# Rain Flow Extrapolation of Diesel Crankshaft Load Spectrum Based on Kernel Density Estimation

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**Abstract:** The load spectrum compression only removes the small damage load of the crankshaft in the load spectrum of each section of the test field. In order to further form the bench test load spectrum suitable for the laboratory, it is necessary to compress and extrude the load spectrum after compression. Based on the method of kernel density estimation, the rain flow matrix extrapolation of crankshaft torsional and bending load is realized.

## 1. Introduction

The load spectrum of the crankshaft of the vehicle engine reflects the dynamic variation of the crankshaft load during the running of the vehicle[1,2]. It is the basis for the reliability test, lightweight design and damage life of the crankshaft. At present, the crankshaft of the armored vehicle engine lacks the load spectrum closer to the actual working condition of the vehicle in terms of design, test, setting and evaluation as the load basis[3].

In this paper, the extrapolation process in the engine crankshaft load spectrum is studied in depth. The extrapolation process is an important step in the preparation of the load spectrum. The loading spectrum suitable for the bench test can be obtained for a certain test mileage requirement. The principle is also derived from the estimation of existing measured load samples, ie how the crankshaft load will change in the future. In this paper, based on the method of kernel density estimation, the distribution of the rainflow counting matrix parameters of the crankshaft torque load is fitted to realize the load extrapolation for the bench test.

## 2. Real Vehicle Test

In order to grasp the load change of the armored vehicle engine during the actual running of the vehicle, the most primitive load data obtained under the interaction of various road excitations, driver operations and work task profiles are obtained. Taking the six-cylinder turbocharged diesel engine mounted on a certain type of armored vehicle as the research object, the load parameter test system was designed to collect and record the load-time history of the engine-related parameters in the actual running of the vehicle.

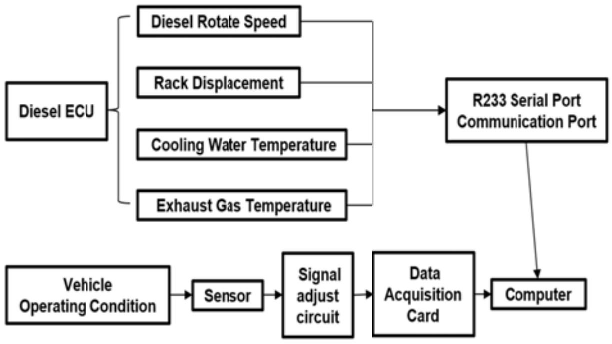


Fig. 1. The test system hardware composition

Fig. 2. The test site

Engine load parameter testing typically involves signal conditioning, real-time acquisition, and data storage of engine load parameters by a dedicated test system. Through the storage and processing of the load information, the actual vehicle load parameters can be collected, providing valuable load information for the design, management and maintenance departments, and providing a basis for engine health assessment, engine condition monitoring and early failure characteristics. Provides load basis for engine component damage, dynamic life management and fault diagnosis. The test system hardware composition and test site are shown in Figure 1 and Figure 2.

The calibration data of the maximum gear displacement of the engine, the external characteristic curve of the engine, and the measured data of the measured rotational speed and the rack displacement are combined to convert the torque load of the crankshaft. Further, the gear displacement data is used to convert the load rate of each sample point, and the load-time history of the equivalent torque of the crankshaft during actual operation is transformed. The load time history of crankshaft torque is shown in Figure 3.

