Research on Load Collection Technology of Loader Working Device

S M Zhu¹,²  Z W Yuan¹,²  L Sun¹,²

¹ Jiangsu Xuzhou Construction Machinery Research Institute, Xuzhou, 221004, China
² State Key Laboratory of Intelligent Manufacturing of Advanced Construction Machinery, Xuzhou Construction Machinery Group, Xuzhou, 221004, China

*380778350@qq.com

Abstract. A convenient and feasible load collection technology for 5 ton loader working device is proposed in this paper. Based on the force characteristics of the working device and mechanics theory, the theoretical calculation model of external load is established. Firstly, the static load test shows that the relative error of the load value between the theoretical calculation and the actual apply is less than 5%. Then, the loader is subjected to the dynamic load test under a typical clay material. The external load values are obtained based on the theoretical calculation model and Adams dynamic simulation. The results show that the external load values between calculation and the simulation are basically the same. This proves that the load collection system is credible, which can provide the basic data for the structural design and the bench test and the fatigue analysis of the loader working device.

1. Introduction

The loader working device is mainly used for cargo loading and freight transportation. Due to the complex and harsh work conditions, the structural strength design is very significant[1,2]. The traditional design of loader working device, which has no effective external load data, is mainly based on the designer's experience and the previous data. As a result, the strength of the working device may be superfluous, and the excess amount is likely too large, and the material is probably wasted[3, 4].

The strength and fatigue life of the loader working device are an important indicator of reliability, and the load spectrum is the premise and basis for studying the static strength and fatigue reliability[5]. Studying a practical and systematic load collection technology is the key to solve the development problems of Chinese loader industry. The external load of working device is not easy to be measured during practical work. The new technology is convenient and accurate to measure the external load and realize the real-time dynamic acquisition of the load during the work process, so that the structure and fatigue strength of the working device can be comprehensively evaluated[6].

In this paper, the 5 ton loader is used as the object. According to the load collection scheme, the corresponding sensors are arranged on the loader. The static and dynamic load tests are implemented in the testing ground to collect relevant data of displacement and pressure and load. A theoretical calculation model of the external load of the bucket is established by the in-depth analysis of the load characteristics of the loader and theory mechanics, and the accuracy of the model is verified by static and dynamic load tests. According to the theoretical theory model of the external load, the dynamic external load can be obtained at any time, which can solve the problem that the external load is difficult to measure during the practical work of the loader working device.
2. Load Collection Technology Program

2.1. Loader working device structure and external load collection system
As shown in Figure 1, the loader working device needs to be modified to facilitate the installation of various sensors. The pin-type force sensors replace the pin, and the pressure sensors and the displacement sensors are welded on the wall of the boom cylinder and the rocker cylinder. The system mainly includes a load measurement module and a position measurement module. The load measurement module composed of a pin-type force sensor at the hinge point of the bucket is used for measuring the load. The position measurement module composed of a boom cylinder displacement sensor and a rocker cylinder displacement sensor and a related displacement sensor mounting device reflects the position. The new working device is mainly composed of the bucket 1, the lateral force sensor 3, the boom 4, the boom hydraulic cylinder 5, the pull rod 6, the rocker arm 7, the rocker cylinder 8, the pressure sensor 9, the displacement sensor 10, the frame 11 and so on.

2.2. Pin-type force sensor
The work principle of the pin-type force sensor is that it can measure the shear strain when the sensor is subjected to the external load. According to the load-bearing characteristics of the hinge point and the installation position of the sensor, the sensor structure shown in Figure 2 is designed.

![Figure 2. Schematic diagram of the pin-type force sensor.](image-url)
is $U_x$, $U_x$ is defined as the output voltage of the pin in the x direction under the external load. Similarly, the output voltage $U_y$ in the y direction of the B-B (location 3 and location 4) section is defined as the output voltage of the pin in the y direction under the external load.

