Characteristics Analysis of Fluid-Structure Coupling Vibration of spray bar for High gap sprayer

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Abstract. With the progressive improvement of the level of mechanization of agricultural production, the high-gap rod sprayer has gradually become an important component of agricultural production equipment. The stability of spray rod has an important influence on the life and operation quality of spray rod. Therefore, considering the stability of the spray rod of high gap sprayer, a fluid-solid coupling vibration simulation model of the spray rod of high gap sprayer is established in this paper. The influence of inlet velocity, inlet pressure, fluid density and fluid viscosity on the flow rate and dynamic pressure in the pipe was analyzed by Fluent. The results show that the exit velocity increases with the increase of the inlet velocity, but when the velocity reaches a certain value, backflow occurs. With the increase of inlet pressure, the dynamic pressure increases, and the local energy loss and the energy loss along the path also increase. The velocity and dynamic pressure decrease with increasing density.

1. Introduction

The high-spacing rod sprayer has effective field performance and operational quality in the agricultural process. It can control the whole process in the growing period of crops. Therefore, it is the main equipment for pest and disease control of tall stalk crops. At the same time, the study of its performance has attracted extensive attention from experts and scholars at home and abroad [1-3]. A novel autonomous air-assisted sprayer is designed to realize automatic spraying and improve droplet deposition uniformity. Meanwhile, Li also studied the best sprays to cover crops evenly [4]. Lin studies an automatic air-assisted solar greenhouse sprayer based on single suspension by studying the flow distribution and static spray distribution of the boom [5]. A CFD model for airflow prediction of orchard sprayer is built by Hong [6]. Holownicki develops asymmetrical variable flow exhaust system for orchard sprayer [7]. Comparing to foreign countries, the high-quality sprayer is manufactured by our country presents problems such as its unstable structure and its weak preventive effect [8-9]. Especially in the spray rod suspension system, the development of high gap spray technology is restricted by such problems as large span, easy instability and fluid-structure coupling vibration of high-pressure fluid in a pipe. In order to solve the problems of low spray range and low bending, the stability of the spray rod, a high-clearance type recycling tunnel sprayer was developed by Niu[10]. Although experts and scholars at home and abroad have carried out extensive research on the spray rod system, there are few studies on the dynamic characteristics of spray rod considering the
influence of fluid dynamic parameters. The dynamic characteristics of the spray rod system are nonlinear under the influence of ground excitation and fluid-structure interaction. At the same time, the jet rod is excited by the dynamic parameters in the tube, and its vibration response law is complex and changeable. Consequently, the fluid-structure coupling vibration characteristics of high gap sprayer are analyzed in this paper, which has important theoretical and practical significance for the development of precision spray technology of high gap sprayer.

2. Mechanical and mathematical model

The pipeline section is shown in figure 1. The pipe diameter is 50mm. The X direction pipe length is 2000mm. The Y direction pipe height is 500mm. The pipe material is steel. Its main parameters are density 800kg/m³, Young's modulus $2 \times 10^{11}$ Pa and Poisson's ratio 0.3. 1 water inlet hole and 4 water outlet holes are respectively set as shown in the figure. Figure 1 and Figure 2 respectively show three-dimensional frame diagram and three-dimensional grid diagram.

![Figure 1. Three-dimensional structure diagram](image1)

![Figure 2. Three-dimensional grid diagram](image2)

FLUENT is the world’s leading software for the study of fluid flow in computation fluid dynamics. Therefore, ANSYS FLUENT is used to simulate the fluid dynamics calculation of the model. Because the standard k-ε model has high stability, economy and calculation degree, and can keep the Reynolds stress consistent with the real turbulence, k-ε model is selected. In the meantime, the calculation takes no account of heat. Then, different inlet fluid velocity from 1m/s to 2m/s and different inlet fluid pressure from 2Mpa to 10Mpa were calculated respectively. Fluid density and viscosity are defined.
based on velocity and pressure analysis. Because the high gap sprayer is mainly used in agriculture, it is mainly calculated and analyzed from the density of water and other agents from 1000kg/m3 to 2000kg/m3. Based on the Fluent Software, the characteristic is simulated. The specific flow chart is shown in Figure 3.

3. Response analysis

Based on the new simulation model presented in this paper, the dynamic response of high clearance sprayer is simulated. The basic parameters are defined as follows: The inlet of the spray rod is the upper end, that is, the inlet speed is from 1m/s to 10m/s respectively. Ambient atmosphere pressure remains stable. The outlet is the next four sprayer nozzle, based on the condition of full development of the outlet. The walls are made of steel. (The density of 8030kg/m3. Young's modulus is $2 \times 10^{11}$ Pa and Poisson's ratio is 0.3) The results are given in Figure 4 and Figure 5.

