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Analysis and numerical simulation of a novel gas–liquid multiphase scroll pump

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ABSTRACT

This paper presents analysis of a novel multiphase scroll pump to transport gas–liquid two-phase mixtures, in which each compression chamber has a flank clearance which forms a pressure unloading gap connected to the discharge port. Therefore, this multiphase scroll pump has the function of unloading gas–liquid mixture pressure automatically during the compression process, so the frequently occurring problem of liquid slugging in displacement multiphase pumps is solved. Hence, safety and reliability are improved. In this paper the working process model of the presented multiphase scroll pump is discussed; and equations of fluid motion and geometry of scroll wrap profiles are given. Grid generation and numerical methods are discussed, and numerical simulation of the working process for a multiphase scroll pump is conducted using the commercial CFD software package Fluent, with results suggesting key parameter values for design of multiphase scroll pumps.

1. Introduction

Multiphase pumping technology has been gaining widespread acceptance and recognition in many areas, especially in the petroleum industry [1]. It allows gas and liquid to be transported simultaneously; hence, using multiphase pumps for gas–liquid multiphase transport can lead to cost savings and simplify the overall process.

Multiphase pumps are divided into two general types: positive displacement and rotodynamic pumps. Positive displacement pumps, such as twin screw, progressing cavity (single screw), piston and diaphram pumps, operate on the principal that a definite amount of fluid is transferred through the pump based on the volume created by the working chamber. Rotodynamic pumps such helico-axial and multi-stage centrifugal pumps, operate on the principal that kinetic energy is transferred to fluid which is then converted into pressure. Among them helico-axial multiphase pumps [1] and twin-screw multiphase pumps [2–4] are frequently employed in industrial applications. The helico-axial pump [1] can provide a large flow but is not suitable for handling multiphase fluids which gas volume fraction is more than 50%. Hence it becomes inefficient when gas volume fractions are high. In a twin-screw pump, multiphase mixtures enters one end of the pump, and then passes through a chamber that moves along the length of the screws to the outlet. The volumetric flow rate is dependent on the pitch and diameter of the screws and the rotational speed. As the gas is compressed, a small amount of mixtures will slip back through the small gaps between the screws, which is called back flow and will lead to a reduced volumetric efficiency.

Many published literatures of studying the working process of the positive displacement multiphase pumps exist. Nakashima [3] presented a thermodynamic model of a twin-screw multiphase pump to determine performance parameters such as absorbed power, discharge conditions and efficiency. Nakashima [4] also presented a model of the heat transfer processes in the casing and rotors of a twin-screw multiphase pump. The model is divided in three parts: heat transfer in the casing, in the rotor and energy balance of fluid. Aleksieva [5] proposed a newly designed pair of screws with declining pitch. The delivery of the pump depends on the declining volumes of the chambers, formed by the intermeshing screws moving from the suction to the discharge side. The improved performance of gas compression gives advantages in the efficiency of power consumption especially for multiphase pumping of mixtures with increasing gas volume fractions. Rabiger [6] developed a new theoretical screw pump model, and calculated the time-dependent conditions inside the several chambers of a screw pump as well as the exchange of mass and energy between these chambers. Cao [7] proposed a mathematical model for describing the pressure distribution inside working chamber. By means of a small pressure transducer embedded into the groove at the root of the rotor, the pressure distributions of a multiphase

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compressor under various running conditions have been recorded to verify the model. Yang [8] presented a new synchronal rotary multiphase pump, and its structural design and working principles are introduced.

According to the above literatures, it can be concluded that the positive displacement pump consists two types: pump with fixed- and variable-compression chamber volume. The former has no volume-decrease process of compression chamber during the compression process, and no internal compression process exists. This type pump create compression chambers with constant volume which move continuously from the suction to the discharge region. The chambers can be treated as storage volumes for mass and energy, which connected by several clearances, through which the leakage flows from high pressure working chamber to low pressure suction chamber take place. However, the back flow effects the thermodynamic behavior and volume efficiency greatly; and due to the backflow, the real volumetric flow is always lower than the pump theoretical capacity. The latter, having volume-decrease process of compression chambers, can easily lead to an increase of pressure of gas–liquid mixtures and consequent high working efficiency; however, it also can result in pressure surge even to the extent of liquid slugging in compression chambers when the liquid volume fraction is high, which is very harmful for operation of multiphase pumps.

