To Evaluate the Optimum Parameters in Vehicle Chassis Model Vibrations

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Abstract. New designs and ideas are always evolving in automobile industries. Along with these, there are many aspects and complexities faced in controlling noise and vibrations in vehicles. Due to uneven roads, vibrations are generated which in turn degrades not only vehicle performance but also passenger comfort. Accidents are undoubtedly the most dangerous which may cause damage to human lives. Proper material selection of vehicle chassis is essential for reducing vibrations and increasing the safety. Wheelbase and the track dimension also influencing the performance of the vehicle while running on the roads. Road roughness is the key factor which may lead to the unnecessary vibrations that may harm the riders or passengers comfort and vehicle accuracy as well. Different techniques are commonly used to reduce such undesired vibrations. This paper describes a study of chassis transient vibrations and response with different materials for different damping properties. The behaviour of vehicle chassis under vibrations is observed through modelling in these conditions with different parameters. The aim of the presented paper is to show the effect of different computational techniques on designing a vehicle along with Taguchi’s method for optimizing the parameters.

Keywords: chassis, damping, materials, optimization, transient, vibrations

1. Introduction
Design of vehicles focuses on lessening the vibrations in order to give comfort for the riders. There are so many developments in the automobile field which results in great improvement in the vehicle performance. We are able to evaluate the performance of the chassis vibrations with various parameters. Walter V. Wedig [1] states that the vibrations are generated by uneven roads are vertical vibrations. The vertical disturbance of vehicle body governs the nature of the driving force required to maintain a constant speed. This is a major reason for investigations of many researchers about vehicles in motion. The vibration measurement and analysis is also the key issue of investigations for many researches. Automobile vibrations are of multiple frequencies, magnitude and orientations. Lifu Wanh et al. [2] states that, active suspensions aims on major motion modes. Their major task is the use of neural networks to identify motion modes with considerable accuracy. Vehicle dynamics is the prediction of responses under extreme conditions and thereby study the effects of these responses on the vehicle itself. Nowadays, the negative side of automobile industries and its growth results in increased traffic, accidents and other fatalities. Temporal instability is always present due to many
basic behavioral causes. Research by Fred Mannering [3] is done by the findings and analyzing many latest accident data available for this study. Roads are never perfect and they provide irregularities. Erdem Y et al. [4] deals with interior noise inside the passenger cabin of automobiles. They investigated a very important source of noise coming from structure. This structure borne noise is an output of vibrations in panels. Panels are enclosing the complete vehicle, and this study greatly contributes in such investigations of noise and vibrations. Ride Dynamics is always critical to investigate. Verros et al. [5] investigated the large vehicles by modeling and simplifying the equations of motions. They also considered the tire and shock absorber effects along with the separation of vehicle from ground for small amount of time and integrated equations are presented for transient road conditions. Newly constructed roads have some amount of irregularities. These irregularities directly interact with wheels of vehicles. Forces are obviously getting induced in wheels due to these irregularities. Even a bump in the road is responsible for the vertical movement of wheels. This movement is perpendicular to the road surface. The magnitude of movement and forces obviously depends on size of a bump. Watts et al. [6] investigated ground borne vibrations by vehicle crossing road humps. Wheels of vehicles always experiences acceleration in vertical direction as they passes over any kind of imperfections. De Moerlooze et al. [7] discovered a latest model for transient motion with rolling and friction effects. They applied it to different dynamic systems. The approach is to simulate the rolling friction effects on the dynamics of any mechanical parametric system. They discovered very interesting results which shows that the behavior of systems depends on the amplitude and the frequency of oscillation. A two level optimization method has been presented by Torsten Butz et al. [8], which categorically make thrust on evaluating unknown chassis model parameters. Their research mainly focuses on parametric estimation process. It leads to improvement in parametric selection done by excitation strategies, adopted by solving the optimal design problem. Karpel et al. [9] presented a paper about steps in analysis of complicated structures. An approach of fictitious mass component mode synthesis is adopted by them. They made the rigid connections in terms of displacement equations. Very importantly, the soft connections are made through stiffness and damping connecting matrices. The effort is made without altering the degrees of the freedom. They also proved the betterment in using fictitious mass that each substructure is presented as a single set of free interfacing modes. Shock absorbers are supposed to be the main nonlinearities responsible for structure related noise in vehicles. The prediction of this noise at the design stage is always a challenge to automotive industries. Marouane Benaziz et al. [10] proposed a unique method in predicating this structure borne noise. They compared the simulation results with the experimental results which identify undesired transitory phenomena. Moment of inertia and vertical oscillations of vehicles are correlated strongly and are directly proportional to each other. A two terminal mass based absorber which provides a variable moment of inertia is proposed by Tongyi Xu et al. [11]. Performance of this newly developed absorber has been analyzed through simulation. In comparison to constant moment of inertia, this method of changing moment of inertia provides early response, very good comfort and a much needed safety. The added advantage is about the reduced suspension deflections. Vehicles are subjected to random excitation by the irregularities and bumps in a road. Werner Schiehlen et al. [12] provided a study on suspension model for vehicles. They showed the uncertainties in shock absorber and tire springs, as these two elements are subjected to wear. For a better ride comfort and driving safety suspensions are very important in designing a vehicle. Heydinger et al. [13] provides an outlook on development of a vehicle dynamic simulation model. Their fundamental study aspects on models used to present a chassis and suspension systems along with tires. Taguchi method for robust design and optimization of control parameters is significant in the vehicle vibrations. Mitra et al. [14] highlights on the effective use of Taguchi method for optimized selection of control parameters.