![Figure 3. Wheatstone full bridge measurement circuit composed of strain gauge.](image)

When the load acts on the x or y axis, the circuit outputs a unidirectional voltage $U_x$ or $U_y$, and the linear relationship between load and voltage which can be obtained by calibration experiments is

$$ F_x = aU_x + b $$  \hspace{1cm} (1)  

$$ F_y = cU_y + d $$  \hspace{1cm} (2)  

Where $a$, $b$, $c$, $d$ is the experimental calibration coefficient.

When the load direction has an angle with the x or y axis, the output voltage ($U_x$ or $U_y$) and the load $F$ are nonlinear. A function $f(U_x, U_y)$ can be established, $f_{val}(U_x, U_y)$ and $f_{deg}(U_x, U_y)$ are used to characterize the function of the load value and the load direction.

$$ f_{val}(U_x, U_y) = (1 + k_1\frac{U_y}{U_x})\sqrt{U_x^2 + U_y^2} $$  \hspace{1cm} (3)  

$$ f_{deg}(U_x, U_y) = \arctan\left(\frac{U_y}{U_x}\right) - k_2\frac{U_y}{U_x} $$  \hspace{1cm} (4)  

Where $k_1$ is the resultant force coefficient and $k_2$ is the angle coefficient.

3. Theoretical Calculation Model of External Load

As shown in Figure 4, the external load acting on the bucket regarded as the analysis target is simplified to the 6th-order tensor on the tip of the bucket. The load at the bucket hinge is measured by three pin sensors, and the lateral force is measured by the left and right lateral force sensors. According to the static force balance and torque balance, the relationship between the measured load and the external load of the working device can be obtained. The relationship is as follows

$$ F_{4L} = (\varepsilon_L \times K_L + b_1) $$  \hspace{1cm} (5)  

$$ F_{4R} = (\varepsilon_R \times K_R + b_2) $$  \hspace{1cm} (6)  

$$ F_x = F_{4L} - F_{4R} $$  \hspace{1cm} (7)  

$$ F_y = F_{y1} + F_{y2} + F_{y3} $$  \hspace{1cm} (8)  

$$ F_z = F_{z1} + F_{z2} + F_{z3} - G $$  \hspace{1cm} (9)  

$$ M_x = F_{z1} \times y_1 + F_{z2} \times y_2 + F_{z3} \times y_3 + F_{y1} \times z_1 + F_{y2} \times z_2 + F_{y3} \times z_3 $$  \hspace{1cm} (10)  

$$ M_y = (F_{z2} - F_{z3}) \times x_2 $$  \hspace{1cm} (11)
\[ M_z = (F_{y3} - F_{y2}) \times x_2 \]  

(12)

Where \( G \) is the bucket gravity, \( \varepsilon_L \) and \( \varepsilon_R \) are the test values of the leftward force sensor, \( K_L \) and \( b_1 \) are the leftward force sensor calibration coefficients, \( K_R \) and \( b_2 \) are the rightward force sensor calibration coefficients. \( L \) is the distance from the gravity centre of bucket to the action point. \((x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3)\) are respectively the coordinates of the hinge point of the pin on the bucket.

4. Verification of Theoretical Calculation Model of External Load

4.1. Static load test

The static load hoisting test of loader is carried out in a testing ground as shown in figure 5.

The specific test steps are as follows:
1) Rotate the no-load bucket to the position 1 (0° angle with the horizontal line). Raise the arm slowly until the lower hinge point of the boom is 400mm away from the ground, and keep the posture unchanged, and record data of each sensor.
2) Lift the weight in the middle of the bucket to the same posture in step (1), and record data of each sensor.
3) Change the bucket to position 2 (30° angle with the horizontal line) and position 3 (limit bucket position, 46.5° angle with the horizontal line), and repeat step (1) and step (2) respectively.
4) Weigh the weight.

