LNCT GROUP OF COLLEGES

Name of faculty-Mr.Niketan Kumar Mishra

Designation-Assistant Professor

Subject-Control Systems(EC-404)

Unit-4

Topic-types of compensators

4.1 Design Problem

The performance of a control system can be described in terms of the time-domain performance measures or the frequency-domain performance measures. The performance of a system can be specified by requiring a certain peak time Tp, maximum overshoot, and settling-time for a step input. Furthermore, it is usually necessary to specify the maximum allowable steady-state error for several test signal inputs and disturbance inputs. These performance specifications can be defined in terms of the desirable location of the poles and zeros of the closed-loop system transfer function T(s). Thus, the location of the s-plane poles and zeros of T(s) can be specified.

The design of a system is concerned with the alteration of the frequency response or the root locus of the system in order to obtain a suitable system performance. For frequency response methods, we are concerned with altering the system so that the frequency response of the compensated system will satisfy the system specifications. Hence, in the frequency response approach, we use compensation networks to alter and reshape the system characteristics represented on the Bode diagram.

Alternatively, the design of a control system can be accomplished in the s-plane by root locus methods. For the case of the s-plane, the designer wishes to alter and reshape the root locus so that the roots of the system will lie in the desired position in the s-plane.

4.2 Compensation

A compensator is an additional component or circuit that is inserted into a control system to

- compensate for a deficient performance.

In order to obtain the desired performance of the system, we use compensating networks. Compensating networks are applied to the system in the form of feed forward path gain adjustment.

- Compensate an unstable system to make it stable.

A compensating network is used to minimize overshoot. These compensating networks increase the steady state accuracy of the system. Also, the increase in the steady state accuracy nstability to the system. Compensating networks also introduces poles and zeros in the system thereby causes changes in the transfer function of the system.

Methods of Compensation

4.2.1 Series Compensation

Connecting compensating circuit between error detector and plants known as series compensation.

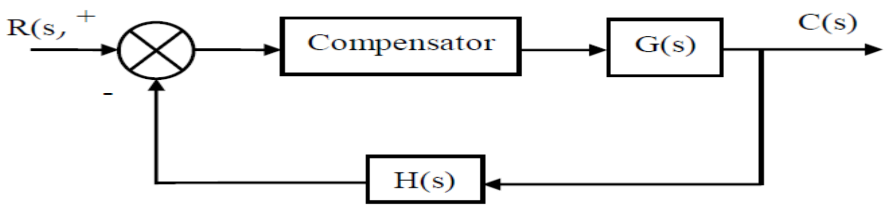

Figure 4.2.1 Series Compensation

When the compensator is placed in series with the forward path gain of the control system, the scheme is called series compensation or the cascade compensation.

4.2.2 Feedback Compensation

When a compensator used in a feedback manner called feedback compensation.

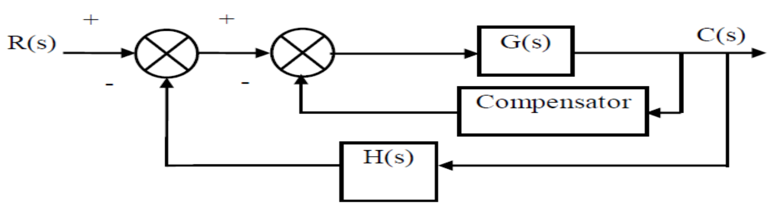

Figure 4.2.2 Feedback compensation

If the feedback is taken from some internal element and a compensator is introduced in such feedback path to provide an additional internal feedback loop, the scheme is known as feedback compensation

4.2.3 Combined Cascade & Feedback Compensation

A combination of series and feedback compensator is called load compensation.

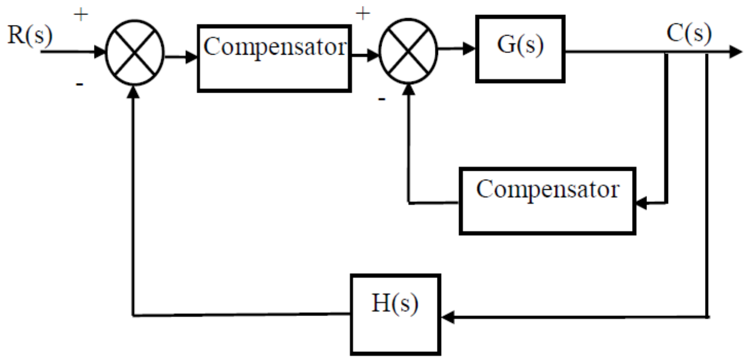

Figure 4.2.3 Combined Cascade & Feedback compensation

Sometimes a situation demands to both type of compensation, series as well feedback. This scheme is called combined series and feedback compensation.

