Sensitivity Analysis of In Wheel Motor Dynamic Vibration Absorbing Structures Based on Monte Carlo Method

Mingming Dong[1,a], Chenchen He[1,b], Jiatong Ye[1] and Fangqing Kong[1]
[1]Beijing Institute of Technology ,Beijing,People's Republic of China
[a]vbmm@bit.edu.cn, [b]hedouble@163.com

Keywords: Monte Carlo, sensitivity analysis,dynamic vibration absorbing structures, parameters

Abstract: As novel drive system, in wheel motor (IWM) attracts more attention in recent years and formed the IWM-suspension system. To better illustrate the influence of system parameters on IWM-suspension system, This paper uses Monte Carlo based method to analyze the parameters uncertain of IWM dynamic vibration absorbing structures, and the influence of parameters on on sprung mass acc, rattle space (RS), tire deflection (TD) and airgap. By comparing the results of the three cases, system performance that all parameters are taken as the random variables are compared and key parameters and non-critical parameters are selected. Through sensitivity analysis, the following parameters optimization process can be greatly reduced.

1 Introduction

With the current social development, energy and environmental crisis are become more and more severe. Therefore, the development of ultra-low emissions or zero emissions of new energy vehicles has become the inevitable trend of the current car development[1][2]. Electric vehicle (EV) with in-wheel motor (IWM) has became one of the hottest topics in the modern vehicle technology research because of the following advantages: 1) simplified structural arrangement 2) higher transmission efficiency 3)low development costs. At present, many well-known vehicle companies have introduced the IWM-driven concept vehicle. However, the traditional IWM driven vehicle's motor is fixed with the wheel, this installation will cause the vertical negative effects as follow[3][4].

1) The introduction of the hub motor will increase un-sprung mass.

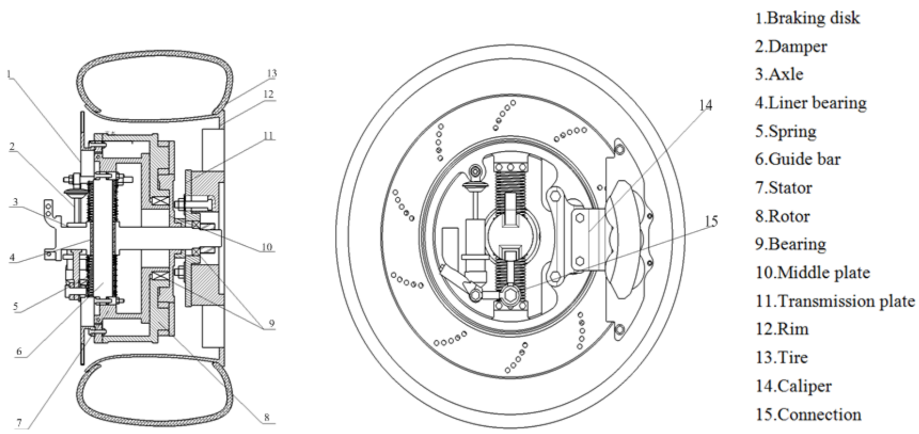
2) Road excitation have negative effect on electromagnetic action.

The application of IWM will cause the vertical negative effects such as the vertical vibration acceleration and tire dynamic load increasing, which will seriously affect vehicle ride comfort and handling stability. Once the vertical negative effect is resolved or improved, the hub motor drive system will be more widely used. In order to solve the problem, a new type of dynamic vibration absorbing structures is presented in this paper, the effect of uncertainty parameters of the structures on vertical vibration negative effect will be researched.

2 Dynamic vibration absorber model

2.1 Physical Model Description

Aiming at solving the vertical vibration negative effect of the IWM, we designed a set of dynamic vibration absorbing structures according to the literature [5][6].The structures are shown in Figure1.



(a)Side view (b)Front view

Fig.1. Dynamic vibration absorbing structures

As shown in Figure1, the dynamic vibration absorbing structures use a set of devices (10 and 11) similar to the cross coupling. This device can isolate the effect of road excitation on the in-wheel motor to reduce the residual radial magnetic force due to the change of the road and also can ensure that the wheel and the motor have the same rotating speeds. In order to solve the problem of the increasing un-sprung mass ,a set of spring and damper structures are installed in IWM, that is (2) and (5) in the Figure1.

