The Application of Highly Accelerated Life Test in Servo System Reliability Study

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Abstract: The servo system is one of the key components of industrial robots. How to quickly shorten the development cycle of the servo system and improve its reliability is an urgent problem to be solved in the development of industrial robots. Highly accelerated life test (HALT) techniques can play an important role in servo system reliability study. Based on the characteristics of servo system, a method for HALT of servo system is proposed and the implementation process of HALT of servo system is described. Furthermore, a typical servo system is selected to carry out HALT to find out its weaknesses and stress limit. The case shows that HALT can quickly and efficiently expose the weaknesses of the servo system, which has certain reference value for improving the reliability of the servo system.

1. Introduction

With the development of science and technology, servo system continues to adopt new technologies and new processes, and its functions are becoming more and more powerful, its structures are becoming more and more complex, and its reliability is getting higher and higher. Due to the long test period, high cost and incomplete exposure of product defects and weaknesses in traditional environmental tests, it is necessary to study a test technique that can quickly and efficiently stimulate the design and process defects and the weaknesses of the servo system. Therefore, the highly accelerated life test (HALT) comes into being. The HALT quickly acquires product defects and exposes weaknesses of the product and obtains and improves the working limit stresses and damage limit stresses of the product. by applying environmental stresses higher than the product specifications. At the same time, through the failure analysis of the failed parts appearing during the test, improvement measures are taken to achieve the purpose of early detection of defects and correction of defects [1, 2].

Since the introduction of the HALT, it has been widely used in various industrial sectors, especially in the fields of electronics, electromechanical and mechanical products, and has achieved remarkable results. Many foreign institutions are engaged in the research of HALT, such as Qual Mark, Dales Engineering Solutions, Hobbs Engineering, IBM, Boring, SONY and other companies [3]. An important service provided by Garwood Laboratories in the United States is the HALT of the product. It regards HALT as an important technical means to comprehensively improve the quality of the user's products and eradicate the recall rate of the product [4]. Dales Engineering Solutions Company helps its industrial equipment companies improve their product quality and processing capabilities through HALT technology, resulting in a 35% increase in sales [5].

Compared with foreign countries, the research and application of domestic HALT technology are still in its infancy and have broad development prospects. Jiang Tongmin [6,7] conducted a lot of research on the quantitative evaluation method of HALT. Wen Xisen [8] carried out research work on HALT method of module-level electronic products. Although the domestic HALT technology

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has developed rapidly, there is still a lack of systematic theory and guidance methods, and data accumulation is scarce in practical applications. In the field of servo systems, there is little literature on HALT. Therefore, the HALT method of servo system based on the characteristics of servo system is proposed in this paper.

2. Characteristics of the Servo System Structure

The servo system consists of three parts: controller, servo driver and servo motor. Its structural characteristics are shown as follows.

1) Different components of the servo system are subjected to different environment stresses

Due to the special working principle and structure of the servo system, different components have different usage environments. In addition to being subjected to environmental stresses such as temperature, vibration and humidity, servo motors are also subjected to various working stresses such as load force, rotational speed, pressure and stroke, and the magnitude of the working stress they are subjected to is usually large. The controller and servo driver are mainly subjected to environmental stress such as temperature, vibration and humidity, and are hardly subjected to working stress.

2) Servo system failure modes are diverse and complex

The failure mode of the servo system is closely related to the material, the specific structural shape, the environmental stress and the load characteristics, and there is also a strong coupling between various failure modes. During the operation of the servo motor, various components are subjected to different stresses, and the failure modes may be damage, misalignment, looseness, and combinations thereof. The same component may have multiple failure modes, and the same failure mode may occur in different parts, which greatly increases the difficulty and complexity of failure mode analysis. In comparison, the failure modes of the controller and the servo driver are relatively simple, mainly including open circuit, short circuit, breakdown, device damage and poor contact. The various failure modes are relatively independent and the coupling is not strong.

