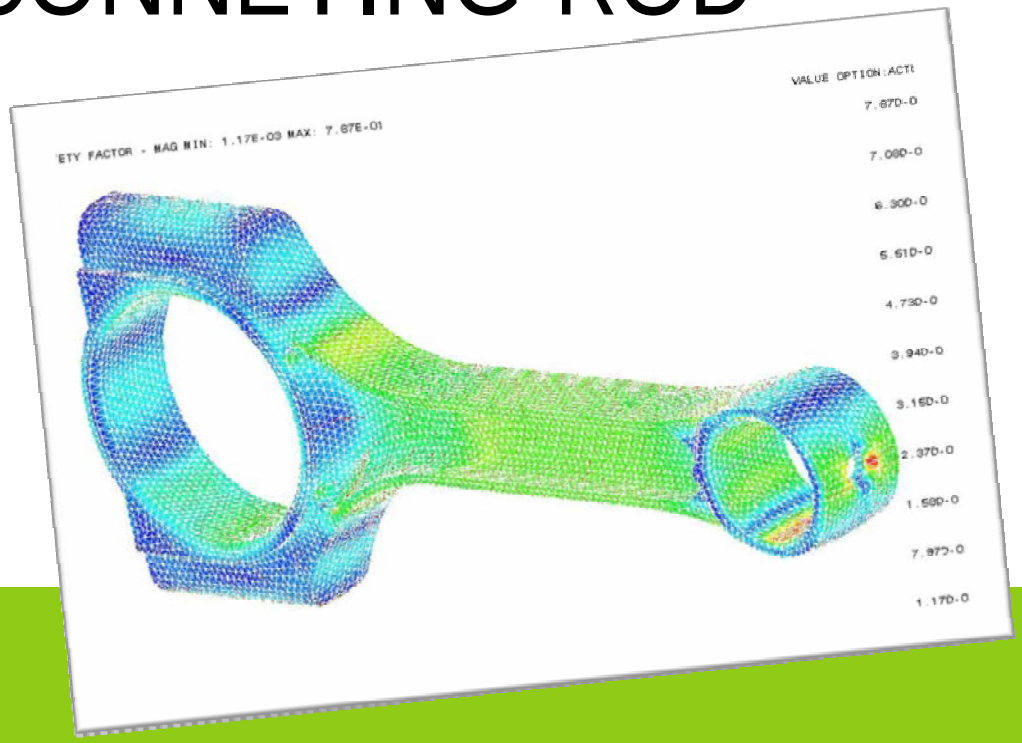
최적설계

OPTIMUM DESIGN OF CONNETING ROD



Op-Rod

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2008-11-17

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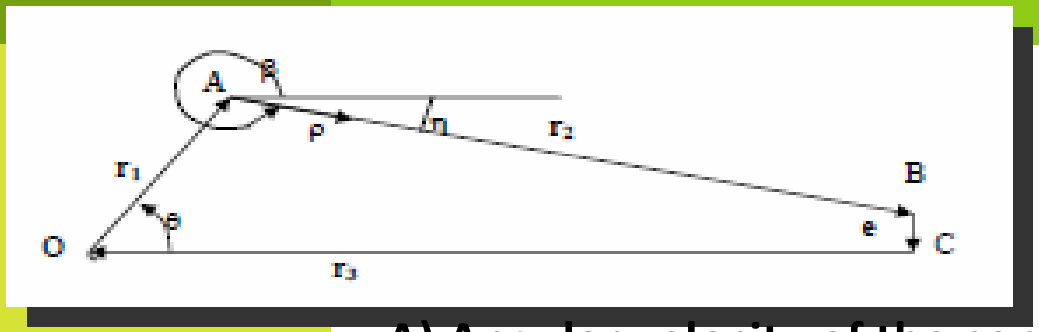
STEP 1: PROBLEM STATEMENT

- Design a Connecting Rod
- The material is a Ti75a
- For low Weight(Cost)
- 허용응력에 만족하고 좌굴이 생기지 않으며 일반적인 성능(토크)을 발휘하는 로드
- 커넥팅 로드의 형상은 자유형상이 아닌 봉(단면넓이,길이)으로 간략화

STEP 2: DATA AND INFORMATION COLLECTION(1)



