Article ID: 1003 - 6326(1999)04 - 0814 - 04

Failure and limit energy of aircraft brake pairs①

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Abstract: The test methods of the limit energy of aircraft brake pairs and the confirming methods for their failure were introduced. The test results of the rejected take-off (RTO) of brake pairs were analyzed. It is confirmed that the failure reality for brake pair is the destruction of the friction materials. Therefore, after the limit energy test of brake pairs, three criteria for their failure were put forword. The definition of the maximum brake pressure and the selection of the initial test energy were introduced. The products of USA and domestic substitute of brake pairs for Boeing 737 airplane were tested by these methods. The test results show that the limit energy of brake pairs can be determined by 2 or 3 experiments, thus the test cost is reduced.

Key words: aircraft brake pairs; brake failure; limit energy tests **Document code**: A

1 INTRODUCTION

According to the documents of the airworthiness recently issued by Civil Aviation Administration of China(CAAC), if use the domestic brake pairs as a substitute for those produced by USA, UK or other developed industry countries, they should satisfy not only the airworthiness of CTSO-C26c[1, 2], but also the limit energy of imported brake pairs. So, the limit energy of both the imported and the domestic brake pairs must be tested seriously. According to the recommended test methods of the limit energy, at least two sets of brake pairs must be tested for many times. Because these tests are conducted under the conditions of high speed, high pressure and high temperature due to friction, every test will produce harms to the equipment such as hydraulic pot and tire. It is important to seek a new test method to decrease test time as possible as we can to get the limit energy data, to reduce harms to the equipment and to lower the test cost. In this paper, in order to find such new method, the melting and the peeling extent of friction materials, the variation characteristics of the brake moment curve occurred in the rejected take-off(RTO) tests and the friction behaviors of the failed brake pairs are studied and analyzed.

2 BRAKE FAILURE AND ITS CRITERIA

According to the recommended test method of the limit energy, limit energy and brake failure are interrelated. Only when brake pairs fail with 5 percent of energy increasing, the limit energy can be determined. In the past, most of researchers focussed on the friction materials[3~5], only a few studied brake failure. Recently, some achievements have been obtained in this aspect[6,7]. Ref. [6] defined the failure as the brake moment does not rise with increasing the brake pressure. The failure was often resulting from the destruction of friction materials, which are porous, usually containing low melting point metals (such as Cu, Sn) and lots of nonmetals(such as graphite), comparing with steel couple material, their strength and melting temperature are much lower. When the applied energy load exceeds the limit load of friction materials (in rejecting take-off test, due to no proper selected materials or excessive energy, it could occurr), for the effect of the friction drag and high temperature, on one hand, materials will be destroyed by oxidation, plastic deformation

① Received Sep. 13, 1999

and recrystallization; on other hand, because of melting and adhering resulting from high temperature, material structure changes completely[8], at last, friction property will decrease perpetually. In the meanwhile, the late part of the moment curve decreases rapidly; sometimes sudden decrease even occurs. So, during the limit energy test, the failure of brake pairs are determined by the following criteria:

(1) After the limit energy test, subsequent test is conducted on the basis of the former designed landing brake parameters, if the energy absorbed by brake pairs is unable to meet the energy of the designed landing brake, it means the brake pairs fail.

(2) During the limit energy test, if the late part of the moment curve decreases rapidly or suddenly, the brake pairs are confirmed to fail.

(3) After the limit energy test, if the severe melting and peeling of the friction materials occurs, it means the brake pairs has failed.

When selecting criterion (1), merely through designed landing brake test, the brake pairs could be ascertained whether they fail. So criterion (1) is better than the other two criteria.

3 LIMIT ENERGY TEST

The main parameters of limit energy test are brake velocity, brake pressure, initial energy and negative acceleration. In order to make brake pairs absorb enough energy during the test, it is necessary to apply high velocity, large brake pressure and small negative acceleration. However, test equipment has limited brake velocity, and friction characteristic between the tire and the flying wheel has confined brake pressure. According to CTSO-C26c, negative acceleration cannot be less than $1.829\ m/s^2$. So, when the parameters were selected, all aspects of the parameters must be considered, and the initial energy and the brake pressure among them are the most important factors.

3.1 Conforming maximum brake pressure of no sliding of tire

During limit energy test, the friction characteristic between the tire and the flying wheel confines the brake pressure, so, the maximum brake pressure is applied only when the tire doesn't slide. It is necessary for the pressure test to apply short-time braking. Increasing pressure begins with the designed landing brake pressure until the tire slides. The maximum pressure before sliding is the brake pressure when the tire dosen't slide. When the limit energy test is done, smaller brake pressure is applied, and then the pressure increases until the maximum brake pressure.

