Tuning of I-PD controller using Quantitative Feedback Theory

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Introduction

Integral-Proportional-Derivative (I-PD) controller is advantageous over a Proportional-Integral-Derivative (PID) controller for disturbance rejection in control systems. Analytical tuning rules for the I-PD controller are derived from optimum disturbance rejection responses, eliminating the need for complex optimization algorithms. Tuning I-PD using QFT will ensure that the I-PD controller is robust to uncertainties and variations in the system. This leads to improved stability and performance in real-world applications. Comparative simulations show that QFT delivers at par performance measures but with better robustness.

I-PD Controller Structure

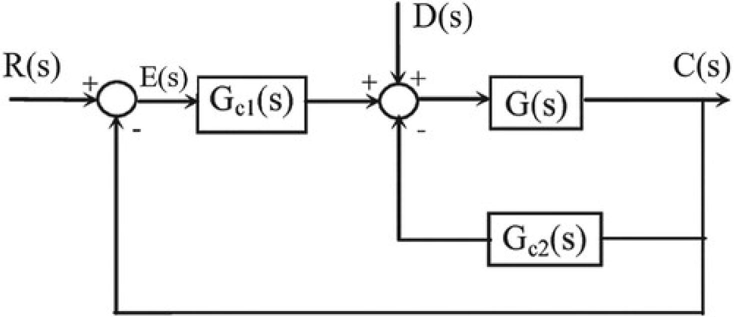


Figure: I-PD Controller Structure

Here:
G(s): Transfer function of the plant considered
$G_{c1}(s)$: Integral controller of the I-PD structure
$G_{c2}(s)$: PD controller of the I-PD structure

QFT based I-PD controller design for UFOPTD Process

A lag-dominant UFOPTD process is considered. The transfer function of the process is given by

$$G(s) = \frac{e^{-0.5s}}{s-1} \tag{1}$$

Using 3rd order Pade approximation

$$G(s) = \frac{120 - 30s + 3s^2 - 0.125s^3}{(120 + 30s + 3s^2 + 0.125s^3)(s-1)} \tag{2}$$

Considering $\pm 10\%$ uncertainity around the nominal values in each parameter. The generalised process function is given by

$$G(s) = \frac{(120 - 60Ts + 12(Ts)^2 - (Ts)^3)(A)}{((120 + 60Ts + 12(Ts)^2 + (Ts)^3)(Bs - 1)} \tag{3}$$

where, $\quad A \in [0.9, 1.1], \quad B \in [0.9, 1.1], \quad T \in [0.45, 0.55]$

Plant templates

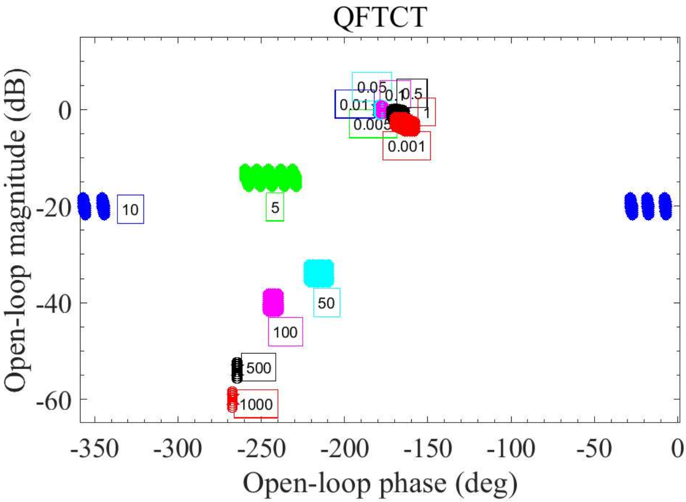


Figure: Plant template for designing the PD part.

Bounds for the Given Process

The following bounds are considered
Robust Stability bounds

$$\left|\frac{R(j\omega)C(j\omega)}{1+R(j\omega)C(j\omega)}\right| \leq \delta_1(\omega) = W_s, \omega \in \omega_1 \tag{4}$$

$$W_s = \frac{0.5}{cos((\pi/180)((180-PM)/2))}, \text{ in magnitude}$$

$$PM = 180 - 2\left(\frac{180}{\pi}\right) a\cos\left(\frac{0.5}{W_s}\right), \text{ in degree}$$

$$GM = 20\log_{10}\left(1+\frac{1}{W_s}\right), \text{ in dB}$$

In our work, we have chosen $W_s = 1.6$ which implies gain margin $= 4.21$ dB and phase margin $= 36.42^\circ$.

