차량의 승차감을 고려한 서스펜션의 C, K값 최적화

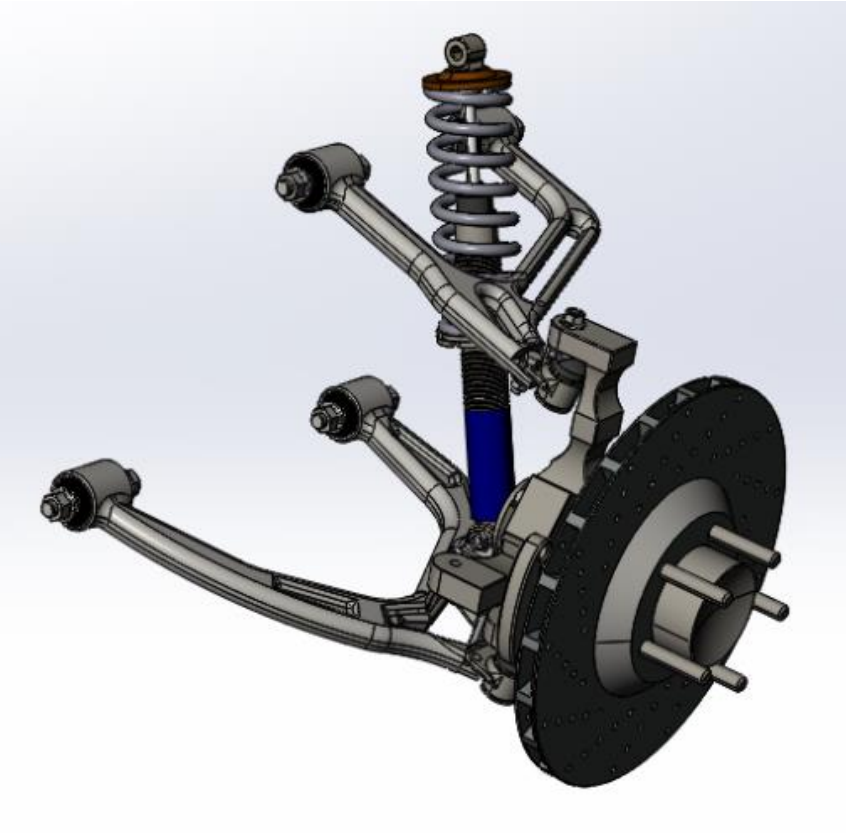
2018016053
우제경

Contents.

Part 1

이론적 배경

Part 1, 서스펜션의 역할

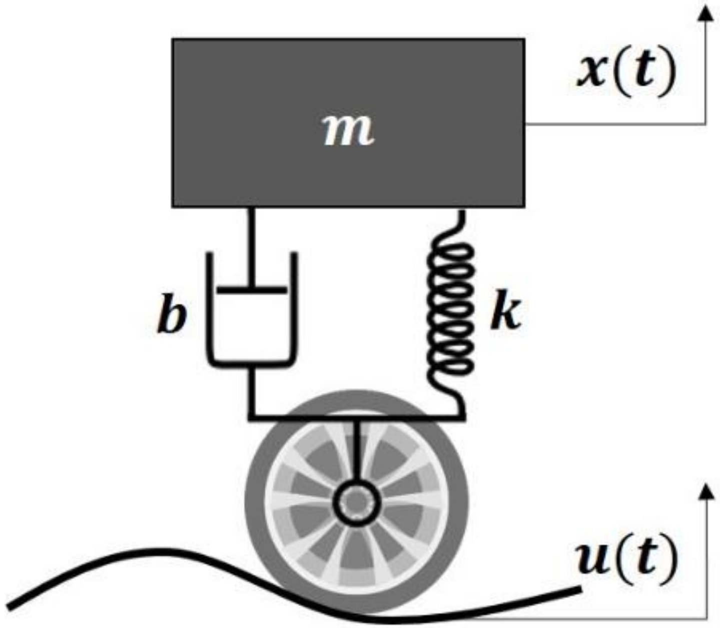


1 차체 무게를 지지

2 타이어 접지면에서의 충격을 흡수

3 핸들링의 안정성을 높임

Part 1, 1 DOF Quarter-Car Model



$$m\ddot{x} = -K(x-u) - C(\dot{x}-\dot{u})$$

$$G(s) = \frac{X}{U} = \frac{Cs+K}{ms^2+Cs+K}$$

$$\left|\frac{\ddot{X}}{U}\right| = \omega^2\left|\frac{X}{U}\right|$$

$$= \omega^2\sqrt{\frac{K^2+C^2\omega^2}{(K-m\omega^2)^2+C^2\omega^2}} = \sqrt{\frac{w^4(2\zeta\omega_n\omega)^2+\omega^4\omega_n^4}{(\omega_n^2-\omega^2)^2+(2\zeta\omega_n\omega)^2}}$$

