

## Ziegler–Nichols closed loop (ultimate gain)

| Mode | Kc      | Ti       | Td     |
|------|---------|----------|--------|
| P    | 0.5 Ku  |          |        |
| PI   | 0.45 Ku | Pu ÷ 1.2 |        |
| PID  | 0.6 Ku  | Pu ÷ 2   | Pu ÷ 8 |

Ku: gain at sustained oscillation, Pu: its period.

## Ziegler–Nichols open loop (step test)

| Mode | Kc                         | Ti            | Td           |
|------|----------------------------|---------------|--------------|
| P    | $\tau \div (K \theta)$     |               |              |
| PI   | $0.9 \tau \div (K \theta)$ | $3.33 \theta$ |              |
| PID  | $1.2 \tau \div (K \theta)$ | $2 \theta$    | $0.5 \theta$ |

K: process gain,  $\tau$ : time constant,  $\theta$ : dead time.

## Lambda tuning (PI)

Self regulating  $Kc = \tau \div (K (\lambda + \theta))$ ,  
 $Ti = \tau$

Integrating (level)  $Kc = (2\lambda + \theta) \div (K (\lambda + \theta)^2)$ ,  $Ti = 2\lambda + \theta$

Choose  $\lambda$   $\tau$  to  $3\tau$ , and at least 30 for robustness

## Cohen–Coon PID

|    |                                                         |
|----|---------------------------------------------------------|
| Kc | $(1 \div K)(\tau \div \theta)(4/3 + \theta \div 4\tau)$ |
| Ti | $\theta (32 + 60/\tau) \div (13 + 80/\tau)$             |
| Td | $4\theta \div (11 + 20/\tau)$                           |

## PID algorithm forms

|                 |                                                                                |
|-----------------|--------------------------------------------------------------------------------|
| Ideal (ISA)     | $u = Kc [e + (1 \div Ti) \int e dt + Td de/dt]$                                |
| Parallel        | $u = Kp e + Ki \int e dt + Kd de/dt$ , $Ki = Kc \div Ti$ , $Kd = Kc \times Td$ |
| Series to ideal | $Kc = Kc' (1 + Td'/Ti')$ , $Ti = Ti' + Td'$ , $Td = Ti'Td' \div (Ti' + Td')$   |

## Units you will meet

Proportional band  $PB \% = 100 \div Kc$

Reset rate  $repeats/min = 1 \div Ti (min)$

Integral time  $min/repeat$  or  $s/repeat$

## Typical starting values

| Loop              | Kc         | Ti              | Td           |
|-------------------|------------|-----------------|--------------|
| Flow              | 0.3 to 0.8 | 0.05 to 0.2 min | 0            |
| Liquid pressure   | 0.5 to 2   | 0.1 to 0.5 min  | 0            |
| Gas pressure      | 2 to 10    | 1 to 5 min      | 0            |
| Level (averaging) | 1 to 5     | 5 to 20 min     | 0            |
| Temperature       | 1 to 10    | 2 to 20 min     | 0.1 to 2 min |

Starting points only; always tune on the real process.

## Troubleshooting

| Symptom                          | Try                         |
|----------------------------------|-----------------------------|
| Fast oscillation                 | Lower Kc                    |
| Slow oscillation                 | Increase Ti (less integral) |
| Sluggish, offset lasts long      | Raise Kc or shorten Ti      |
| Noisy output                     | Reduce Td, filter PV        |
| Oscillates at constant amplitude | Check valve stiction first  |

## Controller action

- Reverse acting: output falls when PV rises (most heating and level outflow loops)
- Direct acting: output rises when PV rises (cooling, level inflow control)
- Wrong action makes the loop run away to a limit