Design of Joint Test Device for Fuel Delivery Shut-off Valve

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Abstract. In view of the fact that the new aircraft units were used, it was common to lack the fuel accessory inspection equipment, a set of combined test equipment for fueling and fuel delivery shut-off valve was designed. The basic work of the fuel delivery shut-off valve was introduced, the composition and principle of fueling test system and electric control system were described, and the realization methods of the hardware and software were given. The practical application shows that the test equipment can meet the test requirements of this type of fuel accessories, fully meeting the design goals.

1. Introduction
The fuel delivery shut-off valve (referred to as the shut-off valve) is the core control accessory of the baby fuel delivery system of certain types of aircrafts. The main functions of shut-off valves include: (1) when the baby is fully fueled normally or in emergency during pressure fueling, the shut-off valve cuts off fuel fueling path; (2) when the fuel in the baby of the machine is exhausted, the shut-off valve cuts off fuel delivery path automatically to prevent the dangerous fuel spills caused by failing to cut off the fuel circuit in time.

The monitoring of the baby pressure on the surface of the aircraft is automatically executed by a shut-off valve located on the fuel line, the performance of which has significant impact on the security and reliability of the aircraft fueling and transportation system. Thus, special performance testing is required on a regular basis in the daily maintenance of the aircraft. However, the lack of land performance testing system for the shut-off valve obstacles the repair work of the aircraft. In that case, we design and develop an fuel delivery shut-off valve testing system for target aircrafts, which demonstrates the capacity for all kinds of performance testing and fully meets the design requirements.

2. Working principle of shut-off valve
The basic structure of the shut-off valve is shown in Figure 1. It mainly consists of a case, a fueling control component, an oil delivery control component, a valve component and an emergency announcator.

The case is installed with a fueling joint A and a delivery joint D; the fueling control component consists of a fuel electromagnetic switch 1 that control the fueling status, and a check valve; the oil delivery control component is composed by a delivery electromagnetic switch 2 that controls the delivery status, and a check valve 5; the valve component mainly include a large valve of rubber diaphragm 4, a check valve 5, a spring, etc., which controls the switch of main channel; the emergency announcator mainly consists of a shutter, a spring and a micro switch, controlling the emergent cut-off of fueling status. The basic working principle is described in the follows text.
2.1. Pressure fueling state control
When the aircraft fueling normal pressure fueling to the baby through the shut-off valve, it is in a high flow rate. The delivery electromagnetic switch 2 keeps open and the fueling electromagnetic switch 1 is energized to open. Then the fuel of the aircraft fueling control path flows downstream through the path a-b-c-d-e-f, so that the pressure of Q chamber is lower than the pressure of B chamber. The large valve of rubber diaphragm 4 opens under pressure, leading fuel flow to the baby of the aircraft through A-B-C-D to complete pressure fueling. When the baby is full, the full fuel annunciator in the baby sends a power off signal to control the shut-off valve of the fueling electromagnetic switch 1 to be powered off, closing port e. And the fuel is guided into the Q chamber through flow a-b-c, balancing the pressure between the Q chamber and the fueling inlet chamber B. Under the action of the spring 6, the large valve of rubber diaphragm 4 is closed to stop the fueling.
If the full fuel annunciator in the baby fails to send control signal, the fueling process may continue. Then when the pressure of g port reaches 0.08 MPa, the shutter compression spring in the emergency annunciator 9 will opens the micro-switch, so that the fuel-operated electromagnetic switch 1 is turned off and the fueling is stopped.

2.2. Fueling status control
It is in a small flow working state when the baby shut-off valve supplies fuel to the aircraft. In this state, delivery electromagnetic switch 2 keeps open while the fueling electromagnetic switch 1 keeps close at gate e. The fuel is guided to flow to engine through h-c-b-a, which makes the pressure in chamber Q is lower than that in chamber C. Under the action of the pressure, the rubber valve 4 is opened, and the fuel flows to the main tank of the aircraft through D-C-B-A to achieve fuel delivery. When the baby is exhausted, the full fuel signal transmitter in the main tank sends a power-on signal to control the delivery electromagnetic switch 2 to be energized, which makes b port closed and the check valve 5 open, controlling air flows into chamber Q through port h. So that the pressure between chamber Q and transportation entrance port C equals. Then under the elastic force of the spring 6, the rubber shutter 4 is closed to prevent a large amount of air from flowing into the tank.