2.2 Mathematical Model

According to the literature [7][8], road excitation which affects electromagnetic action of IWM mainly shows at the residual radial magnetic force due to the gap changes between the stator and the rotor .Therefore, this paper studies the influence of road surface excitation on electromagnetic force by studying the gap changes between stator and rotor. Figure2 shows the mathematical model of the dynamic vibration absorbing structures[12].

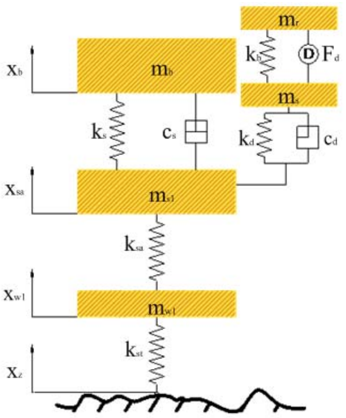


Fig.2.The mathematical model of the structures

Eq.(1) describes the dynamic equation for the dynamic vibration absorbing structures.

$$\begin{aligned}
&m_b\ddot{x}_b + k_s\left(x_b - x_{s1}\right) + c_s\left(\dot{x}_b - \dot{x}_{s1}\right) = 0\\
&m_r\ddot{x}_r + k_b\left(x_r - x_s\right) + c_d\left(\dot{x}_s - \dot{x}_{s1}\right) - F_D = 0\\
&m_s\ddot{x}_s + k_d\left(x_s - x_r\right) + F_D = 0\\
&m_{s1}\ddot{x}_{s1} + k_{sa}\left(x_{s1} - x_{w1}\right) + k_s\left(x_{s1} - x_b\right) + c_s\left(\dot{x}_{s1} - \dot{x}_b\right)\\
&+k_d\left(x_{s1} - x_s\right) + c_d\left(\dot{x}_{s1} - \dot{x}_s\right) = 0\\
&m_{w1}\ddot{x}_{w1} + k_t\left(x_{w1} - x_z\right) + k_{sa}\left(x_{w1} - x_{s1}\right) = 0
\end{aligned} \tag{1}$$

Where m_b is sprung mass, m_{s1} is knuckle and axle mass, m_{w1} is tire and rim mass m_r is rotor mass, m_s is stator mass, k_s and c_s are suspension stiffness and damping, k_{sa} is bearing stiffness between the axle and the transmission plate, k_t is tire stiffness, k_d and c_d are stiffness and damping of mechanisms in the wheel, k_b is stiffness between the stator and rotor, F_D is the residual radial magnetic force due to the gap changes between the stator and the rotor.

3 Sensitivity Analysis Based on Monte Carlo Method

Monte Carlo method [9] uses statistical sampling theory to solve mathematical or physical problems approximately. The basic idea is: Firstly, establish a probability model related to the object to be solved. Then, assume that the statistics of the random variables of some parameters are solutions to the problem and analyze the model by large statistic $(N \to +\infty)$.Finally, obtain the optimal result satisfying the objective function. For this problem, there are two types of parameters that affect the vertical vibration, which are the stiffness parameters and the damping parameters respectively. According to the actual work situation, the distribution of these two types parameters is same in the range. In this paper, it is assumed that the stiffness and damping parameters are uniformly and randomly varied within a certain range. Therefore, when the Monte Carlo method is used to sample these two kinds of uncertain parameters, we all use the uniform function to sample. There are five uncertain parameters in this dynamic vibration absorbing structures. They are shown in Table1.

Tab.1.Uncertain parameters

Parameter	Range	Parameter	Range	Parameter	Range
k_s	10000~30000	k_d	10000~80000	c_d	1000~7000
k_{sa}	3e6~9e6	c_s	600~1600	---	---

Figure3 shows the results of 500 samples of uniform parameters using Simulink .

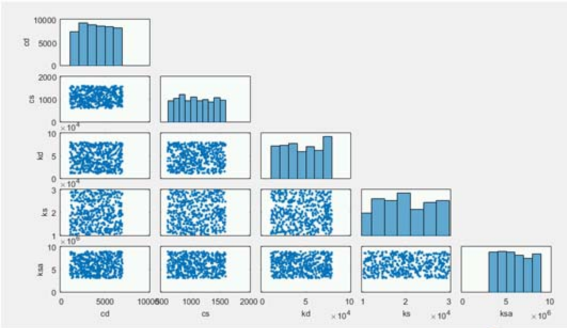


Fig.3.Sampling results

It can be seen from the Figure3 that sampling results of the uniformly distributed random number are shown in a histogram, the frequency of each interval in histogram doesn't have big fluctuation and correlation. Therefore, the number of samples is sufficient and the sampling results conform to the parameter distribution characteristics.

