Fault Study on Valve Based on Test Analysis and Comparision

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Abstract. The valve of a certain type of small engine often has the fault phenomenon of abnormal vibration noise and can’t close under the specified pressure, which may cause the engine automatic stop because of valve incomplete close leading to fuel leakage during test and startup on the bench. By test study compared to imported valve with the same use function and test condition valve, and put forward the thinking of improving valve structure, compared no-improved valve to improved valve by adopting Fluent field simulation software. As a result, improved valve can restore close pressure of valve, restrain abnormal vibration noise phenomenon, and effectively compensate compression value of spring because of steel ball contacting position downward with valve casing.

1. Introduction
As a common mechanical equipment in the flow conveying and control system, the valve mainly regulates and controls the flow rate of the fluid mass, the pressure and the flow direction to meet the requirements of the working system[1]. As the components of the hydraulic system, the variety and quantity of the valve are quite large proportion, so it is necessary to study the valve fault or failure.

At present, in order to suppress the noise is generated by the valve, the research on the valve mainly shows the theory and design of the noise[2,7], The research object is mainly for the valve shell, but few for the force of spool named functional parts, the influence analysis of flow field and fault pieces repair. So it is of great significance to carry out this research.

This type of valve mentioned in the paper often test failed and cause automatic stop failure because of being not closing fully during test on the bench, so the repair scientific research has been carried out, on the basis of structure and test comparison with the valve of introduction, put forward the technical program of the valve repair structure improvement. The valve is easy to cause the valve closed pressure deviation from the design state after use of a TBO life.

2. Structure improvement of the fault valve

2.1. Prototype valve
The prototype valve structure mentioned in this paper is shown in Fig. 1, an engine is fitted with a valve. The working principle of the valve as shown in Fig. 2, the valve assembly as shown in Fig.3, when the small engine startup to work, with the system fuel pressure increasing, the fuel begin to push the ball (spool) to overcome the spring force work, the valve will close in the fuel pressure 15kPa to
25kPa, then the system fuel enter internal of the small engine for combustion by the fuel screw. When the engine stop, the valve will gradually open, the system fuel will change the direction of flow, discharge residual fuel from the small engine casing through the valve. If the valve is vibration screaming during the work, the valve cannot be completely closed, and cannot supply the amount of fuel required for the engine to work, finally causing engine unsuccessful startup or automatically stop.

Fig.1 Schematic diagram of valve structure
Fig.2 Schematic diagram of valve work principle
Fig.3 Cross-section schematic diagram of valve assembly on the engine

The brief diagram of the prototype valve structure at work as shown in Fig. 4, the fuel flow from inlet P1 to outlet P2, when the hydraulic pressure before the steel ball (spool) is greater than the resultant force of hydraulic pressure in the casing P2 and spring together after the steel ball (spool), the ball (spool) will move back to gradually close under the fuel pressure difference, and finally inlet P1 and outlet P2 is not connected. If omit the movement friction resistance of the ball (spool), it must meet the following relationship.

\[ p_1A_1 > p_2A_2 + F_h \]  \hspace{1cm} (1)

Where, \( p_1 \) —fuel inlet pressure or control pressure, \( A_1 \) —the projection area of the steel ball in the horizontal direction under \( P_1 \), \( p_2 \) —fuel outlet pressure or controlled pressure, \( A_2 \) —the projection area of the steel ball in the horizontal direction \( P_2 \), \( F_h \) —spring force.

When the ball (spool) is just closed, the value \( P_2 \) is reduced to 0kPa, and the support force of the valve cone surface face steel ball (spool) is 0N, the amount of spring compression reaches the maximum, and the spring force reaches the maximum, then the Eq.1 becomes.

\[ p_1A_1 > F_{h_{\text{max}}} = k\Delta L_{\text{max}} \]  \hspace{1cm} (2)
Where, \( F_{H\text{max}} \) —maximum force of spring, \( K \) —spring elasticity coefficient, \( \Delta L_{\text{max}} \) —Maximum compression of spring.

