

Research on measurement of aviation magneto ignition strength and balance

Feng Gao, Zhixiang He* and Dingpeng Zhang

China Civil Aviation Flight University of China, Aviation Engineering Institute,
Guanghan 618307, China

*Corresponding author e-mail: 290870224@qq.com

Abstract. Aviation magneto ignition system failure accounted for two-thirds of the total fault aviation piston engine and above. At present the method used for this failure diagnosis is often depended on the visual inspections in the civil aviation maintenance field. Due to human factors, the visual inspections cannot provide ignition intensity value and ignition equilibrium deviation value among the different spark plugs in the different cylinder of aviation piston engine. So air magneto ignition strength and balance testing has become an aviation piston engine maintenance technical problem needed to resolve. In this paper, the ultraviolet sensor with detection wavelength of 185~260nm and driving voltage of 320V DC is used as the core of ultraviolet detection to detect the ignition intensity of Aviation magneto ignition system and the balance deviation of the ignition intensity of each cylinder. The experimental results show that the rotational speed within the range 0 to 3500 RPM test error less than 0.34%, ignition strength analysis and calculation error is less than 0.13%, and measured the visual inspection is hard to distinguish between high voltage wire leakage failure of deviation value of 200 pulse ignition strength balance/Sec. The method to detect aviation piston engine maintenance of magneto ignition system fault has a certain reference value.

1. Introduction

Along with the fast-growing aviation business, the quickly increasing number of multi-purpose aircrafts in operation leads to more failures and maintenance demands of aviation piston engine. During the maintenance of aviation piston engine, the failure of aviation magneto ignition system is frequently encountered, accounting for two thirds or more of aviation piston engine failures ^[1]. Nevertheless, visual inspection is often practiced to test the aviation magneto ignition strength due to technical limitations ^[2]. By visually observing and comparing whether there is spark and how strong it is at each spark plug at various rotational speeds of magneto, visual inspection offers an approach to rough judgment about whether the ignition system has intermittent spark, continuous spark or weakening spark, but it cannot quantify the specific ignition strength and the equilibrium and deviation of ignition strength at each spark plug. For this reason, visual inspection may easily miss the disequilibrium of ignition strength at each cylinder, which may cause a series of problems severely threatening the safety of flight such as uneven cylinder firing pressure or no cylinder firing, speed drop, shaking, significant power drop and unstable operation of aviation piston engine during flight.



Therefore, the test of aviation magneto ignition strength and its equilibrium has become a technical issue to be urgently resolved during the maintenance of aviation piston engine.

2. Aviation Magneto Ignition System

Aviation magneto ignition system is mainly composed of aviation magneto, high-voltage conductors, starting switch, starting oscillator, and spark plugs, etc. Its structure is given in Fig. 1. During normal operation, aviation magneto is driven by piston engine to operate. After a certain rotational speed is reached, aviation magneto will generate the high-voltage electricity of 15~20kV, which is distributed by a shunt through high-voltage conductors at appropriate time to the spark plug of each cylinder based on the sequence of ignition and the setting of magneto timer. In this way, strong electric sparks will be generated by high-voltage discharge inside the slight gap between spark plugs to ignite the mixture of fuel and air, which makes the piston work and drive the rotation of propeller. When the engine is started, the starting switch is turned to electrify the circuit, and the starting oscillator utilizes the onboard battery to generate the high-voltage electricity, and ignite the mixture to drive aviation piston engine. After starting, the spark plug of each cylinder ignites cyclically based on the setting of magneto timer and ignition sequence to make piston work on propeller [3,4].

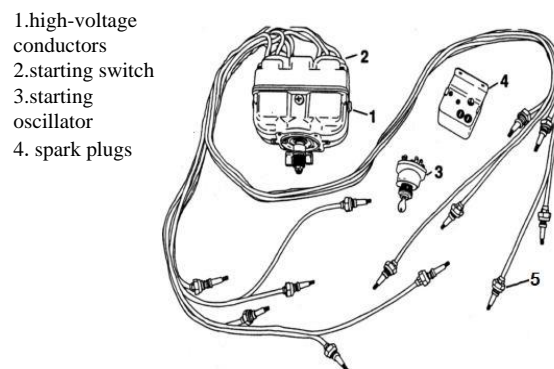


Figure 1. Aviation magneto ignition system

3. Test System Hardware Design

3.1. Design and Realization of Ignition Strength Test Module

The structural design of ignition strength test module is given in Fig. 2, including driving circuit, probe window, ultraviolet light sensing tube, and signal processing circuit [5,6]. After testing the ignition strength, ultraviolet light sensing tube outputs the test result by means of feeble pulse current. Driving circuit utilizes the switch power supply to convert 12V DC into 320V DC, so as to provide the stable working voltage for ultraviolet light sensing tube. The probe window can cluster the detection lights to improve the test sensitivity while protecting the ultraviolet light sensing tube. Signal processing circuit completes the processing of feeble pulse current signal to output the regular pulse signals as the module test results.

