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Parameter optimisation design for a six-DOF heavy duty vehicle seat suspension

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1. Abstract

In this paper, the stiffness and damping parameters of a six-degree-of-freedom (DOF) heavy duty vehicle seat suspension are optimised on the base of different vibration excitations with genetic algorithm (GA). Optimisations are implemented under two conditions, that is, all the legs have same stiffness and damping, and legs which are symmetric with x axis have same stiffness and damping. Swept sinusoidal vibrations are applied as excitations. Translational vibration along x and y axes and rotational vibration around x and y axes are carried out, respectively. The optimisation results show that a smaller weighted value of root mean square (RMS) acceleration in six DOFs according to ISO 2631-1 can be obtained under the second condition, which means the suspension can be more comfortable. But higher acceleration transmissibility from the vibration excitation to the same DOF acceleration output around the resonance frequency is also obtained under the second condition. These results indicate that when optimising multi-DOF heavy duty vehicle seat suspension, the dominant vibration DOF will cause vibrations in other DOFs due to the structural coupling. So the dominant vibration DOF and its related vibration DOFs should be considered at the same time.

2. Keywords: six-DOF, seat suspension, GA.

3. Introduction

Nowadays, the vehicle seat suspension has been an increasing demand because the exposure to vibration transferred from rough road has significant influence on drivers' safety, heathy and comfort[1], especially, for heavy duty vehicles which always work in severe environments . Generally, a one or two degrees of freedom (DOFs) vibrations are considered to design and optimise seat suspension[2, 3]. However, heavy duty vehicles always have special functions, such as digging, dumping and shovelling, and the vibrations will come from different sources besides rough road surface. Therefore, a multi-DOF seat suspension should be designed to satisfy the requirements of heavy duty vehicles.

The multi-DOF motion platform has been widely applied in many fields. Based on its parallel mechanism, a kind of six-DOF vehicle seat suspension is designed. The six-DOF suspension includes one base platform which is fixed on the vehicle cab floor, one top platform which is used for assembling vehicle seat, and six legs which are used to connect the base and top platform. There are springs and dampers in each leg.

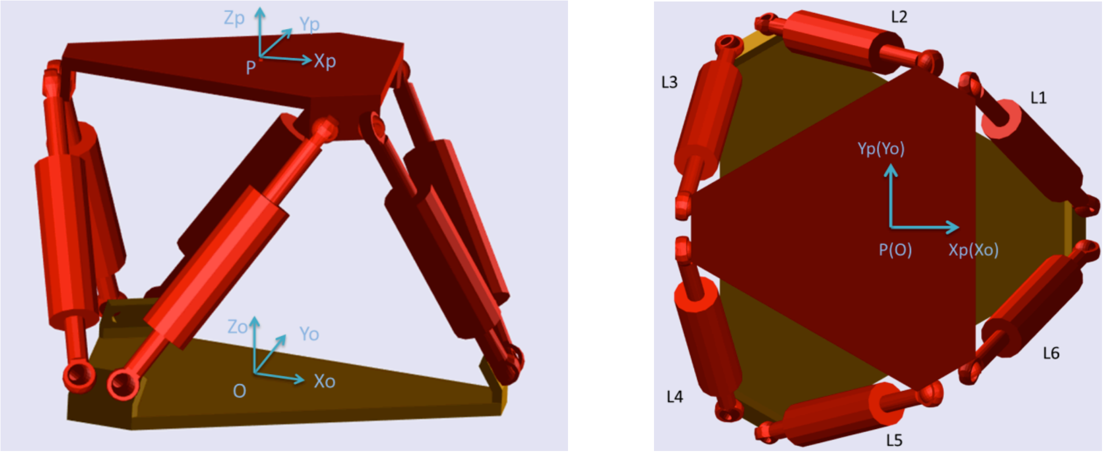
As the suspension performance is closely related to the choices of the spring stiffness and the damper damping property, how to choose the optimal stiffness and damping will be critical for the seat suspension performance. Due to the complex structural configuration of the six-DOF seat suspension and because there are six springs and six dampers in the six-DOF seat suspension, conventional optimisation algorithms based on gradient calculation are hard to be applied. In this paper, the genetic algorithm (GA), which is a well-known stochastic search algorithm for global optimization of complex systems based Darwinian principle of "survival of the fittest" [4, 5], is used to search for the optimal stiffness and damping for six legs. The weighted value of root mean square (RMS) according to ISO 2631-1 in six-DOF of top platform and the relative displacement of top and base platform are considered when optimising the suspension. Numerical results are obtained and analysed in the paper.

