TEST AND CONTROL SYSTEM DEVELOPMENT AND APPLICATION OF LANDING GEAR DROP TEST RIG

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Abstract: A control and test system of a landing gear drop test rig is developed considering the drop test specifications for the "Seagull 300" multi-functional amphibious airplane. In order to realize the automation of drop test process, a servo system is proposed and programmable logic controller(PLC) technology is used. Several key technologies for measuring the horizontal load, the vertical load and the transient rotational speed are studied. According to the requirements of CCAR-23-R3, the drop test of landing gears of the "Seagull 300" airplane is accomplished. Test results show that the system has a high accuracy of data collection. The system is stable and reliable. The drop test satisfies the requirements of the drop test specifications and the results can be used as the certification of airworthiness for this kind of airplane.

Key words: drop test; test and control system; airworthiness; landing gears

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INTRODUCTION

Drop test is necessary for a landing gear design to improve the performance of buffer by adjusting the buffer system. Moreover, the drop test can be used to verify whether the overload, the buffer and the wheel run-length satisfy the design requirements and whether the structural strength and stiffness meet the expectation requirements[1]. Therefore the drop test is an important step for a landing gear to obtain the certification of airworthiness.

As the rapid development of aeronautical industry, the drop-test technology has been given more attention, and a number of key technologies have been broken through. Benjamin and Francis studied the behavior of the conventional type of oleo-pneumatic landing gear during the process of landing impact in 1952[2]. Daughetee studied the drop testing naval aircraft and the VSD landing gear dynamic test facility in 1974[3]. William studied the F-106B airplane active control landing gear drop test performance in 1990[4]. Douglas presented a summary of the testing and the analysis used to quantify the expected airbag landing loads for the Mars Exploration Rovers in 2004[5]. Shi studied the influence of imitation condition of spin-up and spring back drag loads on drop test in 2001[6]. Zhang summarized the research of test system in the drop test in 2004[7]. In the same year, Shi studied the measurement of horizontal load subjected to the airplane undercarriage tyre[8]. Zhang studied the measurement method of the transient rotational speed of a landing gear in the drop test in 2005[9]. Chen stated the servo system for landing gear in the drop test in 2006[10].

In spite of these achievements mentioned above, the drop test lacks the airworthiness qualification specification. This paper aims to develop a dynamic system meeting the requirements of CCAR-23-R3.

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1 CONSTITUTION OF DROP TEST RIG

The aircraft landing weight, angle of attack, sink velocity at the moment of touchdown, forward velocity, wing aerodynamic force and ratio of the friction between wheel and runway are simulated. The drop test is carried out by adapting to the way of free fall. In this test, the effective dropping weight which consists of the landing gear, fixture, hanging basket and additional weights is instead of the weight of drop system in the simulation. The ways to adjust the fixture of landing gear and the height of the drop test are respectively used to simulate the angle of landing attack and the sink velocity. The reverse rotation of wheel at a preset velocity and the concrete flats are respectively used to simulate the horizontal landing velocity of aircraft and the surface of pavement.

The vertical drop test system with no simulation lift system consists of the platform system, the low friction sliding system, the wheel turning speed system, the impact platform system and the acquisition system, as shown in Fig. 1.

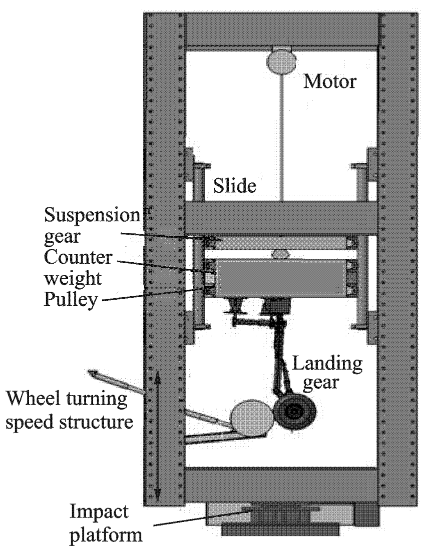


Fig. 1 Drop test rig for landing gear

2 DESIGN OF CONTROL SYSTEM

The general mechanical and hydraulic systems are most adopted in the past drop test control system. It has many shortcomings, such as a great loss of transient rotational speed for landing gears, the low efficiency of control system and the poor reliability, especially the lack of the airworthiness qualification specification. In this paper, the control system of drop test uses OMRON CP1H PLC and the software platform of King View to run the mechanical and hydraulic system to realize the more stable and reliable visual operation. This reduces the emergence of control hysteresis and improves the reliability.