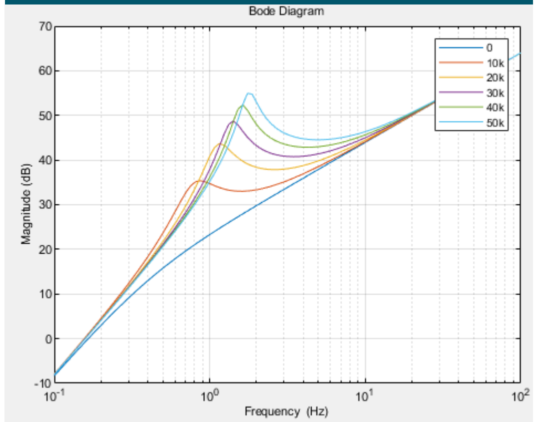
Part 2

설계 과정

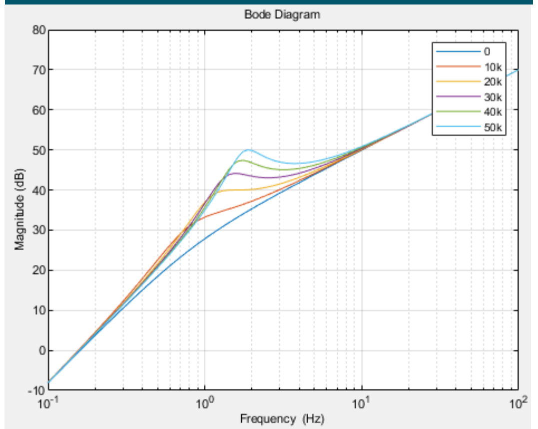
Part 2, C와 K값의 따른 Bode Plot

M=400Kg일 때, C와 K에 따른 그래프 변화

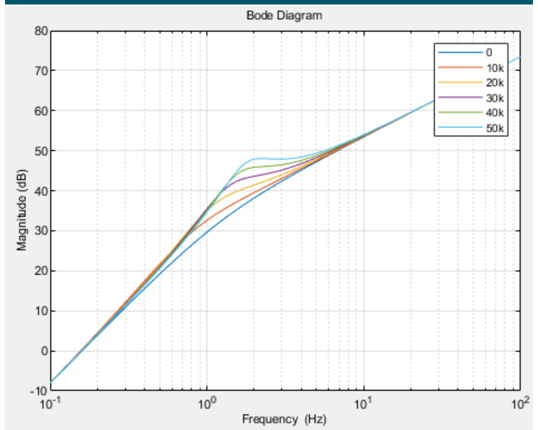
C=1000Ns/m



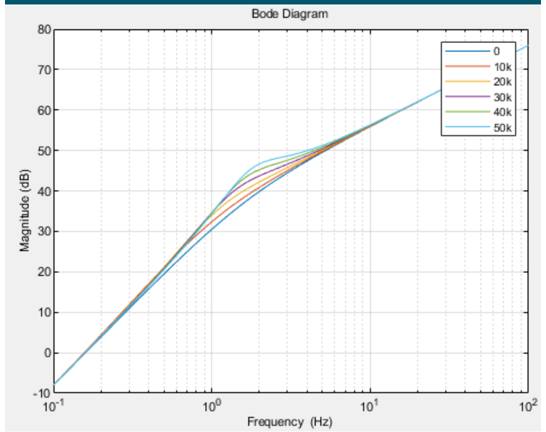
C=2000Ns/m



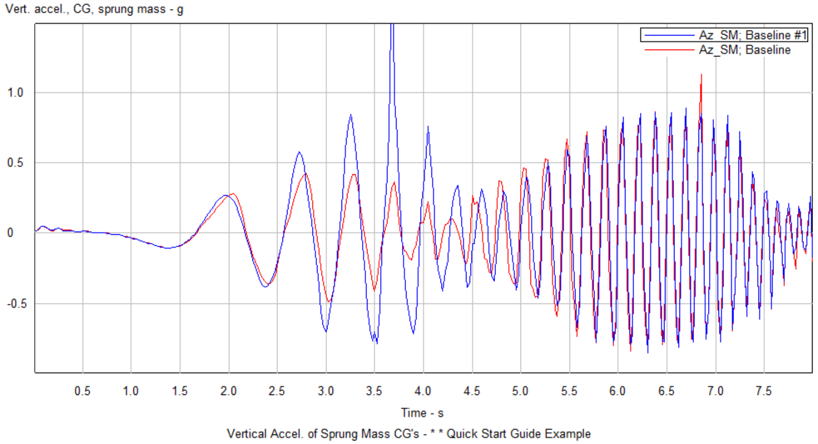
C=3000Ns/m



C=4000Ns/m



K가 커질수록 공명이 커지고, C가 커질수록 w가 Stationary Point보다 클 때, Magnitude가 커진다.



