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Research on characteristics of water motion and influencing factors for the flexible air chamber jig body

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ABSTRACT

The air bag deformation data were obtained by high-speed dynamic videos experiments. Based on gas–liquid flow VOF model, dynamic mesh technique and deformation data, numerical simulations for different structure models were achieved, and the law of water motion and influencing factors were analyzed. The results show that the flow in the length direction of the jig is smooth, and second pulsation appears in the separation time and forms the secondary separation. The installation position of screen and the number of air bags have a great influence on the uniformity of flow and velocity. The screen height cannot be too low to avoid forming the unstable flow. At the same time, the screen height cannot be too high, otherwise water velocity will be too small and was unable to provide enough power. At the height of 1.4 m, velocity unevenness is minimum and the best uniform flow can be obtained. Compared with double air bags, there are the following features of single air bag: water flow is not smooth, the time achieving the maximum velocity is too long, maximum velocity is smaller, and overall effect is worse than double air bags.

1. Introduction

Jigging is one of the important coal preparation technique with hundred years of history. Although the application of jigging declined in recent years, it still had a great advantage in the application of thermal coal washing [1–3]. With the development of coal preparation process and scale, the new jig emerges in endlessly. As a new type of jigging machine, the flexible air chamber jig is mainly used in the underground refuse exhaust and large-scale jigging process. It has a series of advantages of compact structure, less parts and high stratification rate. The laboratory model structure of flexible air chamber jig is shown in Fig. 1.

The experimental system is mainly composed of measuring system, jig and air valve. For the convenience of watching the movement of water and particles in the jig, the body is made of transparent organic glass. The body structure is similar to other kinds of jig, its remarkable characteristic is to use flexible air bag as air chamber. The fixed structure of the traditional air chamber is replaced by air bag. Water flow movement is driven by the deformation of air bags. So the passage way in the jig body is also different from other types of jig.

Water motion is a key problem for particle layering [4]. Researchers were concerned with the influence of water on particle layering [5,6]. Zhang deduced the differential equation of water motion using the fluid dynamics theory [7]. Zeng simulated different flow channel models of jig by using fluid mechanics and the optimum body structure was put forward according to the calculation results [8]. Zhu studied the flow field in the jig body with Navier-stokes method, on the basis of potential flow, the flow velocity and vector distribution in each jig section are computed, in order to judge whether the effect of water flow is uniform in different position of the screen and to choose the jig body structure [9]. Zhang and Zhong made a flow field simulation for different jig by using the similar principle of water-electricity imitation. The experimental results indicated that the pulsating amplitude of water in length and the width direction is uniform for the jig with bottom air chamber [10,11]. Through these study, water flow movement was researched by the single-phase flow method and the interior flow field of jig body was gained to guide the structure optimization. At present, the relevant theoretical and experimental research of water motion for the flexible air chamber jig is still blank. In this paper, multiphase flow method was used to research on water motion inside the jig body to reveal the reason of high efficiency. The calculation and analysis of different structure parameters were achieved to provide a theoretical support for the structure optimization design.

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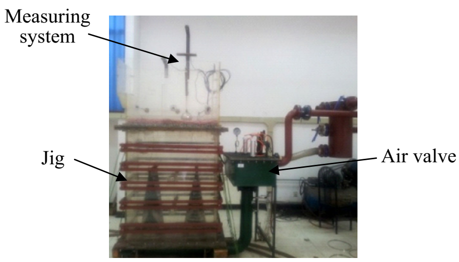

Fig. 1. Experimental system of the flexible air chamber jig.

2. Numerical calculation of water movement

2.1. Boundary movement of air bags

Water flow is driven by air bags, the position and velocity information of air bags are the basis of flow parameters calculation. It is difficult to obtain deformation at each time point by calculation because of the complex deformation of air bag. High-speed dynamic video method is used to obtain deformation process of air bag and record the location of the air bags at each time. This paper focus on the water flow inside the body, so the particles is not added in shooting experiment. The deformation data of air bag is collected under the conditions of water experiment. The Olympus high-speed dynamic camera used in experiments can record 100–2000 images per second. In the "i-speed suite" analysis system, pictures can be singly replayed. The displacement and velocity of air bag boundary can be obtained by using the "i-speed suit" analysis software. Fig. 2 shows the air bag deformation pictures at different time. The location data get by shooting, as the gas bag boundary data, is called in the numerical calculation.

