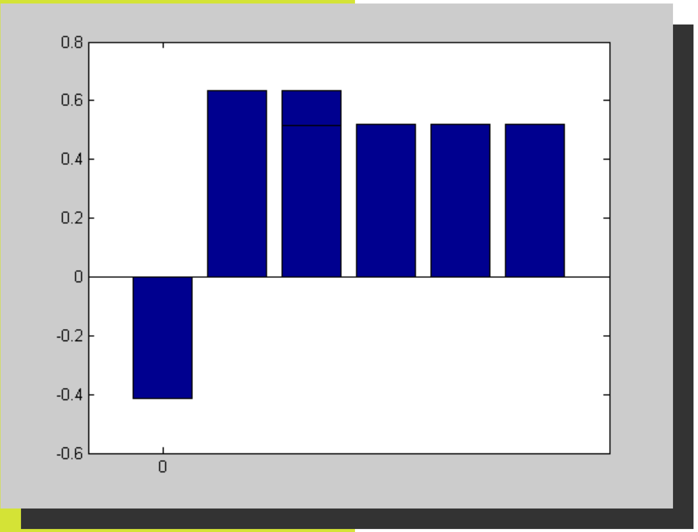
- g1(buckling) & g6(Cross section) are active!
- Modify the Constraint

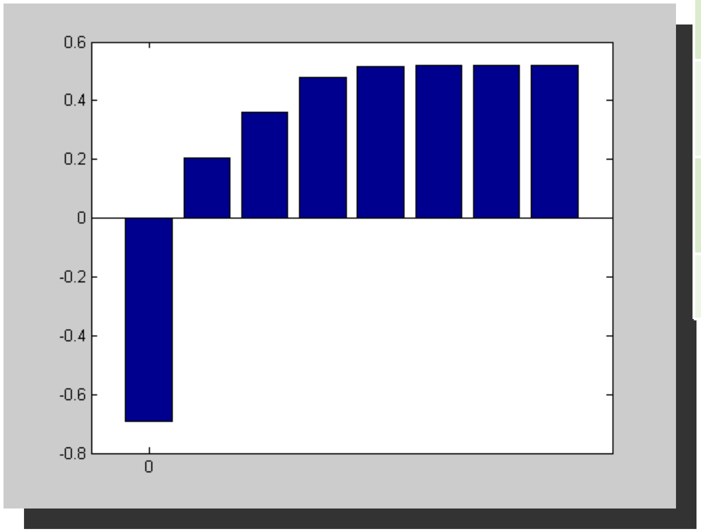
Subjec to
g1 : Minimum Torque
g2 : Fatigue Strength
g3 : Conrod length 1
g4 : Conrod length 2
h1 : Buckling
h2 : Cross section Restriction

MATLAB : FMINCON(SQP)



