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Comparative Analysis and Validation of Automobile Spring in Passive Suspension System to Study Ride Comfort through Non-Linear Approach

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Abstract: *Automobile spring is a crucial component of passive suspension system and has major effect on Ride Comfort and Road Holding performance. Automobile suspension systems are designed by considering the linear behavior of system. In actual practice, system behaves nonlinearly. The present work deals with non-linearity of spring and study its direct effects on the passive suspension system. Mathematical model for the Passive Suspension System is developed and equations of motion are derived. Spring Stiffness Coefficients are obtained by experimentation. The results obtained are used as an input for MATLAB-Simulink to evaluate Ride Comfort. Thus, Ride Comfort determined by Simulation is compared with the experimentation on Quarter Car Test-rig. This study tries to build bridge between theoretical and experimental values of Non Linear behaviour of springs.*
Keywords: *Non-linearity, Passive suspension system, MATLAB-SIMULINK, Ride Comfort, stiffness test rig, Quarter Car Test Rig.*

I. Introduction

Suspension system is a system of tyres, springs, dampers and linkages that connect a vehicle to its wheels. It omfort,stiffness Test-rig,Quarter Car Test-rig.allows relative motion between a vehicle and its wheels. Better body movement, regulation of suspension movement and distribution of forces are the characteristics deal in order to achieve a good suspension system. It should support both Ride Comfort (RC) and Road holding (RH) , which are odd with each other.The main objective of it is to isolate the body of the passengers from road irregularitiesor inertial disturbances arising from braking and acceleration so as to improve Ride Comfort[1]. On the other hand, in order to maintain good RC characteristics, the road to tyre contact must be maintain on all wheels. After detail analysis and experiments by automotive researchers , the main motive is to improve the traditional design, so as to improve the performance of the suspension system.[2]

NOMENCLATURE:

N - Speed (rpm)
C_s - Damping Co-efficient (N.s/mm)
K_s - Spring Stiffness Co-efficient (N/mm)
M_s - Sprung mass (kg)
K_t - Tyre stiffness co-efficient (N/mm)
Z_s - Sprung Mass displacement (mm)
Z_u - Un-Sprung Mass displacement (mm)
Z_r - Road Bump Height (mm)
RC - Ride Comfort

II. Spring Stiffness Test-Rig

The spring stiffness test rig is used to find the spring rate or spring stiffness co-efficient. The two quantities to be measured for spring stiffness measurement are load applied and the deflection observed. The test rig provides means to measure them both.[3] It consists of two vertical columns on which two horizontal plates can slide parallely. The spring is held between the two plates. The upper plate is fixed with the help of bolts inserted in the aligned holes in the plate and the vertical columns. The bottom plate is movable in up and down direction. The hydraulic jack is kept below the bottom plate and a load cell is attached between the hydraulic jack and the spring, separated by another plate for the fixture of the load cell. The displacement sensor is attached on the bottom of the top plate and the reflecting plate is attached on the top face of the bottom plate. When the jack is pumped, the head moves upward and along with it, the spring.[4]

Fig.1 Spring Stiffness Test-rig

When the spring touches the top plate, it starts experiencing a reaction force equal to the force applied. This force is measured by the load cell. The load cell, gives the strain reading to the HX711 circuit which amplifies the voltage and converts the analog data to digital arduino readable data. The spring starts to compress.The displacement sensor shows a decrement in distance. This is the length by which the spring is getting compressed. The data is relayed back to the arduino, which sends it to LabView.[5] The programming and suitable VI is prepared in LabView due to which, the load and displacement is obtained as a graph as interfaced. Thus, a non-linear stiffness co-efficient graph for the spring to be tested. The VI developed for LabView is as given in the figure 2 and figure 3 shows the Spring Stiffness graph obtained from respective Test-rig.[6]

