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DESIGN OF A DRIVER SEAT SUSPENSION SYSTEM FOR BETTER COMFORTNESS

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Abstract-*Road disturbances are the main causes of driver's and passenger's dis-comfortness during vehicle in motion. High speeding vehicle usually faces this kind of situation very much. For better comfortness from road disturbances, it is necessary to rethink about the seat suspension system. The most of the passenger car's driver seat suspension system's natural frequency is 2-3 Hz. If the natural frequency of the seat suspension system could be reduced, the transmissibility between chassis to driver will be reduced. The comfortness will be ensured. But there is a dichotomy relation between cost and comfortness. Providing low cost is not possible in most of the cases. This paper has been presenting a new passive driver seat suspension system and eventually would be compared with an active type driver's seat suspension system for better comfortness at developing flexible and transparent design methods that can be implemented at low cost.*

Keywords: Design; Stiffness; Negative Stiffness; Seat Suspension System; Driver Seat.

1. INTRODUCTION

Seat is an important part of automobile vibration isolation, has an effect on the comfort of the automobile. Designing superior seat vibration isolation components is important to improve the vehicles comfort. Vibration caused by an irregular road profile are transmitted from the wheels to the chassis of the car through its suspension and then to the seat. It is a challenging issue for a seat suspension system to minimize vibration level. Ride and handling characteristics of the car, as well as passenger safety are determined by the suspension geometry and properties of other suspension parts, such as the suspension system, springs, bushings and shock absorbers etc. With the development of mechanical technology, the requirements of ride comfort and driving performance have been major development objectives of modern vehicles to satisfy the expectations of customers. When controllability, not the mechanical design, is the main concern in categorizing the seat suspension systems, they are classified as passive, active and semi-active systems.[1],[2]. Among them passive suspension system, composed of springs and dampers with fixed properties and linear characteristics is currently used in most vehicles. But it has no mechanism for feedback control. Active suspension system using sensors to measure vehicle's dynamic information used in the real-time controller to drive the actuator in order to provide the exact amount of force required, but cannot alter the kinematics.[9]. Active suspension systems are risky and expensive and cannot work in harsh environments like vacuums; high/low temperature extremes, radiation etc. Despite the higher performance of these systems, high power consumption, size, heavy weight, and cost of active suspension systems are more expensive than passive systems, sometimes by a factor of ten, which represents a critical obstacle to expanding their fields of application. Another critical issue with active control is the stability robustness with respect to sensor failure; this problem is a big concern when centralized controllers are used.[10]. On the contrary, semi-active control devices are essentially passive devices in which properties (stiffness, damping) can be adjusted, but they cannot input energy directly into the system being controlled thus, they are robustly stable. The judgment of human body responses with respect to vibration is difficult one. The sensitivity is totally ones individual character. Mechanical vibrations in the infra-frequency range not only affect comfort, but also cause health and safety problems. Reports for adult population indicate that almost 80% of the adult population has reported some form of lower back aches associated with spinal disorders, muscle strains and/or medical problems. Low back pain is a one of the common musculoskeletal impairments, which is often caused when a muscle or ligament holding the vertebra in its proper position is subjected to strain.[6],[7]. When the muscles and ligaments become weak, the spine loses its stability, which results in pain. The total cost a year due to back pain in the US is estimated at $90 billion (Deprez *et al.*, 2004). Vehicle seat design is the most important factor in reducing back pain.[8]. The transmissibility between chassis and seat is the range 2 to 7 Hz, which is still large for human body's least tolerance. If the natural frequency of vehicle suspension system could be reduced then the transmissibility between chassis and seat will be reduced. One way to lessen the adverse effect of transmitted force of vehicle vibration to the operator is through the use of a seat suspension system.[3],[4].

