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REASONS FOR PICK-UP TIME DEGRADATION AND MODELING FOR AEROSPACE RELAY IN STORAGE

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Abstract. *The storage degradation test system for aerospace relay is designed. The degradation data rule of pick-up time parameters for aerospace relay is tested. And the variation law of pick-up time changing with time is obtained. The change of pick-up time which is mainly caused by reeds reaction occurred relaxation, is analyzed and verified. Then, the approximate linear relationship between pick-up time and reed reaction was found. So, the pick-up time can characterize the degradation of reed relaxation. The storage degradation model of pick-up time is estimated through regression theory. The research results in this paper provide the necessary theoretical method and basis for studying storage reliability and life prediction of the aerospace relay.*
Keywords: Aerospace relay, Pick-up time, Degradation, Storage reliability

1. **Introduction.** Aerospace relay is a key component for national defense weapon equipment system. Its storage reliability affects reliability of weaponry equipments directly. Wang et al. analyzed the mechanism of aerospace electromagnetic relay storage, and a kinetic model for evaluating the contact resistance increasing in contact spots of normal close contacts is described [1]. Shao et al. built the storage life prediction model of a single relay by mobile standard deviation method [2].

In the aerospace electromagnetic relay (EMR) storage process, all the reed, coil, varnished wire and magnetic materials, etc., will be degraded to a certain degree. The degeneration will affect relay performance characteristic or contact performance. No matter it is for the relay manufacturer or for its users, it is very important to accurately assess the regression of aerospace relays and to predict the current or future performance characteristics by using the data in the storage process.

The relay characteristic of pick-up time, time for the N.O. contact to close, is sensitive to changes in electromagnetic force, spring force, and other wear factors in the contact system associated with component degradation, so it contains the feature information reflecting relay component degradation. Ren et al. pointed out that there were deterministic relation within some parameters, such as pick-up time, contact clearance and contact pressure [3]. According to the aerospace relay storage accelerated test, it is found that pick-up time changes obviously during the storage process. The foundations for design and storage reliability assessment are provided by finding degeneration reasons and confirming the relay components which lead to the pick-up time changed.

The pick-up time is affected by both coils and reeds. Coils provide attractive force and reeds provide spring force, and relay motions by the resultant force. The degradation

of coil within storage process embodied the changes of insulated wire resistance, and the changes of spring force characteristics mainly generated by stress relaxation. Fox pointed out the fall rate of stress relaxation and time follows a linear relationship, when he researched the bending stresses relaxation characteristics of BeCu alloy strip [4]. Zhu and Lu took accelerated stress relaxation test of domestic tin bronze and beryllium bronze domestic relay contact reed materials, such as tin bronze and beryllium bronze, and they calculated the value of long time stress relaxation by short time change law [5]. Prevenient researches studied the most stress relaxation simply from material views. In this paper, the degradation reasons of relay pick-up time in storage will be analyzed and confirmed, and pick-up time is used to represent characteristics of reed stress relaxation storage degradation. The degradation model which can provide references for the research of aerospace EMR storage reliability will be built.