In order to solve the two problem of liquid slugging in compression chambers of displacement multiphase pumps, a new type of displacement pump named multiphase scroll pump is proposed. Each compression chamber of this multiphase scroll pump has a flank clearance which forms a pressure unloading gap connected to the discharge port. The flank clearance is generated by a new type of scroll wrap profile composed of a combination of fixed-radius and variable-radius circular involutes. In the gas–liquid pressurization process, when the volume of a compression chamber decreases, pressure of gas–liquid mixtures increases gradually; at the same time, small amounts of gas–liquid mixtures are pushed to the discharge port through the flank clearance from compression chambers. Therefore, this multiphase pump functions so as to unload gas–liquid mixture pressure automatically during the compression process, and the frequently occurring problem of liquid slugging in the displacement multiphase pump is avoided; and its volume efficiency is increased. Safety and reliability are improved, and the appropriate range of gas volume fractions is expanded. However, this type of design also has disadvantages such as reduction of isentropic efficiency and machining complexity, etc.; and the flank clearance will reduce the built-in volumetric ratio of the scroll pump which will negatively impact its isentropic efficiency. At the same time, the multiphase scroll pump, as a kind of scroll machinery [9–12], exhibits some distinct advantages of structural compactness, high efficiency and low noise and vibration.

In the current paper, this new type of scroll wrap combination profile, which can generate the flank clearance for compression chambers, is studied; equations for the profiles are obtained; and the principle of changing compression volume and flank clearance are analyzed. A mathematical geometric model for multiphase scroll pumps with flank clearances is established to analyze their theoretical compression processes; numerical simulations of the corresponding working processes are conducted using the commercial CFD software package Fluent [15]. These results provide a foundation for design and application of this new class of multiphase pumps.

2. Working Principle of Multiphase scroll pumps

As shown in Fig. 1, the multiphase scroll pump consists of fixed scroll, orbiting scroll, frame, crankshaft, anti-rotation mechanism, bearing and balance weight [13,14], etc. The fixed scroll and orbiting scroll are assembled with a relative rotation angle of 180° (π rad), and offset by a distance which equals the radius of the crankshaft, so that they can form a series of crescent-shaped working chambers. This multiphase scroll pump has flank clearances which cause the connection between compression chambers and the discharge port, and no flank clearance between compression chamber and suction chamber exists. These features lead to avoidance of pressure surges of gas–liquid mixtures in compression chambers and reduction of back flows.

The suction and compression chambers of a multiphase scroll pump are shown in the sketch of Fig. 2. Compression chambers connect with the discharge port through flank clearances and are separated from suction chambers which are connected to the suction port. These flank clearances form pressure unloading gaps leading from compression chambers to the discharge port. In the compression process these flank clearances begin to open when volume of compression chambers begins to decrease, and very little gas–liquid mixture will be pushed into the discharge port through flank clearances due to gradual pressure rise. However, note that suction chambers are separated from compression chambers at all times, and mixtures in compression chambers cannot leak back into suction chambers.

The working process of the multiphase scroll pump consists of suction, compression and discharge processes, and these take place within specific parts of the scroll wrap, as indicated in Fig. 3. In this figure, a series of crescent-shaped working chambers in multiphase scroll pumps exist. The two chambers, located in the peripheral scroll, are suction chambers, as the cross-hatched areas represented; chambers located in middle portion are compression chambers; and chambers located in the center of the scroll and connected to the discharge port, are discharge chambers. In this figure δ denotes the flank clearance, through which compression chambers are connected to the discharge port. As the Orbiting scroll moving, the crescent-shaped working chambers gradually move into the center, so the working medium is compressed and

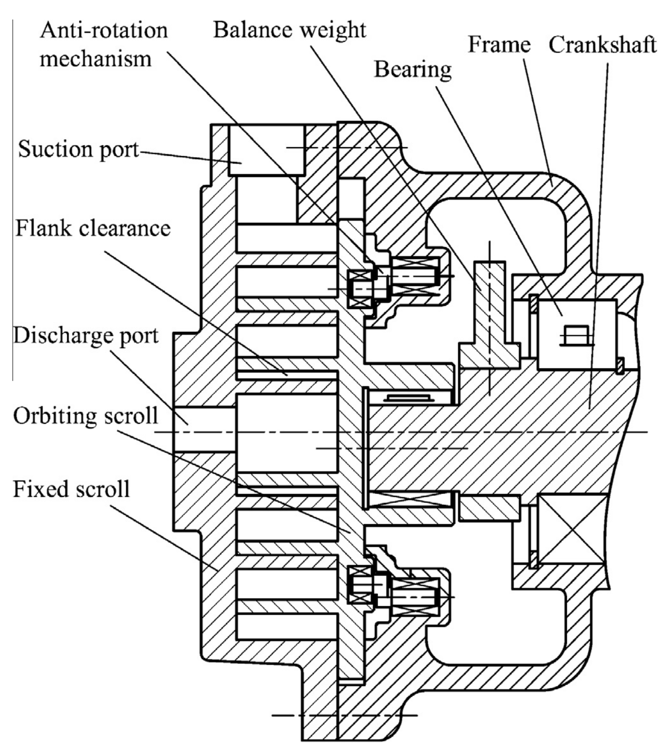

Fig. 1. Structure of a multiphase scroll pump.