2.1 Control procedure

The whole control system consists of the hydraulic system, the up and down mechanism, the structure of turning speed and telecontrol. The steps are shown in Fig. 2.

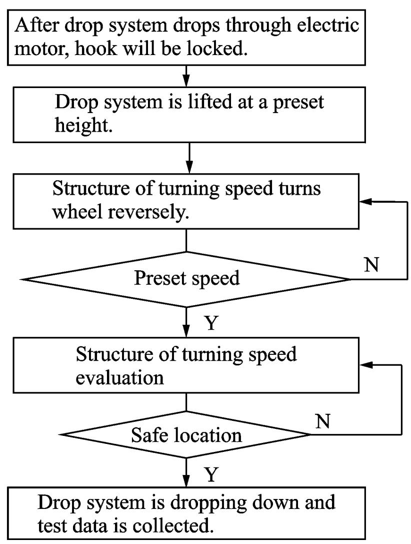
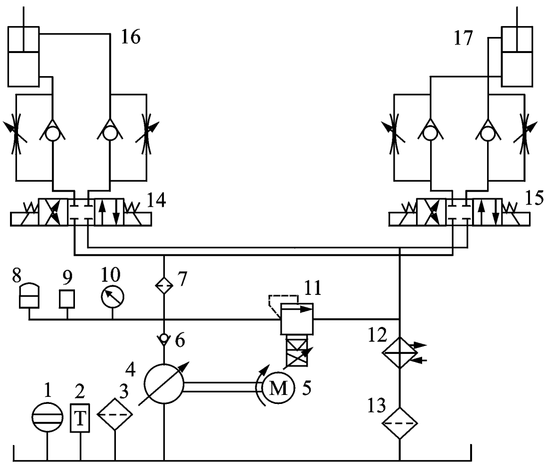


Fig. 2 Control procedure of drop test

2.2 Design of hydraulic system

Original design parameters: The pressure of hydraulic system is 21 MPa; The maximum flow is $Q_{max} = 20$ L/min; The time of protracting the structure of turning speed is 8—20 s and the time of withdrawal is 1—3 s. The maximum effective diameter of actuator cylinder is 24.62 mm; The maximum stroke of actuator cylinder is 400 mm; The biggest load is 10 000 N; The temperature is −50—50 ℃; And the pressure of oil sump tank is 0.15 MPa.

The hydraulic mule is based on the original mule and the action time is designed according to the requirements of the drop test. The longest stroke accords with the adjusting and the limited height for the landing gear and the simulation of CATIA. The biggest load of actuator cylinder is acquired from the dead-weight of the turning speed structure, the requirements of the test and the contact force between the friction pulley and the wheel. The original design parameters are shown in Fig. 3 and the technical index is shown in Table 1.



1. content gauge; 2. thermometer; 3. air cleaner; 4. ram pump; 5. pump motor; 6. check valve; 7, 13. filter; 8. accumulator; 9. pressure transmitter; 10. pressure gage; 11. electromagnetic relief valve; 12. chiller; 14, 15. electromagnetic directional valve; 16, 17. servo valve

Fig. 3 Hydraulic system

Table 1 Major technical index of hydraulic system

Parameter	Technical index
Pump motor/kW	1.5
Hydraulic pump $P_{\max}$/MPa	20, Dextrorotation
ystem rated flow Q/(L · min^{-1})	20
Control voltage V_{DC}/V	24

2.3 Design of operating platform

The core of PLC control system is PLC programming, adapting an OMRON CP1H-XA40D programming with CX-Programmer of 7.3rd version. The computer is connected with CP1H by RS232, the type of Host Link, 9600 Baud rate for port, 7 bit even parity check. The software of King View of 6.5th version is used to monitor the process of the drop test, as shown in Fig. 4. There is no need to aid any other equipment to realize the interaction with computer. All I/Os of the input and output signals are adapted to the photoelectric isolating equipment.

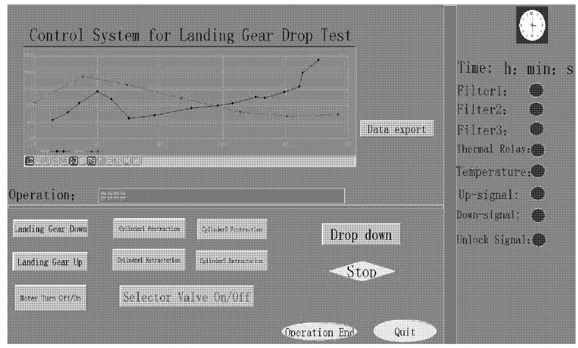


Fig. 4 Operating platform for drop test

Several measures consisting of the safety of unblinking, turning speed, failure of sensor and others are set in the program. Just as when the turning speed structure reversely turns the wheel at a preset speed, there is no permission that the landing gear is broken down by pushing the structure ahead, which is defined as invalid operation. When the wheel is turning at a preset speed, the landing system does not drop down until the structure is set at a safe location. There is an interlock between the movement that the up and down system rises the landing gear and the preparation that the structure of turning speed pushes ahead.

