The Road Spectrum of Combine Harvester Based on Virtual Iteration

Dong Ming Ming¹, Lin Shu Feng¹, Wang Meng Yao¹, Hu Yao Guang², a

¹Beijing Institute of Technology, Institute of Noise and Vibration Control, Beijing, China
²Beijing Institute of Technology, Institute of Industrial and Intelligent Systems Engineering, Beijing, China

a hyg@bit.edu.cn

Abstract—The combine harvester has a complex work environment, and the reliability of the rack is critical to the functionality of the machine. In order to shorten the test time, reduce the cost of research and development, and make the road spectrum can be reproduced on the test-bed, this paper takes the combine harvester as the research object, the acceleration spectrum was measured on asphalt road, hard road in field and wheat field, and the multi-body dynamic equation was established according to the actual parameters of the vehicle. The transfer function between the tire displacement signal and the target signal is established, and the tire displacement spectrum is calculated. The road spectrum is taken as the input load of the four-column test-bed, and the actual load condition is reproduced on the test-bed, which provides the input condition for the fatigue analysis of the combine harvester rack in the later stage, and greatly enhances the efficiency of durability design.

1. Introduction

In recent years, more and more attention has been paid to the durability testing of the key parts of the combine harvester. The traditional fatigue strength test is carried out on the actual road. The advantage of this method is that the data obtained is accurate and direct, but it takes a long time and requires a lot of manpower and material resources. It is not suitable for the research and development process which needs frequent test. With the development and maturity of CAE technology, the study of fatigue durability by virtual simulation technology has been widely used [1]. Indoor road simulation test is a kind of road simulation test with four-column test-bed, which can show the same working condition as road test. The combination of CAE and indoor road simulation test will get the most accurate result at the lowest cost. In laboratory road simulation experiments, the working load is reduced by the output displacement of the combine harvester. Therefore, the accuracy and efficiency of the experimental results depend on the displacement spectrum of the four-column test-bed. In road simulation experiments, the working load is reduced by the output displacement of the test-bed. Therefore, the accuracy and efficiency of the experimental results depend on the displacement spectrum.

At present, one method is to obtain the road condition of the harvester by laser scanning [2], and transform it into displacement spectrum input to four-column test-bed. The advantage of this method is that the combine harvester pavement environment can be accurately reproduced, thus accurately reproducing the load under the combine harvester standard operating conditions. However, this method
has low efficiency in durability test, cannot quickly reproduce the fatigue failure, and it is expensive and costly to collect the displacement spectrum of pavement.

The other method is to collect the load spectrum by the accelerometer in the road test. Through the virtual iteration technique, the load and the response obtained by the road test are used to calculate the vertical displacement excitation at the rack, as the road roughness data input into the four-column test-bed [3]. This method can also reproduce the working load of the combine harvester, accelerate the fatigue failure process by improving the displacement spectrum, shorten the test and improve the efficiency greatly.

In this study, the acceleration of the wheel center is collected by the accelerometer and INV3060 data acquisition instrument. The multi-body dynamic model is established in Adams/Car, and simulate the vertical displacement of the wheel center in Famfat.lab by virtual iteration, then obtain the load at the connection point of the rack.

2. Collection and processing of load spectrum in working environment

2.1 Collection of load spectrum
In order to obtain the acceleration response signal of vehicle body under the impact of uneven road surface, the channel distribution is shown in Table 1. Ensure that the test vehicle condition meets the requirements of GB/T12534-1990 "general rules of road test methods for motor vehicles", the accelerometer is installed at various parts of the rack and magnetic adsorption is applied to the accelerometer. Fig. 1 is a schematic diagram of the installation of the wheel sensor.

![Fig.1 Installation of Wheel Sensor](image)

| Channel number | Channel definition | location |
|----------------|-------------------|----------|
| 1              | Left Front Acceleration | Left Front rack near the wheel |
| 2              | Right Front Acceleration | Right Front rack near the wheel |
| 3              | Left Rear Acceleration | Left Rear rack near the wheel |
| 4              | Right Rear Acceleration | Right Rear rack near the wheel |
Have the combine harvester test on asphalt, gravel, and hard roads in field for 120 seconds and extract the load spectrum. Fig. 2 is the acceleration load spectrum of the rack under three kinds of road surface.

