EE 208

Control Engineering Lab

Experiment-3: Controller design on MATLAB platform by Analog Frequency Response.

Group Number- 20

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OBJECTIVE: -

- To design a cascade ventilator transfer function for a given analog respiratory system transfer function according to the desired specification.

Given: -

A 3rd order transfer function depicting the circulatory system,

$G_{CL}(s) = \frac{0.1}{(s+0.5)(s+0.1)(s+0.2)}$

cascaded with order 1 system for lungs,

$L(s) = \frac{1}{(s+A)}$,where A=1

and a feedback constant for chemoreceptor with nominal value of $K_f = 0.1$.

With the endocrinal problem the patient may lead to flawed chemoreceptors which may change the nominal feedback gain K_f up to ten times in the worst case.

With Endocrinal problem - K_f may change up to 10 times ($0.1 \leq K_f \leq 1$).

With Asthmatic patient - the time constant of lungs can increased up to 10 times ($1 \leq A \leq 0.1$)

NOTE- When Time constant of lungs increases value of parameter A is decreased.

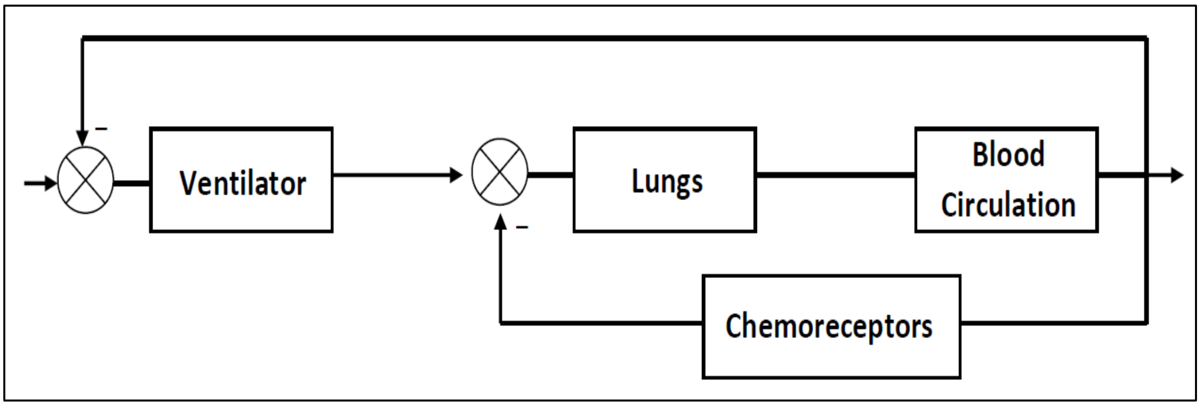
System Modelling: -

CLTF of Respiratory System (without ventilator),

$G(s) = \frac{0.1}{(s+0.5)(s+0.1)(s+0.2)(s+A) + 0.1K_f}$

Practically it isn't possible to have a ventilator inside a biological system.

For our design requirements we will take a ventilator in cascade with the Human Respiratory system and the complete system is enclosed in a feedback path.



Block diagram for final system

Observations: -

We will first analyse our given system,

Without Ventilator:

Phase margin for G(s) (in degrees)						
Kf	**s+A**					
	A=1	**A=0.8**	**A=0.6**	**A=0.4**	**A=0.2**	**A=0.1**
0.1	-15.7	-28.3	-43.8	-62.9	-85	-96.4
0.3	-25.9	-39.5	-55.8	-75	-96.4	-107
0.5	-36.1	-50.5	-67.3	-86.6	-108	-118
0.7	-46.2	-61.2	-78.5	-98.1	-119	-129
0.9	-56.3	-71.8	-89.7	-110	-132	-142
1	-61.3	-77.2	-95.5	-116	-139	-150

(s+A depict pole of Lungs Transfer Function)

From above analysis

- Phase margin **decreases** (increases in magnitude) with **increase** in K_f (chemoreceptor gain).
- Phase margin **decreases** (increases in magnitude) with **increase** in Time Constant of lungs or **decreasing** parameter A.

