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Analysis of Phase Lead Compensation Design for Hot-Ingot Robot Control System Using MATLAB

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***Abstract*— The paper describes the result comparisons that were developed for the phase lead compensator design using MATLAB. The MATLAB m-files that use the implementation of classical experiments are described. The Root locus analysis for stability of Hot-Ingot Robot Control System has been analyzed. The Hot-Ingot Robot Control System can be designed to gain insight into a variety of concepts, including stabilization of unstable control systems, Root locus analysis. The analysis has resulted in a number of important conclusions for the design of a new generation of control support systems.**

***Keywords*— Phase lead Compensator, Hot-Ingot Robot Control System, MATLAB, Root locus**

I. INTRODUCTION

A compensator is an additional component or circuit that is inserted into a control system to compensate for a deficient performance. The purpose of phase lead compensator design in the time domain generally is to satisfy specifications on settling time (2%) and percent overshoot.

The Root locus method is a graphical method for sketching the locus of roots in the s-plane as a parameter is varied. The two types of lead compensator are active and passive lead compensation. In this paper, the active lead compensation has been discussed. The design procedure presented here is basically graphical in nature. The experiments and plots presented here are all done in MATLAB, and the various measurements that are presented in the experiments are obtained from the various data arrays. The primary references for the procedures described in this paper are [1] – [3]. Other references that contain similar material are [4] – [11].

II. PHASE LEAD COMPENSATION

A. *Active lead compensation*

An active lead compensation network is known as an inverting operational amplifier

$$G(s)=K_1(1+T_1s)/(1+T_2s) \qquad (1)$$

Thus from $G(s)$ equation it can be seen that the system designer has complete flexibility since, K_1, T_1 and T_2 are not linked. For a lead network, T_1 must be greater than T_2.

From (1),

$$G(jw)=K_1(1+jwT_1)/(1+jwT_2) \qquad (2)$$

By expanding

$$G(jw)=K_1[(1+T_1T_2w^2)+(jw(T_1-T_2)]/(1+w^2T_2^2) \qquad (3)$$

$$\tan\Phi=[w(T_1-T_2)]/(1+T_1T_2w^2) \qquad (4)$$

To find w_m, differentiate (4) with respect to w, and equate to zero. This gives

$$w_m=1/\sqrt{T_1} \qquad (5)$$

Substituting (5) into (4) to give

$$\Phi_m=\tan^{-1}[(T_1-T_2)/2\sqrt{T_1}] \qquad (6)$$

III. PHASE LEAD DESIGN USING THE ROOT LOCUS

The design of the phase lead compensation network can be readily accomplished using the root locus. The phase lead network has a transfer function

$$G_c(s)= \frac{|s+(1/\alpha\tau)|}{|s+(1/\tau)|} = \frac{l_z}{l_p} \qquad (7)$$

where α and τ are defined for the RC network. The locations of the zero and pole are selected so as to result in a satisfactory root locus for the compensated system. The specifications of the system are used to specify the desired location of the dominant root of the system. The s-plane root locus method is as follows:

- List the system specifications and translate them into a desired root location for the dominant roots.
- Sketch the uncompensated root locus, and determine whether the desired root locations can be realized with an uncompensated system.

- If a compensated system is necessary, place the zero of the phase lead network directly below the desired root location (or to the left of the first two real poles).
- Determine the pole location so that the total angle at the desired root location is 180° and therefore is on the compensated root locus.
- Evaluate the total system gain at the desired root location and then calculate the error constant.
- Repeat the steps if the error constant is not satisfactory.

IV. Hot-Ingot Robot Control System

A computer controller for a robot that picks up hot ingots and places them in a quenching tank is shown in Fig.1. The robot places itself over the ingot and then moves down in the y-axis. The ingots from furnace are carried by robot to quench. After quenching the ingot, the robot gripper will pick up from the quenching tank to another conveyor for main store. In this system, the controller $G_c(s)$ will compensate the signal from feedback of gripper and ingot position in x and y directions by robot vision system. The error signals from the feedback measurement are applied to compensate for the stability of that system.

Fig. 1 is the actual control system for the mass production of industrial life. The robot position will be changed by the command of the controller. The control system is shown in Fig. 2. Based on the ideas of control theory, the controller circuit is designed by using MATLAB root locus and Bode codes to reach the stable state of that control system.