CarSim에서 C-Cl ass Hatchback 선택
K값 20kN/m, 80kN/m에 따른 수직방향 가속도 비교

Part 2, Resonance Frequency 구하기

$$\left|\frac{\ddot{X}}{U}\right| = \omega^2\sqrt{\frac{K^2 + C^2\omega^2}{(K - m\omega^2)^2 + C^2\omega^2}} = \sqrt{\frac{w^4(2\zeta\omega_n\omega)^2 + \omega^4\omega_n^4}{(\omega_n^2 - \omega^2)^2 + (2\zeta\omega_n\omega)^2}}$$

$$\frac{d}{d\omega}\left|\frac{\ddot{X}}{U}\right| = \frac{1}{2}\left(\frac{\omega^4(2\zeta\omega_n\omega)^2 + \omega^4\omega_n^4}{(\omega_n^2 - \omega^2)^2 + (2\zeta\omega_n\omega)^2}\right)^{-\frac{1}{2}}\frac{d}{d\omega}\left(\frac{\omega^4(2\zeta\omega_n\omega)^2 + \omega^4\omega_n^4}{(\omega_n^2 - \omega^2)^2 + (2\zeta\omega_n\omega)^2}\right)$$

$$= \frac{1}{2}\left(\frac{\omega^4(2\zeta\omega_n\omega)^2 + \omega^4\omega_n^4}{(\omega_n^2 - \omega^2)^2 + (2\zeta\omega_n\omega)^2}\right)^{-\frac{1}{2}}\left(\frac{\boxed{4\omega_n^2\omega^3(2\zeta^2\omega^6 + (16\zeta^4\omega_n^2 - 8\zeta^2\omega_n^2)\omega^4 + (8\zeta^2\omega_n^4 - \omega_n^4)\omega^2 + \omega_n^6)}}{((\omega_n^2 - \omega^2)^2 + (2\zeta\omega_n\omega)^2)^2}\right)$$

$$2\zeta^2 W^3 + (16\zeta^4\omega_n^2 - 8\zeta^2\omega_n^2)W^2 + (8\zeta^2\omega_n^4 - \omega_n^4)W^2 + \omega_n^6 = 0$$

Part 2,

Resonance Frequency 구하기

3차 방정식 해 구하기

$$ax^3 + bx^2 + cx + d = 0$$

$$x_1 = -\frac{b}{3a} - \frac{1}{3a}\sqrt[3]{\frac{2b^3 - 9abc + 27a^2d + \sqrt{(2b^3 - 9abc + 27a^2d)^2 - 4(b^2 - 3ac)^3}}{2}} - \frac{1}{3a}\sqrt[3]{\frac{2b^3 - 9abc + 27a^2d - \sqrt{(2b^3 - 9abc + 27a^2d)^2 - 4(b^2 - 3ac)^3}}{2}}$$

$$x_2 = -\frac{b}{3a} + \frac{1 + i\sqrt{3}}{6a}\sqrt[3]{\frac{2b^3 - 9abc + 27a^2d + \sqrt{(2b^3 - 9abc + 27a^2d)^2 - 4(b^2 - 3ac)^3}}{2}} + \frac{1 - i\sqrt{3}}{6a}\sqrt[3]{\frac{2b^3 - 9abc + 27a^2d - \sqrt{(2b^3 - 9abc + 27a^2d)^2 - 4(b^2 - 3ac)^3}}{2}}$$

$$x_3 = -\frac{b}{3a} + \frac{1 - i\sqrt{3}}{6a}\sqrt[3]{\frac{2b^3 - 9abc + 27a^2d + \sqrt{(2b^3 - 9abc + 27a^2d)^2 - 4(b^2 - 3ac)^3}}{2}} + \frac{1 + i\sqrt{3}}{6a}\sqrt[3]{\frac{2b^3 - 9abc + 27a^2d - \sqrt{(2b^3 - 9abc + 27a^2d)^2 - 4(b^2 - 3ac)^3}}{2}}$$

$$2\zeta^2 W^3 + (16\zeta^4\omega_n^2 - 8\zeta^2\omega_n^2)W^2 + (8\zeta^2\omega_n^4 - \omega_n^4)W^2 + \omega_n^6 = 0$$

