Selection of Spring For Spring Coil Dampers Using An Iterative Approach

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Abstract- *Suspension is one of the most vital sub-system in an automobile and has three major tasks namely comfort, control and contact. One major component of the suspen-sion system are dampers and spring which are responsible for handling and comfort of the vehicle. If not designed correctly, suspension system might create problems like difficult control, uncomfortable experience and in worst case scenarios toppling of the vehicle leading to danger of harm to the life of passengers. The purpose of this research is to calculate the optimum stiffness of the coil over spring for the commercial light motor vehicle from where the de-signing of the system can be started and other parameters can be designed later on. An iterative approach has been used to determine the stiffness of the springs to be used in order to optimize the performance of the vehicle, keeping in mind the driver safety and maximum driver comfort. The stiffness of the spring is calculated and through the ride frequencies of the front and the rear of the vehicle and checking if the roll gradient targeted is achieved. If not, the process is repeated till the roll gradient is achieved.*

Keywords- Independent Suspension, Dampers, Stiffness, Wheel Rate, Ride Rate, Ride Frequency, Roll Rate, Roll Gradient, Spring Rate, Motion Ratio

I. INTRODUCTION

The objective of the suspension system is to protect the vehicle body from road shocks and vibrations. It must keep the tires in contact with the road, regardless of road surface. A basic suspension system consists of the parts such as springs, axles, shock absorbers, arms rods and ball joints[1]. The light motor vehicles are generally equipped with independent suspension geometry consisting of MacPherson Strut in front and Torsion beam typed dependent suspension geometry in the rear. The MacPherson Strut comprises of damper, coil over spring and a lower control arm. When the wheel of a vehicle goes over an obstruction, the movement is termed as a 'bump' and the suspension system, through the motion of the linkages and the spring-damper arrangement absorbs the unbalanced forces created by this motion. This unbalanced force depends on the un-sprung mass at each wheel; greater sprung to un-sprung mass ratio implies the occupants will be less affected by road imperfections[2]. Springs are mounted in parallel with the dampers to dampen out the shocks produced through road irregularities over the time. So selecting a spring presents the form of a problem to be solved either through computer analysis or mathematical modelling. The load carrying ability of the spring depends on the diameter of the wire, the overall diameter of the spring, its shape, and spacing of the coils.[1] Hence, the calculated spring rate can be further used to determine the required dimensions of the spring for the spring coil damper system.

A considerable amount of research has been done on suspension and spring of different types for different kind of vehicles[3][4][5][6]. However, majority of research on spring coil dampers for commercial vehicle is based on the designing and failure analysis[7][8][4]. While failure is an important parameter, this study mainly focuses on the determination of the parameters of the suspension system which are necessary to calculate the spring rate for the commercial light motor vehicle by iterative approach. Stiffness is an important design parameter for springs with variable stiffness. This parameter can be calculated using two methods, namely analytical method and rig test. The analytical method is preferred over the rig test due to high manpower and time requirements of the latter [9]. Authors failed to find any study that focusses on the selection of coil using an iterative process. This study is an effort in this direction.

II. METHODOLOGY

The selection of the spring is a tedious task hence an iterative process is used to narrow down the result to the desired objective. The process is started with selecting a Ride Frequency, and then Ride rate is calculated. Once the ride rate is calculated, wheel rate and roll rate can be calculated using standard formulas. Roll gradient is then calculated and seen if it matches with the target roll gradient. If not, the whole process is repeated taking another frequency and this process is repeated till targeted roll gradient is achieved.

Frequencies are taken at an iteration rate of 0.001 Hz. Light motor vehicles also have a moderately stiffer ride i.e.; the ride frequency is above 1 Hz; reason being that the driver does strict maneuvering on the road but with the consideration of the quality comfort for the other occupants. Thus if the ride is kept less than that response of the vehicle is slow to the input causing a lag, thus affecting the ride and handling of the car.

Being aware of the situation of the normal roads, moderately stiff roll gradient should be chosen. Therefore, roll gradient valued 7 to 8.5 deg./g will be prefer depending upon the response wanted by the occupants and the load carrying application of the vehicle.