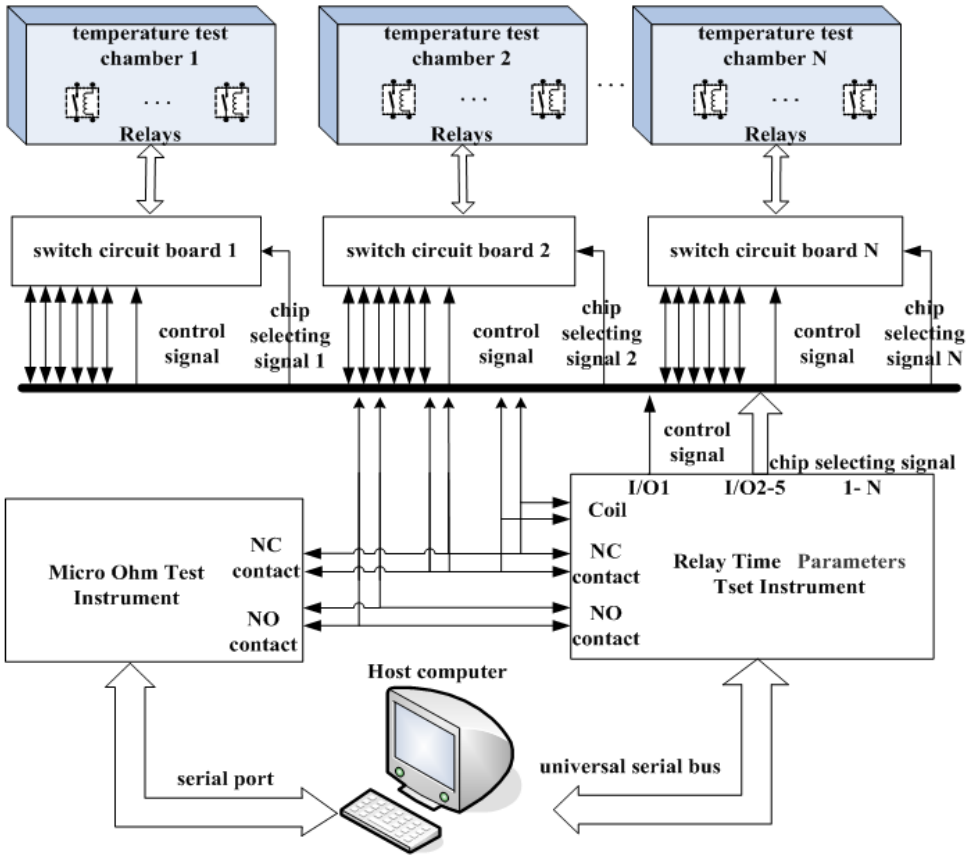
2. Procedure of Aerospace Relay Accelerated Storage Degradation Testing.

2.1. **Test system and test process.** The relay performances degrade slowly at room temperature. The relay storage accelerated test is to speed up the relay performance degradation by increasing the stress in the condition of unchanging failure mechanism. Then properties are tested, and relay storage performance degradation law and reliability are analyzed based on performance degradation data. The contact resistance and time parameter test system, which is developed in [6], is used to take the storage accelerated test. The major structures and physical map of the relay ASDT test system are shown in Figure 1.

The whole test system is composed of temperature test chamber, relay switching circuit, contact resistance measurement circuit, time parameter measurement circuit, upper computer, and upper computer system software. This system can monitor relay contact resistances and time parameters of 40 aerospace relays by turning under different temperatures and transmit the test data to the host computer for processing.

In the test, the thermal stress is accelerated with a storage temperature of 170°C. Relay contact resistance and pick-up time parameters are tested every 72 hours after test temperature restores up to room temperature. The structural schematic of a certain aerospace relay is shown in Figure 2. This relay is a kind of common switch-type contact relay (one movable contact and two static contacts), in which voltage is 28V D.C. and contact load is 5A. The closing process was that when the coil was energized, the armature was moved by electromagnetic force, and the pusher arm pushed moveable spring moving until N.O. contact closed. And, the opening process was that when the electromagnetic system was powered off, movable contact are returned by mechanical spring force until N.C. contact closed.

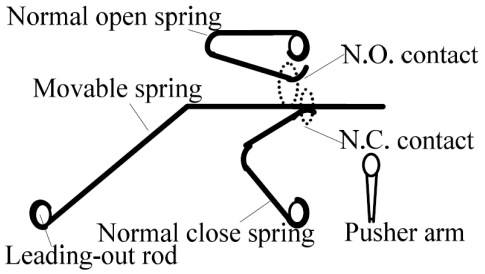
2.2. **Test results of pick-up time.** Pick-up time is the time from the power-on of electromagnetic system to the first contact of movable contact and N.O. contact. With the above test system, the relay pick-up time data were obtained by storage accelerated test on 10 relays over 210 days. The average value of 10 relay pick-up time is shown in Figure 3(a). It is shown that the pick-up time is on a declining trend under high temperature long term storage. The curve has two steps decrease obviously. The first step declines faster and the second step declines slowly. The pick-up time decreases about 220μs in 0-2000h, and decreases about 50μs in 2000-5000h. The most decrease of pick-up time appears on the first step. The box plots are diagram drawn every pick-up time degradation, and the box plot in the whole accelerated storage period is shown in Figure 3(b). The ten groups of pick-up time are all two steps decrease.