A) Angular velocity of the connecting rod

- $\mathbf{e + r_1 + r_2 + r_3 = 0}$ **(e=0)**
- $\boldsymbol{\omega_1 \times r_1 + \omega_2 \times r_2 - V_p = 0}$
- $\omega_2 = - (\omega_1 r_1 \cos\Theta) / (r_2 \cos\beta)$
- $\omega_2 = - \omega_1 \cos\Theta / [(r_2 / r_1)2 - \sin2\Theta] 0.5$

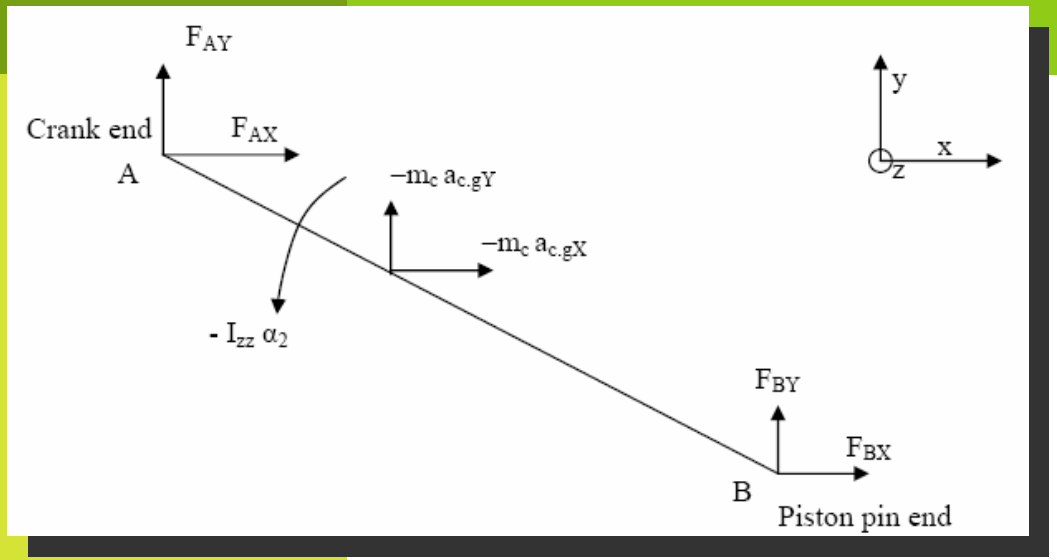
B) Angular acceleration of the connecting rod

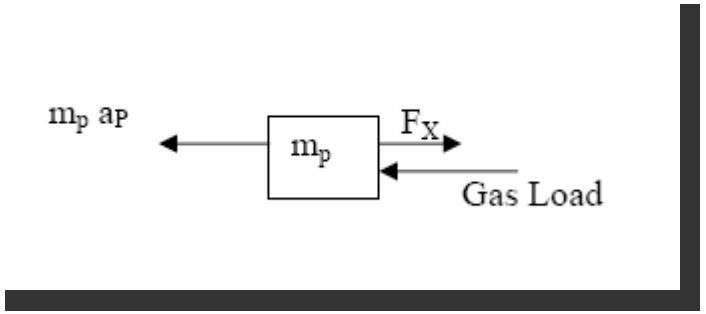
- $\boldsymbol{\omega_1 \times \omega_1 \times r_1 + \omega_2 \times \omega_2 \times r_2 + \alpha_2 \times r_2 - a_p = 0}$
- $\alpha_2 = (- \omega_1 \times \omega_1 \times r_1 \ \mathbf{j} - \omega_2 \times \omega_2 \times r_2 \ \mathbf{j}) / (k \times r_2 \ \mathbf{j})$
- $\alpha_2 = (1 / r_2 \cos\beta) [\omega_1^2 r_1 \sin\Theta - \omega_2^2 r_2 \sin\beta]$

C) Absolute acceleration of the connecting rod

- $\mathbf{a = a_A + \alpha_2 \times \rho + \omega_2 \times \omega_2 \times \rho}$
- $= (- r_1 \omega_1^2 \cos\Theta - \omega_2^2 u \cos\beta - \alpha_2 u \sin\beta)$ **i**
- $+ (- r_1 \omega_1^2 \sin\Theta - \omega_2^2 u \sin\beta + \alpha_2 u \cos\beta)$ **j**

STEP 2: DATA AND INFORMATION COLLECTION(2)



