The Design and Development of the Automatic Trigger Device for the High-Speed Photography

Shengchao Hou*
Institution of Physical and Chemical Engineering, Tianjin 300180, China

*Email: 18335160072@163.com

Abstract. At present, there is a problem, which is inconvenient for people to record structure failure data, in some experimental process of special equipment. Focusing on the trigger method of high speed photography recording in the component strength experiment of special equipment, and choosing the feature of vibration in the situation that the strength of specimen is failure, we design two schemes, which are integration vibration switch basing on velocity and voltage comparator vibration switch basing on acceleration, according the design ideas that include analysis, design, specification and verification. Through the verification of the experiment, the method of voltage comparator vibration switch basing on acceleration is feasible, and the successful rate of auto-trigger can reach 100 percent in the situation of usual strength failure. The device has fine trigger stability and accuracy, can effectively solve the problem that manipulation has low rate of successful operation and reliability.

1. Introduction

High speed photography device is used in many occasions, because its high shooting speed is convenient for recording the key phenomenon of instantaneous high speed, and successful trigger is the first step of successful recording [1].

The purpose of special equipment test is to use the test plan to evaluate the test piece, and through the test record of the key data before and after the test. To judge whether it is feasible and to improve the optimization. The strength test of special equipment components needs to record the real-time image of the specimen running for a certain period of time. Recording the image of the failure process can be more intuitive and clearer to analyse the failure characteristics, and the failure process is usually rapid. Therefore, high-speed photography is used to capture the image of the failure process of the specimen in the test. At present, in the strength test of special equipment components, the operation of triggering high-speed photography records is manually completed by the operator, which has the problems of high labour intensity, low success rate and reliability. In order to ensure the smooth progress of the test, it is urgent to develop an automatic trigger device that can be applied to high-speed photographic records.

Most of the existing automatic trigger methods are software signal processing, that is, CPU programming is used to process the acquisition signal. However, the effective signal at the failure moment is a short impulse pulse, which has high requirements for the acquisition ability of A / D, the input port performance of CPU and the processing time, and the signal output is in the form of voltage change rather than on-off signal [2 – 4]. At present, the high-speed camera model in the laboratory is PhantomV2010, and the external trigger signal needs to be the on-off edge signal lasting at least 3 Ms [5]. Therefore, it is necessary to develop an automatic trigger device that can be applied to current high-speed photography records.
2. Demand analysis

2.1. Introduction of test system
The strength test system of special equipment components includes test bench and auxiliary system, high speed photography test system, acceleration test module and LMS online acquisition and storage system, as shown in Figure 1. The test bench and auxiliary system provide the test environment for the test piece. The high-speed photography test system is used to obtain the instantaneous image of the failure of the test piece. The acceleration sensor is used to test the vibration of the component strength test bench. The LMS system obtains the rotational speed of the component by obtaining the main frequency of the acceleration test signal.

![Figure 1. The composition of the testing system](image)

The failure speed of special equipment components can reach up to 1900 rad/s – 2000 rad/s, so the components in the failure process will have rapid and dramatic changes. LMS acquisition system can record the acceleration signal of the hourly magnitude length, and trigger the acquisition signal in advance without human monitoring; the high-speed photography device needs at least 20,000 fps sampling rate to collect 10 images a week for the movement of components at 2000 s-1 speed, which is limited to the existing hardware conditions in the laboratory and can only be recorded for 3 s. In the current test, the instantaneous deformation process of the failure of the high-speed photography acquisition component is triggered manually.

In order to analyse the characteristics of human-triggered high-speed photography records, 10 experiments with records and close test time were selected. The success rate of human-triggered high-speed photography was 70 %. The delay time of human-triggered operation that successfully triggered seven times was shown in Fig. 2. It can be seen that the trigger time was between 480 ms and 2930 ms. Based on the analysis of the shortest acquisition time of high-speed photography for 3 s, the stability was poor.

