A new solenoid valve application in smart toilet

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Abstract. Solenoid valve is an important part of smart toilet, which plays a very important role in smart toilet products. The influence of comprehensive performance for solenoid valve on the quality of smart toilet is detailed analyzed, the structure of new solenoid valve is designed, comprehensive performance testing system of the solenoid valve is developed, and comprehensive performance for new solenoid valve is tested by using testing system. The test results prove that the new solenoid valve has good comprehensive performance; meanwhile, it also verifies the generality and reliability of comprehensive performance testing system of the solenoid valve.

1. Introduction
With the development of intelligent technology, the smart toilet is popular all over the world; there are still many problems in smart toilet, which can not satisfy customer demand. Solenoid valve failure is one of the most critical issues. Common problems of solenoid valve are: do not flush, do not stop, leakage, etc. The main reasons are listed as follows: cooperation degree of the control system and the solenoid valve is not high, structure design of the solenoid valve is not reasonable, and the filter screen in the triangle valve is not installed; which can lead impurities into the solenoid valve and cause solenoid valve failure.

The future development direction of smart toilet will be "miniaturization", "thinness" and "low water pressure". Flush solenoid valve is a significant component in smart toilet; so solenoid valve must have advantages with a small size, high precision, flow stability, strong ability to resist the impurity, and so on, in order to meet the development trend of the smart toilet.

2. The influence of comprehensive performance for solenoid valve on the quality of smart toilet
Solenoid valve is a critical component in smart toilet; the quality of solenoid valve decides the stability of smart toilet directly. In order to comply with national standard GB/T34549-2017 [1] and water efficiency standard GB 25502-2017 [2], the solenoid valve must be equipped with a vacuum breaker, water hammer and constant flow limiting valve.

   (1) The influence of the vacuum breaker
   To prevent dirty water from being sucked into the supply pipe by the vacuum created when the water supply is cut off, a vacuum breaker is necessary. At present, most of the vacuum breakers are integrated in the flushing valve. The standard GB/T26750-2011 [3] requires that the pressure must be maintained at -0.08MPa for 30 seconds, then the pressure be adjusted to -0.054MPa for 5 seconds, and then the pressure be adjusted to atmospheric pressure within 120 seconds. During the whole process, the water level is required to rise no more than 20mm. If structure design of the solenoid valve is not reasonable, this can lead to the failure of detection.

   (2) The influence of water hammer
Water hammer is the killer which can destroy whole water supply system. If the water hammer is severe, it may cause the destruction of whole pipeline, and the main component that produces water hammer phenomenon is solenoid valve. Through the test, the structure of the solenoid valve without water hammer, it may produce 2 to 3 times of the water hammer pressure than the normal water supply pressure when closing the valve, which can damage the solenoid valve and the water supply system. Therefore, the problem of how to reduce water hammer phenomenon when closing the solenoid valve must be solved.

The common method to reduce the water hammer phenomenon is through extending the closing time of the solenoid valve, but extending the closing time of the solenoid valve will lead to the change of the water consumption of the entire smart toilet.

3. The influence of water flow stability
The flow characteristic of the solenoid valve plays very important role in the smart toilet, which requires the solenoid valve to have a large flow under low water pressure and a stable flow under high water pressure. In order to satisfy the water efficiency standard, some manufacturers install a single constant flow valve in the front of the solenoid valve. Although this method is effective, the cost of a single constant flow valve is high and there is a risk of connection leakage.

The reasons for solenoid valve failure are listed as follows, which may cause failure of the test.
① The structure design of the vacuum breaker of flushing solenoid valve is unreasonable [4], and the suction water level is more than 20mm in anti-siphon performance test, which can lead to the failure of the test [5];
② The solenoid valve has no water hammer device, and the value of water hammer in water hammer performance test is greater than 0.4MPa, which can lead to the failure of the test;
③ The flow stability of the solenoid valve is not good, and the difference of water consumption between 0.24MPa and 0.55MPa in the water flow test is great, which cannot satisfy the requirements of water efficiency level, which can lead to the failure of the test.

3. A new solenoid valve application in smart toilet

3.1. The structural design of new solenoid valve
(1) The structure of new solenoid valve is coupling structure; the explosion-proof ability is strong.
Most of the solenoid valves used in the market are designed as separated structure for the inlet seat and outlet seat, the pressure is generally around 1.6MPa, it is prone to burst especially in the area of high water pressure. The new solenoid valve is designed as coupling structure for the inlet seat and outlet seat, the pressure is above 4.5MPa, which is far greater than specified pressure of the national standard, more than 3.5MPa blasting pressure of North American standards.
(2) Vacuum breaker is integrated in the new solenoid valve
There was no vacuum breaker in solenoid valve at early stage; vacuum breaker was installed separately in the main pipe. The new solenoid valve with vacuum breaker can comply with relevant requirements of standard GB/T 26750-2011. Through the test, the water level in the transparent tube at the outlet has hardly increased, which is less than 20mm of standard requirements.
(3) Water hammer is integrated in the new solenoid valve
The structure of new solenoid valve is simple, lower cost, water hammer is integrated in new solenoid valve, it does not need to extend the closing time of the valve and can greatly reduce the phenomenon of water hammer. Through the test, the closing time of the new solenoid valve can be controlled within 1.5 seconds.
(4) A constant flow limiting valve is installed in the new solenoid valve
A constant flow limiting valve is installed directly at the inlet end of the new solenoid valve; the function of flow limiting valve is not limit water flow in low pressure, but limit water flow in high pressure. When the water pressure is more than 0.1MPa, flow limiting valve will play the role of limiting the flow, with the increasing of water pressure; the water flow always remains stable. No
matter how the water pressure of inlet end is increasing, the static pressure of outlet end will always be maintained below 0.2MPa, which can prevent the tube bursting.

