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# Simulation of the Random Load of 1/4 Vehicle Model Based on the Harmonic Superposition Method

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**Abstract** **Review Article**

The vehicle have the additional dynamic load on the road because of the incentive of the road roughness. In order to get accurate and true results, the vehicle load must be assumed as a random load. In this paper, the vehicle load is assumed as an ergodic and stationary random process. According to the power spectral density of the vehicle load, the vehicle load is simulated by using the harmonic superposition method. And the trend of the random load of the two vehicles under three driving speeds and three road grades are analyzed respectively. Results show that with the increase of the vehicle speed, amplitudes of the vehicle random load increase obviously, and the spatial frequency is reduced, and the frequency increase. With the reduction of road grade, the amplitude and the standard deviation of the road random load increase.
**Key words:** Vehicle random load; power spectrum density; 1/4 vehicle model; harmony superposition method.


## INTRODUCTION

Due to the vibration of the vehicle, the road roughness and the coupling effects of vehicle and road surface, the vehicle load on the road includes the additional dynamic load and weight load. Therefore, the size and role of vehicle load is changing with time, and it should be described as the random load. How can describe the vehicle load will be the precondition of the pavement structure stress analysis and vehicle ride comfort study. In the three influence factors of leading to vehicle addition dynamic load, the effect of road roughness is greater than two factors of the vehicle vibration and vehicle-road coupling.Road roughness level can be regarded as obeying Gaussian probability distribution, which has the random process of zero stationary ergodic [1-3]. Only considering the effect of road roughness, the excitation of road roughness produces the vehicle addition load at speed of stabilization can be regarded as the existence of ergodic stationary random process, which must be described by using the random process theory [4].

Based on the above problems, this paper will regard the vehicle addition dynamic load as the stationary random process of zero mean and ergodicity. The literature [4] gives the power spectral density of vehicle addition dynamic load, and the vehicle random load is simulated by using FORTRAN programming and harmonic superposition method. Through the simulation results, the paper analyzes the influence of the vehicles (cars and 10 t truck), driving speed (10, 30 and 50 m/s) and road grade (A, B and C) to random load vehicle.

### Power spectral density of vehicle addition dynamic load

### Power spectral density of road roughness

Power spectral density of road roughness is as follows:

$$G_q(n) = G_q(n_0)\left(\frac{n}{n_0}\right)^{-w} \tag{1}$$

Formula : $n$ —spatial frequency, unit $m^{-1}$; $n_0$=0.01 $m^{-1}$; $G_q(n_0)$) —pavement roughness coefficient ; $w$—frequency index, $w$=2.

The roughness level of road surface is divided into 8 levels by the road power spectral density, the road surface quality decline gradually from A to H. The geometric average of road pavement roughness coefficient of A, B and C levels are 16, 64 and 256 $\times 10^{-6}$ $m^2$ /$m^{-1}$ respectively.

When the car run at speed of $v$ , the power spectral density of space domain can convert into the frequency domain, and the relationship is as $f = vn$, $\omega = 2\pi vn$ $n$ . The power spectral density of road roughness by using the spatial frequency, frequency $f$ and angular frequency $\omega$ are as follows:

$$G_q(n) = vG_q(f) = 2\pi v G_q(\omega) \qquad (2)$$

Type（1） $\omega=2\pi v$ and is pluged into type（2, and the expression type of pavement power spectral density $G_q(\omega)$ can be represented with $\omega$ . When $w=2$ , the type is as follows:

$$G_q(\omega) = {2\pi v n_0^2 G_q(n_0)}/{\omega^2} \qquad (3)$$

**Power spectral density of vehicle addition dynamic load**

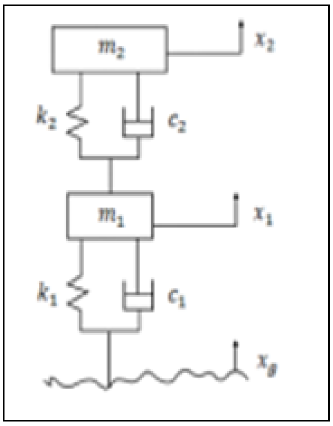


**Fig-1: 1/4 vehicle model**

The literature [4, 5] establishes the relationship of power spectral density of road roughness and vehicle addition dynamic load $P(t)$ , and the type is as followed:

$$G_P(\omega) = \left(k_1^2 + c_1^2\omega^2\right)|H_1(\omega)|^2 G_q(\omega) \qquad (4)$$