3. HALT Mathod of Servo System

3.1 General Idea of HALT

According to the characteristics of the servo system structure, in order to more fully stimulate the defects and weaknesses of the servo system, the HALT program is designed for the electronic part and the mechanical part of the servo system respectively, and the test is carried out accordingly. Then, the electronic part and the mechanical part are assembled together to carry out HALT. The general idea is shown as follows.

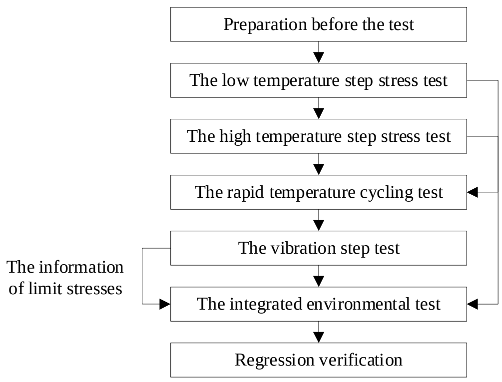
1) The HALT of controller and the HALT servo driver are conducted separately. By applying extremely harsh environmental stresses to controller and servo driver, their design and process deficiencies and weaknesses are fully exposed.

2) The HALT of servo motor if conducted. By applying extremely harsh environmental stresses and working stress to servo motor, its design and process deficiencies and weaknesses are fully exposed.

3) According to the above tests, the HALT conditions of servo system are determined and its HALT is carried out, and the design and process defects and weaknesses of the interaction between the electronic parts and the mechanical parts are fully exposed.

3.2 The HALT Procedure for Controller and Servo driver

The HALT procedure for controller and servo driver is shown in Fig.1.



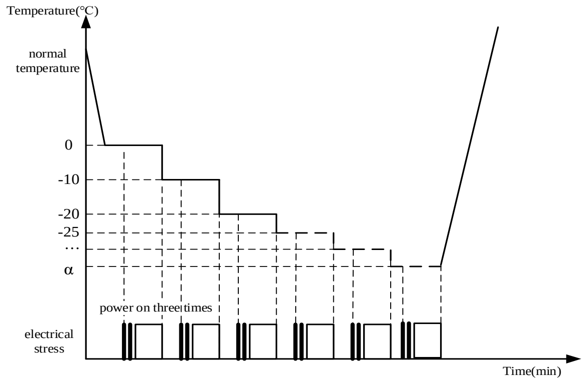


Figure 1.The HALT procedure for controller and servo driver

Figure 2. The test profile of the low temperature step stress test

It includes a low temperature step stress test, a high temperature step stress test, a rapid temperature cycling test, a vibration step test and an integrated environmental test.

Before the HALT, the infrared thermal imager is used to perform non-contact temperature measurement on the controller and the servo driver to understand the heat distribution and temperature rise of the test product. At the same time, vibration response investigation and analysis are conducted in order to obtain their vibration response value and provide reference for troubleshooting in the test.

3.2.1 The low temperature step stress test

The test profile of the low temperature step stress test is shown in Fig.2.

The implementation process of the low temperature step stress test is shown as follows.

Using the temperature point specified by normal temperature or related specifications as the starting temperature of the low temperature step stress test.

Before the temperature reaches the operating temperature specified in the product specification, in steps of -10 ° C, and then in steps of -5 ° C.

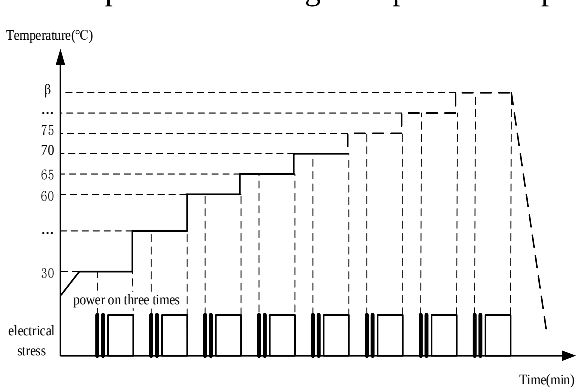
The residence time on each temperature step is the time required for the sample to reach temperature stability + 10 min + test time.