2.4 Exception handling

In the drop test, the exception handling of control system is as follows: The pressure anomaly of hydraulic system, warning from the software, which can be checked by whether the pressure that the gauge shows reaches the preset one; The excessive heating of circuit, alarmed by PLC, checked whether thermal dissipation works well; The block age, cleaned impurity of hydraulic circuit; The circuit fault of hydraulic system and mechanical system, which is set power-off protection, checked the spread of voltage of control loop.

3 DESIGN OF TEST SYSTEM

Nowadays, the number of test parameters, precision and the test equipment of drop test have been improved in domestic. However, the poor ability of anti-interference, the low level of visualization and the poor general usability also exist. In this paper, the system of impact test data acquisition with 48 channels and corresponding sensors are used to realize high-precision, good tracking performance and a high level of visualization. The parameters, such as the vertical load, the horizontal load, the vertical displacement, the axial decrement of buffer and the decrement of tyre should be acquired respectively in the drop test.

3.1 Transient rotational speed test

The turning system turns round the wheel in the opposite direction in order to simulate the horizontal velocity of aircraft and the horizontal velocity of wheel is based on Eq. (1).

$$N = \frac{60V_x}{2\pi R} \tag{1}$$

The rotational speed of wheel should be measured by noncontact photo-sensor and grating tray. Then the variation curve of rotational speed of wheel can be measured by time counting. As shown in Fig. 5, because the room of the wheels is compaction, the directed sensor and grating tray are not suitable to install here. Therefore the reflective sensor is applied and the grating tray is replaced by the grating patch, which are uniformly distributed in the wheel.

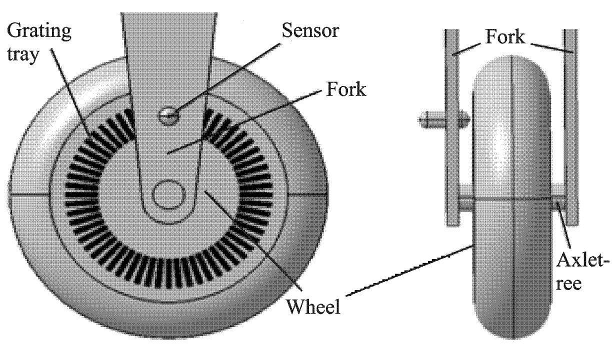


Fig. 5 Measuring transient rotational speed of wheel

In the drop test, the instantaneous velocity of dropping is different from the velocity for the moment of wheel impacting on the platform, due to the damping force of wheel. As shown in Table 2, the contrast of drop speed and impacted speed in the drop test for the landing gear is listed. It can be seen that the speed of wheel is decreasing, and how much the speed of the wheel decreases is decided by different kinds of landing gear and different initial speed. In the moment of the wheel impacting the platform, the wheel velocity declines rapidly due to the friction between the wheel and the platform. The change of speed in drop test provides important reference value for construction and maintenance of airport pavement.

Table 2 Loss of wheel speed

Drop height/ mm	Drop speed/ (r • min^{-1})	Touched speed/ (r • min^{-1})
250	1 021	928
300	1 050	937
350	1 368	1 243
380	1 402	1 284
400	1 514	1 350
410	1 567	1 367

3.2 Horizontal load test

In domestic, the horizontal load and the vertical load are measured by drop platform which is supported by three points. In this paper, the platform is supported by four points and the impact platform is constituted by three layers. As shown in Fig. 6, the upper layer filled with concrete is used to simulate the runway. Four sensors to measure heading load are installed alongside with the upper layer and the other four sensors to measure side load are installed alongside with the middle layer. The bottom layer is supported by four pillars and there are four sensors in them. There are circular guide grooves which are perpendicular in the interface. The steel balls are used here to keep point contact and reduce the friction, applying the upper layer sliding to the course and side direction.