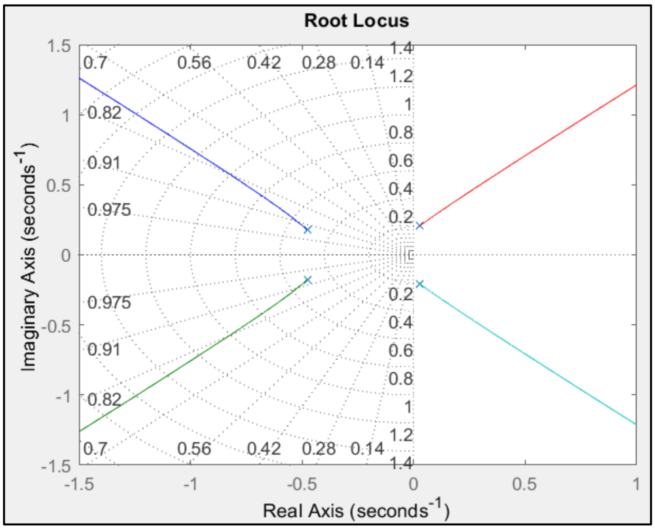
Therefore, it can be concluded that the **worst case for Phase margin variation** is when **both** of the K_f and A are **varied 10 times**. **If we design a ventilator system which can maintain phase margin for the worst case, then rest of the cases will be handled automatically.**

We first start by taking a **constant gain X** as our ventilator, but we found out that our system is **unstable** for **every positive value** of X, across the range of parameters A and K_f. **Therefore, a simple proportional gain won't work out.**

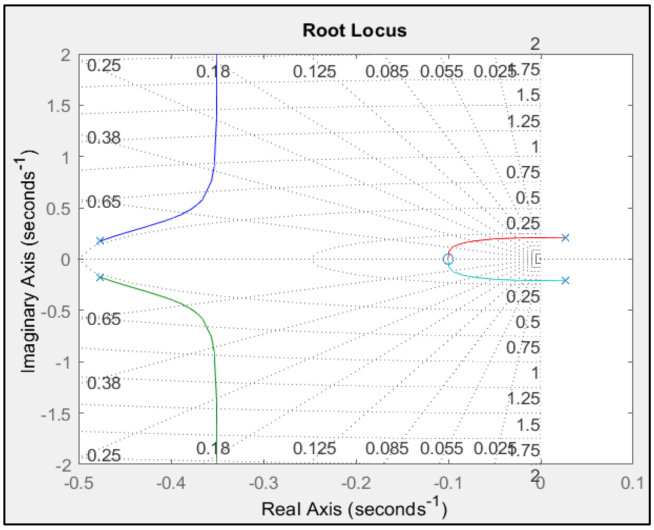
We have **two unstable closed loop poles** which will **require at least two zeroes near to the origin in the left half of the plane to realize a stable system** (or to make phase margin positive).

Taking controller of the type

C(s) = X (s+Y) (s+Z)

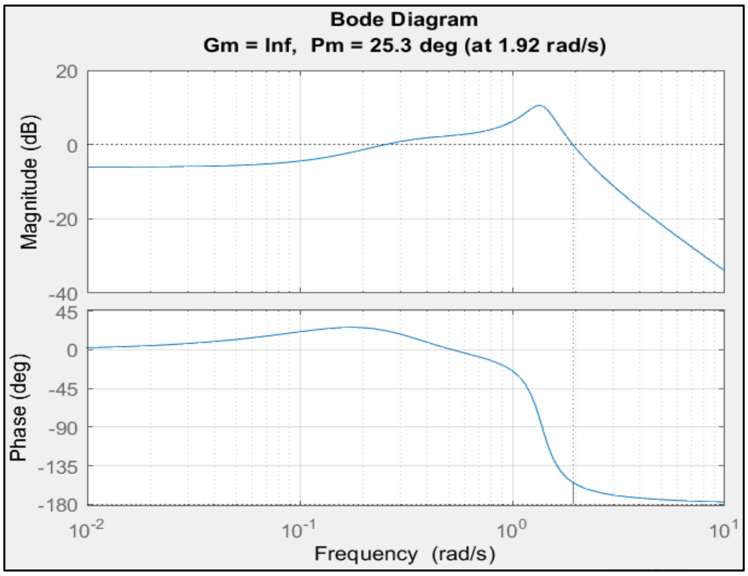


Locus without zeroes



Locus with zeroes

Taking **C(s) = (1+5.3s) * (1+3.7s)**



K_f = 1 & A = 0.1 (worst case)

With the help of two zero's

- **We can achieve a phase margin of 25⁰ in the worst case.**
- **Gain is very less at low frequencies which will result to high steady state error. (poor tracking)**