3. The composition and function of the fuel delivery shut-off valve test device
There are three technical standards for dynamic testing of shut-off valves: delivery flow resistance and closing time, fuel flow resistance and closing time, and fueling emergency shutdown time test. Following the technical standards, our integrated test device is mainly composed of a fueling test system and an automatic control system.

3.1. Fueling Test System
According to the technical standards of the shut-off valve, the composition and working principle of the shut-off valve test system is shown in Figure 2. Since the flow of fueling is about 9 times of transportation flow, they cannot share the same pump source. So the fueling system has three separate components: fueling, delivery and flow resistance test. When performing fueling and delivery performance tests, the flow resistance test section must be connected to pressure point X and pressure point Y.

**Figure 2.** The composition and working principle of the shut-off valve test system.

By setting the large and small flow pump, the performance of the shut-off valve can be detected, which is fueling and delivery flow, pressure and pressure loss when passing shutting off valve. Therefore, there are quantitative requirements for the flow capacity and pressure of the system, and it's required to be able to adjust the flow capacity and pressure. We use variable frequency motor and intelligent servo regulating valve which can work coordinately to achieve fueling system flow and pressure adjustment. The closing time test of the valve is strictly executed in accordance with the definition of the navigational aid, which is real time collected by the sensor and measured by the PLC.

1) Fueling test section

The main function of fueling test section is to provide a pressurized fuel source with a rated fueling flow to the fueling joint A of the shut-off valve. For the pressure fueling test, the fueling joint A shall be imported and connected to the large pipeline of the fueling test section. Mainly composed of oil pump 3, relief valve 4, filter 5, turbine flow transmitter 8, servo regulating valve 9, electric flow-off valve 10 and accessory outlet relief valve 32. During this part of operation, the fueling electromagnetic switch is opened and the shut-off valve is energized to open, then the oil pump 3 is driven by the variable frequency motor to suck fuel from the tank 33, and the fuel is pressurized by the fuel pump and sent to the fueling port A of the shut-off valve 7. When the fuel passes through the accessory, the inlet pressure, outlet pressure and flow resistance are detected by the flow resistance test section, and
then flow back to the fuel tank through the turbine flow transmitter, servo regulating valve and electric flow-off valve.

(2) Delivery test section
The main function of delivery test section is to provide the pressurized fuel source with the rated fuel flow rate to the fuel delivery port D of the shut-off valve. During the fuel delivery test, the fuel connection connector D should be used as the inlet and connected to the small pipeline of the fuel delivery test section. So the fuel flows in reverse direction with that when fueling. The system composition is similar to that of the fueling part, except that the oil flow is small, the electric outlet valve and the safety valve are not provided at the outlet, and only one auxiliary ball valve is added to adjust with the servo regulating valve. When this part is working, the fuel supply solenoid valve of the shut-off valve does not need to be energized, and it is normally open.

The pump 13 is composed of a three-phase motor and a pipeline centrifugal pump (IHGB25-160) with continuously variable transmission. The power is 1.5KW; the rated flow is 4m3/h.

(3) Flow resistance test section
The flow resistance test section mainly detects the inlet and outlet pressure and the pressure difference, in manual or automatic modes.

In the manual test mode, it first confirms that the left oil inlet switch 28, the balance switch 29, and the right oil inlet switch 30 of the differential pressure transmitter 31 are all in the close position. When the test conditions are met, the front and rear pressures of the tested accessories are observed through the accessory inlet pressure gauge 22 and the accessory outlet pressure gauge 23. When the current pressure difference does not exceed the range of the differential pressure transmitter 31, three switches are opened according to a preset sequence: the balance switch 29 of the differential pressure transmitter, the left oil inlet switch 28 and the right oil inlet switch 30. After that the differential pressure transmitter balance switch 29 is closed. The signal of the differential pressure transmitter 31 is to PLC or the digital display to display the differential pressure of the shut-off valve value. When the flow resistance test is completed, the differential pressure transmitter balance switch 29 is opened first, and then the differential pressure transmitter left oil inlet switch 28 and the differential pressure transmitter right oil inlet switch 30 are closed.

When the PLC is working automatically, those three switches (28/29/30) of the manual function are in the close position. Three solenoid valves (25/26/27) are used to replace the work of the three switches. When the fuel flow entering the shut-off valve inlet reaches the test condition, the flow resistance value can be detected. The inlet/outlet pressure is collected by the accessory inlet pressure transmitter 21 and the accessory outlet pressure transmitter 24, respectively. And the pipeline inlet and outlet pressure difference is collected by the differential pressure transmitter 31. The three solenoid valves are controlled by the PLC according to the preset working procedure, and the inlet and outlet pressures and differential pressure values are collected in real time.

