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RESEARCH ON CONICAL PLUG VALVE PIEZOELECTRIC PUMP APPLIED TO METALLURGICAL EQUIPMENT COLLING

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In this paper, a valve piezoelectric pump structure is proposed, which provides a method for the cooling of metallurgical equipment and avoids the hidden danger of damage to key components due to long-term exposure to high temperatures. In this paper, the research results of simulated flow rate and test flow rate of valved piezoelectric pump are introduced. The results show that the flow rate of the pump is sensitive to the influence of driving voltage, and it has certain feasibility for the cooling of metallurgical equipment.

Keywords: valved piezoelectric pump, metallurgical equipment, cooling, drive voltage, flow rate

INTRODUCTION

The precision microcomponents in metallurgical equipment are related to the working performance of production equipment,and their long-term exposure to high temperature will change the strength of the parts and there is a risk of destruction, so it is of great significance for the research on the cooling of precision equipment [1-2]. As a kind of miniature pump, piezoelectric pump has the advantages of small size, light weight, and can realize the pumping function of different fluids [3-4]. There are a variety of coolant options for different metallurgical equipment. In this paper, according to the proportion of kangaroo leg bones, a conical plug valve piezoelectric pump was designed. The mode shapes at different natural frequencies are obtained by modal analysis using the COMSOL simulation software, and the displacement of the amplitude of the measuring point is obtained by harmonic response analysis based on t he reasonable mode shapes. Based on the resonant frequency obtained fromthe harmonic response analysis,the multifield coupling was carried out, the oscillator was excited by an external. AC voltage of 150 V,the outlet position was selected by the flow probe, and finally the flow simulation was calculated.Take this model size as a reference the prototype of the piezoelectric pump with a conical plug with valve was made and the flow rate was detected by a flowmeter through the flow test method with zero pressure difference, and the test results were compared with the simulation results, and the pumping performance of the conical plugged valve piezoelectric pump under different drining voltages was analyzed and studied.

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Main components

The pump is mainly composed of piezoelectric oscillators, elastic elements and tapered plugs,as shown in Figure 1.

The pump is a positive displacement piezoelectric pump, in which the key actuator is a piezoelectric oscillator composed of piezoelectric ceramic(PZT) and copper film matrix(Cu),the relevant dimensions are shown in Figure 2.

The volume of the cavity is changed by applying an external excitation voltage to the oscillator and driving it to reciprocate and vibrate.When the oscillator produces a bending vibration to the left, the volume of the cavity increases, the pressure inside the chamber is less than the atmospheric pressure, and the fluid is pumped into the chamber from the outside.At the same time, the elastic element of the left chamber is compressed, the right elastic element is stretched, the left end of the tapered plug is