![Figure 2. Statistics of the trigger delay time of manual operation](image)
2.2. Automatic Triggering Principle of High-Speed Photography Device

The specific type of high-speed photography used is PhantomV2010, shooting speed can reach 22500fps. As shown in Fig. 3, this camera has the controllable function of trigger point (i.e., the trigger point is arbitrarily adjustable within the time period of storage record), and supports the software/hardware trigger mode (manually controlling the host computer trigger/external trigger). The controllable function of trigger point can record the image before the trigger time point. The external trigger mode is the basis for automatic trigger, and the trigger requires at least 3 microseconds of rise or fall edge signal [5].

![Figure 3. The stored record of the high-speed photography](image)

2.3. Summary of needs analysis

1) The designed trigger device should be compatible with the current test system; in order to realize the automatic trigger of high-speed photography, the designed device has high success rate of trigger, and the trigger delay time is smaller than the recording time of high-speed photography in the component strength test, which has good stability.

2) The output signal of the designed trigger device shall be a on-off switching signal lasting at least 3 microseconds.

3. Ideas and Scheme Design

3.1. Summary of needs analysis

The overall design idea is shown in Fig. 4. Firstly, the failure process of special equipment components is analysed, and the physical quantities with obvious characteristics and easy to test at the failure moment are selected. According to the selection of physical quantities, the overall scheme is designed, and the key technical indexes are designed combined with the results of demand analysis. The detailed design is carried out according to the overall scheme and technical indexes. Finally, the designed scheme is verified by experiments.

![Figure 4. The total design ideas](image)

3.2. Failure process analysis and physical quantity selection

With the instantaneous failure of special equipment components, first of all, the fragments of the components collide with the inner wall of the sleeve, resulting in severe vibration of the whole test bench, and accompanied by a large sound. Secondly, the inner sleeve of the test bench will have angular displacement relative to the outer sleeve. Finally, the powder produced by the failure of the components will cause the vacuum of the test system to deteriorate sharply.

The vibration change of the test bench is easy to obtain the preliminary test data, and the change is obvious. The measured vibration can be expressed by three parameters: displacement, velocity and
acceleration. These three parameters represent the characteristics of different types of vibration and have
different sensitivities to different types of vibration. Mechanical vibration signals can be divided into
low frequency (1000Hz) by frequency. The vibration displacement should be used in the vibration
measurement of low frequency band, the vibration velocity should be used in the vibration measurement
of middle frequency band, and the vibration acceleration should be used in the vibration measurement
of high frequency band [6]. The failure process of rotor components is a rapid change process, so the
vibration acceleration is a test quantity that can be considered.

3.3. conceptual design
According to the physical quantities selected in the previous section, the scheme is designed: the existing
acceleration test module is used, and the vibration change is converted to the switch output with the
comparator, relay and peripheral auxiliary circuit; the working principle is shown in Figure 5. The
acceleration sensor collects the vibration acceleration signal and outputs the electrical signal. By
comparing the voltage comparison circuit with the threshold value, the closed-off of the high- and low-
level control relay is output. The reset circuit is used to reset the output state of the relay. The power
switch and protection circuit are used to control the power supply and provide overvoltage and
overcurrent protection.

![Figure 5. Working principle of the scheme](image)

Note: Hollow solid wire arrow is the direction of test signal processing, hollow dotted wire arrow is
the direction of relay reset signal, and linear arrow is the direction of power supply.

3.4. Key technical indicators and implementation ideas
1) The designed device can trigger automatically, and the trigger delay time is less than 3s.
Ideas: through the selection of key components and peripheral circuit design, automatic trigger and as
short as possible trigger delay time.

2) The trigger success rate of the designed device should be 100 %, and the stability of the trigger
delay time is better than that of the artificial trigger mode.

Ideas: The characteristics of vibration signals at the moment of component failure are obtained by
analysing the previous test data, and the necessary conditions for threshold selection are determined.
The threshold is determined by combining the designed device.