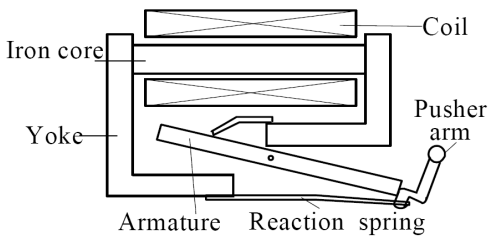
(a) Major structures of relay testing system

(b) Physical map of relay testing system

FIGURE 1. Major structures and physical map of relay ASDT testing system

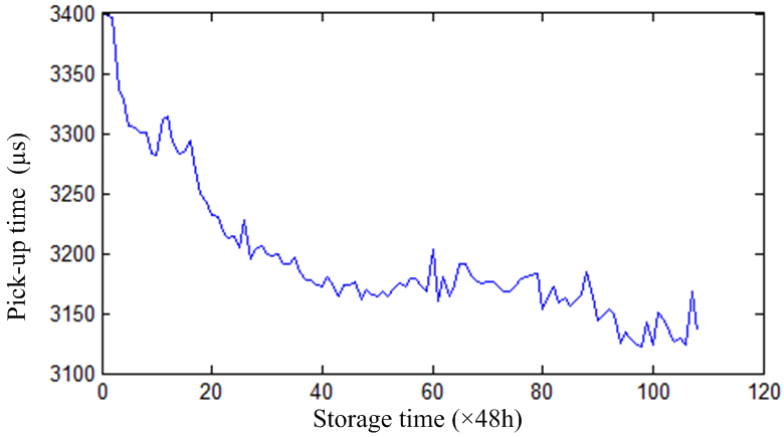


(a) Contact system

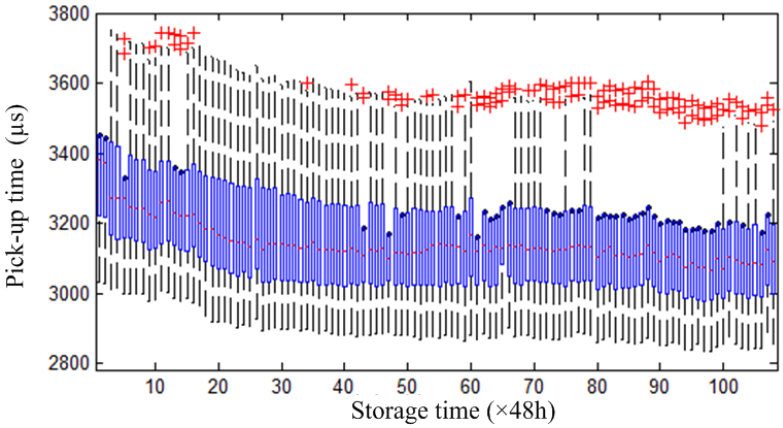


(b) Electromagnetic system

FIGURE 2. Schematic structure of aerospace EMR



(a) Trend of pick-up time average value



(b) Box plots of pick-up time

FIGURE 3. Degradation trend chart of pick-up time

3. **Reasons for Pick-up Time Changing.** Attractive force characteristic is the relationship of the reduction value of electromagnetism force (or torque) caused by electromagnetic system and armature stroke (or armature corner) in air gap. Spring force characteristic is the relationship of the reduction value of mechanical reacting force (or torque) caused by touch-spring system and armature stroke (or armature corner) in air gap. When attractive characteristic curve is higher than spring force characteristic curve, the relay closed, and conversely released. The typical attractive force and spring force characteristic curves are shown in Figure 4.

The closing process of relay is under the mutual effects of attractive force and spring force. Because of changing air gap, there are two possible reasons for pick-up time reduction: attractive force increasing or spring force decrease. It causes the reed resultant force of attractive force and spring force becomes bigger, reed moves faster, and pick-up time becomes shorter.

3.1. **Change of attractive force and spring force characteristic in storage.** When the coil exciting magnetizes the magnetic system, the attractive force is produced. The degradation of coil during storage represents the change of insulated wire resistance. When the coil resistance increased, the attractive force becomes smaller. Otherwise, the attractive force becomes bigger when coil resistance becomes smaller. The measurements of coil resistance in relay storage accelerated test are shown in Table 1. The coil resistances increase slightly, but the change of resistance was very small (just 0.2%). It means that attractive force will remain the same, and this leads to the consideration that the change of pick-up time during storage is not caused by attractive force.

