Ceramics International xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

The numerical and experimental research on injection performance of piezoelectric micro-jet

Kai Li[a,*], Jun-kao Liu[a], Rui Yang[a], Wei-shan Chen[a], Lu Zhang[b]

[a] State Key Laboratory of Robotics and System, Harbin Institute of Technology, Harbin 150001, China
[b] AVIC, Harbin Dongan Engine Corporation LTD, Harbin 150001, China

ARTICLE INFO

Keywords:
C. Mechanical properties
E. Actuators
E. Functional applications

ABSTRACT

The injection characteristics of a piezoelectric micro-jet are analyzed in this paper by numerical simulations and experiments. The effect of acoustic-structure interaction on the working frequency of the vibrator are analyzed by simulations and experiments. The vibration statuses of the vibrator are given when the cavity is filled with liquid or air. A simulation method for analyzing the frequency response characteristics of micro-jet is proposed, and the influences of the shell materials on the nozzle pressure are analyzed. In order to improve the injection performance, the recommended working frequency and adjustment methods of the excitations are given when selecting different shell materials. Experiments are carried out and the actual injection performance is obtained which prove the numerical simulation method can be effective.

1. Introduction

Based on the piezoelectric ink-jet technology, the piezoelectric micro-jet is a micro-electro mechanical system which can achieve drop on demand requirement. Thanks to its advantages of good stability, fast response and high precision, the piezoelectric micro-jet is used in a number of different fields, such as Lab-on-Chip system [1], electronics device [2,3], medical science [4–6], material science [7,8], biological field [9–11], patterning [12,13], bearing lubricating [14] and additive manufacturing [15,16] etc.

The forming process and characteristics of the droplet can be obtained by analyzing the hydrodynamic characteristics of the piezoelectric micro-jet [17–19]. The influences of pulse voltages on the injection performance can be gained by simulations and experiments in order to obtain suitable excitation method [20–22]. Normally, the effects of structure size and characteristics of bubbles in the cavity are analyzed based on acoustic theory [23,24]. As the acoustic impedance of different materials is different, the injection performance of the micro-jet is also influenced by the material of the shell.

A simulation method, which is based on the theory of acoustics and for analyzing the injection performance of the designed micro-jet, is proposed in this paper. In general, the piezoelectric vibrator works in the resonant state for obtaining strong injection performance and the resonant frequency of the vibrator is affected by the acoustic structure coupling. Thus, the influences of the coupling effect on the resonance frequency and vibration status of the vibrator are analyzed here by simulations and experiments. The frequency responses of the nozzle pressure, when selecting different shell materials, are analyzed by simulations and the corresponding excitation adjustment methods are given in order to get well injection performance. The experiments when micro-jet works at different frequencies are carried out, and the simulation method is proved to be effective by comparing the experimental results and simulation results.

2. Structure and method

A kind of piezoelectric micro-jet is designed as shown in Fig. 1, and the micro-jet is mainly composed of piezoelectric vibrator, shell and nozzle part. The core part of the piezoelectric micro-jet is the piezoelectric vibrator which is made by gluing the piezoelectric ceramic to the copper film. As shown in Fig. 1a, when pulse voltages are applied on the vibrator, acoustic pressure waves are created in the fluid domain, then, the droplets are pushed out by the pressure waves which spread to the nozzle part. As we can see from Fig. 1b, there is an O-shaped ring at the interface between the vibrator and the cavity, and when the cavity is assembled with the End cover, the cavity body is sealed and leakage will not be produced. The volume of the chamber is 1.5 ml, and the material of the end-cover is aluminum alloy. The diameter of the piezoelectric ceramic is 17 mm which is easy for manufacturing and assembling. As with the same excitation, the thinner the ceramic is, the larger the vibration intensity is, and in consideration of the supplier's manufacturing capacity, we take 0.2 mm

* Corresponding author.
E-mail address: sdcxlikai@126.com (K. Li).

http://dx.doi.org/10.1016/j.ceramint.2017.05.200

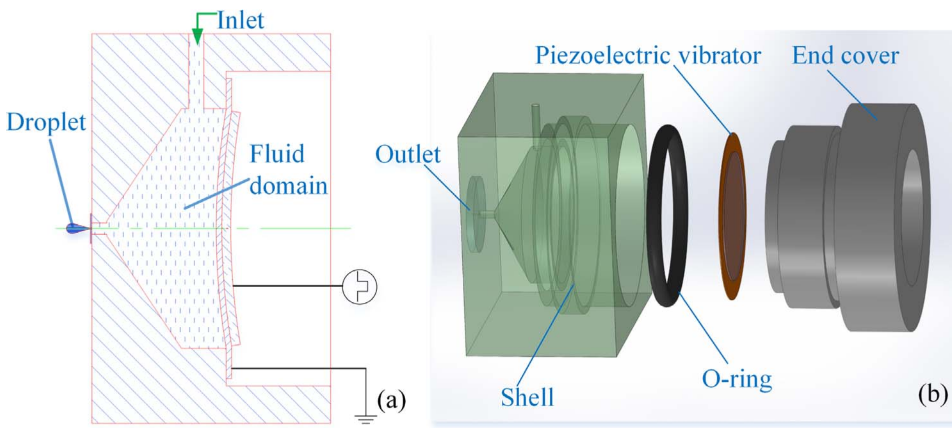

Fig. 1. The structure of the piezoelectric micro-jet: (a) the schematic diagram of working principle (b) the structure of the micro-jet.

as the thickness of piezoelectric ceramic. The thickness and effective diameter of the copper film are 0.15 mm and 18 mm respectively. The length and diameter of the nozzle are 1 mm and 0.1 mm respectively.