2.2. Mathematical model

Due to the flow passage shape changing, the water movement should be researched in entire jigging cycle. By using single-phase flow method, the fluid information of the fluid flowing out the outlet boundary will be lost, which leads to a distorted calculation for suction stroke. In addition, it is difficult to accurately detect transient parameters of water movement in jig body, water level is measured by using ultrasonic level meter to reflect the water movement. In order to reflect real movement on liquid surface and be convenient for comparing with the experimental data analysis, the method of two phase flow is used to calculate.

2.2.1. VOF model

Two phase are water and air respectively, the main phase is water, and the second phase is the air. Due to the obvious gas–liquid interface, VOF method was suitable for the surface tracking [12,13]. In VOF method, by solving volume fraction equation, the volume fraction of fluid in the unit can be obtained so as to track water level.

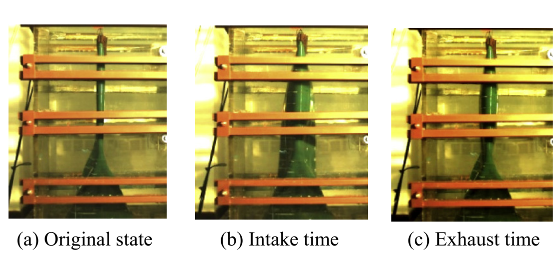

Fig. 2. Results of high-speed dynamic experiments of air bag actual deformation.

Control equation can be expressed as:

$$\frac{\partial(\rho)}{\partial t} + \nabla \cdot (\rho U) = 0 \tag{1}$$

Momentum equation can be expressed as:

$$\frac{\partial(\rho U)}{\partial t} + \rho U \nabla \cdot (\rho U) = -\nabla p + \nabla \mu S + \rho g + F \tag{2}$$

where ρ is the density, kg/m^3; U the velocity vector, m/s; t the time, s; p the pressure, Pa; μ the coefficient of dynamic viscosity; and F the effect of the body force and surface tension, N.

The property of fluid in the research unit can be determined by Eqs. (3) and (4):

$$\rho = C_1\rho_1 + C_2\rho_2 \tag{3}$$
$$\mu = C_1\mu_1 + C_2\mu_2 \tag{4}$$

where C_1 and C_2 stand for the volume fraction of water and air respectively; ρ_1 and ρ_2 stand for the density of water and air respectively, kg/m^3; μ_1 and μ_2 stand for the coefficient of dynamic viscosity of water and air respectively, Pa s.

Volume fraction equation is defined as:

$$\frac{\partial C_i}{\partial t} + U \cdot \nabla C_i = 0 \tag{5}$$

It is all water in the unit if $C_i = 1$ and all gas in the unit if $C_i = 0$; there is an interface of gas and water when $0 < C < 1$.

2.2.2. Dynamic mesh model

The computing boundary was changed because of the deformation of air bag. The area of air bag deformation need be dealt with dynamic grid technique. The dynamic grid technology is a method to solve moving boundaries problem [14–16].

Within the motion region, the conservation equation for any flux ϕ can be expressed as:

$$\frac{d}{dt}\int_V \rho\phi dV + \int_{\partial V} \rho\phi(\vec{u} - \vec{u_s})d\vec{A} = \int_{\partial V} \Gamma\nabla\phi d\vec{A} + \int_V S_\Phi dV \tag{6}$$

where ρ is density of water, kg/m^3; $\vec{u}$ the motion vector of water, m/s; $\vec{u_s}$ the deformation velocity of movement grid, m/s; Γ the flare coefficient; S_Φ the source item of flux; and ∂V the boundary of control volume V.

In Eq. (6), it is necessary to provide the velocity and the location of the air bag at each time for calculation. Velocity and position information of each point can be obtained by shooting experiment and the mesh was updated according to the location information.

2.3. Geometric calculation

According to the laboratory model machine, 2D geometric model is established as shown in Fig. 3. Jig dimensions is

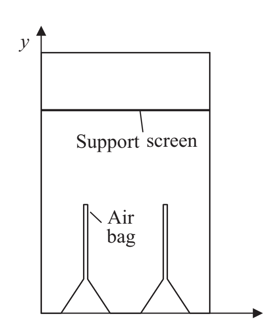

Fig. 3. Schematic diagram of jig geometric model.