4. Six-DOF heavy duty vehicle seat suspension

Vertical and horizontal vibrations are always involved for the design of passenger vehicles seat suspension. For heavy duty vehicles such as excavators and drill rigs which have special functions, vibrations come from multiple sources except road surfaces. Therefore, the drivers will suffer multi-DOF vibration.

4.1. Six-DOF suspension design

Multiple-DOF motion platform is a kind of parallel mechanism which has a six-DOF movable top platform. Based on the structure of multiple-DOF motion platform, the six-DOF vehicle seat suspension is designed as shown in Figure 1. The six-DOF suspension includes one base platform which is fixed on the vehicle cab floor, one top platform which is used for assembling vehicle seat, and six legs connecting the base and top platform. There are springs and dampers in each leg. The x axis points to the vehicle traveling direction, and the two sides of x axis are symmetric. When the base platform suffers a six-DOF vibration translating along x, y and z axis, and rotating around x, y and z axis, the suspension can attenuate it in six-DOF.



(a) (b)

Figure 1: Six-DOF vehicle seat suspension. (a) Side view (b) Top View.

4.2. Six-DOF suspension model

The traditional modelling method used to compute dynamics and derive equations is error-prone and complicated. SimMechanics is a new way which can model 3D multibody system easily and accurately using blocks in Matlab/Simulink. In this paper, a 3D model is designed in PTC Creo firstly. Then the 3D model is transferred into SimMechanics. An 80kg load is added on the top platform to imitate the weight of seat and driver. The stiffness *k* and damping *c* of six legs can be set independently. The translation displacements and rotation angles of six-DOF vibration can be implemented on the base platform. Using sensor blocks in SimMechanics, we can get the vibration response of seat surface.

5. Optimisation method

Parameter optimisation of vehicle seat should involve two things, drivers' comfort and vehicle handling. Attenuating the vibration acceleration transmitting to seat surface can enhance drivers' comfort, which always need soft springs when the vibration frequency is higher than resonance frequency. And in low frequency band, hard springs can perform better in attenuating seat surface acceleration. The displacement between seat surface and cab floor is an important factor which influence vehicle handling. So the seat surface acceleration and relative displacement should be considered comprehensively when optimise suspension parameter.

5.1. Vibration evaluation

Root-mean-square (RMS) acceleration is always used to evaluate vibration. The six-DOF vibration total value of RMS acceleration can be determined as Eq. (1). The translational vibration RMS accelerations a_x, a_y and a_z are expressed in m/s^2, and the rotational vibration rms accelerations a_{rx}, a_{ry} and a_{rz} are expressed in rad/s^2. The multiplying factors *k* are given by ISO 2631-1 for seat surface vibration [6]. In Eq. (1), $k_x = 1$, $k_y = 1$, $k_z = 1$, $k_{rx} = 0.63\ m/rad$, $k_{ry} = 0.4\ m/rad$, $k_{rz} = 0.2\ m/rad$. A small a_v implies the driver fell comfortable when operating a vehicle.

$$a_v = (k_x^2 a_x^2 + k_y^2 a_y^2 + k_z^2 a_z^2 + k_{rx}^2 a_{rx}^2 + k_{ry}^2 a_{ry}^2 + k_{rz}^2 a_{rz}^2)^{\frac{1}{2}} \tag{1}$$

5.2. GA optimization

GA is a well-known stochastic search algorithm for global optimization of complex systems. It applies Darwinian principle of "survival of the fittest" and uses selection, crossover, and mutation operators to breed good solutions. For optimizing the six-DOF seat suspension parameters of springs and dampers, GA is utilised to search the optimal stiffness and damping of suspension legs to obtain a minimal seat surface vibration total value a_v. The stiffness band of springs is set as 9000 to30000 *N/m*, and the damping band of dampers is set as 50 to 1000 *N*s/m*. At the same time, the relative displacement between seat surface and cab floor is limited in $\pm 0.025m$ in three axes.

