# Modelling and Simulation of the Opening Process for the Aircraft Engine Starter Valve

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Abstract: The structure and principle of the aircraft engine starter valve with dual pneumatic actuators are introduced. Characteristics of the valve, in particular the opening behaviours are analysed using mathematical models. The butterfly valve opening process under different inlet pressure is simulated on AMESim simulation environment. By comparing with test data, the model is proved to be accurate and reliable. The simulation results show that inlet pressure plays an important role in the opening process. The variables of primary interest are the rotating angle and time of the butterfly valve. In the dual actuators architecture, the valve requires less inlet pressure to rotate the butterfly disc full open and has higher reliability during aircraft operational cycle.

## 1 INTRODUCTION

When starting a gas turbine aircraft engine such as turbojet, turboshaft and turbofan, rotation of the compressor to a speed is required to provide sufficient air to the combustion chamber. The starting system of the engine often utilizes pressurized air to drive a turbine at high speed. This turbine applies a torque to the engine high pressure rotor system through a reduction gear in the (starter) turbine and through the engine accessory drive system. The air which is necessary to drive the starter comes from the built-in auxiliary power unit (APU) or the second engine or a ground power unit. In most cases, the first engine needs be started using the APU or ground pneumatic power unit. Then the remaining engine(s) can be started using cross-bleed air from the running engine.

The starter air supply is controlled by a starter valve, which closes and removes pneumatic power from the starter when the N2 speed reaches 50 percent. The turbine and reduction gears slow and the clutch disengages when N2 speed is higher than 50 percent. The starter output shaft then turns with the gearbox and engine. While the turbine and reduction gears continue to slow until they stop.

The starter valve usually is a butterfly type, pneumatically operated and electrically controlled. The civil industries offer a wide range of pneumatic valves usually equipped with a spring and driven by pneumatic-based actuators. There have been many research and development activities, including mathematical modelling, numerical simulation and experimental analysis, are undertaken in order to design and develop an advanced valve (J.T. Ahn, 2011; F. Danbon, 2000; N. Gulati, 2009; ZHU Su, 2016).

But there is a very limited amount of research on accurate dynamic modelling of butterfly valve used on aircraft engine. The airline maintenance records indicate that typical failure of the starter valve is abnormal opening, including too small open angle and too long open time (P. Naseradinmousavi, 2011). This paper conducts an investigation of the valve behaviour in the opening process. The influence of the inlet pressure on the open angle and the open time is emphatically analysed.

## 2 DESCRIPTION OF THE VALVE

Figure 1 shows a starter valve with dual actuators, which is a pneumatically operated and electrically controlled shutoff valve. The valve is composed of two major sections, the valve flow body section and the pneumatic actuator and control section. The valve flow body section consists of the flow body, butterfly plate shaft, bearings and seals enclosed in



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the valve body. The pneumatic actuators and control section consist of the controlling solenoid, diaphragms, torsion closing mechanism, shaft connecting link, actuating arm and electrical position indicating switch.

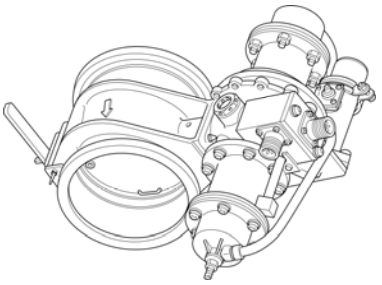

Figure 1: Starter valve.

Figure 2 shows the section schematic of the starter valve. The valve remains closed with the solenoid de-energized. Inlet air pressure is routed through a downstream facing probe and an opening rate orifice in a chamber solenoid closed by non-return valve (position shown). The pressure in opening chambers is vented to ambient through the solenoid ball and the closing-rate orifice. The pressure in chambers at opposite position of the opening chambers is vented to ambient through the vent orifices. The internal springs of the pneumatic actuators in combination with the closing torsion spring force, closes the starter control valve.

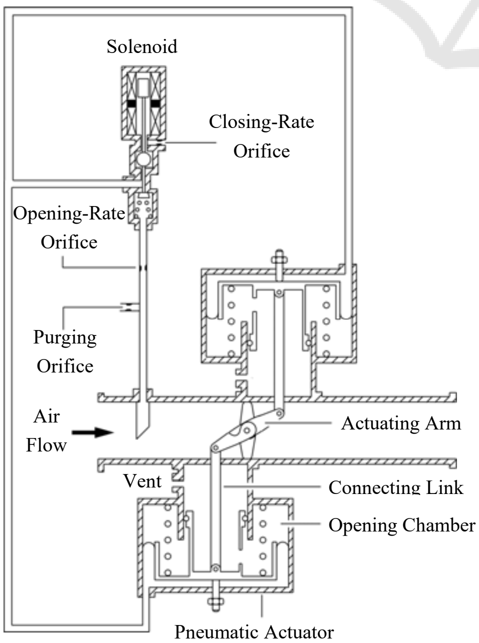


Figure 2: Starter valve section schematic.