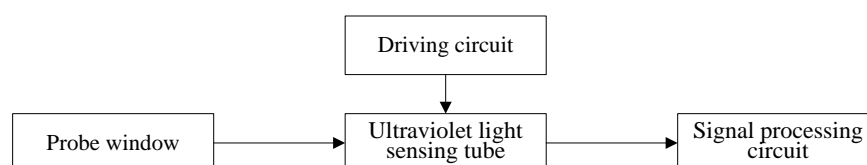


Figure 2. Module structure of ignition strength test

3.2. Speed Test Module Design

Fig. 3 presents the circuit design of speed test module, which uses SS94E linear Hall sensor and whose working voltage is 3~6.5V DC. The output voltage is linear with the magnetic field strength. The maximum voltage is 4.21V, and the minimum voltage is 0.86V^[7]. In the design, LM7805 voltage stabilizing circuit is employed to convert 12V DC of the power supply VCC into 5V DC, so as to complete the power supply for SS94E. Based on the work features of SS94E linear sensor, the magnetic field strength is linear with the output voltage. The LM393 voltage comparator is utilized to compare the voltage at the output end of SS94E with the setting voltage of slide rheostat R1. The result of comparison is output by means of OC through the output end of LM393, and output at the high/low level through pull-up resistor R2. Additionally, LED indicator lamp is also used to display the real-time change of magnetic field in the test.

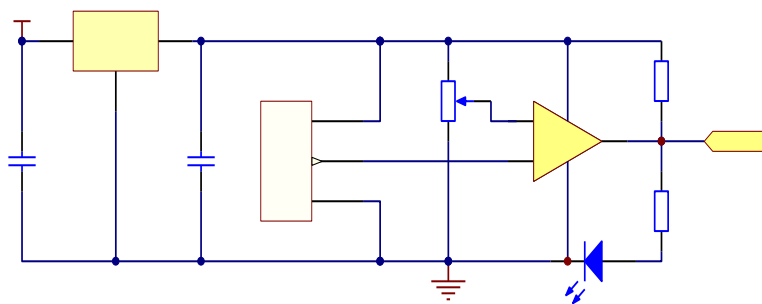


Figure 3. Circuit design of speed test module

During aviation magneto speed test, the shorter distance from the magnetic SMD on the rotating axis of aviation magneto to Hall sensor, the larger Hall voltage output by Hall sensor^[8]. By comparing the Hall voltage V_1 of linear Hall sensor SS94E with the setting voltage V_0 of resistor R1 through LM393, the comparison result V_{out} is output in the form of regular pulse. When aviation magneto rotates at a constant speed, the output Hall voltage V_1 waveform of SS94E is shown by V_1 in Fig. 4. When the Hall voltage V_1 is greater than V_0 , voltage comparator will output at the low level. When the Hall voltage V_1 is lower than V_0 , voltage comparator will output at the high level. Along with the rotation of the rotating axis of aviation magneto, the speed test module will output the regular rectangular pulse to reflect the speed of aviation magneto by means of rectangular pulse frequency [9,10].

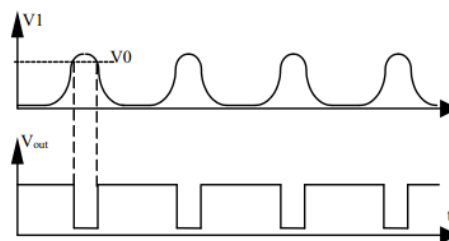


Figure 4. Output waveform of speed test module

4. System Hardware Test

System hardware test is completed by the commissioned system software that can collect, analyze and calculate the test data and display the test results in a real-time manner. During the test, motor speed test stand is employed to complete the test with speed test module, while candlelight is utilized to simulate ultraviolet light source to complete the test with ignition strength test module.

4.1. Accuracy Check for Speed/Module Tests

Motor speed test stand is used to check the accuracy of speed test ranging from 0 to 3,500rpm at the interval of 50rpm. As shown in Fig. 5, after the test system is inspected and commissioned, the speed test module is moved to face the magnetic chip on the rotating axis of stepper motor, and the speed knob on the test stand is turned to provide different speeds. Meanwhile, the speedometer among virtual instruments is observed to check the test results, which are compared with the speeds of stepper motor on its speed test stand.