$$a = 2\zeta^2$$

$$b = 16\zeta^4\omega_n^2 - 8\zeta^2\omega_n^2$$

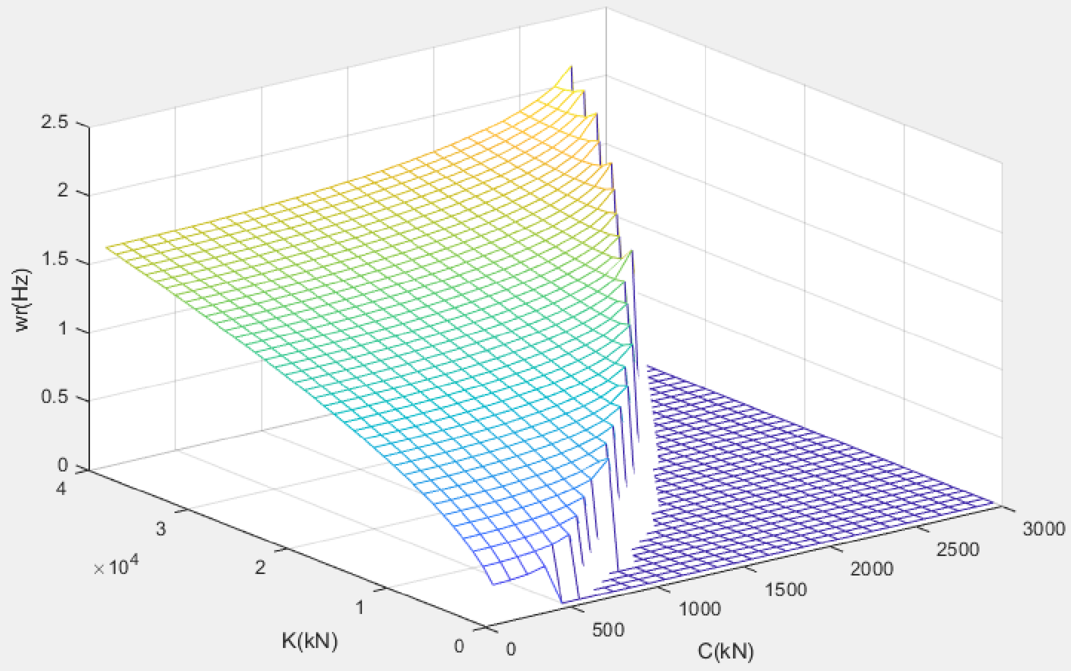
$$c = 8\zeta^2\omega_n^4 - \omega_n^4$$

$$d = \omega_n^6$$

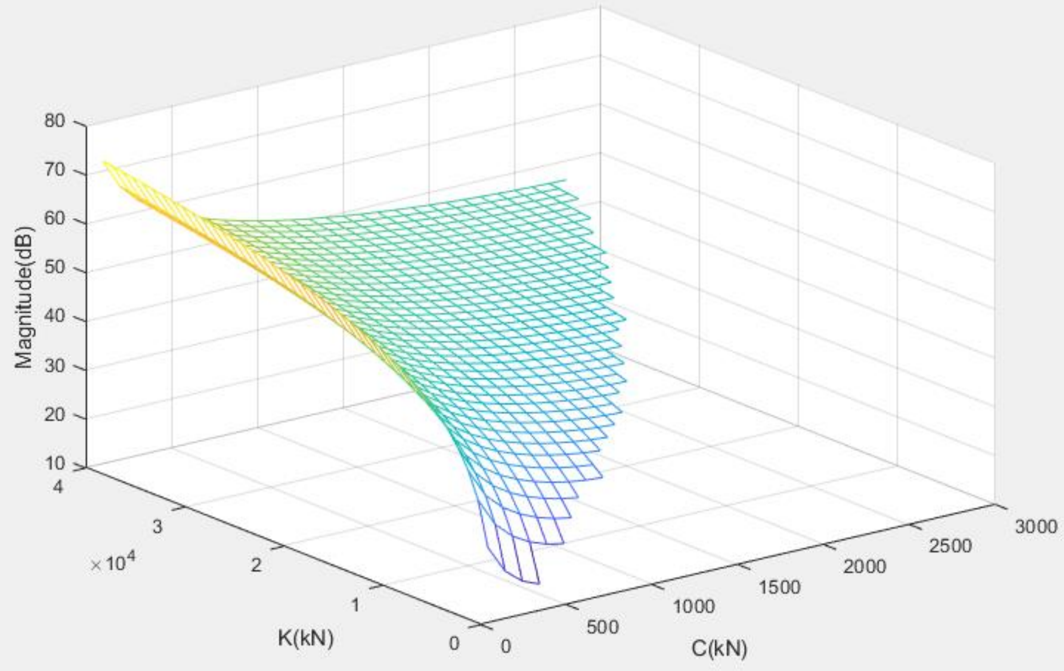
W의 근 중 양의 실수에서 작은 값을 선택

Part 2, Resonance Frequency & Magnitude

Resonance Frequency



Magnitude

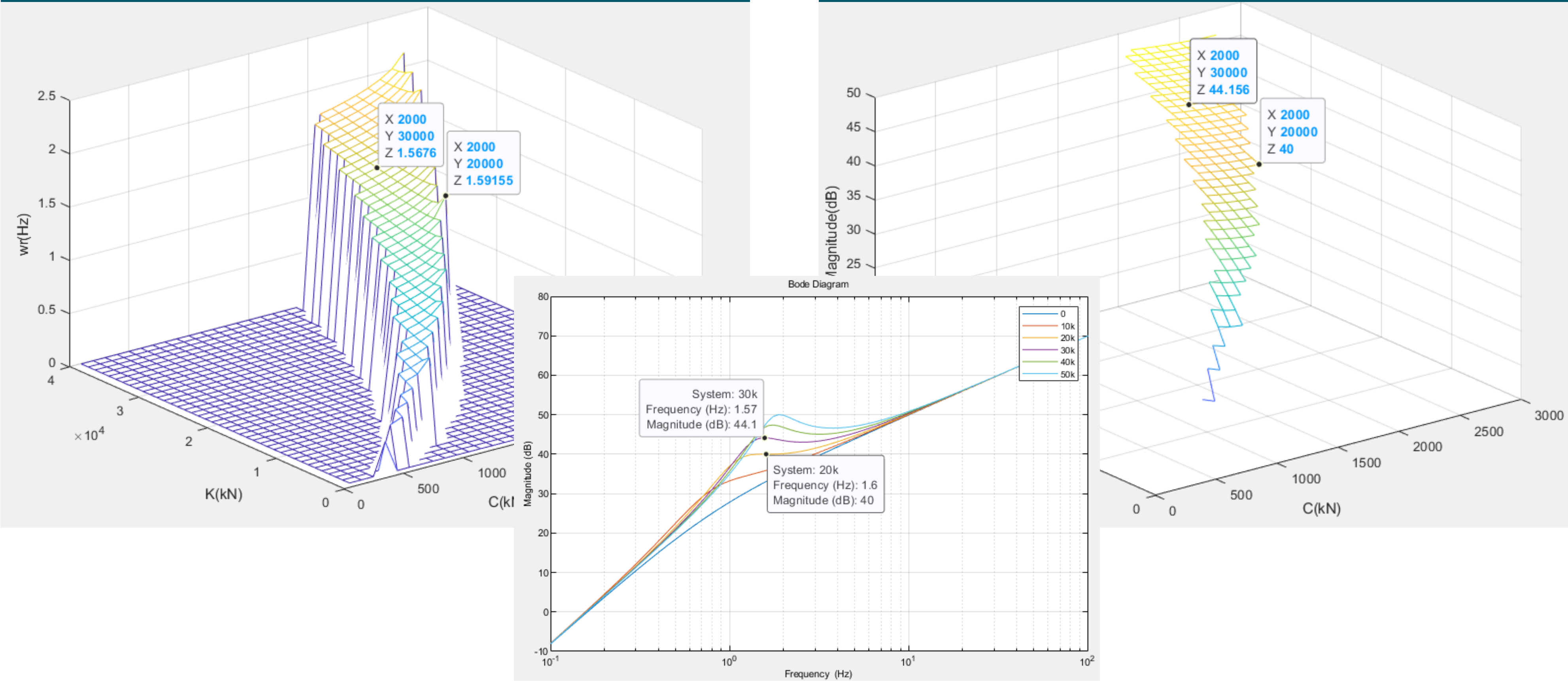


Jeta를 고려한 Resonance Frequency & Magnitude

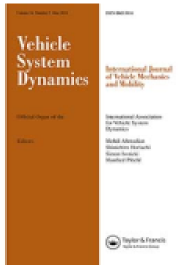
실제 차량에서는 $0.25 \leq \zeta \leq 0.4$ 로 설계 $\left(\zeta = \dfrac{C}{2\sqrt{mK}}\right)$

Resonance Frequency

Resonance Frequency



Part 2, K, C 경계조건



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Vehicle System Dynamics

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Table 2. Suspension parameters and optimal normalised damping for various vehicle types.[7,8]