2.2 processing of load spectrum
The signals collected from the test site will inevitably have some burrs, drift and noise interference, so it is necessary to preprocess and edit the collected load spectrum before the indoor test, can be used as the iterative target signal of indoor road simulation test.

In the process of load spectrum acquisition test, the main software used is the DASP V10 data acquisition and analysis software which comes with INV3060V data acquisition instrument, the INV3060V data acquisition instrument can be controlled for data acquisition.

Processing of the load spectrum includes inspection, correction of drift signal, stationarity test and normality test, and low pass filtering. Comparing the results of editing method based on damage time with the editing method which considers both damage and PSD (power spectral density), and the accelerated editing method which considers both damage and spectral density, as close as possible to the actual parts failure while retaining the damage. At the same time, the load spectrum is modified according to the capacity of the test-bed. The corrected load spectrum is shown in figure 3.

3. Collection and processing of load spectrum in working environment
The accuracy of displacement spectrum obtained by virtual iteration depends on the precision of multi-body dynamic model, so it is very important to establish the corresponding multi-body dynamic model based on the sample vehicle of load spectrum. Therefore, in order to establish the relevant parameters for the model input needs to be measured and the multi-body dynamics model is adjusted appropriately [4], table 2 is the combine harvester parameters. The parts and components parameters selected in this model are all parameters produced by the combine harvester

| No. | Parameters | value    |
|-----|------------|----------|
| 1   | Mass       | 5400kg   |
The overall structure of the simulation model is shown in figure 5 and consists of 4 wheels, rack, cab and body working parts.

![Multi-body dynamic model](image)

The combine harvester in this study used a rigid suspension with a front engine, front wheel drive and rear wheel steering. The rack will bend and twist when traveling on the working road, so the it is treated with flexibility, and the modal synthesis method and the finite element software are used to calculate the modal information to soften the rack \(^5\), thus, the multibody dynamics model shown in Fig.4 is established.

4. Virtual iteration

4.1 Virtual iteration theory

The fatigue simulation technology based on virtual iteration is to build a multi-body dynamic model by using the signals (such as strain signals and acceleration signals) which are collected by vehicles on the actual road, and to calculate the transfer function and inverse function of the system by using virtual iteration, the force signal, moment signal and displacement signal at the target position are obtained, which are used as load spectrum input to carry out fatigue simulation \(^6\). The virtual iteration process is shown in fig.5 below and consists of three main processes.

![Virtual Iteration Process](image)
(a) Signal Collection: The acceleration of the rack is the target signal of the iteration, and the vertical displacement of the wheel center is the external impact signal of the iteration;

(b) System Identification: This step is to obtain the transfer function of the vehicle dynamics model, input the white noise signal U into the vehicle dynamics model, get the corresponding output signal Y, transfer function \( F(x) = Y/U \);

(c) Virtual iteration: Using inverse function and target signal obtain the displacement signal at the tire contact point, and obtain the simulation result under the displacement signal, and compared with the target signal, the error correction and iteration are carried out until the simulation result and the target signal reach the state of convergence.

4.2 Method of Virtual iteration

In this study, a multi-body dynamic model of combine harvester was developed. The load signal is taken as the target signal, and the vertical displacement of the wheel center is taken as the input signal to be iterated until the error between iterated signal and target signal is satisfied and the iterative process is stopped.

