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Experimental Study of the performance characteristics, internal flow and noise characteristics of washing machine mini pimp under gas-liquid two-phase flow

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Abstract
The upper drainage method is often used in drum type washing machines by using a miniature drainage pump. With the decrease in water level, the pump undergoes in the state of gas-liquid mixed transportation, empty discharge, at the end of drainage and produce unsteady flow. This unstable flow not only results in the deterioration of pump performance but also induces larger vibration and noise, which affects the quality of the equipment seriously. In order to explore the internal flow characteristics of the drainage pump during the empty discharge period, pump performance test was processed under pure water condition as well as under different air void fraction. The results show that head drop slowly with the increase of flow rate and the pump exhibits low efficiency. But the efficiency of the model pump is in good agreement with the value recommended by the manufacturer and the influence of gas on the drainage pump is smaller when the gas content is 1%. As the gas content increases, the slope of the flow-head descending curve becomes larger, and the influence of gas content on the pump performance increases with the increase of flow rate. Besides, the overall and local results of internal flow field and gas phase distribution are obtained and analyzed.

Keywords: washing machine, drain pump, gas-liquid two-phase, vortex, pressure fluctuation

1. Introduction

Mini pumps having radial vane impellers are widely used in many fields such as electronic industries, blood pumps for medical industries, aerospace industries and in some home appliances (drainage pumps used in washing machines, dryers and dishwashers) [1-4]. These pumps are known as mini-pumps because their sizes are smaller than 50 mm [5] and use the radial impellers because the radial impellers are easy to manufacture as well as these impellers have a stable head [6]. But the usage of radial impellers is less than the conventional impellers, because the pumps having radial impellers are less efficient such as drainage pump for washing machine.

Drainage pumps for home appliances [7, 8] such as washing machines are some special kind of mini pumps that consist of synchronous motor with a splined shaft, a radial impeller connected with the splined shaft and the pressure chamber [4]. Thereinto, the washing machine has become an essential household appliance with the development of people's living standards, which has huge market value. At present, the important quality of the drum type washing machine are the water saving, power saving and low noise ability [9]. The drainage pump is the prime drainage power component in drum type washing machine. When the washing machine is running in the empty discharge period, the performance is reduced and the noise is produced because of the transportation of the gas-liquid mixture, which restrict the product quality. In order to improve the running efficiency and reduce the noise of the drainage system of the drum washing machine, it is necessary to study the internal flow characteristics of the drainage pump during the empty discharge period deeply.

The washing machine drainage pump is a kind of centrifugal pump, and related research has been carried out. Kim *et al* [10] considered that the drainage pump is one of the main noise source in the operation of washing machine and they invented an apparatus that can control the vibration and noise in drainage pump during the initial drainage period. But the initial drainage period doesn't have much effect on the noise and vibration of the drain pump. Because the gas-liquid transportation period, which is caused by the unsteady internal flow field and lower water level in pumps, has a higher impact on the noise and vibrations. Therefore, Murakami [11, 12] analyzed the influence of gas-liquid two phase flow on the performance of centrifugal pump and published the first study related to the internal flow-field, data-analysis and flow visualization. This was the first study which focused on the flow pattern inside the impeller in relation with pump performance. Also, Hench *et al* [13] have studied the gas-liquid two-phase flow characteristics of the vane-type centrifugal pump through visualization experiments. Further, Gulish *et al.* [14] considered that the clearance between the front and back cover plate and pump cavity of centrifugal pump impeller has certain influence on the pump two-phase flow transport capacity. Pessoa and Prado [15] observed cyclical head variation of the centrifugal pump under gas-liquid two-phase flow, and pointed out that this may be caused by the periodic variation of the air pocket in the pump. The above research mainly focused on the internal flow and induced noise of the washing machine drainage pump under pure water condition, but the complex flow state, that is pump under empty discharge period, has less attention to the influence of pump drainage and vibration noise performance.

