Design, Simulation and Fabrication of a Time-Delay Device Based on Micro-Channel

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Abstract. With the development of micro-machining technology, the application of micro-channel is becoming more and more popular. In this paper, we design a set of time-delay device based on micro-channel and micro-fluidics technology. This paper describes the time-delay device’s working principle and analyses the micro-channel’s flow characteristics by simulation method based on Coventerware. From studies on the micro-channel’s cross section, geometry and dimension parameters, the micro-channel’s optimal form and dimension can be obtained. Finally, this paper chooses ultra-machining process to fabricate the time-delay device.

1. Introduction

With the development of MEMS, fluid technology referring to the micro-channel or even the nano-channel has drawn more and more people’s attention [1]. Micro-channels are important components in micro-systems, and are widely used in various flow control field to achieve micro-mixing, micro-separation, micro-condensation, micro-detection and other functions [2-4]. Here we propose a new kind time-delay device based on micro-channel, and it may be used as a time delay fuse for explosives or for the delayed operation of a mechanical, fluoric or fluidic circuit. Heretofore most of the time-delay devices have been mechanical or electrical in nature. Problems have been raised by the use of electronic circuitry [5]. The time-delay device based on micro-channel can solve the above problems availably. This paper discusses the design, simulation and fabrication results for the time-delay device.

2. Working principle

The time-delay device based on micro-channel in this paper can be used in safe and arming system of fuze. These kind of devices can guarantee that the fuze is safe near the muzzle, avoiding accidental fire.

2.1 Clock mechanism

There are a lot of time-delay devices can be used in fuze, and among them, clock mechanism is the most common type of time-delay mechanism, shown in figure 1.

According to the principle of clock mechanism, it can be divided into three parts: motor, wheel train and runaway escapement. Escape wheel component and pallet component compose runaway escapement. The spine axis and centre of the mass of the motor don’t coincide with the spine axis of
the projectile. Therefore, due to the centrifugal force during rotation of the projectile around symmetry axis, the spin movement of the motor and the force on the motor that drives the coupled components of clock mechanism are supplied simultaneously. The pallet’s movement is a kind of cyclical swing by the escape wheel impacting the pallet again and again. This movement can limit the rotational speed of the motor, and realizes the aim of time-delay.

2.2 Time-delay device based on micro-channel

The time-delay device based on micro-channel’s plan view is shown in Figure 2, and it comprises slide block having two piston rods, micro-channel and working liquid in the micro-channel. In order to solving the long-time storage problem and avoiding leakage, we choose Polydimethylsiloxane as the device’s working liquid which is a simple silicon fluid, referred to as silicon oil. The micro-channel has two orifices, inflow and outflow. Piston I will move along the micro-channel’s inflow because the effect of external force and must overcome the damping force causing by silicon oil during its moving. Meantime piston II moves out of the micro-channel’s outflow. The movement time of the piston I from assembly position (point A) to point B is the time delay device’s total delay time.

3. Micro-channel fluid flow characteristics analysis

The surface roughness, structural morphology, aspect ratio, and size of the micro-channel all have an effect on the flow of fluid within the channel. This paper will use Coventerware software to study the influence of the cross-section and geometry the micro-channel on the delay time of the time-delay device, and provide a basis for the design of the time-delay device based on the micro-channel.

3.1 Effect of cross-section on flow characteristics

The cross-sectional shape of a typical micro-channel is shown in Figure 3. The micro-channels in the form of (a), (b), and (c) are first processed one-half of the structure by micro-fabrication techniques, and then the two structures are bonded together by various bonding techniques. The fluid flows in micro-channel of different cross-sectional shapes and the resistance is different. Studies have shown that in the above-mentioned structural form, the circular pipe has the highest flow resistance, the rectangular pipe is second, and the V-shaped pipe has the smallest flow resistance.

Figure 1. 3-D view of clock mechanism. Figure 2. Time-delay device based micro-channel.
Considering that this paper intends to process micro-channel using LIGA technology, diagrams (a) and (c) are not applicable to the delay device studied in this paper, and the delay device is to use the resistance of the fluid in the micro-channel to perform the delay function. It is hoped that the cross-section of the micro-channel can generate a large flow resistance, so we choose (d) as the cross-section of the micro-channel.

3.2 Effect of geometry on flow characteristics

In this section, we will study the effects of three geometric shapes of micro-channel on fluid flow characteristics, namely S-shaped, Z-shaped and O-shaped, with the structure as shown in Figure 4. Except for different geometrical shapes, the bending numbers of the three channels are 8, the thickness is 500 microns and the width is 50 microns.

![S-shaped channel](image1) ![Z-shaped channel](image2) ![O-shaped channel](image3)

Figure 4. Three geometries of micro-channels.

The reasons for choosing these three shapes are mainly based on the following considerations:

1) The three geometric structures mentioned above are relatively simple pipeline types, and the use of such pipeline type is conducive to future processing.