In this paper, the vibration intensity of vibrator is mainly depend on its bending deformation which is produced by the radial deformation of piezoelectric ceramic. According to the standard on Piezoelectricity form IEEE [25], the piezoelectric strain constant along the radial direction (d31) of PZT-5H is relatively large than that from others. Thus, PZT-5H, which is provided by Baoding HengSheng Acoustics Electron Apparatus Co., Ltd. [26], is selected in this paper. The density, elasticity modulus and Poisson ratio of the copper film used here are 8.2×10^3 kg/m^3, 7.65×10^{10} N/m^2 and 0.32 respectively. And the physical properties of PZT-5H (elastic stiffness constant matrix $[c^E]$, piezoelectric stress constant matrix $[e]$ and dielectric constant matrix $[\varepsilon^T]$) are:

$$[c^E] = \begin{bmatrix} 12.6 & 7.95 & 8.41 & 0 & 0 & 0 \\ 7.95 & 12.6 & 8.41 & 0 & 0 & 0 \\ 8.41 & 8.41 & 11.7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2.3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2.3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 2.35 \end{bmatrix} \times 10^{10}(\mathrm{N/m^2})$$

$$[e] = \begin{bmatrix} 0 & 0 & -6.55 \\ 0 & 0 & -6.55 \\ 0 & 0 & 23.3 \\ 0 & 0 & 0 \\ 0 & 17 & 0 \\ 17 & 0 & 0 \end{bmatrix} (\mathrm{C/m^2})$$

$$[\varepsilon^T] = \begin{bmatrix} 1700 & 0 & 0 \\ 0 & 1470 & 0 \\ 0 & 0 & 1470 \end{bmatrix} \times 10^{-11}(\mathrm{F/m})$$

The finite element analysis software ANSYS is used to analysis the acoustic-structural coupling and frequency response characteristics of the micro-jet, the established finite element model is shown in Fig. 2. The piezoelectric micro-jet designed in this paper is used for ejecting water based solution, thus, the material of the fluid domain is set as water and its density, sound speed and dynamic viscosity are set as 1×10^3 kg/m^3, 1480 m/s and 1×10^{-3} Pa s respectively.

The interface between vibrator and fluid domain is set as fluid-solid-interaction surface. The boundary conditions of the liquid inlet and outlet surface are set as acoustic impedance boundary conditions with acoustic impedance values as 1.48×10^6 Pa s/m (water) and 4×10^2 Pa s/m (air) respectively. The upper and lower surfaces of piezoelectric ceramic are applied with voltage constraints and the effective outer ring of the copper film is set as fixed constraint. Acoustic impedance boundary conditions are also applied at the interfaces between the fluid domain and the shell to replace the shell element, and the acoustic impedance of the shell is related with the

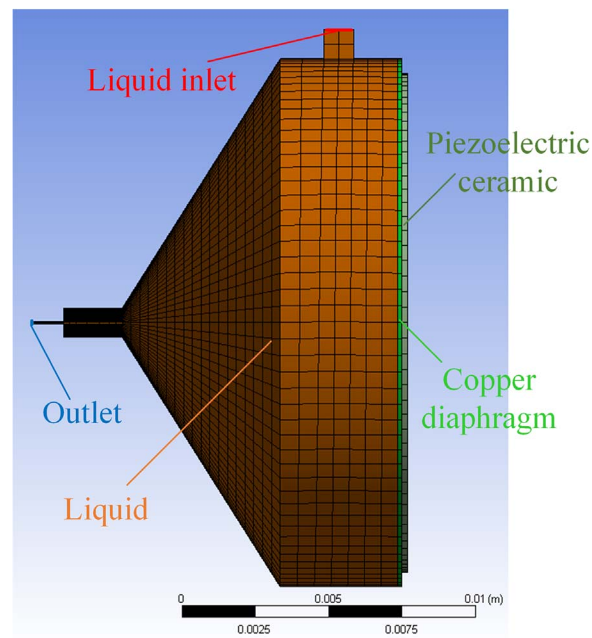

Fig. 2. The finite element model of the piezoelectric micro-jet.

Table 1
Acoustic impedance values of different materials ($\times10^6$ kg m^{-2} s^{-1}).

Material	Plexiglass	Magnesium	Aluminum	Iron	Copper
Impedance	3.1	10.0	17.1	33.2	41.6

shell material. The acoustic impedance values of different materials are shown in the Table 1.

3. Acoustic-structural coupling

Due to the acoustic-structural coupling between the vibrator and the fluid domain, the resonance frequency of the vibrator changes when the cavity is filled with fluid. And as the working frequency of the micro-jet is determined by the resonance frequency of the vibrator, modal analyses are carried out to study the acoustic-structural coupling of the micro-jet.

3.1. Simulation results

The vibration modes and corresponding resonant frequencies of the vibrator in air are shown in Fig. 3. It can be seen that the resonance