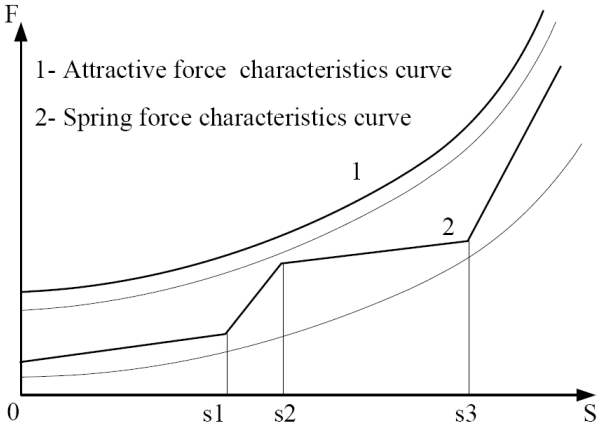


FIGURE 4. Typical curves of attractive force and spring force characteristics

The reed as elastic element provides spring force, but it will show stress relaxation (shown in Figure 5). The result is that the spring force of reed reduces. If attraction force basically unchanged, the resultant force of attractive force and spring force becomes bigger, and the pick-up process speeds up. Then the pick-up time decreases.

During the stress relaxation process, the stress decreases sharply in the initial stage, and then decreases slowly. It just corresponds to two steps decrease of pick-up time (as shown in Figure 5). So the preliminary judgment is that the change of pick-up time, during storage process, is caused by spring force relaxation.

Spring force and pick-up time have a direct linear relationship which makes it possible to predict spring stress force degradation from changes in pick-up time measurements. This is an important factor for the research on storage reliability.

3.2. **Relationship between pick-up time and spring force.** To study the relationship between relay pick-up time and spring force, finite element modeling was carried out and dynamic characteristics are simulated on a certain aerospace EMR by MSC.ADAMS.

Changes in spring force are directly related to changes in pickup time. The characteristic of spring force is the curve "2" in Figure 4, and the change of the spring force

TABLE 1. Measurements of coil resistance in relay storage

Time	0h	200h	400h	600h
Coil Resistance	974.2Ω	974.9Ω	975.0Ω	976.2Ω

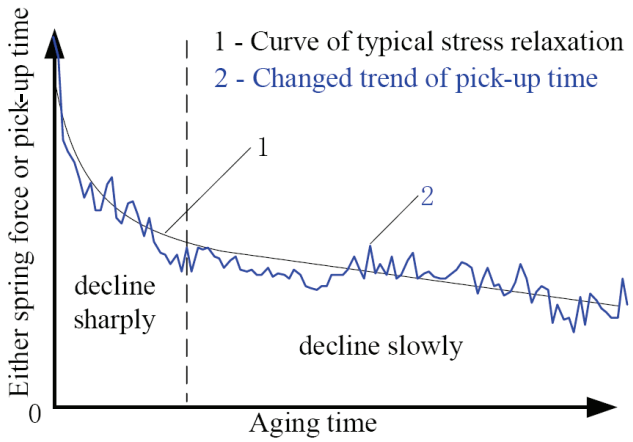


FIGURE 5. Comparison or pick-up time readings with typical stress relaxation plot

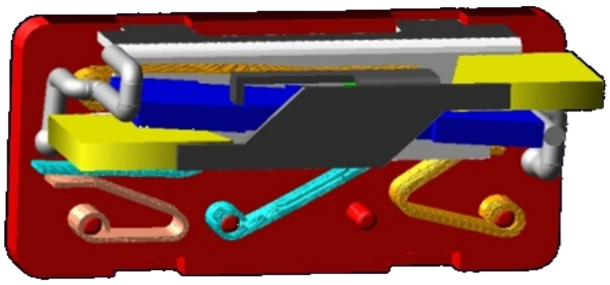


FIGURE 6. Finite element model of aerospace EMR

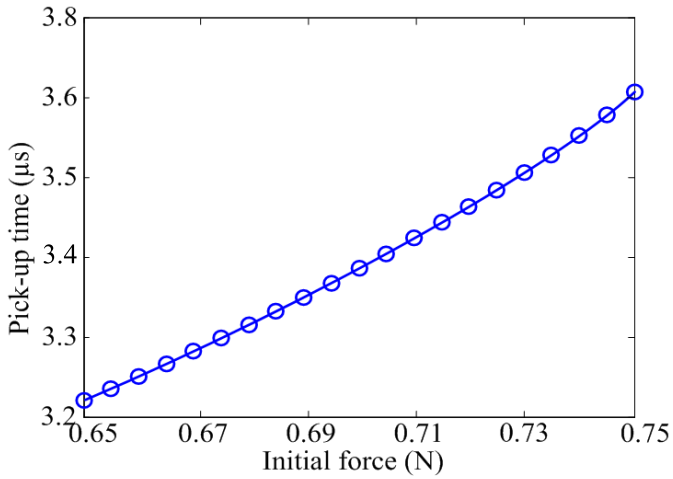


FIGURE 7. Relationship of reed initial forces and pick-up time obtained in simulation