2 Vibration response of vehicle on road bumps
Steel and aluminium are two common materials for chassis. Now a days European cars consist of around 135-140 kg of aluminium parts in the body structure, mainly chassis and suspensions. For
reducing the vibration levels, general concern is to achieve considerable damping in terms of a whole system response. In case of vehicle travel on road bumps, jump or bounce of wheels occurs. This is a transient condition that occurs with high speed vehicles. With jump, the vehicle and road surface separate owing to high amount of unbalanced forces. In this situation all of the wheel energy is transferred to the chassis

2.1 Chassis model for transient vibrations
Chassis materials should be easy to weld and form so that repairs and modifications can be easily done. Also chassis materials should get easily painted in wide variety of colours. A chassis model as shown in fig.1 is built to perform the transient analysis through ANSYS for simulating the vehicle movement on road bumps like speed breakers. Table 1 shows the significant properties and dimensions of the chassis model.

| Material Properties | Values for Structural Steel | Values for Aluminium |
|---------------------|-----------------------------|----------------------|
| Young’s modulus     | $200 \times 10^3$ N/mm$^2$  | $69 \times 10^3$ N/mm$^2$ |
| Yield stress        | $250$ N/mm$^2$              | $290$ N/mm$^2$       |
| Density             | $7.85e-006$ kg/ mm$^3$      | $2.86e-006$ kg/ mm$^3$ |

Major dimensions of chassis model in three directions

| X = 807 mm; Y = 500 mm; Z = 233.2 mm |

Fig 1. Vehicle chassis model

3. Taguchi’s Method
Many different factors, inputs, or variables need to be considered when making a product. However, there is a better way to design an experiment to find out the best combination of variables to make your product. The Taguchi method is a standardized approach for determining the best
combination of inputs to produce a product or service. This is accomplished through design of experiments (DOE). The Taguchi method provides:

- A basis for determining the functional relationship between controllable product or service design factors and the outcomes of a process.
- A method for adjusting the mean of a process by optimizing controllable variables.

### 3.1 Controlling factors

Control factors are those variables in a process that management can manipulate. Optimal levels are the targets or measurements for performance. The goal is to fine the most efficient process and service design. These parameters can be determined through experimentation. Table 2 shows the variable selected for this research with L16 analysis.