2) These three types can make full use of space. In relatively narrow space, the flow distance of micro-channel can be adjusted by changing the number of bends in the pipe and different flow time can be obtained. Then the relationship between flow distance and delay time can be studied.

Table 1 shows the simulation results of the delay time of three micro-channel structures. The delay time refers to the time when the piston I moves from point A to point B (in Figure 2).

| Geometric type | S-shaped | Z-shaped | O-shaped |
|----------------|----------|----------|----------|
| Delay time (ms) | 31.8     | 30.5     | 5.89     |

Table 1. Delay time for different geometries.

It can be seen from Table 1 that the geometry of the S-shaped and Z-shaped micro-channels are similar in delay time. Although the circumference of the O-shaped pipeline is longer than the former two, the delay time is a lot shorter compared with the former two. This phenomenon is probably caused by the characteristics of the O-shaped pipe itself. The micro-fluidics is split into two after entering from the entrance of each O-ring, although the circumference of the O-shaped pipe is longer than the former two, the moving distance of the fluid is shorter, so the delay time is much shorter than the other two. Therefore, the O-shaped geometry micro-channel will not be adopted in the design of the time-delay device.

Figure 5 is a vector diagram of the simulation speed of the S-shaped and Z-shaped micro-channels in the initial stage of motion. Fig. 5(a) is a vector diagram of the overall velocity of the S-shaped
micro-channel at the initial stage of motion, Fig. 5(b) is an enlarged view of the velocity vector at a certain turn in Fig. 5(a), and Fig. 5(c) is a vector diagram of the overall velocity of the Z-shaped micro-channel at the initial stage of motion, Figure 5(d) is an enlarged view of the velocity vector at a certain turn in Figure 5(c).

![Simulation speed vector of S-shaped and Z-shaped micro-channels.](image)

It can be seen from Fig. 5(b) and Fig. 5(d) that the velocity of the S-shaped micro-channel is smoother and the flow is more stable at the bend, while the velocity of the Z-shaped micro-channel at the bend is abrupt and the flow is blocked, so the S-shaped geometry will be adopted in the design of the time-delay device.

3.3 Effect of structural size on flow characteristics

In this section, the influence of the thickness and width of the micro-channel on the fluid flow characteristics in the micro-channel will be discussed, which will lay the foundation for the dimension design of the micro-channel. The simulation model is an S micro-channel with a rectangular cross section and the number of bends is eight.

3.3.1 Effect of channel thickness on fluid flow characteristics.

Figure 6 is a plot of the delay time of micro-channel simulation at different thicknesses. It can be seen that in the case when the thickness of the micro-channel is greater than 100 μm, the delay time and the thickness are approximately linear, but as the thickness is reduced to less than 100 μm, the change in the delay time tends to be gentle, and a mutation occurred near 40 μm, then the delay time increased sharply with the decrease of the thickness of the micro-channel. The delay time with a thickness of 10 μm was similar to that with a thickness of 300 μm. This indicates that when the thickness of the micro-channel is less than 100 μm, the surface force plays a key role in the influence of flow characteristics, and the smaller the size, the greater the impact.
Figure 6. Effect of thickness on flow characteristics. Figure 7. Effect of width on flow characteristics.

3.3.2 Effect of channel width on fluid flow characteristics.
The reason why the thickness of the micro-channels in this section selects 500 μm and 30 μm is that the study in Section 3.3.1 finds that when the thickness is less than 100, the delay time and thickness of the micro-channel are no longer linear. And mutations occurred at approximately 40 μm, so the purpose of this simulation was to investigate the relationship between the thickness and delay time.

Figure 7 shows the correspondence between micro-channel’s width and delay time. It can be clearly seen that the delay time of the micro-channels of both thicknesses increases significantly with the decrease of the width, and the growth rate also increases. There is no linear relationship between the two. But the growth rate of the micro-channel’s delay time with a thickness of 30 μm is significantly larger than that of the micro-channel with a thickness of 500 μm, which indicates that the surface force in the flow channel at the micro scale gradually becomes the main factor hindering the fluid motion, and the conclusion is the same as the result of 3.3.1.

4. Production of micro-channel time-delay device
In this paper, the micro-channel time-delay device is fabricated using LIGA processing technology, the process flow is shown in Figure 8. Figure 9 shows the processed micro-channel. The design size of the micro-channel width is 50 μm, and the measurements of the four micro-channels widths under the microscope were 47.6 μm, 45.5 μm, 44.9 μm, 46.5 μm.

5. Conclusion
In this paper, a time-delay device is designed and fabricated by using micro-channel fluid technology. This device can be used for the delay mechanism of the fuze safety system. Compared with the
traditional delay mechanism, this device has the characteristics of simple structure and small size. The paper studies the flow characteristics of micro-channels in various forms through different design parameters such as cross section, geometry and geometrical dimensions, and analyses the influence of various parameters on flow characteristics, which lays a foundation for its application in fuze.

References

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