# Optimization of Motorcycle Pitch with Non Linear Control

Dankan V Gowda, Kishore D V, Shivashankar, Ramachandra A C, Pandurangappa C

*Abstract*-**Motor cycles are the common mode of transport of the middle class India. When the rider driving on the bumping road circumstances rider has to face problems results in exposure to whole body vibration. Motorcycle pitch is produced due to a sudden acceleration/ sudden deceleration or whenever the vehicle hits the pot hole / bump. The goal of this research was to design of motorcycle suspension system and optimize the pitch using nonlinear controller, modeling and simulation is carried out using MATLAB and the results are compared with existing work. To give the prominent to improve the ride eminence and increase in comfort due to substantially reduced the amplitude of disturbances by presenting nonlinear controllers to decrease the effect of travelling over rough ground.**

***Keywords-Motorcycle, Nonlinear Control, Suspension system, Pitch, Bump.***

## I. INTRODUCTION

In India many enterprises are using motorcycles, these includes in transportation, courier services, postal delivery, police etc. vibration in motor cycle riding had out us an interesting case to concerning for assessment of entire body vibration.

In any design endeavor with limited time for research and development, tools that increase productivity or decrease necessary testing are crucial for success. This gives rise to a need for development tools such as computer models of suspension, chassis, and engine systems. Because of schedule constraints, the suspension design of most automobile two wheeler is based primarily on steady state analysis [1]. There are many types of automotive suspension dampers, which are commonly referred to as shock absorbers. This is misnomer because the damper does not actually absorb the shock. That is the function of the suspension springs. As is well known, a spring/mass system without energy dissipation exhibits perpetual harmonic motion with the spring and the mass exchanging potential and kinetic energy, respectively. The function of the damper is to remove the kinetic energy from the system and to cover it into thermal energy.

The suspension system in motorcycle is assembled by springs, shock absorbers and linkages that connected to vehicle and which intern connects to its wheels. [2]

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If the road is irregular vehicle suspension isolates chassis for these conditions.

The leading functions of vehicle suspension system are: providing vertical defiance so the wheel can follow the bumpy alleyway.

It maintains the steer and camber postures appropriate to road surface. It gives immediate reaction to control forces created by the tires and also maintain the tries in contact with motorway with minimal load variants [3], [4].

A motorcycle's suspension system consists of a spring coupled to a viscous damping element, a piston in a cylinder filled with oil. It assists vehicles handling and braking, if provides a safety and comforts to the vehicles and passengers by secluded from road noise, bumps and vibrations.

To reduce the effect of vibration in the motorcycles mainly we have to use vehicle suspension system [5]. The conventional passive system is composed of flexible apparatuses, which is imperiled to many constraints. To make vehicle activity in good condition and to improve the comfort stability of vehicle we need to introduce the dynamic suspensions so that we obtain the dynamic responses to the road and vehicle condition because its external energy inputs can produce the subsequent force with peripheral excitations. The spring and damping parameters are normally fixed in subservient suspension system which has a capacity to stock the energy through spring and it dissipate via damper to achieve level of conciliation between road handling, load carrying and ride comfort [6]. These parameters in a dynamic suspension system are having ability to hoard, dispel and familiarize energy to the system. Depending upon the operating conditions all these parameters is varied.

## II. LITERATURE SURVEY

F. Baronti, [7] presents a system in order to compensate the load variation which is capable of incessantly correcting the suspension preload of motorcycle without user intrusion. This system measures the suspension stroke by the utilization of electronic system is based on microcontroller and linear position sensor. To maintain average value of suspension constant system executes a closed loop control algorithm that adjust the preload.

F. Baronti, [8] presents the application of electronics to the control of the rear suspension of motorcycle. The main objective of the system designed to make the suspension work around its optimum operating point which intern improves the safety and comfort of the vehicles. To move the operating point away from the optimal value, variations has to be taken in load carried by the vehicle determine a change of suspension spring compression. A designed electronic system revels load changes and automatically adjusts the motorcycle suspension preload in order to compensate the load variation and keep the suspension to its optimal operating point.

B. Pratheepa,[9] To improve the performance a suspension system there need to be designed mathematical model and simulation of a controller for active and passive suspensions with Linear Quadratic Regular(LQR) controllers. A controller is designed for active suspension system and simulated for passive and active suspension system using MATLAB and SIMULINK.

