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Control Systems Interview Questions

INSIDE

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Modelling, block diagrams and signal flow graphs

1. What is a transfer function, and what do its poles and zeros tell you?

A transfer function is the ratio of the Laplace transform of the output to that of the input, with zero initial conditions, for a linear time-invariant system. The poles (roots of the denominator) set the natural modes and stability. The zeros decide how those modes are mixed in the response.

2. Why does negative feedback make a system less sensitive to changes in the plant gain?

With forward gain G and feedback H, the closed-loop gain is $G/(1+GH)$. Its sensitivity to G is $1/(1+GH)$, so when $|GH|$ is large a change in G produces a much smaller fractional change in the overall gain. The price is that the overall gain falls by the same factor $1+GH$.

3. A forward path $G(s) = 10/(s+1)$ is closed with negative feedback through a constant $H = 0.4$. Find the DC gain of the closed loop.

Closing the loop gives $T(s) = G/(1+GH) = 10/(s+5)$, a stable first-order system with its pole at -5. Setting $s = 0$ gives the DC gain $T(0) = 10/5 = 2$. Without feedback the DC gain would be 10, so feedback cuts it by the factor $1 + G(0)H = 5$.

WORKING

1. $T(s) = \dfrac{G}{1+GH}$
2. $1 + GH = 1 + \dfrac{4}{s+1} = \dfrac{s+5}{s+1}$
3. $T(s) = \dfrac{10}{s+5}$
4. DC gain: $T(0) = 10/5 = 2$

Time response and steady-state error

4. How does the damping ratio of a second-order system shape its step response?

For $\zeta < 1$ the poles are complex and the response overshoots and rings. At $\zeta = 1$ it is critically damped: the fastest rise with no overshoot. For $\zeta > 1$ it is overdamped: slower and with no overshoot. At $\zeta = 0$ the output oscillates forever at ω_n.

5. An underdamped second-order system has a natural frequency of 10 rad/s and a damping ratio of 0.5. Find the peak percentage overshoot of its unit step response.

With $\zeta = 0.5$, the overshoot is $M_p = e^{-\pi\zeta/\sqrt{1-\zeta^2}} = e^{-1.814} = 0.163$, about 16.3 %. Overshoot depends only on the damping ratio; the natural frequency of 10 rad/s sets the timing, not the overshoot.

WORKING

1. $M_p = \exp\left(-\dfrac{\pi\zeta}{\sqrt{1-\zeta^2}}\right)$
2. $\sqrt{1-0.25} = 0.866$
3. Exponent: $-\pi(0.5)/0.866 = -1.814$
4. $M_p = e^{-1.814} = 0.163$, that is 16.3 %

6. What is the type of a unity-feedback system, and how does it set the steady-state error?

The type is the number of poles of the open-loop transfer function at the origin. Type 0 gives a finite unit-step error $1/(1+K_p)$. Type 1 gives zero step error and a finite unit-ramp error $1/K_v$. Type 2 gives zero ramp error. These results hold only if the closed loop is stable.

Stability and the Routh–Hurwitz criterion

7. What does the Routh-Hurwitz criterion tell you about a characteristic polynomial?

It gives the number of roots in the right half of the s-plane without solving the polynomial. Build the Routh array from the coefficients. The number of sign changes in its first column equals the number of right-half-plane roots. The system is stable only if there are none.

8. A unity-feedback loop has the characteristic equation $s^3 + 6s^2 + 11s + K = 0$. Find the upper limit of K for stability.

The Routh array gives stability for $0 < K < 66$. At $K = 66$ the s^1 row becomes zero, so the loop is marginally stable and oscillates at $\sqrt{11} \approx 3.32$ rad/s. The upper limiting gain is 66.

WORKING

1. Row s^3: $1,\ 11$. Row s^2: $6,\ K$
2. Row s^1: $b_1 = \dfrac{6(11) - K}{6}$
3. Need $b_1 > 0$, so $K < 66$
4. Row s^0: $K > 0$
5. At $K = 66$: auxiliary $6s^2 + 66 = 0$, so $s = \pm j\sqrt{11} = \pm j3.32$

9. Why does a complete row of zeros appear in a Routh array, and what do you do about it?

A row of zeros means the polynomial has roots placed symmetrically about the origin, such as real pairs $\pm\sigma$, imaginary pairs $\pm j\omega$ or complex quadruplets. Form the auxiliary polynomial from the row above, differentiate it, and use its coefficients in place of the zero row. The roots of the auxiliary polynomial are roots of the original.

Root locus

10. What are the angle and magnitude conditions of the root locus?

For negative feedback, a point s lies on the locus if the angle of $G(s)H(s)$ is an odd multiple of 180° (for $K \geq 0$). The magnitude condition $|KG(s)H(s)| = 1$ then gives the value of K at that point.

11. How do you find the asymptotes of a root locus?

With n open-loop poles and m zeros, there are $n - m$ asymptotes. Their angles are $(2k+1)180^\circ/(n-m)$. They meet on the real axis at the centroid, the sum of the poles minus the sum of the zeros, divided by $n - m$.

12. What is the difference between adding an open-loop pole and adding an open-loop zero to a root locus?

An added pole pushes the branches towards the right half plane, which lowers relative stability and can limit the stable gain range. An added left-half-plane zero pulls the branches to the left, which improves stability and damping. Both change the number of asymptotes.