In the research, pump performance and noise characteristic were experimental test in order to explore the performance characteristics and the influence of the inlet air fraction on the head characteristics of the drainage pump for washing machine.

2. Experimental setup for pump model

Washing machine drainage pump used in this project is shown in fig 1, that can provide kinetic energy and potential energy for the liquid after washing, which is necessary for the drainage process of washing machine. If the pump model is not properly designed, it will weaken the hydraulic performance and produce vibration and noise. The design parameters of model pump are shown in table 1 and the test loop is shown in fig 2.

Table 1: Model pump parameters

Parameters	Values	Parameters	Values
Design Flow rate Q_d	1.08 m^3/h	Blade thickness δ	1.5mm
Head H_d	1.2 m	Blades number Z	6
Rotating speed n	3000 r/min	Specific speed n_s	68
Impeller outlet diameter D_2	37 mm	Volute base circle diameter D_3	50 mm
Blade outlet width b_2	6.24 mm	Volute outlet diameter D_d	29 mm

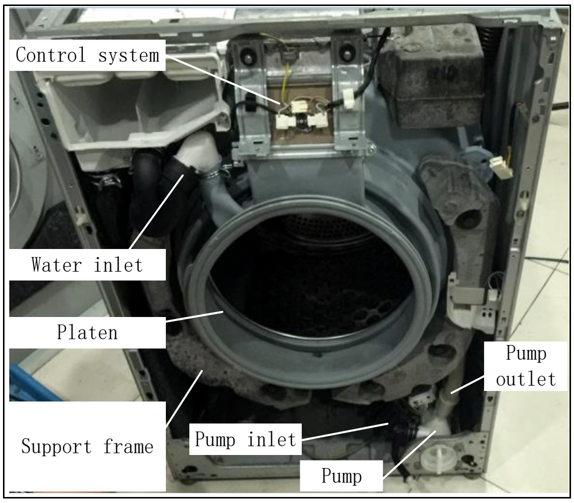

Fig 1: Working scenario of the pump

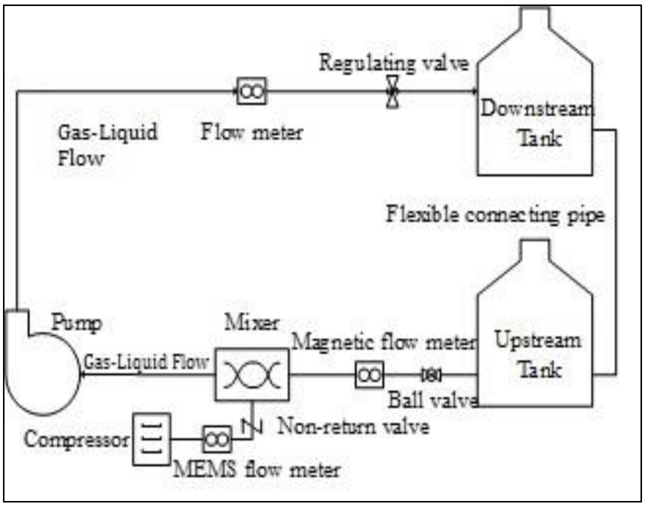

Fig 2: Test loop

2.1 Test equipment and loop

The hydraulic performance and noise experiments of drainage pump are performed in semi-anechoic chamber having a size of 4.2m× 3.2m× 3m. The background noise of the semi-anechoic chamber is 20dB and the cutoff frequency is 50Hz. The test setup of drainage pump re-build in semi-anechoic chamber and the experiment measuring system of the drainage pump is shown in fig 2 and fig 3 respectively. The study firstly measured the pump noise characteristic as it used in washing machine, which means working for a drainage period. Three microphones typed as PCB 14043 located around the pump as a circle with 1m to collect noise signal together with LMS SCADAS Mobile equipment. Then, pump performance both under pure water and different air void fraction are measured for further analysis. Air flow rates are measured by a micro-electro mechanical system flow sensor, which supplies volume air flow rate values under normal pressure and temperature condition (25°C, 101325Pa). Water flow rate was measured by an electromagnetic flow meters set between