Input disturbance Rejection bounds

$$\left|\frac{R(j\omega)}{1+R(j\omega)C(j\omega)}\right| \leq \delta_2(\omega) = M_s, \omega \in \omega_2 \tag{5}$$

where,

$$M_s = 0.1 = \left|\frac{s}{s+10}\right|.$$

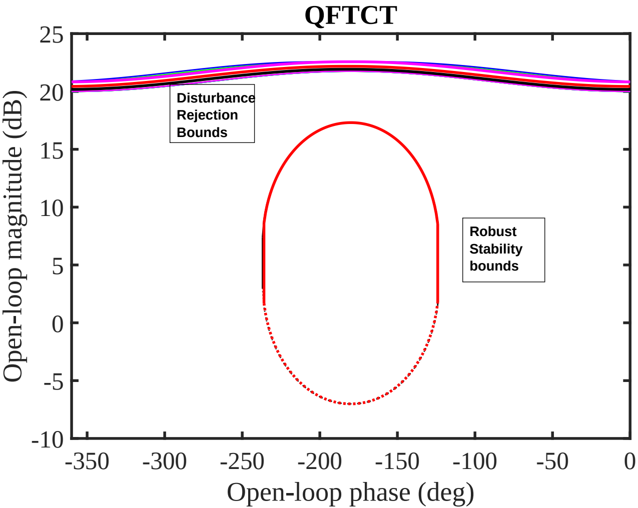
Output disturbance Rejection bounds

$$\left|\frac{R(j\omega)}{d_o(j\omega)}\right| = \left|\frac{1}{1+R(j\omega)G(j\omega)}\right| \leq \delta_3(\omega) = S_s, \omega \in \omega_3 \tag{6}$$

where,

$$S_s = 0.1 = \left|\frac{s}{s+10}\right|.$$

Intersection of Bounds



Loopshaping

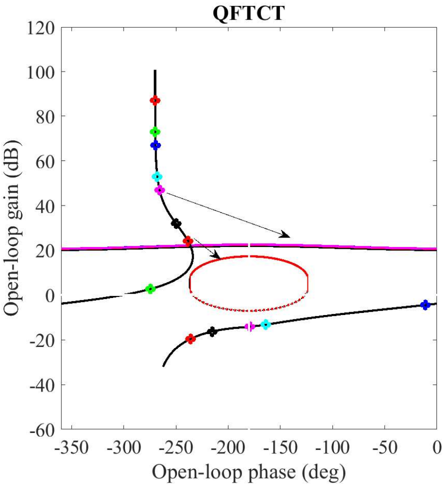


Figure: PD Controller design using QFT

The controller obtained via loop shaping to satisfy stability and performance specifications is given by:

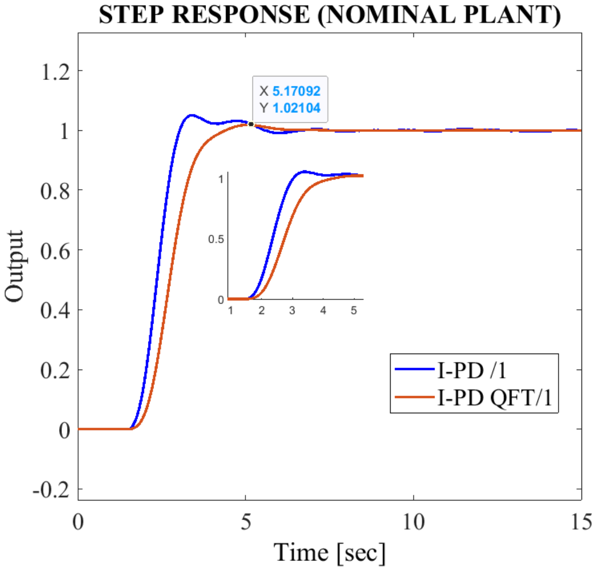
$$G_{c2}(s) = 2.52 + 0.5s$$

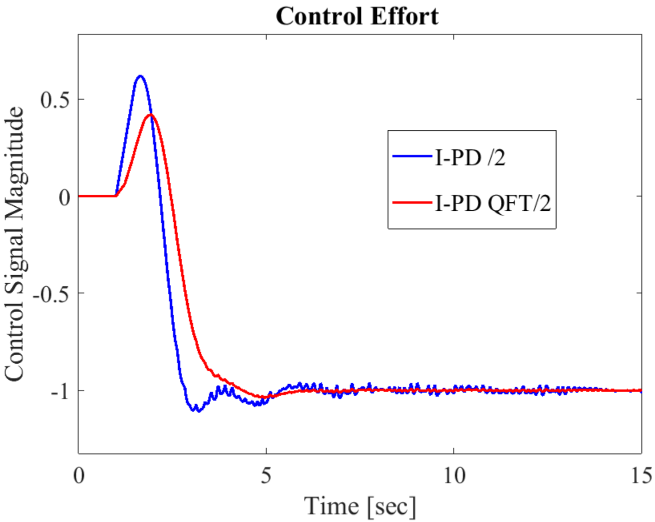
Pre-filter Design

G$_{c1}(s)$which is the integral controller, acts as a pre-filter to PD controller loop. So b
it is obtained as

$$G_{c1}(s) = \frac{1.0876}{s}$$

Simulations




Control Effort
Control Signal Magnitude
0.5
0
-0.5
-1
0
5
10
15
Time [sec]
I-PD /2
I-PD QFT/2