It is examined for both active and passive systems using conventional method and acceleration method. After simulation the results are represented by graphically for the various parameters such as passenger displacement and acceleration. From these graphical simulations got to know that active suspension system is more proficient than passive system [11],[12].

## III. MATHEMATICAL MODELING

Consider the motorcycle as shown in figure.1To reduces the ambiances and a force caused by uneven road environments motorcycle suspension system is designed. Because of road's apparent asymmetries reason the motorcycle to move plumb as well as revolve around an axis. By ignoring the mass of tires, the system comprises of a single mass (Vehicle frame plus driver) that has plumb motion and spin. Figure 1shows the system and force balance for motorcycle suspension.

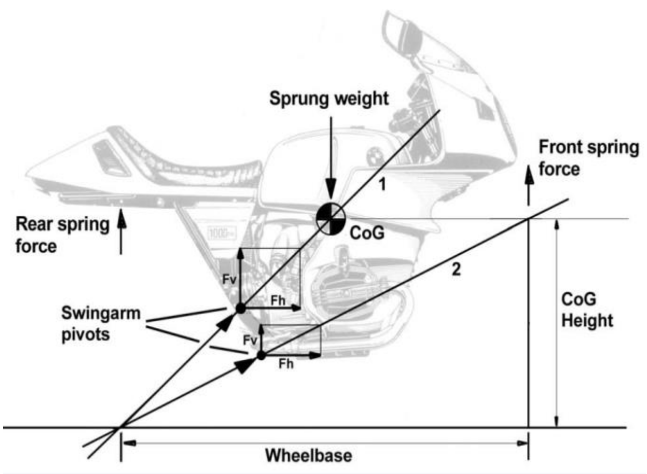


Fig.1: Motor cycle suspension system [12]

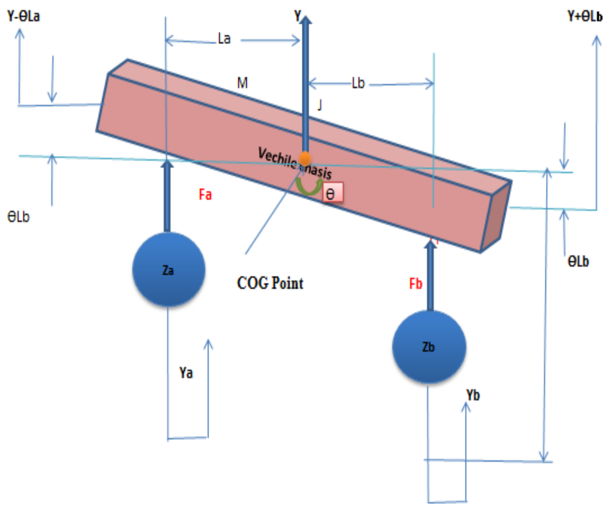


Fig.2: Undeveloped system and force stability for motorcycle suspension system

Mass M and moment of inertia J is single rigid body can be considered as the motorcycle structure and driver. $Y_a$ and $Y_b$ are the input displacement at each wheel represents the road conditions. A each axle of suspension system has Spring and dashpot .Therefore the sum of the damping force ($F_a$ ) (Newton's Law) and the spring force ($F_b$) are the total forces exerted on the motorcycle structure by each wheel.

$$a = -\left(Ca\frac{d}{dt} + Ka\right)Ya(t)$$

$= -(Ca\,S + Ka)Ya(s)$ And

$$Fb = -\left(Cb\frac{d}{dt} + Kb\right)Yb(t)$$

$$= -(Cb\,S + Kb)Yb(s) \qquad (1)$$

Each spring $Y_a$ and $Y_b$ from the reference represents the instantaneous displacement. The plumb and revolving displacements of the center of mass, Y (t) and θ (t) are the plumb displacement and is given by

$$y_a = (Y - \theta L_a) - Y_a \qquad and$$

$$y_b = (Y + \theta L_b) - Y_b \qquad (2)$$

The terms, $\theta L_a$ and $\theta L_b$ are geometry considerations as ashown in the figure 3. Let us assume that $\sin\theta \approx \theta$ for minor angular displacements, and positive θ is a counter clock wise rotation.

