Research on Centrifugal Mechanism Based on Microfluidic Chip

Zhou Lulu\(^1\), Ding Yuan\(^2\)*, Ma Haitao\(^3\)

\(^1\)College of Machinery and Vehicle Engineering, Changchun University, Changchun, China
\(^2\)College of Machinery and Vehicle Engineering, Changchun University, Changchun, China
\(^3\)College of Communication Engineering, Jilin University, Changchun, China

\(^*\) zonghao1023@stu2018.jnu.edu.cn
\(^*\)331689559@qq.com

Abstract—In order to improve the accuracy and safety of blood test, the research of centrifugal mechanism in automatic blood group analysis system is proposed. According to the theoretical research of centrifugal microfluidic, the structure of microfluidic chip is designed; According to the requirements of blood centrifugation, the appropriate motor is selected, and the three-dimensional model of the centrifugal mechanism is established by using Solid Works software, and the structure of the centrifuge is determined; The success rate and average time were calculated by centrifugation test of microfluidic chip on automatic blood group analysis system. The rationality and validity of the centrifugal structure were verified.

1. INTRODUCTION

With the development of medical devices, the laboratory automation has been realized. The speed and success rate of blood centrifugation affect the efficiency of the automatic blood group analysis system. At present, there are many research results on centrifugal microfluidics \(^{[1-3]}\). A kind of "LabCD" centrifugal microfluidic platform was put forward by Ohio University, which introduced the mixing and classification of liquid into the centrifugal force microfluidic disk respectively, and used the micromachining technology, which provided a new direction for the centrifugal microfluidic platform \(^{[4]}\); Kameel has successfully realized the installation of power coupler on the centrifugal disk to make the centrifugal disk rotate continuously to measure the speed of the fluid, but the Joule heat produced may affect the accuracy of the measurement results \(^{[5]}\); Morijiri classifies blood by controlling the difference between the drag force and centrifugal force of blood in the centrifugal field, but the mechanism of the chip is complex and the processing technology is very high \(^{[6]}\). This article is based on a microfluidic chip to study the blood centrifuge mechanism that meets the needs of major medical institutions to process blood samples, to overcome the problems of long blood testing cycles and inaccurate test results, to ensure the safety of the laboratory and reduce the level of infection factors exposed to blood samples by medical staff.
2. DESIGN OF MICROFLUIDIC CHIP

2.1. theoretical analysis of centrifugal force microfluidics

There are three kinds of forces produced by rotating blood of centrifuge: centrifugal force, Euler force and Coriolis force, as shown in Fig. 1. These three forces act on the blood, effectively pushing the blood into each micro control.

\[ F_c = 2 \rho rv \]  \hspace{1cm} (2)

Among them, \( v \) is the speed of blood flow on the microfluidic chip.

Eulerian force is the lateral movement of blood when the microfluidic chip accelerates, and the direction is opposite to the rotation acceleration of the microfluidic chip, that is, Eulerian force may have two directions [7-9], the calculation formula is:

\[ F_E = \rho rv \frac{dw}{dt} \]  \hspace{1cm} (3)

2.2. design of microfluidic chip

Microfluidic chip is used to detect the blood group of four people. Under the action of centrifugal force, the blood sample can enter each microcavity through microfluidic channel, and the red blood cell antigen and antibody in the microcavity react specifically. when the blood sample flows in the channel along the circular curve, centrifugal force will be generated. The centrifugal force is outward along the radial direction of the microfluidic chip. The centrifugal force makes the blood sample of the microfluidic channel flow towards the outer wall of the channel, and generates two rotating vortices on the upper and lower sides of the channel. The eddy current in one direction will push the blood sample forward along the channel, the vortex in another direction causes the blood sample to flow in a direction perpendicular to the outer wall of the channel [10-12]. These two directions of eddy current can better promote the mixing degree of antigen and antibody, and improve the mixing rate.

The structure of the designed microfluidic chip is shown in Fig. 2, and the physical figure of the microfluidic chip is shown in Fig. 3, which can realize 4 people time blood type detection.

