Research of Intensity Contrast between Different Testing Roads Based on PSD Analysis and Fatigue Damage Cumulation Theory

Wei-qiang YUE\textsuperscript{1,2} and Chuan-xue SONG\textsuperscript{1}

\textsuperscript{1}Jilin University State Key Laboratory of Automobile Simulation and Control, Changchun, China
\textsuperscript{2}Institute of Military Transportation, Tianjin, China

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\textbf{Abstract.} Use the same acceleration collector to get the loading spectrums of two typical different testing roads by the same truck, and then make a contrast analysis of the distributing character by PSD analysis. Extrapolate the two spectrums into the same testing mileage, then make the fatigue analysis of them by the LMS software base on Miner fatigue damage cumulation theory, form the result we can get the equivalent coefficient of two different testing roads. So we get a key method to have regulations and evaluations in road testing.

\textbf{Introduction}

In most new vehicle endurance test, the proving ground plays a very important role by its convenience and efficiency. Because the characteristic roads can usually examine some specifical parts of the vehicle very pertinence. But another question appears, that is we have some different proving grounds which are build since 1980s, such as the Hainan proving ground, the Dingyuan proving ground and so on\cite{1}. Because the difference of the criterions and design, the main character such as intensity, length and layout of testing roads often shows most difference, which put forward a bother to the test engineers, that is how to make a evaluation between the different roads or the different testing. So this paper aimed at solving this problem from researching on the test intensity contrast of two different roads, using several technical measure to analyze the distinct loading spectrum of different road by the same truck, and then give a equivalent test intensity base the modified Miner rule, this research provides a foundation of the road simulation test.

\textbf{A Survey of Two Testing Roads and the Loading Spectrum Acquisition}

\textbf{A Survey of Two Testing Roads}

Aimed at the examining heavy truck’s road reliability, we choose two representative testing roads as pertinence, because they are so different. One is constructed by its landform, which needn’t many manmade character roads, and its most consumers are the remodeled or special used cars. But the other has more manmade roads such as the stone road the washboard road the Belgium road and so on. Comparing with the first road, the second one are more rigour, and we can forecast entirely different testing result for the same truck from them. But the most important thing is how to scale them, so you have to keep on reading us.

\textbf{The Loading Spectrum Acquisition}

The equipment is the LMS SCM05 which uses the Text.Xpress software, we use them to acquisition acceleration transferred by 6 PCB sensors which are fixed on the end of truck’s 6 wheels’ axes. The truck is loading at its 80\% full scale, and then we drive it through all the character roads separately in the two proving grounds. And always by the same standard velocity which is 50km/h in the ecumenical road and 20km/h in the extremely hard road. Then we can get the loading spectrum of the two testing roads by the same truck, and the Fig.1 show the acceleration of left front wheel’s axle
which is analyzed by replacing burr removing singular points and wiping off the trend item.

In figure 1, the first part is loading spectrum date from testing road No.1, we call it data A, the second one is from testing road No.2, we call it data B. we can get some apparent difference of two dates. The average acceleration of Date A is about 2g, and the extremum is 5g, its total time is 200s, we can't find intense diversification in it only because there are not so many characteristic roads. On the other hand, the average acceleration of Date B is about 5g, and the extremum is 14g, its total time is 780s, we easily find there are many characteristic roads in the testing roads from the distinct boundary of the date.

**The Contrast of Two Loading Spectrum by PSD Analysis**

The vibration of truck stimulated road loading is usually regard as stochastic process, so the power spectral density (PSD) which concerns the statistical character is an important analyze method.

**The Power Spectral Density (PSD)**

We can suspect that the object of PSD is power in frequency domain, and the density indicates the distribution of it. The PSD of a stable stochastic process $X(t)$ is the Fourier transform of its self-correlation function we call it $R_s(\tau)$

$$S_s(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} R_s(\tau)e^{j\omega \tau} d\tau$$

(1)

The inverse transformation is,

$$R_s(\omega) = \int_{-\infty}^{\infty} S_s(\omega)e^{-j\omega \tau} d\omega$$

(2)

In formula (2), if $t = 0$, then,

$$\varphi_s^2 = R(0) = \int_{-\infty}^{\infty} S_s(\omega)d\omega$$

(3)

So the PSD of $S_s(\omega)$ expressed the destruction of the vibration energy.

