[2.2절]

2.27 $\Sigma M_o = J\ddot{\theta}$

$-k(l_1\theta)l_1 - c(l_2\dot{\theta})l_2 - mgl\theta + F(t)l = (ml^2)\ddot{\theta}$

$\Rightarrow \quad (ml^2)\ddot{\theta} + (cl_2^2)\dot{\theta} + (kl_1^2 + mgl)\theta = lF(t)$

$J = ml^2 \ , \quad c_t = cl_2^2 \ , \quad k_t = kl_1^2 + mgl$

$\omega_n = \sqrt{\frac{k_t}{J}} = \sqrt{\frac{kl_1^2 + mgl}{ml^2}}$

$\zeta = \frac{c_t}{2\sqrt{Jk_t}} = \frac{cl_2^2}{2\sqrt{(ml^2)(kl_1^2 + mgl)}}$

$\omega_d = \omega_n\sqrt{1-\zeta^2}$

$= \sqrt{\frac{kl_1^2 + mgl}{ml^2}}\sqrt{1 - \frac{(cl_2^2)^2}{4(ml^2)(kl_1^2 + mgl)}}$

$= \sqrt{\frac{kl_1^2 + mgl}{ml^2} - \frac{(cl_2^2)^2}{4(ml^2)^2}}$

resonance at $\omega = \omega_p$

$\omega_p = \omega_n\sqrt{1-2\zeta^2}$

$= \sqrt{\frac{kl_1^2 + mgl}{ml^2}}\sqrt{1 - \frac{2(cl_2^2)^2}{4(ml^2)(kl_1^2 + mgl)}}$

$= \sqrt{\frac{kl_1^2 + mgl}{ml^2} - \frac{(cl_2^2)^2}{2(ml^2)^2}}$