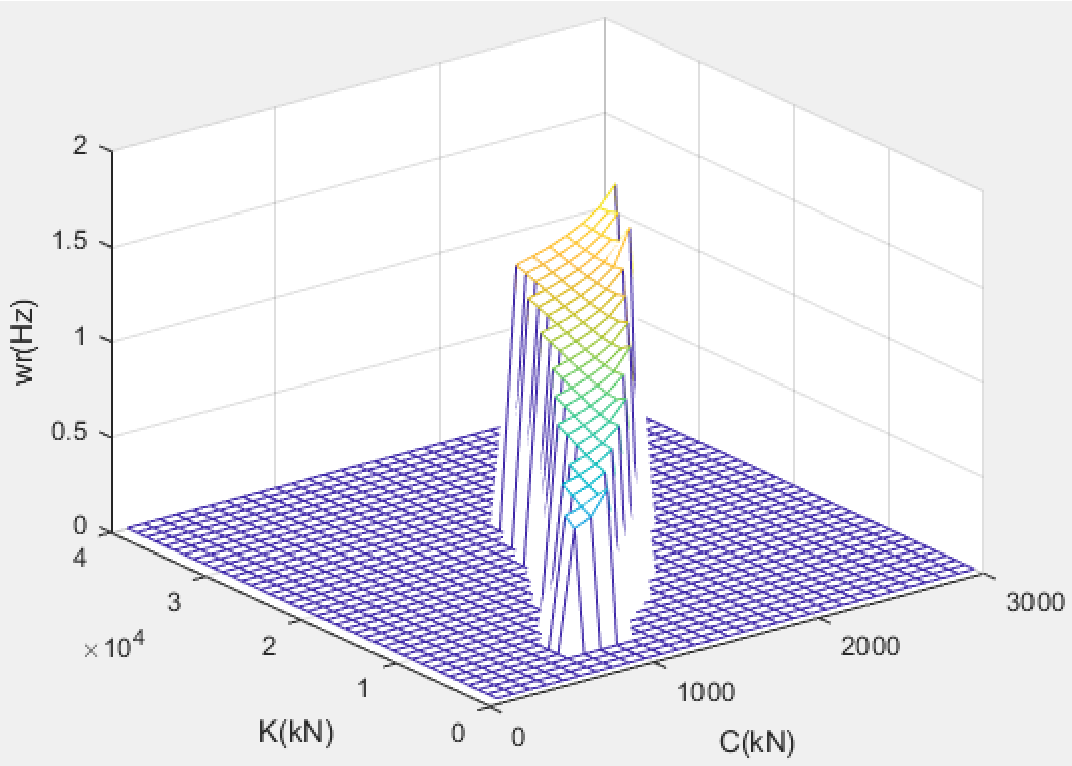
Vehicle type		m_u (kg)	m_s (kg)	k_s (N/mm)	k_t (N/mm)	c_s bump (kNs/m)	c_s rebound (kNs/m)
C	Front	46	323	12.80	170	1.0	2.0
Coupe	Rear	60	264	13.80	150	0.8	1.4
D	Front	53	380	12.95	180	1.2	1.8
Saloon	Rear	44	337	14.72	170	1.0	1.8
F	Front	45	400	20.00	250	4.1	5.8
Sports	Rear	50	400	20.00	250	4.1	5.8
G	Front	23	125	300	228	6.0	10.0
F1car	Rear	30	188	200	228	11.0	15.0
H	Front	35	209	230	375	8.0	12.0
C1 prototype	Rear	45	301	400	398	12.0	16.0
Truck	Front	177	1872	232	1030	26.2	–
	Rear	277	1411	500	2060	34.7	