4. Concrete design

4.1. Vibration data analysis of preliminary test
The typical acceleration signal waveform of the failure process of the special equipment components is
shown in Fig. 6. The time period for obvious acceleration change caused by specimen failure is about 1
s. The peak value of acceleration voltage output can reach ± 10V (20g), and the amplitude is inversely
proportional to the time when the signal waveform maintains the amplitude. The maximum disturbance observed during multiple rotor component strength tests was 0.9 V (1.8 g), and the minimum peak value of failure signal impulse was 1.7 V (3.4 g).

Figure 6. Acceleration signal waveform of special equipment component failure

Therefore, the necessary conditions for selecting thresholds are as follows:

1. The threshold should be higher than the disturbance value and lower than the peak acceleration of the failure process;
2. It is necessary to ensure that the duration of the signal waveform amplitude at the threshold is greater than or equal to the duration of the external excitation required by the trigger device.

It can be seen that the effective information of the test signal waveform for the design of the device is only the time when the amplitude of the waveform continues to exceed the threshold. Therefore, the test signal data are referred to below, and the effective information is only listed.

The text of your paper should be formatted as follows:

4.2. Concrete design

4.2.1 Acceleration test module. Basically, each test specimen strength and mechanical structure are different, namely the failure mode of special equipment components and failure vibration characteristics are different. Therefore, the amplitude or effective time of the vibration acceleration signal change caused by the failure of the specimen is only a fuzzy range. This paper does not pay attention to the failure mode and reason of the specimen. Therefore, the acceleration sensor used does not have a clear requirement for the sensitivity of the vibration amount. The accuracy only needs to be able to distinguish the two states of the smooth operation and noise (i.e., transient instability or abrasion) of the component from the failure state of the component. The dynamic characteristics need to meet the dynamic test requirements of the specimen speed. The current acceleration sensor is used to test the rotational speed of the specimen for a long time, and the early test waveform can clearly distinguish the failure signal, so this sensor fully meets the above requirements.

The acceleration test module includes an acceleration sensor and a rear adjustable gain constant current source, and the specific type parameters are shown in Table 1 [7].

| Sensor Model | sensitivity | operating frequency | Range  | weight | Constant current source model |
|--------------|-------------|---------------------|--------|--------|------------------------------|
| 4507-B-006   | 500mV/g     | 0.2-6000Hz          | ±14g   | 4.8g   | 1704-A-002                   |

Note: g in the range is gravity acceleration, g in the weight is mass unit.

4.2.2 Voltage comparison circuit. The comparator has the function of comparing two analogy signals and outputting a binary digital signal according to the comparison results. The performance parameters of the comparator are mainly divided into two categories, static characteristics and dynamic characteristics. Static characteristics mainly refer to comparator gain, input common mode range, etc. The dynamic characteristic mainly refers to the transmission delay time of the comparator, in which the
gain is the most important characteristic of the comparator. It defines the minimum amount of input voltage that can change the output of the comparator [8].

Definition of comparator gain: \( A_V = \frac{V_{OH} - V_{OL}}{V_{IH} - V_{IL}} \)

where, \( V_{OH} \) and \( V_{OL} \) are the maximum output voltage and minimum output voltage of the comparator, and \( V_{IH} \) and \( V_{IL} \) are the upper and lower limits of the differential input voltage at both ends of the comparator. The required \( V_{OH} \) and \( V_{OL} \) of this device are 24 V and 0 V, and \( V_{IH} \) and \( V_{IL} \) are 0.9 V and 0 V, respectively. Substituted into Equation (1), the gain is about 27.

The core device of the voltage comparator circuit is LM393 chip, LM393 is a more commonly used voltage comparator chip, using differential amplifier stage plus output stage structure [9], the output limit current is 16 mA. As a CMOS process chip, the barefoot must be grounded [10]. The upper limit of gain is 200, much larger than 27. The maximum response time of LM393 comparator is 1.3 \( \mu \)s, much less than 3s.

As shown in Figure 7, the input signal is input from the input side. After diode D2 half-wave rectification, compared with the upper potential of the adjustable resistance R9, the threshold potential can be set in the range of 0-9.6V, covering the 0-7V range of the accelerometer. When the former is greater than the latter, the output side outputs a high level of 24V. When the former is less than the latter, the output side output low level 0V. Among them, R6 and R7 are pull-up resistors, shunt reduces heat, R8 and R9 realize threshold potential adjustable, R10 is pull-down resistor.

