Research of Equivalent Testing Coefficient Between Different Roads Based on Multi-axial Rain-flow Method and Miner Theorem

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ABSTRACT

In order to have a measurement of the equivalent testing coefficient between different proving grounds, we use the same data acquisition terminal with same acceleration sensor by the same truck, to get the loading spectrums of two typical different testing roads, and then make a contrast analysis by multi-axial rain-flow counting method in time domain. Extrapolate the two spectrums into the same testing mileage by the LMS software, then make the fatigue damage analysis of them base on Miner theorem, form the result we can get the equivalent testing coefficient of two different roads. Finally we get an efficient method to have regulations and evaluations in road testing.

INTRODUCTION

The road testing in proving ground plays a very important role in most new vehicle development, because the characteristic roads can usually examine some specific parts of the vehicle very pertinence. So the road testing become much efficient and convenient. We have some proving grounds which are build science 1980s, such as the Hainan proving ground, the Nongan proving ground, the Dingyuan proving ground and so on[1~2]. Then the question appears which perplex most automotive testing engineers. Because the difference of the criterions and designing, the main characters such as layout, length and intensity of testing roads often shows most difference, and how to make a measurement between the different roads or the

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different testing is a big problem. This paper aimed at solving this trouble from researching on the equivalent coefficient of two different testing roads, using several technical measures to analyze the distinct loading spectrum of roads by the same testing truck, and then give an equivalent calculation base on the liner damage cumulation theory, this research provides a foundation of the road testing.

THE GENERAL SITUATION OF TWO TESTING ROADS AND THE DATA ACQUISITION

The General Situation of Two Testing Roads

For testing the road reliability of a heavy truck, we choose two representative testing roads in different proving ground. One is constructed by its landform, there are not many manmade character roads, and its most consumers are the remodeled or special used vehicles. 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 testing of second one is harder, 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.

The Data Acquisition of Loading Spectrum

Use the LMS SCM05 matched Text.Xpress software as data acquisition equipment, and then we can get the acceleration data 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 the selected character roads separately in two proving grounds. And the standard velocity is 50km/h in ecumenical road and 20km/h in extremity 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 in 3 coordinates, which is analyzed by replacing burrs, removing singular points and wiping off the trend items.

Figure 1. Two loading spectrums of the same truck’s left front axle in 3 coordinates.
In figure 1, the first part is loading spectrum data 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 3g, and the extremum is 10g, its total time is 150s, 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 15g, its total time is 900s, we easily find there are many characteristic roads in the testing roads from the distinct boundary of the date.

THE CONTRAST ANALYSIS OF LOADING SPECTRUM DATA BY MULTI-AXIAL RAIN-FLOW METHOD

In the durability test, the most factors of fatigue damage are contributed by the stress amplitude and the cycle number [3~4]. Base on this theory, the time-domain signal’s counting method analysis appears. The counting method is a process translates the load stress into some full cycles and half cycles, and then we can get the load cycles frequency. Normally the counting method includes one parameter counting and two parameters counting, and the rain-flow counting method is most efficient.

The Rain-Flow Counting Method

The rain-flow counting is also called tower top method, which is put forward by two English engineers Matsuiski and Endo. They consider that plastic deformation is the necessary condition to cause fatigue damage, and plastic character shows the delay regression line of stress and strain.

The full cycle is the mark of the fatigue damage, presume small delay regression line don’t affect the large degree cycle, after taking out the small cycles in order,
then we can get the stress and strain counting result under the effect of amplitude of variation load[5-6].

So we can get the principle of the rain-flow counting, a rain-flow cycle corresponding to a stress and strain delay, and any time-domain signal can be translated into a rain-flow matrix and a residue, just shown as figure 2. The method can count all the full stress and strain cycles whereas they are large and small, and it is very precise and convent. The result of the method is easily to be statistic by computer counting which is widely used in the fatigue damage research.

