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Research Article

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Research of Electro-hydraulic servo valve accelerated Degradation test based on wear mechanism

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ABSTRACT

Electro-hydraulic servo valve belongs to the high reliability, long life products. This paper chooses the method of accelerated degradation test to evaluate the life of electro-hydraulic servo valve. The method solves the problem of Long test period and high test cost of the Traditional life test . This paper does the research of electro-hydraulic servo valve accelerated degradation test based on wear mechanism. The purpose is to evaluate the electro-hydraulic servo valve's performance using the shortest time . It puts the oil pollution as the stress test, the pressure gain as performance standard. And it does the SSADT for the electro-hydraulic servo valve, because there is no ready-made system for this test. It designs a test system for the pollution wear mechanism by itself. In terms of test data processing, this paper created accelerated Life Testing Model of Brown movement in drift and Inverse Power law model, in obtained the parameters estimation of model by using least square method and best linear unbiased estimation method, forecasted and analyzed normal lifetime and reliability of electro-hydraulic servo valve, verified the feasibility and efficiency of accelerated degradation testing.

Key words: Electro-hydraulic servo valve, SSADT, Brown movement, parameters estimation, Reliability analysis

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INTRODUCTION

Electro-hydraulic servo valve is a key component of electro-hydraulic servo control system, because of its fast dynamic response, high control precision, long life and other advantages, is widely used in aviation, aerospace, shipbuilding and other fields [1].

At present, in the development of hydraulic technology and the electro-hydraulic servo control system, it faces the two technical problems: one is the pollution, the second is leak [2], especially the oil pollution. According to the statistics, the 70% to 80% fault of hydraulic equipment is caused by the oil pollution. Because of the electro-hydraulic servo valve has high precision, so it sensitivies the oil pollution. The oil pollution, can lead to wear and influence the control accuracy.

Wear severely threatens the safe operation of the hydraulic system. Therefore, it is a great significance to predict it life and guarantee it works safety and reliability by understanding how the oil pollution level influences the wear of the electro-hydraulic servo valve. This article through the accelerated degradation test method to quantitative study the effect of wear to the servo valve's life.

The wear failure mechanism analysis of the electro-hydraulic servo valve

Due to the different prestage electro-hydraulic servo valve is usually divided into nozzle baffle type and jet pipe type. The two kinds of valve has the similar wear failure mechanism, and jet pipe valves has higher price, So considering the feasibility of the experiment and the cost-effectiveness ratio, this article selects the double nozzle flapper type electro-hydraulic servo valve for accelerated degradation test.

Double nozzle flapper valve wear failure is divided into prestage wear and slide valve wear. The prestage wear including nozzle baffle wear and abrasion of ball feedback, slide valve level wear work including valve spool valve sleeve edge wear and fitting clearance valve core set of radial wear. The figure below shows the different servo valve performance index that is affected by the wear and tear parts. Ultimately it determines the internal leakage quantity, amount of overlap with the pressure gain as the performance appraisal indexes of the electro-hydraulic servo valve wear accelerated degradation test.

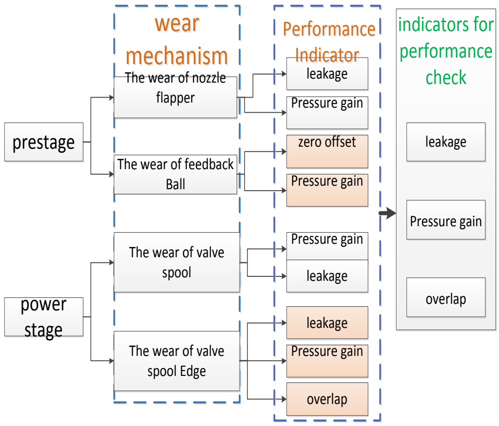

Fig. 1 Failure mechanism analysis of the electro-hydraulic servo valve

The determination of the test program

Through the above analysis of electro-hydraulic servo valve pollution Wear mechanism, combined with the general process of accelerated degradation test, the paper gives the following electro-hydraulic servo valve pollution wear accelerated degradation test flow chart:

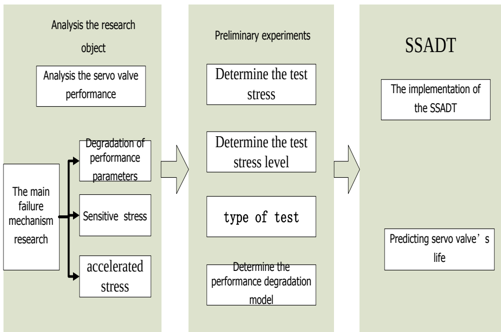

Fig. 2 The flow chart of the SSADT

Through to analysis and research the electro-hydraulic servo valve wear failure mechanism, we learned that the oil pollution particle size, concentration, hardness is the main influence factors of the electro-hydraulic servo valve's wear. And the present studies were conducted in the hydraulic element pollution test all adopted standard AC powder or MTD powder, namely the impact stress is mostly only consider the size of the particles and the concentration. Combined with research and learning the GJB 420-2006, and considering the feasibility of test, ultimately determine the oil pollution level for the accelerated stress. And using the preliminary experiments to validate if the accelerated stress can be accelerated; The performance indicators has been given in the failure mechanism analysis, in the amount of leakage, pressure gain, overlapping; As a result of the electro-hydraulic servo valve is expensive, test sample size is limited, so the test choice to step-stress accelerated degradation test[9].

At the same time, because the current pollution test device for hydraulic products are mostly based on standard AC powder or MTD powder. Adopting this method that using single hardness pollution particles instead of the oil pollution of the actual working environment, the test results and the actual result will exist deviation. While this paper designs a experiment, it imitates the real work environment conditions of electro-hydraulic servo valve, the test pollution oil is composed of the impurities of the working environment and its working system's products. Therefore, the structure chart of the test system as shown below:

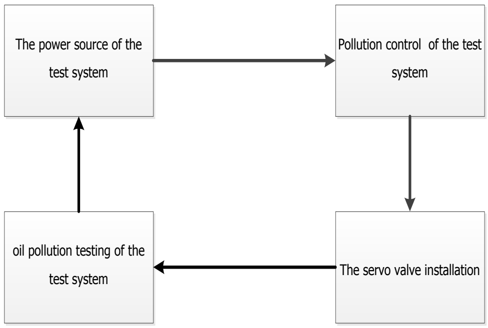

Fig. 3 The testing system structure chart

Summarizing the results of the analysis above, this paper presents a electro-hydraulic servo valve pollution wear accelerated degradation test points, as follows:

1)Choosing the oil pollution as the stress of the test;
2)Because of the electro-hydraulic servo valve is expensive, sample size is limited, so this article chooses three sample size to doing the step stress accelerated degradation test;
3)To determine the stress of the test, we have chosen four stress levels between the electro-hydraulic servo valve normal working oil pollution and electro-hydraulic servo valve working limit, so the class is 8,9,10,11.
4)To determine the time of test, we choose the same degradation way, Under each stress level, with a 10% performance degradation, then rosing to the next stress level to continue the test ,until finishing the test of class 11 .

Analysis the testing data

In this test ,we choose the pressure gain to behalf the wear of the electro-hydraulic servo valve, the more serious wear and tear, and the smaller the pressure gain. First, establishing the degradation model of the pressure gain and the time of test. Second ,statistics and analysis the test data. Finally extrapolating the life of the electro-hydraulic servo valve in normal working stress level.

Here are the three pressure gain changing curves under the four stress level:

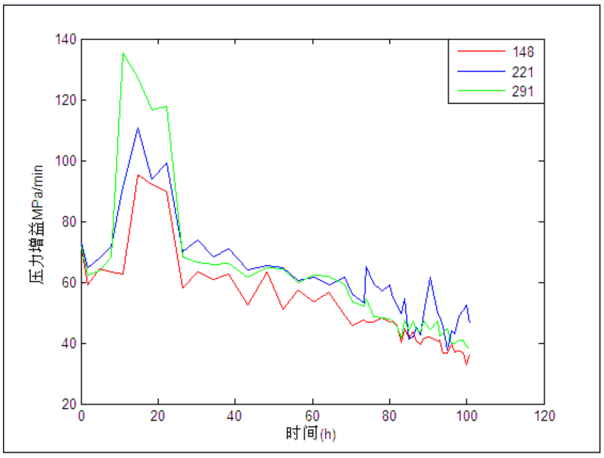

Fig. 4 The degradation curves of the three valves' pressure gain

From the graph ,we can see, the three subjects have a better consistency .The 30 hours before the test, three pressure gain of the electro-hydraulic servo valve has the same rising trend. The reason is: the electro-hydraulic servo valve we choose are zero overlap valves. When valve overlap quantity is zero, the performance of the valve is the best and the most stable . However the valve's productions in order to guarantee the high reliability and long life, generally making the valve overlap is positive. In the process of pollution wear test, Servo valve overlap amount from positive to zero overlap and then to negative overlap. The test data can fully prove that the higher the oil pollution ,the more serious wear on the electro-hydraulic servo valve.