The setup of the multi-body dynamic model channel needs to be determined by the external impact received by the vehicle, and use the AKISPL function in driving mode. In this paper the impact channel of the model is the vertical (Z axis) displacement of four wheels, the response channel is located in the corresponding position of the multi-body dynamics model according to the installation position of the accelerometer. The exact location of the output channel for iteration model is shown in Table 3.

| Number | Name     | Location               |
|--------|----------|------------------------|
| 1      | LF_Z     | Left Front Wheel Z axis|
| 2      | LR_Z     | Left Rear Wheel Z axis |
| 3      | RF_Z     | Right Front Wheel Z axis|
| 4      | RR_Z     | Right Rear Wheel Z axis|

The input and output channels set in Famfat.lab virtual iteration module should be the same as the multi-body dynamics model, and the input and output values should be limited, the input value should be greater than the maximum value of the measured data, and the output value should not exceed 400mm stroke of the four-column test-bed. The model channel settings are shown in table 4 and Table 5.

| Number | Name  | Range +/- (9.8m/s²) |
|--------|-------|---------------------|
| 1      | @LF_Z | 10                  |
| 2      | @LR_Z | 10                  |
| 3      | @RF_Z | 10                  |
| 4      | @RR_Z | 10                  |

| Number | Name    | Range +/- (mm) |
|--------|---------|----------------|
| 1      | Disp_LF_Z | 200            |
| 2      | Disp_LR_Z | 200            |
| 3      | Disp_RF_Z | 200            |
The detection signal is used to test the accuracy of the solution of the road spectrum. The selected detection signal in this experiment is shown in Table 6.

| Number | Name    | Location               |
|--------|---------|------------------------|
| 1      | LF_Z    | Left Front Wheel Z axis|
| 2      | LR_Z    | Left Rear Wheel Z axis |
| 3      | RF_Z    | Right Front Wheel Z axis|
| 4      | RR_Z    | Right Rear Wheel Z axis|

Using the noise generator function in Famfat.lab generate a white noise signal, as the impact signal input to the established multi-body dynamics model. The transfer function of the system is calculated by using transfer function. Taking the signals in Table 4 as iteration signals and the multi-body dynamics model as the carrier, the virtual iteration is carried out under the iteration function module of Famfat.lab. After 11 iterations, the signal starts to diverge, then stop the iteration.

4.3 Reliability Verification of the road spectrum.

After the virtual iteration, extract the acceleration signal of the monitoring channel. In order to verify the reliability of the road spectrum obtained by virtual iteration, the time-domain and frequency-domain characteristics are used.

Taking the acceleration spectrum extracted from the front wheel as an example. The acceleration curve of the detected signal and the measured acceleration curve are as follows, and the similarity can be seen. The signal time domain data comparison results are shown in Fig.6 and Fig.7.

![Fig.6 The Time Domain of the Collected Signal of Left Front](image)

![Fig.7 The Time Domain of the Iterated Signal of Left Front](image)

After comparing the two signal characteristics, we can see the result which is as shown in Table 7.

| Signal  | Maximum | Minimum | Average | Effective |
|---------|---------|---------|---------|-----------|
| Collected | 7.471   | -9.252  | 0.3410  | 2.601     |
| Iterated | 9.108   | -6.614  | 0.0458  | 2.354     |

The time domain signal is processed with the Fourier transform, and the frequency domain curve is obtained, and the iterative signal is compared with the measured signal, as shown in Fig.8 and Fig.9.
After comparing the two signal characteristics, we can see the result which is as shown in Table 8.

Table 8 frequency domain signal comparison

| Signal   | Frequency hz/peak m/s² | Frequency hz/peak m/s² | Frequency hz/peak m/s² |
|----------|------------------------|------------------------|------------------------|
| Collected| 2.5/0.743              | 22.5/1.090             | 44/0.875               |
| Iterated | 2/0.853                | 22/1.153               | 44/1.109               |

Through the analysis of the iterated signal and the collected signal in the time and frequency domain, it can be seen that although there is a certain error between them, it is within the acceptable range, the validity of the results is verified.

5. Conclusion

In this paper, the virtual iteration technique is used to obtain the road spectrum. Adams/Car is used to establish the multi-body dynamic model of the combine harvester, and Famfat.lab is used to calculate the road spectrum. The reliability of road spectrum is verified in time domain and frequency domain. The combination of CAE technology and indoor road simulation test can shorten the endurance test cycle and obtain the most accurate result at the lowest cost, which has a certain guiding effect on the research and development of combine harvester.

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