**The Multi-Axial Rain-Flow Counting of Two Different Loading Spectrum Dates**

If more than one directional input to a unit but we only think it by uniaxial rein-flow counting method, some loading information must be lost, and then we can’t get the real fatigue damage result, so the analysis is not good. Fortunately, the multi-axial rain-flow counting method appears which pay attention to three-dimensional input loading, combine them by some liner relation, and then project it into rein-flow matrix by all the coordinate of the space. The multi-axial rain-flow counting method can show the potential damage by any direction, and then give more objective forecast to the damage of the unit under integrated loading.

In this paper, take the turning and driving force effect to front axle into consider, the three-dimensional acceleration sensor is installed to the front axle, which can record the loading of the truck steering on two testing roads. Then we use the multi-axial rain-flow counting analyzer of LMS Tec Ware to process the two different loading spectrum dates, then we can get their three-input rain-flow matrix, which projected into the three-dimensional coordinate system, just shown as figure 3 and figure 4.

![Figure 3. The rain-flow matrix of Date A.](image1.png) ![Figure 4. The rain-flow matrix of Date B.](image2.png)

We can get some conclusions from Figure 3 and Figure 4.

Firstly, the fatigue damage magnitude of two roads to the same truck are very distinct, the value of date A is 1.7e-16, but the value of date B is 5.64e-14, the
difference is over 300 times. The reason is that the testing road No.2 is harsher and longer than the No.1.

Secondly, the fatigue damage distribution of two loading are also very distinct, the coordinates of highest and secondary highest valve in Fig.4 is [0.58,0.58,0.58] and [0.71,0.00,0.71], which means that the main fatigue damage of testing road No.1 focus on the first quartile, that is the compound direction of X, Y and Z. On the other hand, the coordinates of highest and secondary highest valve in Fig.5 is [0.33,-0.89,0.33] and [0.00,1.00,0.00], which means that the main fatigue damage of testing road No.2 focus on both ends at coordinate axis Y, that is the transverse loading.

THE EQUIVALENT TESTING COEFFICIENT ANALYSIS OF TWO DIFFERENT ROADS

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 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 [7-9], 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 [10].

The 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 $\sigma_1, \sigma_2, \sigma_3 \ldots \sigma_n$, 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 cumulation:

$$D = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \ldots + \frac{n_i}{N_i} = \sum \frac{n_i}{N_i}$$

When $D = 1$, the part is broken.
The Equivalent Testing 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 testing mileage to establish the equivalence. Then as shown if Figure.5, indicate the equivalent fatigue damage of two proving grounds by the same testing mileage.

![Diagram](image)

Figure 5. The contrast analysis of two roads 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 34% of testing road No.2, which means to the same truck under the same test mileage, it endure the 3 times fatigue damage.

<table>
<thead>
<tr>
<th>item</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>1.18067</td>
<td>3.17851</td>
<td>0.37</td>
</tr>
<tr>
<td>Front right</td>
<td>1.34626</td>
<td>4.01022</td>
<td>0.34</td>
</tr>
<tr>
<td>Middle left</td>
<td>1.39683</td>
<td>4.19662</td>
<td>0.33</td>
</tr>
<tr>
<td>Middle right</td>
<td>0.75637</td>
<td>2.37680</td>
<td>0.32</td>
</tr>
<tr>
<td>Rear left</td>
<td>0.76074</td>
<td>2.19471</td>
<td>0.35</td>
</tr>
<tr>
<td>Rear right</td>
<td>0.82659</td>
<td>2.46543</td>
<td>0.34</td>
</tr>
<tr>
<td>Average value</td>
<td></td>
<td></td>
<td>0.34</td>
</tr>
</tbody>
</table>
CONCLUSIONS

In this paper, we study the equivalent testing coefficient of two different roads, use the same truck, the same equipment and same rule to get the loading spectrum dates. Then comprehensively apply the time-domain contrasting and multi-axial rain-flow counting to indicate the difference. Based on the liner fatigue damage cumulation theory, we get the equivalent coefficient of two testing roads. The research method give an important precondition to formulate the road testing program and evaluate the testing result, also put forward a feasible solution to this kind of problem.

REFERENCES