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Simulation analysis of various PID controller algorithms and their impact on design of Anti Lock Brake

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Abstract—Proportional Integral Derivative (PID) is one of the oldest and most widely used control strategies in industries. Designing and tuning this controller is relatively easy and despite being very old strategy, is still in use in various industries for process control, automotive and aerospace systems. Several PID tuning methodologies and empirical formulas evolved such as Ziegler–Nichols algorithm, Chien–Hrones–Reswick formula, Cohen–Coon formula etc.

In this paper we are not discussing on the tuning aspect of PID controller but on the basic design configurations of various P-I-D and their impact on design of Antilock Brake (ABS) as a case study .There are three basic design approaches for a PID controller: Ideal, Parallel and Series. These three configurations are separately studied by using them as an Antilock Brake Controller and their impact on stopping distance and stopping time is analyzed.

Stopping distance is the distance travelled by the vehicle after applying the brake and time for the vehicle to reach to complete halt is stopping time. We can, in general consider a controller as a good controller if it helps to reduce both stopping distance and time.

Under the influence of Drive torque, the vehicle moves and due to air drag, braking torque, surface friction and inertia, vehicle come to stop. A dynamic combination of all these torques and forces are responsible for motion of vehicle on a surface and coefficient of friction between tyre and road-surface, amount of steering etc contribute further to vehicle dynamics.

Due to drive torque generated by engine, the wheels starts rotating and when brake applied it comes to halt after sometime.
Vehicle speed and wheel angular speed are proportional in normal condition but when hard braking is made it is possible that vehicle speed is not slowing down at the same rate as wheel angular speed, causing the slip.
Slip is a situation created by locking of wheels, means wheels not rotating but vehicle is moving. This is a fatal driving condition and driver can lose the control of vehicle and the time to stop the vehicle increases.

Index Terms— PID controller. Antilock Brake,stopping distance,stopping time,slip ratio,wheel locking

1 introduction

The influence of individual elements on the characteristic of a PID controller is summarized below:

Closed Loop Response	Rise Time	Overshoot	Settling Time	Steady-State Error
P	Decrease	Increase	Small Change	Decrease
I	Decrease	Increase	Increase	Eliminate
D	Small Change	Decrease	Decrease	Small Change

Although from implementation point of view, PID controller seems easier but tuning it to an appropriate combination is very tedious job and this is the exact reason which gives scope of developing several tuning algorithms. Particularly for complex mechanical system with certain lag or hysteresis, the PID controller does not yield good result due to non-linearity.

A good control system should ideally have smaller rise time, less overshoot, smaller settling time and steady state error. So having a combination of P, I and D in such a way that an ideal controller design can be obtained using any generic empirical formula; unfortunately does not exist.

A design tuned for any particular application may be completely unsuitable in other scenario.

When we speak about a PID, it's not a unique design but has three basic approaches. There are three configuration of PID controller: Ideal, Series and Parallel [2].

In time domain, these three configurations are defined as below:

Ideal P-I-D

$$u(t)=K_C\left[e(t)+\frac{1}{I}\int e(t)d(t)+D\frac{de(t)}{dt}\right] \quad \text{……equation(1)}$$

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Parallel P-I-D

$$u(t) = K_P[e(t)] + \frac{1}{I}\int e(t)d(t) + D\frac{de(t)}{dt} \quad \text{.......equation (2)}$$

Series P-I-D

$$u(t) = K_C\left[e(t) + \frac{1}{I}\int e(t)d(t)\right]\left[1 + D\frac{d}{dt}\right] \quad \text{......equation (3)}$$

Where, u(t) is the input signal to the plant model, the error signal e(t) is defined as e(t) =r(t) − y(t), and r(t) is the reference input signal.

K_C and K_P are gain, I is integral and D is derivative component.

2 Comparison of various PID configurations

2.1 Designing controllers

The controller design of three PID approaches described above is given below in Figure 1, 2 and3 respectively. Design is done using SIMULINK blocks and equations (1) through (3) described above.

For simulation, fixed step solver ode1(Euler) type is used.