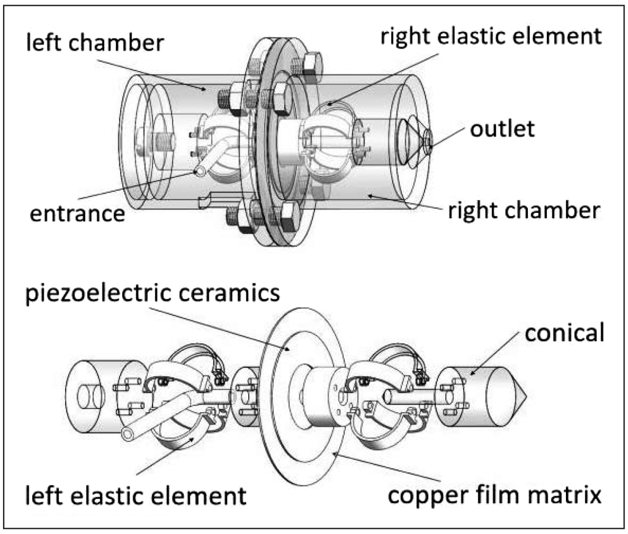


Figure 1 Schematic diagram of the model

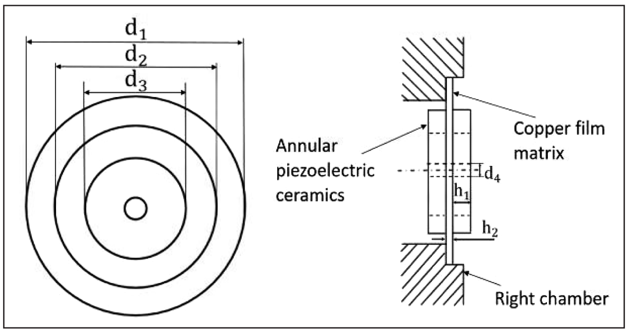


Figure 2 Schematic diagram of a piezoelectric oscillator

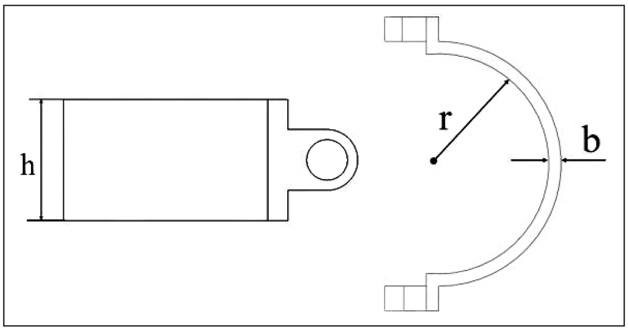


Figure 3 Schematic diagram of an elastic element

detached from the tapered inlet, and the right end is matched with the tapered outlet,so as to realize the one-way pumping function of the fluid. Conversely,when the oscillator bends and vibrates to the right,it is the pumping stage of the piezoelectric pump. The structural dimensions of the elastic element are shown in Figure 3.

From the perspective of the working process of the piezoelectric oscillator, the oscillator performs reciprocating vibration, and its deformed surface is similar to that of a sphere, so the model can be simplified, and the amount of change in the volume of the chamber in a vibration cycle of the pump can be calculated by using the integration tool, and the flow rate generated by a single vibration of the oscillator at the outlet can be obtained according to the empirical formula of fluid dynamics theory

$$Q = \Delta V \times f \times \eta \tag{1}$$

Where ΔV is the volume change of the chamber produced by the oscillator in one cycle of a single vibration, f is the external excitation frequency that drives the piezoelectric oscillator to work normally, η is the volumetric efficiency of the conical plug piezoelectric pump, which is mainly affected by the elastic element and the external excitation frequency and other related parameters. A simplified schematic diagram of the oscillator deformation is shown in Figure 4. According to the surface generated by the oscillator deformation, the volume change of the chamber can be approximately equivalent to a spherical deficiency model, where O is the centroid of the spherical absence, that is, the origin of the coordinate axis, according to the equation of the circle

$$x^2 + y^2 = R^2 \tag{2}$$

$$x = \pm\sqrt{R^2 - y^2} \tag{3}$$

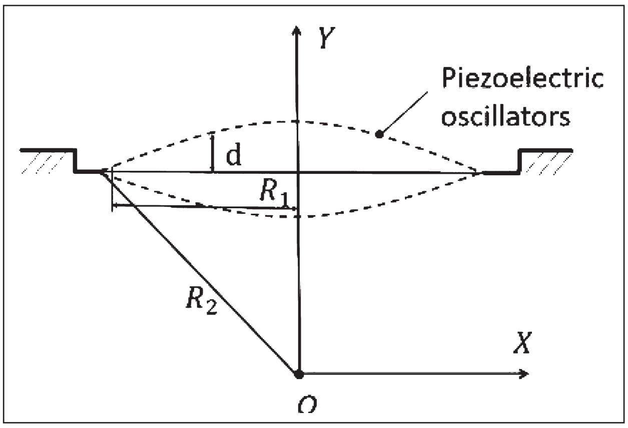


Figure 4 Simplified diagram of the ball missing model

Table 1 **Parameter design of piezoelectric oscillators**

Parameter	d_1/mm	d_2/mm	d_3/mm	d_4/mm	h_1/mm	h_2/mm
Size	50	40	15	5	3	0,3

Table 2 **Parameter design of elastic components**

Parameter	h/mm	r/mm	b/mm
Size	5	10	1

Integral operation on the missing part of the ball

$$\Delta V = \int_{R_2-d}^{R_2} \pi x^2 dy = \int_{R_2-d}^{R_2} \pi (R_2^2 - y^2) dy \tag{4}$$

where d is the height of the ball-missing model, it is the displacement of the piezoelectric oscillator in the Y-axis direction, R_1 is the radius of the oscillator, which is also the radius of the pump chamber, R_2 is the radius of the spherical model.

