In the time domain design, we adopt the sinusoidal approximation idea in Eq.(5.17) and use only the frequency component with $\omega_h = 2 \cdot \omega_p$ to describe the human torque fluctuation. The overall control system structure is shown in Fig. 5.4, where $P(q^{-1})$ is the discretization of $P(s) = 1/(J_{eq}s + B_{eq})$. $C(q^{-1})$ represents a band-pass filter $C_{bpf}(q^{-1})$, which is a discretized version of the band-pass filter

$$C_{bpf}(s) = \frac{0.0025(20s+1)}{(0.1s+1)(0.05s+1)}. \tag{5.19}$$

$C_{lpf}(q^{-1})$ is a discretization of the feedforward low-pass filter

$$C_{lpf}(s) = \frac{1}{10s+1}. \tag{5.20}$$

The assistive torque is made proportional to the output of $C_{lpf}(q^{-1})$. k_{assist} is set to one, so that the EPB system has approximately two times the original open-loop DC gain of the bicycle, realizing 1:1 assistance at DC.

$$C_R(q^{-1}) = \frac{K_{rr}(1 - aq^{-1})(1 - p_o q^{-1})}{1 - 2\cos\omega_h q^{-1} + q^{-2}} \tag{5.21}$$

is the repetitive controller that is used to reject the sinusoidal disturbance contained in the human input with a frequency of ω_h rad/sample. In this expression, p_o is the pole for the discrete open loop bicycle transfer function, i.e. $P(q^{-1}) = b_o q^{-1}/(1 - p_o q^{-1})$. K_{rr} and a vary with changing ω_h and have the forms $K_{rr} = (2\cos\omega_h - 1)/b_o$ and $a = 0.75/(2\cos\omega_h - 1)$. The changes in the closed loop poles of the overall system with respect to the changing human input frequency ω_h from $\pi/40$ rad/sample to 0.2π rad/sample (the sampling time is 0.1 second) are shown in Fig. 5.5. The closed loop system has five poles. One is located at 0.9987, which coincide with the bicycle's open loop pole. The pair of complex conjugate poles inside the two boxes in Fig. 5.5 does not change very much with respect to changes in ω_h. The other pair shifts away from the real axis while ω_h increases. All the closed loop poles remain stable.

The controller implementation structure is shown in Fig. 5.6, where the feedback and feedforward controller inputs are combine together into one control input u, which is the input to the motor.