A common method used to reduce vehicle operators' exposure to vehicle vibration is to design seat suspension with low natural frequency than the typical operating frequency generated by the vehicle by a large decrease in seat stiffness. In this paper a driver seat suspension system is presented with Negative Stiffness System (NSS) for very low vertical natural frequency and totally in passive way. Transmissibility with negative-stiffness is substantially improved. NSS vibration isolation is a highly workable solution and costs significantly less than conventional alternatives up to one-third the price making it an economical solution to cost-conscious administrators.

2. CURRENT SEAT SUSPENSION SYSTEM

Ride is perceived as most comfortable when the natural frequency is in the range of about 1Hz to 2Hz. When the frequency approaches 2Hz, occupants perceive the ride as harsh. Most of the_modern seat suspension systems are spring damper types and semi active with the dissipation of energy. According to researchers at the National Institute for Occupational Safety and Health –Pittsburgh Research Laboratory (NIOSH – PRL), evaluation performed on seat suspension systems to determine how they would be seat performance on large heavy vehicles used at mining operations test masses are 40 and 80 kg. A test frequency range from 2 to 8 Hz at 0.25Hz intervals was added to measure the transmissibility characteristics for each seat suspension system in the range most sensitive to the human body overall. Transmissibility ratio which is commonly used as a measure of how well the seat suspension is isolating the occupant from vehicle vibration. The test result is that the isolation frequencies for the most seat suspensions are occurred from 2.1 Hz to 3.0 Hz that is not in much comfortable limit.[7]. The natural frequency of this current vehicle suspension can be reduced by increasing the mass or damping coefficient of the system and decreasing the stiffness of the system. But in actual practice those are not efficient and practical too. This paper will present a novel solution to this problem of vibration isolation using negative stiffness.

3. PROPOSED NEW SEAT SUSPENSION SYSTEM

An isolation system studied in this paper includes two parts: a main system and a negative stiffness system. The main system consists of a mass and a main spring which is a compression spring that supports the mass. Negative stiffness system at the equilibrium position consists of an extension spring. Two springs are combined to reduce the stiffness of the overall system. The natural frequency of any spring mass system is given by

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad (1)$$

Equation (1) shows that reducing stiffness of the spring the natural frequency of the suspension system could be reduced. Here we are reducing the mathematical model of the new suspension system with NSS. The Fig.1 shows the new suspension system with NSS.[3],[4],[5].

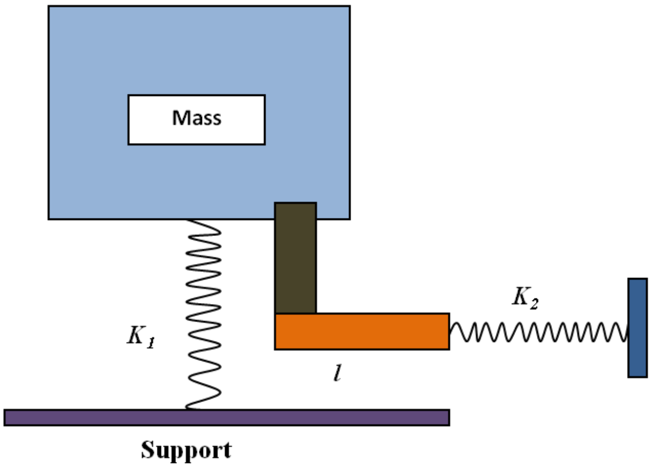

Fig.1: Proposed Model

Here, k_1 and k_2 is the stiffness of the main isolation system and the added system respectively, l is the length of the bar and x is displacement from its equilibrium position. The potential energy of the system can be given as,

$$U = U_1 + U_2 \qquad (2)$$

Where,

$U_1 = \frac{1}{2} K_1 x^2$

$U_2 = \frac{1}{2} k_2 \left(\partial_0 - l + \sqrt{(l^2 - x^2)}\right)^2$

∂_0 = spring's initial deflection and

l = bar length.

Again, U_1 and U_2 is the potential energy of the main and added isolation system.