The analysis process requires sprung mass acc (acc), suspension working space(SWS), tire deflection(TD),gap between stator and rotor (airgap) has the smallest RMS value, so we set some restrictions according to the requirements. The correlation between the parameters and acc, SWS, TD and airgap is represented by R in Simulink [10][11].

R is calculated as follows

$$
\begin{aligned}
&R(i,j)=\frac{C(i,j)}{\sqrt{C(i,i)C(j,j)}}\\
&C=\operatorname{cov}(x,y)=E\left[\left(x-u_x\right)\left(y-u_y\right)\right]\\
&u_x=E[x]\\
&u_y=E[y]
\end{aligned}
\qquad (2)
$$

x contains Ns samples of Np model parameters. y contains Ns rows, each row corresponds to the cost function evaluation for a sample in x. R values are in the $[-1 \quad 1]$ range. The (i,j) entry of R indicates the correlation between $x(i)$ and $y(i)$.

$R(i,j)>0$ — Variables have positive correlation. The variables increase together.

$R(i,j)=0$ — Variables have no correlation.

$R(i,j)<0$ — Variables have negative correlation. As one variable increases, the other decreases.

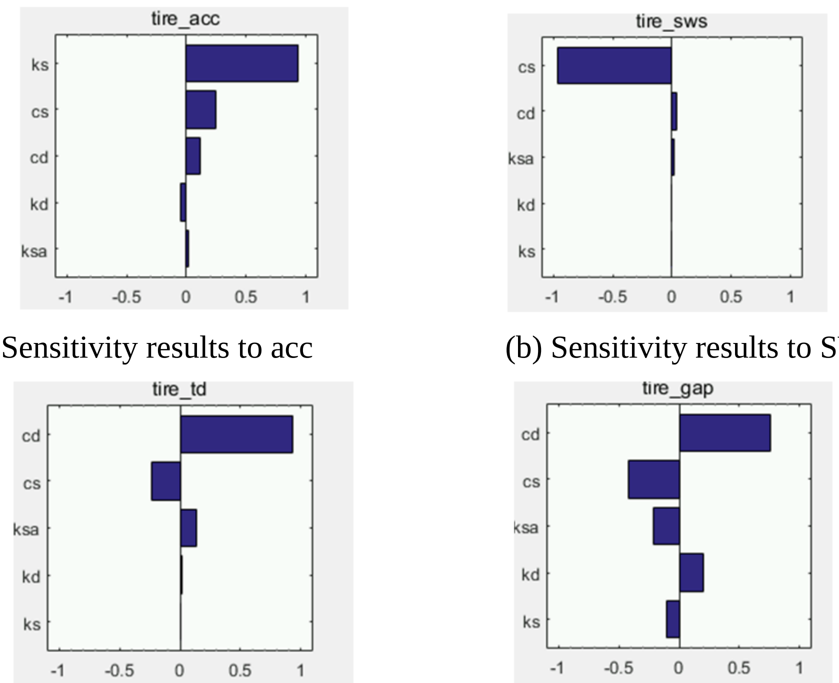
3 Results and Discussion

This paper focuses on the influence of five uncertain parameters on acc, RT, TD and airgap. Sensitivity result is shown in Figure4, from the figure, the following conclusions can be drawn.

1) k_s, c_s, c_d have more effect on sprung mass acc, while k_d, k_{sa} has little effect on it. If we want to reduce acc, we should pay more attention on these sensitive parameters.

2)Suspension working space is affected by c_s larger and c_s, c_d and k_{sa} have more effect on the tire deflection

3) c_d and c_s have more effect on the airgap . In order to reduce road excitation on residual radial magnetic force, we should consider the both effect of these two parameters.



(a) Sensitivity results to acc (b) Sensitivity results to SWS

(c)Sensitivity results to TD (d)Sensitivity results to airgap

Fig.4. Sensitivity results

In order to verify the reasonableness of the key parameters, this paper compares the effects of the key parameters change and the non-critical parameters change with all parameters change on acc, SWS, TD and airgap.