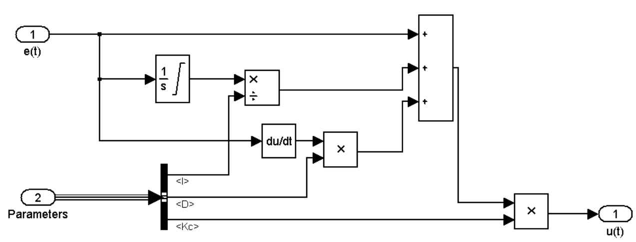

Figure 1: Ideal PID design approach

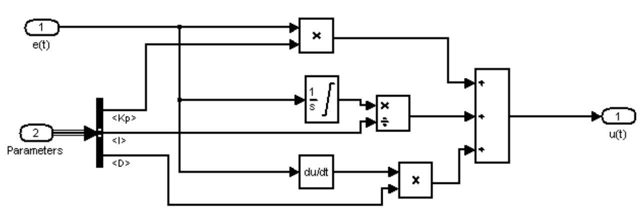

Figure 2: Parallel PID design approach

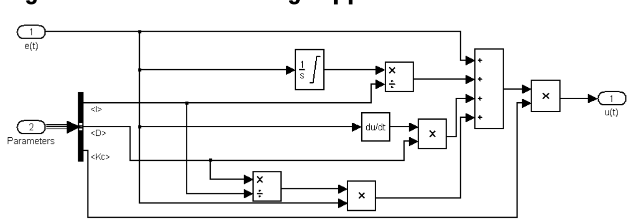

Figure 3: Series PID design approach

2.2 Response of controllers

These three types of PID design approaches were subjected to standard step input and uniform random signal, their response obtained is shown in Figure 4 and Figure 5 respectively.

For reference, an On-Off (Bang-Bang) controller is used.

Output of On-Off controller is having just two levels saturated to limits and is easiest to implement.

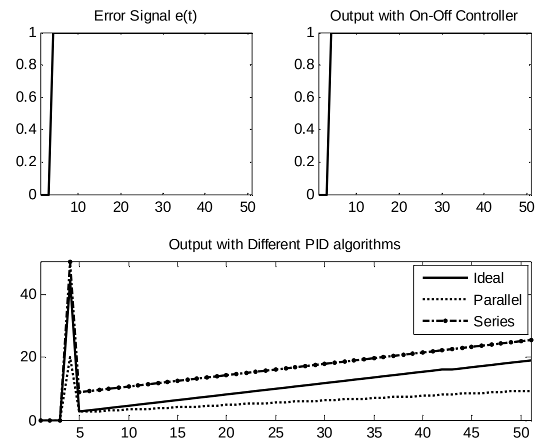

Figure 4: Response to step input error signal

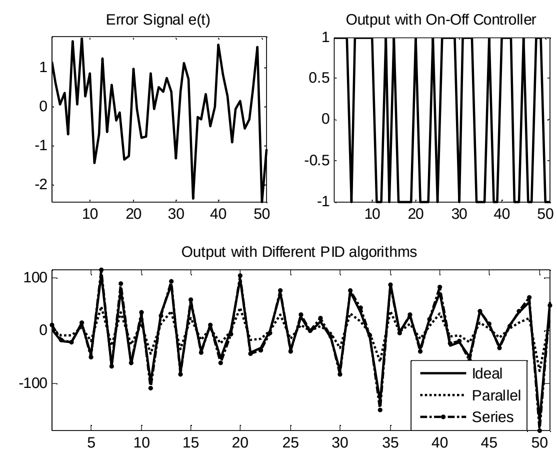

Figure 5: Response to a random input error signal

3 A case study

To determine suitability of any particular PID approach, we have considered its potential application in antilock brake system.

Due to non linearity in vehicle model and controller algorithm, tuning it for all kind of road situation is very difficult and various studies ongoing to find an optimal solution. Although, we are just trying to assess suitability of a basic PID approach in this study; without going in the discussion of any such algorithms in particular.

In Figure 6, we have constructed a SIMULINK model of vehicle (plant model) and derived wheel speed and vehicle speed and subsequently stopping distance.

Stopping distance is the figure of merit for our analysis, although smaller stopping distance is not the only objective of any ABS but controllability of vehicle is equally important during hard braking.