3.2. Automatic Control System
The automatic control system is based on tablet PC, PLC, intelligent regulating valve and frequency converter. It monitors and adjusts the working process of the shut-off valve, fully meeting the requirements of automatic testing, such as two-way flow, the inlet and outlet pressure difference of the accessory, the shutter opening and closing characteristics and the emergency closing characteristics.

(1) Hardware composition
The structure block diagram of hardware is shown in Figure 3. The system hardware is mainly composed of flat panel controller, PLC, servo regulating valve, electric flow-off valve, frequency converter, flow transmitter, pressure transmitter, input and output module, solenoid valve, switch button and printer. The upper computer uses an industrial tablet. The lower computer PLC and the industrial tablet calculator are applied to the electronic control system as well. Advanced sensor and actuator are also used to build the hardware foundation of the automatic control system. The logic control of the working process can be programmed and implemented by programmable controllers.
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Figure 3. The structure block diagram of hardware.

(2) Software part

The software is the core of the automatic control system monitoring hardware work. The tablet controller program is compiled by Delphi2010. It communicates serially with the PLC and other devices through the RS232 interface, and displays all the status information in the field test process in real time. The PLC program is shown in Figure 4.

Figure 4. The PLC program.

4. Technical characteristics

4.1. Dual pump source settings

The fueling flow rate of the shut-off valve is relatively much larger than the transportation flow rate, the difference of which can be nearly 10 times. Therefore the test system is designed with two pump sources and a double-line test section for large and small flow. Taking into account the pressure and flow requirements of the tested components, as well as the noise, the pump source consists of two three-phase frequency conversion motors and centrifugal pump.

Connect the fuel delivery port D of the shut-off valve to the inlet, and connect it to the pipeline of the fuel test part. The pipeline status is the fuel delivery state (see Figure 5(a)). The test procedure is...
designed as follows: ① energize the product fuel delivery solenoid valve, start the fuel delivery pump 13, adjust the opening speed of the fuel pump and adjust the opening degree of the fuel return valve 19 to achieve the fuel delivery rated test flow. PLC collects the fueling pressure loss (pressure difference) of the shut-off valve in real time; ② power off the fuel delivery solenoid valve. The valve is closed after receiving the electric signal. PLC collects the flow rate through the turbine flow meter and calculates the valve fueling closing time in real time. The closing time is calculated from time of the electromagnet power-off signal, and ended when the flow rate from the turbine flow sensor is less than 15% of the rated flow rate.

![Figure 5](image_url)

**Figure 5.** Fuel delivery test process.

### 4.2. Detection of fueling emergency shutdown time

The function of shutting off the valve and fueling: When the aircraft ground pressure is fueling, if the normal full oil level control fails, the fuel oil surface continues to rise, and after the baby is full of oil, when the pressure in the baby increases to 0.08 MPa, the diaphragm in the valve is cut off. Pressing the micro-actuated electric door to close the fueling solenoid valve, the oil-removing valve is closed under the pressure of the membrane chamber, and the fueling circuit is cut off. In order to simulate the actual working condition of the shut-off valve, the design of the fueling and returning oil pipeline is to adjust the rotation speed of the fuel pump 3 through the frequency converter to close the outlet pressure of the oil pump and the shut-off valve after the electric oil return valve 10 is used to close the fuel returning oil circuit. When the outlet pressure reaches 0.08 MPa, the valve should be able to be shut down in an emergency, and the PLC collects the flow value in real time through the turbine flow meter and calculates the emergency shutdown time.

### 5. Conclusion

We have designed and implemented a fuel delivery shut-off valve test system and tested it by an aviation repair factory. The evaluation demonstrates that the fuel delivery shut-off valve test system is sophisticatedly and reasonably designed. The operating of the system is reliable and stable, and the electronic control system based on tablet PC, PLC and inverter technology is powerful and efficient. The control and test automation of the shut-off valve is also supported. In conclusion, the shut-off valve test system is not only fully functional, comprehensive, compact and safe, but also has the advantages of flexible control and convenient operation. It can complete all the performance testing of a certain type of aircraft fueling cut-off valve, and fully meets the design requirements.

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