6. Optimisation results

To simplify the optimisation process and at the same time present more optimisation options, the optimisation is operated in two conditions. In the first condition, all the legs of the suspension are assumed to have the same stiffness and damping. The second condition considers the symmetry of the suspension, so leg 1 and leg 6, leg 2 and leg 5, leg 3 and leg 4 share the same stiffness and damping respectively. In each condition, the suspension is optimised in four kinds of vibration excitations. Translational vibrations along x and y axis and rotational vibrations around x and y axis are respectively implemented on the base platform of the suspension. In this paper, the swept sinusoidal signal is applied as vibration sources. The amplitudes are 0.01*m* for translational vibration and 1 *degree* (about 0.0174 *rad*) for rotational vibration. And the vibration frequency band is between 0.5 to 10 *Hz*.

6.1. Optimised stiffness and damping

The GA optimisation results with two conditions are shown in Table 1. In the same legs condition, the optimisation results of translational vibration along x axis and rotational vibration around x and y axis have the same stiffness around the lowest value and different damping. This is because lower stiffness always leads to smaller acceleration, and proper damping can limit the biggest displacement around resonance frequency. Figure 2 shows the total value of RMS acceleration of the optimised suspension. It implies that when taking the symmetry of the suspension into account, we can get more comfortable optimisation parameters under these four kinds of vibration excitation.

Table 1: GA optimisation results

Vibration DOF	Symmetric Legs						Same Legs	
	L1 and L6		L2 and L5		L3 and L4		All Legs	
	k(N/m)	*c(N*s/m)*	*k(N/m)*	*c(N*s/m)*	*k (N/m)*	*c(N*s/m)*	*k(N/m)*	*c(N*s/m)*
x	17366.1	979.2	12643.7	703.6	12893.5	320.8	9000.3	682.6
y	9407.9	531.1	10436.5	785.8	13953.3	812.2	10148.5	782.3
rx	29111.6	830.1	11039.8	59.5	12414.8	621.9	9000.3	410.9
ry	9000.2	287.6	12597.7	499.4	9001.3	54.3	9000.3	511.9

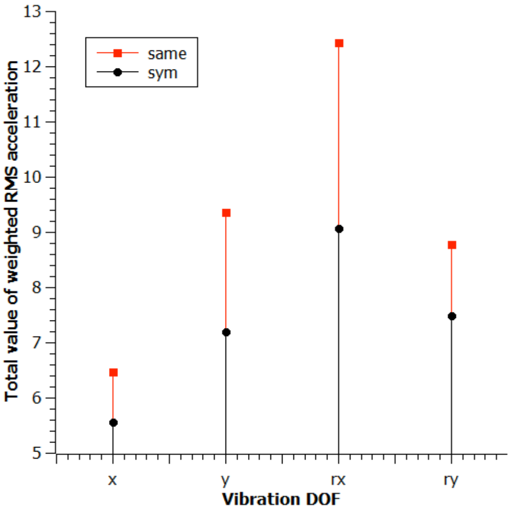
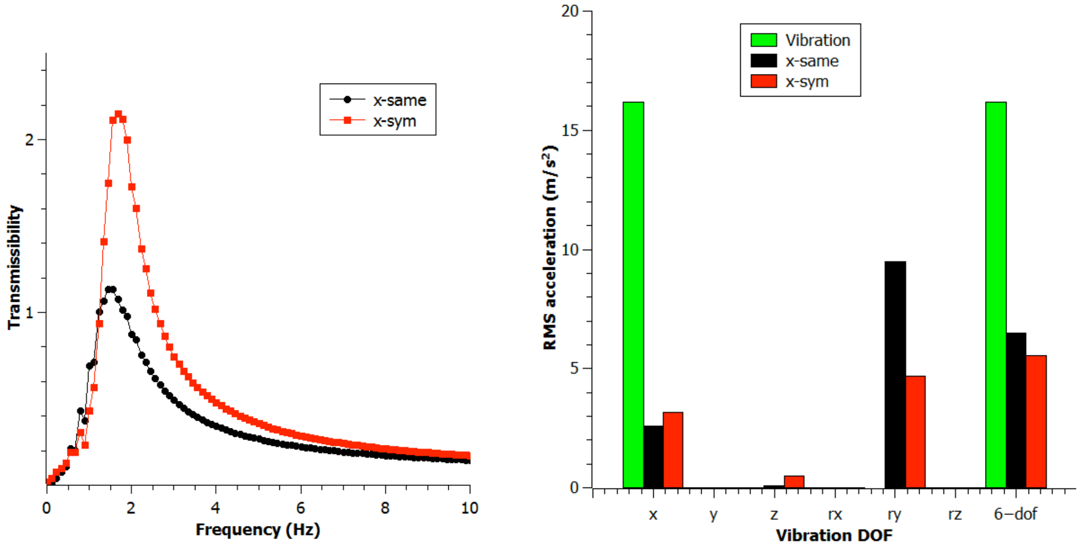