4.2.3 Relay. There are two purposes of using self-locking relay instead of ordinary relay. One is to reduce the number of relay switches, prolong the service life and increase reliability. Second, in order to reduce the interference of relay coil frequent power outage. As shown in Fig. 8, the type of self-locking relay used here is G6AU-274P-ST-US 24VDC of OMRON Company. A DPDT relay, whose contact closure and release time are about 2.5 Ms, is larger than the 3 \( \mu \) s required for the trigger of high-speed camera device. By changing the polarity of 1 and 16 pins, the 4 and 6 pins are controlled to turn on and off the self-locking state output, and the left and right contact states are synchronized. Therefore, the LED D4 is used to indicate the turn on and off between the output pins. The state of DPDT can be reset by changing the state of key S1 [11].
4.2.4 Reset-circuit. The reset circuit consists of two parts. In Figure 8, the power polarity of the S1 control relay is changed. In Figure 9, the S2 auxiliary circuit realizes effective reset and input switching.

The control principle of the reset circuit for the relay is shown in Figure 10. The S2 reset signal is effective only when the relay output is disconnected, the S1 is pressed and the relay output is closed, and the S1 is bounced. The reset is divided into two parts, which can flexibly define the initial state and effectively reset.
4.2.5 Power Switch and Protection Circuit. The power switch and protection circuit are shown in Fig. 11, which has the function of switching power supply and protection of the whole circuit. 1A fuse RT1 can block high current in time; and in order to avoid high voltage signal interference, using voltage regulator diode D5, C1, C2 as power filter capacitor. Using the switching function of the transistor Q1, after S3 is connected, the base electrode and the emitter of Q1 are connected, so that the emitter and the collector are connected, and + 24 V can be effectively output. R3, R1 and R5 all play the role of voltage dividing and current limiting, and D3 is used to indicate the power supply [12].

![Figure 11. Power switch and protection circuit](image)

4.3. Threshold potential setting

4.3.1. Device circuit debugging. The acceleration test module is connected with the device circuit to excite the sensor and observe the waveform of the relay coil control signal. As shown in Fig. 12, the input signal is higher than the threshold, and the coil control signal is effective. After many debugging confirmations, the effective condition of the coil control signal is that the excitation signal measured by the acceleration sensor continues to exceed the threshold for at least 2 Ms.

![Figure 12. Acquisition signal waveform under simulated excitation](image)

Note: Yellow signal is output signal of acceleration test module, green signal is control signal of relay coil.

4.3.2. Acceleration data analysis. The threshold value of 1.6 V is taken to analyse the vibration acceleration waveform in the early failure process. Table 2 shows the statistics of multiple component strength test data. It can be obtained that whether positive or negative, the acceleration amplitude is 1.6 V and the time length above is more than 10 Ms, which is much larger than the 2 Ms required by the device circuit. Therefore, it is feasible to take the positive threshold value of 1.6 V for the designed device circuit.

| Part Number | Acceleration signal output 1.6 V and above time length 1 | Acceleration signal output 1.6 V and above time length 2 | Acceleration signal output 1.6 V and above time length 3 | Acceleration signal output 1.6 V and above time length 4 |
|-------------|--------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------|
| 1           | 196ms                                                  | 132ms                                                  | 233ms                                                  | 391ms                                                  |
| 2           | 124ms                                                  | 285ms                                                  |                                                         |                                                         |
| 3           | 98ms                                                   | 17ms                                                   | 95ms                                                   |                                                         |
| 4           | 116ms                                                  | 111ms                                                  |                                                         |                                                         |
| 5           | 125ms                                                  | 370ms                                                  |                                                         |                                                         |
5. experimental verification

5.1. test scheme
Before the test, the circuit of automatic trigger device is connected with its front and rear ends, and the test is carried out according to the general process of failure test of special equipment components. The entire test system is shown in Fig. 13. The signal collected by LMS is the same signal source as the signal transmitted to the circuit of the automatic trigger device. LMS can be used to verify whether there is a vibration signal that meets the trigger conditions of the trigger device.