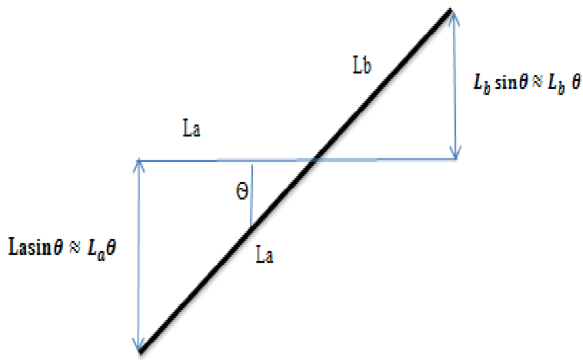


Fig.3: Geometry contemplations for plumb displacement v/s revolution angle

By combining the equations the negative sign force expression in (1) and the displacement terms in equation (2) gives

$$F_a = (C_a\,S + k_a)\,[Y_a - (Y - \theta L_a)] \quad \text{and}$$

$$F_b = (C_b s + k_b)\,[Y_b - (Y + \theta L_b)]$$

or defining

$$Z_a = (C_a S + ka)\ ,\ Z_b = (C_b S + k_b) \ \text{ gives}$$

$$F_a = Z_a\,[Y_a - (Y - \theta L_a)] \quad \text{and}$$

$$F_b = Z_b\,[Y_b - (Y + \theta L_b)] \qquad (3)$$

Finally, to satisfy Newton's law the sum of the vertical forces we have

$$M\,\frac{d^2}{dt^2}\,Y = F_a + F_b \qquad (4)$$

$$Ms^2Y = Z_a\,[Y_a - (Y - \theta L_a)] + Z_b\,[Y_b - (Y + \theta L_b)]$$

and

$$(Ms^2 + Z_a + Z_b)Y - (Z_aL_a - Z_bL_b)\theta = Z_aY_a + Z_bY_b \; 6.5)$$

$Y_0 = 0$ and $dY/dt|_{t=0} = 0$ gives initially no vertical motion i.e the force stability for the system with hypothesis that motorcycle structure and driver.

If we now perform a torque balance (i.e.$= J\alpha, where\ \alpha = \frac{d2t}{dt^2})$ ) on the above system with the center of mass (CM) as the pivot point, one has

$$J\,\frac{d^2}{dt^2}\theta = F_bL_b\,cos\theta - F_aL_a\,cos\theta$$

$$\approx\; F_bL_b\,F_aL_a\;\;(for\;\theta\;\approx 0, cos\theta\;\;\approx 1\;\;\;)$$

$$JS^2\,\theta = Z_bL_b[Y_b - (Y + \theta\,L_b)] - Z_aL_a\,[Y_a - (Y - \theta L_a)] \qquad (5)$$

and

$$\mathbf{(JS^2 + Z_aL_a{}^2 + Z_bL_b{}^2)\,\theta - (Z_aL_a - Z_b\,L_b)Y = -Z_aL_aY_a + Z_bL_bY_b} \qquad \mathbf{(6)}$$

Again, let assume that initially all conditions are zero (i.e. $\theta_0 = 0\;and\;{}^{d\theta}/_{dt}\,|_{t=0}= 0$).

From zero initial conditions finally we can write matrix for the force and moment balance equations as shown below

$$\begin{bmatrix}(MS^2 + Z_a + Z_b) & -(Z_aL_a - Z_bL_b)\\ -(Z_aL_a - Z_bL_b) & (JS^2 + Z_aL_a{}^2 + Z_bL_b{}^2)\end{bmatrix}\begin{bmatrix}Y\\ \theta\end{bmatrix}$$

$$= \begin{bmatrix}Z_a & Z_b\\ -Z_aL_a & Z_bL_b\end{bmatrix}\begin{bmatrix}Y_a\\ Y_b\end{bmatrix} \qquad (7)$$

For the simplification matrix can be written as

$$\begin{bmatrix}\mathbf{A_{11}} & \mathbf{A_{12}}\\ \mathbf{A_{21}} & \mathbf{A_{22}}\end{bmatrix}\begin{bmatrix}\mathbf{Y}\\ \boldsymbol{\theta}\end{bmatrix} = \begin{bmatrix}\mathbf{B_{11}} & \mathbf{B_{12}}\\ \mathbf{B_{12}} & \mathbf{B_{22}}\end{bmatrix}\begin{bmatrix}\mathbf{Y_a}\\ \mathbf{Y_b}\end{bmatrix} \qquad \mathbf{(8)}$$