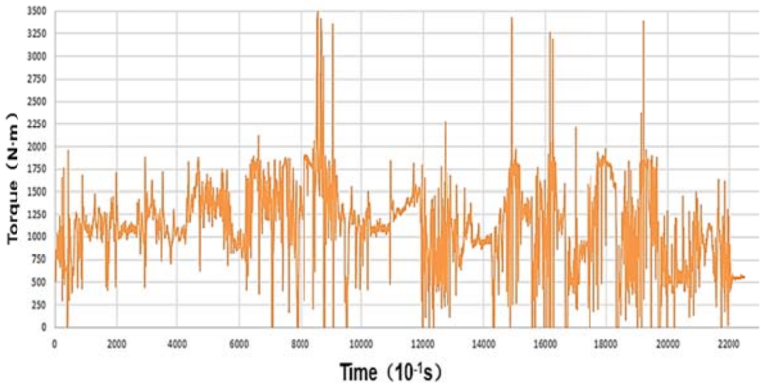


Fig. 3. The load time history of crankshaft torque

## 3. Rain flow Statistics

The rain flow cycle counting method, because its processing method of the load cycle counting process can well match the action law of the fatigue damage hysteresis loop of mechanical parts, can realize the description of dynamic variable amplitude load cycle of the crankshaft and other components[4,5]. The rain flow counting method is used to cycle the bending and torsion loads of the crankshaft, and the rain flow cycle counting matrix of the load spectrum is obtained, thereby realizing the transformation from the load-time time history to the rain flow counting matrix. Since the two main influencing factors of the damage of the crankshaft are the amplitude and frequency of the bending and torsional loads, combining the rainflow cycle counting matrix with the cumulative damage mechanism can further obtain the fatigue damage of each rainflow cycle. As shown in Figure 3, the rain flow matrix of the torque load can clearly observe the number of cycles in which the load amplitude changes from one magnitude to another.

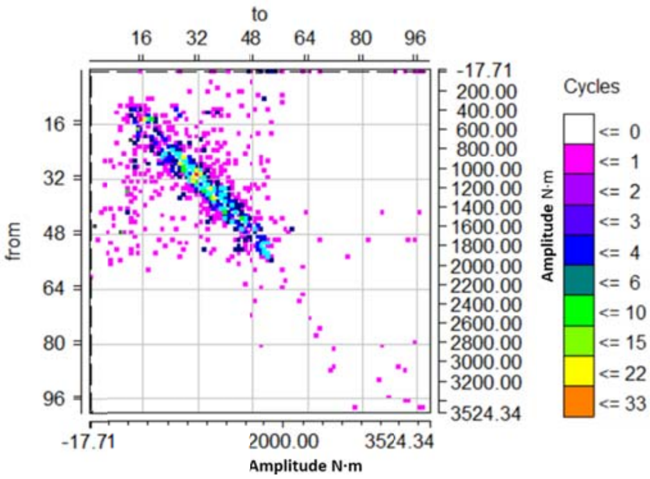


Fig. 4. The rainflow cycle count results of crankshaft torque

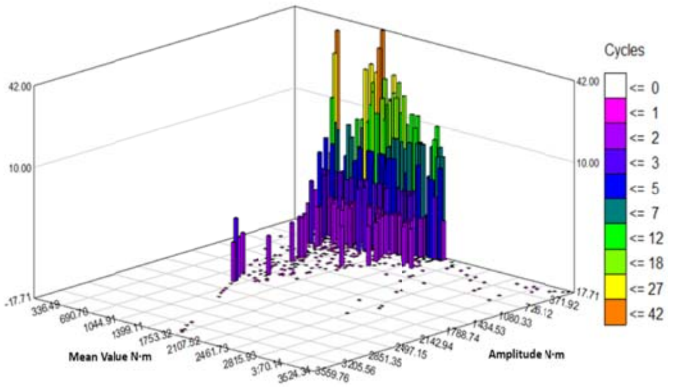


Fig. 5. The rainflow cycle count results of crankshaft torque

## 4. Load Spectrum Extrapolation

### 4.1 Kernel Density Estimation

The mean amplitude values of the rain flow cycle counting matrix belong to the two-dimensional probability distribution, and the probability distribution law is fitted by the kernel density estimation method. Given a data set, you need to observe the distribution of its samples, usually using a histogram method for visual display. This method is simple and easy to calculate, but when plotting the histogram, you need to determine the bins. If the bins are different, the final histogram will make a big difference, as shown in Figure 6. The right side is more divided than the left histogram, resulting in a big difference in the final result, the double peak on the left and the single peak on the right.

