RESEARCH ON RELIABILITY GROWTH TECHNOLOGY OF ELECTROMECHANICAL-HYDRAULIC SYSTEM

QIAO JIAN JUN *, TIAN GUANG LAI **, YUAN YI DONG **
***Xi' an Aviation Brake Technology Co., Ltd, P.R. China**
****Northwestern Polytechnical University, P.R. China**

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Abstract

Products that had carried out reliability test (reliability qualification test etc)happen many failures in use, not only the cycle of existing reliability test technology is longer ,cost is dearly, but also the failures can not eliminate thoroughly in use. This problem condition development of aviation and spaceflight engineering, and turn into attention pivot of reliability engineering field. For an example of a certain aircraft carbon wheel brake system, we study acceleration stress reliability growth technology that apply to complex electromechanical-hydraulic system, the latent failures of the break system is activized at short time, and solve above question in reliability test in this paper.

It is different from general test profile that is using extensively. General test profile is established according to real environment stress and sequence of action to check reliability of the products in action of real environment and operation stress (main it is electric stress in static state), and test is proceeded in nor-working state general. By careful analysis, we think that: failures of products occur in working process, it is of advantage to excite latency failures of the system when the reliability testing is proceeding in working state. Besides of electromechanical-hydraulic system which volume and weight is larger, action time of high temperature 70℃ and low temperature -55℃ is too short in general test profile, in which blaze action is small for inner binding of kinematics pair in engineering products, brittle failure in low temperature etc that is due to change of temperature is small, and excitation action of temperature drift in electric appliances is small, too. In which there is possibility that it keeps long time in low temperature or high temperature in actual usage, and exist possibility of celerity temperature-change, bottle neck be likely to conk. So when test profile is established, it is in first position that excite latent failures and elimination potential danger.

Test profile that is established for potential dangerous can answer that potential danger is eliminated in possible limiting temperature, fast temperature change, vibration etc environment stress, dynamic amplitude working stresses conditions, which can assure that application is safe and range of application for environment and operation stress is wider, there is salience acceleration effect of saving time and resource.

1 Purpose of Research

The Mean Time Between Failures [MTBF] is 700h of carbon wheel brake system of certain airplane, first overhaul period is 1000 times takeoff-landing, using life of brake equipment is 1000 times takeoff-landing. The using application experience for the same kind of products indicates that the failure rate of this new system is high in home and abroad. We proceed the reliability measure test that cost about 150h to excite and correct failures in order to assure safety in test hop, we study the acceleration stress reliability growth technology to be the same with electromechanical-hydraulic

system, and make it possible that apply this technology to deal with test data according to Military Standard of P.R. China GJB1407 [1], and carry out reliability continuity growth on the brake system.

2 Research Direction

It is for the bottle neck obtained by failure model analysis to establish special purposes test profile, and to proceed above reliability test, reliability of the brake system is increased by eliminating incipient fault.

3 Research Content

We study the testing technology of simulating operation for the carbon wheel brake system in different kinds of environment conditions. Analysis different kinds of working stress to define bottle necks which sensitivity for working stresses, propriety cut out test content which no check action for bottle necks, form the test profile which can excite incipient fault of the brake system at short time. We study the acceleration stress test technology which is simple and effective depend on design feature of the brake system, make it possible that adopt the reliability growth model to deal with test data. The life test content is made into reliability test profile, saving life test time and resource.

4 The Key Technology of Research and Apply

4.1 Acceleration Stress Test Technology Adopted for Reliability Growth

There are sensitivity factors in the break system by means of failure model analysis: temperature drift of control-box and hydraulic products leak at high temperature, contamination block, may be organ binding because of temperature change, may be over loading damage because of applied working stress of dynamic amplitude, fatigue etc. For sensitivity factors we define the acceleration factors them are: temperature, vibration, contaminate stress, working stresses which are dynamic and amplitude. It is obtain acceleration effect under combined action of these stresses.

