Analysis of Weak Point of Fluid Material Tank Based on FLUENT

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Abstract. In view of the high reliability requirements of fluid material tanks and the difficulty of quality inspection, FLUENT is used to construct the tank model as a set of physics variable values on a finite number of discrete points. The original continuous physical field (pressure field and velocity field, etc.) of the fluid in the time system and the space system is replaced by certain laws and principles. At the same time, algebraic equations are established for the relationship between these finite number of discrete points, and then the basic method of finite element method is used to solve the algebraic equations, and then the relative approximation of the stress acting on the tank in the time and space systems is obtained. After a continuous accelerated simulation, the weak link of the tank is finally determined.

1. Introduction
At present, the fluid material leakage monitoring device based on electrochemical sensor has various advantages and has been widely used. But its shortcomings are also quite obvious, such as short life (usually two to three years), longer response times, and the need for frequent calibration. Moreover, considering that the sloshing problem of the fluid level is unsteady flow, the law of conservation of the physics is followed in the non-inertial coordinate system, and the liquid inside the container is subjected to mass force and gravity. If the acceleration of the container changes with time, it is subject to the quality of the force will also be constantly changing. With FLUENT, the appropriate reference frame can be selected to convert the continuous physical quantity field into a quantitative algebraic equation, which is a powerful complement and optimization for the monitoring of electrochemical sensors. Among them, Shang Chunyu and Zhao Jincheng used the examples of linear motion of water with equal acceleration and basic self-vibration of rectangular water tank, combining with the research results of Tait et al, and the feasibility and superiority of solving the problem of page sloshing in rigid containers were verified.

2. Establishment of non-static process model of fluid materials
The non-static process of fluid material mainly refers to the flow of fluid. The basic conservation laws of fluid flow include: mass conservation law, momentum conservation law, energy conservation law. In this paper, due to the interaction between different components, it is also necessary to add component conservation law and the turbulent transport equation, the specific equations are as follows;

Mass conservation equation:
\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = S_m
\]  

(1)

Momentum conservation equation:

\[
\frac{\partial (\rho u_i)}{\partial t} + \frac{\partial (\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_i} + \rho g_i + F_i
\]  

(2)

\( p \) is static pressure, \( \tau_{ij} \) is the stress tensor, \( F_i \) and \( g_i \) are the external volume force and gravitational volume force in the direction.

Energy conservation equation:

\[
\frac{\partial (\rho T)}{\partial t} + \text{div}(\rho u T) = \text{div}(k \text{grad} T) + S_r
\]  

(3)

\( c_p \) is specific heat capacity, \( T \) is temperature, \( k \) is fluid heat transfer coefficient, \( S_r \) is fluid viscous dissipation term.

Turbulent transport equation:

\[
\frac{\partial (\rho Y_i)}{\partial t} + \text{div}(\rho u Y_i) = -\text{div} \vec{J}_i + R_i + S_i
\]  

(4)

\( \vec{J}_i \) is \( J_i \)'s diffusion flux, \( R_i \) is the net amount of chemical reaction for the \( i \)th substance, and \( S_i \) is the rate of generation of the user-defined source and discrete items.

3. Numerical simulation of fluid material movement and tank stress

In the long-term storage process, due to transportation, technical preparation, maintenance and repairment, the tank will be subjected to different degrees of external impact, which in turn will drive the fluid material for various irregular movements. In this paper, the non-static process of liquid propellant is simplified into a combination of sinusoidal motion and sloshing, and the two irregular motions are integrated into a motion function to numerically simulate the fluid material tank.

Establish a geometric model for non-static processes of fluid material, as shown below:

![Fluid material tank geometry model](image)

This paper mainly simulates the flow of fluid material during the irregular movement of the tank. It is necessary to pay attention to the force on the tank wall during the movement of the fluid material. At the same time, the speciality of the connection between the filler port and the tank cannot be ignored. Therefore, non-uniform meshing is required, and the grid is encrypted where the tank and the filler are connected, resulting in more accurate results. The specific mesh is as shown below.
The pressure-based solver does not directly solve the Navier-Stoke equation, but performs pressure correction on the momentum equation to achieve the purpose of the solution, and the compatibility of the multi-phase flow model is better. The program flow chart of the solver is as follows:

1. solving the momentum equation
2. solving the pressure correction equation and the continuity equation
3. update pressure and velocity fields
4. solving other scalar equations such as turbulence
5. whether convergence

In this paper, for the motion simulation of the fluid material tank model, the simulation data of the 7-day and 300-day time nodes are selected respectively, and the CFD-post software in Fluent is used to convert the pressure and velocity cloud map. The simulation results of the tank are as follows:

4. Tank model simulation analysis
speed cloud map (XY plane)
From the above-mentioned velocity maps at different times, it can be seen that during the random motion of the tank model, the internal fluid materials also perform irregular movements, and the velocity distributions in the various grid units are not the same, but a common feature is in the connection between the tank and the filling port and its vicinity, the speed and rate of change are greater than other locations. This feature is particularly prominent in the 300-day simulated speed cloud.

Pressure Cloud Diagram
In the pressure cloud diagram, a similar situation to that in the velocity cloud diagram can be found, that is, the pressure of the fluid on the connecting portion is slightly larger than that in the surrounding area. In the real fluid material storage tank, the tank and the filling port are welded and connected, and there are a large number of welding points in the joint portion. Unlike the overall structure, the strength of these solder joints is not large, and when it becomes a stress concentration point, it is easy to cause damage, which leads to leakage of fluid material.

5. Conclusion
In this paper, the random motion of the fluid material tank model is simulated, and the non-static state of the fluid material is simulated, which corresponds to the use of the fluid material storage tank in the long-term storage process. The simulation results show that under different motion modes, the fluid material has different forces on the tank, and the local force obviously makes the tank have the risk of being destroyed. By using FLUENT to establish a numerical simulation model, it can accurately find
the weak link of the fluid material tank for more precise monitoring and management in the long-term storage station.

References

[1] Yue Chun-guo, Zhang Yu-xiang, Zhang You-Kong, Chang Xin-long, Zhang Wei. Some Problems Discussed of Liquid Propellant Long-term Storage and Management [C]. 2011 3rd World Congress in Applied Computing, Computer Science, and Computer Engineering Advances in Communication Technology, 2011.

[2] K.W. Woodis, Leak detector for use in space environment, Marshall Space Flight Center, NASA TN D-5841, 1970.

[3] Chutjian A., Darrach M R, etc. A miniature Quadrupole Mass Spectrometer Array and GC For Space Flight: Astronaut EVA and Cabin-Air Monitoring. OICES-202:1-10.

[4] Perez E.F., Oliveira N G, Tanaka A A, et al. Electrochemical sensor for Hydrazine based on silica modified with nickel tetrasulfonated Phthalocyanine [J]. Electroanalysis, 1998, 10(2): 111-115.