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Design and Application of Dynamic Impact Test System for Auto Body Structures

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Abstract. This paper presents a specialized test system used for the dynamic impact of auto body structures. The detailed structure of the host machine, the anti-secondary impact system, and the human-computer interaction interface for data acquisition and processing are designed and integrated with the control system to form a complete dynamic impact test system. The typical single-hat thin-walled beam structure is token as an example, and the functional test of the system is carried out. The results show that the test system has comprehensive functions, high test accuracy and convenient operation, and can meet the requirements of auto body structures dynamic impact test.

1. Introduction

Automotive crash safety and lightweight are the research hotspots in the automotive industry. During the structural design process of auto body, dynamic impact tests on structures and materials are required to obtain the important mechanical properties such as impact force, energy absorption, deformation mode, etc [1].

Based on the drop-hammer principle, the main structures, control system and human-computer interaction interface of the dynamic impact test system are designed. The test system is used to conduct the impact performance test of a thin-walled beam. With the test system the energy absorption and failure mode of the auto body structures under high speed impact load, and the impact performance parameters of structures and materials can be obtained. The advantages of the dynamic test system are high test accuracy, safe operation, integrated data acquisition and analysis, etc. It can not only be used to automotive crash and lightweight design, but also be applied in the fields of auto body manufacturing, mechanics, material forming and so on.

2. Test system working principle

The working principle of the dynamic impact test system for auto body structures is through the use of gravity and the energy storage device to perform initial acceleration on the drop-hammer in order to apply the impact load on the auto body structure. The drop-hammer can obtain the impact speed in a small height range [2, 3].

The energy conversion involved in the test system mainly includes two stages. The first stage is the process in which the hammer begins to fall until it contacts the test piece. In this stage, the gravitational potential energy of the hammer and the spring potential energy stored by the compressed springs are converted into the kinetic energy of hammer, and a small part of the friction and thermal energy loss can be ignored. The second stage is that the hammer begins to impact the test piece until the hammer is stationary (the end of the test). The kinetic energy of the hammer is approximately equal to the energy absorbed by the plastic deformation of the test piece.

Energy conversion in the first stage:

$$E_1 = \frac{1}{2}kx^2 + mgh \tag{1}$$

$$E_2 = \frac{1}{2}mv^2 \tag{2}$$

$$E_1 = E_2 \tag{3}$$

Where E_1 is the total energy of hammer gravitational potential energy and spring potential energy, E_2 is the kinetic energy of hammer. k is the stiffness of the spring, x is the compressed length of the spring, m is the mass of the hammer, h is the height of the hammer, g is the gravity acceleration, v is the impact velocity of the hammer which can be calculated as:

$$v = \sqrt{\frac{k}{m}x^2 + 2gh} \tag{4}$$

Energy conversion in the second stage:

$$E_2 = E_3 \tag{5}$$

$$E_3 = F_m \Delta d \tag{6}$$

Where E_3 is the energy absorbed by the test piece, F_m is the average impact force of the test piece, and Δd is the deformation of the test piece in the impact direction.

3. Test system structural design

The dynamic impact test system for the auto body structures is consisted of the host machine, the anti-secondary impact system, the control system, and the data acquisition and processing system.

3.1. Host machine

The host machine of the dynamic impact test system uses a four-column frame structure, which is a double-space structure. The upper space is the hammer lifting space, the lower space is the test piece installation space. The main structures of the host machine include a hammer, a hammer head, a sensor, a beam, two energy storage springs, two guide rods and so on, as shown in Figure 1.

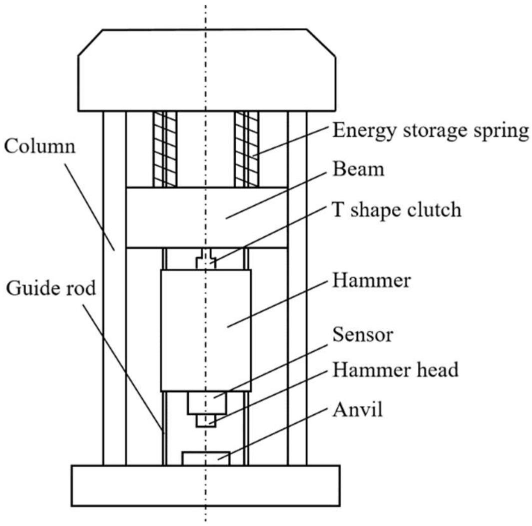

Figure 1. Main structures of the host machine.