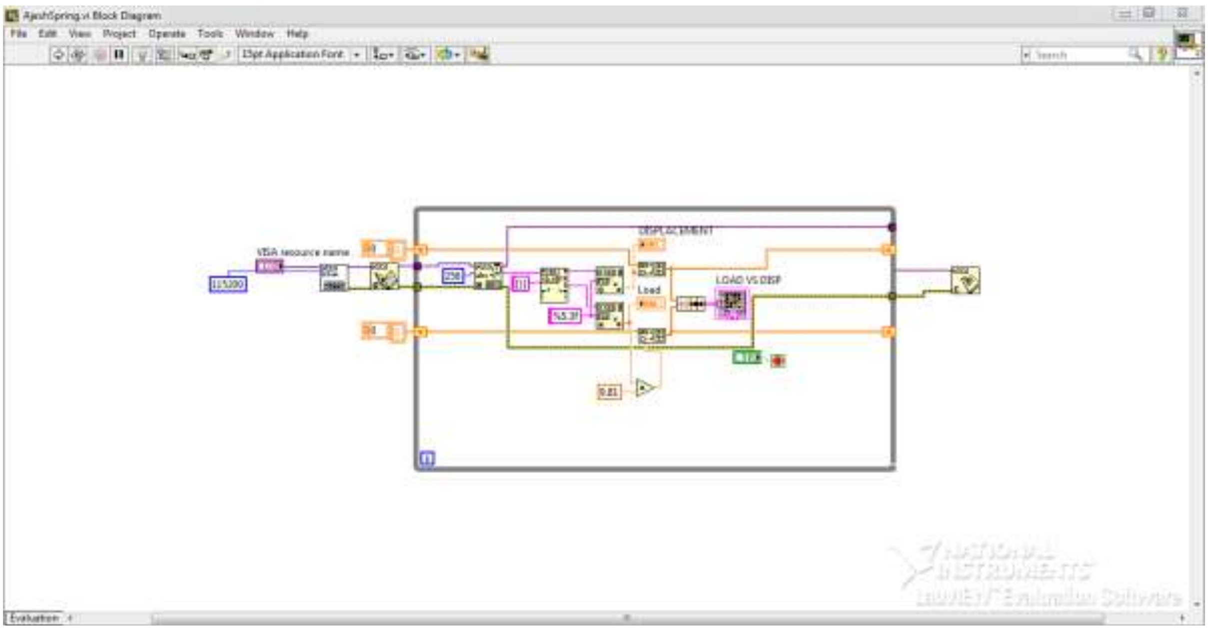

Fig.2 Ni-LabView Program

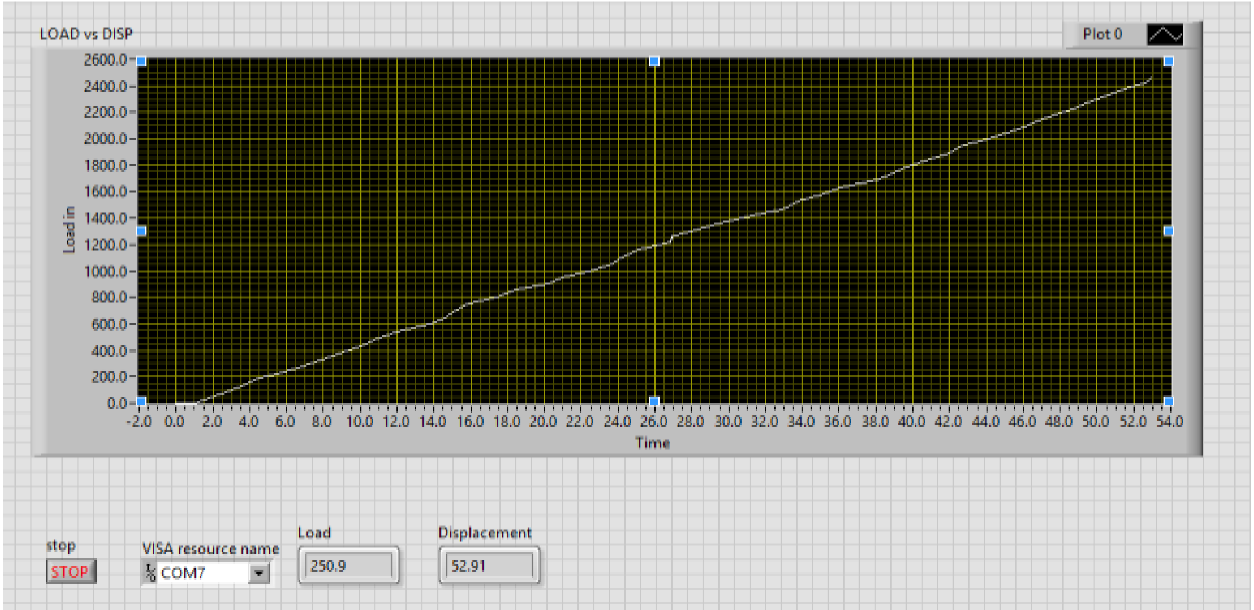

Fig.3 Result Obtained From Spring Stiffness Test-rig

III. **Mathematical Modelling And Equation Forming For Linear Models Having 2 DOF :**

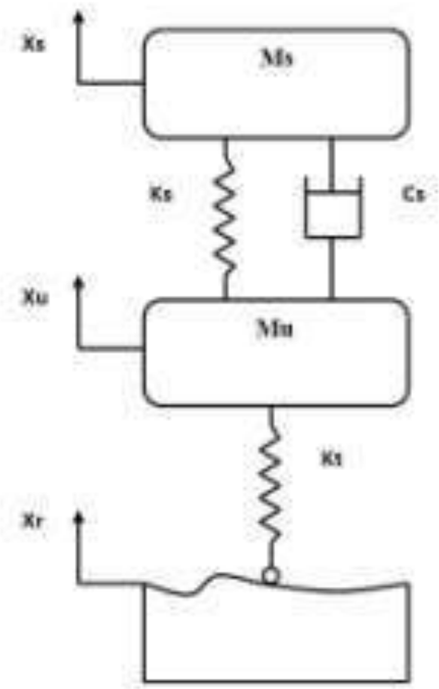

Fig.4 Linear Model Having Two Degrees Of Freedom

Quarter car model has 2 DOF and it consists of springs, dampers & tyres arrangement, which provides values of spring stiffness, damping co-efficients, and tyre stiffness respectively. The linear model consists of spring mass denoted by M_s, unsprung mass denoted by M_u, damping co-efficient C_s, spring stiffness K_s, tyre stiffness K_t. The non-linear model consists of non-linear spring stiffness (K_{s1}, K_{s2}), non-linear damping co-efficients (C_{s1}, C_{s2}). $\dot{X}_s$, X_u, X_r represents displacements for sprung mass, unsprung mass tyre respectively. By applying Newton's 2^{nd} law the differential equations of system are obtained.[7]

For sprung mass-

$M_s(ddX_s)= -K_s(X_s-X_u)-C_s(dX_s-dX_u)$

For unsprung mass-
$M_u(ddX_u)= -K_s(X_s-X_u)+C_s(dX_s-dX_u)-K_t(X_u-X_r)$
Where,
$\dot{X}_s$= Velacity for sprung mass (mm/s)
$\ddot{X}_s$= Acceleration for sprung mass (mm/s^2)
$\dot{X}_u$= Velacity for unsprung mass (mm/s)
$\ddot{X}_u$= Acceleration of unsprung mass (mm/s^2)
From above equation's MATLAB-Simulink model is developed for linear suspension system. The below figure 5 and figure 6 shows matlab Simulink model and result obtained for the simulation.[8]