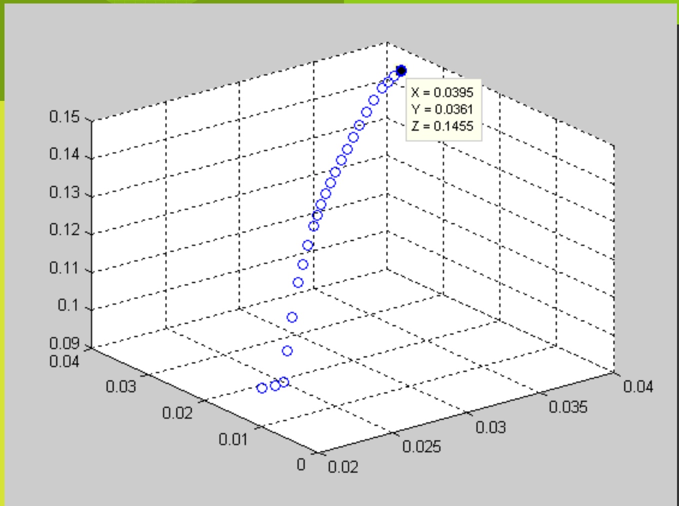


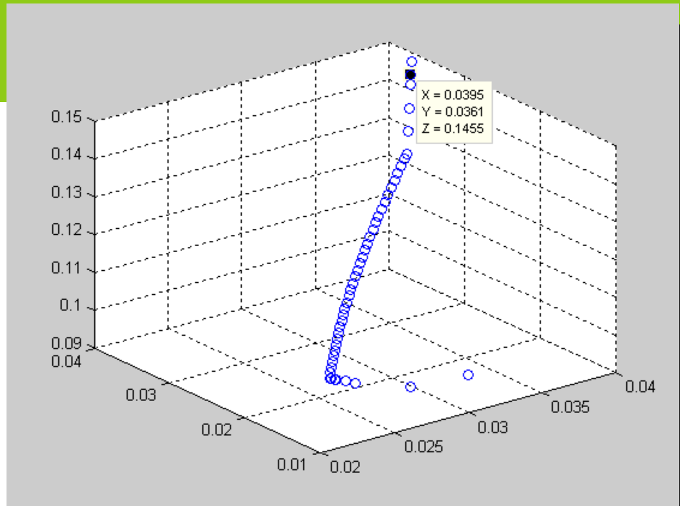


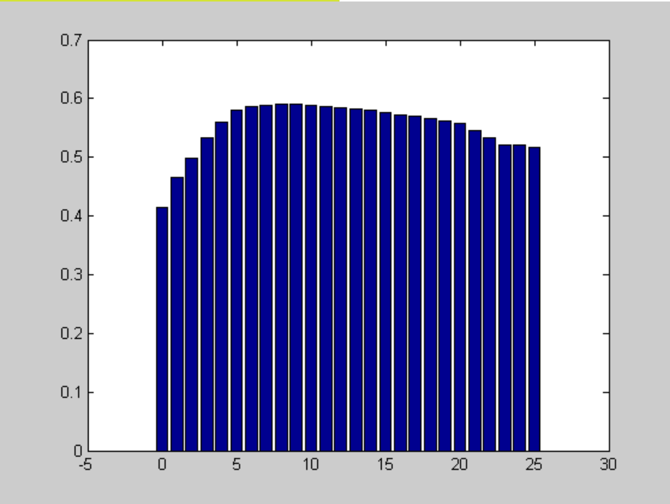


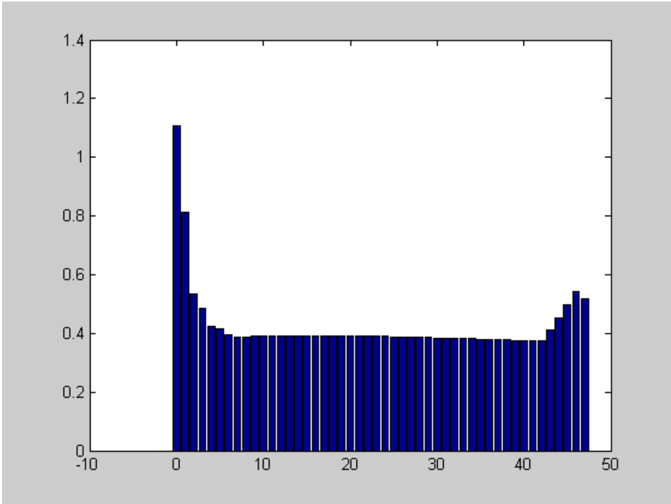
초기값	최적해	Mass
X1=0.01	0.0395	0.519
X2=0.02	0.0361	
X3=0.1	0.1455	
X1=0.02	0.0395	0.519
X2=0.03	0.0361	
X3=0.1	0.1455	

EXCEL : SOLVER(GRG)