The starter valve is opened by energizing either of the solenoid coils. Energizing the solenoid actuates the solenoid ball to the position opposite that shown and open the non-return valve. Inlet air pressure is routed in the opening chambers, then is sensed on both diaphragms and pistons of the pneumatic actuators. The pressure increases in the opening chambers and actuate the pistons when the pressure is sufficient to overcome the internal springs and the closing torsion spring. The pistons actuate to the butterfly open position. The starter air valve opening rate is controlled by the rate at which chambers at opposite position of the opening chambers vents to ambient. These rates are controlled by the open rating orifice, the purging orifice and the closing rate orifice.

The valve has a manual override capability which permits the valve to be opened or closed in case of failure of the electrical control. The starter valve is manually opened by rotating the lever because there is no diaphragm force and pressure in the pneumatic actuators. The handle can be rotated against the closing torsion spring to open the butterfly. When the handle is released, the torsion spring turns the shaft to the butterfly closed position and the valve returns to normal operation.

When the butterfly is in any position except closed, the normally open redundant electrical position switches provide remote indication. In this case the switches are actuated by the closing end of the actuator. The solenoid has two independent coils including 3 wires wound together (1 active winding per channel and 1 shunt winding to both active channels), either one of which when energized will open the valve. A relief valve is incorporated to limit the actuator pressure in the event that the inlet pressure exceeds the normal maximum value.

## 3 MATHEMATICAL ANALYSIS

### 3.1 Fluid Mechanics

When air flows through the purging orifice, opening-rate orifice, closing-rate orifice and the butterfly valve, as shown in Figure 2, it can be assumed as isentropic process, and the mass flow ($Q_m$) can be written as (SUN Muqiao, 2012):

$$Q_m = A \cdot C_q \cdot C_m \cdot \frac{p_u}{\sqrt{T_u}} \tag{1}$$

where $A$ and $C_q$ denote the area and the throttle coefficient of the flow respectively, $p_u$ and $T_u$ are the pressure and temperature of the upstream air respectively, and $C_m$ is the flow coefficient. The expression of $C_m$ is written as follows:

$$C_m = \begin{cases} \sqrt{\dfrac{2\kappa}{R_g(\kappa-1)}} \cdot \sqrt{\left(\dfrac{p_d}{p_u}\right)^{\frac{2}{\kappa}} - \left(\dfrac{p_d}{p_u}\right)^{\frac{\kappa+1}{\kappa}}}, & \left(\dfrac{p_d}{p_u}\right) > p_{cr} \\ \sqrt{\dfrac{2\kappa}{R_g(\kappa+1)}} \left(\dfrac{2}{\kappa+1}\right)^{\frac{1}{\kappa-1}}, & \left(\dfrac{p_d}{p_u}\right) \le p_{cr} \end{cases} \quad (2)$$

where $R_g$ is ideal gas constant, $\gamma$ is constant entropy index, $p_d$ is downstream pressure; and $p_{cr}$ is critical pressure ratio, whose expression is written as follows:

$$p_{cr} = \left(\frac{2}{\kappa+1}\right)^{\frac{\kappa}{\kappa-1}} \quad (3)$$

Using their corresponding parameters, Eq. (1) - (3) can be applied to calculate the mass flow for the purging orifice, opening-rate orifice, closing-rate orifice and the butterfly valve, respectively.

## 3.2 Dynamics

As shown in Figure 2, for the opening and closing process, the dynamical equation of the piston assembly in the actuator can be expressed as:

$$-m\frac{d^2x}{dt^2} = B\frac{dx}{dt} + Kx + F_a + F_i + F_t \quad (4)$$

where $m$ and $x$ are the mass and the displacement of the piston assembly respectively, $B$ the damping coefficient, $K$ the spring stiffness, $F_a$ the aerodynamic force, $F_i$ the internal spring force, and $F_t$ the closing torsion spring force.

The connecting link and actuating arm assembly, as showed in Figure 2, can be seen as the crank-connecting rod mechanism. Then the relationship between the displacement of the piston ($x$) and the rotating angle of the butterfly disc ($\theta$) can be expressed as (LI Bin, 2006):

$$x = r[(1-\cos\theta) + \frac{r}{4L}(1-\cos 2\theta)] \quad (5)$$

where $r$ and $L$ represent the length of the actuating arm and the connecting link respectively.

# 4 AMESIM MODELLING AND SIMULATION

## 4.1 Modelling

Based on the previous mathematical modelling analysis, we select the suitable component from the AMESim signal library, the machine library and the gas component design library.

According to the structure principle of Figure 2, we use three throttle holes to simulate the orifices respectively.

The displacement ($x$) of the piston in the actuator determines the rotating angle ($\theta$) of butterfly disc, and it can be measured by displacement sensor. Then we use a function to represent the relationship between displacement and rotating angle.

The models of the above parts are connected according to the schematic diagram of the system. The function between the displacement of the piston and the rotating angle of the butterfly disc is set up. Also, the input pressure and the temperature signal source are set up. Finally, the whole AMESim model of the starter valve is created, as shown in Figue 3.

