ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
Volume 1, Issue 7, September 2012

Optimization of PID Controller for Quarter-Car Suspension System using Genetic Algorithm

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***Abstract*— In order to improve the ride comfort and stability by reducing the body acceleration in vehicles caused by the road irregularities, suspension system plays an imperative role in retaining the continuous road wheel contact for better road holding. In this paper, a quarter-car suspension model has been considered and a PID controller has been designed for the same. The aim of the work described in this paper is to illustrate the improvement of response of the system by optimizing the PID controllers using genetic algorithms. In the conclusion, by a comparative analysis between the conventional PID tuning methods and optimization carried out using genetic algorithms offers lesser oscillatory and better response.**

***Index Terms*— PID Controller, PID Optimization, Genetic Algorithm, Controller Optimization.**

I. Introduction

A suspension system plays an imperative role in increasing the ride comfort, and their application is evident from the bullock carts to the new age vehicles. The car suspension supports the vehicle body on the axles, and the main purpose is to ensure ride comfort and handing. In order to increase the riding comfort and to cancel out the effect of irregularities of the road by isolating the vehicle body, the suspension system tries to maintain a continuous road-wheel contact to provide better holding [1]. The suspension system improves the ride quality by changing its response according to the varying road conditions, to offer better wheel road contact and safety. In this paper, a quarter car suspension system with 2-DOF is considered, and with the designing of a PID controller for the same. The paper focuses on the optimization of the response PID controllers by using the genetic algorithms. By tuning the PID controller gains by genetic algorithm results in a lesser oscillatory response and better performance indices.

The development of the model has been carried out in MATLAB and Simulink environment and the optimization has been done using Global Optimization toolbox. From the results obtained in this paper, it is evident that Genetic Algorithm offers best results by offering a decreased overshoot percentage and better rise and settling time values.

***Manuscript received September2012*.**

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II. PID Controller

Proportional Integral and Derivative –PID controllers because of their simplicity and wide acceptability, are playing an imperative role in control systems, and for regulating the closed loop response in industrial controls, PID controllers alone contribute 90% of all the PID's used today. A PID controller based system is represented in simple block level diagram as in Figure 1

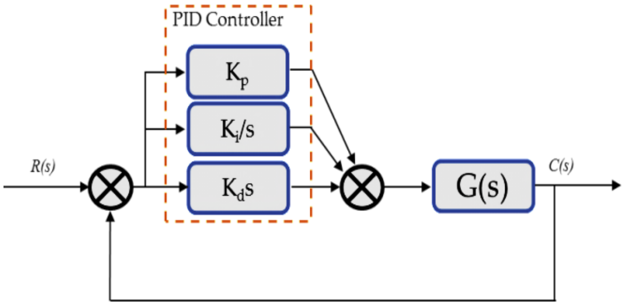

Figure 1. Schematic representation of unity feedback PID controller system architecture.

The general equation for a PID controller for the above figure can be given as [5]:

$$C(s) = K_p.R(s) + K_i \int R(s)dt + K_d \frac{dR(s)}{dt}$$

Where K_p, K_i and K_d are the controller gains, *C(s)* is output signal, *R(s)* is the difference between the desired output and output obtained.

Some of the prime methods for tuning are: Mathematical criteria, Cohen-Coon Method, Trail and Error Method, Ziegler-Nichols Method and now a days the Soft-Computing techniques, being lesser prone to error when compared to conventional methods; like Fuzzy Logic, Genetic Algorithms, Particle Swarm Optimization, Neuro-Fuzzy, Simulated Annealing and Artificial Neural Networks, are also becoming dominant in research methodologies..

III. Mathematical Modeling of Quarter-Car Suspension System

The quarter car suspension model considered in this paper is one of the four suspensions in a typical car. This second order system, can be approximated as mass-spring-damper system, with input as the change in the height of the road i.e. disturbances present in road and the output as the vertical displacement of the body of the car.

The dynamics of the system can be modeled using a second order differential equation given by eq. 1 and the schematic diagram in Fig. 2.

$$m_{ij}(t) = k(u(t) - y(t)) + (b(\dot{u}(t) - \dot{y}(t))) \quad \ldots 1$$

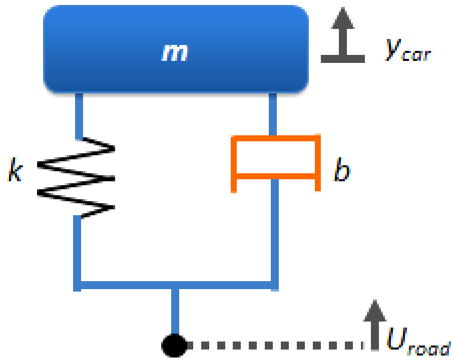

Figure 2. Schematic representation of Quarter-Car Suspension Model.