The test results are calculated and processed as shown in Table 1. The relative error between the calculated load value and the measured load value is within 5%, and the angular deviation is within 4° under different postures and different external loads. The calculated load value nearly agrees with the measured load value, which shows that the accuracy of the collection system is better.
Table 1. Comparison table of static load test results.

| Position | Measured load (kN) | Calculated load (kN) | Relative error (%) | Angle deviation (°) |
|----------|--------------------|----------------------|--------------------|---------------------|
| Position 1 | 49.68 | 50.62 | 1.89 | 3.15 |
|          | 100.43 | 101.5 | 1.06 | 1.18 |
|          | 149.77 | 153.08 | 2.21 | 1.77 |
|          | 49.68 | 50.89 | 2.43 | 2.58 |
| Position 2 | 100.43 | 102.09 | 1.65 | 3.02 |
|          | 149.77 | 153.93 | 2.78 | 2.06 |
|          | 49.68 | 51.82 | 4.31 | 2.11 |
| Position 3 | 100.43 | 102.99 | 2.55 | 1.49 |
|          | 149.77 | 154.53 | 3.18 | 2.66 |

4.2. Dynamic Load Test

Dynamic load test of the loader under the work conditions of typical clay material is carried out in a national standard testing ground as shown in Figure 6.

The geometry model of the working device established by 3D software Creo is imported into the Adams software, in which the materials and properties and constraints of each component are defined. The finite element model has a total of 8 revolute joints, 1 ball joint, 2 translational joints and 1 fixed joint. The 2 translational joints are set as motions. The initial motion values are from the actual measurement values Disp_1 and Disp_2 for Adams. The hinge test load is defined as the load boundary. And take 1000s dynamic simulation. As shown in Figure 7.

The dynamic test load data of pin sensors is imported into Matlab software to calculate the external load, which will be compared with the external load of Adams dynamic simulation. The whole cycle is divided into five phases, test preparation phase 1, shovel phase 2, heavy-load transport phase 3, unload phase 4 and light load transport phase 5, as shown in Figure 8.
Figure 8. Comparison of calculation and simulation load values for dynamic load tests.

Since the bucket is placed on the level ground and not affected by the external load, the load values of theoretical calculation and Adams dynamic simulation during the phase 1 are almost equal and close to zero. During the phase 2, the load rises sharply, but the two curves are almost identical. During the phase 3, the load tends to fluctuate in a small range due to the unevenness of the test ground and the inertia acceleration. During the phase 4, the load values of the two curves may be slightly deviated and the maximum relative error is 10.3% due to impact load and rigid-body simulation. During phase 5, the load fluctuation is very small and the two curves are nearly consistent. From the whole cycle, the calculation load value nearly agrees with the simulation load value, and the test data can meet the engineering application.

5. Conclusion
1) A high-precision pin-type force sensor is designed to ensure the accuracy of the data by the collection system. The theoretical calculation model of the external load combined with theory mechanics has great theoretical and universal suitability.
2) The static load test shows the relative error between the calculated load value and the measured load value is within 5%, and the angular deviation is within 4°, which satisfy engineering application requirements.
3) The dynamic load test shows the calculation value of the theoretical model is highly in agreement with the simulation except some special conditions such as impact load or rigid-body simulation.
4) According to the static and dynamic load test, it is verified that the load collection system is reliable and the load value of theoretical calculation model is credible.

References
[1] Zhang X H. Optimization of ZL-50 Loader Working Device Based on ADAMS [J]. Mining &Processing Equipment, 2011, 39(6): 44-48
[2] Meng G L. Determination of the external load in the calculation of the strength of the wheel loader working device [J]. Construction Machinery, 1999, 30(12): 64-66
[3] Qiu X H, Guo K Q, Wu Z Z, et al. Mechanic Design[M]. Bei Jing: Higher Education Press, 1997: 15-18
[4] Li H Z, Wang Y G. Chai S, et al. Finite Element Analysis of Loader Working Device Structure [J]. Agricultural Equipment &Vehicle Engineering, 2007, (9): 13-16
[5] Ning X B, Meng S, Yao H, et al. Dynamic Simulation Analysis of the Loader Working Device Strength [J]. Construction Machinery and Equipment, 2008, 39(5): 16-19
[6] Zhu Y M, Wang M Q, Liu Y L. Structural Strength Analysis and Fatigue Life Estimation of Crankshaft System[J]. Journal of Mechanical Strength, 2010, 32(6): 1018-1021