Design & Stability Analysis of Vehicle Suspension System

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Abstract- This exploration depends upon the attestation of the parameters and fragmentary sales PID controllers anticipated vehicle suspension framework. From the beginning, without considering dynamic suspension, introduction of uninvolved suspension layout for various wheel load were recorded and introduced on utilizing an exchange furthest reaches of the framework. As the examination subsequent to assessing the exhibition of old style PID controller, fragmentary request PID controller was applied that improves presentation of old style controller. Thus, variables of the controller were additionally acquired on utilizing a similar improvement calculations. In this paper, street had been demonstrated with sinusoidal (street includes slope) or arbitrary changes, i.e. a saw tooth signal. Execution results were shown that introduction of fragmentary solicitation PID controller is inconceivably improved than normal PID controller.

Keywords: Fragmentary request PID, suspension framework, quarter-vehicle.

1. Introduction
Suspension structures were presented between vehicle body and wheel to hold an unexpected vibration because of road condition. Road dealing with capacity of vehicle was key factor for security and comfort. Need for suspension frameworks can be abridged as below

• To assimilate the vibration because of the defective states
• solace of travellers
• To moves braking power to the haggle the respectability among haggle body.

Like air stages, wheeled vehicles having three fundamental wavering power as introduced in Fig. 1. Saltation was the movement in vehicle from high to low caused from light harsh street on rapid conditions. Swing was the development on front and end of vehicle due to over whelming unpleasant street at moderately moderate speed (quick speed isn’t recommended). Rollover was development of right and left of vehicle, caused due to turns. Every one of these developments relates to the power upon the suspension. As it were, the situation of wheel causes these motions to deal with the conditions and assurance a safe and solace travel.

The models of the suspension can be separated into three structures regarding the control point of view: inactive, semi-dynamic and dynamic suspension frameworks. Uninvolved suspension
frameworks a pre-planned and module gadgets with the end goal that practically all parameters are resolved at the creation stage.

Figure 1. Wheeled Vehicle Oscillation Behaviour

In the above diagram the three oscillation behavior are marked as 1 (rapid swing), 2(saltation) & 3 (roll over). Semi dynamic suspension frameworks having variable damping power and coefficients [1]. The upside of these frameworks are their moderately minimal effort, since they by and large contain less number of gadgets (additionally don't have interconnected gadgets, for example, actuator, pneumatics and power through pressure identified with suspension framework).

A functioning suspension framework is an issue condition and the improved form of the uninvolved frameworks upon controllable actuators. These frame work can prepared to gracefully essentialness when it is needed [3].

Suspension structures were confined to two classes as Depended and Independent Systems. Depended frameworks demonstrates its truly associated frameworks and don't lean toward as front suspension frameworks (at present day vehicles) for quite a long time because of their weight and comparing wavering. However, they are commonly favored as back suspension frameworks. The notable autonomous suspension framework was "McPherson" created in 1947 [4]. As suspension frameworks were partitioned two sections and are correspondingly isolated into three gatherings such as Quarter-vehicle, half-vehicle and full-vehicle models. In Quarter vehicle model only one wheel of vehicle is taken into consideration [5]. Half-vehicle model is used as subordinate suspension systems [6]. Full-vehicle model is on overall model that consists of front and back structures [7].
2. Mathematical Approach for the Problem

In mathematical approach the difficult condition, numerical depiction of the issue, and the advancement calculations utilized for tackling control issue were examined.

**Problem Definition**

This paper focusses on structure controller for altering distinction between street conditions and body position. In this way, at first the impact of change at degree of wheel to vehicle position is clarified on latent suspension model. At that point, controller intended for dynamic framework. The parameters at fig. 2 from base to top is specified as “u” that refers changing position at wheel base. Wheel is considered as an unspring mass “M2” with a spring “K2” Spring and damper (with coefficient “K1” and “b”) are put in the middle of the haggle body with mass M1. Mathematical equation of framework in fig 2 is as

\[ M_1 \ddot{x} = b (\dot{y} - \dot{x}) + k_1 (y - x) + \frac{1}{A} \dot{Q} \]  

\[ M_2 \ddot{y} = b (\dot{y} - \dot{x}) + k_1 (y - x) - k_2 (u - x) - 1/A \]  

\[ \dot{Q} = -c_f \dot{Q} + k_f i \]  

*Figure 2. Model for Approximated Description of Suspension System-Active Type*

**Passive Type Suspension Model Evaluation**

At first, effect of vehicle body was explored from Step reaction of framework. By considering wheel load list, different vehicle loads were applied to exchange work and comparing step reaction plots shown in Fig. 4.