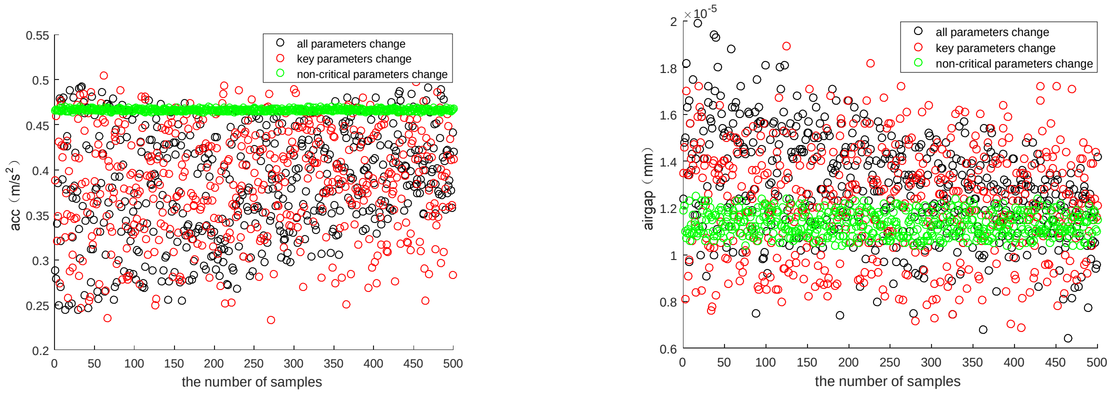


Fig.5. Scatter plot of acc and airgap

It can be seen from the Figure5 that the result range of the key parameters change and all parameters change is basically similar, while when the non-critical parameters change, the result varies in a very small range. This result shows that the results of parameter sensitivity analysis are correct.

4 Conclusion

This paper uses the Monte Carlo method to analyze the uncertain parameters who has effects on acc, RT, TD and airgap. Firstly, the correlation coefficient is calculated. Then the key parameters by the correlation coefficient are identified. At last, all the parameters, including the key parameters and the non-critical parameters are respectively taken as the random variables into the dynamic model to verify correctness of sensitivity analysis by comparing the results of three cases .By using the Monte Carlo method in sensitivity analysis, analysts can overcome the influence of the factors caused by lack of experience and subjective assumptions on the analysis results, so as to improve the accuracy of the analysis. This method can greatly reduce the work load on the basis of ensuring the coverage of parameters. Through the sensitivity analysis of the dynamic vibration absorber, the process of parameter optimization will be greatly reduced, and the development cycle is shortened.

References

[1] Chan C C, Wong Y S. The state of the art of electric vehicles technology[C]// Power Electronics and Motion Control Conference, 2004. Ipemc 2004. the, International. IEEE Xplore, 2004:46-57 Vol.1.

[2] David A Hensher and Kenneth J Button. Handbook of transport and the environment[M]. Vol. 4. Amsterdam: Elsevier, 2003:185-199.

[3] Go Nagaya, Development of an in-Wheel Drive with Advanced Dynamic-Dampe r Mechanism[J], JSAE Review2003(24) : 477-481.

[4] Eastham J F.Disc Motor Reduced Unsprung Mass for Direct EV Wheel Drive[J]. IEEE Catalog Number: 95TH8081.

[5] Yange Zhao ,Wujian Zhang,Xu Han.Design and Research on Vibration Reduction Mecha nism of electric car[J].Mechanical technology and techenology,technology,2008,(3):395-40 4.

[6] Ying Ma,Zhaoxiang Deng,Dan Xie.Design and Research of Active Vibration Reduction System in Electric Wheel.Journal of System Simulation, 2014, (11): 2770-2778.

[7] Sun W, Li Y, Huang J, et al. Vibration effect and control of In-Wheel Switched Reluctance Motor for electric vehicle[J]. Journal of Sound & Vibration, 2015, 338:105-120.

[8] Sun W, Li Y, Huang J, et al. Vibration effect and control of In-Wheel Switched Reluctance Motor for electric vehicle[J]. Journal of Sound & Vibration, 2015, 338:105-120.

[9] Qin Y., He C., Shao X., et al. Vibration control for in-wheel switched reluctance motor driven electric vehicle with dynamic vibration absorbing structures, Journal of Sound and Vibration, Submitted.

[10] Molina M, Ercolifinzi. Monte Carlo techniques for ther-mal analysis of space vehicles: practical examples of ro-bustness determination in preliminary design[C]//ⅩⅧCongresso Nazionale AIDAA. Volterra, Italy, 2005

[11] Shuming Gong.Applied Statistics[M]. Version 2.Beijing:Tsinghua University Press,2005

[12] Dingyu Xue,Yangchuan Chen.System Simulation Technology and Application Based on MATLAB / Simulink[M].Beijing:Tsinghua University Press,2002.