**The PSD Analysis of Two Different Loading Spectrum Dates**

Base on the PSD theory, use the PSD analyzer of LMS TecWare to process the two different loading spectrum dates, then we can get their Z coordinate PSD, just shown as Figure.2. We can see that the high energy concentrated at the frequency of 3~15Hz, and the curve shape is the similar. But we also can see some differentia. Firstly, the total energy of the date 2 is 2~3 times of that of date 1. Secondly, the highest value of the date1 is 0.263241 at the frequency of 8.4Hz, and the highest value of the date2 is 2.19061at the frequency of 6.3Hz, which is more than 8 times higher.
So we can see that the fatigue damage of two testing roads are obviously different, not only at the damage degree but also the position.

The Equivalent Coefficient Analysis of Two Loading Spectrums

From the analyze result above, we can easily find out the distinct of two testing roads. So we want to give out a method to quantify the equivalent fatigue damage of them, which play a fatal role in the test formulating. The equivalent fatigue damage analysis is based on the damage theory, which express the damage in numerical values, then relate them in some equivalent.

The Miner Fatigue Damage Cumulation Theory

Most invalidation of the auto parts are caused by fatigue, which is the conception of the fatigue damage. Consider when the truck running, the continuous loading from the ground make damage to some of its parts. In the mechanics of materials, when a metallic part endures a stress over its yield value, there will be some damage to it which can not be recovered. With more and more damage cumulated to the critical value, the part will be broke, this is the fatigue damage cumulation theory [5-7], and the process is called fatigue life. There are many methods to research the fatigue life, generally speaking, there two types, one is nominal stress method, and the other is local stress and strain method [8].

Miner liner fatigue damage cumulation theory is a simpler and convenient method, which is more popular used in the truck and its parts, the basic theory is shown below. Consider the extreme value of the vibration energy is $W$, the total fatigue cycle is $N$, and the value of No. $n_i$ is $W_i$, so there is a proportional relation between the loading cycles and absorbed energy, that is $\frac{W_i}{W} = \frac{n_i}{N}$. If the stress sequence is $s_1$, $s_2$, $s_3$\ldots$s_n$, and the corresponding fatigue life sequences is $N_1$, $N_2$, $N_3$\ldots$N_n$, the loading cycle sequence is $n_1$, $n_2$, $n_3$\ldots$n_n$, according to the theory above, we can get the fatigue damage accumulation.

$$D = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \ldots + \frac{n_n}{N_n} = \sum_{i=1}^{n} \frac{n_i}{N_i}$$

(4)

When $D = 1$, the part is broken.

The Equivalent Coefficient Analysis

Base on the equivalent fatigue damage theory, use the analyzer of LMS TecWare to process the two different loading spectrum dates, then we can get their Z coordinate fatigue damage. Because the mileage of two testing roads is not the same, so we should extrapolate them to the same extent to
establish the equivalence. Then as shown if Figure 3, indicate the equivalent fatigue damage of two testing roads by the same test mileage.

Figure 3. The contrast analysis of two loading spectrum by equivalent fatigue damage analysis.

Table 1 shows the equivalent fatigue damage of the loading dates by two testing roads in 6 axle’s Z coordinate. From the Table 1, we can get the equivalent fatigue damage of two loading spectrum, which also shows the test intensity of two testing roads to the same truck. We can get the conclusion that the damage of testing road No.1 is 32% of testing road No.2, which means to the same truck under the same test mileage, it endures 3 times the fatigue damage.

Table 1. The 6 axles' Z coordinates equivalent fatigue damage.

<table>
<thead>
<tr>
<th>item</th>
<th>axle</th>
<th>Date1 (E-15)</th>
<th>Date2(E-15)</th>
<th>equivalent fatigue damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front left</td>
<td>0.96067</td>
<td>3.2687</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>Front right</td>
<td>1.2462</td>
<td>4.0497</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>Middle left</td>
<td>1.3499</td>
<td>4.3791</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>Middle right</td>
<td>0.75637</td>
<td>2.3299</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Rear left</td>
<td>0.72074</td>
<td>2.1518</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Rear right</td>
<td>0.87442</td>
<td>2.4340</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>Average value</td>
<td></td>
<td></td>
<td>0.32</td>
<td></td>
</tr>
</tbody>
</table>

Conclusions
This paper aimed at the test intensity of different of two testing roads, driving the same truck to get the loading spectrum dates. Use the time-domain contrasting and PSD method to analyze the difference. Then based on the Miner liner fatigue damage cumulation theory, we get the equivalent coefficient of two testing roads, which give the important precondition to formulate the testing program and evaluate the testing result, also put forward a feasible solution to this kind of problem.

References