It can be seen from the Eq.2, the minimum position of the spring compression is further reduced with the valve closing because of the tangential position of the steel ball (spool) and the cone surface moving downward in the valve, that is value \( \Delta L_{\text{max}} \) further increases, the spring force increases, the right side of the Eq.2 becomes larger, when reaches a certain amount, the Eq.2 may not exist to establish.

\[ \text{Fig.4 Schematic diagram of valve simplification symbol} \]

2.2. Sprototype failure valve
During the repair process, the valve parts are further disassembled and checked. Under the premise of spring and ball qualified, it is found that there was a slight tendency to increase the cone angle of the inner surface of the valve, as shown in Fig. 5. After analysis, the reason is that the material for the stainless steel ball repeatedly collision and contact with the cone surface inside the aluminum shell during valve use a TBO time, because the material of aluminum shell is soft, the collision process can cause micro-deformation, resulting in tangential position of the steel ball and cone surface downwards, the amount of spring compression increased, causing the spring force much more when the valve closing, the corresponding fuel closure pressure also increased.

\[ \text{Fig.5 Comparison schematic diagram of steel ball tangent to valve casing} \]

2.3. Improved valve
Compared with the valve of introduction and the prototype valve with both the same function of use and the same parameters of test, the steel ball (spool) technical status of two kinds of valve are the same, the difference is mainly as following, First, the spring of the introduction valve is in three groups, but the spring of prototype valve only one, Second, the shell depth of introduction valve is about 1.0mm deeper than the prototype valve. To sum up the reasons above, the pressure adjustable range of introduction valve is wider, and the shell is deeper, spring compression deformation amount is relatively small, which explains test pass rate of the introduction valve is much more than the prototype valve.

According to the above analysis, in order to restore the function of the failure valve, the spring or the shell must be improved, but because the processing of spring improvement is complex, so we can refer to the depth size of the introduction valve shell, processing 1.0mm deep for the prototype valve shell. At the same time, repair and surface treatment the cone surface of the failure valve, the processing flow chart of improved valve is shown in Fig. 6.
In order to avoiding depth processing of the shell is too large, and the valve closing pressure is less than the lower limit of the technical documents, in the specific engineering applications, only the upper limit of the valve closing pressure as a reference object to calculate the amount of processing, the depth processing amount of the shell as following.

$$\Delta L = \frac{(P_1 - 25) A_1}{K} \quad (0 < \Delta L < 1.0\text{mm})$$  \hspace{1cm} (3)

In the Eq.3, $P_1$ is the unqualified pressure measurement value when the valve is closed.

### 3. Simulation analysis of internal flow field before and after Improvement of Valve

#### 3.1. Physical model establishment

According to the product structure, the establishment of steel ball (spool) valve model shown in Fig. 7, and grid shown in Fig. 8. Set the steel ball (spool) opening value is 0.3mm at actual work, when the fuel inlet pressure $P_1$ is 20kPa, under 20°C fuel temperature condition, the dynamic viscosity $\mu = 2.500\text{N} \cdot \text{s} / \text{m}^2$, density $\rho = 0.785 \times 10^3\text{kg} / \text{m}^3$. Fluent software is used to respectively simulate analysis and compare flow field before and after the valve improvement, the simulation is steady-state simulation, and total iteration 20 thousands steps.

#### 3.2. Set boundary condition

**Inlet boundary:** opening $x = 0.3\text{mm}$, pressure inlet $P_1 = 20\text{kPa}$;

**Exit boundary:** pressure outlet $P = 0\text{kPa}$ (relative pressure).

The process of the ball (spool) opening from the maximum rapid drop to 0.3mm and the valve on the fuel blocking are abstracted same as transient flow in the opening 0.3mm of the valve, transient simulation is based on stabilized simulation and initial condition for iterative calculation.
3.3. Analysis results of flow field

It can be seen from Fig. 9 and Fig. 10, when the opening of the steel ball (spool) is 0.3mm, the inlet fuel is encountered by the steel ball, making the hydraulic pressure contact with the steel ball (spool) is the largest, while the speed is the smallest, because of continuous inflow of inlet fuel into the valve casing, making the fuel into the channel between the steel ball (spool) and the cone surface, finally expansion to discharge, so the pressure is continuous reduced to the minimum, speed continues to increase, and finally to the maximum.

It can be seen from Fig. 9 and Fig. 11, when the opening of the steel ball (spool) is 0.3mm, the fuel is contracted and expanded inside the valve because of the obstruction of the steel ball (spool), causing the fuel to be compressed before the steel ball and forming partial high pressure zone, while the fuel to be expanded after the steel ball and forming partial low pressure zone, because of the influence of the cone taper and the spherical geometry of the steel ball, the fuel is separated at the edge of the rear surface of the valve channel, resulting in eddy current, and the turbulence intensity increases first, then decreases, finally reaches the strongest in the valve cone channel because of throttling.