Once, the target roll gradient is achieved and other parameters corresponding to it are already known, then spring rate can be calculated using Motion ratio as shown in calculation section.

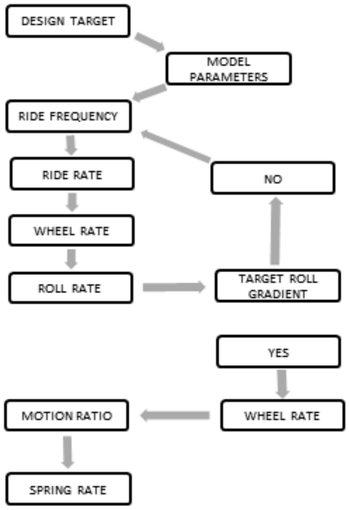


Fig 1. Shows an algorithm for the selection process

III. RELATED PARAMETERS AND ASSUMPTIONS

Before proceeding to any further investigations, it is important to make various assumptions relating to the vehicle for calculations. Here, we have used data for a typical light motor vehicle. The total mass of the vehicle (*W*) is assumed to be 3800 kg, with a mass distribution of 60:40::Front: Rear. With this mass distribution, the mass per front wheel ($\frac{wf}{2}$) becomes 1140kg and mass per rear wheel ($\frac{wr}{2}$) will be 760kg. Further it's assumed that the height of Centre of gravity (H_c) of the vehicle is 457.2mm. And Front (T_f) and Rear Track width (T_r) of the vehicle are 1695mm each. Also, wheelbase (W_b) is 2470mm. Another important parameter which is needed while calculating wheel rate is Tire stiffness (K_T) is taken 350253.67 N/m[10]

Table 1: Roll Gradients for different vehicle types[10]

Vehicle Type	Roll Gradient
Light Motor Vehicle	8.5 deg./g
Light Motor Vehicle	7.0
Sports Vehicle	6.0
High-Performance Vehicle	4.2
Racing Vehicle	1.5
Active Suspension Vehicles	According to occupants need

IV. ITERATIVE PROCESS

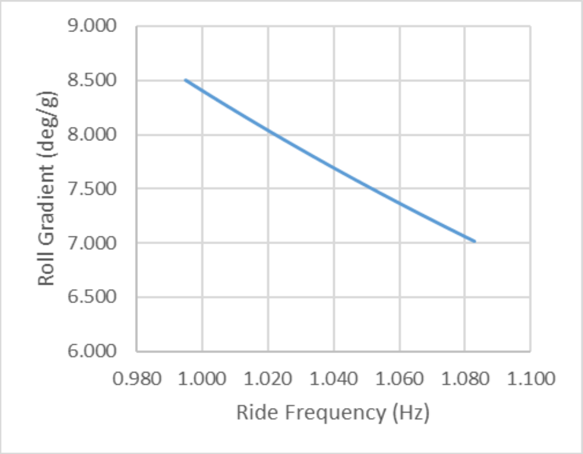


Fig. 2 Ride Frequency Vs Roll Gradient for a LMV

A graph is drawn between Ride frequency and respective roll gradients achieved. From the Graph it is clear to achieve a Roll gradient near to 7.5 deg/g we need to achieve Ride frequency between 1.04Hz to 1.016Hz. Choosing Ride Frequency 1.058Hz (front) and 1.005Hz (Rear) for further investigation.

1) Ride Rate:

$$Kr = 2\pi^2 \times \omega^2 \times \frac{Wf}{g}$$

2) Lateral Weight Transfer (@1.5g):

$$\Delta W = W \times 1.5g \times Wf,r \times \frac{Hc}{Tf}$$

3) Tire Rate:

$$Kt = 350253.6\ N/m$$

4) Wheel Rate:

$$Kw = \frac{(Kr \times Kt)}{(Kr - Kt)}$$

5) Wheel Travel:

$$Wheel\ Travel = \frac{(\Delta W \times 1000)}{Kr}$$

6) Roll Rate:

$$K\o = \frac{\pi(T^2 \times Kr)}{360}$$

7) Roll Gradient:

$$\frac{\o}{Ay} = W \times \frac{Hc}{K\o f + K\o r}$$

After calculating the ride and roll rates, the motion ratio was selected. One of the tricky tasks is to find the motion ratio. Motion ratio (M.R.) as defined is:

$$M.R. = \frac{Spring\ Travel}{Wheel\ Travel}$$

$$Spring\ Travel = \frac{Wheel\ Rate}{M.R.^2}$$

Wheel travels for several classes of vehicles are typically[10]
Off-road trucks: ±304.8 mm
Passenger cars: ±101.6 mm
Sports cars: ±50.8 to ±101.6 mm
Indy type cars (ground effects) : < ±12.2 mm