4.1.1 The Magnitude Values of Environment Stress Are Properly Advanced

Usually, both the action time of 70℃ high temperature and -55℃ low temperature are about 1 h in general test profile, so the brake system is not fully cold or hot; moreover the magnitude of vibration stress is lower, as a result sensitivity factors are not yet bear actual environmental stresses, incipient fault of control box, servo valve etc are not enough excited, so we add the magnitude of environmental stresses to establish the test profile.

- Amplitude values of temperature between -55 ℃ ～ 70 ℃ are increased, low temperature are all -55 ℃ and high temperature are all 70℃, duration of low (or high) temperature gets temperature balance within the test bed which main consist of brake system. The test profile consists of two low temperature sections, three high temperature sections and the amplitude values of low (or high) temperature are equal to amplitude values of the design test.

- In order to obtaining test data of control box in thermal shock, proof organ binding owing volume contract or expand out of step, we control the time of test bed which consist of brake system from high (or low) temperature test box to low (or high) temperature test box within 1 min(connect process is no more than 10 min), carry out the thermal shock under temperature difference of 125 ℃.

- We proceed test according to Airline Industry Standard of P.R. China

HB5830.5E [2] level vibration spectrum （see Fig.1） on condition that from -55 ℃ nature warm up or from 70℃ nature cooling. The temperature balance time of the test bed is about 4h depend on HB6-71-76[3] that is heavy about 80kg, test effect under temperature change is equal to under colligate environment.

- Increase the magnitude value of high temperature, low temperature and vibration stresses not only achieve purpose of reliability test combine with life test, but also have fine effect to excite incipient fault.

4.1.2 The Technology on Increase Frequency of Working Stress

We analysis to consider that the break system has many functions, there are coincidence relation between import amplitude of working stress and output property of the brake system, if we increase import amplitude of working stress, will cannot establish failure criterion, hence the method of addition amplitude of working stress is not applicable for the brake system. Inasmuch as the bottle necks are sensing for dynamic working stress and speed of loading or uninstall, so have condition of working frequency acceleration. We define the frequency fuzzy in state of critical loading for the break system is n_1, real working frequency n_2 is obtained by the task profile, and the working frequency of the acceleration test is n_s, $n_1 > n_s > n_2$. The method of increase working frequency is applied in the reliability measure test (test time 1h act for working time 2h) and in the reliability growth test (test time 1h act for working time 25h).

4.1.3 Testing Technique Applied Working Stress of Dynamic

Because failures occur in working process, bottle necks of the brake system may be not occurring failures before long in case of applied quiescent working stress. But the organ binding, electric parts breakdown, possible overload damage etc can be accelerated excitation in applied working stress of dynamic amplitude, in order to define and eliminate these incipient fault, the reliability test has to be conducted in working state, it is applied working stresses which are dynamic load. These dynamic load are: The electric current value changes from (0～40) MA, voltage changes from (0～28.5±10%) V according to antiskid rule, there are three pulsation hydraulic pressure stress: 21MPa, 10MPa, 3MPa, of which the time that switch on or break off 21MPa hydraulic pressure by solenoid valve is less than 0.05s. Velocity sensors of aircraft wheels are loaded by shift dynamo which are simulation wheel speed of rotation.

4.1.4 Test Technology for Contamination Tolerance

Since cumulative contamination, many failures occur in precise hydraulic product. We proceed the contamination tolerance test within the reliability growth test for solve this question. The dustiness of oil in the break system is excel GJB 420A 8 class[4] in use, we increase the dustiness to GJB420A (9～12) class, the brake system is split into some states of no filter, and setting up filter its accuracy is10 μ, 7 μ etc in turn, mechanism of nozzle flapper within the servo valve is suitable changed, the contamination stresses are applied by their combination. We assay dustiness of the oil which sample time is 100 times takeoff-landing in output of oil box, input and output of the servo valve and brake equipment. We monitor property of the brake system in the test process, define contamination tolerate after the test is completed.