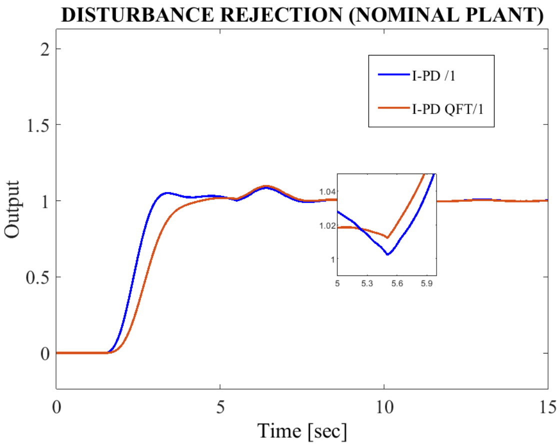
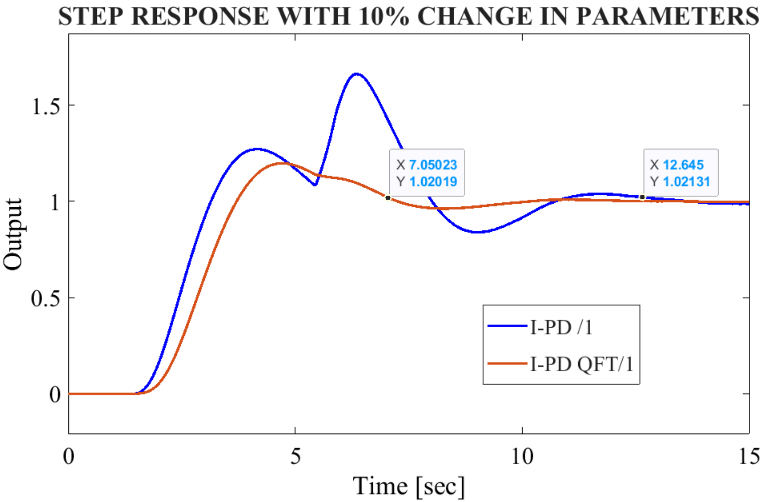
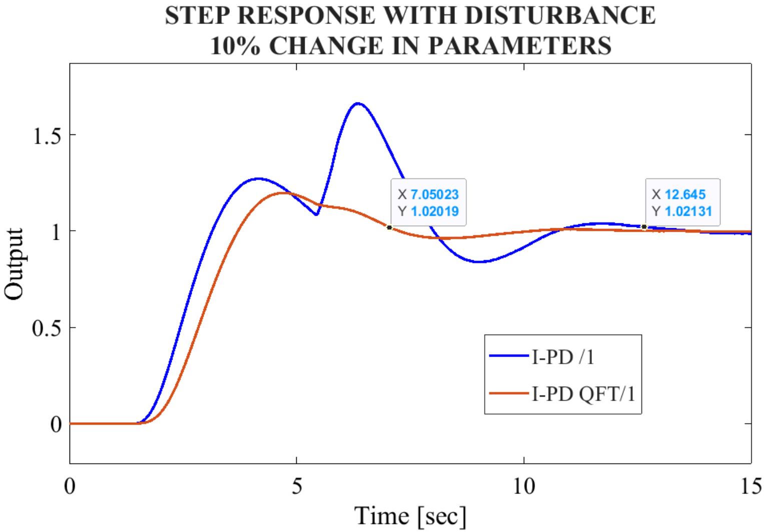


Figure: Disturbance Rejection

Simulations with up to 10% change in parameters




STEP RESPONSE WITH DISTURBANCE
10% CHANGE IN PARAMETERS
Output
1.5
1
0.5
0
0
5
10
15
Time [sec]
X 7.05023
Y 1.02019
X 12.645
Y 1.02131
I-PD /1
I-PD QFT/1

Conclusion

In conclusion, tuning an Integral-Proportional-Derivative (I-PD) controller using Quantitative Feedback Theory (QFT) offers performance comparable to traditional methods but with improved robustness. The analytical tuning rules derived from QFT ensure that the I-PD controller can deliver optimal disturbance rejection responses while remaining robust to uncertainties and variations in the system. This combination of performance and robustness makes the I-PD controller tuned using QFT a highly effective solution for control systems requiring stable and reliable operation in the face of disturbances and uncertainties.

References

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[5] M. Garcia-Sanz, Robust control engineering: practical QFT solutions. CRC press, 2017.


Thank you