![Figure 4. Velocity at different positions at the same inlet velocity.](image1)

![Figure 5. Dynamic pressure at different positions at the same inlet velocity.](image2)

First of all, with the change of the inlet velocity, the single outlet velocity generally presents upward trend. The velocity of exit 1, exit 2 and exit 3 are close to each other in linearity. The difference between the velocity of exit 4 and other exits may be caused by backflow. Then, by comparing the dynamic pressure changes, the dynamic pressure at outlet 4 rises rapidly due to backflow. However, the slope of the dynamic pressure change rate at other outlets is small relative to the slope of the velocity change, which indicates that under the same inlet velocity, the higher the outlet velocity is, the greater the dynamic pressure loss is. But the backflow phenomenon can affect the dynamic pressure loss, and also indicates that the vibration frequency is related to the backflow phenomenon.

The inlet of the spray rod is the upper end, that is, the inlet pressure is from 2MPa to 10MPa. Ambient atmosphere pressure remains stable. The outlet is the next four sprayer nozzle, based on the condition of full development of the outlet. The walls are made of steel. (The density of
8030 kg/m³. Young's modulus is $2 \times 10^{11}$ Pa and Poisson's ratio is 0.3. The results are given in Figure 6 and Figure 7.

Figure 6. Velocity curves at different positions under different inlet pressures.

Figure 7. Line chart of dynamic pressure at different position under different inlet pressure.

The change curves of outlet 2 and outlet 3 are close to coincidence, and the corresponding velocity and dynamic pressure are larger than those of outlet 1 and the outlet 4. This indicates that the closer it is to the entrance, the smaller the dynamic pressure loss and the lower the vibration frequency. However, the change curves of outlet 1 and outlet 4 both rose firstly and then fell. It was close to coincidence at the beginning. As the pressure increase, the coincidence rate decreases, indicating that when the inlet pressure is small, the pressure loss is small and there is no backflow phenomenon. When the inlet velocity is large, the pressure loss becomes larger and larger, and the phenomenon of backflow begins to appear, leading to uneven dynamic pressure distribution at both ends of the spray rod and large vibration frequency, which has a great influence on the stability of the spray rod.

The high gap sprayer is mainly engaged in agricultural use. The fluid agricultural sprayer is all kinds of medicament, and the density and viscosity are different. Therefore, the simulation has been done, the results are given in Figure 8 and Figure 9.

As the density increases, the outlet velocity decreases, indicating that the greater the density, the greater the dynamic pressure loss. It is observed that the velocity plummets at outlet 4, and the main factor affecting the stability of the spray rod is the uneven pressure distribution caused by backflow phenomenon, which further affects the stability of the spray rod. With the increase of viscosity, the velocity of each outlet fluctuates relative to the distance from the inlet, the greater the fluctuation, indicating that the position of pressure loss changes, and the superposition of pressure loss along the path and the locally becomes larger and larger. When the viscosity continues to increase, the velocity fluctuation becomes smaller and smaller, indicating that properly increasing the viscosity will improve the stability of spray rod.
4. Conclusions
In this case, fluid-structure coupling analysis is adopted. Through the analysis of experimental values under several different conditions, it is concluded that:

1. The fluid-structure coupling method maximizes the computational accuracy.

2. With the increase of the inlet velocity, the outlet velocity presents an upward trend, but when the velocity reaches a certain value, backflow phenomenon will occur, thus disturbing the velocity distribution.

3. Because the energy loss along the path and the local energy loss always exist, and maintain a certain relationship, the velocity distribution is not uniform, which leads to the dynamic pressure distribution is not uniform, so that the spray rod force is not uniform, which causes vibration.

4. With the increase of the inlet pressure, the dynamic pressure increases, and the local energy loss and energy loss along the path also increase, so that the pressure amplitude of the applied force increases on the basis of the unevenness, so that the vibration frequency increases, and the fatigue failure of the spray rod is accelerated.

5. The influence of density on spray rod is mainly the change of dynamic pressure. The higher the density is, the lower the speed is, and the lower the dynamic pressure is. In a sense, increasing the density is beneficial to improving the stability of the spray rod, while viscosity affects the velocity and dynamic pressure distribution. The farther away from the entrance, the greater the force fluctuation is, and the location of fatigue failure caused by vibration will also have a certain influence.

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