In Fig. 2, the needle injects the blood into the channel through the injection hole, and the blood enters the channel through the centrifugation and then flows into each microcavity. The blood sample reacts with the antibody in the microcavity.
In Fig.3, we can see more clearly the positions and the flow direction of blood in the microfluidic chip.

![Fig. 2 structure of microfluidic chip detection card](image)

**Fig. 2 structure of microfluidic chip detection card**

![Fig. 3 real picture of microfluidic](image)

**Fig. 3 real picture of microfluidic**

### 3. DESIGN OF CENTRIFUGAL MECHANISM

#### 3.1. selection of centrifugal motor

The centrifugal motor in this study is to introduce blood into each microcavity, and the blood reacts fully with antibody through centrifugation. The working principle is that the motor drives the rotating head to rotate at high speed through the coupling, so that the microfluidic chip generates centrifugal force, which injects blood into each microcavity [10-12], and its calculation formula is:

\[
F_w = 1.118 \times 10^{-5} n^2 r \times g = prw^2
\]

\[
= \frac{1.055}{10} \times 3000 \times 314^2 \approx 4160.8N
\]

Where \( n \) is the speed \( r/\text{min} \); \( r \) is the radius of rotation.

According to the requirement of processing microfluidic chip and mechanism, the space range is 50mm, 40A2A01030-SCO motor is selected, and its maximum rated speed is 3000 \( r/\text{min} \).

From formula \( F_w = 1.118 \times 10^{-5} n^2 r \times g \),

\[
r = \frac{F_w \times 10^5}{1.118 \times n^2 \times g}
\]

Substituting \( F_w \) and \( n \) into the above formula, we get,

\[
r = \frac{F_w \times 10^5}{1.118 \times n^2 \times g} = \frac{4160.8 \times 10^5}{1.118 \times 3000^2 \times g}
\]

\[
= 4.2cm = 42mm
\]

Its rotation radius is less than the space range of 50mm, which meets the use requirements. When the centrifuge rotates, the distance between blood sample and microfluidic chip is \( R_{\text{max}} = 38mm, R_{\text{min}} = 33m \). The time required for blood centrifugation and sedimentation is \( T_s \). It can be seen
from the data that the blood density $\rho = 1.055 \ g/\ cm^3$, blood viscosity $\mu = 0.06 \ p$, red cell radius $r = 3.5 \times 10^{-4} \ cm$, red cell density $\rho = 1.115 \ g/\ cm^3$, substitute the parameters into the formula to get:

$$
T = \frac{27.4 \times (InR_{\text{max}} - InR_{\text{min}})\mu}{n^2 r^4 (\sigma - \rho)} = 27.4 \times (In38 - In33) \times 0.06 \approx 1.98 \text{ min}
$$

(7)

Where, $\rho$ - blood density $g/\ cm^3$  
$\mu$ - blood viscosity $p$  
$n$ - speed $r/\ min$  
$r$ - particle radius $cm$  
$\sigma$ - particle density $g/\ cm^3$

According to the above calculation, the motor meets the requirements of blood centrifugation.

3.2. structure design

The automatic blood group analysis system is fully automatic for blood centrifugation and interpretation. In order to judge the reliability of the results, the design of the centrifugal mechanism should consider the influence of the camera light on the results, and add a backlight plate on the centrifugal mechanism to prevent the adverse effect of reflection when taking photos and sampling. The integral centrifugal mechanism is composed of shaft sleeve, motor, motor frame and backlight, as shown in Fig.4.

![Fig. 4 integral centrifugal mechanism](image)

The manipulator in Automatic blood group analysis system places the microfluidic chip on the backlight of the centrifugal mechanism. Meanwhile, the empty key of the microfluidic chip is required to be stuck on the key of the shaft sleeve to ensure the accurate positioning of the microfluidic chip. In this way, the blood sample can enter the injection hole of microfluidic chip accurately. The motor drives the rotating shaft to rotate, and the microfluidic chip is centrifuged and vibrated to complete the full mixing and reaction of blood sample and antibody, so as to facilitate the subsequent image acquisition and interpretation.