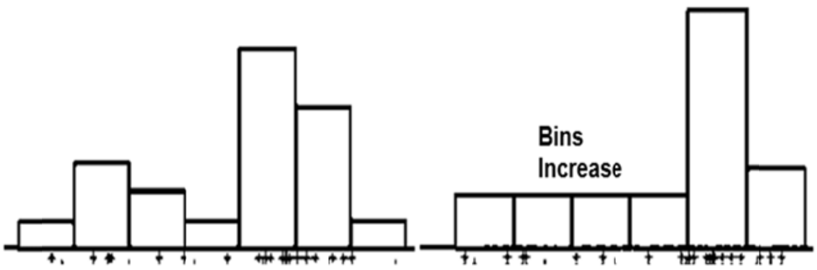


Fig. 6. Histogram distribution of different bins

In addition, there is a problem with the histogram. The histogram shows that the distribution curve is not smooth, that is, the samples in a bin have equal probability density. Obviously, this is often not suitable. The solution to this problem is to increase the number of bins. When bins is increased to the maximum value of the sample, it will have a probability of owning each point of the sample, but at the same time it will bring other problems, and the sample does not appear. The probability of the value is 0 and the probability density function is discontinuous. If we continue these non-continuous intervals, then this can largely meet the requirements. One of the ideas is the probability density of a point in the sample. If the information of the neighborhood can be used, then the final probability. Density will greatly improve the problem of discontinuity, as shown in Figure 7.

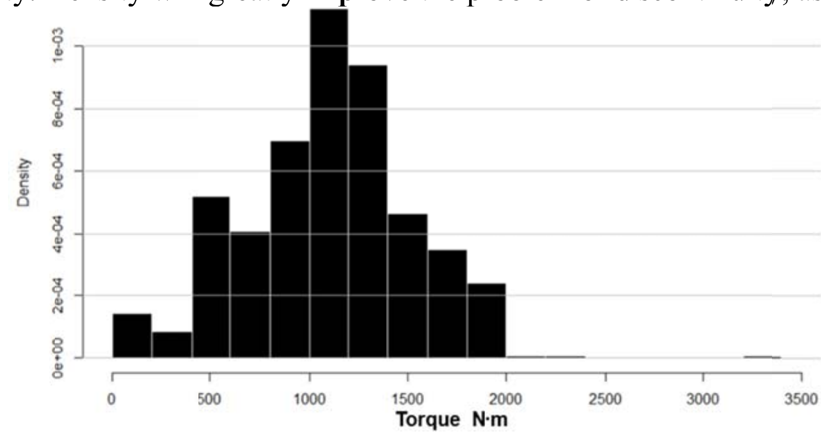


Fig. 7. Histogram of torque distribution

In order to get the density function value at a certain point x, if the neighborhood of x is[x-$h$,x+$h$], when $h$→0, we can regard the density function value of the neighborhood as the density of the x point. The function value, as shown in equation (1):

$$\hat{f}(x) = \frac{1}{2h}\lim_{h\to 0}\frac{N_{xi\in[x-h,x+h]}}{N_{total}}$$

Where $N_{xi\in[x-h,x+h]}$ is the number of sample points in the neighborhood, $N_{total}$ is the total number of sample sets, and finally the density values in the neighborhood are averaged to obtain the density function value of the x points. Rewrite equation (1):

$$\hat{f}(x) = \frac{1}{2hN_{total}}\sum_{i=x-h}^{x+h} x_i = \frac{1}{hN_{total}}\sum_i \frac{|x-x_i|}{2h} < 1, h \to 0$$

If field h is too large, it does not meet the requirement that h tends to 0; If h is chosen too small, the point used to estimate $f(x)$ is actually very small. This is the balance of deviation and variance in the non-parametric estimate. There is also a problem that the probability density function is still not smooth enough (because there are innumerable numbers between the two numbers). Since the integral required to satisfy the probability density is 1, so:

$$\int \hat{f}(x) = \frac{1}{hN_{total}}\sum_i \int K(\frac{|x-x_i|}{h})\, dx = \frac{1}{N_{total}}\sum_i \int K(t)dt = \int K(t)dt$$

As long as the integral of K(t) is equal to 1, the integral of $\hat{f}(x)$is satisfied. If K(t) is treated as another known probability density function, then the final density function is continuous.