Interpolating the test data[8] ： However, due to the limitation of experimental conditions, the test data is less. it makes the test data processing and electro-hydraulic servo valve life assessing is difficult. Through the research, the neural networks can be based on historical data, to forecast data. So this paper uses the neural network to interpolate the test data, The interpolation results as shown in the figure below:

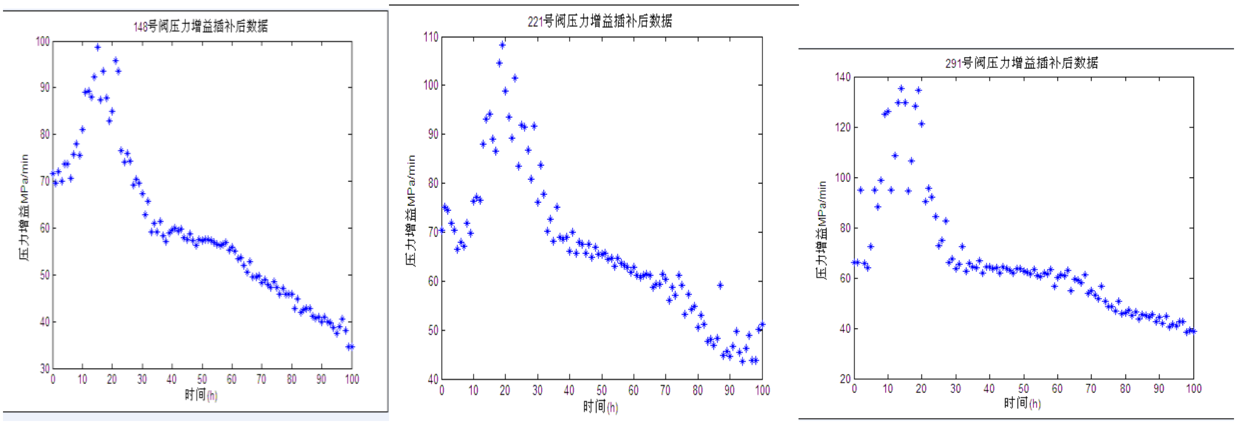

Fig. 5 The supplementary data figure of the three valves

The electro-hydraulic servo valves we selected in the test are zero overlap valves by rules. In fact, the valves used in the test are overlapped. Each pressure gain's initial value is different, In order to eliminate the differences, so when we process the test data,we should remove the before 30h data.

The acceleration degradation model : After fitting the interpolation test data, we find Pressure gain linearly decreased with time, Assumes that the relations of the change of electro-hydraulic servo valve's pressure gain and time accord of the drift Brown motion[3][4][5].

$$x(t) = \sigma B(t) + \mathrm{u}t \tag{1}$$

In the formula, x(t) is the pressure gain of the valve ; u>0， σ >0; u is the drift coefficient, σ is the diffusion coefficient, B(t) is standard Brown motion, B(t)~N(0, t).

As a result ,the oil pollution level is the stress of the accelerated test, this stress is not the temperature stress. So we can assume that the drift coefficient is the power law function of the accelerated stress S . Represented as $u=aS^b$; a,b are the unknown parameters.

Estimating the accelerate degradation model parameter : Assuming that it has q accelerated stress levels in the electro-hydraulic servo valve accelerated degradation test, that is S1<S2<…<Sq, and all of them are greater than the normal working stress S_0. ni is the product number of the ith stress level, it makes m times performent measurement in the test. The measurement time is t1<t2…<tm. xiik is the kth performance of the jth sample in the ith stress level(i=1,…,q， j=1,…,ni， k=1,…,m).

When the pressure gain changing of the electro-hydraulic servo valve along with the time conform to the drift Brown movement, xi(t) is the pressure gain of the ith accelerated stress in the t moment ,and it obeys the normal distribution. Expectation and variance of the variable quantity xi(t) shows in below[6] :

$$\begin{cases} E[\mathrm{x}_i(t)] = aS_i^b t \\ Var[x_i(t)] = \sigma^2 t \end{cases} \tag{2}$$

Through the data of $\left\{x_{ijk}, i=1,\cdots q, j=1,\cdots n_i, k=1,\cdots,m\right\}$,we can obtain the unbiased estimation of the expectation and variance in the formula (2).