Formula： $G_P(\omega)$ —power spectral density of vehicle addition dynamic load; $G_q(\omega)$ —power spectral density of road roughness; $H_1(\omega)$ —frequency response function of the first degree of freedom in double degrees of freedom vehicle model, the type is determined as follows:

$$H_1(\omega) = D_1(\omega)/D(\omega)$$

Formula： $D_1(\omega) = m_1 m_2\omega^4 - (c_2 m_1 + c_2 m_2)i\omega^3 - (k_2 m_1 + k_2 m_2)\omega^2$

$$D(\omega) = m_1 m_2\omega^4 + (c_1 m_2 - c_2 m_2 - c_2 m_1)i\omega^3 + (c_1 c_2 + k_1 m_2 - k_2 m_1 - k_2 m_2)\omega^2 + (c_1 k_2 + c_2 k_1)i\omega - k_1 k_2$$

Formula： $m_1$ —quality of not suspension parts; $m_2$ —quality of suspension parts;

$k_1$ —stiffness coefficient of tire; $k_2$ —stiffness coefficient of suspension system;
$c_1$ —damping coefficient of tire; $c_2$ —damping coefficient of suspension system.

This paper chooses two kinds of cars and 10t truck model for vehicle random load simulation, the vehicle parameters are shown in table 1 [6].

**Table-1: Parameters of vehicles**

| vehicle parameter | car | 10t truck |
|---|---|---|
| $m_1$ | 40kg | 1000kg |
| $m_2$ | 320kg | 8900kg |
| $k_1$ | 200kN/m | 3500kN/m |
| $k_2$ | 18kN/m | 2000kN/m |
| $c_1$ | 3kNs/m | 4kNs/m |
| $c_2$ | 1kNs/m | 30kNs/m |
| tyres quality | 15kg | 100kg |
| vehicle weight load | 3.75kN | 100kN |

Type 3）is pluged into type（4, the power spectral density of vehicle addition dynamic load is as follows:

$$G_P(\omega) = {2\pi v n_0^2 G_q(n_0)\left(k_1^2+c_1^2\omega^2\right)|H_1(\omega)|^2} / {\omega^2} \qquad (5)$$

**Simulation of vehicle addition dynamic load**

This paper will regard the vehicle addition dynamic load as the stationary random process of zero mean and ergodicity, and use the harmonic superposition method to simulate [7-8].The main idea of this method will take vehicle addition dynamic load as the expression of a large number of random phase sine or cosine wave superposition.

Due to the effect of vehicle vibration isolation system, the response of vehicle to some road excitation is small. Therefore, the calculation of vehicle addition dynamic load may not consider the influence of these frequency components. The angular frequency of the upper limit and lower limit are showed $\omega_1$和$\omega_2$, when the speed is 10-50 m/s, the pavement on the time and frequency of tire is between 0.5-30 Hz [15]. Using $\omega = 2\pi f$ relationship, the numerical value is $\pi$ and 60 $\pi$ respectively, and the type (5) is simplified as follows:

$$G_P(\omega) = \begin{cases} {2\pi v n_0^2 G_q(n_0)\left(k_1^2+c_1^2\omega^2\right)|H_1(\omega)|^2} / {\omega^2} & \omega_1 \le \omega \le \omega_2 \\ 0 & \omega_1 > \omega \text{或} \omega > \omega_2 \end{cases} \qquad (6)$$

The power spectral density is calculated by using the harmonic superposition method to simulate the vehicle addition dynamic load. In order to to avoid frequency aliasing, the distance interval $\Delta x$ of the sampling should be satisfied as follows:

$$\Delta x \le \frac{1}{2\omega_2} \qquad (7)$$

Through type（6, the variance of vehicle addition dynamic load can be obtained as follows:

$$\sigma_P^2 = \int_{\omega_1}^{\omega_2} G_P(\omega) d\omega \tag{8}$$

Interval $[\omega_1, \ \omega_2]$ is divided $n$ interval, and the power spectral density $G_P(\omega_{mid\_i})$ on central value $\omega_{mid\,i}(i = 1 \sim n)$ of each interval replace $G_P(\omega)$ of entire interval value. Type （8）is approximate calculated as follows:

$$\sigma_P^2 \approx \sum_{i=1}^{n} G_P(\omega_{mid\_i}) \cdot \Delta\omega_i \tag{9}$$

