# MECH 6323 - HW 07

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## Problem 1

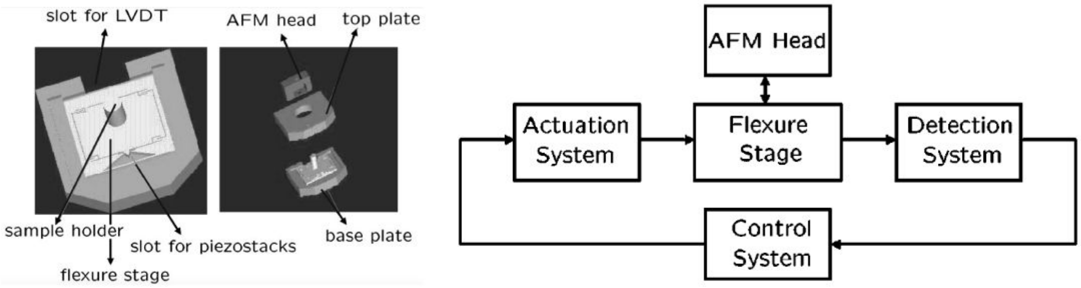



Fig. 1: Nanopositioning flexure stage (left) and feedback diagram (right); figures adapted from Salapaka et. al, *Rev. Sci. Instrum.* 2002.

```
clear
close all
```

### Part a

Load data: G, w, nano_sp.Gfr

```
% load('C:\Users\Jonas\OneDrive - The University of Texas at Dallas\2022_Spring\MECH6323\Homewo
nano_rsp = load('npresp.mat')
```

```
nano_rsp = struct with fields:
    Gfr: [1×1 frd]
      w: [1748×1 double]
      G: [1×1×1748 double]
```

```
omega_min = min(nano_rsp.w);
omega_max = max(nano_rsp.w);
```

#### Estimate system transfer function

```
tf_order = 6;
G_sys = fitfrd(nano_rsp.Gfr, tf_order)
```

```
G_sys =

  A = 
          x1      x2      x3      x4      x5      x6
   x1  -1468    8540   -8540    8540   -8540    4270
   x2  -4681    6559   -3757    3757   -3757    1878
   x3  -2174    4348   -7150    9952   -9952    4976
   x4  -4695    9390   -9390    6588   -3786    1893
   x5  -1687    3374   -3374    3374   -6176    4489
   x6  -3428    6856   -6856    6856   -6856   625.7

  B = 
```

```
         u1
   x1  5.156
   x2  11.36
   x3   16.7
   x4  18.15
   x5  11.59
   x6  11.18

  C = 
          x1      x2      x3      x4      x5      x6
   y1   114.1  -228.1   228.1  -228.1   228.1  -114.1

  D = 
           u1
   y1  0.08876

Continuous-time state-space model.
```

```
G_sys_tf = tf(G_sys)
```