After turning, the rotating wheel of landing gear drops on the platform, and friction force is produced which is the horizontal load of the wheel. It is difficult to measure the friction force directly, so the indirect method is used. The mechanics model is shown in Fig. 7 and the heading

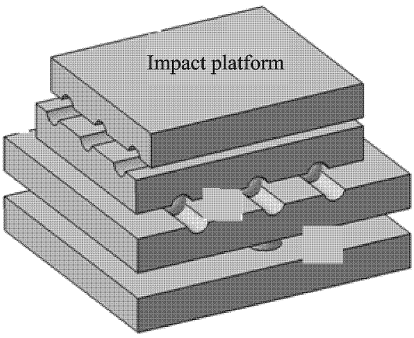


Fig. 6 Measuring flat for landing gear drop

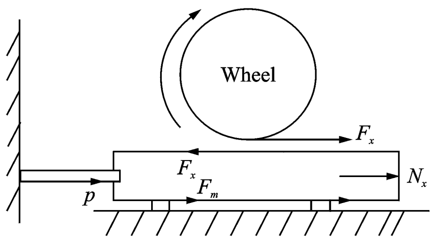


Fig. 7 Horizontal mechanical model of platform

load can be shown in Eq. (2)

$$F_x = p(t) + F_m(t) + N_x(t) \tag{2}$$

where $p(t)$ is the tension-compression load of platform in the drop test, $F_m(t)$ the total friction force between platform and the four supported pillars, and $N_x(t)$ the inertia force of platform.

The tension-compression load $p(t)$ is measured by the heading sensors. The inertia force of platform $N_x(t)$ ($N_x(t) = m * a(t)$) is measured by the sensor of horizontal acceleration speed, which is installed in the centre of a side. The total friction force $F_m(t)$ can be measured through many methods before the test, which can also be acquired theoretically by measuring the friction factor between steel balls and platform, and the vertical load imposed on the platform.

$$F_m = aP_x + bP_z + c \tag{3}$$

where P_x is the horizontal load and P_z the vertical load. Bring Eq. (3) to Eq. (2), and then the horizontal load will be computed.

3.3 Vertical load test

Before the measurement of vertical load, assume that the platform and the steel balls are both rigid bodies. Four sensors are symmetrically installed under the laminate of platform. When the landing gear drops on the platform, the impact load of the wheel is passed by the platform and the steel ball gained from the sensors, as shown in Fig. 8. The conversion relationship between the vertical load of wheel and the load measured by the sensors is based on the theorem of static force balance Eq. (4).

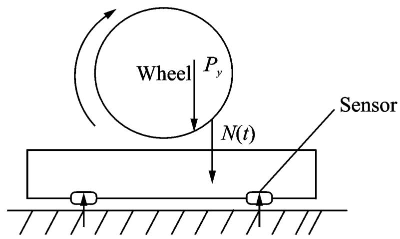


Fig. 8 Vertical mechanical model of platform

$$F_y(t) = P_y(t) + ma(t) \tag{4}$$

where $F_y(t)$ is the vertical load of wheel, $P_y(t)$ the resultant force measured by four sensors, m the mass of platform, and $a(t)$ the vertical acceleration. Generally speaking, the sidewise load of wheel is light, so there is no need to measure.

3.4 Axial compression of buffer and wheel compression

The drop test is to verify whether the buffer system satisfies its capacity of absorbed energy and the wheel compression satisfies the requirements of design. According to the original parameters of the buffer pillar stroke and the wheel stroke, a cable-type displacement sensor is installed between basket and pillar to measure the vertical displacement (h) of basket center, and another sensor is installed at the end of buffer to measure the compression (δ) of the buffer. The wheel compression can be obtained from the vertical displacement (h), the compression (δ) and the strut front angle of landing gear which is also the angle of attack.

3.5 Data collection of drop test

Data of drop test is collected by the system of impact test data acquisition with 48 channels, concurrent working, 100—512 kHz frequencies from Nanjing University of Aeronautics and Astronautics, as shown in Fig. 9. Table 3 gives the equipment needed in the drop test.