#### Table 2. Controlling factors for L16 analysis

| Sr. No | Stiffness (N/m) | Speed (rpm) | Mass (kg) | Damping Ratio |
|--------|----------------|-------------|-----------|---------------|
| 1      | 180            | 300         | 20        | 0.21          |
| 2      | 180            | 300         | 50        | 0.22          |
| 3      | 180            | 400         | 20        | 0.23          |
| 4      | 180            | 400         | 50        | 0.24          |
| 5      | 260            | 300         | 20        | 0.25          |
| 6      | 260            | 300         | 50        | 0.26          |
| 7      | 260            | 400         | 20        | 0.27          |
| 8      | 260            | 400         | 50        | 0.28          |
| 9      | 180            | 300         | 20        | 0.29          |
| 10     | 180            | 300         | 50        | 0.30          |
| 11     | 180            | 400         | 20        | 0.32          |
| 12     | 180            | 400         | 50        | 0.34          |
| 13     | 260            | 300         | 20        | 0.39          |
| 14     | 260            | 300         | 50        | 0.42          |
| 15     | 260            | 400         | 20        | 0.45          |
| 16     | 260            | 400         | 50        | 0.50          |

#### 4. Results

The results for chassis transient vibrations through ANSYS are important to observe in deciding the most significant parameter.

#### 4.1 Transient vibrations and stress-strain values for steel and aluminium chassis

For a time period of 6 sec as an interval period for moving a chassis model over bouncing surface reveals following results are found:

- Structural Steel shows induced stress as 10.565 N/mm².
- Aluminum shows induced stress as 10.589 N/mm².
- The maximum deflection for steel is 7.5289e-002 mm.
- The maximum deflection for aluminum is 0.21849 mm.
- Strain Energy for Steel chassis is 12.367 mJ.
- Strain Energy for aluminum chassis is 35.94 mJ.
4.2 Taguchi results for parameter optimization

It is important to evaluate the signal to noise ratio on the basis of larger is better. It is shown in table 3 and the response for means is shown in table 4.

**Table 3. Signal to noise ratio levels in Taguchi’s analysis**

| Level | Damping Ratio | Stiffness N/m | Speed rpm | Mass kg |
|-------|---------------|---------------|-----------|---------|
| 1     | -12.255       | -11.543       | -10.922   | -10.687 |
| 2     | -8.643        | -9.355        | -9.977    | -10.211 |
| Delta | 3.612         | 2.188         | 0.945     | 0.476   |
| Rank  | 1             | 2             | 3         | 4       |

**Table 4. Response for means through Taguchi’s method**

| Level | Damping Ratio | Stiffness N/m | Speed rpm | Mass kg |
|-------|---------------|---------------|-----------|---------|
| 1     | 0.2450        | 0.2688        | 0.2925    | 0.3013  |
| 2     | 0.3763        | 0.3525        | 0.3288    | 0.3200  |
| Delta | 0.1312        | 0.0838        | 0.0363    | 0.0187  |
| Rank  | 1             | 2             | 3         | 4       |

4.3 Taguchi’s results for main effects

Taguchi’s experimental analysis reveals the main effect plots as shown in figure 2. The graphs for all four factors, mass, stiffness, damping and speed are available through this technique and are important in robust design of chassis.

![Fig 2. Main effect plot for means](image-url)
5. Conclusion
Strain Energy is nothing but the internal work done in deforming the body by the action of external forces. Aluminium is seen better than steel in this regard. On comparing with the amount of energy dissipated for steel, the amount of energy dissipated for aluminium is more. This feature provides good damping to the structural vibrations. Weight saving is an additional benefit with aluminium chassis, as compared with conventional steel chassis. Benefits in terms of improving driving comfort along with safety, due to the reduction of the mass is a key feature of using aluminium as a chassis material. Also, aluminium provides good manufacturing feasibilities like formability and weld ability. Good corrosion resistance of aluminium is an important feature in wet conditions, which is desirable for chassis design. Table 3 and table 4 shows through signal to noise ratio and response for means, the most critical component is damping factor in the vehicle vibrations and comfort. Fig2 shows the similar effect through main effect plots. Analysis also shows that the damping factor should be selected in the range of 0.2 to 0.5 for the effective vibration damping and comfortable riding of vehicles.

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