upstream tank and the mixer. Air void fraction could be calculated. Two pressure sensors with accuracy 0.25% were set at pump inlet and outlet to calculate the pump head. Digital power meter with accuracy 0.4% were used to measure the hydraulic shaft power after dividing a constant motor efficiency coefficient. Pump head and efficiency also could be obtained followed the way in ISO 9906, [16]. The biggest uncertainties of the measurement are ±1.8% error of pump head, ±5% error of pump efficiency, ±0.5% error of water flow rate and ±0.5% of air void fraction calculated by instrument precision.

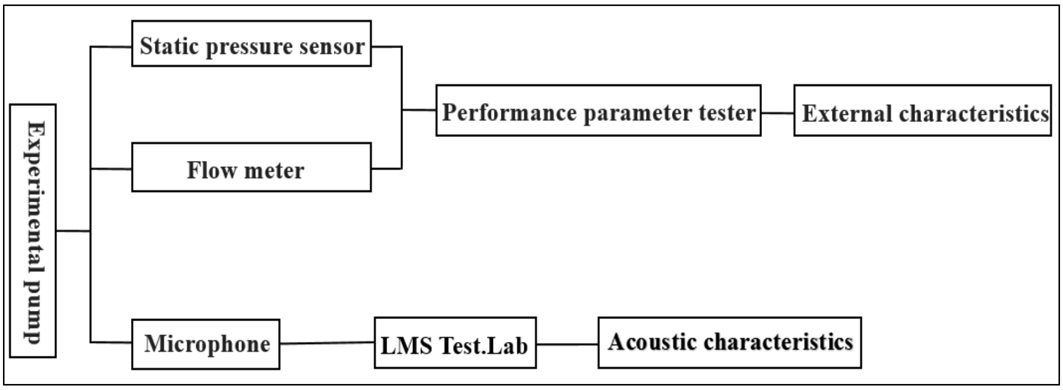

Fig 3: Experiment system of the drain pump for washing machine

2.2 Pump performance analysis

The performance of the model pump, determined using these equipments are defined as,

$$\eta = \frac{\rho g Q H}{p_m} \quad (1)$$

Where, Where, ρ is the density of water and p_m is power of the motor.

According to the Bernoulli equation, the Head of the model pump is defined as,

$$H = \frac{p_2 - p_1}{\rho g} + \frac{v_2 - v_1}{2g} + (z_2 - z_1) \quad (2)$$

H = model pump head (m)
p_1 = average static pressure of the fluid at inlet (kPa)
p_2 = average static pressure of the fluid at outlet (kpa)
v_1 = average velocity of the fluid at inlet (m/s)
v_2 = average velocity of the fluid at outlet (m/s)
z_1 = height of the model pump at inlet (m)
z_2 = height of the model pump at outlet (m)

3. Results and Discussions

3.1.1 Pump performance curve under pure water condition:

Fig 4 shows the hydraulic performance curve of the washing machine drain pump. According to Euler formula, the impeller's working capability does not change with the flow rate. But in actual test, with the increase in the flow rate, the pump head has a certain decrease, but the decrease is not big. When the pump is running at zero flow rate, the head shows maximum value of 1.82m. But at design flow rate, the head value is 1.07m and the pump exhibits the maximum efficiency of 11.19%. Then at 1.1Q_d points corresponding to the head is 0.965m. The above phenomenon can be explained in a way that in actual flow conditions, with the increase in the flow rate, the hydraulic loss in the pump increases, which leads to the drop in the pump head and efficiency.