If the value of $n$ is greater, the type（9） is close to integral formula type（8）.It is showed as follows:

$$A_i = \sqrt{G_P(\omega_{mid\_i}) \cdot \Delta\omega_i} \ \ (i = 1 \sim n) \tag{10}$$

The standard deviation of sine wave $\sqrt{2}A_i \cdot \sin(2\pi \cdot x \cdot \omega_{mid\_i} + \theta_i)$ is for $A_i$, $n$ individual of sine wave is superposed to get values of vehicle addition dynamic load, which is as follows:

$$P(x) = \sum_{i=1}^{n} \sqrt{2}A_i \cdot \sin(2\pi \cdot x \cdot \omega_{mid\_i} + \theta_i) \tag{11}$$

Formula : $x$ —road horizontal displacement, the random number of $\theta_i$—[0, 2π] contents with uniform distribution.Type（11）results are added to vehicle gravity load can get vehicle random load.

## Analysis of vehicle random load

### Curve of vehicle random load

The paper simulates that cars run at speed of 10, 30 and 50 m/s respectively, and the curve of vehicle random load changes with the displacement in figure 2. Calculation results show that the car road load is not vehicle weight load 3.75 kN. But it is vehicle random load around the fluctuating value of 3.75 kN, the amplitude significantly is greater or less than the vehicle weight load. With the increase of speed, the amplitude and dynamic load coefficient of vehicle random load have increased significantly. For example, when the speed is 10, 30 and 50 m/s, the maximum amplitude of the positive and negative direction are 294 N and 269 N, 487 Nand 667N, 686 N and 451N, the maximum dynamic load coefficient of three speeds is 0.08, 0.13 and 0.18, and the frequency of random load decreases with the increase of speed.

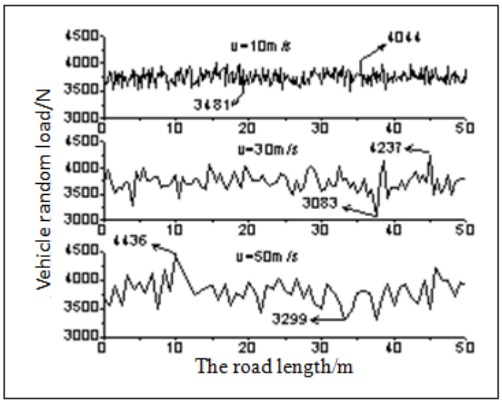


**Fig-2: The curve of random load**

The abscissa (displacement) of figure 2 divide by the velocity is converted into time, which can get the time history curve of random load in figure 3. Three curves in the figure 3 express the time curve of vehicle random load at speed of 10, 30 and 50 m/s, and the time frequency of random load curve increases with speed.

 

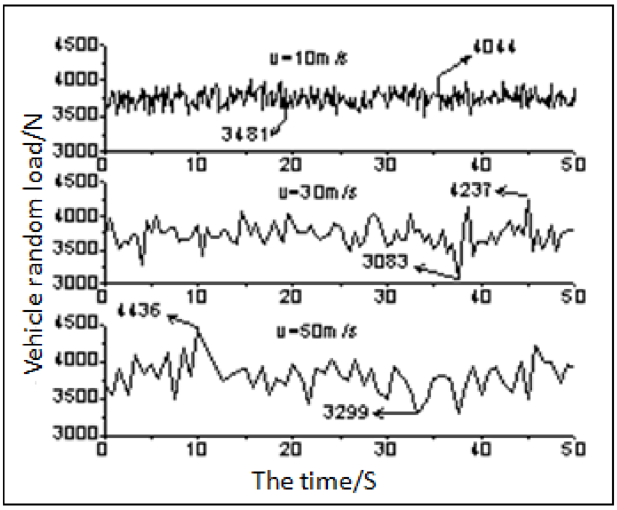


**Fig-3: The time curve of random load**

Change curve of random load displacement（figuure 4）is formed that 10t truck run on level road at speed of 10, 20 and 30 m/s. Calculation results show that the curve of vehicle random load vibrates around 100kN (gravity load), and the amplitude of random load increases with speed. The maximum amplitude is 25.3 and -26.0kN,36.9 and -37.7kN,47.6 and-47.6kN at speed of 10, 20 and 30 m/s.The coefficient of the maximum dynamic load is 0.25, 0.37 and 0.48 respectively.

