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# Adaptive Cruise Control Design of Small Electric Car using Root Locus Control

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***Abstract: The Adaptive Cruise Control (ACC) is a software based electronic control system that increases the convenience and safety features. Though it provides an accountable safety, the driver should get adopted to the cruise control and should respond appropriately to the feedback. In this research, We have focused on the proportional gain [Kp] by considering Rise time (r) less than 5 seconds, overshoot (P) less than 30% and steady state error (e) less than 3% with a damping ratio of 0.5.***
***The program was entered in the MATLAB and corresponding Root Locus and Step response were plotted. In the first iteration, it was observed that the rise time and overshoot met the required criteria and in the second iteration steady-state-error also met the required criteria. Here in-order to compensate the lag in steady-state-error, a log controller is used and corresponding root locus and step response were plotted.***
***Keywords: Adaptive Cruise Control, Controller, Design, Electric car, MATLAB, Root Locus Control, Transfer function, Vehicle Dynamics***

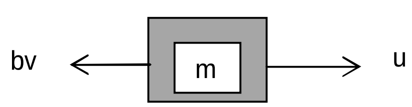
## I. INTRODUCTION

The electric car is propelled with one or more electric motors by drawing the energy from a battery or connected to an external source like catenary (used in trams). With the advancements in the technology, research's are being done to improve the mobility in day-to-day life. One such technology is the cruise control which gave its presence more than two decades ago and still the research continues to make it error free.
The ACC is an available cruise control system for road vehicles that automatically adjusts the speed when a vehicle or an obstacle are found on the same line of travel. There should not be any lag in response after a vehicle or an obstacle are found as it leads to accident. So to avoid this, a perfect feedback system is to be adopted which gives the correct information at the required time without any delay. The authors in [1] present an energy saving cooperative ACC which minimizes the energy consumption of autonomous electric vehicles. [2] introduced a design of cooperative ACC systems for automated driving of platoons of vehicles in the longitudinal direction. [3] proposed an ACC in order to maintain the appropriate distance to the lead vehicle.

## II. METHODOLOGY

### *A. Methodology*

ACC is the best cruise control feedback system for road vehicles that adjust their speed automatically to maintain a constant speed and safe distance despite of external disturbances. This is fulfilled by measuring the vehicle speed and compare this to the desired speed by automatically adjusting the throttle.The free body diagram of a vehicle dynamics model can be represented in fig(1).




Fig(1): Free body diagram of electric car

The first order system of equation for mass - damper system can be written as:

$$m\dot{v} + bv = u \longrightarrow \quad \text{eq.(1)}$$

We do consider in controlling the speed of the car, so the output equation can be written as:

$$y = v \quad \longrightarrow \quad \text{eq.(2)}$$

As the first order system of equation is applied.

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*B. State-space model*

The first order system have only kinematic energy storage. Therefore only velocity is needed.

$$\dot{x} = [\dot{v}] = [-c/m][v] + [1/m]\,[u] \longrightarrow \quad eq.(3)$$

$$y = [1]\,[v] \longrightarrow \quad eq.(4)$$

eq.(3) & (4) represent the relationship between the input and output of the system, and can be described as Transfer function model.

$$P(s) = V(s)/U(s) = 1/(ms+c)$$

*C. System Parameters*

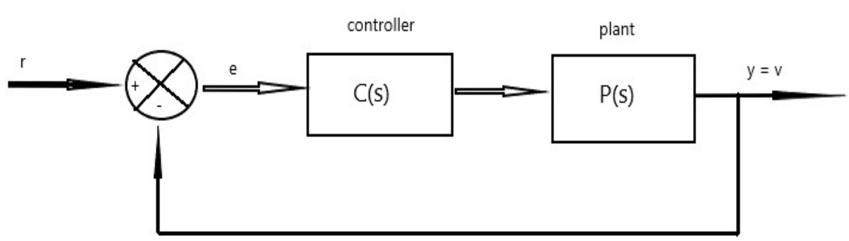
Mass of the small electric car ; m = 1310 kg
Damping coefficient ; c = 50 N.s/m
Reference speed ; r = 20 m/s

*D. Performance Specifications*

Rise time < 5 seconds
Overshoot < 20%
Steady-state-error < 3%

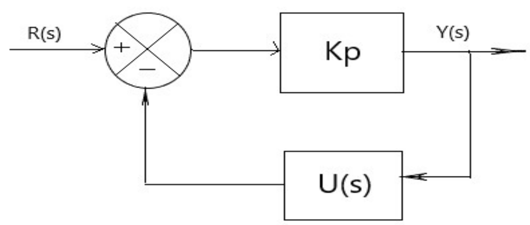
*E. Feedback control*

Feedback systems process signals like signal processors. The processing part of a feedback system may be electrical or electronic. The fig(2) below shows the block diagram of the feedback system showcasing the rise time, error, input and final output.