![Diagram of test system](image)

Figure 13. Diagram of test system

5.2. test result
Three strength tests of common strength components were carried out, and all of them were successfully triggered. It can be considered that the trigger success rate of conventional failure of special equipment components is 100%. Then, three strength tests of high-strength components were carried out. There was no mis-trigger after two successful standbys for five hours and one successful standby for eight hours. It can be considered that the reliability of the trigger device is very high.

5.3. Supplementary simulation test
Due to the short completion time of the vibration switch and the small number of test samples, the simulation test is supplemented to fully verify its reliability. A total of seven simulation tests were carried out, all of which were successfully triggered. As shown in Fig. 13, the trigger delay time of the vibration switch was distributed between 8 MS and 20 Ms, and the difference was small. The stability of the trigger delay time between the designed device and the manual operation is compared with the coefficient of variation reflecting the degree of data dispersion in statistics. As shown in table 3, the stability of the trigger delay time is better than that of the manual trigger mode.

![Statistics of trigger time of vibration switch](image)

Figure 14. Statistics of trigger time of vibration switch
### Table 3. Statistic and analysis of trigger delay time Data

| Mode of triggering | Human trigger | Device trigger |
|--------------------|---------------|----------------|
| Coefficient of variation | 0.879 | 0.240 |

Note: The statistical data are from Figure 2 and Figure 14.

### 6. Conclusion

Aiming at the problems of manual operation success rate and low reliability in the failure process record trigger of various special equipment strength tests, the automatic trigger device is designed to solve the problem based on the strength test of special equipment components. The specific work and conclusions are as follows:

1) An electronic automatic trigger device based on impact acceleration was developed. The voltage comparison circuit is designed and the trigger device is made based on the characteristic signal of the impact acceleration of the component failure. It is proved that the device has high reliability and good stability, and the trigger delay is less than 20 Ms.

2) The device is successfully applied to high-speed photography trigger acquisition when components fail, and the electronic automatic trigger is realized, with a success rate of 100 %.

### References

[1] Zhang Sanxi, Yao Min, Sun Weiping. *High-speed camera and its application technology* [M]. National Défense Industry Press, 2006: III.

[2] Design of micro intelligent vibration switch sensor based on ATtiny13 [ J ]. Instrument technology and sensor, 2009(08): 83–85.

[3] Zou Wenli. Electronic vibration switch: CN202916000U[P]. 2013.

[4] Qi Jinyu. Electronic vibration switch: CN2877143Y[P]. 2007.

[5] AMETEK Material Analysis Division, Camera Hardware Help[EB/OL]. (2012-8-16)[2021-4-30]. https://www.phantom cameras.cn/products/cameras/ultrahigh speed

[6] Qin Min, Liu Zhiguo, Liu Gang, etc. Monitoring and analysis of high frequency vibration signal based on acceleration sensor[J]. Measurement and control technology, 2013, 32(5): 1-4.

[7] Brüel & Kjær, Accelerometers & conditioning catalogue -Bf0212-2009 [EB/OL]. (2009-1)[2021-4-30]. www.bksv.com

[8] Zhang He. IC chip design of white LED driver circuit[D]. Liaoning: Dalian University of Technology, 2006.

[9] Bin Yuanjie. Design of current limiting comparator in switching power supply[D]. Sichuan: Southwest Jiaotong University, 2008.

[10] Quan x.LM393 dual voltage comparator integrated circuit pin diagram and function _ working principle and application circuit [EB/OL]. (2019-3-15)[2021-04-28].https://www.cnblogs.com/ Xuxiangquan/p/10537098.html.

[11] Omron, PCB Relay G6A [EB/OL]. [ 2021-4-30]. https://docs.rs-online.com/6b27/0900766b812 ce015.pdf

[12] Zhuoqing. Power switch circuit [ EB / OL ]. (2019-3-15)[2021-04-28]. https://www.cnblogs.com/Xuxiangquan/p/10537098.html.