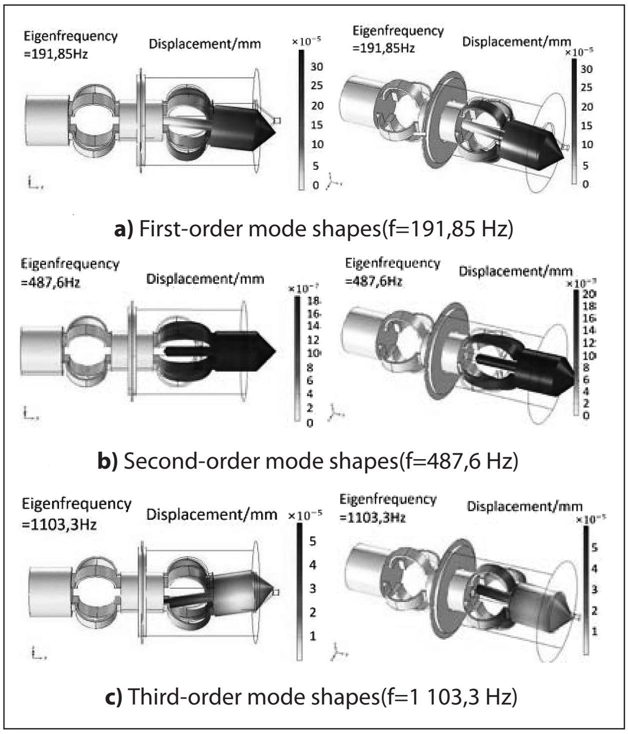
Since the piezoelectric oscillator is driven by a sine wave signal, the excitation signal is symmetrically distributed, so the piezoelectric oscillator also exhibits reciprocating symmetrical deformation when driven.So the flow rate of the conical plug valve piezo pump in one vibration cycle is

$$Q_v = 2Q = \pi f \eta (\frac{d^3 + 3dR_1^2}{3}) \tag{5}$$

Numerical simulation:

The model was imported into COMSOL for modal analysis,and the relevant mode shapes and corresponding frequencies were obtained, as shown in Figure 5.

From the obtained mode shape diagram,it can be seen that the cone plug in the first and third order mode shapes deviates from the outlet and inlet respectively, which will affect the one-way pumping performance of the piezoelectric pump to varying degrees, and secondly, the elastic element will also be damaged due to torsion.In the secondorder mode, the mode shape is that the tapered plug and the elastic element are displaced along the axis,and in this state, the tapered plug will move along the conical hole channel of the inlet and outlet, and the elastic element will not have the risk of torsion, and finally the second-order mode shape is selected as the basis for research.



a) First-order mode shapes(f=191,85 Hz)

b) Second-order mode shapes(f=487,6 Hz)

c) Third-order mode shapes(f=1 103,3 Hz)

Figure 5 The first three mode shapes of the oscillator

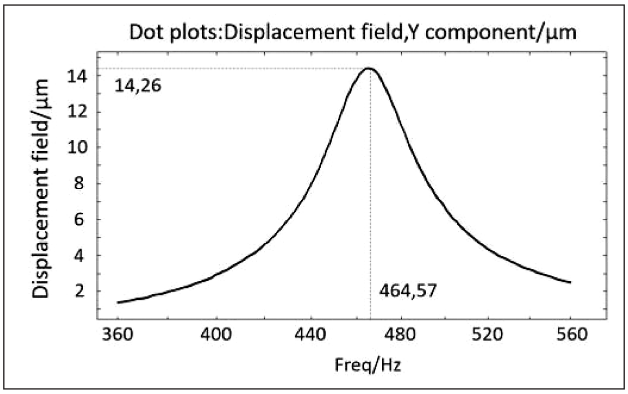


Figure 6 Harmonic response simulation analysis

The harmonic response of the frequency corresponding to the second-order mode (487,6 Hz) is analyzed,the right end tapered plug is selected as the tapered plug is selected as the measurement point,and the frequency domain span range is set to 200 Hz. The amplitude distribution curve with frequency is shown in Figure 6.