characteristics during the storage can be described by set of curves. To make the analysis and discussion easier, here initial force is selected as the parameter on behalf of the relay spring force characteristics. Initial force is the representative value on the relay spring force curve. The initial force is a point force at the time of movable contact and N.C. static contact breakaway by the bottom of armature pushed (s2 in Figure 4). When the size of relay and the relative location of movable contact and static contact are not changed, the relationship between spring force characteristic and pick-up time under the condition that the initial force is [0.65, 0.75]N and step size is 0.005N is shown in Figure 7. It can be seen that there is a nearly linear relationship between reed initial force and pick-up time, and the slope is 3900μs/N.

3.3. **Experimental verification.** The high temperature storage tests of new aerospace relays were performed, and the relay spring forces and attractive forces were measured periodically. The spring force characteristics were measured by using the relay static attractive force and spring force characteristics fixture as shown in [7]. The relay pick-up time was measured by using the time parameters fixture as shown in [6]. In order to measure the relay spring force characteristics, relay shells need to be removed before storage test. The relay storage test was conducted under 170°C for 600 hours, and the relay pick-up time and spring force characteristics were tested every 200 hours after test temperature restores up to room temperature.

The trend for the relay initial force was indicated in Figure 8. In this figure the relay initial force dropped rapidly, which means stress relaxation has happened.

In the accelerated storage degradation test, the relay initial force has shown the reduced trend in Figure 8. The results showed that there were two obvious phases in the initial force changing process. The two stages are as follows: stage 1: rapid drop under 200 hours, stage 2: gradual further decline above 200 hours.

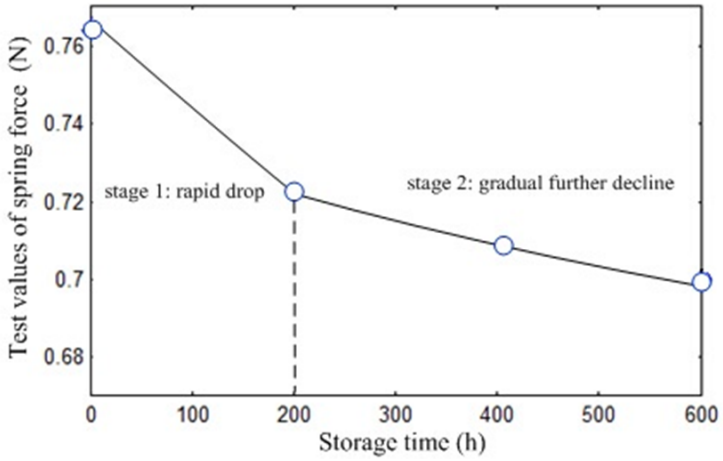


FIGURE 8. Trends of relay spring force in storage

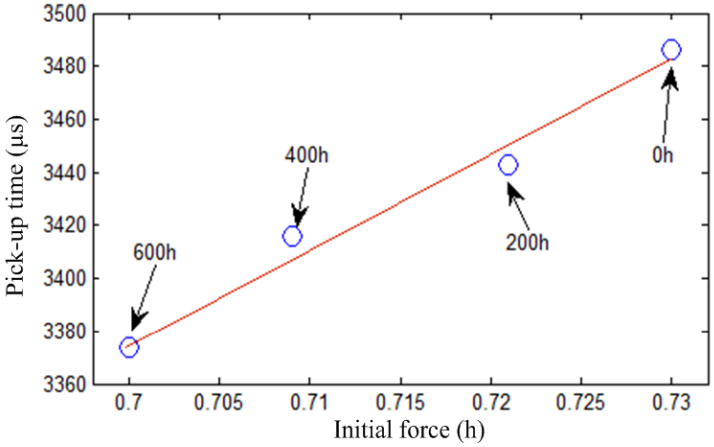


FIGURE 9. Relationship of reed initial forces and pick-up time obtained in test

Figure 9 gives the relationship between pick-up time and initial time of relay during 600h. It can be seen that pick-up time and initial force both decrease with time elapsing, and it is nearly a straight line. The line in Figure 9 is the fitting result, and the slope is $3770\mu s/N$.