The natural frequency of this spring mass system has shown in [3]

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k1-k2}{m}} \qquad (3)$$

4. CAD MODEL OF NEW SEAT SUSPENSION SYSTEM

In order to complete an optimization study the seat has to be modeled accurately enough so that when changes are made to the model it would accurately predict how the real seat would respond with similar changes. The optimal solution found using the model should then also be the optimal solution for the real seat.

The CAD model is shown in Fig.2 where fluid friction of a damper is replaced by metal to metal friction of the linkages that helps in vibration isolation.

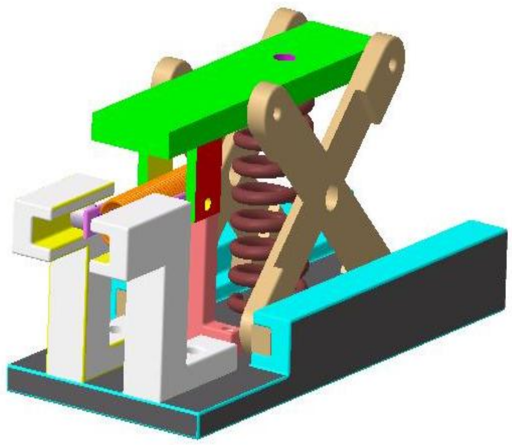

Fig.2: CAD model for new Seat Suspension System

With the reference [2] we want to tell that using the parameters given in the following table it is possible to reduce natural frequency can be reduced from 3.112Hz to 1.72Hz, hence comfortness will be found more quickly than other past seat suspension systems. From where it is found that if we want to reduce the natural frequency of the seat suspension system, we need the stiffness of negative spring as the same proportion of main isolation system.

Table 1: Parameter of new Seat Suspension System with NSS

<table>
<tr><th>Serial no.</th><th colspan="2">Name</th><th>Value</th></tr>
<tr><td>01</td><td colspan="2">Mass</td><td>3kg</td></tr>
<tr><td>02</td><td colspan="2">Main Spring Stiffness(k_1)</td><td>1150 N/m</td></tr>
<tr><td rowspan="2">03</td><td rowspan="2">Negative Spring</td><td>Stiffness(k_2)</td><td>800 N/m</td></tr>
<tr><td>Initial length</td><td>7cm</td></tr>
<tr><td>04</td><td colspan="2">Bar length (l)</td><td>5cm</td></tr>
<tr><td>05</td><td colspan="2">Initial Deflection(∂_0)</td><td>5cm</td></tr>
</table>

5. EXPERIMENTAL MODEL

In order to obtain a realistic computer model of the seat, one would have to represent the real seat as comprehensively as possible in mathematical terms. Instead of modeling the seat exactly as it is, a number of assumptions are made to simplify the model, reduce the number of calculations required and speed up the modeling process. The correct assumptions, that will enable a much simplified model to give solutions within reasonable accuracy of the real seat, need to be determined. The designed model for new seat suspension in Fig.3 is able to reduce fundamental frequency to a level that is not harmful for our health, hence reduces the lower back pain in a great extent as well as lowers the cost.

Fig.3: Designed model

The simulation curve for natural frequency vs. Adding system stiffness shows a tremendous comparison between new seat suspension system using Negative Stiffness and present seat suspension system.

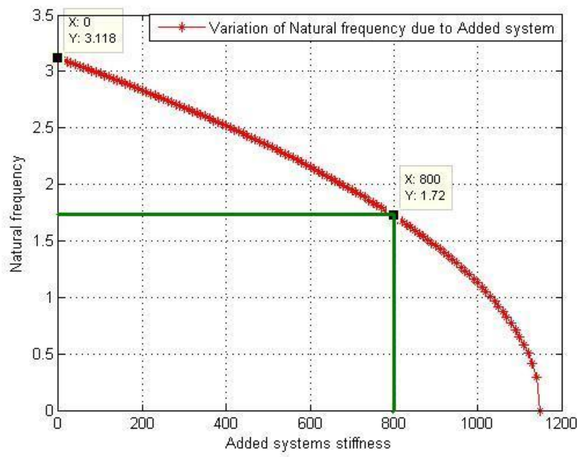

Fig.4: Computer simulation for NSS (Natural Frequency vs. Negative stiffness)