Fig(2): Feedback control

*F. Proportional Control*




Fig(3): Proportional control

The root locus plot shows all possible closed loop plots when gain is varied from zero to infinity. So Kp is considered.

$$[Y(s) \div R(s)] = Kp \div [ms + (c + Kp)]$$

Natural frequency ; $\omega n \geq 1.8 / Tr$

Damping ratio ; $\varsigma \geq \sqrt{\dfrac{\ln(Mp)^2}{\pi^2 + \ln(Mp)^2}}$

The design criteria for this electric car model is mentioned in the performance specifications and designed accordingly. The design of this model was made to run in MATLAB R2018b and discussed in the further sections.

*G. Lag controller*

To reduce the steady state error, a lag controller is used. The transfer function of the lag controller is given by:

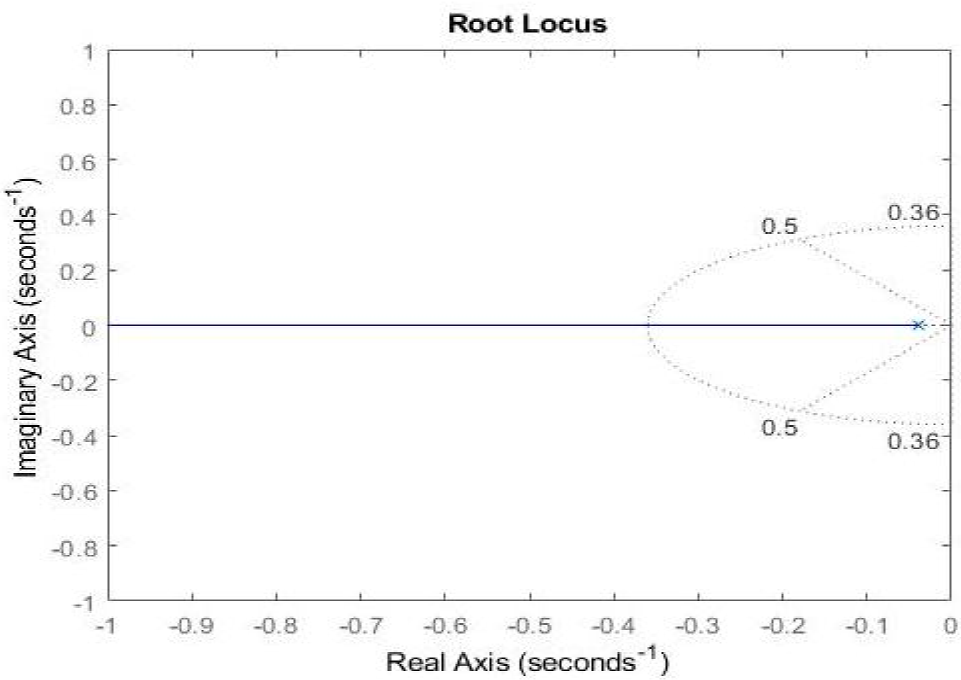
$$C(s) = \frac{s + zo}{s + po}$$

Closed loop transfer function with Kp ; $\frac{Y(s)}{U(s)} = \frac{KpS + KpZo}{ms2 + (c + mPo + Kp)s + (cPo + KpZo)}$

## III. RESULTS & DISCUSSION

*MATLAB commands*

```
m=1310;
c=50;
r=20;
s=tf('s');
P_cruise=1/(m*s+c);
Rlocus(P_cruise)
axis([-0.6 0 -0.6 0.6]);
sgrid(0.6,0.36)
```




Fig(4): Root locus plot

In fig(4), the V-angled dotted lines indicate the location of damping ratio (ς=0.5) and the dotted semi ellipse indicate the location of constant natural frequency (ωn=0.36)

rlocfind command is used to find the gain, to place the closed loop poles in the desired region.

Enter the command [Kp,poles]=rlocfind(P_cruise)

to the end of the m-file and run the code. This command helps us to choose a specific loop again by picking a point on the root locus ie., the blue line in the plot and can find a cross shape in the figure. The gain value is obtained from the MATLAB command window.