One cycle on test profile （omit） of reliability measure test is 50 equipment-hours, which is equivalent to 100 working hours or 125 times takeoff-landing. One circle on test profile (see Fig .2)of reliability growth test is 16 equipment-hours, which corresponds to 400 working hours or 500 times takeoff-landing.

4.1.5 Technology of Design Refinement for Bottle Necks

- The design refinement of fine structure and filter has been completed to aim at low cycle fatigue damage in the servo valve.
- The material formula of hydraulic pressure transform valve is improved, the wear life is extended.
- The design refinement of anti pollution have been finished in the hydraulic subsystem, the contamination tolerance is extended.

5 Test Effect

5.1 Test Effect of Reliability Measure Test

5.1.1 The Time of Proof Test

We have finished proof test according to test profile that is 20 equipment - hours and 2800 times hydraulic scragging (amplitude value of hydraulic stress is 21MPa that switch on or break off by solenoid valve within 0.05s) on low temperature condition after we have finished the design refinement of servo valve, there is better effect.

5.1.2 Failure Data of The Reliability Measure Test

Failure data collection of the reliability measure test see table 1.

5.1.3 The Test Effect Analysis of Reliability Measure Test

The failure in Table 1 Order 1 is excited only 100 times working; the time of solenoid valve switch on or break off is no more than 0.05s, the filter within servo valve bear alternation hydraulic shock which the amplitude is 21MPa, so it occurs low cycle fatigue damage at -55℃. According to fracture analysis of the filter itself cracked by shock of scavenge tension. Servo valve is no failure in design test which the pressure amplitude is 21MPa and hydraulic shock is proceeded 5000 times on general test bench, prove that the test technology possess evidence effect to excite incipient fault.

The failure in Table 1 Order 2 is the reappearance of order 1; the failures of Order 3 and order 4 are correlated with cumulative contamination.

The object matter of reliability growth is uplift anti contamination capacity of the brake system which is definitude by reliability measure test.

5.2 The Test Effect Analysis of Reliability Growth

- The test time is 200 equipment hours after adopt acceleration technology, which equivalent to 5200 working hours/6500 times takeoff- landings.
- We simulate undetected in use on condition that apply dynamic working stress and contamination stress, it is uncleanness the oil on trial, and we monitor property of the brake system. The failure in left chamber of the servo valve is excited that the brake pressure is less than index value after the test is proceed 400 working hours/ 500 times takeoff-landing, and dustiness of the oil is GJB420A 10 class (demand the anti contamination capacity of the brake system is GJB420A 8 class). It is showing that periodic to clear oil is very important to pollution prevention.
- The cycle of clear oil is 200 times takeoff-landing from 500 times takeoff landing to 3375 times takeoff-landing ((3375-500) times takeoff-landing =2875 times takeoff-landing are conform with rule of 2.3 multiple MTBF of GJB1407),

there is no failure in test, prove that reliability of the brake system has evidence growth on condition that there are specified dustiness and defined servicing.

- The brake system is proceeded contamination tolerance test in each class of contamination stress at 3375 times takeoff-landing, the brake system is recovery normal working as oil dustiness from GJB420A12 class cleaning to GJB420A 9 class and filter precision of the system upgrade to 7μ etc, from 3375 times takeoff-landing to 6500 times takeoff-landing there is no failure in test, and the reliability growth test is truncated. Cumulate contamination life of the brake system reaches 2750 times takeoff-landing, from where we obtain the test data to define the contamination tolerance.

- The brake equipments within wheel are excited 9 times failures of leaking since O-ring seals are split (they are no leaking in design test) on low temperature, we analysis consider that seal malformation under alternating hydraulic pressure shock, and the plasticity of O-ring seals are build down in low temperature, so these O-ring seals are split by trough rim in testing. Hence we have had design refinement for charge formula and seal construction, in next test of 1750 times takeoff-landing the two brake equipments are all no failure. We overhaul the two brake equipments which the O-ring seals are all perfect. Operating life of the brake equipment reaches 1000 times takeoff-landing as empirical coefficient is 1.5.