At the same time, it can be seen that the pressure cloud diagram, velocity cloud diagram and turbulence intensity are almost unchanged before and after improvement of the valve, that is compared with before improvement of valve, when the opening degree is the same as before the improvement, improved valve does not affect and change the original internal flow field distribution essentially. Therefore, in the valve closed fuel pressure recovery and improvement, the key consideration to eliminate the extra spring force is mentioned, indirectly proved that the Eq.3 is similar to the actual rationality, that is, the results of calculation is consistent with the actual compensation trend.

(a) Before improvement

(b) After improvement

Fig.9 Comparision cloud schematic diagram of total pressure
4. Test content and comparison analysis

4.1. Close pressure test comparison
Respectively select a new shell of the introduction valve, a new shell of domestic prototype valve, a failure shell of domestic prototype valve and a improved shell of domestic prototype failure valve that processing depth 1.0 mm, have valve closed tests for 30 times respectively, the test results as shown in Fig. 12.
Test result of Fig.12 shows that, closing pressure test of the new part of domestic prototype valve is qualified, after use a TBO time, under the premise of the spring, steel ball technical state meeting the original design requirements, the valve closing pressure becomes larger and beyond the technical documents value 15kPa to 25kPa, proved that cone surface of the shell changed in the course of use, at last affects the valve pressure. Closing pressure test of the improved valve is qualified, It is proved that the improvement of the depth of the shell can improve the closing pressure of the valve, and the improvement measures are effective. At the same time found that as long as the valve closing pressure is qualified, vibration & screaming phenomenon will be disappeared in the test process.

4.2. Test verification
Select the three pieces of failure valve, under the premise of the spring mechanical properties, the appearance quality of the steel ball qualified, calculate the amount of processing of the valve shell by the Eq.3, have the test for 50 times respectively, select the average closing pressure to test data comparison, as shown in Table1 and Fig.13.

| valve No. | unqualified closing pressure(kPa) | processing amount(mm) | average closing pressure(kPa) |
|----------|----------------------------------|------------------------|-------------------------------|
| 1        | 27.5                             | 0.25                   | 23.1                          |
| 2        | 29.0                             | 0.30                   | 23.4                          |
| 3        | 30.0                             | 0.33                   | 23.5                          |

Fig.12 Schematic diagram of different valve close test

Fig.13 Schematic diagram of no-improved valve close test compirison to improved

The results of the test results in Table1 and Fig. 13 show that the processing amount of the valve carried out according to the Eq.3 can achieve the normal closing of the valve, and reflect the reason that the valve closing pressure is less than 25kPa compensation because not considering the friction and hydrodynamic forces of the steel ball (spool) in the Eq.3 [8], but the hydrodynamic force in the actual working process is the same direction as the steel ball (spool), and is greater than the friction
force, that is to say, the hydrodynamic force urges the spool to close, So the actual closing pressure value is actually less than the theoretical compensation target value 25kPa. At the same time found that vibration & screaming phenomenon of the valve disappeared during the test process. Installation the three valves for the test, three types of small engine all can successfully startup, performances are stable and the valve can normal open or close. After the test run, inspected and found no damage on the cone surface of three valve shells.

According to the test results, the root cause of the failure is that the steel ball in the valve repeatedly contact with the shell cone surface in the work process, the shell comes up micro-deformation because of collision, the tangent position of the steel ball and the shell moves downwards, opening range of the valve becomes widened, and resulting in instability of the valve work.

5. Conclusion

Through the test comparison, the following conclusions are drawn:

1) The failure analysis of the valve is reasonable, the formula deducted of the valve processing is effective, more accurately reflect the work of the valve characteristics.

2) Improved valve can effectively solve and compensate for the problem of tangent position moving downwards of the steel ball (spool) and the cone surface.

3) Through the test, the test parameters of the improved valve are verified. Through the comparison of the test, the closing pressure of the improved valve is less than the prototype valve and the failure valve, but still higher than the introduction valve.

4) The improved valve can meet the functional test requirements, stable work and reliable performance in the process of use, so the effect of improvement is obvious.

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