As can be seen from the Figure, the amplitude displacement is normally distributed, with a peak displacement of 14,26 μm, and the corresponding second order frequency is 464,57 Hz.Taking this frequency as the excitation frequency,the alternating potential on the surface of the piezoelectric oscillator is set to V = 150 × sin(2 × pi × 464,57 × t), The flow velocity detection probe is set at the outlet position,and the meshing selection is a free tetrahedral mesh suitable for fluid mechanics, The largest unit is 3 mm the smallest unit is 0,5 mm, and the mesh is about 8 000 cells.After simulation calculation, the flow velocity at the probe outlet is obtained as a function of time,and the curve is Figure 8.

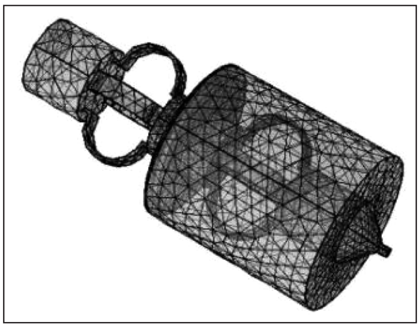


Figure 7 Divided mesh

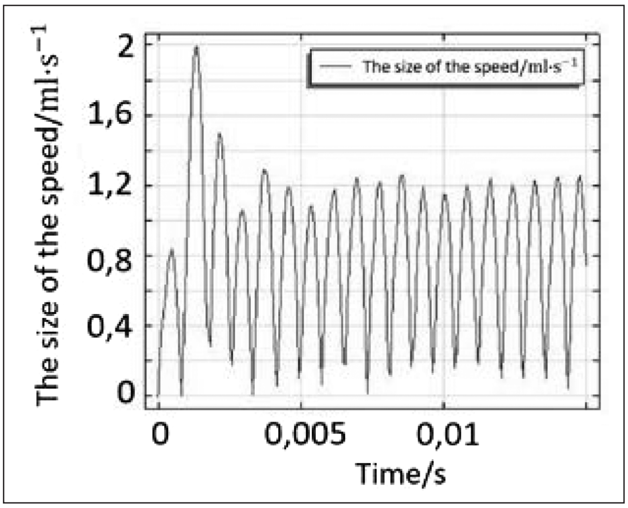


Figure 8 Egress traffic

According to the change curve, it can be seen that the flow velocity at the outlet increases and then decreases with time, and finally gradually stabilizes. The reason for the large change of the curve in the early stage is mainly because the oscillator is affected by pressure and fluid viscosity in the initial stage of work, and the pumping performance is unstable.However,with the change of time and the cooperation of the conical plug,the flow rate of the outlet is stable at 0,17 cm^3/s during the pumping stage, and the outlet flow velocity is small at this time, indicating that the cone plug has obvious effect on the outlet control. The flow rate is stable at 1,2 cm^3/s during the pumping phase.

Prototype test:

The finished piezoelectric pump prototype is shown in Figure 9, which is mainly composed of a liquid inlet tube, a left chamber,an elastic element,and a right chamber.In order to investigate the pumping performance of a conical plugged valve piezo pump, a zero-differential flow rate test method will be used to test the piezo pump.

The test equipment mainly includes: Signal generators, power amplifiers,water reservoirs, sinks, lifting tables, measuring cups, flow meters,fixed brackets, etc. The test process is shown in Figure 10.

When the conical plug valve piezoelectric pump is working stably, the flow meter is used to monitor the outlet flow rate in real time.

