Analysis of Instantaneous Collision Process of Axial Flow Check Valve Closing

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Abstract: When the pump stops suddenly, the axial flow check valve will shut down suddenly under the action of the medium pressure differential force, and the impact load between the disc and the valve seat will produce when the valve closes, which will have a certain impact on the structural strength and life of the check valve. In this paper, the display dynamics is used to simulate the impact process of the disc and the valve seat when the valve is completely closed. The dynamic response of the disc and the seat, the velocity of the disc and the energy change during the collision are obtained. The research has certain guiding significance for the practical application of axial flow check valve.

1. Introduction
Axial-flow check valve is an automatic valve that depends on the pressure difference of medium to realize opening and closing. When the pump stops suddenly, the check valve will act quickly under the pressure difference of medium itself to prevent the driving equipment in front of the valve from reversing due to the backflow of medium. It is widely used in long-distance pipeline system [1]. In case of emergency, the medium in the pipeline behind the valve flows back quickly, which makes the pressure behind the valve greater than the pressure before the valve, so that the disc moves towards the closing direction. With the increase of the pressure difference of the medium, the speed of the disc reaches the maximum at the moment of closing, colliding with the sealing surface of the valve seat, causing some damage to the sealing surface and reducing the service life of the check valve. In severe cases, the whole pipeline system can not run normally [2].

Sibilla S etc. used dynamic grid technology to simulate the opening and closing process of axial flow check valve, and obtained that the parameters such as disc size and spring stiffness have important influence on its dynamic response [3]; YAMASHITA Akihiko etc. studied the characteristics of rapid braking and closing of the check valve when the pump stops suddenly, and obtained that the impact acceleration will be generated when the valve clack hits the valve seat and the water hammer caused by low pressure [4]. Junfeng Wang studies the impact force between the impact hammer and the impact table in the impact testing machine, and simulates the impact moment with LS-DYNA software, and obtains the dynamic response characteristics and laws of the whole system [5]. Weiqun Xu analyzed the dynamic response characteristics of simply supported beam under arbitrary impact load, taking Dengzhou Bridge as an example, ANSYS/LS-DYNA software was used to simulate and analyze the collision moment between automobile and bridge, and the stress-strain law during collision and the deformation...
characteristics of bridge body after collision were obtained[6]. It is difficult for researchers to measure
the impact directly because of its short action time and high destructiveness. In this paper, the impact
process between the valve disc and the valve seat at the moment when the axial flow check valve is
completely closed when the pump stops suddenly is studied by using the explicit dynamic numerical
simulation method.

2. the basic concept of impact movement
Impact is a process in which the impact load instantly acts on the system in millisecond time, causing
sudden changes in the stress and motion state of the system. Impact load is an external load that changes
arbitrarily with time, and impact process is a series of dynamic changes of the system with time. Impact
dynamics mainly studies the change of stress wave and the dynamic response of each component in the
system. The research in this paper belongs to the problem of system dynamic response.

Non-persistent collision is the effect of system constraints in the collision process, and once the
collision ends, the constraints are automatically eliminated. For this kind of problems, the dynamic
response results of the system after collision are related to the motion state of the system before collision,
the recovery coefficient and collision impulse in the collision contact process, this paper studies this
kind of collision problem[7].

3. Explicit dynamics
According to the classical mechanics theory, the dynamic equation is:

\[
\begin{bmatrix}
M \\
C \\
K
\end{bmatrix} \begin{bmatrix}
x'' \\
x' \\
x
\end{bmatrix} + \begin{bmatrix}
x' \\
x
\end{bmatrix} = \{F(t)\}
\]

In which: \( [M] \) is the model quality matrix; \( [C] \) is the model damping matrix; \( [K] \) is the model
stiffness matrix; \( \{F(t)\} \) is the load vector; \( \{x\} \) is the infinitesimal displacement vector; \( \{x'\} \) is the
infinitesimal velocity vector and \( \{x''\} \) is the infinitesimal acceleration vector. Explicit solution method,
also known as closed solution method, is calculated by matrix multiplication in each step, which does
not need balanced iteration, has fast solution speed, and occupies little memory. When the time step is
small enough, convergence problem generally does not occur, so it is suitable for solving transient
collision problems[8].

ANSYS LS-DYNA is a world-famous software for solving nonlinear dynamics, which can simulate
and solve various complex problems, such as collision and explosion of various nonlinear structures,
and has a variety of contact calculation models, good parallel solving ability, grid adaptive ability and
etc.[9].