- Anti pollution life of the brake system is in effect prolong on condition that accuracy of the system filter increase to about 1/6 clearance between nozzle flapper within the servo valve and the hydraulic subsystem is finished design refinement for anti pollution which the output pressure of the brake system has a little change.
- The test time is 200 equipment hours, act for 5200working hours/6500 times takeoff-landing, there is salience effect of saving time and cost.

6 Valuation of Reliability Growth

6.1 MTBF Evaluation of The Brake System

Working stress amplitudes are no exceed technical code in test, the test time is shorten but cumulate working times is not change after adopt testing technical of acceleration stress, so the failure criterion is no change, hence we may not establish acceleration model to deal with test data. Continuous reliability growth is realized by continuous improve, have condition of adopt AMSAA model.

6.1.1 Test Data Use for Statistical Calculation

We define the experimental data use for statistical calculation. According to GJB1407 define the test time of no-failure is: MTBF (times takeoff-landing) × 2.3 times = 2875 times takeoff-landing, the brake system occur 1 time contamination failure at 500 times takeoff-landing, truncate time of the test delay to3375 times takeoff-landing. The environment condition of the reliability measure test and reliability growth test are homology, serve the purpose of data of statistical calculation. The truncate time of the reliability measure test and growth test are: (1825+3375) times takeoff-landing = 5200 times takeoff-landing, cumulative time of the fifth failure is: (1825+500) times takeoff-landing = 2325 times takeoff-landing, see Table 2.

6.1.2 Calculation Result of The Test Data

Take the confidence level $\gamma = 0.9$, we calculate the MTBF of the brake system according to GJB1407 formula B1～B11

(AMSAA model) obtained: point estimate of the MTBF is 3010 times takeoff-landing, confidence lower limit coefficient $K_L(5,0.9)=0.352$, confidence upper limit coefficient $K_U(5,0.9)=4.517$. So the interval estimation of the MTBF is:

$MTBF_L=3010\times0.352=1059$ times takeoff-landing.

$MTBF_U=3010\times4.517=13596$ times takeoff-landing.

Reliability growth rate is 0.65.

Interval estimation of the MTBF is converted into working hour:
$MTBF_L=848h$, $MTBF_U=10877h$.

6.1.3 Contrast of MTBF Between Beginning of Reliability Growth and End

- We take failure data from table 1 number 1～2 to calculate MTBF, as confidence level is 0.9, $MTBF_L=28h$, $MTBF_U=506h$.

- After is adopted a series of failure correct action, MTBF of the brake system is increased from 28 h to 848h, is 30 times before reliability growth.

6.2 First Overhaul Period Evaluation for New Electromechanical Products

The first overhaul period of brake valve, switch valve and servo valve etc has all achieved 1250 times takeoff-landing when the empirical coefficient is 1.5.

7 Conclusion

- We carry out the test process of acceleration stress on condition that simulation working state, since the failure criterion is not change, so the test method is available to proceed the reliability growth test for electromechanical-hydraulic system.

- Design refinement for increasing capability of anti contamination and shock resistant on fine structure of servo valve, improvement charge formula and material formula, improvement performance on hydraulic subsystem etc had been proceeded in test process, the capability on anti contamination of the brake system is improved greatly which had been proved by the testing of contamination tolerance and test hop .

- It is successful for adopting test technical which are increase magnitude values and duration of some environment stresses, simulation working of brake system, increasing working frequencies and proceeding contamination tolerance test to study the technology of acceleration stress reliability growth.