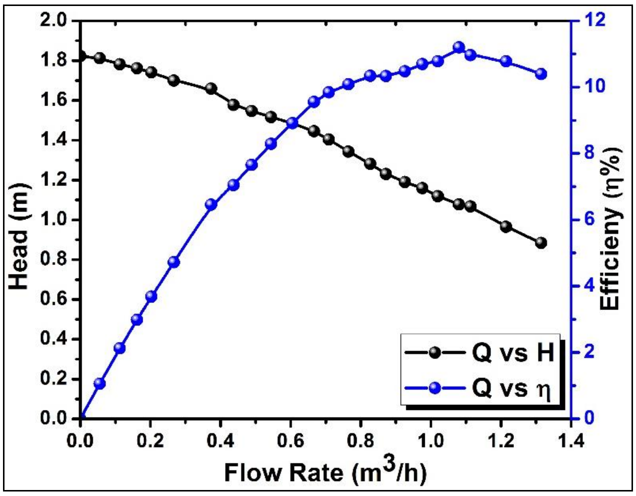

Fig 4: Pump performance characteristics curve

3.1.2 Head Characteristic curve under air-water two-phase flow condition

Fig 5 shows the head characteristic curve of the washing machine drain pump at different gas contents as well as at different flow rates (gas-liquid mixture transportation). The experimental conditions and parameters remain the same as pure water but only the compressor is added in this case near the inlet, in order to inject the air into the pump. Under the condition of lower inlet gas content (<1%), the change of flow rate has a little effect on the pump head characteristics. With the increase of gas content, the slope of head descending curve becomes larger and the effect of gas content on pump performance starts increasing with the change in flow rate condition from design to the lowest flow rate. Under the least value of flow rate (0.4Qd condition), the pump exhibits the maximum values of head at all gas contents, which are minimum in case of Qd condition. But when the gas content increases between 1 to 2%, a sudden decrease in head happened and the head descending curve becomes more irregular. It is only because of some surrounding and personal errors. Under the maximum value of gas content (2.9%), the highest part load condition is (Q_d), which can meet the drainage requirement (0.8m).

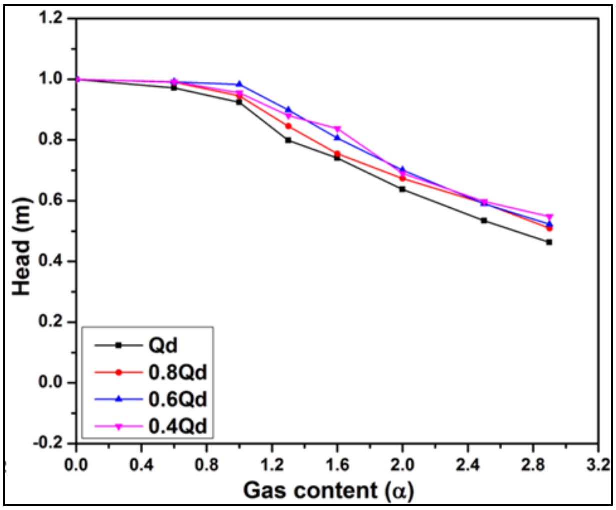

Fig 5: Head curve at different flow rates in air-water two-phase flow condition.

3.2 Radiated noise of the drain pump at different measuring points

Fig 6 shows radiated noise of the drain pump during one cycle of operation at different measuring position, which clearly divided into three parts. According to it, the abrupt increase in radiated noise occur during the starting period which is mainly caused by the collision of the clutch inside the motor and the maximum peak appeared at this period. During the normal drainage period with pure water, the pressure pulsation caused by the flow in the pump chamber gradually increases, and the noise level kept at a low level about 38.5dB(A). Then at the end of discharge period, the sound pressure level increase sharply and reached about 50dB (A). The difference in the above sound pressure level is related to the pressure pulsation phenomenon corresponding to the specific flow state of the two-phase flow in the drain pump.