4. Establish a numerical model
The 3d model of the assembly is established by Solidworks software, as shown in fig.1, the check valve
is mainly composed of seven parts as shown in the figure. The inlet and outlet diameters of the valve
body are 252 mm, the total length of the cavity body is 622 mm, the front and rear lengths of the valve
seat are 156 mm and 462 mm respectively, and the medium in the valve is water. Under normal working
conditions, the medium goes in and out from the left, and the pressure in the valve is high on the left
and low on the right. When the pump is stopped, the high-pressure medium flows backwards, so that
the valve clack impacts the valve seat to generate impact load during the closing process.

Meshing platform is used to mesh the model in ANSYS Workbench, the grid diagram of check valve
collision calculation is shown in Fig.2, with 22,322 nodes and 93,480 units.
5. Ansys Workbench Simulation and Result Analysis

5.1. analysis settings
Given the initial speed of -3.624 m/s and the end time of impact of 0.005 s, other settings remain the default, and a fixed constraint is imposed on the front flange face of the valve, and the displacement constraint in the x direction is imposed on the rear flange face of the valve. The K file is calculated and then imported into the LS-DYNA solver for solution, and then the solution result is post-processed by LS-Prepost software.

5.2. Analysis of simulation results

5.2.1. Dynamic response results of valve body
It can be seen from Fig.3 and Fig.4 that the stress mainly occurs at the sealing surface of the valve seat because the disc collides with the sealing surface of the valve seat at the moment of closing. At t=0.5 ms, the stress on the valve body reaches the maximum 289.53 MPa. At t=0.5 ms, the disc is separated from the sealing surface of the valve seat, the collision end, and the stress of the valve body drops rapidly to 16.874 MPa. In the period after reaching ms, the stress and strain value of the valve body changed little, and
the stress changed in the range of 14 MPa~24 MPa.

Fig. 3  Stress strain curve of valve body during collision

Fig. 4  Stress nephogram of valve body

5.2.2.  Dynamic response results of valve clack
According to fig.5 and fig.6, when t=0.25ms occurs, it is distributed in a 120 array around the sealing surface of the disc, and the stress of the disc reaches the maximum 155.68MPa. At t=0.5ms, 1.75ms and 2ms, the corresponding maximum stresses are 64.405MPa, 62.409MPa and 53.424MPa in turn. The occurrence position of the maximum stress continuously moves from the sealing surface to the center of the disc, and then from the center of the disc to the sealing surface of the disc, which is the result that stress waves are propagated, reflected and unloaded many times in a short time. The stress varies from 72.426 MPa to 42.1 MPa in the time of reaching 5 ms.
5.2.3. Valve disc speed response result

It can be seen from fig. 7, at $t=0.5$ ms, the collision is completed, the valve disc is no longer in contact with the valve seat. The valve disc bounces back due to the collision obstruction, because of the energy loss during the collision, the speed of the valve disc changes from the initial speed of -3.624 m/s to 3.11 m/s. After 0.5 ms, the speed remains unchanged at 3.11 m/s, because the change law of the medium force on the right side of the valve disc has not been obtained, so numerical simulation is conducted.
5.2.4.  System energy absorption and conversion

According to fig.8, a indicates the energy change trend of valve body and B indicates the energy change trend of disc, where the energy includes kinetic energy and internal energy. When t=0.5 ms, the energy of the valve flap decreases from 20.4J to 17.2 J, and the energy of the valve body increases from 0 to 2.28 J. In the period of 5 ms, the energy of the valve flap slowly changes to 17.0 J, and the energy of the valve body decreases slightly to 2.14J. According to fig.9, the energy of the system consists of internal energy and kinetic energy. During the collision, part of the kinetic energy of the valve flap is transformed into the internal energy of the valve body and the valve flap, \( \Delta E = 1.3 \) J, which is irreversible.

6. Conclusion

1) Through numerical simulation of the dynamic response of the whole collision process between the valve disc and the valve seat, the stress of the valve body and the valve disc reaches the maximum value at t=0.25 ms, and the whole collision process lasts for 0.5 ms.

2) The velocity of clack after collision is 3.11m/s through numerical simulation of display dynamics.

3) In the process of collision, due to the action of damping and friction, there is energy conversion in the collision system, which is about 1.3 J, and the energy conversion is irreversible.

In a word, the research in this paper has certain guiding significance for the practical application of axial-flow check valve when the pump is stopped.

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