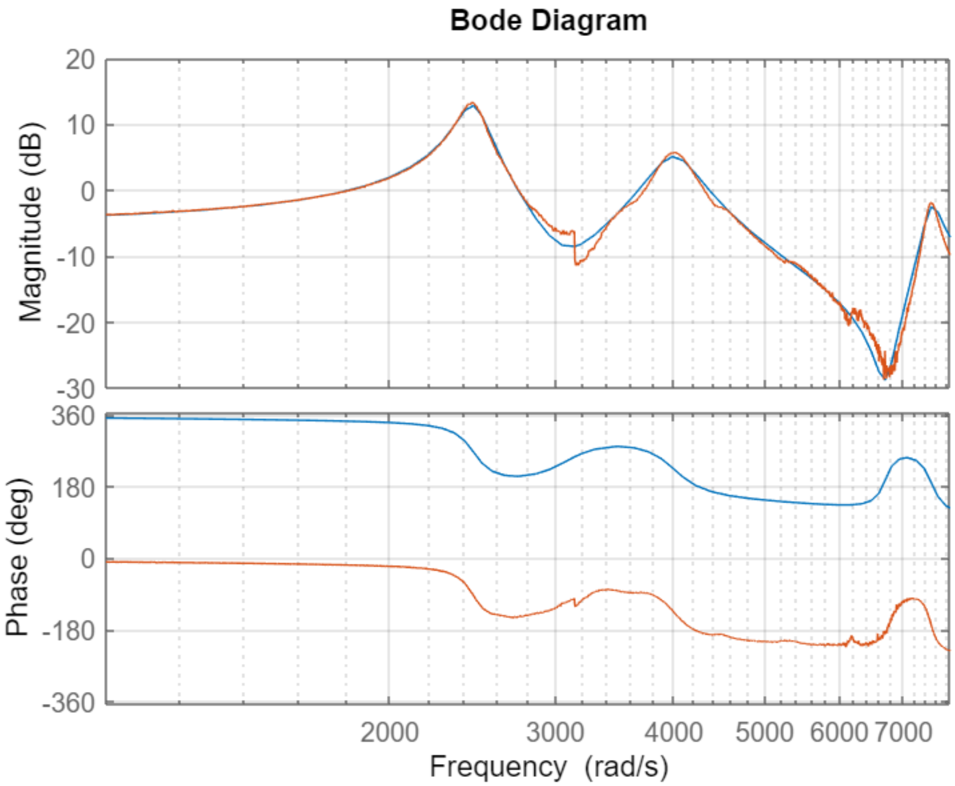
```
G_sys_tf =
 
  0.08876 s^6 - 876.1 s^5 + 1.136e07 s^4 - 4.345e10 s^3 + 4.097e14 s^2 - 2.095e17 s + 3.082e21
  --------------------------------------------------------------------------------------------
       s^6 + 1021 s^5 + 7.856e07 s^4 + 5.129e10 s^3 + 1.342e15 s^2 + 3.65e17 s + 5.421e21
 
Continuous-time transfer function.
```

```
G_sys_zpk = zpk(G_sys)
```

```
G_sys_zpk =
 
  0.088762 (s^2 + 526.7s + 9.417e06) (s^2 + 276.6s + 4.494e07) (s^2 - 1.067e04s + 8.207e07)
  -----------------------------------------------------------------------------------------
         (s^2 + 186.2s + 6.029e06) (s^2 + 482.7s + 1.6e07) (s^2 + 352.5s + 5.621e07)
 
Continuous-time zero/pole/gain model.
```

### Bode Diagram Data

```
figure()
bode(G_sys)
hold on
bode(nano_rsp.Gfr)
grid on
xlim([omega_min, omega_max])
```




Clearly this plot is a good estimation for the frequency response of the system, noting that the phase of the system is offset by a 360 degree phase shift (which implies a need for another set of integrators)

## Part b

### PI - Implimentation

```
PM_min = 75;
opt = pidtuneOptions( ...
    'PhaseMargin', PM_min, ...
    'DesignFocus', 'disturbance-rejection' ...
    )
```

```
opt = 
  pidtune with properties:

        PhaseMargin: 75
    NumUnstablePoles: 0
        DesignFocus: 'disturbance-rejection'
```

```
[C_pi, info] = pidtune(G_sys, 'pi', opt)
```

```
C_pi =
 
 
        1
  Ki * ---
        s
 
  with Ki = 240
```

