

$$V_3 = V_1 + \frac{\gamma}{2} z_2^2 + \frac{\gamma}{2k_0} \tilde{M}_L^2 \quad (1)$$

$$\dot{V}_3 = \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} \dot{\mathbf{z}}_1 + \gamma z_2 \dot{z}_2 + \frac{\gamma}{k_0} \tilde{M}_L \dot{\tilde{M}}_L \quad (2)$$

$$= \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} (\mathbf{f}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) + \gamma (x_2 - \alpha_1(\mathbf{x}_1)) \left( \dot{x}_2 - \frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} \dot{\mathbf{x}}_1 \right) + \frac{\gamma}{k_0} \tilde{M}_L \dot{\tilde{M}}_L \quad (3)$$

$$= \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} (\mathbf{f}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) + \gamma (x_2 - \alpha_1(\mathbf{x}_1)) \left( u - \frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} (\mathbf{f}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) \right) + \frac{\gamma}{k_0} \tilde{M}_L \dot{\tilde{M}}_L \quad (4)$$

$$= \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} (\mathbf{f}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) \alpha_1(\mathbf{x}_1) - \mathbf{g}_1(\mathbf{x}_1) \alpha_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) + \gamma (x_2 - \alpha_1(\mathbf{x}_1)) \left( u - \frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} (\mathbf{f}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) \right) + \frac{\gamma}{k_0} \tilde{M}_L \dot{\tilde{M}}_L \quad (5)$$

$$= \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} (\mathbf{f}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) \alpha_1(\mathbf{x}_1)) + \gamma (x_2 - \alpha_1(\mathbf{x}_1)) \left( u - \frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} (\mathbf{f}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) + \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} \frac{\mathbf{g}_1(\mathbf{x}_1)}{\gamma} \right) + \frac{\gamma}{k_0} \tilde{M}_L \dot{\tilde{M}}_L \quad (6)$$

$$= \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} (\mathbf{f}_1(\mathbf{x}_1) + \hat{\mathbf{f}}_1(\mathbf{x}_1) - \hat{\mathbf{f}}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) \alpha_1(\mathbf{x}_1)) + \gamma (x_2 - \alpha_1(\mathbf{x}_1)) \left( u - \frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} (\mathbf{f}_1(\mathbf{x}_1) + \hat{\mathbf{f}}_1(\mathbf{x}_1) - \hat{\mathbf{f}}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) + \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} \frac{\mathbf{g}_1(\mathbf{x}_1)}{\gamma} \right) + \frac{\gamma}{k_0} \tilde{M}_L \dot{\tilde{M}}_L \quad (7)$$

$$= \underbrace{\frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} (\hat{\mathbf{f}}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) \alpha_1(\mathbf{x}_1))}_{\leq 0} + \underbrace{\gamma (x_2 - \alpha_1(\mathbf{x}_1)) \left( u - \frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} (\hat{\mathbf{f}}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) + \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} \frac{\mathbf{g}_1(\mathbf{x}_1)}{\gamma} \right)}_{=-k_1(x_2 - \alpha_1(\mathbf{x}_1))} + \underbrace{\frac{\gamma}{k_0} \tilde{M}_L \dot{\tilde{M}}_L + \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} (\mathbf{f}_1(\mathbf{x}_1) - \hat{\mathbf{f}}_1(\mathbf{x}_1)) + \gamma (x_2 - \alpha_1(\mathbf{x}_1)) \left( -\frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} \right) (\mathbf{f}_1(\mathbf{x}_1) - \hat{\mathbf{f}}_1(\mathbf{x}_1))}_{=0} \quad (8)$$

$$\mathbf{f}_1(\mathbf{x}_1) - \hat{\mathbf{f}}_1(\mathbf{x}_1) = \begin{bmatrix} 0 \\ \frac{M_L - \hat{M}_L}{I_a} \end{bmatrix} \quad (9)$$

$$\frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} = \frac{\partial}{\partial \mathbf{z}_1} \left( \int_0^{z_{11}} (M(\xi + x_{11R}) - M_L) d\xi + \frac{I_a}{2} z_{12}^2 \right) \quad (10)$$