8) Spring Rate:

For MacPherson Strut suspension system the Motion Ratio remains to be 1:1, since it's a direct installation.

Spring Rate in Front (K_{SF}):

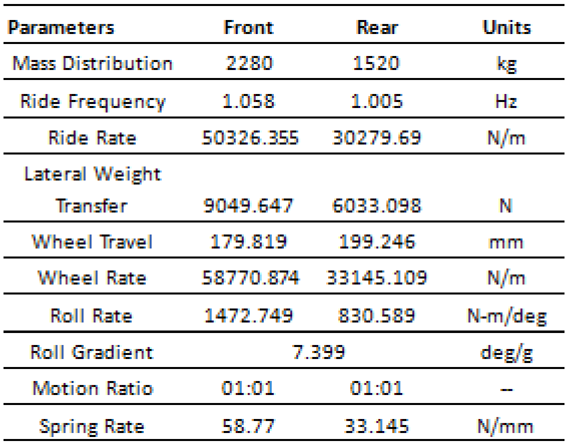
$$Ksf = \frac{Kwf}{M.R.^2}$$

Spring Rate in Rear (K_{SR}):

$$Ksr = \frac{Kwr}{M.R.^2}$$

V. RESULT AND DISCUSSION

For a light motor vehicle of 3800 kg, the front and the rear spring's rate have been determined considering the various vehicle suspension parameters like Ride Rate, Wheel Rate, Roll Rate, Roll Gradient to make sure the roll-over stability of the vehicle and the comfort quality of the occupants.



Parameters	Front	Rear	Units
Mass Distribution	2280	1520	kg
Ride Frequency	1.058	1.005	Hz
Ride Rate	50326.355	30279.69	N/m
Lateral Weight Transfer	9049.647	6033.098	N
Wheel Travel	179.819	199.246	mm
Wheel Rate	58770.874	33145.109	N/m
Roll Rate	1472.749	830.589	N-m/deg
Roll Gradient	7.399		deg/g
Motion Ratio	01:01	01:01	--
Spring Rate	58.77	33.145	N/mm

From the results obtained we can select the springs of the required stiffness, and hence move on to designing suspension system of the vehicle and analysis of the geometry through simulations after deciding the hard points of the A-Arms on wheel and chassis side. This iterative approach is simple and is really helpful in optimizing the performance and handling of the vehicle.

The calculated spring rate can be used for calculating the dimension of the helical spring, generally used in the front suspension system of the LMV i.e.

$$K_S = Gd^4/64nR^3$$

Ks= Spring-rate
G= Shear Modulus of Spring Material
d= Diameter of wire
n= No. of turns
2R= Diameter of turns

VI. CONCLUSION

An iterative approach to selection of springs for a Light Motor vehicle using coil damper have been developed. Rather than involving complex simulations, simple calculations have been used.

The conclusions drawn from this study can be summarized as follows:

- Calculations start with ride frequency and varying them at intervals of 0.001 Hz and calculating ride rates, wheel rates and roll rates.
- Roll gradient is then calculated and is checked if it is in accordance with the targeted roll gradient.
- If not, ride frequency is varied and all parameters are calculated again till the targeted roll gradient is achieved.
- Once the target roll gradient is achieved, it’s corresponding wheel rate is used to calculate the spring rate with the help of motion ratio which is 1:1 in case of McPherson strut which is generally used in LMVs.
- This research can be used for other suspension geometries where motion ratio can be varied.

This research can be expanded to designing of custom made springs and to further design Anti-roll bars and deciding the amount of stiffness to be given to springs and to Anti-roll bars to improve the cornering performance of the vehicle.

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