$A_{ij}$ and $B_{ij}$ terms are coefficients of Y and θ and these are expressed as

$$Y = \frac{1}{A_{11}}[B_{11}Y_a + B_{12}Y_b - A_{12}\,\theta]$$

$$\boldsymbol{\theta} = \frac{\mathbf{1}}{\mathbf{A_{22}}}[\mathbf{B_{21}Y_a + B_{22}Y_b - A_{21}Y}] \qquad \mathbf{(9)}$$

## IV. SIMULATION

Major sub-systems of the Simulink model are: Road model and Suspension system. The front-suspension displacement and rear-suspension displacement information are obtained from in Longitudinal Dynamic model. The corresponding info at tire-level is obtained by using the spring co-efficient. When bump enable signal is received from graphics model, Road-model is enabled.

In the Road model, front-suspension displacement and rear-suspension displacements are evaluated based on length and height of Bump/pot-hole as well as considering the current vehicle speed. The block also evaluates the precise status of bump occurrence using Bump Model. This status information is used to select the input to the suspensionsystem

The suspension system then evaluates the pitch of the vehicle using the front-suspension displacement and rear-suspension displacement that are evaluated above.

4.1 Pitch: In a vehicle, during sudden acceleration, the normal force acting on rear-wheel increases while the normal force on the front wheel reduces. This results in a positive pitch.

During sudden deceleration, the normal force acting on the front wheel increases while the normal force on the rear-wheel reduces. This results in a negative pitch.

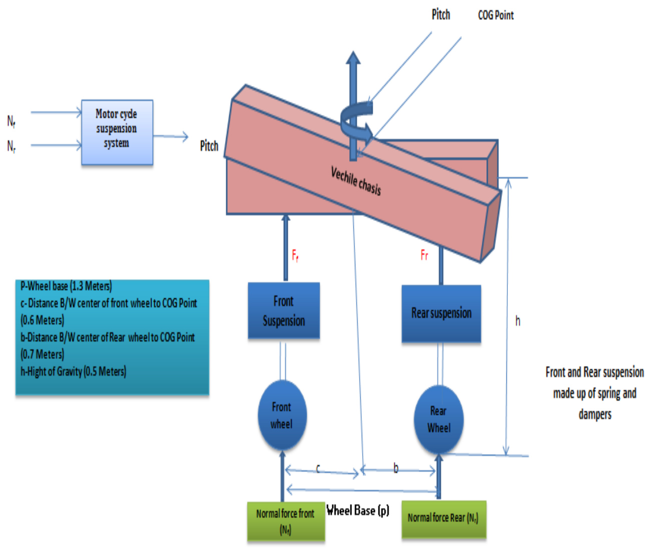


Fig. 5: Motor cycle positive pitch

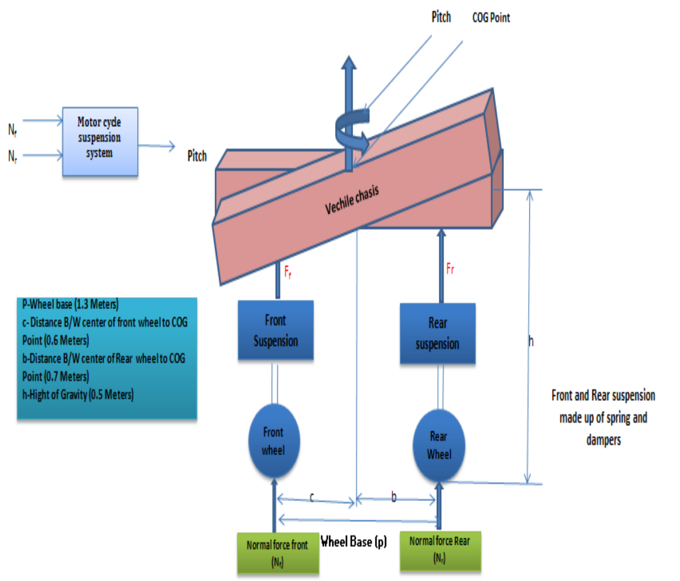


Fig. 6: Motorcycle negative pitch

## V. RESULTS AND DISCUSSION

The simulation parameters used in motorcycle suspension system and road model is tabulated in Table I.

