**Advanced Control Laboratory (034406)**

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Preparatory Work 5

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**Question 1**

Figure 1 describes the control system which is similar to that of the laboratory process. The transfer function

transforms the control voltage to the arm angle , and converts the arm angle to the pendulum

angle . The transfer function Cy(s) is the arm angle servo controller. It is assumed that the effect of the

pendulum motion on the arm angle is negligible and

The servo controller is /

1. Show Bode plot of the transfer function between r and θ.

* What are the conclusions?
* What are the resonant peak and frequency?

Diagram

Description automatically generated

Figure 1 open loop control system

**Solution:**

The bode diagram of the open loop system is as shown below. All the cross over frequencies and stability margins are marked as well in the same figure.

A picture containing chart

Description automatically generated

Figure 2 Bode diagram for the open loop system with critical values

Conclusions:

The system has large response peaks and little delay margins. Meanwhile, there are two cross frequencies for this system as shown in the figure, , . It is also noticeable that bode diagram returns that the closed loop system is unstable. Therefore, a negative gain is necessary.

1. Show step response of the transfer function between r and θ.

**Solution:**

Chart, histogram

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Figure 3 Step response of the open loop system

There exists severe oscillation with large amplitude.

1. In order to decrease an amplitude of the pendulum oscillations the outer closed loop is added as

shown in Figure 4. Design a controller that reduces the resonance peak of the outer closed loop transfer function between r and θ to a value which is no more than 75[dB].

Note: the minimal order of that satisfies the specification above is the first order.

Diagram

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Figure 4 Close loop control

**Solution:**

By the observing Root Locus and Nichols plot of the open loop system with assembled plant as shown below, we can find that the unit feedback close loop of this plant is not stable for most of proportional controller, and will be easier to control if we add a negative controller.

|  |  |
| --- | --- |
| Diagram  Description automatically generated  Figure 5 Root locus plot of the assembled plant | Chart  Description automatically generated  Figure 6 Nichols plot of the assembled plant |

With a negative proportional controller, we can find from Nichols plot that the margins are still very small, as shown in Figure 7 in blue line, which might result in great oscillatory responses. To have a better response, we added another inverse lead controller. The Nichols plot with this additional controller is as shown in figure 7 in red line.

The frequency where we want to increase the margins is , therefore the overall controller that we design is:

Diagram

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Figure 7 Nichols plot for systems with controllers

1. Compare the following characteristics of the systems described in Figure 1 and Figure 2 respectively:

* Bode plots of the transfer functions between r and θ,
* step responses of the transfer functions between r and θ,
* Bode plots of the transfer functions between r and y,
* step responses of the transfer functions between r and y.

What is the contribution of ? Utilize the plots above to answer the question.

**Solution:**

|  |  |
| --- | --- |
| Chart, line chart  Description automatically generated  Figure 8 Bode plot of | Chart, histogram  Description automatically generated  Figure 9 Step Response of ­ |
| Chart, line chart  Description automatically generated  Figure 10 Bode plot of | Chart, line chart  Description automatically generated  Figure 11 Step response of |

From the comparisons, we can find that the designed greatly improve the performance of by reducing the oscillations and decrease the settle time. However, as a cost, the performance of is greatly influenced, resulting in large overshoot, and long settling time.

There always exist a trade off between the performance of and , which is similar to the trade of between the tracking and disturbance resistance for a unity feedback control loop. Further approach for controller design might exist that could better solve this problem.