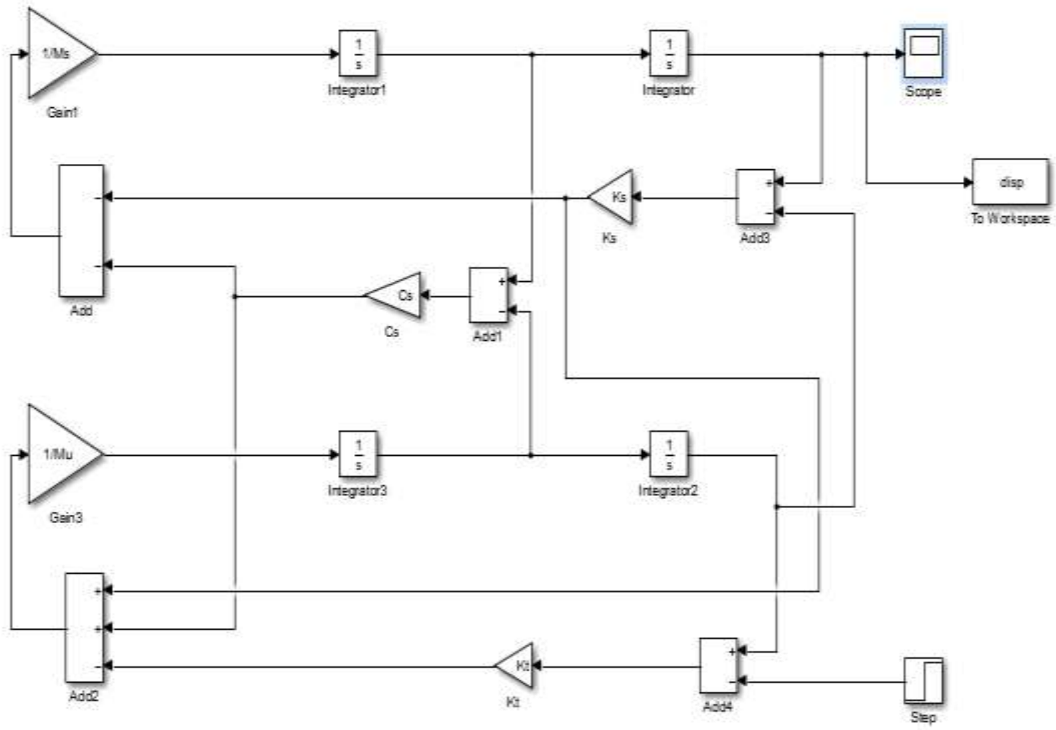

Fig.5 MATLAB Simulink Program For Linear Model having 2 DOF

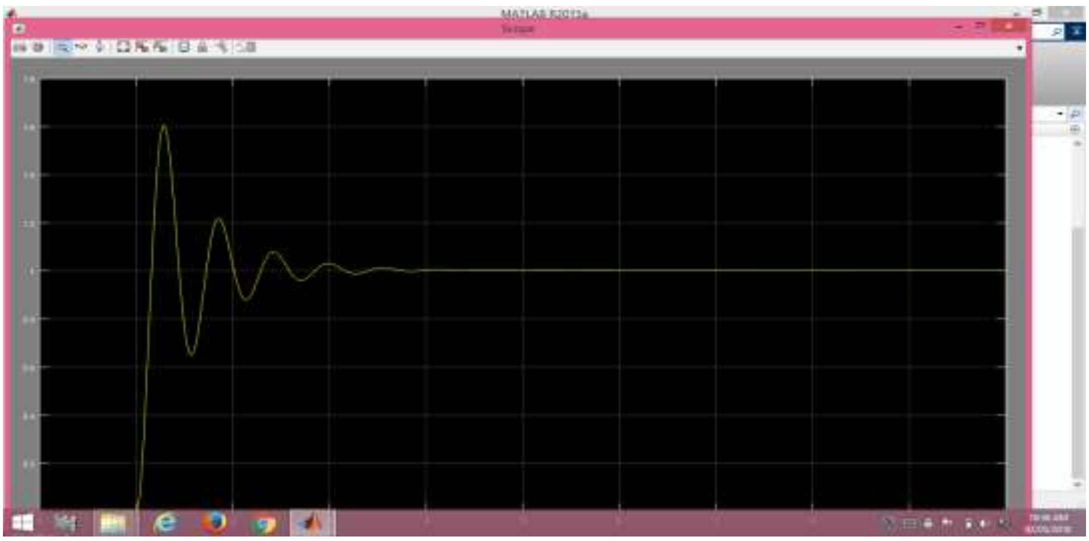

Fig.6 Results for Linear Suspension MATLAB Simulink

IV. Quarter Car Test-Rig

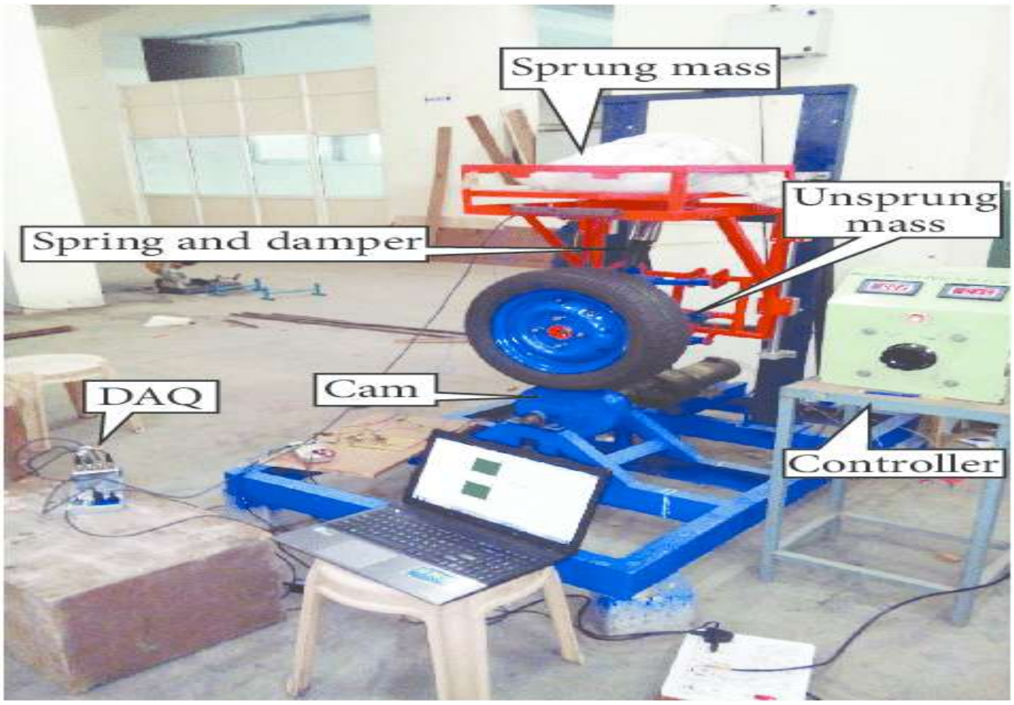

Fig.7 Quarter Car Test-Rig

To study Ride Comfort, a Quarter car test rig is integrate with NI-Labview based data acquisition system designed and originated is shown in figure 7. RMS acceleration of sprung mass from the experimentation gives the Ride Comfort, which is in m/s ^{2}[9]. A cam profile is attached in the test rig to obtain the relative motion between the road and wheel. When cam is actuated with a motor, wheel acts as a follower to the cam profile.The acceleration of the sprung and unsprung mass which is measured by the two accelerometers attached to the sprung mass and unsprung mass respectively. The Quarter car test rig assembly is interfaced with NI-Labview data acquisition system.The speed of the cam profile is measured by tachometer in rpm. The results are obtained as the graph of acceleration Vs time of sprung and unsprung masses.[10]

V. Conclusion