### 4.2 Extrapolation based on kernel density estimation

The rain flow matrix extrapolation of the crankshaft load can further predict the cycle that does not occur in the load time history[6]. After the rainflow matrix is extrapolated, both the load amplitude and the load cycle frequency will increase in the crankshaft load spectrum. The extrapolation based on the rainflow matrix is equivalent to further enhancement, and the amplitude and frequency of the load are further increased to meet the needs of the bench test loading, which also reflects the crankshaft under complicated and variable conditions to some extent. The characteristics of the load spectrum. The amplitude cumulative frequency curve of the measured load time history is obtained by the rain flow counting method, and the rain flow matrix frequency extrapolation based on the kernel density estimation is performed. Taking the 6-time extrapolation factor as an extrapolation target, the torque load and the equivalent bending moment load of the crankshaft are extrapolated. The rain flow matrix, the rain flow average amplitude matrix and the cumulative frequency curve after extrapolation of the torque load extrapolated from the rain flow matrix frequency are shown in Figure 8 - Figure 9.

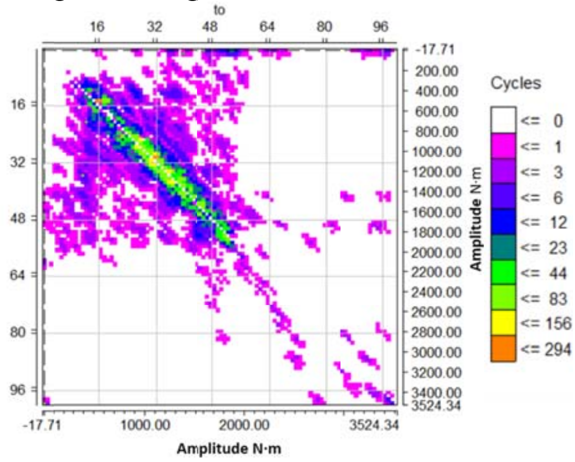


Fig. 8. The rainflow cycle count results of crankshaft torque after extrapolation

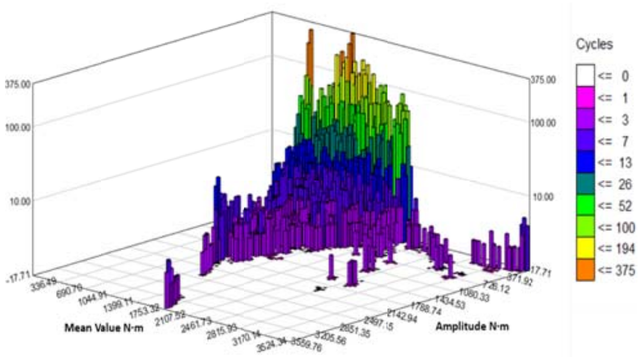


Fig. 9. The rainflow cycle count results of crankshaft torque after extrapolation

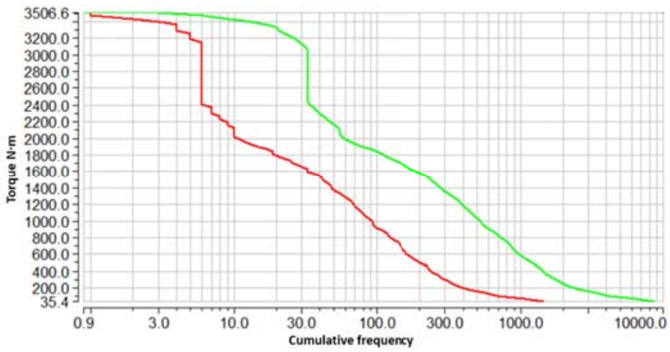


Fig. 10. Cumulative frequency distribution before and after torque load extrapolation

## 5. Conclusions

In this paper, the crankshaft of a certain type of armored vehicle engine is taken as the research object. The load time history of the crankshaft torque is obtained through the real vehicle test. The rain flow cycle count is used to count the load time history of the crankshaft, and the rain flow counting matrix of the crankshaft is obtained. The method based on kernel density estimation implements the extrapolation of the rainflow matrix. The results show that this method can further expand the loading range of the load spectrum, so as to better meet the needs of the bench fatigue test.

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