$10000 < K < 25000$

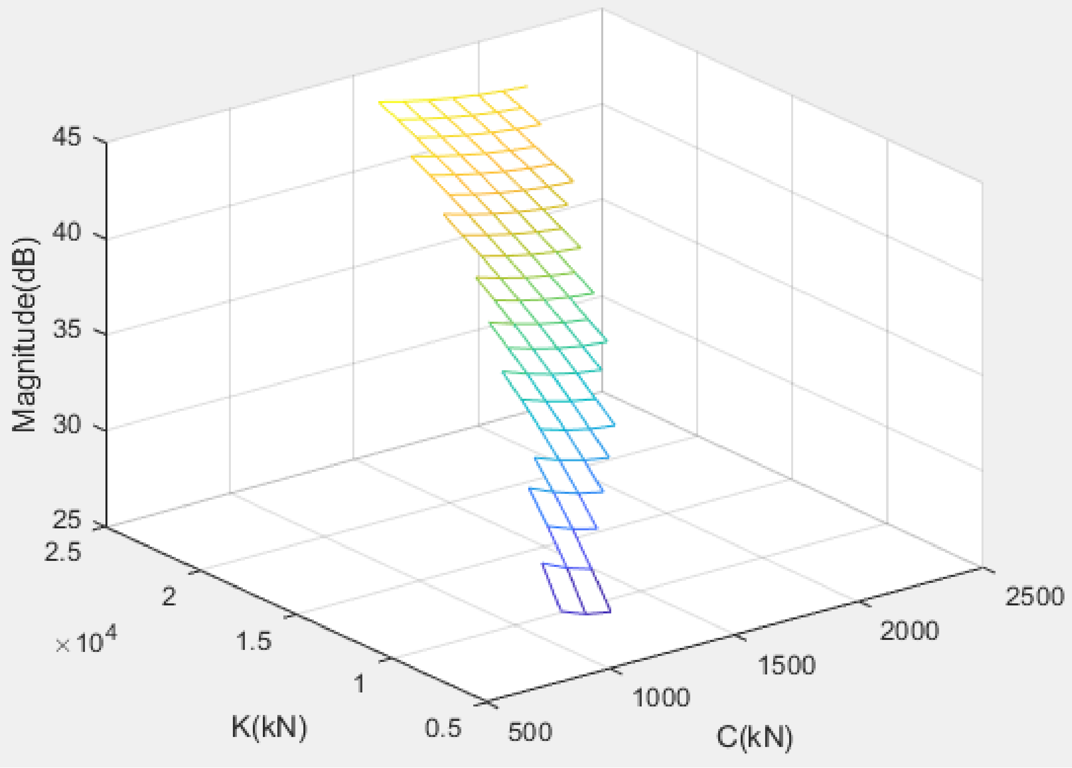
$500 < C$

Part 2, K, C 경계조건 적용

Resonance Frequency

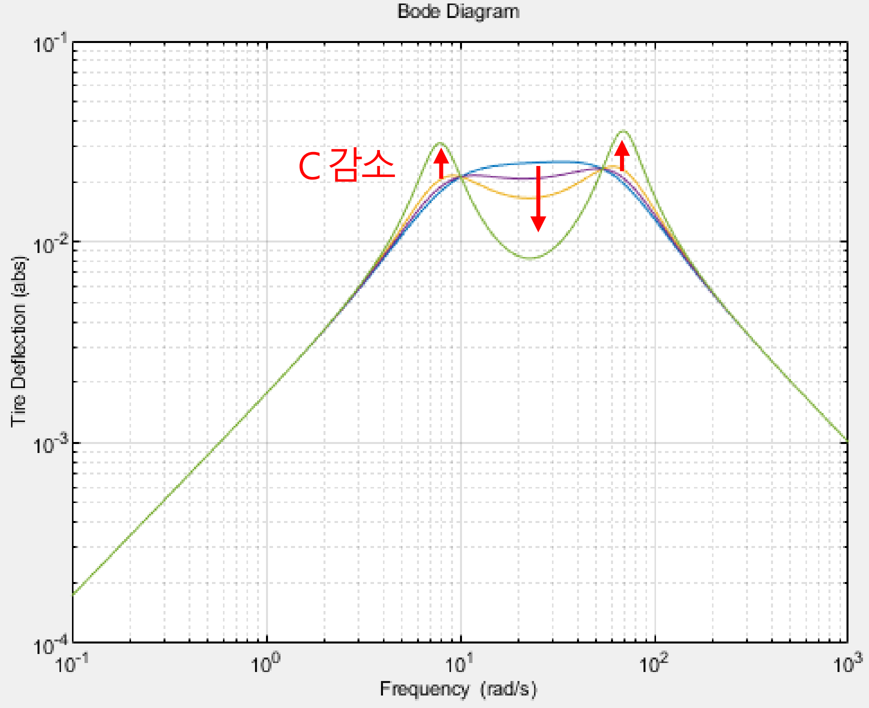


Magnitude

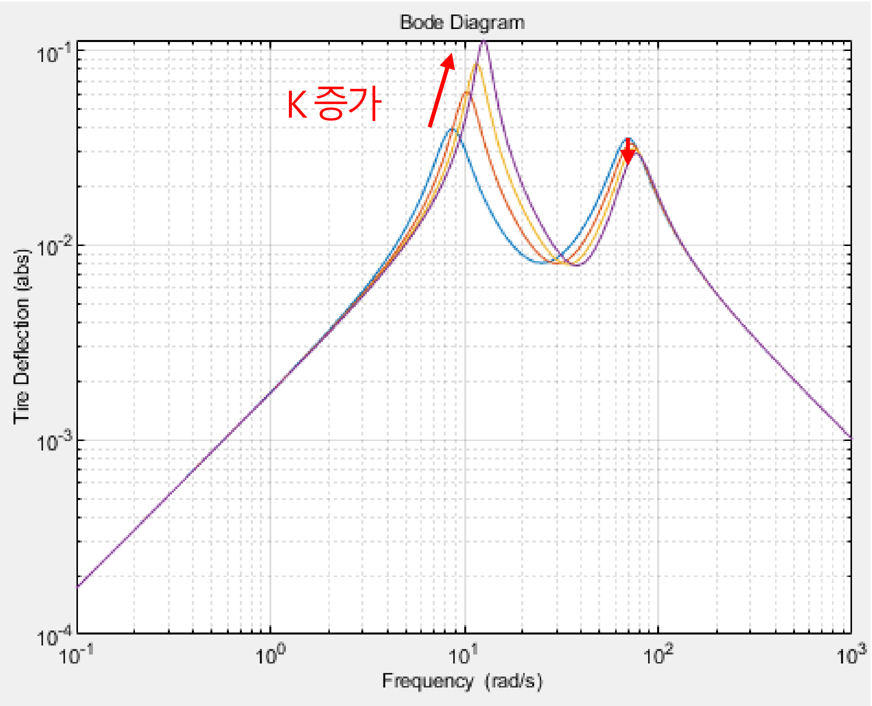


Part 2, 2-DOF 핸들링 관점에서 C, K 따른 Bode Plot

K고정, C변화



C고정, K변화



Part 3

발전 방향

1. KKT 필요조건

1 라그랑지 함수 만들기

$$2\zeta^2 W^3 + (16\zeta^4\omega_n^2 - 8\zeta^2\omega_n^2)W^2 + (8\zeta^2\omega_n^4 - \omega_n^4)W^2 + \omega_n^6 = 0$$

목적함수를 w에 대한 식으로 나타내고, 부등호제약조건을 적용한다.

2 경사도 벡터 조건

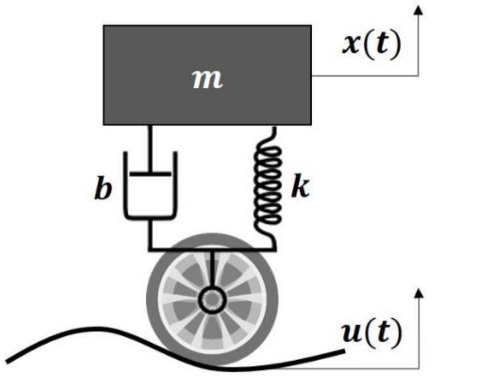