Three start tests should be carried out before the sample test to check the starting ability of the sample under extreme temperature. After three starts, the sample function and performance test are performed, and the power is turned off after the test is completed.

Low temperature step stress test termination conditions: α is the end temperature of the low temperature step test or the low temperature working limit of the sample has been found.

3.2.2 The high temperature step stress test

The test profile of the high temperature step stress test is shown in Fig.3.



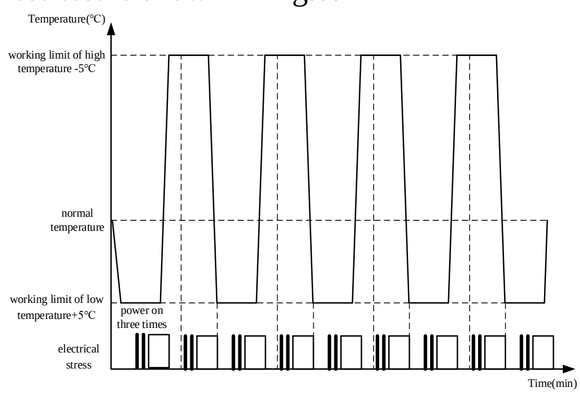


Figure 3.The test profile of the high temperature step stress test

Figure 4. The test profile of the rapid temperature cycling test

The implementation process of the high temperature step stress test is shown as follows.

Using the temperature point specified by normal temperature or related specifications as the starting temperature of the high temperature step stress test.

Before the temperature reaches the operating temperature specified in the product specification, in steps of -10 ° C, and then in steps of -5 ° C.

The residence time on each temperature step is that the sample reaches the temperature stabilization time + 10 min + test time.

Three start tests should be carried out before the sample test to check the starting ability of the sample under extreme temperature. After three starts, the sample function and performance test are performed, and the power is turned off after the test is completed.

High temperature step stress test termination conditions: β is the end temperature of the high temperature step test, or the high temperature working limit of the sample has been found.

3.2.3 The rapid temperature cycling test

The test profile of the rapid temperature cycling test is shown in Fig.4.

The implementation process of the rapid temperature cycling test is shown as follows.

The rapid temperature cycling test begins at the low temperature stage.

Temperature range: working limit of low temperature +5 ° C ~ working limit of high temperature -5 ° C.

Number of cycles: 5 complete cycle periods.

The rate of temperature change is 40 ° C / min.

The residence time of the low temperature and high temperature stages in each cycle is: the sample reaches the temperature stabilization time + 10 min + test time.

Each cycle of low and high temperature steps should be tested 3 times before the test to assess the starting ability of the sample at extreme temperatures. After 3 starts, the sample is continuously energized and tested.

3.2.4 The vibration step test

The test profile of the vibration step test is shown in Fig.5.