To select a proper compensation scheme, the nature of the signals available in the system, the power levels at various points available components, the economic considerations and the designers experience are important.

4.3 Compensating Network:

A compensating network is one which makes some adjustments in order to make up for deficiencies in the system. Compensating devices are may be in the form of electrical, mechanical, hydraulic etc. Most electrical compensator is RC filter. The simplest network used for compensator is known as lead, lagnetwork.

A compensator is a physical device which may be an electrical network, mechanical unit, pneumatic, hydraulic or a combination of various type of devices. The following electrical compensating networks are generally used for series compensation. The following electrical compensating networks are generally used:

1. Lead Compensation Network
2. Lag Compensation Network
3. Lag-Lead Compensation Network

4.3.1 Phase Lead Compensation

The lead compensator is an electrical network which produces a sinusoidal output having phase lead when a sinusoidal input is applied. The lead compensator circuit in the S domain is shown in the following figure.

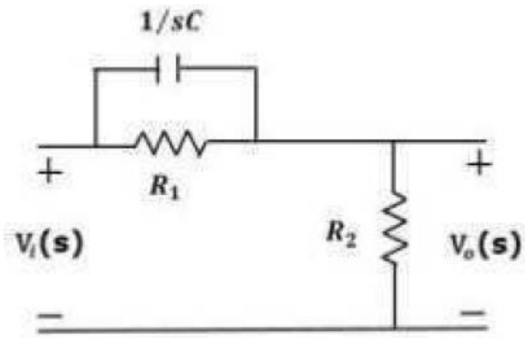

Figure Phase Lead Compensator

Here, the capacitor is parallel to the resistor

The transfer function of this lead compensator is-

$$\frac{V_0(s)}{V_i(s)} = \beta\left(\frac{s\tau + 1}{\beta s\tau + 1}\right)$$

Where $\tau = R_1 C$ and $\beta = \frac{R_2}{R_1 + R_2}$

From the transfer function, we can conclude that the lead compensator has pole at $s = -1/\tau$ and a zero at $s = -1/\beta\tau$.

Substitute, $s = j\omega$ in the transfer function.

$$\frac{V_0(j\omega)}{V_i(j\omega)} = \beta\left(\frac{j\omega\tau + 1}{\beta j\omega\tau + 1}\right)$$

Phase angle $\emptyset = tan^{-1}\,\omega\tau - tan^{-1}\,\beta\omega\tau$

We know that, the phase of the output sinusoidal signal is equal to the sum of the phase angles of input sinusoidal signal and the transfer function.

So, in order to produce the phase lead at the output of this compensator, the phase angle of the transfer function should be positive. This will happen when $0 < \beta < 1$. Therefore, zero will be nearer to origin in pole-zero configuration of the lead compensator.

Effects of a Lead Compensator:

1. Since a Lead compensator adds a dominant zero and a pole, the damping of a closed loop system is increased.

2. The less overshoot, less rise time and less settling time are obtained due to increase of damping coefficient and hence there is improvement in the transient response of the closed loop system.
3. It improves the phase margin of the closed loop system.
4. Bandwidth of the closed loop system is increased and hence the response is faster.
5. The steady state error does not get affected.

Limitations:

1. Since an additional increase in the gain is required, it results in larger space, more elements, greater weight and higher cost.

2. From a single lead network, the maximum lead angle available is about 60^0. For lead of more than 70^0 to 90^0, a multistage lead compensator is required.

4.3.2 Phase Lag Compensation

The phase lag compensator is shown in diagram 4.3.2 below

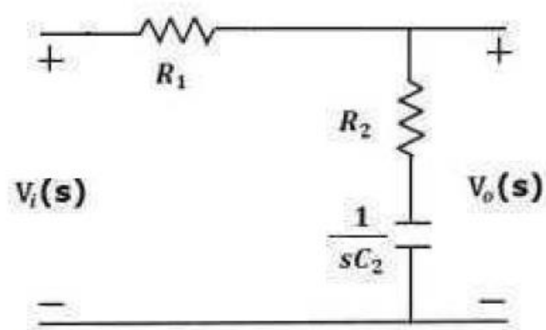

Figure 4.3.2 Phase Lag Compensator

Here, the capacitor C2 is in series to the resistor R2 and the output is measured across the series combination of the resistor R2 and Capacitor C2 as shown in figure.

The transfer function of this lead compensator is –

$$\frac{V_0(s)}{V_i(s)} = \frac{1}{\beta}\left(\frac{s+\frac{1}{\tau}}{s+\frac{1}{\beta\tau}}\right)$$

Where $\tau = R^2 C$ and $\beta = \frac{R_1+R_2}{R_2} > 1$, Generally β is taken to be 10.