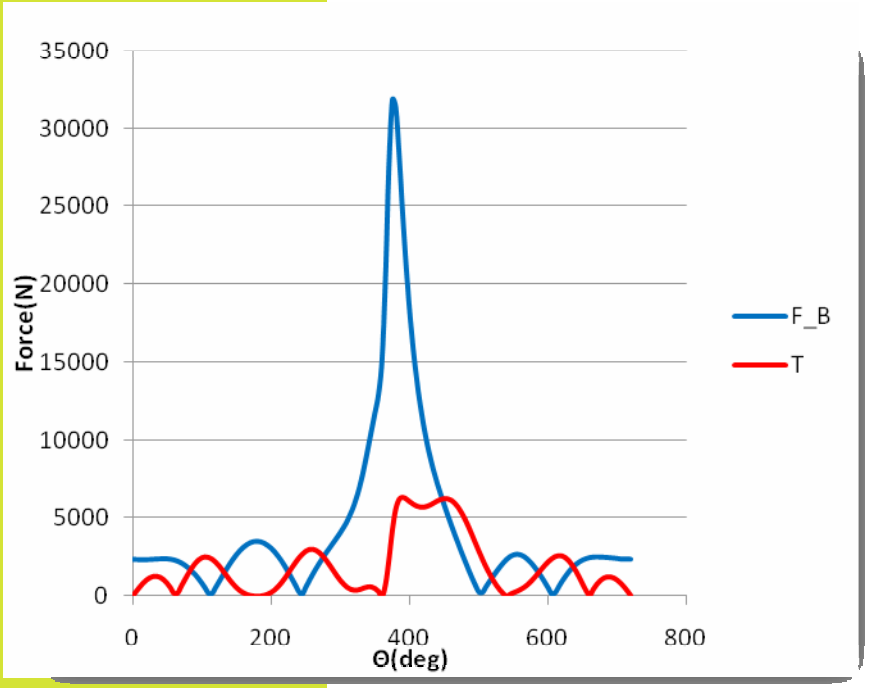


D) Forces at the connecting rod ends

- $F_X - m_p\, a_P$ - Gas Load = 0
- $F_{BX} = -(m_p\, a_P + \text{Gas Load})$
- $F_{BY} = [m_c\, a_{c.g}Y \text{ u } \cos\beta - m_c\, a_{c.g}X \text{ u } \sin\beta + Izz\ \alpha_2 + FBX\ r_2\ \sin\beta] / (r_2\ \cos\beta)$
- $F_{AX} = m_c\, a_{c.g}X - F_{BX}$
- $F_{AY} = m_c\, a_{c.g}Y - F_{BY}\alpha_2 \text{ x } r_2 = \alpha_2\ k \text{ x } (r_2\ \cos\beta\ \mathbf{i} + r_2\ \sin\beta\ \mathbf{j})$

STEP 2: DATA AND INFORMATION COLLECTION(3)

로드에 작용하는 토크 및 힘 분석



초기값	
A	0.141
M_c	0.55
r_2	0.141

Crank	P@3600rpm	F_B	Force Torque
deg	kpa	N	N
0	85.4	2380.888	1.26328E-13
30	59.0	2381.542	1275.228867
60	53.6	2332.838	190.4569697
90	60.8	1417.259	2088.283049
120	75.8	568.2137	2184.689301
150	88.7	2672.384	558.0798266
180	100.2	3529.265	5.05573E-14
210	106.3	2584.953	614.2581958
240	128.5	301.3427	2448.954488
270	202.8	2151.428	2784.197639
300	400.2	4089.722	1015.85862
330	1077.1	7422.419	465.348669
360	2681.5	15106.36	5.59546E-13
390	4507.0	24481.26	6329.635723
420	1747.7	10990.13	5705.481168
450	910.5	5837.229	6252.986912
480	621.6	2239.875	4919.019897
510	507.9	601.4987	1896.06664
540	335.3	2376.882	6.0252E-13
570	147.5	2380.574	745.6070533
600	82.4	534.3491	2218.004249
630	95.3	1595.198	2257.513204
660	84.3	2486.999	83.70260768
690	77.7	2473.346	1243.214414
719	85.4	2381.078	59.29979793

STEP 2: DATA AND INFORMATION COLLECTION(4)

Corretion Factors	
C_load	Aixal load
C_size	Very small
C_surf	Machined
C_temp	<450℃
C_reliab	99%