Figure 2: Total value of RMS acceleration

6.2. Comparison of optimisation results under two conditions

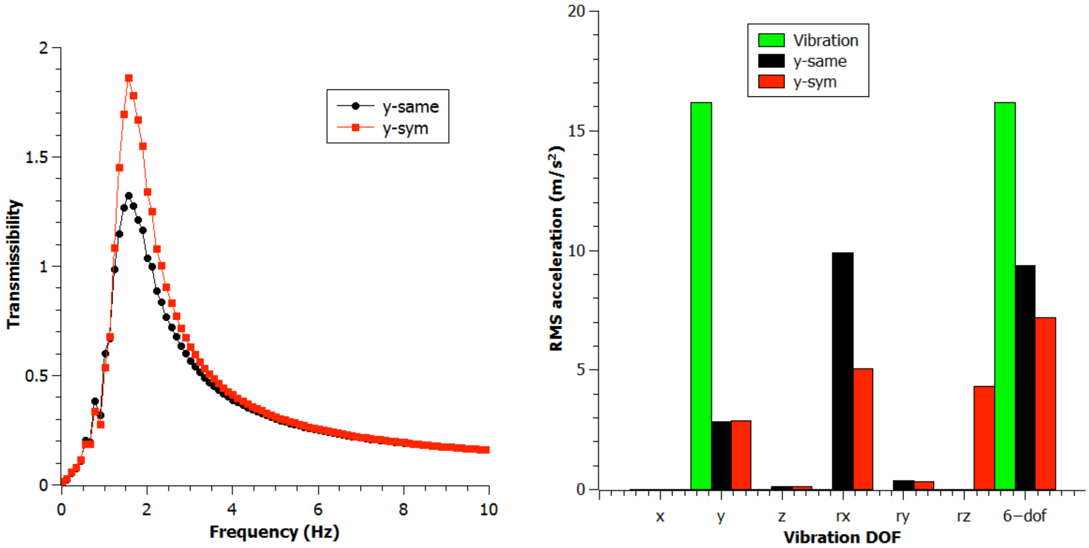
When only translational vibration along x axis is implemented on the base platform of the 6-DOF seat suspension, the optimisation result considered the symmetry property can get a lower total value of RMS acceleration. But it gets higher acceleration transmissibility along x axis in resonance frequency, as shown in Figure 3 (a). Figure 3 (b) shows the RMS acceleration in six-DOF respectively and the six-DOF total RMS acceleration. It notes that the condition with same legs has a bigger rotational acceleration around y axis. While in condition with symmetric legs has a third dominant acceleration along z axis.

Figure 4 shows that there is a similar result when only translational vibration along y axis is implemented.



(a) (b)

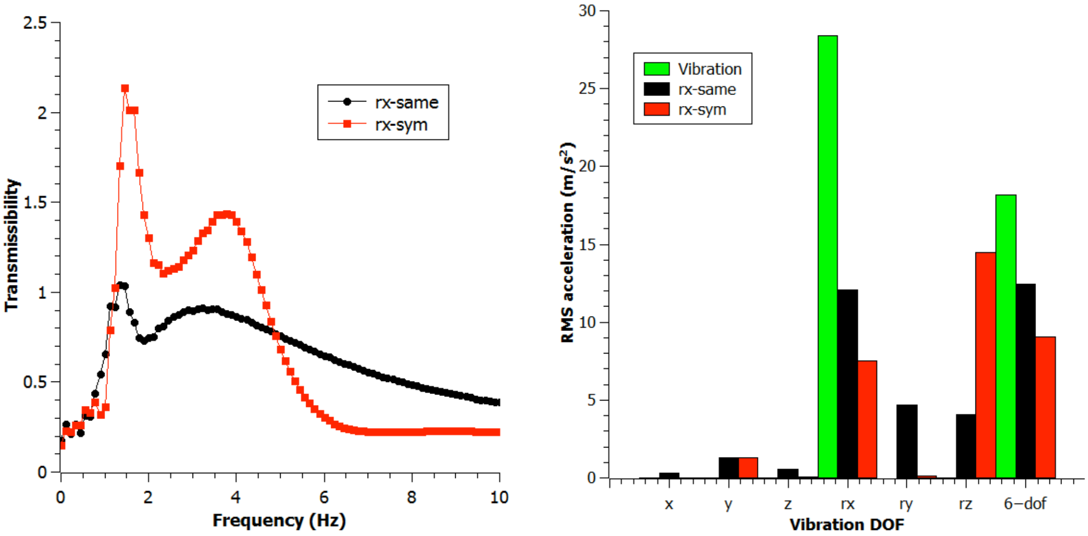
Figure 3: Vibration along x axis. (a) Transmissibility (b) RMS acceleration