Frequency response

13. What are gain margin and phase margin?

Gain margin is the factor by which the loop gain can rise before the loop becomes unstable. It is read at the phase crossover frequency, where the phase is -180°, as $1/|GH|$. Phase margin is $180^\circ + \angle GH$ at the gain crossover frequency, where $|GH| = 1$. It is the extra lag the loop can take.

14. Why are Bode plots drawn with magnitude in decibels against a logarithmic frequency axis?

The logarithm turns the product of factors in a transfer function into a sum, so each factor can be plotted on its own and then added. On a log frequency axis each factor becomes straight-line asymptotes with slopes in multiples of 20 dB per decade. This makes hand sketching quick.

15. A unity-feedback loop has $G(s) = 10/\,[s(s+1)]$. Find its phase margin.

The gain crossover, where $|G(j\omega)| = 1$, is at about 3.08 rad/s. The phase there is $-90^\circ - \tan^{-1}(3.08) \approx -162^\circ$, so the phase margin is about 18°. Such a small margin means the closed loop is lightly damped.

WORKING

1. $|G(j\omega)| = \dfrac{10}{\omega\sqrt{1+\omega^2}} = 1$, so $\omega^4 + \omega^2 - 100 = 0$
2. $\omega^2 = \dfrac{-1+\sqrt{401}}{2} = 9.51$, so $\omega_{gc} = 3.08$ rad/s
3. $\angle G = -90^\circ - \tan^{-1}(3.08) = -162^\circ$
4. $PM = 180^\circ - 162^\circ = 18^\circ$

The Nyquist stability criterion

16. State the Nyquist stability criterion.

$Z = N + P$. Here N is the number of clockwise encirclements of $-1 + j0$ by the Nyquist plot of the open-loop GH, and P is the number of open-loop poles in the right half plane. Z is the number of closed-loop poles in the right half plane. The loop is stable when $Z = 0$.

17. Why is the Nyquist contour indented around an open-loop pole on the imaginary axis, such as an integrator?

The principle of the argument needs the contour to avoid poles and zeros. So a small semicircle is drawn round the pole. It bulges into the right half plane, which treats the pole as outside the contour and not counted in P. Its image is a large arc in the Nyquist plot.

Compensators and PID controllers

18. What is the difference between a lead and a lag compensator?

A lead compensator has its zero nearer the origin than its pole. It adds phase lead near crossover, raising phase margin and bandwidth and speeding up the response. A lag compensator has its pole nearer the origin. It raises the low-frequency gain to cut steady-state error, with little change in the transient, and it lowers bandwidth.

19. A lead compensator is $G_c(s) = \dfrac{1 + s/2}{1 + s/20}$. Find the maximum phase lead it provides.

The zero is at 2 rad/s and the pole at 20 rad/s, a ratio of 10. The maximum lead is $\sin^{-1}(9/11) \approx 54.9°$, reached at the geometric mean $\sqrt{2 \times 20} \approx 6.32$ rad/s.

WORKING

1. Zero at 2 rad/s, pole at 20 rad/s, so $a = 20/2 = 10$
2. $\phi_{max} = \sin^{-1} \dfrac{a - 1}{a + 1}$
3. $= \sin^{-1} \dfrac{9}{11} = 54.9°$
4. It occurs at $\omega_m = \sqrt{2 \times 20} = 6.32$ rad/s

20. Why is derivative action filtered in practical PID controllers?

The gain of a derivative term grows in proportion to frequency, $K_d\, j\omega$. High-frequency measurement noise is therefore amplified and can saturate the actuator. A first-order low-pass filter on the derivative limits its gain at high frequency while keeping the damping benefit at the frequencies that matter.

State-space models

21. What is controllability, and how is it tested?

A system is controllable if some input can take any initial state to any final state in finite time. For $\dot{x} = Ax + Bu$ with n states, it is controllable when the matrix $[B\ AB\ \cdots\ A^{n-1}B]$ has rank n. Then state feedback $u = -Kx$ can place the closed-loop poles at any chosen locations, with complex poles in conjugate pairs.

22. A system has $A = \begin{bmatrix} 0 & 1 \\ -6 & -5 \end{bmatrix}$, $B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$, $C = \begin{bmatrix} 1 & 0 \end{bmatrix}$ and $D = 0$. Find the steady-state output for a unit step input.

The transfer function is $G(s) = C(sI - A)^{-1}B = 1/(s^2 + 5s + 6)$, with poles at -2 and -3, so the system is stable. The final value theorem then gives the step response's steady value $G(0) = 1/6 \approx 0.167$.

WORKING

1. $G(s) = C(sI - A)^{-1}B = \dfrac{1}{s^2 + 5s + 6}$
2. Poles at -2 and -3, so the system is stable
3. Final value for a unit step: $G(0) = 1/6$

Actuators, time delay and industrial control

23. Why does dead time reduce the stability margin of a loop without changing its magnitude plot?

A pure delay e^{-sT} has magnitude 1 at every frequency, so the gain plot and the gain crossover frequency stay the same. It adds a phase lag of ωT radians that grows with frequency, so the phase margin falls. The loop becomes unstable when the lag uses up the whole margin.

24. What is the difference between a linear and an equal-percentage control valve?

At constant pressure drop, the inherent characteristics differ. In a linear valve the flow changes in proportion to stem lift, so its flow gain is constant. In an equal-percentage valve each equal step of lift changes the flow by the same percentage of the current flow, so its gain rises with flow. When pressure drop across the valve falls as flow rises, the installed equal-percentage valve behaves closer to linear.

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