From the Fig.4 it is clear that for the new added system natural obtained frequency is 1.72Hz but whereas in case of present seat suspension system it is found somewhere at more higher level. As a result it can be said that a driver seating in new seat suspension will get comfort more quickly than that of in present seat. As natural frequency is reduced for the added system, hence it can be said that the peak of transmissibility curve will be achieved at a frequency level below than present system. The simulation curve also expresses that the natural frequency of the system will be zero at adding system stiffness 1150N/m that is a critical value because the system will not be feasible.

A comparison on potential energy curves between two seat suspension systems is shown in Fig.5.

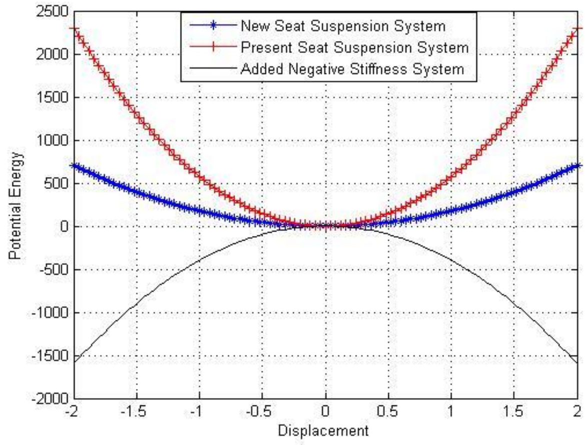

Fig.5: Simulation curve for Potential energy vs. Displacement

Figure 5 shows that the natural frequency is reduced because the slope of the potential energy curve of the new isolation system is less than that of present system due to adding "Negative Stiffness" system. The adding system has a negative value of potential energy that cancels out the positive value of potential energy of present system to some extent.

6. COST COMPARISON

The cost of each a typical design consists of a sum of the following: material, manufacturing, assembly and tooling cost (if applicable) plus engineering design hours and any preliminary testing (if required). An hourly engineering design rate of two hundred and fifty dollars and hour shall be used. Each of the alternate designs will be compared to the baseline. Engineering design hours and material costs are approximated. Hence, although more refined seat suspensions certainly mean increased procurement cost and complexity, there is much to be gained besides improved ride comfort, both economically and environmentally. A study on price of driver seat of various famous and remarkable automobile companies shows that cost is a main important factor for driver seat suspension system. The price of "Mercedes 300420560LH" is $200.00 and that is of "ISUZU" is $3900.00. So the latter has lower natural frequency than the former with high comfortable limit. If we add a "Negative Stiffness" system of our designed model with the former seat suspension system then we will get comfortable ride closer to a "ISUZU" seat. [12]. The adding system of our designed model will cost maximum $30 for its supporting bar and extension spring, hence cost is reduced with comfortness.

7. CONCLUSION

Minimization of fundamental frequency of a vibratory system by means of spring with "Negative Stiffness" will enrich the isolation field. With the approach of a generic model of a simple driver seat using spring element with "Negative Stiffness" in the large is presented. Validity of this approach is accessed by a comparison of computation and measurement results. Mathematical details and theoretical proofs can be found in the referenced literature. The system has simulated and it has been presenting the reduced natural frequency from 3.112Hz to 1.72Hz. So, the system is too much effective in high frequency range as well as low frequency range. The probable cost of this system with respect to other system will be very low. Hence, improved seat suspension systems will also lead to increased task performance. Moreover, the system only contains mechanical element like conventional spring and bar. Due to this simple construction, this model will increase its workability in working area. Good design of a passive suspension can optimize ride comfort and driving safety to some extent, but cannot eliminate this compromise. In future, addition of a damper with the designed structure will provide a new dimension to our designed structure. This is due to because damped natural frequency is always less than undamped natural frequency.

6. ACKOWLEDGEMENT

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