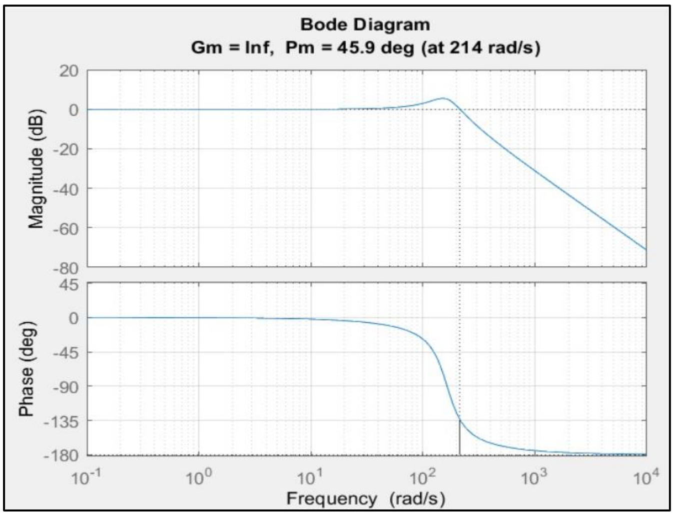
To solve the above issues, we introduce a lead compensator in our controller and tune the controller gain.

Now, **C(s)** = $\frac{X(s+Y)(s+Z)(s+W)}{(s+V)}$

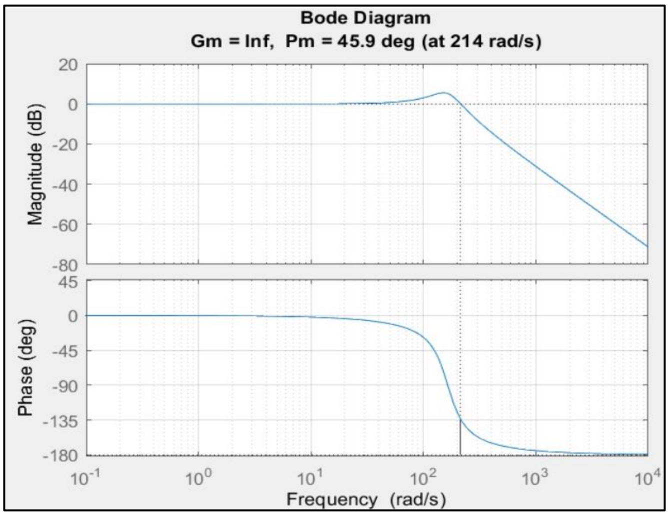
C(s) = $\frac{79.923\ (1+5.3s)(1+3.7s)(1+1.9s)}{(1+0.011s)}$

H(s)= $\frac{297.8s^3+293.4s^2+87.13s+7.993}{0.011s^5+1.02s^4+299.6s^3+294.4s^2+87.31s+8.103}$ (Closed loop Transfer Function of the designed system)

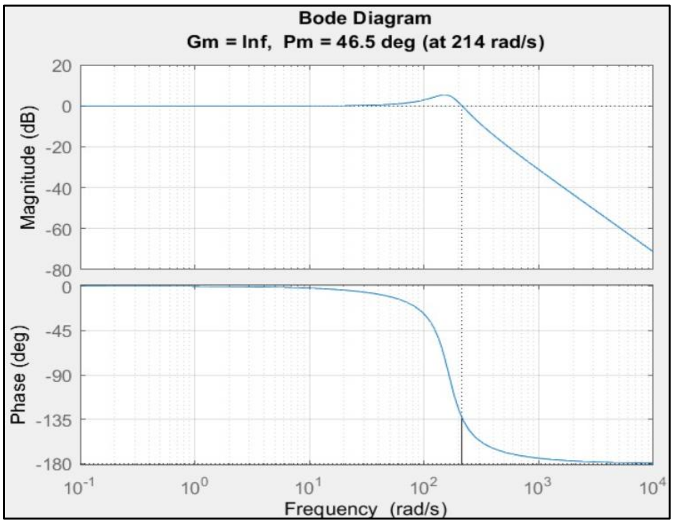
Phase margin for H(s) (in degrees)						
K_f	**s+A**					
	A=1	**A=0.8**	**A=0.6**	**A=0.4**	**A=0.2**	**A=0.1**
0.1	46.4721613323	46.3549756375	46.2379025929	46.1209416627	46.0040923150	45.9457108846
0.3	46.4721613325	46.3549756377	46.2379025932	46.1209416629	46.0040923152	45.9457108848
0.7	46.47216133301	46.3549756381	46.2379025936	46.1209416633	46.0040923156	45.9457108852
1	46.4721613333	46.3549756385	46.2379025940	46.1209416637	46.0040923160	45.9457108856