(a) (b)

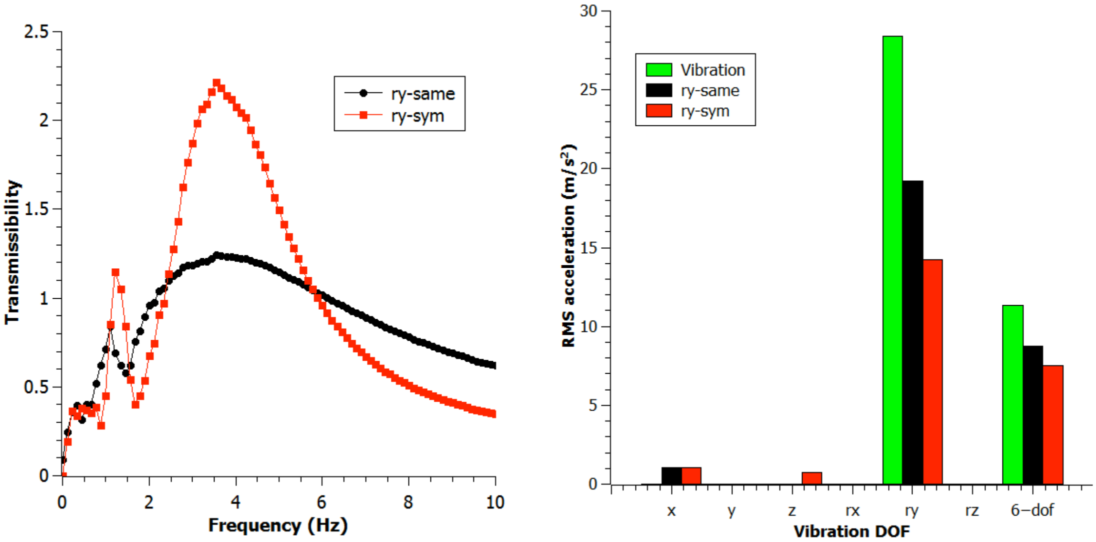
Figure 3: Vibration along y axis. (a) Transmissibility (b) RMS acceleration

When optimising the 6-DOF suspension under rotation vibration, in the vibration excitation DOF, the transmissibility of the one optimised based on symmetric property in resonance period is higher than the other one. But it will decline quickly unlike optimisation under translational vibration.



(a) (b)

Figure 3: Vibration around x axis. (a)Transmissibility (b) RMS acceleration



(a) (b)

Figure 3: Vibration around y axis. (a)Transmissibility. (b) RMS acceleration

7. Conclusion

In this study, a 6-DOF heavy duty vehicle seat suspension is designed in PTC Creo, and modelled in SimMechanics. GA is applied to search the optimal stiffness and damping of suspension legs. The optimisation is implemented under two conditions which are taking the suspension symmetry into account and taking all the legs to have the same stiffness and damping. Swept sinusoidal vibration signals which including translational vibration along x and y axes, and rotational vibration around x and y axes, are carried out on base platform of the suspension respectively. Eight sets of optimisation results are compared and analysed. The condition considering symmetry can get smaller total value of RMS acceleration which means it can be more comfortable. But its transmissibility in vibration excitation DOF is always higher in resonance period. When taking multi-DOF vibration optimisation, the dominant vibration DOF will cause vibrations in other DOFs. Heavy duty vehicles always have special working environments in which the dominant vibration DOFs are different. Designing and optimising the multi-DOF heavy duty vehicle seat suspension should consider the dominant vibration DOF and other related DOFs vibration at the same time.

8. References

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