Table1 Faults Analysis of Servo Valve (Contain Repair Data, Test Time: 2002 year, Life Unit: Times Takeoff-landing)

No	1	2	3	4
NR	047	088	088	024
Storage time	100	225	375	1825
Fault mode	Not brake before takeoff	Not loose brake	Disable loose brake	Disable loose brake
Fault reason	Filter failure	Filter failure	Heap pollute	Heap pollute
Deal action	Change	Improve filter	Stiffen filter	Stiffen filter
Ambient	-55℃	Vibration		

Table2 Collect of Failures Data (Life Unit: Times Takeoff-landing)

Cumulate Test time	Is or no Failure	Data origin
100	1	See table 1
225	1	See table 1
375	1	See table 1
1825	1	See table 1
2325	1	Reliability growth test
5200	0	Reliability growth test

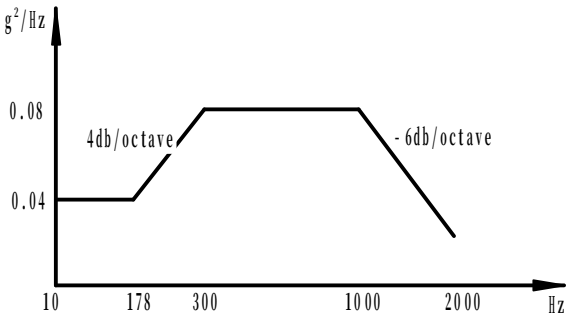

Fig1 Wide-Band Random Vibration Spectrum of HB5830.5E Level

Reference

[1] Military Standard of P. R. China. GJB1407-92, *Reliability Growth Test*. 1st edition, 1992.

[2] Airline Industry Standard of P.R. China. HB5830-82, *Environmental Condition and Test Method of The Equipments in Aircraft*. 1st edition, 1982.

[3] Airline Industry Standard of P.R. China.HB6-71-76. *Environmental Test Method of Dynamo and Electric Appliance in Aircraft*. 1st edition, 1976.

[4] Military Standard of P. R. China. GJB420A-96. *Solid Particle Contamination Classes for Fluids in Aircraft Hydraulic System*. 2nd edition, 1996.

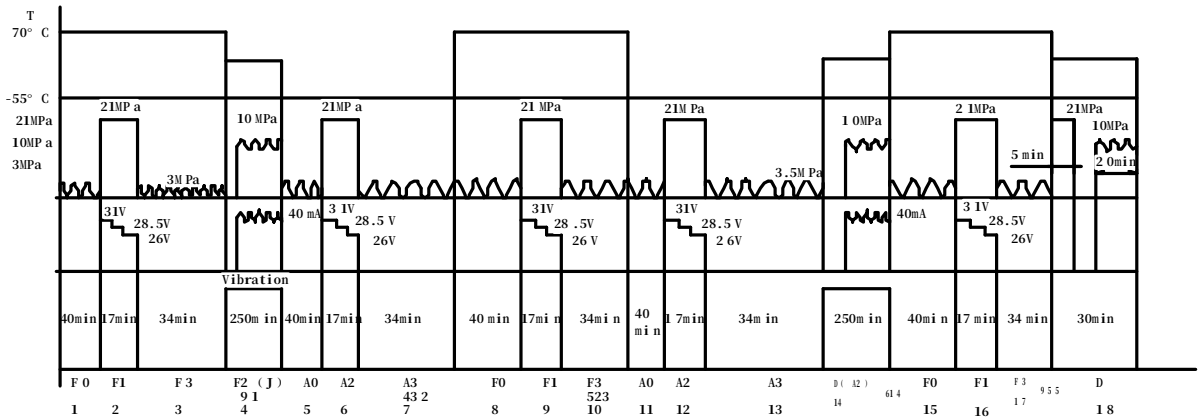

Fig.2 Test Profile of Reliability Growth for Carbon Wheel Brake System(Cycle 13 Times)

Indication:

F_0, F_3, A_0 and A_3 Intervals: Working times of brake valve is longer than design life times (simulate differential brake of the aircraft on ground).

F_1 and A_2 Intervals: Working times of solenoid valve is longer than design life times when the voltage is 31V, 28.5V and 26V (simulate takeoff line brake of the aircraft before takeoff).

F_2(J) and D(A_2) Intervals: Working times of anti-skid brake system is longer than design life times, working time is 125min and vibration time is 250min, brake valve is brake state (simulate the states of takeoff rolldown and anti-skid brake of the aircraft).

D Interval: Performance checking for the brake system. We monitor performance of the brake syatem in each interval of the profile.