From the transfer function, we can conclude that the lead compensator has pole at $s = -1/\beta\tau$ and a zero at $s = -1/\tau$.

Substitute, $s = j\omega$ in the transfer function.

$$\frac{V_0(j\omega)}{V_i(j\omega)} = \frac{1}{\beta}\left(\frac{j\omega+\frac{1}{\tau}}{j\omega+\frac{1}{\beta\tau}}\right) = \frac{1+j\omega\tau}{1+j\omega\beta\tau}$$

Therefore the magnitude $M = \frac{V_0(j\omega)}{V_i(j\omega)} = \frac{\sqrt{1+\omega^2\tau^2}}{\sqrt{1+\omega^2\beta^2\tau^2}}$

And the phase angle is given by, Phase angle $\emptyset = tan^{-1}\,\omega\tau - tan^{-1}\,\beta\omega\tau$

The above equations gives the frequencies at which the phase lag is maximum and the ω_m is the geometric mean of two frequencies. Here $\omega_{c1} = \frac{1}{\tau}$ and $\omega_{c2} = \frac{1}{\beta\tau}$ are the two corner frequencies.

Effects and Limitations of the compensating =

1. Since Lag compensator allows high gain at low frequencies, it is basically a low pass filter. Therefore it improve the steady state response.

2. In Lag compensation, the attenuation characteristics is used for the compensation, whereas the phase lag characteristic is of no use in compensation.
3. The system is very sensitive to parameters variation.

4. Since a lag compensator approximately acts as a PI controller, it thus tends to make a system less stable.

4.3.3 Lag Lead Compensation Network

Lag-Lead compensator is an electrical network which produces phase lag at one frequency region and phase lead at other frequency region. It is a combination of both the lag and the lead compensators. The lag-lead compensator circuit in the S domain is shown in the following figure

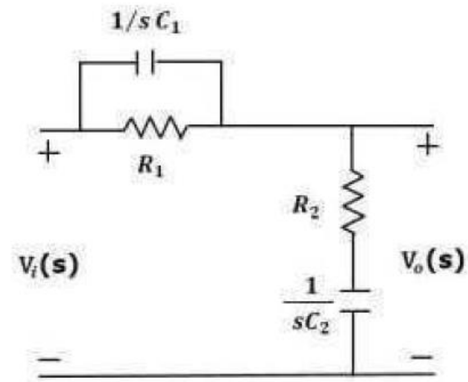

Figure4.3.3 Lag-Lead Compensator

This circuit looks like both the compensators are cascaded. So, the transfer function of this circuit will be the product of transfer functions of the lead and the lag compensators.

$$\frac{V_0(s)}{V_i(s)} = \beta\left(\frac{s\tau_1+1}{\beta s\tau_1+1}\right)\frac{1}{\alpha}\left(\frac{s+\frac{1}{\tau_2}}{s+\frac{1}{\alpha\tau_2}}\right)$$

$$\frac{V_0(s)}{V_i(s)} = \left(\frac{s+\frac{1}{\tau_1}}{s+\frac{1}{\beta\tau_1}}\right)\left(\frac{s+\frac{1}{\tau_2}}{s+\frac{1}{\alpha\tau_2}}\right)$$

We know that $\alpha\beta = 1$, $\tau_1 = R_1C_1$ and $\tau_2 = R_2C_2$

Therefore the magnitude $M = \frac{V_0(j\omega)}{V_i(j\omega)} = \frac{\sqrt{1+\omega^2\tau_1^2}\sqrt{1+\omega^2{\tau_2}^2}}{\sqrt{1+\omega^2\beta^2\tau_1^2}\sqrt{1+\omega^2\beta^2{\tau_2}^2}}$

And the phase angle is given by, Phase angle $\emptyset = tan^{-1}\,\omega\tau_1 + tan^{-1}\,\omega\tau_2 - tan^{-1}\,\beta\omega\tau_1 - tan^{-1}\,\alpha\omega\tau_2$

The above equations gives the frequencies at which the phase lag is maximum and the ω_m is the geometric mean of four frequencies. Here $\omega_{c1} = \frac{1}{\tau_1}$, $\omega_{c2} = \frac{1}{\tau_2}$, $\omega_{c3} = \frac{1}{\beta\tau_1}$ and $\omega_{c4} = \frac{1}{\beta\tau_2}$ are the corner frequencies.

Effects of Lag Lead Compensator:

To get fast response and good static accuracy, a lag lead compensator is used. It also increase the low frequency gain, which improves the steady state response. Since it increases the bandwidth of the system, the system response becomes very fast. In general the phase lead portion of this compensator provides large bandwidth & hence shorter rise time and settling time, while the phase lag portion provides the major damping of the system.