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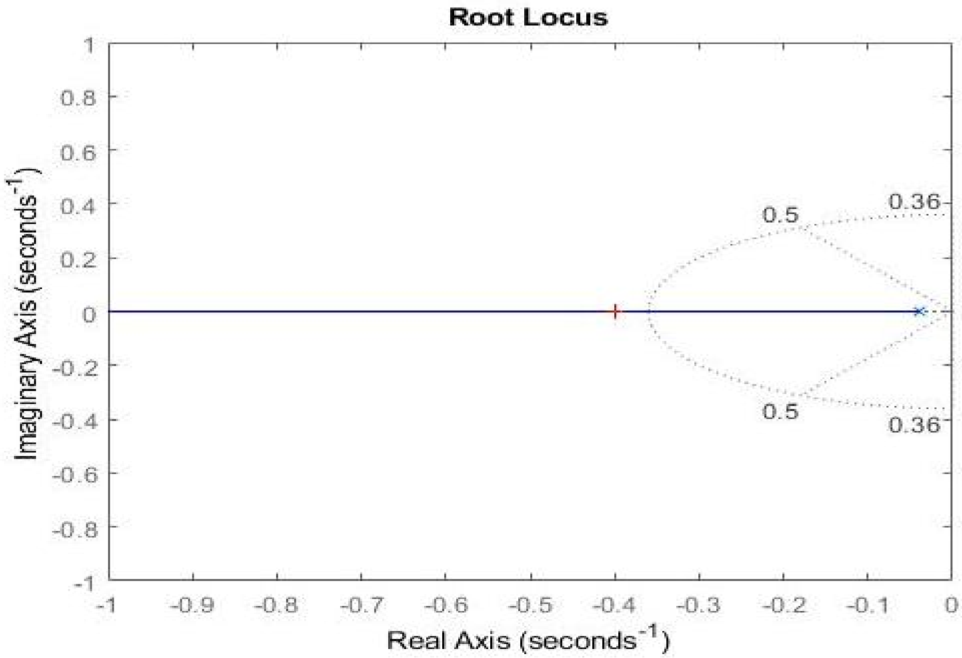
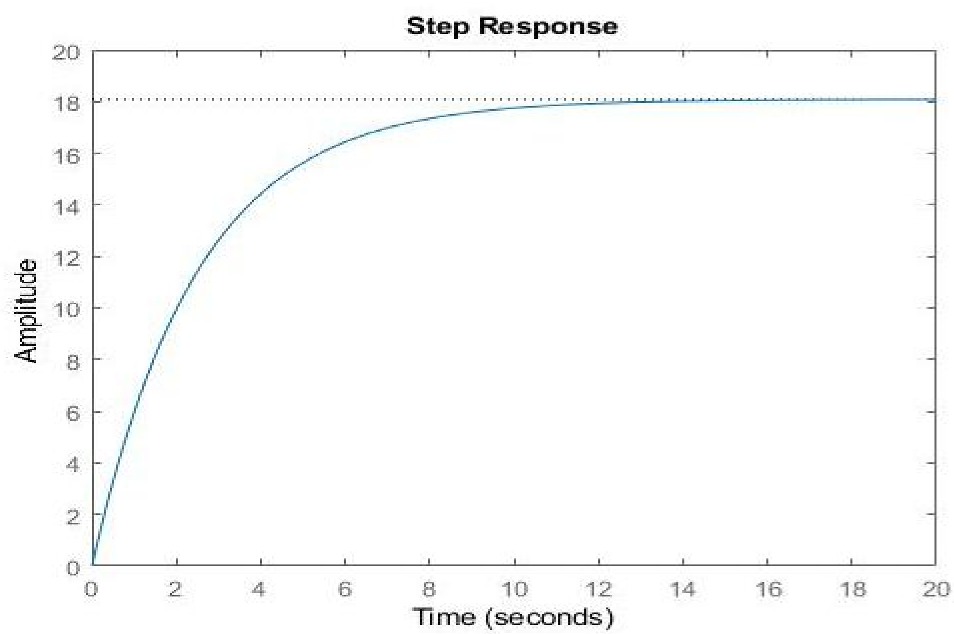