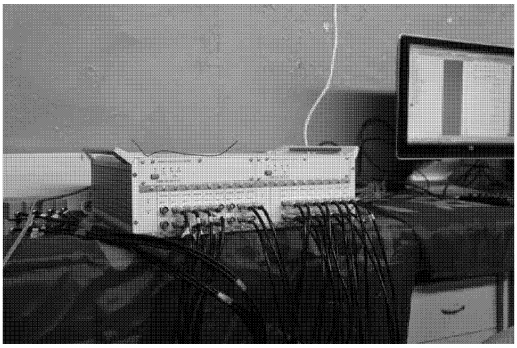


Fig. 9 Measuring instrument

Table 3 Measuring instrument and their precision

No.	Equipment	Type	Precision	Quantity
1	Collection system	DH5927	0.5%	1
2	Force sensor	5114	0.1%	8
3	Acceleration sensor	DH311	0.1%	2
4	Displacement sensor	DH801	0.5%	2
5	Speed sensor	DH5640	0.3%	1
6	Electronic scale	OCS	2 T/0.2 kg	1

4 APPLICATION

"Seagull 300" is a light multi-functional amphibious civil airplane. It is necessary for the landing gear to take the drop test under the certification of airworthiness. The drop test of the landing gear is divided into three parts, the adjusting parameters drop test, the limited drop test and the reserve energy absorption drop test of the landing gear.

Adjusting the filling pressure of buffer and wheel, the diameter of the major oil hole and one-way oil hole makes the property of buffer to be the best in the adjusting parameter drop test. The result of adjusting is shown in Table 4. The diameter of oil hole is so small that the maximum vertical load 17 245 N exceeds the limited load of design, yet the compression of buffer is 118.8 mm and the efficiency of buffer is 60.5%. After the adjusting test, when the diameter of the major oil hole is 4.2 mm and the diameter of one-way oil hole is 2.5 mm, the result is the best, as shown in Fig. 10. In this drop test, the system capacity and the vertical load factor are within the range of design. According to the limited drop test, the coefficient of inertial load is smaller than the coefficient of design. The reserve energy absorption drop test shows that the landing gear is not damaged.

Table 4 Result of adjusting parameter drop test

No.	Subject	Origin		Final	
1	Drop height/m	410	410	410	410
2	Wheel speed/$(r \cdot min^{-1})$	1 365	1 365	1 365	1 365
3	Effective weight/kg	325	325	325	325
4	Major oil hole diameter/mm	3.2	4.0	4.2	4.5
5	One-way oil hole diameter/mm	1.6	2.0	2.5	2.5
6	Oil volume/cm^3	342	342	342	342
7	Wheel pressure/MPa	0.4	0.4	0.4	0.4
8	Air chamber pressure/MPa	0.6	0.6	0.6	0.6
9	Buffer compression/mm	118.8	135.7	155.8	158
10	Vertical load/N	17 245	16 766	14 996	13 587
11	Vertical load factor	4.4	3.9	3.6	3.2
12	Measured capacity/J	1 925	1 936	1 985	1 980
13	Capacity error/%	−2.1	−1.6	0.9	0.7
14	Buffer efficiency/%	60.5	62.7	69.2	69.5
15	System efficiency/%	53.3	57.7	59.0	60.4
16	Friction factor	0.65	0.54	0.71	0.55

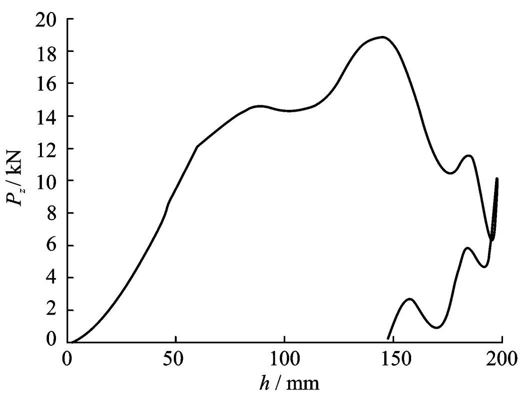


Fig. 10 Bumper capacity of reserve energy

5 CONCLUSION

Landing gear control system realizes the free fall drop test with high column-free imitation lift and passes the certification of airworthiness. The control and test system finishes the adjusting parameters drop test, the limited drop test and the reserve energy absorption drop test of the "Seagull 300" airplane, and realizes the simulation of aircraft landing and test.

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飞机起落架落震试验测控系统开发与应用

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摘要:针对“海鸥300”飞机起落架落震试验的技术要求,研制了起落架落震试验测控系统。提出飞机起落架落震试验电液伺服系统的设计方案,采用可编程式逻辑控制器(PLC)技术实现了试验过程的自动化,解决了起落架落震试验机轮水平载荷、垂直载荷、机轮转速等测量技术难点。根据CCAR-23-R3要求,完成了“海鸥300”起落架落震试验。结果表明:试验系统工作稳定可靠,数据采集精度高,符合“海鸥300”飞机起落架试验技术要求,可作为其飞机适航取证的依据。

关键词:落震试验;测控系统;适航;起落架
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