Computation of wheel and vehicle speed's angular component, slip and stopping distance is explained in subsequent sections.

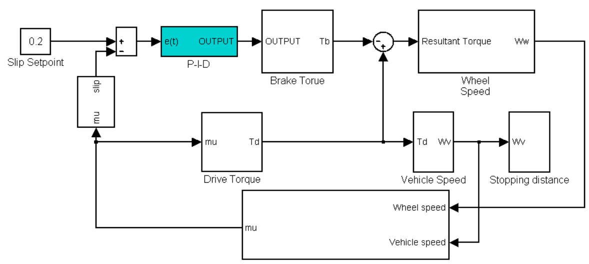

Figure 6: Design of Antilock braking system incorporating P-I-D controller

As we know, that to ensure correct analysis ,a good representative model of the process/plant (in this case vehicle model) is required, so going by classical control system theory, we here developed a plant model of a vehicle.

3.1 Plant Model of Vehicle

To evaluate the various controller algorithms which could be used in design of antilock brake, we have used a plant model of a vehicle which under the influence of drive torque produces angular velocity in the wheels and linear velocity of the vehicle.

Due to the friction we always find difference in angular velocity of wheel and vehicle velocity which is known as slip.

The basic forces acting on vehicle are: drive torque as a response to gas pedal pressed and brake torque and steering applied by driver .Combination of these three forces give direction and movement to the vehicle.

Consider a wheel resting and rotating in contact with ground surface as shown in Figure 7.

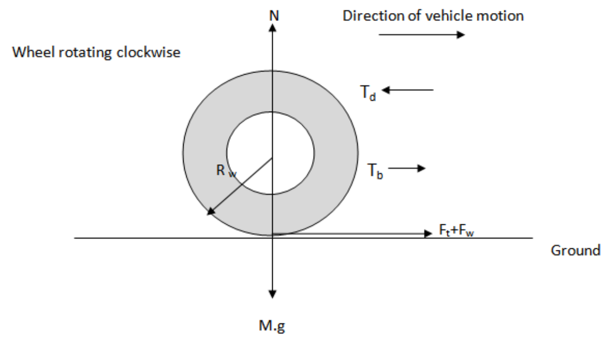

Figure 7: Various forces acting on wheel

Angular velocity is calculated as [12]:

$$\frac{d\omega_w}{dt} = \left[\boldsymbol{T_d - T_b - R_w . F_t - R_w . F_w} \;/_{\boldsymbol{J_w}}\right] \quad \text{.............equation(4)}$$

$$\text{Or },\boldsymbol{\omega_w} = \int \left[\boldsymbol{T_d - T_b - R_w . F_t - R_w . F_w} \;/_{\boldsymbol{J_w}}\right] \boldsymbol{dt} \quad \text{....equation(5)}$$

Where, ω is angular velocity, Td is torque generated by engine(in Nm), Tb is torque produced by pressing brake pedal(in Nm), Rw is radius of wheel(in m), Ft is traction force(in N) ,Fw is wheel viscous friction(in N).

The, traction force is given by [12],

$F_t = \mu(\lambda).\ N = \mu\ .M\ .g$ .....equation (6)

Where, µ is coefficient of friction between tyre and road surface, M is the mass component of the vehicle acting on a wheel and theoretically it is quarter of total mass of the vehicle.

Vehicle speed is given by

$$\frac{dV}{dt} = \left[\boldsymbol{N_w\ F_t - F_v} \;/_{\boldsymbol{M}}\right] \quad \text{.............equation (7)}$$

$$\text{Or, } \boldsymbol{V} = \int \left[\boldsymbol{N_w\ F_t - F_v} \;/_{\boldsymbol{M}}\right] \quad \text{.............equation (8)}$$

Where, Nw is number of wheels, Fv is air drag force and M is mass of vehicle.

Vehicle angular velocity ωv is given as

$\omega_v = V/R_w$ ....equation (9)

And wheel slip is defined as

$$\lambda = \left(\frac{\omega_w - \omega_v}{\max(\omega_w, \omega_v)}\right) \quad \text{......................................equation (10)}$$

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Using equation (4) through (10), we derive stopping distance achieved by using various PID approaches in subsequent sections.