$$\begin{cases} \hat{\mu}_{ik} = \dfrac{1}{ni}\sum_{j=1}^{ni} x_{ijk} \\ \hat{\sigma}_{ik}^2 = \dfrac{1}{ni-1}\sum_{j=1}^{ni}\left(x_{ijk} - \hat{\mu}_{ik}\right)^2 \end{cases} \tag{3}$$

Assuming that $\mu_i = aS_i^b, i = 1, \cdots, q$,it can obtion the estimate based on formula (3):

$$\begin{cases} \hat{\mu}_i = \dfrac{\sum_{k=1}^{m}\left(\hat{\mu}_{ik} t_k\right)}{\sum_{k=1}^{m}(t_k)^2} \\ \hat{\sigma}_i^2 = \dfrac{\sum_{k=1}^{m}\left(\hat{\sigma}_{ik}^2 t_k\right)}{\sum_{k=1}^{m}(t_k)^2} \end{cases} \tag{4}$$

Using the method of parameter estimation in literature [6], it gets estimate of the a,b, σ^2 are $\hat{a}, \hat{b}, \hat{\sigma}^2$:

$$\begin{cases} \hat{a} = \dfrac{1}{q}\sum_{i=1}^{q}\dfrac{\hat{\mu}_i}{S_I^{\hat{b}}} \\ \hat{b} = \dfrac{1}{q(q-1)}\sum_{i=1}^{q}\sum_{i=1, l\neq i}^{q}\dfrac{\ln(\hat{\mu}_i / \hat{\mu}_l)}{\ln(S_i / S_l)} \\ \hat{\sigma}^2 = \dfrac{1}{q}\sum_{i=1}^{q}\hat{\sigma}_i^2 \end{cases} \tag{5}$$

The following table shows the estimations of the modle parameters a,b, σ^2 :

Table 1: Estimations of the modle parameters

Parameters	a	b	σ^2
Estimations	414.1908	57.5653	1.5504*10^3

This article assumes that Electro-hydraulic servo valve fails when the pressure gain reaches 40 MPa/mA. The kolmogorov forward equation is used to get the failure distribution function of electro-hydraulic servo valve and the reliability of the normal working condition[7].

$$R(t) = \Phi\left[\frac{C - aS_0^b t}{\sigma\sqrt{t}}\right] - \exp\left(\frac{2aS_0^b c}{\sigma^2}\right)\Phi\left[\frac{-C - aS_0^b t}{\sigma\sqrt{t}}\right] \tag{6}$$

In the formula ,t is the working time, R(t) is the reliability, $\Phi(\cdot)$ is the probability density function of the standard normal distribution, S0 is the mean value of the three valves' initial pressure gain, C is the failure threshold. Now it substitutes the estimations of the modle parameters into formula(6), then we get the reliability estimations at normal working condition.

Table 2: Reliability estimations at normal working condition

Time/h	600	900	1200
Reliability	0.997	0.935	0.698

From the table, when the Electro-hydraulic servo valves work 600h and 900h at normal working condition , the reliability estimations is 0.997 and 0.935. it indicates that using traditional life test to forecast the valves life will cost much more time.

Using the formulas (6) and the estimations of the modle parameters, we get the reliability curve at normal working condition.

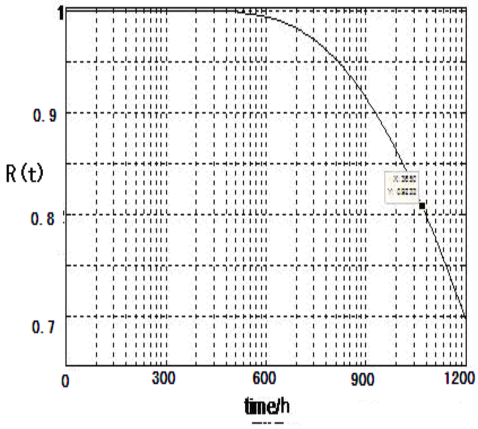

Fig. 6 Reliability curve at normal working condition

CONCLUSION

1)This paper adopts the SSADT to forecast the life and reliability of Electro-hydraulic servo valve, take oil pollution degree as the stress, and take pressure gain of Electro-hydraulic servo valve as assessment indicators of Performance Degradation.
2)After creating the accelerated Life Testing Model of Brown movement in drift, proposing a method of parameters estimation, the life and reliability of Electro-hydraulic servo valve can be obtained through extrapolation.
3)Due to many influential factors in pressure gain, and the failure criterion for Electro-hydraulic servo valve is assumed during data analysis in this Testing, it is necessary to make respective analysis of all influential factors in the following data processing and make strict definition of failure criterion.

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