TABLE I: PRELOADED PARAMETERS USED IN MOTORCYCLE SUSPENSION SYSTEM AND ROAD MODEL

| Symbol | Quantity | Value |
|---|---|---|
| m | Mass of the vehicle + rider | 230 kg |
| $L_a$ | Distance from COG to front wheel | 0.5 m |
| $L_b$ | Distance from COG to rear wheel | 0.8 m |
| $K_a$ | Stiffness of rear suspension | 2800 (N/m) |
| $K_b$ | Stiffness of front suspension | 2100 (N/m) |
| $C_a$ | Damper coefficient rear suspension | 2500 (N-sec/m) |
| $C_b$ | Damper coefficient front wheel | 2000(N-sec/m) |
| J | Moment of inertia | 2100 (kg-m$^2$) |
| L | Length of the bump/pothole | 1 m |
| h | Height of the bump/pothole | 0.5 m |
| p | Wheel base | 1.3 m |

The model simulation results for the cases of Bump and Pot-hole are shown below. The model simulation results for the cases of Bump and Pot-hole are shown below.

### A. *Pitch Due To Bump And Sudden Acceleration /Deceleration:*

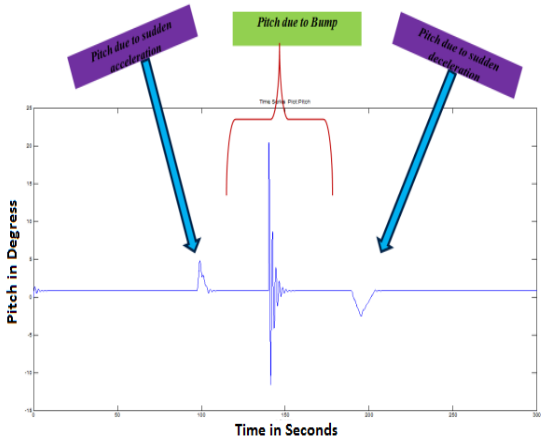


Fig.7: Pitch due to bump and sudden acceleration/deceleration

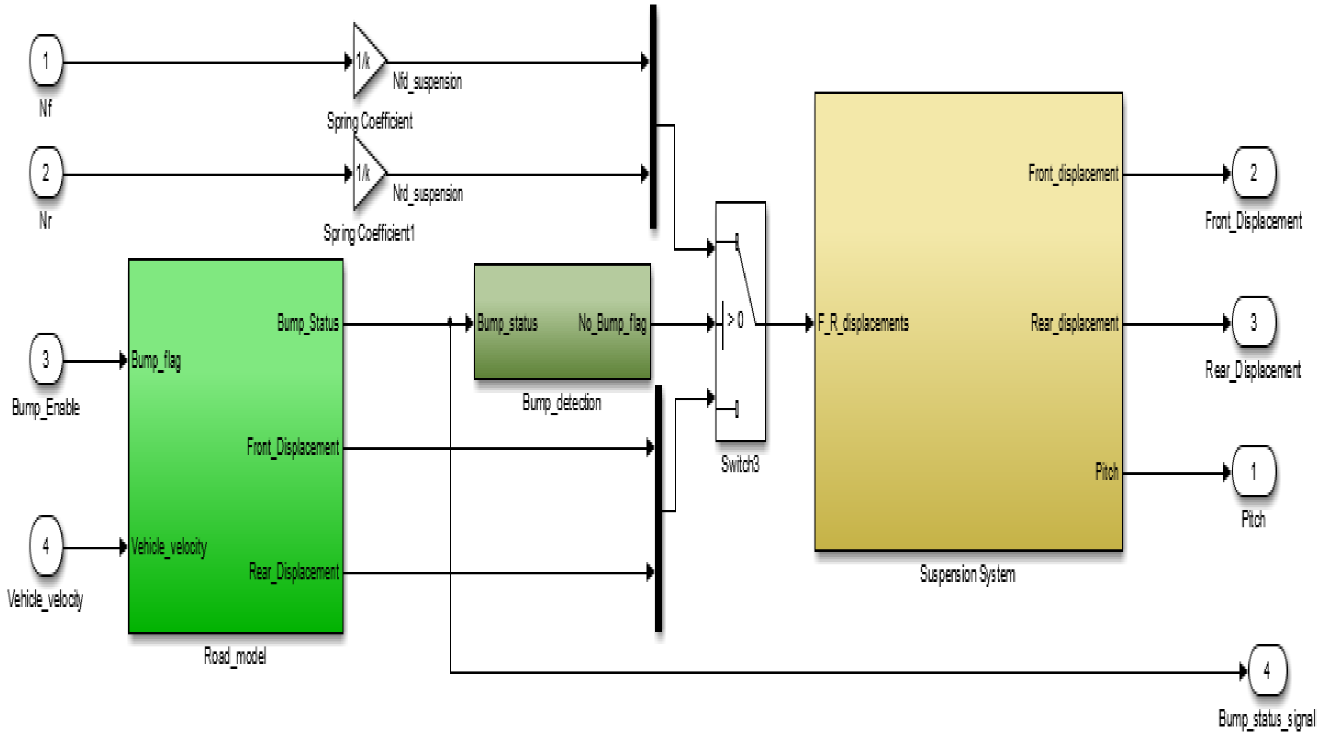


Fig. 4 : Simulink model of Motor cycle Suspension and Road Model

From the fig.7, We can observe that, the vehicle is moving with constant velocity results a zero pitch at time t=95 sec given sudden throttle due to which results in positive pitch variation of up to 5 degrees, and at time t=140 sec vehicle encounter a bump of height and length 1m respectively, results a oscillatory pitch of range from 20 to 10 degrees. At time t=185 sec given a sudden deceleration due to which motorcycle pitch is negative with rage of -5 degrees.