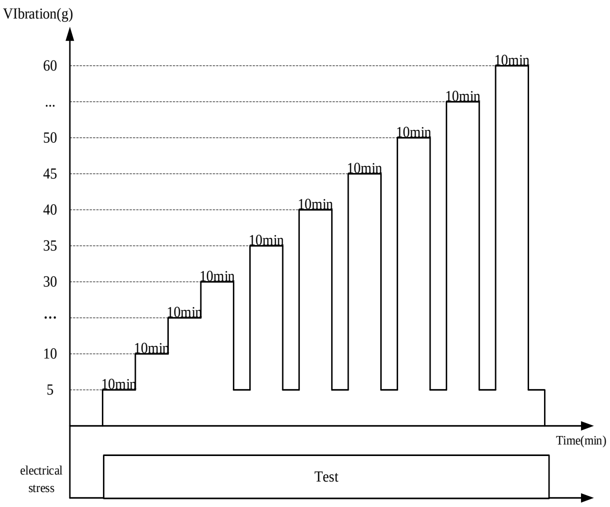


Figure 5. The test profile of the vibration step test

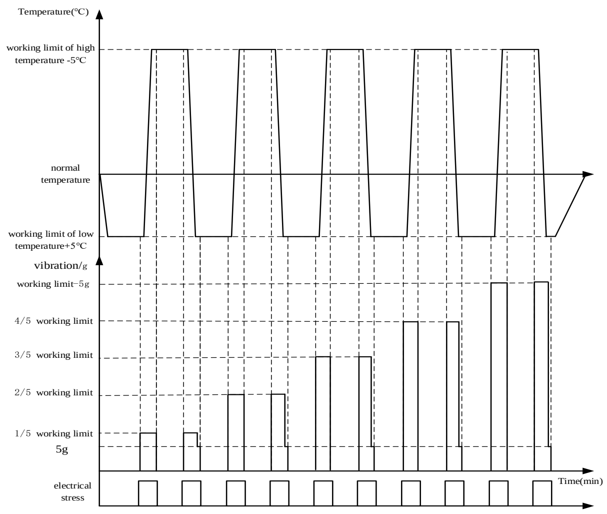


Figure 6.The test profile of the integrated environmental test

The implementation process of the vibration step test is shown as follows.

- Vibration frequency range: 5Hz ~ 10000Hz.
- Vibration form: three-axis six-degree-of-freedom super Gaussian random vibration.
- Initial vibration level: 5g.
- The vibration step is progressing: 5g.

- Each vibration level is maintained for 10 minutes, and testing is required at each vibration step.
- Applying a nominal voltage to the sample.
- Vibration step stress test termination conditions: 60 g as the end of the vibration step test or the working limit of the sample has been found.

3.2.5 The integrated environmental test

The test profile of the integrated environmental test is shown in Fig.6.

The implementation process of the integrated environmental test is shown as follows.

The method of applying the temperature stress is the same as the method of applying the rapid temperature cycle.

Number of cycles: 5 complete cycle periods.

The vibration working limit of the sample is divided by 5 as the initial vibration level of the vibration step, and each time the value is increased as the vibration level of the next cycle and the fifth cycle vibration level is the vibration working limit minus 5 g.

Each vibration level corresponds to a temperature cycle.

Timing and duration of vibration application: The corresponding vibration level is applied 5 minutes before the start of the heating period of each cycle until 5 minutes after the end of the heating section and the corresponding vibration level is applied 5 minutes before the start of the cooling section of each cycle until the end of the cooling section. And then reduce the vibration level to 5g and maintain 5min.

Conducting a power test on the sample during the application of the vibration stress.

The residence time of the low temperature and high temperature phases in each cycle is: the sample reaches the temperature stabilization time + 10 min + test time.

3.3 The HALT Procedure for Servo Motor

In addition to being subjected to environmental stresses, servo motors are also subjected to working loads. These working loads have a great influence on the reliability of servo motor components. When carrying out the HALT of the servo motor, it is necessary to analyze the failure mode, failure mechanism and sensitive stress. And the magnitude of the damage effect of the servo motor is sorted according to the working load to determine the types of stress to be applied in the HALT.

Related studies have shown that the characteristics of environmental stress and working stress on the cumulative damage of electromechanical products are basically the same, and the effect of the two stress couplings is generally to accelerate the cumulative damage of the product [9]. Therefore, the application of two kinds of stresses needs to be considered when formulating a high accelerated life test program. Under the conditions allowed by the HALT equipment, it is generally required to apply environmental stress and working stress to the servo motor at the same time, and the application method needs to consider the rate at which the accelerated defect portion is converted into a fault. The environmental stress test implementation process and stress mode refer to the controller and servo driver.

3.4 The HALT Procedure for Servo System

In combination with the results of the HALT of the controller and the servo driver and the HALT of the servo motor, the profile of the HALT of the servo system is designed. The application process of the environmental stress refers to the flow of the HALT of the controller and the servo driver and the application process and mode of the working stress refer to the stress application mode of the HALT of the servo motor. The cut-off condition of the test stress can be determined based on the test results of the above two types of components.