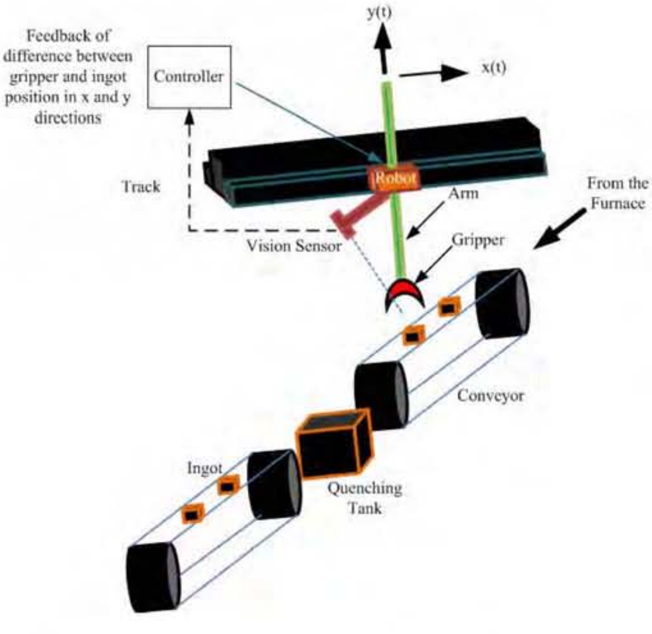


Fig. 1.Hot ingot robot control system

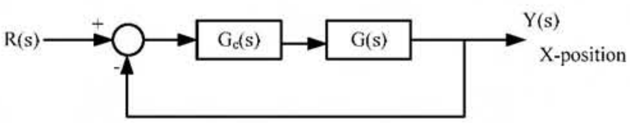


Fig. 2 Block diagram of control system

The Performance Specifications are as follows:
Settling Time (2% criterion), T_s ≤4 seconds
Percent overshoot for a step input ≤35%
The characteristic equation of the uncompensated system is
$1+G(s)H(s)=0$

$$=1+K_1/s^2 \quad (8)$$

The uncompensated root locus plot is shown in Fig. 3.

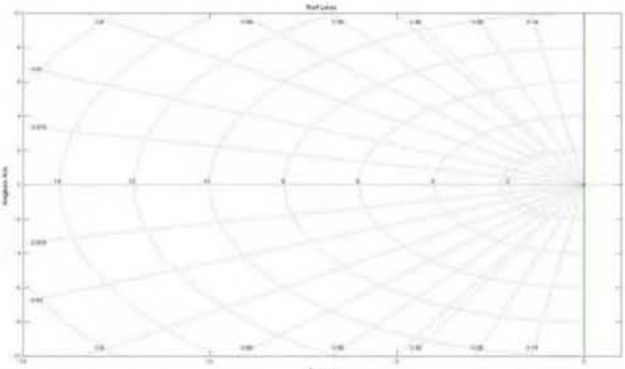


Fig. 3 Uncompensated root locus plot for control system

Therefore we desire to compensate this system with a network, $G_c(s)$, where

$$G_c(s)=(s+z)/(s+p) \quad (9)$$

The damping ratio should be 0.32. The settling time requirement is

$T_s= \; = 4,$

and therefore ζ=1. Thus we will choose a desired dominant root location as

$r_{1,2}=-1 \;\; j2,$

as shown in Fig.4.(thus =0.45)

Now we place the zero of the compensator directly below the desired root location at s=-z=-1, as shown in Fig.4. Measuring the angle at the desired root, we have

$$= -2(116°)+90°=-142° \quad (10)$$

Therefore to have a total of 180° at the desired root, we evaluate the angle from the undetermined pole, , as

$$-180°=-142°- \quad (11)$$

or =38°. Then a line drawn at an angle =38° interesting the desired root location and real axis, as shown in Fig.4. The point of intersection with the real axis is then s=-p=-3.6.

Therefore the compensator is

$$G_c = \frac{(s+}{(s+} \quad (12)$$

and the compensated transfer function is

$$GH(s)G_c(s)= \frac{K_1(s+}{s^2(s+} \quad (13)$$

The gain K_1 is evaluated by measuring the vector lengths from the poles and zeros to the root location. Hence

$$K_1= \qquad =8.1 \quad (14)$$

Finally the error constants of this system are evaluated. We find that this system with two open-loop integrations will result in a zero steady state error for a step and ramp input signal. The acceleration constant is