3.2 Controller Model

As shown in Figure 6, we connected various PID controller strategies one by one and after running the simulation, results are obtained.

The desired slip ratio is kept 0.2 and PID controllers as shown in Figure 1,2 and 3 are connected keeping all other parameters unchanged.

3.3 Results

Case I: Using Ideal P-I-D Controller Approach

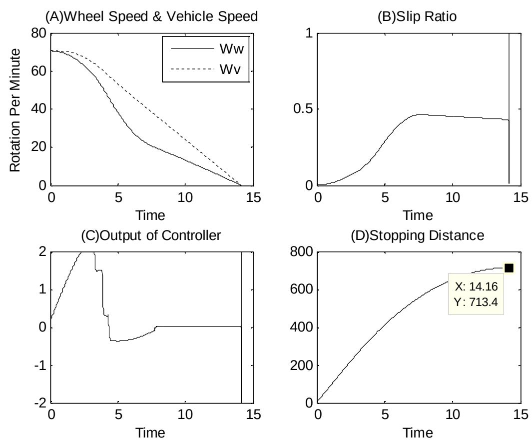

Figure 8: Stopping distance and Stopping time obtained with Ideal configuration.

Case II: Using Parallel P-I-D Controller Approach

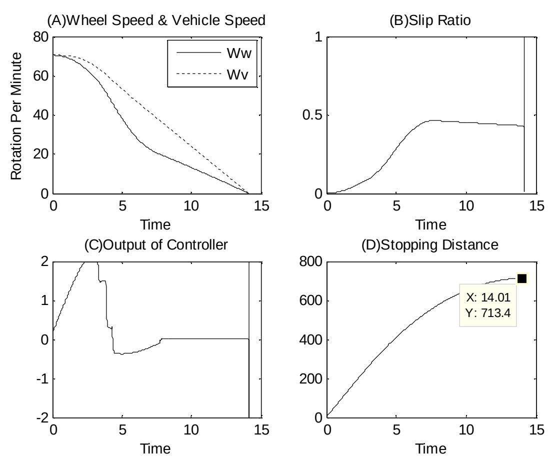

Figure 9: Stopping distance and Stopping time obtained with Parallel configuration

Case III: Using Series PID Controller Approach

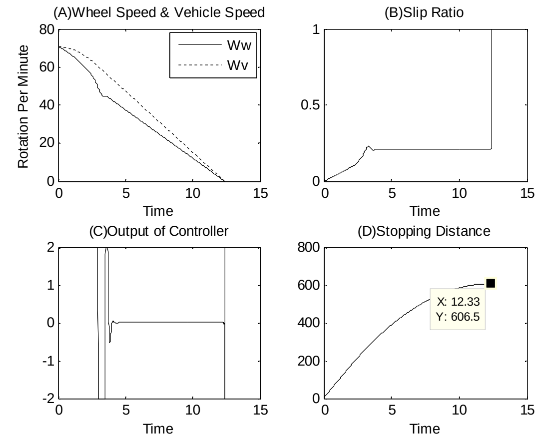

Figure 10: Stopping distance and Stopping time obtained with Series configuration

4 Conclusion

Two most important parameters: Stopping distance and stopping time of vehicle are summarized below:

	Stopping Distance(m)	**Stopping Time(S)**
Ideal Configuration	713.4	14.16
Parallel Configuration	713.4	14.01
Series Configuration	606.5	12.33

We can conclude that performance of ideal and parallel configurations are marginally different i.e. same stopping distance is obtained but the time required to fully stop is less in case of parallel configuration(14.01 sec against 14.16 sec).

But, the series configuration has distinct advantage over other two configurations, as we see reduction in both stopping distance and stopping time.

5 Summary

By analysing the results it can be safely concluded that in application like ABS where quicker stopping of vehicle is crucial, use of series configuration of PID could be recommended. After having designed a PID with series configuration,performance could be further enhanced by carefully selecting Kc,Kp,I and D values.

Ziegler Nichols or Cohel-Coon tuning methods could be additionally used to get a better stopping distance or shorter stopping time.

6 Acknowledgements

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