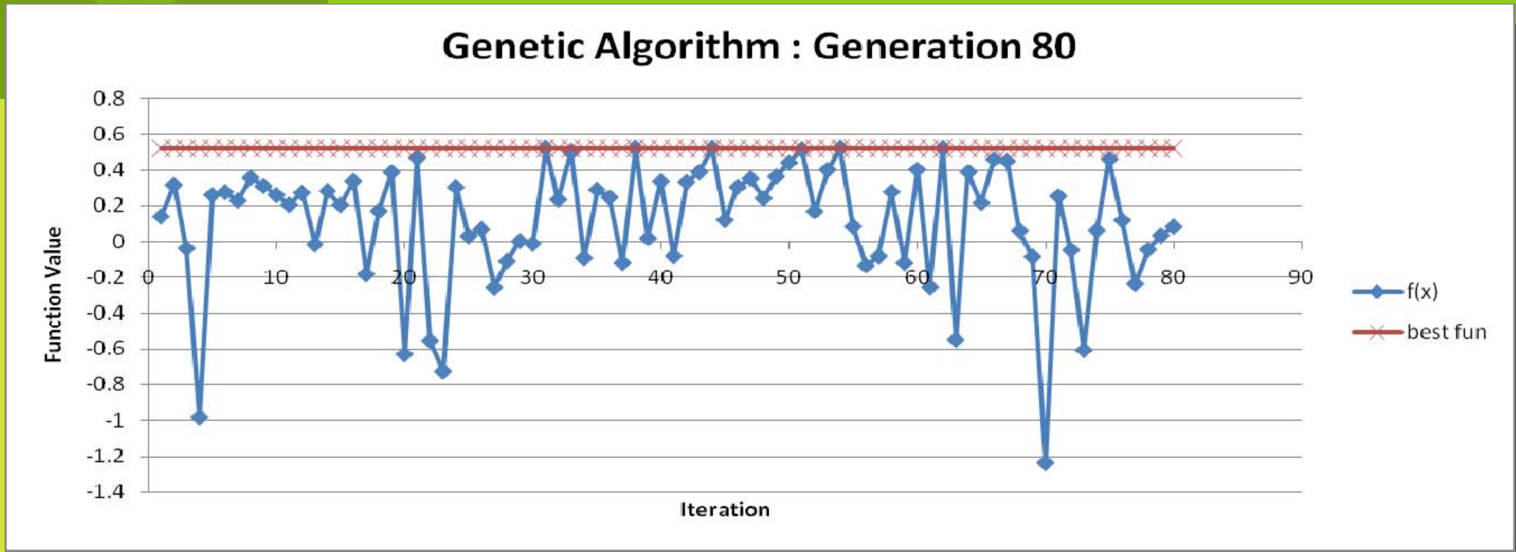


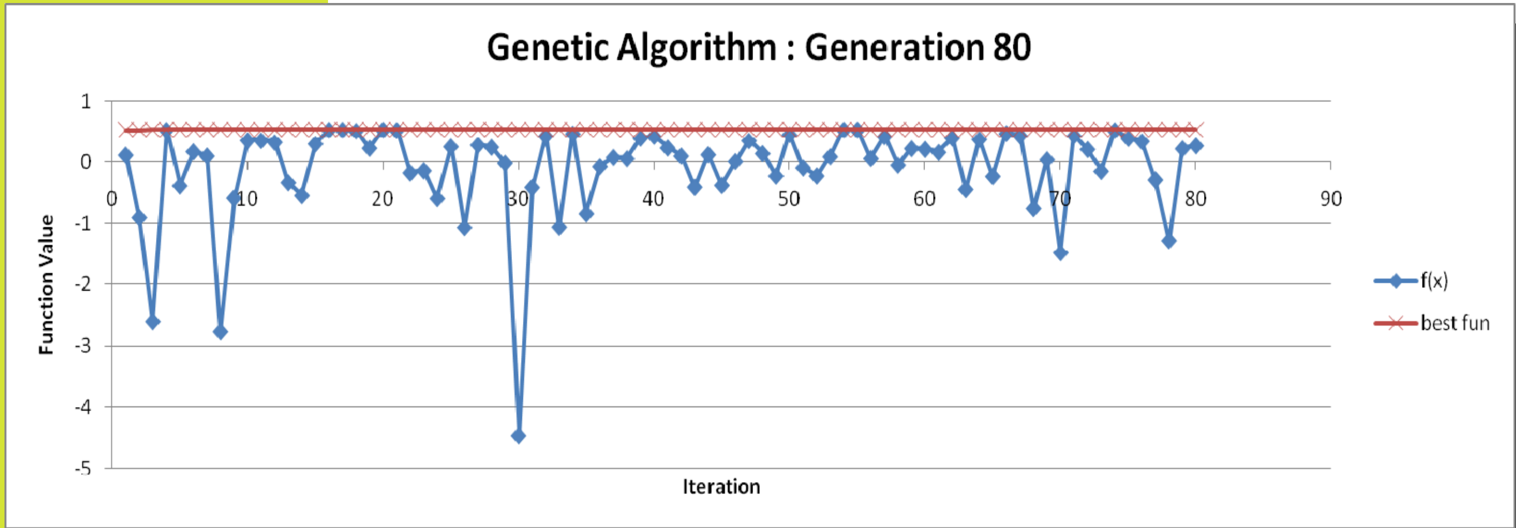




초기값	최적해	Mass
X1=0.02	0.0395	0.517
X2=0.01	0.0361	
X3=0.1	0.1455	
X1=0.03	0.0395	0.517
X2=0.01	0.0361	
X3=0.1	0.1455	