$$K_a=8.1/3.6=2.25 \quad (15)$$

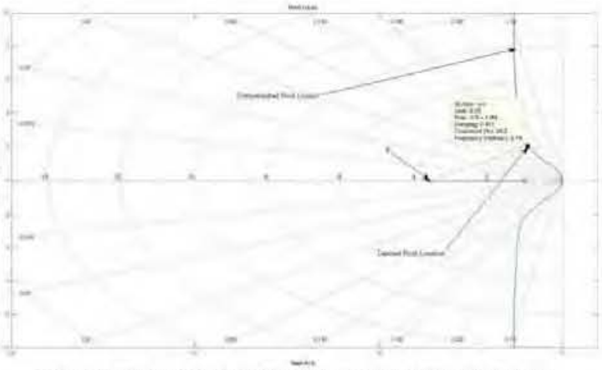


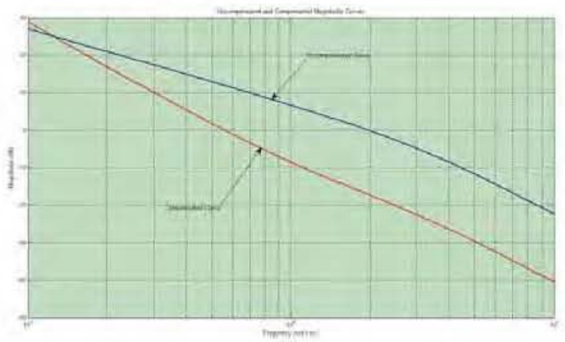
Fig. 4 Phase lead design for Hot ingot robot control system

The steady state performance of this system is quite satisfactory, and therefore the compensation is completed.

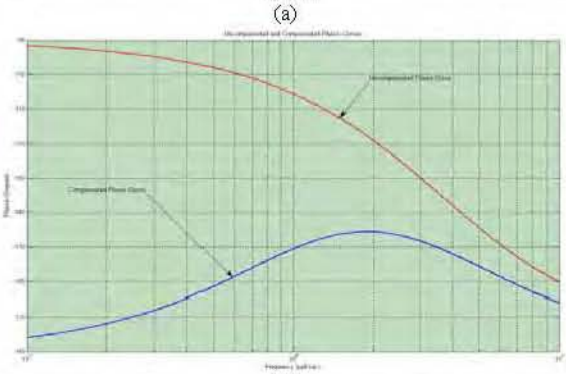
The procedure that I use when working in MATLAB rootlocus generates the data arrays from the following instructions:

```
num= [1 1];
den= [1 3.6 0 0];
sys=tf(num,den);
clf; rlocus(sys);hold on
zeta=0.45;wn=2.22222222222222222222222222222222222222
2222222222222;
x=[-10:0.1:-zeta*wn];y=-(sqrt(1-zeta^2)/zeta)*x;
xc=[-10:0.1:-zeta*wn];c=sqrt(wn^2-xc.^2);
plot(x,y,':',x,-y,':',xc,c,':',xc,-c,':')
axis([-15,1,-10,10]);
```

The Bode plots for that system are shown in Fig. 4. The magnitude and phase curves for uncompensated and compensated system are also implemented. After applying the compensator, the gain margin and phase margin are matched the performance specifications.



(a)



(b)

Fig. 4 (a) The Uncompensated and Compensated Magnitude Curves (b) The Uncompensated and Compensated Phase Curves

The procedure that I use when working in MATLAB Bode code generates the data arrays from the following instructions:

```
num= [1 1];
den= [1 3.6 0 0];
w=logspace(-1,1,200);
[mag,phase,w]=bode(num,den,w);
num1=[8.1 8.1];
den1=conv([1 1 0],[1 3.6]);
[mag1,phase1,w]=bode(num1,den1,w);
semilogx(w,20*log10(mag),w,20*log10(mag1))
xlabel('Frequency (rad/sec)')
ylabel('Magnitude (dB)')
title('Uncompensated and Compensated Magnitude
Curves')
grid;
```

To implement the original lead compensator G(s) in this paper, we can use the following values

$C_1 = 0.47\,\mu F$,

$C_2 = 0.47\,\mu F$

$R_1 = 2.13M\Omega$,

$R_2 = 133K\Omega$,

The ogata's lead compensator circuit is as shown in Fig. 5.

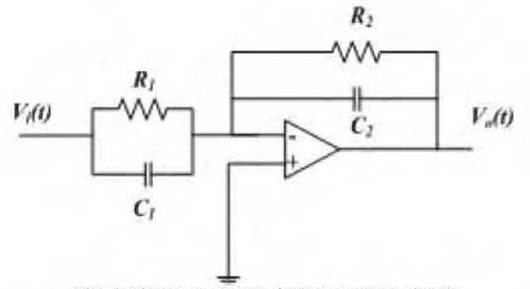


Fig. 5 The Ogata's Lead compensator circuit

V. Conclusion

In this paper the comparison between uncompensated and compensated system has been discussed by Root Locus method. The design circuit has been presented the control system point of view. And the MATLAB root locus and bode plots analysis codes for simulation results have been implemented in this paper. The designer has been assumed the frequency components C_1 and C_2 .The Op-Amp is used as an ideal case. In the further extension, the designers are applied with high performance Op-Amp according to the actual control system.

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