Fig(5): Root locus plot

Select a point in the graphic window
Selected point = -0.3993+0.0062;
Kp = 473.1383
Poles = -0.3993
The value Kp mentioned above is the returned value from the output signal. This returned value can be used as the gain compensator and the closed loop step response can be generated from MATLAB by entering the code below.

```
Kp = 473.1383;
Sys_cl = feedback(Kp*P_cruise,1);
t = 0:0.1:20;
Step(r*sys_cl,t)
```




Fig(6): Step response for Kp=473.1383

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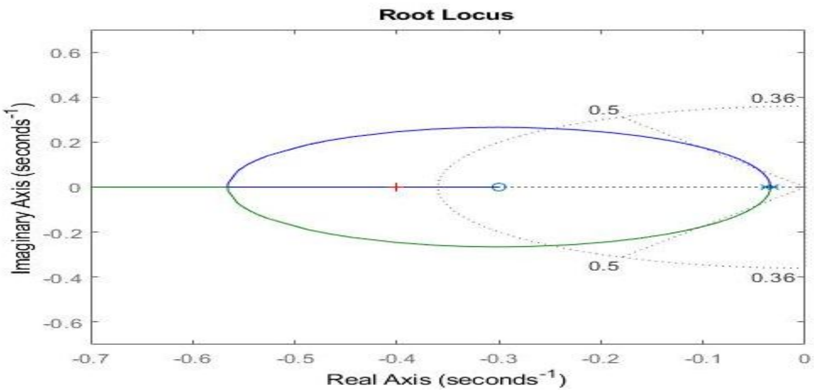
With the gain Kp, the rise time and overshoot criteria were met. However, a steady state error of more than 12% still exist. This can be eliminated by a lag controller.

Consider the values of zo=0.3 and po=0.03 and write the folllowing code.

```
Zo=0.3;
Po=0.03;
S=tf('s')
C_lag = (s+zo)/(s+po);
Rlocus(C_lag*P_cruise);
Axis([-0.7 0 -0.7 0.7])
Sgrid(0.5,0.36);
[Kp,poles] = rlocfind(C_lag*P_cruise)
```



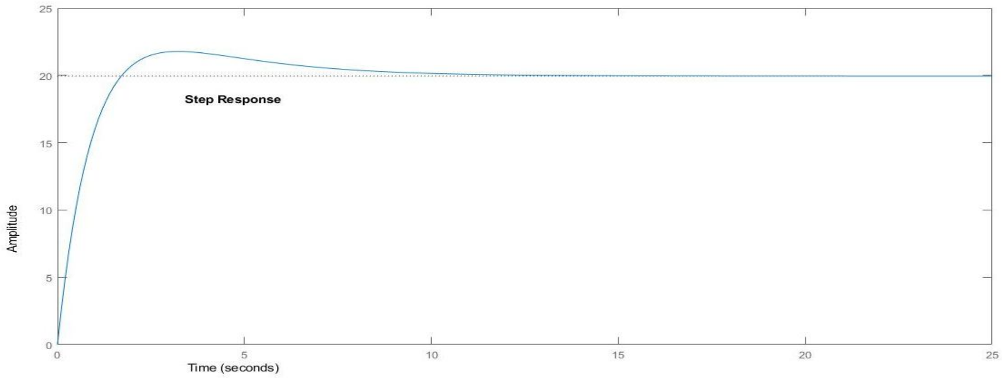

Fig(7): Root locus plot with lag

After obtaining the cross mark in the ellipse,the below code is generated mentioning the Kp value of the second iteration.

```
Selected_point = -0.4006-0.0000i
Kp = 1.7491e+03
Poles = 2x1
    -1.0028
    -0.4006
```

The new closed loop response can be generated as follows:

```
Kp = 1749.1;
Sys_cl = feedback(Kp*C_lag*P_cruise,1);
t = 0:0.1:20;
Step(r*sys_cl*t)
Axis([0 20 0 20])
```




Fig(8): Step response for Kp= 1749.1

## IV. CONCLUSION

The experiment was performed to see the effect on the closed loop system response whether it is functioning according to the input given and to note the settling time of the response generated. The starting performance specifications of 5 seconds rise time, less than 20% overshoot and less than 3% steady state error were attained at a gain of Kp=1749.1 considering zo=0.3 and po=0.03. However, with a change in values of zo and po, the steady state error may vary as it will be reduced by a factor of (zo/po). From fig(8) it is clear that the rise time is less than 5 seconds, overshoot is less than 20% and less than 3% steady state error were occured for our design.

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