$$= [M(z_{11} + x_{11R}) - M_L \quad I_a z_{12}] \quad (11)$$

$$\dot{x}_{12,ist} = \dot{x}_{12,soll} \quad (12)$$

$$\frac{1}{I_a} (M_L - c_0(x_{11} - \alpha_1(\mathbf{x}_1) - d_a x_{12})) = \frac{1}{I_a} (M_L - M(x_{11}) - d x_{12}) \quad (13)$$

$$-c_0(x_{11} - \alpha_1(\mathbf{x}_1)) - d_a x_{12} = -M(x_{11}) - d x_{12} \quad (14)$$

$$\alpha_1(\mathbf{x}_1) = x_{11} + \frac{(d_a - d)x_{12} - M(x_{11})}{c_0} \quad (15)$$

$$\frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} = \left[ 1 - \frac{\partial M(x_{11})}{\partial x_{11}} \frac{1}{c_0} \quad \frac{d_a - d}{c_0} \right] \quad (16)$$

$$0 = \frac{\gamma}{k_0} \tilde{M}_L \dot{\tilde{M}}_L + \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} (\mathbf{f}_1(\mathbf{x}_1) - \hat{\mathbf{f}}_1(\mathbf{x}_1)) + \gamma (x_2 - \alpha_1(\mathbf{x}_1)) \left( -\frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} \right) (\mathbf{f}_1(\mathbf{x}_1) - \hat{\mathbf{f}}_1(\mathbf{x}_1)) \quad (17)$$

$$= \frac{\gamma}{k_0} \tilde{M}_L \dot{\tilde{M}}_L + (-\tilde{M}_L) z_{12} + \gamma (x_2 - \alpha_1(\mathbf{x}_1)) \left( -(-\tilde{M}_L) \right) \frac{d_a - d}{c_0 I_a} \quad (18)$$

$$\dot{\tilde{M}}_L = \frac{k_0}{\gamma} \left( z_{12} - \gamma (x_2 - \alpha_1(\mathbf{x}_1)) \frac{d_a - d}{c_0 I_a} \right) \quad (19)$$

$$= \frac{k_0}{\gamma} \left( z_{12} - \gamma \left( x_2 - x_{11} - \frac{(d_a - d)x_{12} - M(x_{11})}{c_0} \right) \frac{d_a - d}{c_0 I_a} \right) \quad (20)$$

$$-k_1(x_2 - \alpha_1(\mathbf{x}_1)) = u - \frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} (\hat{\mathbf{f}}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) + \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} \frac{\mathbf{g}_1(\mathbf{x}_1)}{\gamma} \quad (21)$$

$$u = \frac{\partial \alpha_1(\mathbf{x}_1)}{\partial \mathbf{x}_1} (\hat{\mathbf{f}}_1(\mathbf{x}_1) + \mathbf{g}_1(\mathbf{x}_1) x_2) - \frac{\partial V_1(\mathbf{z}_1)}{\partial \mathbf{z}_1} \frac{\mathbf{g}_1(\mathbf{x}_1)}{\gamma} - k_1(x_2 - \alpha_1(\mathbf{x}_1)) \quad (22)$$

$$= \left[ 1 - \frac{\partial M(x_{11})}{\partial x_{11}} \frac{1}{c_0} \quad \frac{d_a - d}{c_0} \right] \left[ \frac{1}{I_a} \begin{pmatrix} x_{12} \\ \hat{M}_L - c_0 x_{11} - d_a x_{12} + c_0 x_2 \end{pmatrix} \right] - \frac{1}{\gamma} [M(z_{11} + x_{11R}) - M_L \quad I_a z_{12}] \begin{bmatrix} 0 \\ \frac{c_0}{I_a} \end{bmatrix} - k_1 \left( x_2 - x_{11} - \frac{(d_a - d)x_{12} - M(x_{11})}{c_0} \right) \quad (23)$$

$$u = x_{12} - \frac{\partial M(x_{11})}{\partial x_{11}} \frac{x_{12}}{c_0} + \frac{d_a - d}{c_0 I_a} (\hat{M}_L - c_0 x_{11} - d_a x_{12} + c_0 x_2) - \frac{z_{12} c_0}{\gamma} - k_1 \left( x_2 - x_{11} - \frac{(d_a - d)x_{12} - M(x_{11})}{c_0} \right) \quad (24)$$