By taking the Laplace transformation, the Transfer function can be obtained in eq. 2.

$$G(s) = \frac{Y(s)}{U(s)} = \frac{b.s + k}{m.s^2 + b.s + k} \quad \ldots 2$$

Using the values for *m=550 kg* , *b=1250 Ns/m* and *k=22500 N/m* in Eq. 2, the transfer function is obtained as:

$$G(s) = \frac{1250.s + 22500}{550.s^2 + 1250.s + 22500}$$

IV. Design and Optimization of PID Controller

A. PID Tuning using Ziegler-Nichols Method

One of the most widely used method for the tuning of the PID controller gains is to use the open loop response as inferred by Ziegler-Nichols(ZN), yet this method finds its in application till the ratio of 4:1 for the first two peaks in the closed loop response[3], which leads to a oscillatory response of the system.

Initially, the unit step function (Fig. 3) is derived, and hence as suggested by the Ziegler-Nichols, the parameters required can easily be estimated as given in Table 2.

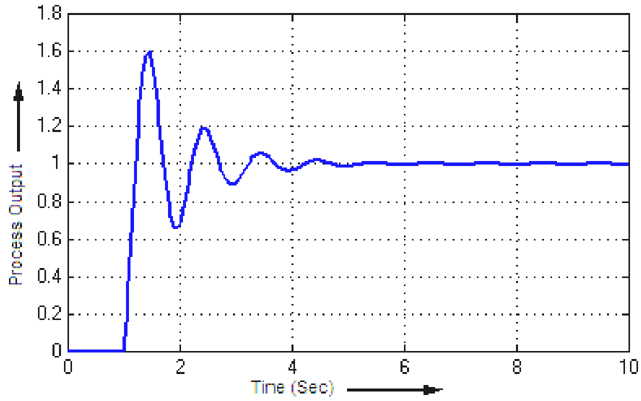

Fig. 3. Open loop step response of the system.

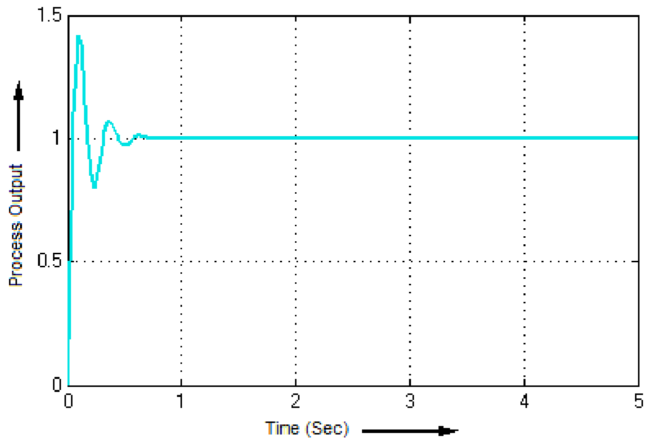

Fig. 4. Closed loop step response of the system with ZN-PID Controllers.

Table 1: Parameters of the PID Controller Calculated by Ziegler-Nichols Method.

Ziegler Nichols PID Parameters	*Value*
K_p	10.53
K_i	219.375
K_d	0.12636

B. PID Optimization using Genetic Algorithms

Since the designing of the PID controllers by Ziegler-Nichols methods, gives an oscillatory response; hence the controller parameters obtained from ZN are not optimum for the directly implementation for the plant, so their organized optimization must be carried out, so that the better possible parameters can be estimated and implemented for the best performance of the system.

So, the Genetic Algorithms can be used along with the parameters obtained by the Ziegler-Nichols response, as the parameter determined by ZN helps in the determination of the lower and upper bound limits to be used for the estimation of parameters using Genetic Algorithms.

