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**Abstract**—This manual is an introduction to control systems based on GATE problems. Links to sample Python codes are available in the text.

Download python codes using

```
svn co https://github.com/gadepall/school/trunk/
control/codes
```

## 1 STABILITY

## 1.1 Second order System

## 2 ROUTH HURWITZ CRITERION

## 3 COMPENSATORS

## 4 NYQUIST PLOT

- 4.1. Using Nyquist criterion, find out the range of K for which the closed loop system will be stable.

$$G(s) = \frac{K(s+2)(s+4)}{s^2-3s+10}; H(s) = \frac{1}{s} \quad (4.1.1)$$

- 4.2. Find the open loop transfer function  $G(s)H(s)$

**Solution:** From (4.1.1),

$$G(s)H(s) = \frac{K(s+2)(s+4)}{s(s^2-3s+10)} \quad (4.2.1)$$

$$G(j\omega)H(j\omega) = \frac{K(j\omega+2)(j\omega+4)}{j\omega((10-\omega^2)-3j\omega)} \quad (4.2.2)$$

$$\text{Re}\{G(j\omega)H(j\omega)\} = \frac{K(84\omega^2 - 9\omega^4)}{\omega^6 - 11\omega^4 + 100\omega^2} \quad (4.2.3)$$

$$\text{Im}\{G(j\omega)H(j\omega)\} = \frac{K(-\omega^5 + 36\omega^3 - 80\omega)}{\omega^6 - 11\omega^4 + 100\omega^2} \quad (4.2.4)$$

- 4.3. Sketch the Nyquist plot.

**Solution:** The Nyquist plot is a graph of

$\text{Re}\{G(j\omega)H(j\omega)\}$  vs  $\text{Im}\{G(j\omega)H(j\omega)\}$ . Let's take  $K=1$  and draw the nyquist plot .

The following python code generates the Nyquist plot in Fig. 4.3

```
codes/ee18btech11016.py
```

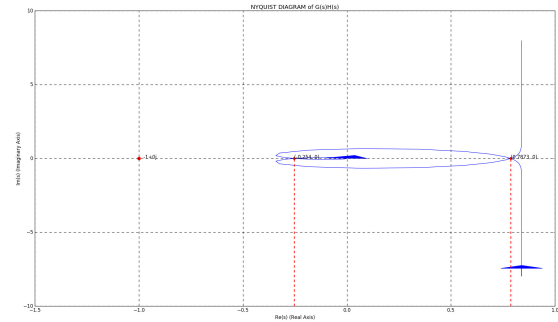


Fig. 4.3

Note that this nyquist plot is plotted when  $K=1$ .

- 4.4. Use the Nyquist Stability criterion to determine the value of K since we know that the system in (4.1.1) is stable.

**Solution: Nyquist criterion**-For the stable system :

$$Z = P + N = 0, \quad (4.4.1)$$

Variable	Description
Z	Poles of $\frac{G(s)}{1+G(s)H(s)}$ in right half of s plane
N	No of encirclements of $G(s)H(s)$ about $-1+j0$ in the Nyquist plot
P	Poles of $G(s)H(s)$ in right half of s plane

TABLE 4.4

Since from the equation (4.2.1),  $P = 2$  as the number of poles on right hand side of s-plane is equal to 2 .So, for Z to be equal to 0 ,we have to choose the range of K such that N should be equal to -2.

- 4.5. Find the range of K from Nyquist criterion.

**Solution:** If we consider the Nyquist plot with

K term i.e. of equation (4.2.1) , then it will cut x-axis at  $x = -0.254K$  ,  $x = 0$  and at  $x = 0.7873K$  (as we have nyquist graph at  $K=1$ , now we just need to multiply the intersected coordinates on x-axis by K).

So, we have to make sure that  $(-1 + j0)$  should be included in between  $x = -0.254K$  to  $x = 0$ , because then only  $N = -2$  (as the no. of encirclements are 2 in anticlockwise direction in this case so  $N=-2$ )

$$-0.254K < -1 < 0 \quad (4.5.1)$$

So,

$$K > \frac{1}{0.254} \quad (4.5.2)$$

i.e.

$$K > 3.937 \quad (4.5.3)$$

Hence  $K > 3.937$  ensures that the system is stable as no. of poles on the right hand side of s-plane (in this case) is 0.