\[ M_1 \dddot{x} + b \dddot{x} + (k_1 + k_2) \dot{x} = b \ddot{y} + k_2 y + k_i u \]  

\[ M_2 \dddot{y} + b \dddot{y} + k_2 y = b \ddot{x} + k_2 x \]

In Fig. 4, just heaviness of vehicle body (M1) is changed with step reactions were introduced. As body size expands, exhibition markers for transient reaction additionally diminishes, as in Table 1.
Figure 2. Model for Approximated Description of Suspension System - Passive Type

Figure 2. Step Response of Changing Load Rating for Passive Type Suspension System

Table 1. Time Domain Specifications values for the Step Response of Changing Load Rating for Passive Type Suspension System

| Load (kg): | 265kg | 400kg | 600kg | 900kg | 1320kg |
|-----------|-------|-------|-------|-------|--------|
| T_P       | 0.3707| 0.4747| 0.5694| 0.6988| 0.8465 |
| T_R       | 0.1277| 0.1616| 0.2013| 0.2589| 0.3188 |
| M_P       | 0.5804| 0.6221| 0.6752| 0.7185| 0.7533 |
| T_s       | 2.2213| 3.6701| 5.2078| 7.9126| 11.4748|

3. Stability Analysis

Indeed, PID controller were intended of dynamic suspension framework, a traditional root locus.
configuration is employed with additional “K” is made and results are displayed in graphical
manner. Fig. 5 shows root locus structure of main relatively controlled suspension framework.
Fig. 5a shows an estimation for addition of fundamentally stable framework, increase in nature
which makes framework insecure. Fig. 5b shows an ideal damping proportion esteem
comparing gain. At the end of the day, with just relative increase it isn’t conceivable to get a
steady framework with an ideal shut circle shafts as exhibited in Fig. 5c. Thus, right now,
controllers are structured and parameters were enhanced. In following segment, PID controller
(both traditional and partial request) clarified with advancement calculations.

**PID and Fractional-order PID Controller**

Three parameters should have been improved for the ideal execution. To sum things up,
corresponding parameter (KP) diminishes the ascent time and consistent state mistake. Be that as
it may, for a generally enormous consistent state blunder fundamental term (KI) is expected to
wipe out this mistake. The inconvenience of an essential term is expansion at the overshoot. In
this manner, sometimes the expansion on peak overshoot and settling time is moderately little. In
different situations, subordinate term is expected diminish overshoot and settling time of the
transient reaction. Table 2 gives rundown impacts.

\[
G_c(s) = K_p + \frac{K_i}{s} + K_d s \quad (6)
\]

The commitment of parameters isn’t acknowledged fragmentary request PID controller (FRPID).
Nonetheless, FRPID controller has a bigger number of degrees adaptable than traditional PID
controller that expands adaptability of controller and conceivable to all more likely to modify
framework.

\[
G_{FR}(s) = K'_p + \frac{K'_i}{s^2} + K'_d s^\mu' \quad (7)
\]

For an alternate estimation of \( \mu \) and \( \lambda \), fragmentary request PID controller becomes traditional
PID , where for \( \mu''=1 \) and \( \lambda''=1 \) relate to old style PID, for \( \mu''=0 \) and \( \lambda''=1 \) compare to PI , for
\( \mu''=1 \) and \( \lambda''=0 \) compare to PD , and for \( \lambda''=0 \) and \( \mu''=0 \) compare to corresponding controller.

![Figure 5.a Root Locus Plot: Passive Type Suspension System for critically stable condition.](image)
Figure 5.b. Passive Type Suspension System of desired damping ratio line

Figure 5.c. Root Locus Plot: Passive Type Suspension System corresponding unstable system

Table 2. Time Domain specifications of PID Parameters

| Closed Loop response | T_r | M_p | T_s | E_ss |
|----------------------|-----|-----|-----|------|
| K_p                  | Low | High| -   | Low  |
| K_i                  | Low | High| High| Eliminate |
| K_d                  | -   | High| Low | -    |

4. Conclusion

The presentation of the inactive suspension framework is researched concerning the distinctive wheel load file. An active type is replaced with an optimal PID controllers. At that point to show the significance of controller which need for moderately unpredictable calculation, Straight forward relative coefficient was applied to solidarity input framework with the guide of root
locus, an exhibition of framework talked about. In an accompanying areas, first classical PID controller was intended on dynamic framework. At that point to improve presentation of PID controller, a fragmentary request PID (FRPID) controller was applied with general framework rather than classical PID controller. The best outcomes from FRPID controller with little overshoot greater undershoot at the slope fall second. In this paper, dynamic suspension framework issue is explained with ideal PID controllers.

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