### B. *Pitch due to Pothole:*

From the fig.8,We can observe that, the vehicle is moving with constant velocity results a zero pitch at time t=100 sec given sudden throttle due to which results in positive pitch variation up 5 degrees, at time t=185 sec given a sudden deceleration due to which motorcycle pitch is negative variation up to -5 degrees. And at time t=230 sec vehicle encounter a pothole of height and length 1m respectively, results a oscillatory pith range form 15 to -20 degrees.

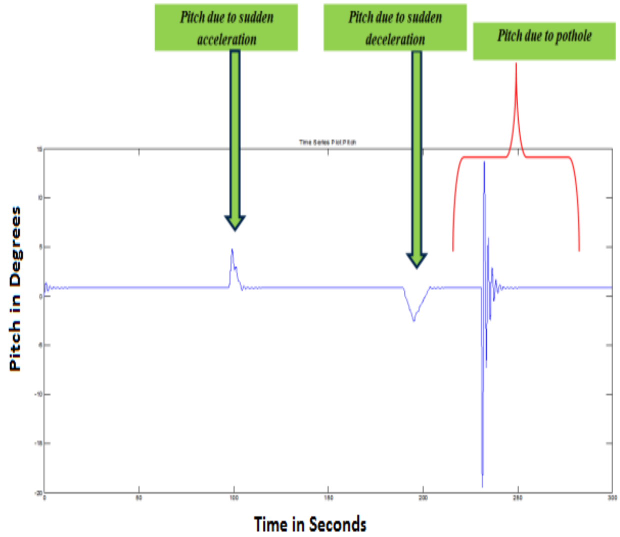


Fig.8: Pitch due to pothole and sudden acceleration/deceleration

## VI. CONCLUSION

Any automotive industry is concern the Motorcycle pitch optimization is a thought-provoking task. In this paper motorcycle modeling of suspension system is done and the pitch is controlled using a Non-linear controller. Simulation results matched very closely with the reality. Road disturbances (bumps/potholes) simulated accurately. The suspension model when integrated with the other components in the vehicle model, gave very good results in terms of final forces and acceleration. Motorcycle pitch without controller is of range between 25 to 30 degrees. From the above results it can be concluded that suspension with Non-linear controller, the motor cycle pitch can be optimized to maximum of 20 degrees. Thus the reduction in pitch results better rider comfort and road handling. Further research can be done to measure the motorcycle pitch for random road profiles. To investigate the consistency and thoughtfulness of the comfort and vehicle handling indexes to influence parameters.

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