The host machine uses the motor driven method. The hammer rising and falling movements are pulled by the beam which has position limitation mechanism. The hammer release is controlled by an air cylinder release mechanism. The automatic interlocking mechanism of the hammer lifting and releasing can prevent the hammer from dropping when the power is off, which can ensure the safety of the test. In addition, in order to prevent personal injury caused by material splash during the impact process, the protective panels are installed around the host machine, and the hammer can be released only by the control program when the protective panels are in the locked state.

Due to the limitation of height, the energy storage methods used in the test system include the gravitational potential energy of the hammer and the spring potential energy of the springs. When the springs are not used, the hammer can be lifted by a height of 1.5 m, and the impact energy is 2000J (the hammer mass is 136kg). When a larger impact energy is required, a certain spring potential energy is stored by compressing the springs. The test system contains two energy storage springs, each has a maximum compressible length of 0.5m and a maximum storage energy of 1834J. By using formula (1), the maximum impact energy of the entire test system can be calculated, which is 7000J, and the maximum impact velocity is 10.15 m/s.

3.2. Anti-secondary impact system

The anti-secondary impact system is mainly composed of a lifting air cylinder and a buffer, as shown in Figure 2. After the impact hammer performs an impact test, the control system gives a command, then the lifting air cylinder lifts up to achieve the purpose of lifting the hammer. The buffer can effectively absorb the residual energy after impact.

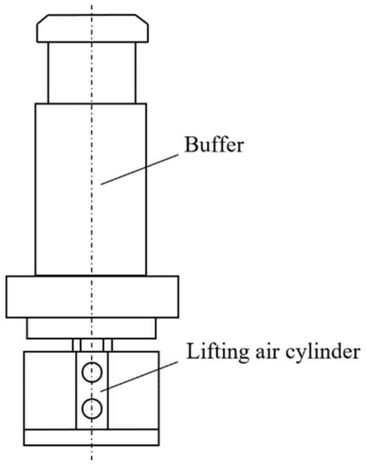

Figure 2. Anti-secondary impact system.

3.3. Control system

The control system of the dynamic impact test system is realized by the PLC (Programmable Logic Controller) [4]. The PLC is connected to the computer and all operations are incorporated into the computer. The control cabinet is placed next to the host machine. The functions of the operation buttons on the console include power on and off, beam lifting, beam falling, and impact. An emergency stop button is set, and the host machine can be stopped quickly if any problems occur during the test.

3.4. Data acquisition and processing system

The dynamic impact test is a transient process. The data acquisition of the test system adopts the US imported SOC (System on Chip), combined with FPGA (Field Programmable Gate Array) technology, the high speed acquisition, high speed operation and real time display can be realized. The sampling frequency of the system is 1MHz, which can completely reproduce the whole process of impact and draw the curves of impact energy and force.

A human-computer interaction interface is designed for the convenience of operation. The operating software includes four main areas: parameter setting area, input area, command area, and results display area.

3.4.1. Parameter setting area. In this area, parameters such as test unit, test name, and participants can be input.

3.4.2. Input area. The test serial number, hammer mass, sensor type can be selected in this area. When the impact energy is input, the software can automatically calculate the height at which the hammer should be lifted.

3.4.3. Command area. This area includes the functions such as beam lifting, beam falling, pre-set height, and impact.

3.4.4. Results display area. Display the data of the height of the test piece, the impact energy, and the force-time, force-displacement curves collected during the test.

In addition, the software also has the functions such as file creation, saving, data export, test reports generation and so on.