4. Case

The servo system of a certain type of robot consists of a controller, a servo driver and a servo motor. It uses the Ether CAT bus for high speed communication. The controller issues a control command, which is processed by the servo driver signal to drive the servo motor to achieve precise motion control of the robot. This type of robot servo system is widely used in 6-joint standard robots, SCARA, DELTA, multi-axis Cartesian robots, and multiple robot linkages.

According to the composition and actual application of the robot servo system, the controller and servo driver, servo motor and servo system are tested separately.

There are 4 faults in the high-acceleration life test of this type of robot servo system. They are shown in Table I.

Through the high accelerated life test, the working stress limit of the robot servo system is as follows.

The low temperature working limit: -35 °C for controller and servo driver, -60 °C for servo motor.

The high temperature working limit: 90 °C for controller and servo driver, 105 °C for servo motor.

The vibration working limit: 50g for controller and servo driver and 60g for servo motor.

TABLE I. Summary of faults in THE HALT

NO.	Test phase	Stress	Phenomenon	Cause
1	The low temperature step stress test of controller and servo driver	-45℃	The servo driver reported a fault "Er74"	The ambient temperature exceeds the lower operating temperature limit of the devices in the driver, resulting in unstable devices parameters.
2	The high temperature step stress test of controller and servo driver	90℃	The servo driver reported a fault "Er650"	Temperature stress causes internal damage of some parts of the servo driver
3	The high temperature step stress test of servo motor	105℃	The servo motor stops working	The temperature stress reaches the working limit of the servo motor, resulting in unstable servo motor
4	The integrated environmental test of controller and servo driver	85℃, 45g	The servo driver reported a fault "Er201"	The internal wiring port of the servo driver is loose, resulting in poor line contact

Part of the fault pictures are shown in Fig.7 and Fig.8.

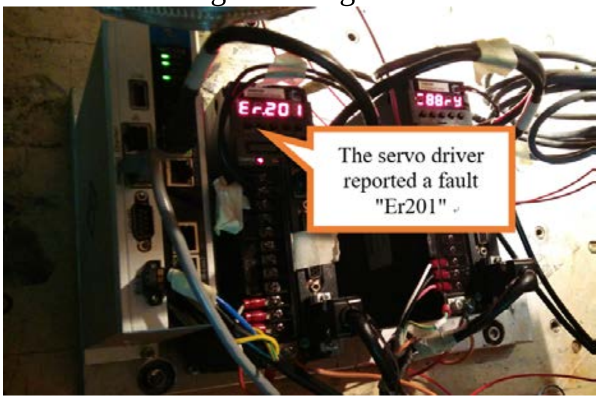


Figure 7.The test profile of the vibration step test

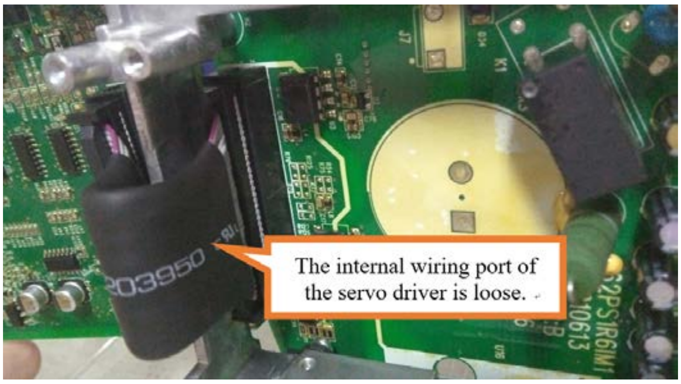


Figure 8.The test profile of the vibration step test

5. Conclusion

In this paper, a HALT method for servo system is proposed. Different HALT schemes for different components of the servo system and the whole machine are used to more effectively expose the defects and weakness of the servo system, reduce the test period, save the test cost and improve the efficiency of the test. Through the HALT of a certain type of robot servo system, four potential defects and working limit stress of the servo system are proposed. At the same time, the case also verifies the effectiveness of the HALT method of the servo system proposed in this paper, and it has certain reference and guiding significance for carrying out HALT for other types of servo system.

Acknowledgment

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