4. CENTRIFUGAL TEST

Combined with the above parts, the assembly is used for test to verify its rationality. First, according to the design of the microfluidic chip and the parts of the centrifugal mechanism for processing and purchase of the motor, assembly and combination, get the test mechanism. Randomly select 60
microfluidic chips and divide them into two groups for test. The calculation success rate and centrifugal
time are shown in Table 1. The centrifugation of blood samples with centrifugation structure is shown
in Fig. 5.

| Time of centrifugation |
|------------------------|
| 1.92 | 1.94 | 1.96 | 1.98 | 2.00 |
| 1 | 1.58 | 1.56 | 1.54 | 1.52 |
| 2 | 2.00 | 2.02 | 2.04 | 2.06 |
| 3 | 3.00 | 3.02 | 3.04 | 3.06 |
| 4 | 4.00 | 4.02 | 4.04 | 4.06 |
| 5 | 5.00 | 5.02 | 5.04 | 5.06 |
| 6 | 6.00 | 6.02 | 6.04 | 6.06 |
| 7 | 7.00 | 7.02 | 7.04 | 7.06 |
| 8 | 8.00 | 8.02 | 8.04 | 8.06 |
| 9 | 9.00 | 9.02 | 9.04 | 9.06 |
| 10 | 10.00 | 10.02 | 10.04 | 10.06 |
| 11 | 11.00 | 11.02 | 11.04 | 11.06 |
| 12 | 12.00 | 12.02 | 12.04 | 12.06 |
| 13 | 13.00 | 13.02 | 13.04 | 13.06 |
| 14 | 14.00 | 14.02 | 14.04 | 14.06 |
| 15 | 15.00 | 15.02 | 15.04 | 15.06 |
| 16 | 16.00 | 16.02 | 16.04 | 16.06 |
| 17 | 17.00 | 17.02 | 17.04 | 17.06 |
| 18 | 18.00 | 18.02 | 18.04 | 18.06 |
| 19 | 19.00 | 19.02 | 19.04 | 19.06 |
| 20 | 20.00 | 20.02 | 20.04 | 20.06 |
| 21 | 21.00 | 21.02 | 21.04 | 21.06 |
| 22 | 22.00 | 22.02 | 22.04 | 22.06 |
| 23 | 23.00 | 23.02 | 23.04 | 23.06 |
| 24 | 24.00 | 24.02 | 24.04 | 24.06 |
| 25 | 25.00 | 25.02 | 25.04 | 25.06 |
| 26 | 26.00 | 26.02 | 26.04 | 26.06 |
| 27 | 27.00 | 27.02 | 27.04 | 27.06 |
| 28 | 28.00 | 28.02 | 28.04 | 28.06 |
| 29 | 29.00 | 29.02 | 29.04 | 29.06 |

**Table 1 success times and average time**

**Fig.5 blood sample centrifugation of centrifugal mechanism**

The results of centrifugation test showed that the success rate of the first group was 100%, and the
average time was 1.97s; the second group was 100%, and the average time was 1.98s. The results show
that the centrifugal mechanism can fully mix and react the antibody of blood sample page to achieve the
projected goal.

**5. CONCLUSION**

According to the requirement of centrifugal mechanism in automatic blood group analysis system, a
centrifugal mechanism applied to microfluidic chip is designed and tested. The conclusion is as follows:
(1) Through the theoretical analysis and calculation of centrifugal microfluidics, the three-
dimensional structure of microfluidics chip is established by using solid works software, and a new type
of microfluidics chip is designed;
(2) According to the needs of centrifugation, the appropriate centrifugal motor is selected and the
three-dimensional structure of the centrifugal mechanism is established;
(3) The success rate of centrifugal test is 100%, and the average time is 1.97s and 1.98, respectively.
It can achieve blood centrifugation and fully mix with antibody.

The centrifugal structure designed in this paper is simple, and the structure innovation is carried out
for the centrifugal mechanism, so that the blood antibody can be fully mixed and reacted, and work
together with the full-automatic blood group analysis system, so as to realize the detection automation
in the blood group detection process.

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