$$\frac{\partial L}{\partial v_i} = 0 \quad , \quad \frac{\partial L}{\partial u_j} = 0$$

3 전환 조건

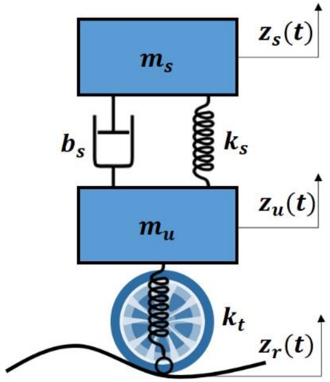
$$\frac{\partial L}{\partial s_j} = 0$$

Part 3,

2. 2 DOF Model



1-DOF Model



1-DOF Model

$$m_s\ddot{z}_s = -k_s(z_s - z_u) - b_s(\dot{z}_s - \dot{z}_u)$$
$$m_s\ddot{z}_u = k_s(z_s - z_u) + b_s(\dot{z}_s - \dot{z}_u) + k_t(z_r - z_u)$$

$$x_1 = z_s - z_u$$
$$x_2 = \dot{z}_s$$
$$x_3 = z_u - z_r$$
$$x_4 = \dot{z}_u$$

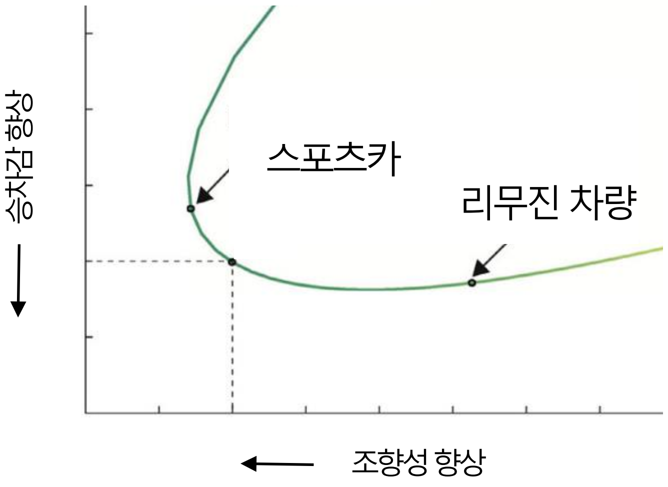
State Equation

3. 해석 프로그램 이용

3D Model

or

승차감과 조향성 사이의 상충곡선




감사합니다