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The valve motion characteristics of a reciprocating pump

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ABSTRACT

In previous studies on a reciprocating pump, the state, behavior simulation, or experimental analysis of the valve was seldom reported. In the paper, taking a triplex single-acting reciprocating pump as the research object, we established an experimental system for testing valve disc's motion parameters to directly acquire the valve disc motion parameters (acceleration, velocity, and displacement) under actual conditions. Moreover, testing results were compared with the calculation results obtained according to U. Adolph Theory and Approximation Theory. In Approximation Theory, the valve disc motion was not fully considered, thus leading to the large deviation from the actual situation. Compared with the Approximation Theory, U. Adolph Theory is more suitable for the determination of valve disc motion parameters during different strokes and can explain the jumping and hysteresis phenomena of the valve well. A new pump testing method and an experimental system were proposed to provide a new study approach for valve design theory, disc damage mechanism, and pump failure diagnosis.

1. Introduction

A reciprocating pump is the heart of an oil rig. The valve disc is also a key component in the reciprocating pump hydraulic end and its main role is to make the suction valve and discharge valve alternately connected or separated in the hydraulic cylinder, thus controlling the drilling fluid flow in one direction. Pump valve disc is also a wearing part. In order to improve the working performance and working conditions of the pump and prolong its service life, the reciprocating pump valve dynamics and its damage mechanism had been extensively studied [1–6]. Domestic and international studies on reciprocating valve disc motion mainly focused on the numerical calculation and simulation. The motion characteristics of reciprocating pump valve disc and the influences of various parameters were studied through simulating the motion of the reciprocating pump valve with mathematical models [7,8]. Mathematical models and finite element models [9–13] were established and then the motion of the valve disc was explored based on the U. Adolph motion differential equation [14,15]. Related experimental studies were mainly concerned about the fault diagnosis and signal processing of wearing parts of reciprocating pumps [16–19]. Pump parameters were generally acquired with pressure gauges and flow sensors installed on the pump suction or discharge pipe, and acceleration sensor mounted outside of the pump valve. So far, valve disc's motion

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parameters have not been directly experimentally detected. Theoretical analysis has not been combined with actual pump testing parameters to investigate its motion rules. The accuracy of various theoretical calculations is still unknown.

In this paper, a new experimental approach was proposed to test motion parameters of a reciprocating pump valve disc. In the new approach, the piezoelectric accelerometer and the inductance frequency–modulation displacement sensor were installed on the valve disc under the hydraulic pressure. Moreover, a testing system was established to analyze the valve disc's motion parameters (acceleration and displacement) in real time under different working conditions. Then, we compared the computation results of valve disc motion obtained by Approximation Theory [20,21] and U. Adolph Theory and found the motion rules of the valve disc for further studies on reciprocating pump design, valve damage mechanism, and fault diagnosis.

2. Pump valve disc motion theories

Fig. 1 shows the motion principle of a reciprocating pump valve. Taking the discharge valve as an example, it is assumed that the piston is on the right side of the discharge valve. When the discharge process begins, the piston starts discharging liquid from right to left. Then the liquid in the hydraulic cylinder pushes the discharge valve disc to rise. Then the discharge valve is opened and the liquid flows into the discharge chamber via the gap between the valve disc and valve seat. At the end of the discharging process, this disc drops down from a certain height (h) to its seat under the action of its own weight, the elastic force of the spring, and the liquid pressure ($\Delta P = |P_1 - P_2|$). In this way, the discharge valve is closed and the piston chamber is separated from the discharge chamber. Finally, the opening and closing process of the discharge valve is completed. The Approximation Theory and U. Adolph Theory are widely used in the calculation and design of reciprocating pump valve. These two theories are respectively described as follows.

2.1. Approximation Theory

The Approximation Theory is based on the following assumptions. Firstly, the valve disc is massless. Secondly, the spring force (R) keeps unchanged. Thirdly, the fluid is incompressible and the parts of the pump are inelastic. Fourthly, hydraulic cylinders are fully filled with continuous liquid during the valve disc motion. According to Bernoulli's Equation, the maximum of valve disc displacement, velocity and acceleration can be expressed as follows [22]:

$$h_{\max} = \frac{Fr\omega}{\mu\pi d_v \sqrt{2gH_v}\ \sin\theta} \quad (1)$$

$$v_{\max} = \frac{Fr\omega^2}{\mu\pi d_v \sqrt{2gH_v}\ \sin\theta} = h_{\max}\omega \quad (2)$$

$$a_{\max} = \frac{Fr\omega^3}{\mu\pi d_v \sqrt{2gH_v}\ \sin\theta} = h_{\max}\omega^2 \quad (3)$$

$$H_v = \frac{G+R}{f_v\gamma} \quad (4)$$

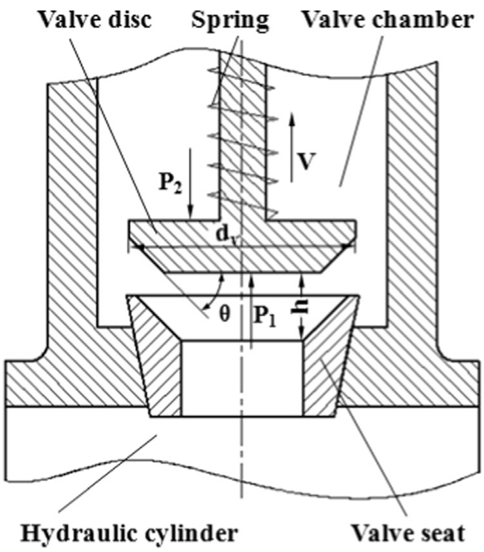

Fig. 1. The motion principle of a pump valve disc.