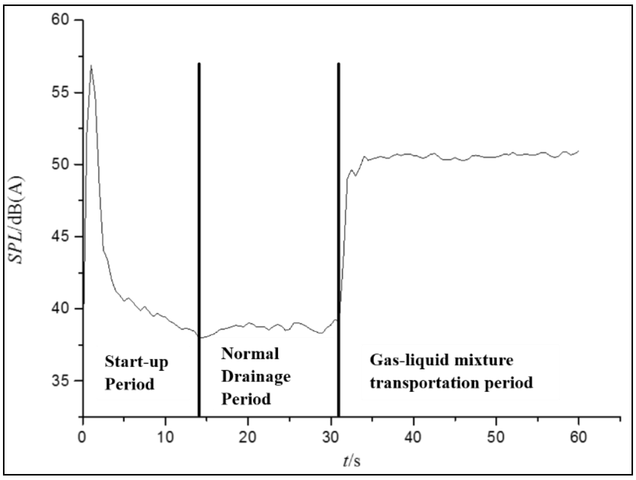

Fig 6: The radiated noise of the drain pump during one cycle of operation at different measuring position

In addition, Fig 7 shows the spectrum comparison between the normal drainage period and the empty discharge period. The ordinate represents the sound pressure level and the abscissa is processed as a multiple of the shaft frequency (f_n). During the normal drainage period and the empty discharge period, there is an obvious discrete noise, the frequency of which is the axial frequency and its multiple frequency, and the discrete noise is related to the motor. In two-phase flow state, the unsteady flow in the pump, gives rise to the instability of the pump rotor, which in turn makes the discrete noise of the empty discharge period higher. Thus, we could conclude that SPL is bigger at the end of drainage period because of gas-liquid two phase flow. It happens due to the unsteady flow inside the rotating part of the pump that causing the flow induced structure vibration and noise.

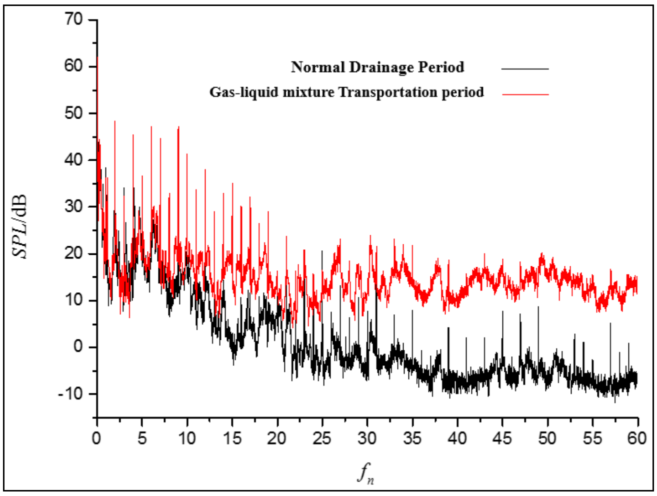

Fig 7: Comparison between the frequency responses of the two conditions

4. Conclusions

The following conclusions were mainly involved;

(1) The performance results show that the head drop slowly with the increase of the flow rate and the pump exhibits low efficiency. But the efficiency of the model pump is in good agreement with the value recommended by the manufacturer. Under small flow rate conditions, the change of inlet gas content has a little effect on the head characteristics of drainage pump. When the gas content is 1%, the influence of gas on the head characteristics of drainage pump is smaller. With the increase of gas content, the slope of the flow-head descending curve of the pump becomes larger. The influence of gas content on pump performance gradually increases with the increase of flow rate. When the gas content reaches 2.9%, the head curve decreases obviously at all flow rates.

(2) The sound pressure level is bigger at the end of drainage period (empty discharge period) because of gas-liquid two phase flow. This happens due to the unsteady flow inside the rotating part of the pump that causing the flow induced structure vibration and noise. Besides, during two-phase flow condition, the unsteady flow in the pump, gives rise to the instability of the pump rotor, which in turn makes the discrete noise of the empty discharge period higher.

5. Acknowledgement

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6. Conflicts of Interest

The authors declare no conflict of interest.

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