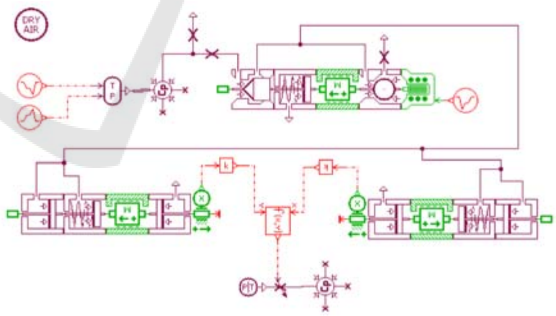


Figure 3: The AMESim model of the starter valve.

## 4.2 Simulation and Discussion

As previously mentioned this starter valve often fails due to too long open time and/or too small open angle. Therefore our main interest here is the investigation of the valve behaviour in the opening process, particularly the open time under different inlet pressures.

In the opening process, the rotating angle and time of the valve disc under different inlet pressures are given in Figure 4. The curves indicate that the time butterfly disc rotates 80° from full close, seen as an acceptable full open angle in opening process, requires less than 3s when the inlet pressure is no less than 70 kPa. Obviously this dual actuators architecture allows the actuating mechanism to produce a high torque to open the valve, compared with the single actuator valve.

Normally the upstream pressure of the starter valve is approximately 0.3MPa when engine starting, largely greater than 70kPa, the minimum full open pressure. Hence the valve can open successfully even if it is frozen with ice.

But when the inlet pressure is too low, for example 20kPa, it is not sufficient to overcome the internal springs and the closing torsion spring, and the valve will not open normally.

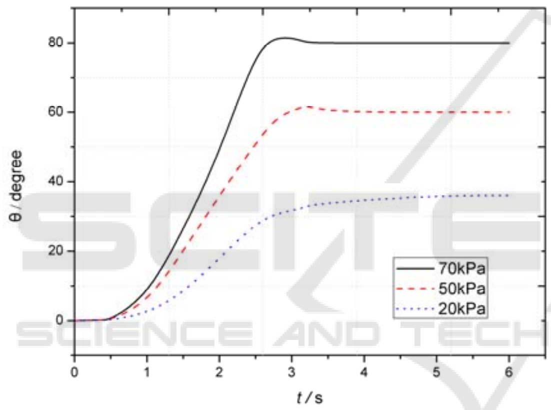


Figure 4: The open time and open angle of the valve under different inlet pressures.

Table 1 shows the comparison between simulation results and test data under inlet pressure at 70 kPa. It indicates that our model is more accurate and reliable, and is a valuable reference for pneumatically operated butterfly valve design.

Table 1: Comparison between simulation results and test data.

| Time (s) | Simulation θ (degree) | Test θ (degree) | Error (%) |
|---|---|---|---|
| 1 | 7.2 | 7.0 | 2.5 |
| 2 | 48.3 | 47.2 | 2.3 |
| 3 | 80.1 | 82.7 | 3.2 |
| 4 | 80 | 82.5 | 3.1 |
| 5 | 80.1 | 79.1 | 2.3 |
| 6 | 80 | 78.3 | 2.1 |

# 5 CONCLUSIONS

An accurate model for aircraft engine starter valve is created based on AMESim simulation environment. The opening process of this butterfly valve is emphatically investigated. The simulation results are compared with the test data. The model is proved to be correct and the simulation system is useful.

The analysis results indicate that the dual actuators architecture butterfly valve requires less inlet pressure, produces higher rotating torque, and provides higher reliability during aircraft operational cycle. But it is recommended to use the manual override lever to open the engine starter valve in severe freezing environment.

# REFERENCES

Information on https://www.faa.gov.

J.T. Ahn, K.C. Lee, K.H. Lee, and SH Han, Investigation of the mechanical behavior of a flexible solid metal seal for a cryogenic butterfly valve, Journal of Mechanical Science & Technology, 2011, 25 (9) :2393-2400.

F. Danbon, C. Solliec, Aerodynamic Torque of a Butterfly Valve—Influence of an Elbow on the Time-Mean and Instantaneous Aerodynamic Torque, Journal of Fluids Engineering, 2000, 122 (2) :337-344.

N. Gulati, E.J. Barth, A Globally Stable, Load-Independent Pressure Observer for the Servo Control of Pneumatic Actuators, IEEE/ASME Transactions on Mechatronics, 2009, 14 (3) :295-306.

ZHU Su, Fault analysis of starter valve on A320 series aircraft, Aviation Maintenance & Engineering, 2016,1:78-80. (in Chinese)

P. Naseradinmousavi, C. Nataraj, Nonlinear mathematical modeling of butterfly valves driven by solenoid actuators, Applied Mathematical Modelling, 2011, 35 (5): 2324-2335.

SUN Muqiao, SU Sanmai, CHENG Jian, SONG Ruitao, Air turbine starter presure controler modeling and numerical simulation based on AMESim, Journal of Aerospace Power, 2012, 27(2):450-456. (in Chinese)

LI Bin,YANG Chunlei, LIU Yong, Analysis on characteristics of the movement and force of crank-connecting rod mechanism, Machinery, 2006, 1(33): 10-12. (in Chinese).