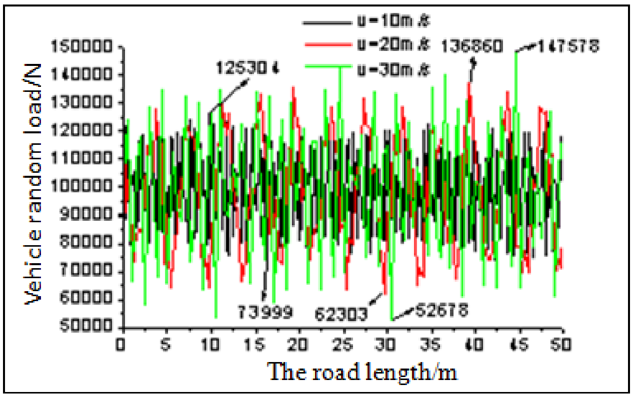


**Fig-4: The random load curve of truck**

**Influence of road surface level**

At speed of 30m/s, the random load curve of A, B and C level pavement is shown in figure 5, and the statistical characteristics of random load are expressed in table 2. Calculation results show that the amplitude and dynamic load coefficient of random load increase obviously with the decrease of the road level.

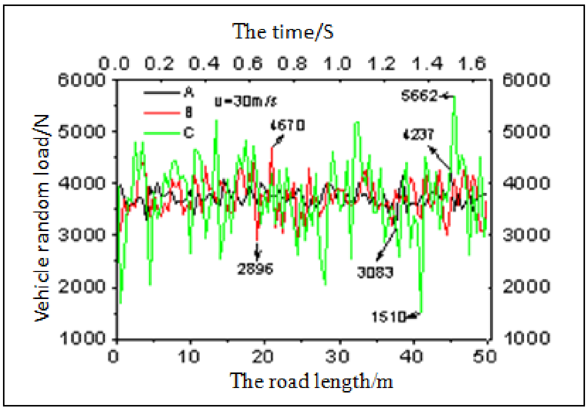


**Fig-5: The random load curve of the car**

**Table-2: Statistical characteristics of random load**

| load level | average value/N | standard deviation /N | minimum value /N | maximum value /N |
|---|---|---|---|---|
| A | 3726.26 | 175.28 | 3082.97 | 4236.76 |
| B | 3731.23 | 366.71 | 2896.31 | 4669.93 |
| C | 3739.53 | 784.03 | 1509.70 | 5662.38 |

**The influence of the driving speed**

Whern the paper is written at programming, the computer system time is used as a random number, the same parameters of vehicle random load is different at different time to simulate, and the statistical analysis will be a little deviation. The data of table 3 can undertake qualitative analysis and not quantitative analysis. Calculation results show that the maximum deviation is 1.37% (the speed of 50 m/s) at the vicinity of 3.75 kN (vehicle gravity load) of vehicle random load average.

**Table-3: Statistical characteristics of random loads on level A pavement**

| speed m/s | average value /N | standard deviation /N | minimum value /N | maximum value /N |
|---|---|---|---|---|
| 10 | 3750.83 | 104.30 | 3480.71 | 4044.14 |
| 15 | 3752.07 | 140.04 | 3390.78 | 4129.64 |
| 20 | 3751.76 | 147.84 | 3399.68 | 4074.10 |
| 25 | 3764.17 | 164.98 | 3182.23 | 4351.39 |
| 30 | 3726.26 | 175.29 | 3082.97 | 4236.76 |
| 35 | 3732.51 | 204.74 | 3158.86 | 4171.65 |
| 40 | 3745.63 | 192.57 | 3310.03 | 4184.18 |
| 45 | 3767.28 | 229.14 | 3142.38 | 4379.40 |
| 50 | 3801.47 | 223.00 | 3298.68 | 4435.64 |

## CONCLUSIONS

- Considering the road surface roughness of vehicle load, the simulation of vehicle load curve is the random curve of up and down vibration around vehicle weight load.
- With the increase of speed, the amplitude of vehicle random load curve increases, the space frequency decreases, the time frequency increases and the discreteness enhances.
- With the decrease of road level, the amplitude of vehicle random load curve increases, and the discreteness enhances.
- With the increase of speed, the standard deviation of vehicle random load has the increasing trend.

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