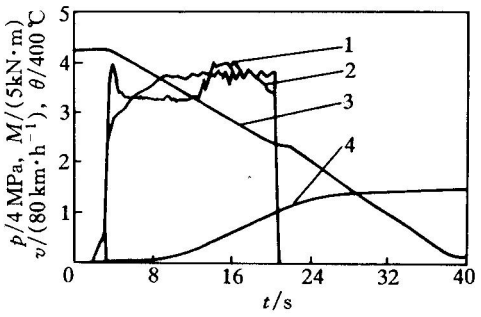

Fig.1 Test curve of unfailed imported product by limit energy test
Absorbed energy 54.2 MJ, brake time 18.6 s
1—Brake pressure, p; 2—Brake moment, M; 3—Brake velocity, v; 4—Temperature, θ

3.2 Selecting initial energy

It is important for the limit energy test to select the initial energy. Too high energy might lead to brake pairs failure, thus, the limit energy couldn't be sought, and another brake pairs must be used. Too small energy makes test times increase, equipment destroy and test expenses rise. According to CTSO-C26c, when the energy in RTO test reaches the kinetic energy $E_{K.RT}$, of the rejected take-off, it is necessary for brake assembly to slide. $E_{K.RT}$ is not sure to be the limit energy of brake pairs. Whether the brake pairs fail, and provided they do not be destroyed and blocked, brake assembly could be used to slide. Though $E_{K.RT}$ is not sure to be the limit energy, the difference between them could not be large. So, the amount of the initial energy in the limit energy test is determined by RTO test. $E_{K.RT}$ is calculated by the kinetic energy formula, according to the maximum take-off

mass, take-off velocity and the number of wheels with brake pairs.

3.3 Test procedure of limit energy

According to the limit energy requirements and test parameters selected by the above methods, brake pairs are tested. During the test, when the energy absorbed by brake pairs reaches the initially selected energy, it is forced to discharge pressure and to cool. After the test, they are disintegrated and examined to confirm whether they failed. If the brake pairs fail, according to the time of the sudden drop of the moment curve, the time of failure and the energy value are determined. Then the test parameters are revised and another brake pairs should be tested. If it is difficult to determine whether brake pairs fail, test must be done by criterion (1). If brake pairs do not fail, test must be made by increasing 5 percent of energy each time than the former one until the brake pairs fail. When the corresponding energy is the limit energy of the brake pairs, then another brake pairs will be used to verify.

4 LIMIT ENERGY TEST OF IMPORTED BRAKE PAIRS AND DOMESTIC SUBSTITUTES OF BOEING 737 AIRPLANE

According to the kinetic energy formula, the kinetic energy $E_{K.RT}$ of RTO of Boeing 737 airplane is 51 MJ, and the designed landing kinetic energy $E_{K.DL}=23$ MJ. Test was conducted by the above limit energy test method. The results are listed in Table 1. It is known from Table 1 that three times and one set of brake pairs are necessary for the imported brake pairs to find their limit energy. Another set is used to verify the results according to the requirement in the airworthiness. The number of test was just once more than the best. The best test is that for first time the brake pairs didn't fail, but for second time they failed after 5 percent of energy increasing. The brake moment curves of limit energy test with regard to the imported and domestic brake pairs are shown in Figs. 1 ~ 4. Compared Fig. 1 with Fig. 2, it is obvious that the late part of moment curve of failed pairs decreased rapidly in Fig. 2. Through designed landing condition testing, the energy absorbed by failed brake pairs in Fig. 2 is just 12.2 MJ, but the energy absorbed by unfailed brake pairs in Fig. 1 is 23.3 MJ. The disintegrated results are shown in Fig. 5. Friction materials of the failed brake pairs are severely peeled and melted, (as shown in Fig. 5(a)), and those of the unfailed brake pairs locally are peeled and melted, (as shown in Fig. 5(b)). These are consistent with the results to determine whether the brake pairs fail. It is known by comparing Fig. 3 with Fig. 4 that though brake pairs didn't fail, the late part of moment curve decreased faster with the test energy increasing.

5 CONCLUSIONS

(1) The failure reality for brake pairs is the destruction of the friction materials.

(2) After the limit energy test, failure can be confirmed according to the amount of the energy that is absorbed by the brake pairs in the test under the condition of the designed landing brake.

(3) The energy of rejected take-off test can be taken as an important basis for selecting the initial energy in limit energy test.

(4) It is possible for the methods studied to determine the limit energy of brake pairs through

Table 1 Results of limit energy test of imported brake pairs and domestic products

Brake pairs number	Absorbed energy/MJ	Failure state	Absorbed energy/MJ	Failure state	Absorbed energy/MJ	Failure state	Limit energy/MJ
No.1(imported)	54.2	unfailed	57.5	unfailed	60.7	failed	60
No.2(imported)			57.4	unfailed	60.5	failed	60
No.3(domestic)	57.8	unfailed	60.5	unfailed	63.5	unfailed	>63
No.4(domestic)			60.6	unfailed	63.4	unfailed	>63