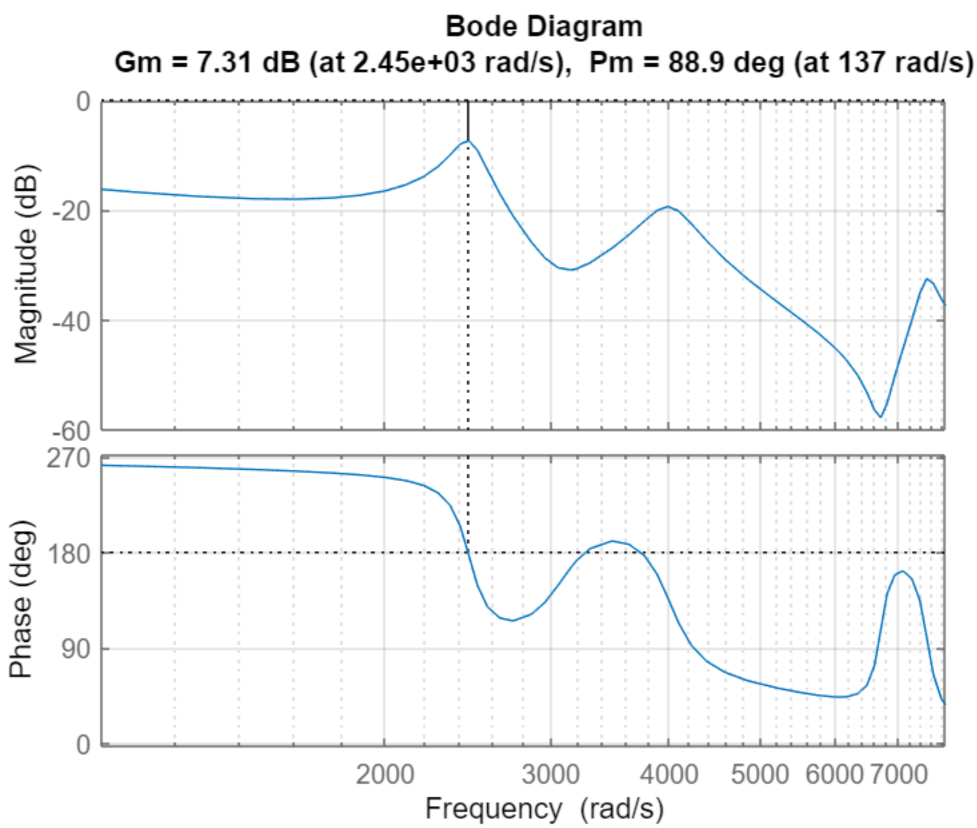
```
Continuous-time I-only controller.
info = struct with fields:
                Stable: 1
    CrossoverFrequency: 136.5946
           PhaseMargin: 88.9408
```

```
allmargin(C_pi * G_sys)
```

```
ans = struct with fields:
     GainMargin: [2.3213 31.8215 13.3190]
    GMFrequency: [2.4472e+03 3.2556e+03 3.7346e+03]
    PhaseMargin: 88.9408
    PMFrequency: 136.5946
    DelayMargin: 0.0114
    DMFrequency: 136.5946
         Stable: 1
```

### Bode Diagram of Margin

```
figure
margin(C_pi * G_sys_tf)
xlim([omega_min, omega_max])
grid on
```



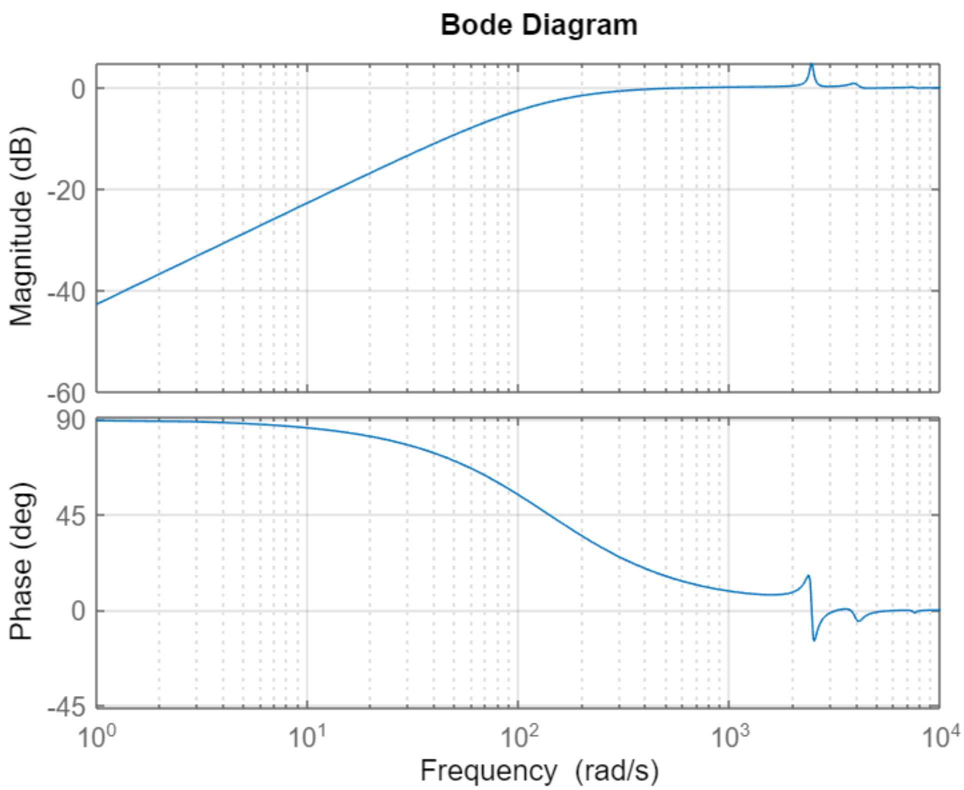

As a result, the single only integral controller is a pretty weird result. However, looking at the results it does make sense.