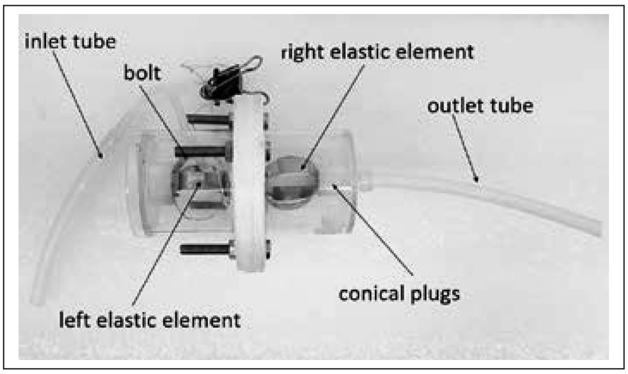


Figure 9 Prototype in kind

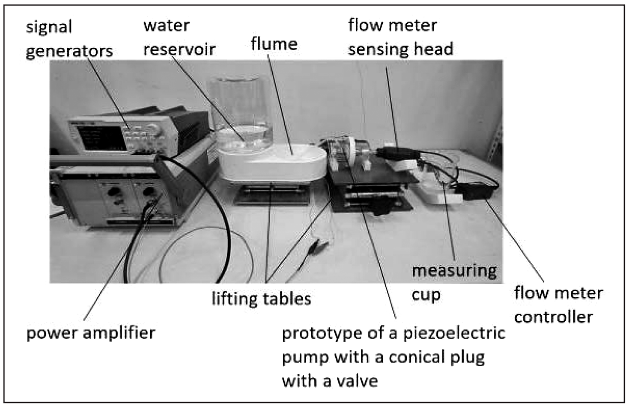


Figure 10 Flow test platform with zero differential pressure

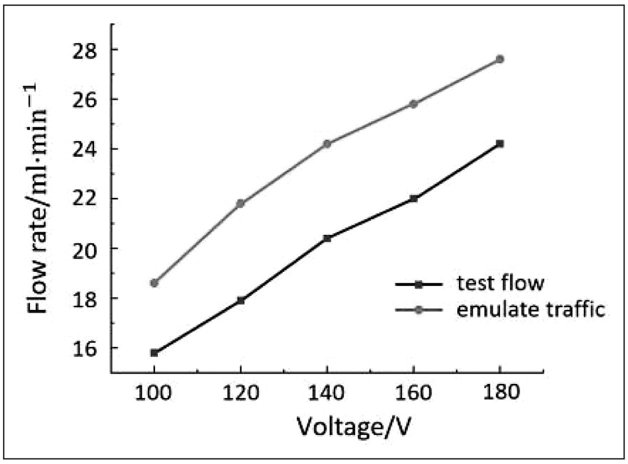


Figure11 Experiment-simulated flow comparison

Because different driving voltages have different driving effects on the oscillator,the pumping performance of the piezoelectric pump is affected, but the excessive voltage will break down the piezoelectric oscillator.Therefore, in the process of testing, 100-180 V AC voltage is used to drive each Other[5], and the results of the simulation are compared with the flow rate of the test results, as shown in Figure 11.

As can be seen from the flow comparison curve, both the simulated and experimental flow rates show an upward trend with the change of driving voltage. The test flow rate is less than the flow rate in the simulation under different voltage drives.This result may be due to the inevitable human error during the prototype and the interference caused by the environment during the test.When the driving voltage is 180 V, the simulated flow rate is 27,9 ml/min, and the test flow rate is 23,6 ml/min, and the error of the two is 15,4 %.

CONCLUSION:

According to the results of prototype test and simulation,the flow error of the two is relatively small, which verifies the feasibility of the conical plug valve piezoelectric pump.The outlet flow is sensitive to the influence of external external excitation voltage,and the pumping flow can be controlled by adjusting the intensity of the voltage, so as to meet the requirements of metallurgical equipment for coolant flow in different working environments.

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Note: The responsible translator for English language X. Q. Hu, Zaozhuang University, Zaozhuang, China