4. Dynamic impact test of thin-walled beam structure

4.1. Preparation before test

The auto body structures are mostly thin-walled beam structures, such as bumper beams and front longitudinal rails. These thin-walled beam structures play a major role in energy absorption and force transmission when the automobile crashes [5,6]. A typical single-hat thin-walled beam is token as an example, the dynamic impact test system for auto body structures designed in this paper is used to test the performance of the beam such as energy absorption, deformation and force-deformation curve.

The material of the test piece is Q235 and the yield strength σ_s = 235 MPa. The axial length L = 400 mm, the thickness t = 0.8 mm, and the cross section is shown in Figure 3, where a = b = 60 mm, and f = 25 mm.

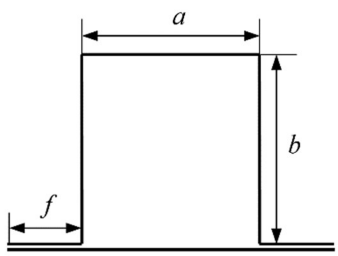

Figure 3. Cross section of the test piece.

4.2. Test procedure

4.2.1. Test piece installation. Place the test piece on the anvil vertically and ensure that the deviation between the impact point and the lateral centre of the test piece is less than 1mm.

4.2.2. Hammer positioning. Enter the test energy 2000J in the operating software, click “Pre-set height”, “Hammer positioning” and “Beam lifting” buttons successively to complete the calculation of the impact height, determination of the impact point and lifting the hammer to the required impact height.

4.2.3. Test piece impact. Click “Impact” button to release the hammer and complete the impact on the test piece. The deformation of the test piece recorded by the high speed camera is shown in Figure4.

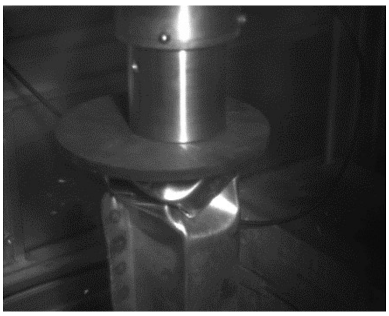

Figure 4. Deformation of the test piece.

When the impact is over, click “Hammer grabbing” and “Beam lifting” to rise the hammer to a certain height, and then take out the test piece.

4.3. Test data analysis

The deformation comparison of the test piece before and after the impact test is shown in Figure 5.

(a) Before test

(b) After test

Figure 5. Deformation comparison before and after test.

The real time data measured by the sensor is transmitted to the operating software and exported to Excel to draw the force-deformation curve of the single-hat thin-walled beam, as shown in Figure 5. After measurement and calculation, the deformation of the test piece is 96mm, the energy absorption is 1986J, and the average crush force is 20.6kN.

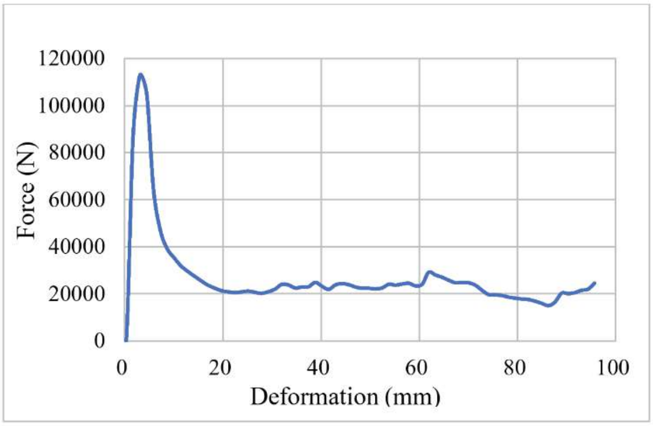

Figure 6. Deformation-force curve of the test piece.

5. Conclusion

A dynamic impact test system specially used for auto body structures crashworthiness and lightweight is designed. The design of the host machine, anti-secondary impact system, control system and data acquisition and processing system are detailed introduced respectively. The impact test of a single-hat thin-walled beam is carried out by using the dynamic impact test system, and the impact performance parameters are obtained. The results show that the test system can realize high speed impact on the auto body structures and record test data accurately, which can meet the test requirements of the auto body structures.

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