### Sensivity Transfer Function

```
S_pi = zpk(1/(1+C_pi*G_sys))
```

```
S_pi =

      s (s^2 + 186.2s + 6.029e06) (s^2 + 482.7s + 1.6e07) (s^2 + 352.5s + 5.621e07)
  ------------------------------------------------------------------------------------
  (s+138.6) (s^2 + 108.1s + 5.995e06) (s^2 + 446.2s + 1.584e07) (s^2 + 349.8s + 5.615e07)

Continuous-time zero/pole/gain model.
```

```
figure
bode(S_pi)
grid on
```




### Bandwith Calculation

```
bw_threshold = -3; %db
bw = getGainCrossover(S_pi, db2mag(bw_threshold))
```

```
bw = 134.4361
```

## Double Integrator implimenation

Instead we can also include an additional integrator into the controller, i.e.

```
G_int = tf(1,[1, 0]);
[C_pi_int, info] = pidtune(G_int * G_sys, 'pi', opt)
```

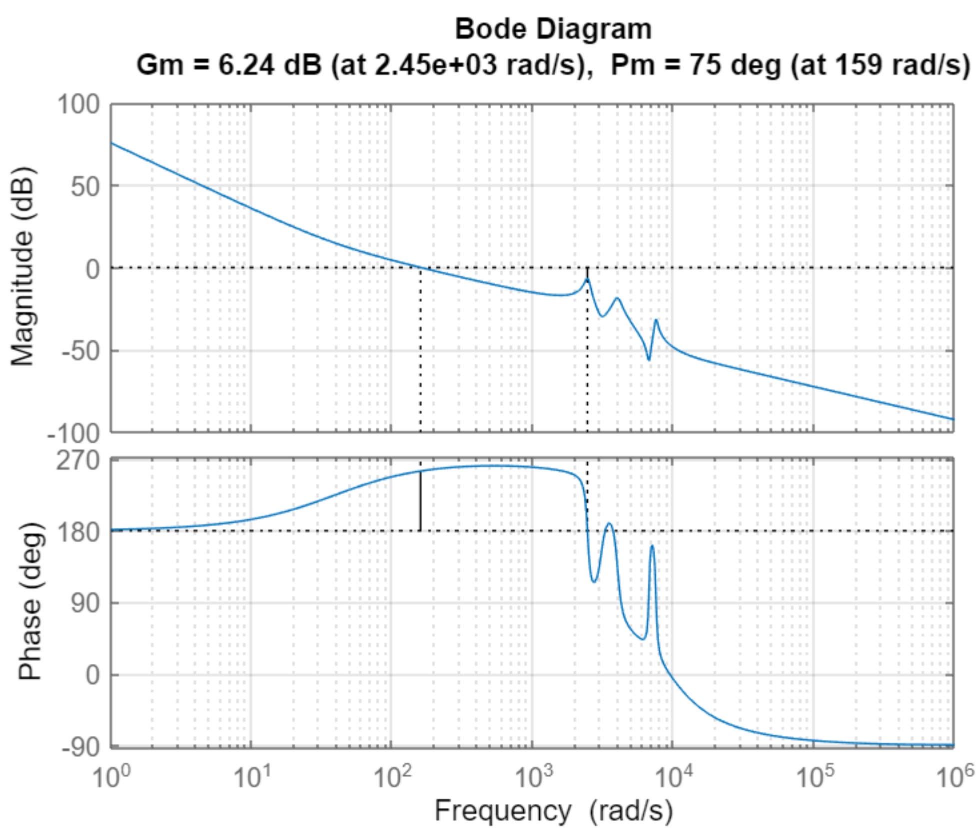
```
C_pi_int =

             1
  Kp + Ki * ---
```

```
           s

  with Kp = 271, Ki = 1.06e+04

Continuous-time PI controller in parallel form.
info = struct with fields:
                Stable: 1
    CrossoverFrequency: 159.0729
           PhaseMargin: 75.0000
```

```
allmargin(C_pi_int * G_int * G_sys)
```

```
ans = struct with fields:
     GainMargin: [0 2.0518 27.8933 11.9425]
    GMFrequency: [0 2.4457e+03 3.2626e+03 3.7282e+03]
    PhaseMargin: 75.0002
    PMFrequency: 159.0759
    DelayMargin: 0.0082
    DMFrequency: 159.0759
         Stable: 1
```

```
figure
margin(C_pi_int * G_int * G_sys)
grid on
```