It further testifies that the change of pick-up time during storage is caused by spring force rather than attraction force, and there is a local linear relationship between pick-up time and initial force.

The results of simulation and test prove the linear relationship exists between pick-up time and initial force. The uncertain factors during the production process of aerospace relay cause the small deviation between simulations and test.

The analysis above shows that it is feasible to reflect the change of stresses of reed during the storage by using the test results of pick-up time. There is a great necessity to study the performance deterioration and reliability of aerospace relay during storage. Furthermore, the storage reliability of reed and even the whole reed can be evaluated and predicted by building the pick-up time degradation model.

4. **Storage Degradation Model of Pick-up Time.** There is linear relationship between the pick-up time and spring force, and according to the stress relaxation theory, the degradation model of pick-up time in storage can be inferred.

The most common model of stress relaxation is Larson Miller method [8]. The empirical formulae of Larson Miller method can be expressed as:

$$\theta = F(S) = (T + 460)(\log t + C) \tag{1}$$

where θ is Larson-Miller parameter, T is Fahrenheit, t is time, and the constant C is 20.

So, the values of the percentage of remaining initial force in stress relaxation test can be represented as:

$$F_S/F_0 = (T + 460)(\log t + 20) \tag{2}$$

And, the pick-up time is nearly linear with the spring force as:

$$T_x = kF_x + \alpha \tag{3}$$

Then put Formula (1) into Formula (2) to get the model of pick-up time in storage as:

$$T_x = kF_0(T + 460)(\log t + 20) + \alpha \tag{4}$$

The accelerated storage data is disposed by least square method that the contours fit using Formula (4), which adjusts the non-linearity of test data shown in Figure 10. The storage test data of pick-up time and storage degradation model (based on fitted parameters) are in good agreement.

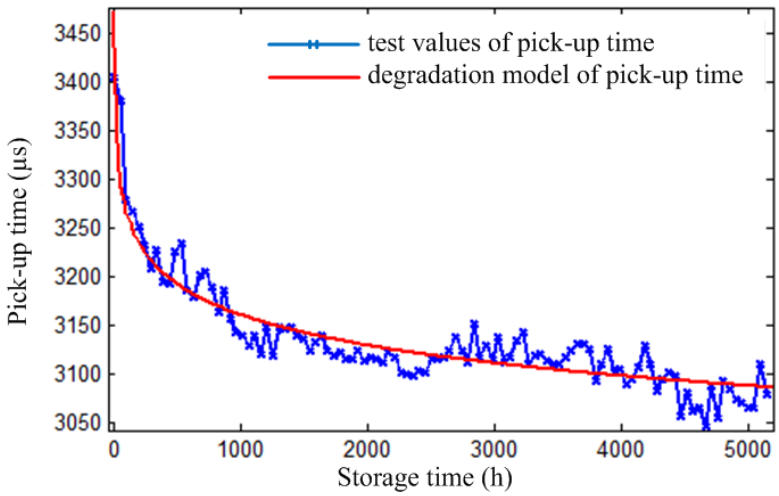


FIGURE 10. Test data of pick-up time and storage degradation model

5. **Conclusions.** This paper has made research on the degradation modeling of pick-up time for aerospace electromagnetic relay in long-term stockpile. Based on previous tests, following results are gotten:

a) Pick-up time showed the reduced trend in the accelerated storage degradation test. The result showed that there were two obvious phases in the pick-up time changing process. The two stages are: stage 1: rapid drop in closing time for aging under 2000 hours, stage 2: gradual further decline in closing time above 2000 hours.

b) Both the tests and simulation result proved that the presumption "pick-up time change rule is associated with stress relaxation" is right.

c) The simulation and test results showed that pick-up time is nearly linear with the spring force. This proved the estimate of stress relaxation on relays in storage by doing pick-up time measurements.

d) The model for pick-up time and stress relaxation in storage has been tested and found to predict stress relaxation. This provides a reference base for improving relay storage reliability in the future.

However, more work is required to identify the contact storage failure mechanism and the competition relation among failure mechanisms. Along with the test to continue,

more experimental data will be acquired, test data mining methods and latter aerospace relay storage life prediction are being performed, and it will be published in the future.

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