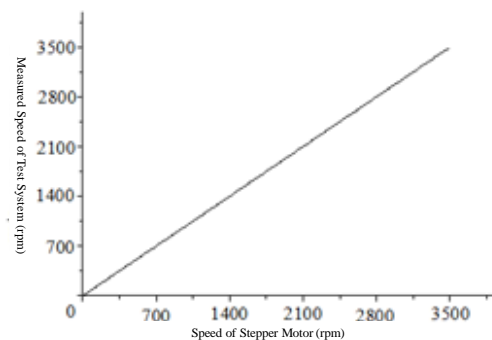


Figure 5. Stepper motor speed test result

4.2. Functional Test of Ignition Strength Test Module

During the test with ignition strength test module, sunlight and daylight are taken as the sources of disturbance to test the module's capacity of resisting disturbance. When ignition strength test module is moved to face the sunlight, the pulse output of the module is zero. When the module faces the 6,500K incandescent tube with the power of 36W under the test spacing of 0~15cm, the pulse output of the module is also zero. Hence, ignition strength test module can effectively avoid the disturbance of daylight during the test, so as to guarantee the validity of test data.

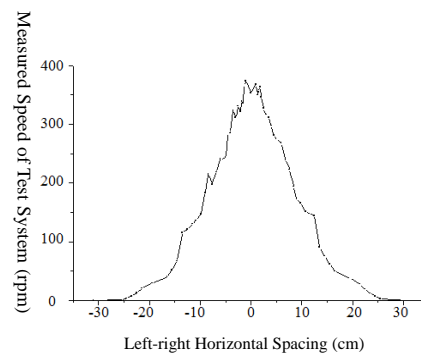
With ignition strength test module, candle, as a simulated light source, is used to: 1) test the ignition strength of the same light source under different longitudinal test spacing; 2) test the ignition strength of the same light source under different horizontal test spacing; 3) perform the overlap test of ignition strength of two light sources at fixed test points.

The ignition strength of the same light source under different longitudinal spacing is tested by taking the candlelight the ignition strength test module faces as the light source to complete the ignition strength test under the longitudinal test spacing of 5~100cm. The test results are given in Table 1. During the ignition strength test under different spacing, ignition strength test results fluctuate within a certain range of strength, and decrease along with the increase of test spacing. Hence, test should be completed under a short spacing to guarantee higher test sensitivity.

The ignition strength test of the same light source under different horizontal test spacing is performed to estimate the test angle for ignition strength test module. Taking 70cm as the longitudinal spacing, the test results under different left-right horizontal spacing are shown in Fig. 6. As revealed in the test data, ignition strength decreases along with the increase of horizontal spacing. When the horizontal spacing is 28cm, the measured ignition strength is only 0~2pulse/sec. When the horizontal spacing reaches 32cm, the value obtained in the test is zero. It is estimated that the test angle of ignition strength test module ranges from 21.8° to 24.6°. The overlay test of two light sources takes Candles A and B as the light sources, and takes the longitudinal spacing of 70cm. The test is carried out in three cases: 1) Candles A and B are lit at the same time (A+B); 2) Candle A is lit but Candle B goes out (A); and 3) Candle A goes out but Candle B is lit (B). In such three cases, 5 groups of ignition strength tests are carried out to obtain the results as shown in Table 2. In the first group of tests, when Candles A and B are both lit, the ignition strength is 614pulse/sec; when Candle A or Candle B is lit, the ignition strength is 491pulse/sec and 297pulse/sec respectively.

Table 1. Ignition strength test results under different longitudinal spacing

| Test Spacing (cm) | Ignition Strength (Pulse/Sec) |
|-------------------|-------------------------------|
| 5 | 1230~1405 |
| 10 | 1004~1120 |
| 20 | 730~830 |
| 30 | 540~620 |
| 40 | 430~481 |
| 50 | 370~402 |
| 60 | 322~343 |
| 70 | 251~263 |
| 80 | 220~231 |
| 90 | 174~192 |
| 100 | 152~162 |

**Figure 5.** The ignition strength test result in different horizontal spacing**Table 2.** Ignition strength test results under different overlay mode

| Test Group No. | Lit Candle | Ignition Strength (pulse/sec) |
|----------------|------------|-------------------------------|
| Test Group 1 | A+B | 614 |
| | A | 491 |
| | B | 297 |
| Test Group 2 | A+B | 677 |
| | A | 563 |
| | B | 264 |
| Test Group 3 | A+B | 693 |
| | A | 559 |
| | B | 327 |
| Test Group 4 | A+B | 627 |
| | A | 548 |
| | B | 252 |
| Test Group 5 | A+B | 683 |
| | A | 559 |
| | B | 261 |

In the other groups, the same way is practiced to find the same condition, that is, the ignition strength measured with ignition strength test module when Candles A and B are both lit is always lower than the sum of the ignition strengths measured when Candles A and B are lit separately.