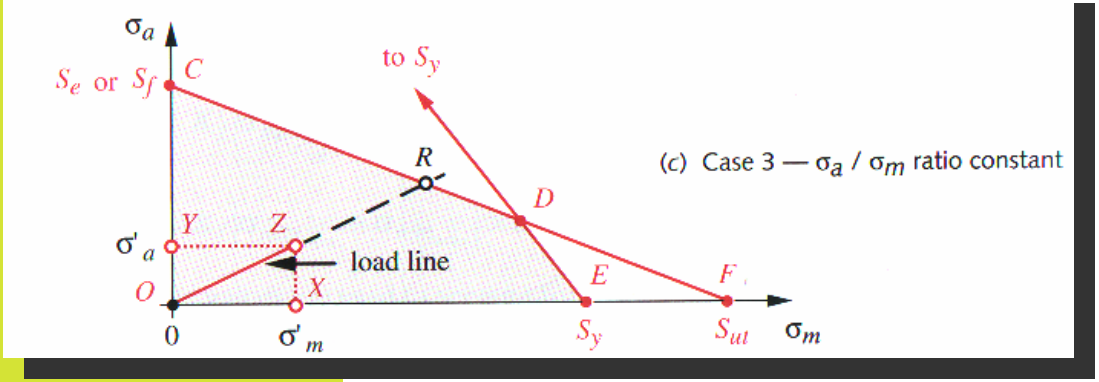
- Alternating stress & Mean stress

$$\sigma_a = \frac{\sigma_{\max} - \sigma_{\min}}{2} \qquad \sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2}$$

- Fatigue strength

$$S_f = C_{load} C_{size} C_{surf} C_{temp} C_{reliab} S_f'$$
$$= (0.7)(1)(1)(0.833)(0.814)(0.5 \times 586) = 139 \ \ (MPa)$$

- Safety Factor from Modified-Goodman Diagram



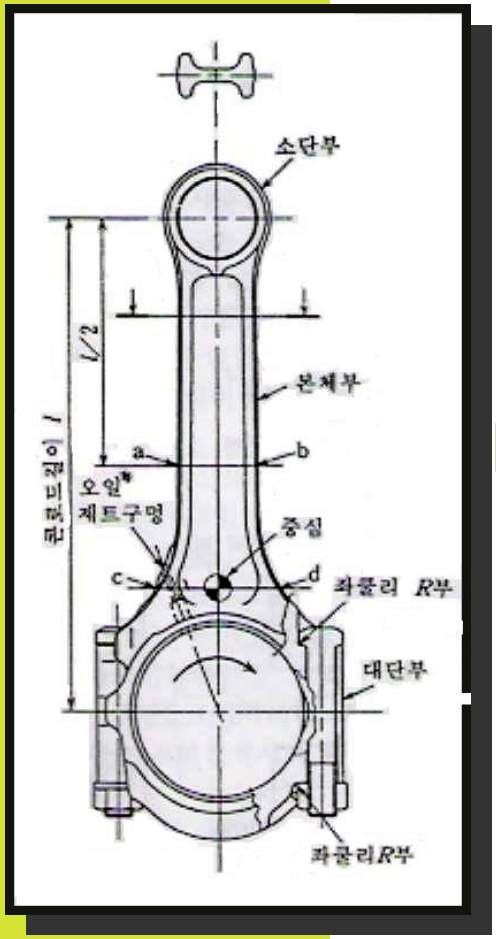
$$N_f = \frac{S_f S_{ut}}{\sigma_a S_{ut} + \sigma_m S_f}$$

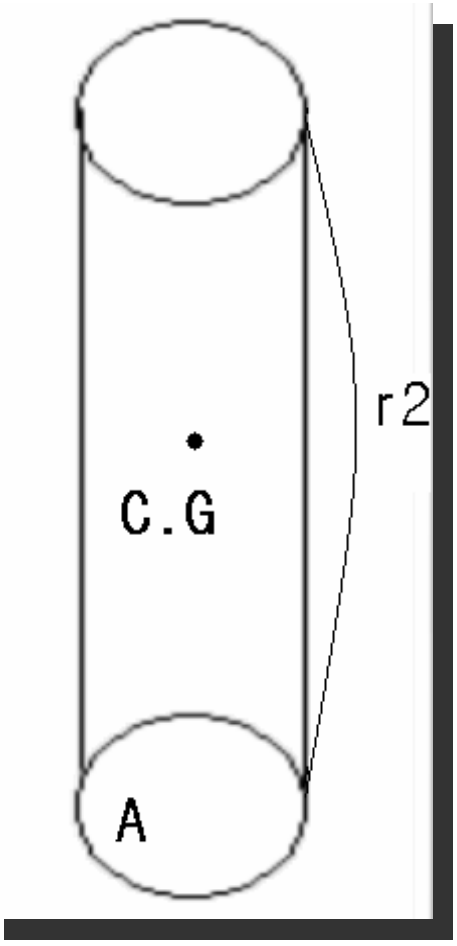
STEP 2: DATA AND INFORMATION COLLECTION(5)