(5) The new solenoid valve has good waterproof performance and long working life

Waterproof performance of the new solenoid valve is excellent; the coil is all filled with epoxy resin, which can reach IP67 of waterproof grade.

The working life of new solenoid valve is more than 1 million times, which is far more than 200000 times of the national standard.

Structural drawing of new solenoid valve is shown in the figure 1.

![Figure 1. Structural drawing of new solenoid valve](image)

3.2. The development of comprehensive performance testing system of the solenoid valve

3.2.1. Hardware component of performance testing system of the solenoid valve. The comprehensive performance testing system of the new solenoid valve mainly includes air source module, data acquisition equipment module, and electrical equipment module.

(1) Air source module mainly includes air compressor, air filter, dryer, pressure regulating valve, air tank, etc., which is responsible for filtering, drying and discharging compressed air, providing the source of stable pressure for the system.

(2) Data acquisition equipment module includes multi-functional data acquisition card, sensor parts, industrial control computer and other equipment, which is responsible for data acquisition and processing, it is the core of the hardware system.

(3) Electrical equipment module includes power supply, relay, drive circuit and other equipment, which can ensure that each component of the system has enough power to drive.

Each module coordinates with each other to ensure the normal operation of the system.

The system structure diagram of hardware part is shown in the figure 2.

![Figure 2. The system structure diagram of hardware part](image)
The measured values in the test process are converted into electrical signals by the corresponding sensors, and the electrical signals are isolated, amplified, filtered and converted by the signal conditioning module to meet the input requirements of the data acquisition card. The multi-function DAQ transmits the measured values to industrial control computer and virtual instrument platform, and meanwhile obtains control signals from industrial control computer and virtual instrument platform. In this system, industrial control computer is the carrier of the test software, and the test software is the core of the whole system, which can process, analyze the input signal and control the output signal.

3.2.2. Software component of performance testing system of the new solenoid valve. The test software mainly includes parameter setting module, data acquisition and processing module, control module and data management module, etc.

(1) Parameter setting module includes system parameter setting and test parameter setting. System parameter setting mainly refers to the parameters of selection of acquisition card, acquisition channel setting, sampling frequency and sampling number, and also includes the settings of sensor parameters and filtering parameters. Test parameter setting mainly sets the related parameters to each test item.

(2) The data acquisition and data processing module is responsible for reading data from the acquisition card according to the time sequence, and converting it into actual physical values, writing files, calculating relevant parameters and inspecting qualification.

(3) Test control module includes the selection of test items, the automatic switch of the corresponding loop, and control of starting, pausing, stopping, resetting and taking points of each test item.

(4) The data management module includes saving and querying test data, generating and saving report, printing curve and reports. Test data refers to the value of water hammer, the value of pressure and the value of flow.

4. The testing of the comprehensive performance of the new solenoid valve

The steps of test operation are listed as follows: Installing the solenoid valve sample on the test machine, starting the test system, turning on the pump, clicking the button of start test, system automatic analysis, calculation of test values, displaying the test results on the operation interface, after the test, printing the test value and the curve.

(1) The test of water hammer performance

Water hammer is integrated in new solenoid valve. The test interface of water hammer performance is shown in the figure 3. The test interface below is the comparison between the new solenoid valve with water hammer and the earlier solenoid valve without water hammer. After testing, the solenoid valve without water hammer, it may produce 2 to 3 times of the water hammer pressure than the normal water supply pressure at the moment of closing the valve. The value of water hammer pressure is 1.075MPa, the peak pressure is 1.563MPa. But the solenoid valve with water hammer, the closing time of the new solenoid valve can be controlled within 1.5 seconds, the value of water hammer performance test is 0.159MPa, the peak pressure is 0.652MPa, which is less than 0.2MPa. In accordance with requirements of national standard GB/T34549-2017, the value is not more than 0.4MPa, the test of water hammer performance accords with national standard completely.
(2) The test of flow stability test

A constant flow limiting valve is integrated in new solenoid valve, the function of flow limiting valve is not limit water flow in low pressure, but limit water flow in high pressure. When the water pressure is more than 0.1MPa, flow limiting valve will play the role of limiting the flow, the water flow always remains stable.

The test interface of flow stability is shown in the figure 4. The test interface below is a comparison of flow curve of the new solenoid valve with constant flow limiting valve and solenoid valve without constant flow limiting valve. In the curve of the solenoid valve without constant flow limiting valve, system flow is 13.74 L/min. But in the curve of the new solenoid valve with constant flow limiting valve, water pressure is more than 0.1MPa, system flow is zero, which is hardly increasing.
(3) The test of working life test
The working life of new solenoid valve is more than 1 million times, which is far more than 200,000 times of the national standard, so the new solenoid valve application in smart toilet can greatly improve working life of smart toilet products.

The test interface of working life is shown in the figure 5.

![Figure 5. The test interface of working life](image)

5. Conclusion
Based on the influence of comprehensive performance for solenoid valve on the quality of smart toilet, the structure of new solenoid valve is designed, through the test, results show the new solenoid valve has good comprehensive performance; the new solenoid valve application in smart toilet can greatly improve the reliability and working life of smart toilet products. At the same time, comprehensive performance testing system of the solenoid valve is developed; test results prove the testing system has the advantages with strong universality, simple operation and powerful function, which can effectively improve the detection efficiency of solenoid valve product.

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