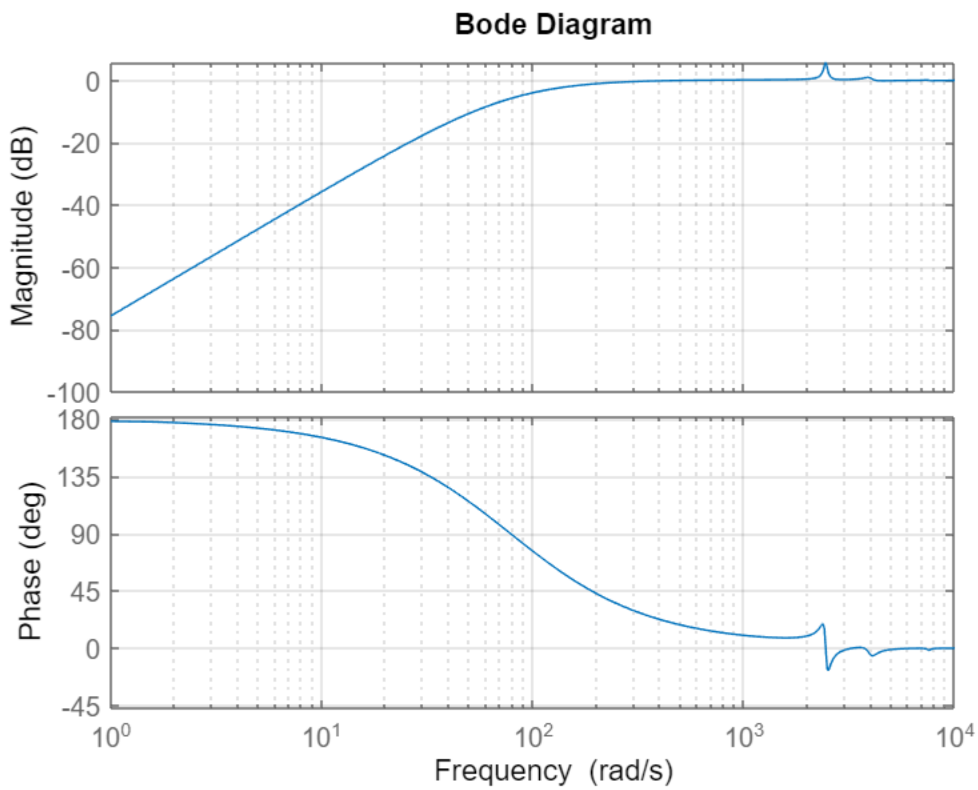

### Sensivity Transfer Function

```
S_pi_int = zpk(1/(1+C_pi_int*G_int*G_sys))
```

```
S_pi_int =

            s^2 (s^2 + 186.2s + 6.029e06) (s^2 + 482.7s + 1.6e07) (s^2 + 352.5s + 5.621e07)
```

```
  -------------------------------------------------------------------------------------------------
  (s^2 + 156.3s + 6120) (s^2 + 97.81s + 5.989e06) (s^2 + 441.9s + 1.582e07) (s^2 + 349.5s + 5.614e07)

Continuous-time zero/pole/gain model.
```

```
figure
bode(S_pi_int)
grid on
```




### Bandwith Calculation

```
bw_threshold = -3; %db
bw = getGainCrossover(S_pi_int, db2mag(bw_threshold))
```

```
bw = 117.7945
```

The bandwidth of this method is not as great as the original PI implimenation. I think the performance is better in certain situation though and may be worth implimenting (even if it isn't really a PI controller)

## Part c

## Final Parts

```
fname = matlab.desktop.editor.getActiveFilename;
export(fname, 'MECH6323_HW07.pdf')
```

```
ans =
'C:\Users\Jonas\OneDrive - The University of Texas at Dallas\2022_Spring\MECH6323\Homework\HW07\MECH6323_HW07.pdf'
```