The most appropriate level of Suspension system performance is determined by spring. This study approaches the Simulation and Quarter car study through Ride Comfort is obtained. Spring tested on Spring Stiffness Test-rig and further simulated on simulation software (MATLAB). Similarly, the spring is tested on Quarter Car Test-rig and we get RMS values at the respective RPM. Study focuses on comparison and also validation of Spring Stiffness Test-rig. The Comparative curve drawn from RC obtained of both tests. This change is due to non-linearity caused in Spring geometry. Hence, this study will be focused towards Non-linear approach.

Comparison curve between Simulink and Quarter Car Test-rig:

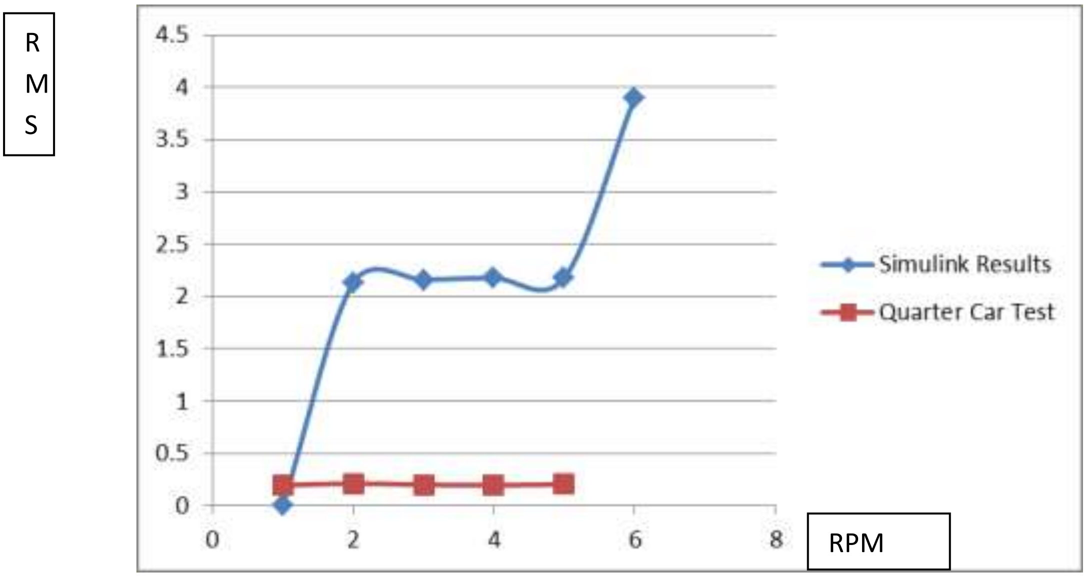

Fig.8 Comparison curve between Simulink and Quarter Car Test-rig

VI. Future Scope

The springs for variable pitch can be manufactured to separately study their effects. The test rig can be modified to accommodate a wider range of spring sizes by modifying the hydraulic jack placement height. The result obtained from the spring stiffness test rig can be used to make a model on ANN. The study can be extended by considering the non-linearity in tire stiffness which thereby can be optimized to obtain better RC and RH.

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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