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| **Started on** | Tuesday, 9 March 2021, 9:01 AM |
| **State** | Finished |
| **Completed on** | Tuesday, 9 March 2021, 10:08 AM |
| **Time taken** | 1 hour 6 mins |

Question **1**
Correct
Marked out of 1.00

The phase plane analysis technique permits to compute **exact** characterizations of stability domains for second-order nonlinear systems described by a linear model in feedback loop with a piecewise affine nonlinearity.

**Select one:**

- True ✓
- False

The correct answer is 'True'.

Question **2**
Correct
Marked out of 1.00

Consider a linear system characterized by $\dot{x} = Ax$ and assume that all the eigenvalues of $A$ lie strictly inside the right half plane. Then this system is locally stable.

**Select one:**

- True
- False ✓

The correct answer is 'False'.

Question **3**
Correct
Marked out of 1.00

Based on the first harmonic approximation, the describing function approach permits to detect and accurately characterize limit-cycles in high order systems that are composed of a linear part $G(s)$ in feedback loop with an isolated nonlinearity whatever the frequency-domain properties of $G(s)$..

**Select one:**

- True
- False ✓

The correct answer is 'False'.

Question **4**
Correct
Marked out of 1.00

The sinusoidal-input describing function (SIDF) of a static nonlinearity does not depend on the pulsation of the sinusoidal-input signal.

**Select one:**

- True ✓
- False

The correct answer is 'True'.

Question **5**
Correct
Marked out of 2.00

Consider a linear system $G(s)$ in a standard negative feedback loop with a relay nonlinearity of magnitude $M = \pi$. Assume that $G(3j) = -0.5$.

If you think that a limit-cycle may appear in the system, compute its amplitude $x_0$.

Otherwise, reply $0$

$x_0 = ?$

Answer: 2 ✓

The correct answer is: 2

Question 6
Correct
Marked out of 1.00

The sinusoidal input describing function of a static nonlinearity depends on the magnitude of the sinusoidal-input signal.

Select one:
- True ✓
- False

The correct answer is 'True'.

Information

**(use Matlab/Simulink -- total of following questions : 13 pts)**

One considers a double-interator plant $\ddot{\theta} = u_s$. The control signal $u_s$ is delivered by a first-order actuator with a time-constant $\tau = 0.1\ s$. A rate-limitation is introduced in this actuator via a standard amplitude saturation placed before the integrator. The limited amplitude is fixed to $L = 0.5$. A proportional derivative control law $u_c = k_p(\theta_c - \theta) - k_d\dot{\theta}$ is used to stabilize the system. It is assumed that both $\theta$ and $\dot{\theta}$ are available for feedback.

**In the following, the proportional gain $k_p$ is fixed to $k_p = 1$**

Question 7
Correct
Marked out of 2.00

Compute the smallest value of $k_d$ with only **one digit after the decimal point** which ensures (without saturation) that the closed-loop system is dominated by a well-damped second-order behaviour with damping $\xi > 0.75$.

$k_d = xxx,x[?][?]or[?][?]xx,x[?][?]or[?][?]x,x$

Answer: 1.5 ✓

The correct answer is: 1.5

Question 8
Correct
Marked out of 1.00

What is the corresponding pulsation (rad/s) of the second-order mode that you have placed ?

$\omega = ...$

Answer: 1.09 ✓

The correct answer is: 1.09

Information

**In the following, the gain is fixed to $k_d = 1.5$.**

Check with time-domain simulations that the system behaves well in the presence of saturation with step input $\theta_c = 1$. However, oscillation starts to appear with $\theta_c \geq 1.5$. Characterize the amplitude, the pulsation (rad/s) and the nature of this oscillation:

Question 9
Correct
Marked out of 1.00

$x_{LC_{SIM}} = ...$

Answer: 11.54 ✓

The correct answer is: 11.4

Question 10

Question 10
Correct
Marked out of 1.00

$\omega_{LC_{SIM}} = ...$

Answer: 0.91

The correct answer is: 0.92

Question 11
Correct
Marked out of 1.00

This corresponds to a **unstable limit-cycle**

**Select one:**

- True
- False

The correct answer is 'True'.

Information

Compare the above results with the describing function technique and compute the pulsation and magnitude obtained by this method considering that the equivalent gain of the saturation can be approximated by that of a relay operator.

Question 12
Correct
Marked out of 1.00

$x_{LC_{DF}} = ...$

Answer: 9.5493

The correct answer is: 9.55

Question 13
Correct
Marked out of 1.00

$\omega_{LC_{DF}} = ...$

Answer: 1

The correct answer is: 1

Information

To improve the behavior of the system, a **dynamic anti-windup** device is introduced. The control law is then modified as follows:

$$u_c = k_p(\theta_c - \theta) - k_d\dot{\theta} - F(s)\epsilon_{aw}$$

with

$$F(s) = \frac{1}{s+1}$$

As usual, the signal $\epsilon_{aw}$ is obtained as $\epsilon_{aw} = v - w$ where $v$ and $w$ respectively denote the input and output of the amplitude saturation.

Using simulations, check that the new closed-loop system remains stable for step inputs of increased magnitude $\theta_c$ and determine experimentally the critical value $\theta_c^*$ for which a limit-cycle appears. Determine also the characteristics of this limit-cycle. Note that for this particular case, the anti-windup device leads to a reduced size limit-cycle.

Question 14
Correct
Marked out of 1.00

$x_{LC_{SIM}} = ...$

Answer: 3.72

The correct answer is: 3.75

Question 15
Correct
Marked out of 1.00

$\omega_{LC_{SIM}}=\ldots$

Answer: 0.6327

The correct answer is: 0.61

Question 16
Correct
Marked out of 1.00

The limit-cycle is **unstable**

**Select one:**
- True
- False

The correct answer is 'True'.

Information

Check the above results with the describing function technique and compute the pulsation and magnitude obtained by this method:

Question 17
Correct
Marked out of 1.00

$x_{LC_{DF}}=\ldots$

Answer: 3.2881

The correct answer is: 3.29

Question 18
Correct
Marked out of 1.00

$\omega_{LC_{DF}}=\ldots$

Answer: 0.6633

The correct answer is: 0.66