상수명	상수값	설명
D	0.079(m)	피스톤 내경
Izz	0.00144(Kgm^2)	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)	.

STEP 3: DEFINITION OF DESIGN VARIABLES





- Connecting rod length : r2
- Cross sentional area : A

Step 4: Identification of a Criterion to Be Optimized

- Mass of the Connecting rod

$$f(A, r_2) = \rho A r_2$$

STEP 5: IDENTIFICATION OF CONSTRAINTS

- Buckling by axial load on Conrod

$$g_1 = \frac{F_{max}}{A} - \frac{\pi^2 E A^2}{l^2} \leq 0$$

- Minimum Torque

$$g_2 = 134 - \cos\left(\frac{\pi}{2} - \theta\right) \mathrm{F\_AX} + \sin\left(\frac{\pi}{2} - \theta\right) \mathrm{F\_AY} \leq 0$$

- Fatigue strength by Fluctuaing Stress

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

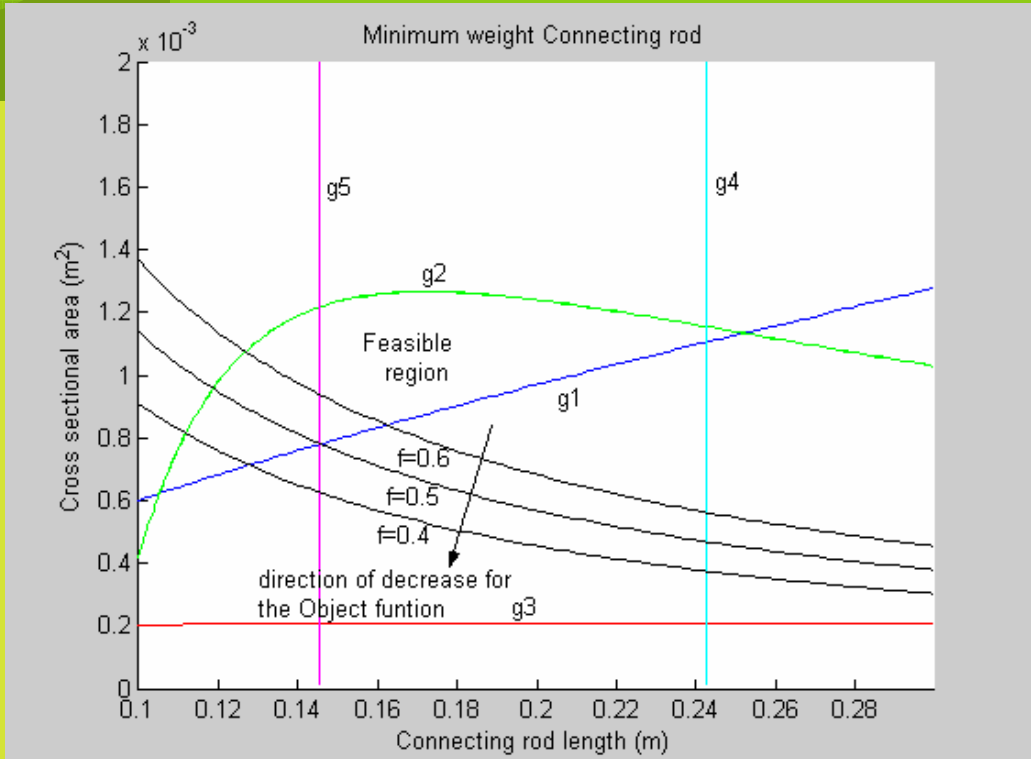
- Conrod length/Crank radius Recommendation 1

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

- Conrod length/Crank radius Recommendation 2

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

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

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

THANK YOU

-Reference

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