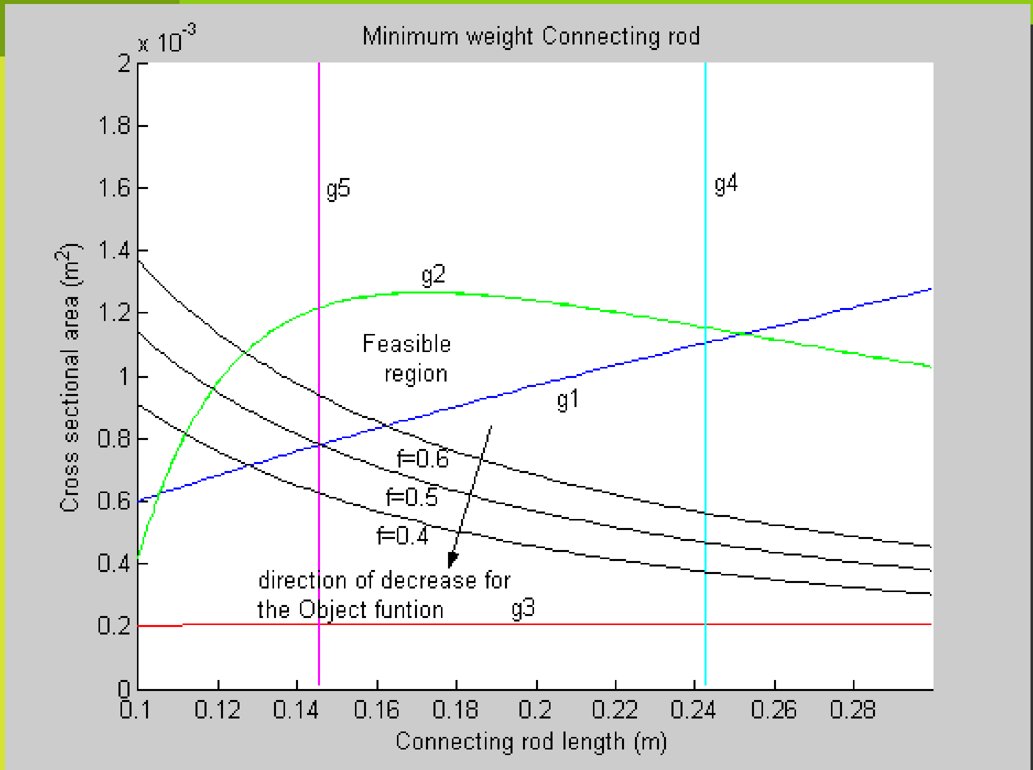
MATLAB : GA





최적해	Mass
0.0394	0.522
0.0361	
0.1459	
0.0395	0.527
0.0361	
0.1466	

PREVIOUS GRAPHICAL SOLUTIONS

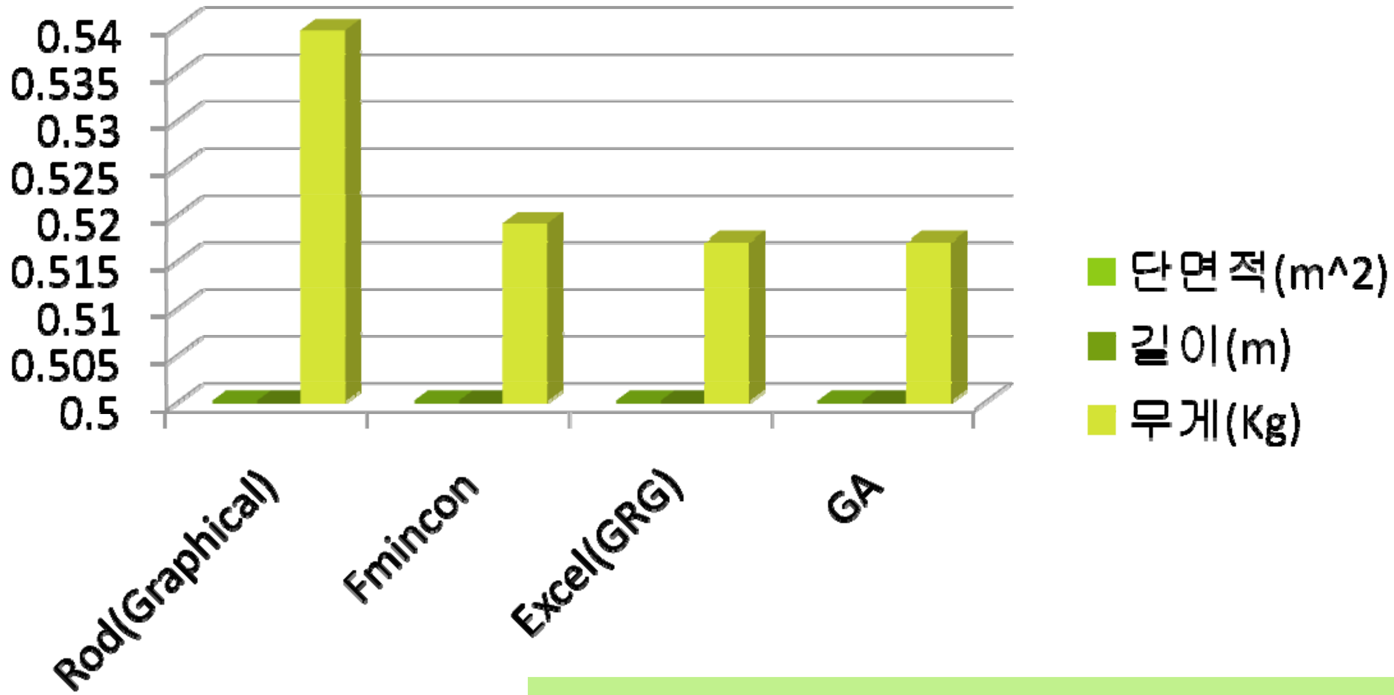


	초기값	해찾기
r_2	0.141	0.1455
A	0.0009	0.00084278
g1	-24.7362	-0.0002113
g5	0.0045	0
sum	611.879611	4.4651E-08

- 도해기법을 통한 최적해 도출

$$f = \rho A r_2$$
$$= (4400)(0.00084278)(0.1455)$$
$$= 0.53954[kg]$$

COMPARE OF THE SOLUTIONS



	단면적(m^2)	길이(m)	무게(Kg)
Rod(Graphical)	0.000843	0.1455	0.53954
Fmincon	0.000845	0.1455	0.519
Excel(GRG)	0.000845	0.1455	0.517
GA	0.000808	0.1462	0.524

THANK YOU

-Reference

- Shoichi Furuhama, 엔진 핸드북
- www.autosteel.org, Dynamic load analysis
- Norton, Machine design
- 한국자동차공학회, 자동차 기술핸드북:설계편