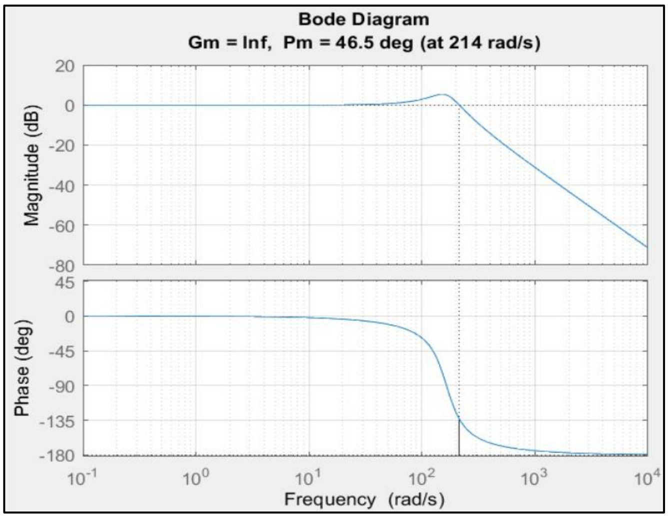
K_f = 0.1, A=0.1



K_f = 1, A=0.1



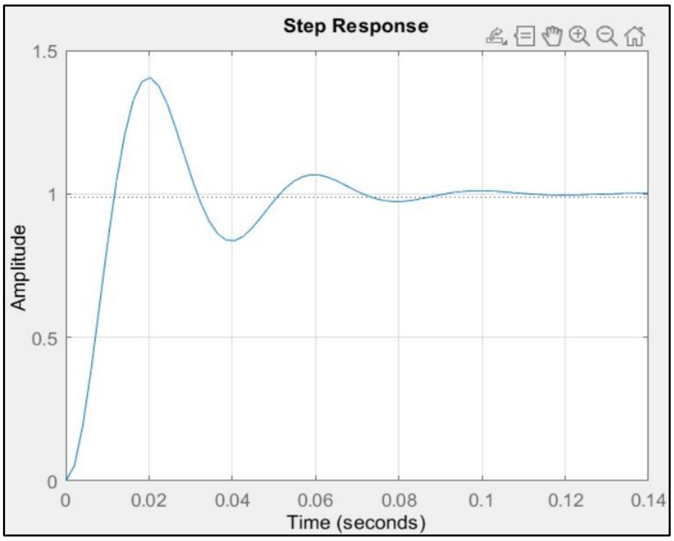
K_f = 0.1, A=1



K_f = 1, A=1

For the above controller:

- **We achieved a minimum phase margin of 45^0 throughout our range of A and K_f.**
- **We also achieved nearly zero steady state error for our function with improve response,** which can be verified from the step response attached below.




```
        RiseTime: 0.0079
   TransientTime: 0.1052
    SettlingTime: 0.1052
     SettlingMin: 0.8372
     SettlingMax: 1.4051
       Overshoot: 42.2893
      Undershoot: 0
            Peak: 1.4051
        PeakTime: 0.0203
```

Step response for the system in worst case

Analysis

We get our controller of the form,

$$C(s) = \frac{79.923\ (1+5.3s)(1+3.7s)(1+1.9s)}{(1+0.011s)}$$

Addition of zeroes to the original system,

- increases the phase margin.
- makes the system response faster.

But while achieving these characteristics, steady state error (tracking) of the system gets compromised. This is indicated by very small value of gain at low frequencies.

- Increase in the respirator gain reduce the steady state error of the system.

Further **addition of lead compensator** to this

- Increases the phase margin of the system to a minimum value of 45^{o} for every possible range.
- It also maintains the previous value of steady state error.

For our final design of system,

- There were oscillations along with a significant overshoot.
- Oscillations (and overshoot) depends on the value of phase margin.
- Higher the phase margin results in less overshoot and oscillations.

Therefore, the system can be **further optimized by increasing the minimum phase margin that we have for our worst case.**

MATLAB Script:

```
close all;
clear
clc
s=tf('s');
L=1/(s+1) ;
%L=(10)/((10*s)+1);          % 10 times time constant
CS=0.1/((s+0.5)*(s+0.1)*(s+0.2));
Vent=79.932*(1+5.3*s)*(1+3.7*s)*(1.9*s+1)/(1+0.011*s);
Kf=1;                        % 0.1 to 1
Gcl=feedback(L*CS, Kf);
Gf=Gcl*Vent;
Gg=feedback(Gf,1);
b=stepinfo(Gcl);
t=[0:100];
%stepplot(Gf, t);
%bode(Gcl);
margin(Gg);
damp(Gg);
isstable(Gg)
```

Conclusion:

In this lab,

- We designed a ventilator transfer function for a given respiratory system.
- Ventilator is optimised by considering the parameter variations due to both endocrinal and asthmatic patients individually, as well as simultaneously.
- We analysed various aspects that affect our ventilator design and improved the system accordingly.

THANK YOU!