The steps involved in the implementation of the Genetic Algorithms for a control system are shown in Figure 5

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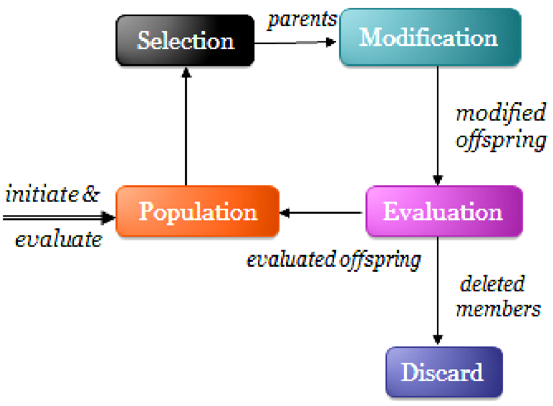

Fig. 4. Genetic Algorithm Cycle.

The optimization of the system has been designed and simulated in MATLAB and Genetic Algorithm toolbox, with population size of 100, scattered crossover, and migration direction in both sides. Table 2 shows the GA optimized PID parameters and Figure 5 shows the GA-PID step response of the system.

Table 2: Parameters used in Optimization by Genetic Algorithm.

Genetic Algorithm Optimized Parameters	*Value*
K_p	28.3492
K_i	121.5028
K_d	0.0151

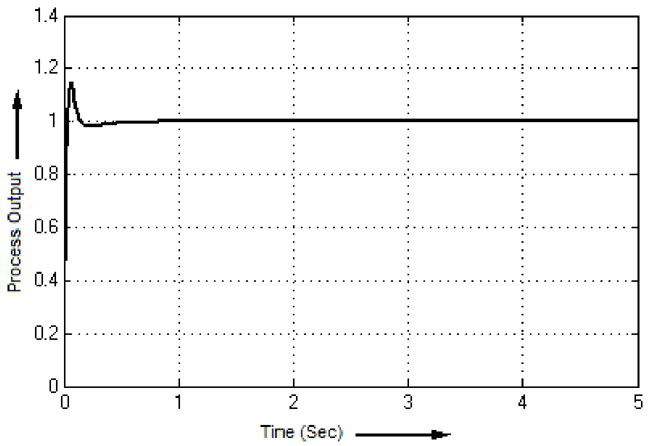

Fig. 5. Closed loop step response of the system with GA-PID Controllers.

V. Results and Discussions

In this paper, a dynamic model of a quarter car suspension system has been designed and implemented in MATLAB along with the optimization using the Genetic Algorithms. The value of parameters obtained using Ziegler-Nichols rules [2] were used in the formation of the boundary limits for the intervals for the design parameters in Genetic Algorithms.

The computation of the gain parameters are done both by the Ziegler-Nichols rules and the Genetic Algorithms. It is clearly shown in figures that the Genetic Algorithms solutions present lesser oscillatory response in contrast to the Ziegler-Nichols design in both the step response and the controller output. The results have been presented in Table 3. Concluding, Genetic Algorithms offers superior results in terms of system performance and controller output for the tuning of PID controllers when the values are compared in tables and figures.

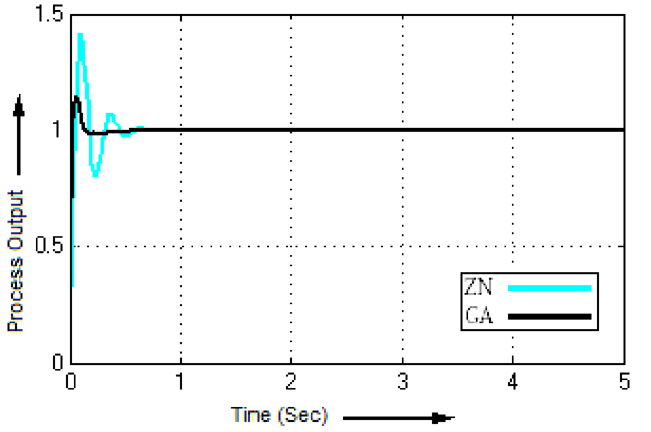

Fig. 6. Compared Closed loop step response of the system with ZN-PID Controllers.

Table 3: Comparison of the results.

Method of Design	*Overshoot %age*	*Rise Time*	*Settling Time*
Ziegler Nichols	31.8	0.0339 sec	0.51 sec
Genetic Algorithm	17.5	0.025 sec	0.27 sec

VI. Conclusions

The use of Genetic Algorithms for optimizing the PID controller parameters as presented in this paper offers advantages of decreased overshoot percentage, and increased rise and settling times. When compared to the conventional tuning parameters, the Genetic Algorithms have proved better in achieving the steady-state response and performance indices.

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