The following conclusions are drawn based on the above tests with ignition strength test module:

(1) Based on the results of ignition strength test under different longitudinal spacing, the ignition strength of the same light source decreases when the test spacing increases. Hence, the ignition strength of each spark plug should be tested under the same or shorter test spacing during the ignition strength test of ignition system.

(2) Based on the analysis of ignition strength test results under different horizontal spacing, the test angle of ignition strength test module ranges from 21.8° to 24.6° . During the ignition strength test of ignition system, the test angle should be kept within this range.

5. Slick4372 Aviation Magneto Ignition Equilibrium Test and Failure Analysis

The test stand designed in this paper was employed to conduct the scanning test of Slick4372 aviation magneto that has passed visual inspection. The dynamic waveform of ignition strength within a test period is shown in Fig. 7. In the waveform display interface, the ignition strengths of spark plugs 1, 2, 3 and 4 are represented by the dynamic curves in four different colors, that is, blue, red, yellow and black. Also, the test data in the text box on the left can display the rotational speed of aviation magneto and the ignition strength of each spark plug in a real-time manner.

By analyzing the results of scanning test, it is concluded that: 1) The ignition strength of each spark plug increases when aviation magneto speeds up constantly within the range of 0~3,500rpm. During the process of acceleration, the ignition strength of each spark plug fluctuates, and the maximum difference between its amplitude of fluctuation and average measured value has reached 100 pulse/sec; 2) After the speed reaches 120~150rpm, sparks appear at each spark plug; when the speed is 0~2200rpm, the ignition strength of each spark plug fluctuates dramatically, but the difference between their ignition strengths is less than 40pulse/sec; 3) When the speed is around 2,200rpm, as show in Fig. 7, spark plug 3 has lower ignition strength that the other three. Along with the increase of speed, the difference is more noticeable, and the maximum difference has reached to 65 pulse/sec.

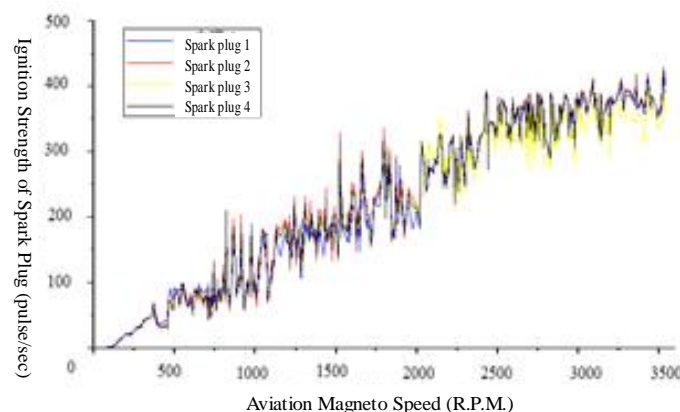


Figure 7. Slick4372 aviation magneto scanning type test result

Scanning test can check the work status of aviation magneto at different speeds within 0~3,500rpm. However, when offline test stand motor drives aviation magneto at variable speeds, it cannot improve the working capacity rapidly, causing unstable instantaneous high voltage of aviation magneto ignition, and dramatic fluctuation of ignition strength test results. To improve the accuracy of test data and conduct fault diagnosis, different points must be selected for speed test, and test must be completed at a constant speed for aviation magneto ignition strength and its equilibrium. When the speed of Slick4372 aviation magneto reaches 2,200rpm, the difference of equilibrium is more noticeable along with the acceleration. Hence, constant speed test takes 2,050rpm as a test point as well as 3,150rpm and 3,350rpm as test points, which have noticeable difference of equilibrium.

6. Conclusion

The “solar blind” ultraviolet sensor with the detection wavelength of 185~260nm and the driving voltage of 320V DC is taken as the core instrument for ultraviolet detection to detect the ignition strength of aviation magneto ignition system as well as the equilibrium deviation of ignition strength at each cylinder. As verified by test, the detection system has the test deviation less than 0.34% within the speed range of 0~3,500rpm, and its error of calculation in the ignition strength analysis is less than 0.13%. Thus they satisfy the designed requirements of the system. In the field test of project, the test system detects the equilibrium deviation of ignition strength, that is, 65 pulse/sec, which is caused by the minor change of spacing between distribution station and distribution arm, and not easily found by visual inspection. Also, it can detect the ignition strength equilibrium deviation of 200 pulse/sec, which is caused by the leakage fault of high-voltage conductors, and not easily identified by visual inspection, this approach provides a valuable reference for detecting the failure of magneto ignition system during the maintenance of aviation piston engine.

Acknowledgments

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