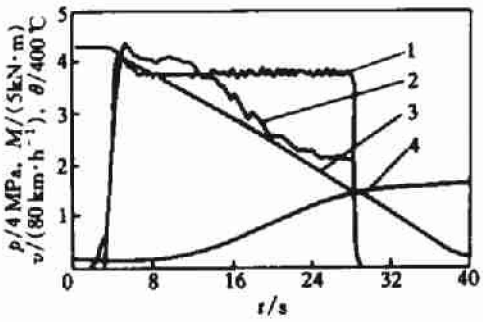

Fig.2 Test curve of failed imported product by limit energy test
Absorbed energy 60.5 MJ, brake time 26.4 s
1—p; 2—M; 3—v; 4—θ

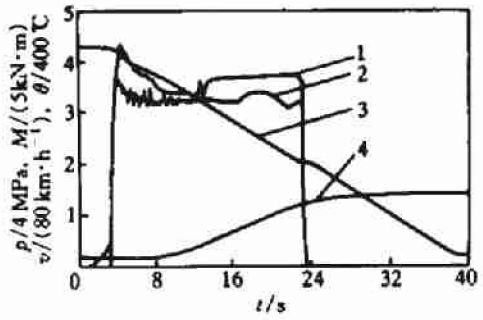

Fig.3 Test curve of unfailed domestic product by limit energy test
Absorbed energy 57.8 MJ, brake time 20.6 s
1—p; 2—M; 3—v; 4—θ

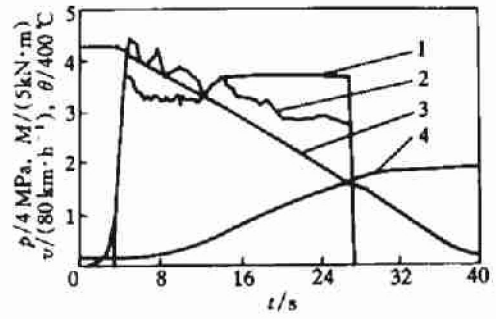

Fig.4 Test curve of unfailed domestic product by limit energy test
Absorbed energy 63.5 MJ, brake time 24.8 s
1—p; 2—M; 3—v; 4—θ

2 or 3 tests, and the test cost will be reduced.

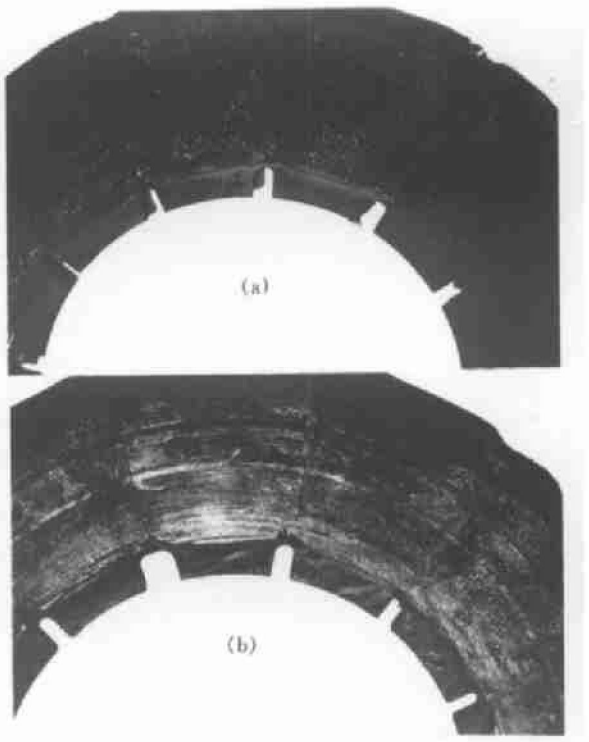

Fig.5 Surface morphologies of failed (a) and unfailed (b) friction materials

REFERENCES

1 CAAC. CTSO-C26C-92 Aircraft Wheels and Their Brake Assemblies, (in Chinese). Beijing: Chinese Civil Aviation Press, 1992: 10～18.

2 CAAC. Aircraft Airworthiness of Civil Aviation Administration of China, (in Chinese). Beijing: Chinese Civil Aviation Press, 1994: 141～144.

3 Li D S, Tan Q C, Song M D *et al*. Materials Engineering, (in Chinese), 1997, (4): 36～39.

4 Zhang Z M and Liu H Y. Journal of Central South University of Technology, (in Chinese), 1997, 28(4): 359～362.

5 Yuan G Z and Zhang Z S. Non-metal Ore, (in Chinese), 1999, 22(2): 47～48.

6 Yan Y E and Wang H H. Mining and Metallurgy Engineering, (in Chinese), 1997, 17(2): 68～72.

7 Ho S W, Ho D, Wu K F *et al*. Advances in Powder Metallurgy, 1991, 5: 229～236.

8 Fedrochenko E M *et al*. Modern Frictinal Materials, (in Russian), Translated by Xu Yunze, (in Chinese). Beijing: Metallurgical Industry Press, 1983: 149～158.

(Edited by Huang Jinsong)