A New Starting Curve Based on Acceleration and Deceleration Theory of Stepping Motor

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Abstract. This paper makes a comprehensive analysis of various research methods to improve the sampling accuracy of automatic biochemical analyzer, and confirms that the starting mode of plunger pump is taken as the research object to improve the sampling accuracy. A new type of S-curve is designed based on the S-curve proposed by acceleration and deceleration theory. This new type of curve ensures high precision sample addition by accurately controlling the plunger pump to run the same distance in each step of the stepping motor. In order to confirm the validity of the new S-curve, an experimental platform was established to compare the confirming that the optimized S-curve can obviously improve the stability of the sample addition result.

1. Introduction

The automatic biochemical analyzer is an automatic checkout equipment that provides various biochemical testing items, and plays an important function in the diagnosis, treatment and prevention of diseases [1-5]. With the increasing requirements for the accuracy of modern medicine, the detection accuracy of the automatic biochemical analyzer has been improved [6-10].

In order to achieve high detection accuracy of automatic biochemical analyzer, different research methods has been to optimize and redesign the automatic biochemical analyzer. In the aspect of control system, Wang Xu et al [11] put forward a design scheme of a centralized control system for full-automatic biochemical analyzer based on field programmable gate array (FPGA); Chau et al [12] realized the micro-step control of the motor through the ultrasonic stepping motor, improving the controllability of the motor. In the aspect of detection of the sample adding system, M, L Blomquist et al [13] used a multi-detector system to supervise the performance of the stepper motor that drives the micropump operation, so as to hold in the suction and discharge of the micropump to improve the accuracy of the sample; Yaxin Liu [14] took a high-speed liquid flow sensor for non-contact reagent dispensing based on principle of differential pressure and MEMS technology to accomplish rapid, accurate and real-time flow detection. In the aspect of droplet formation, Nguyen Q H et al [15] obtained the conditions for accurately controlling droplet formation by optimizing and analyzing various sample addition methods; Utada A S, et al [16] analyzed the formation process of water droplets in detail and obtained the main factors of water droplet formation; Bala A et al [17] obtained the effect of flow rate on droplet morphology by simulation.

In all, it can be found that the previous research direction neglected the influence of plunger pump starting mode on sampling accuracy and sampling stability. For this reason, this paper makes a detailed
study of the starting mode of plunger pump and designs a new starting mode to improve the sampling accuracy and sampling stability of the automatic biochemical analyzer.

2. Control theory
The speed control of the stepping motor that drives the plunger pump to start is determined by the number of pulses and pulse frequency input by the driver [12]. Dong Jin et al's [18, 19] research shows that the acceleration and deceleration theory of the S-curve can effectively improve the stability of the stepping motor at startup, and the smooth operation of the stepping motor has a significant impact on improving the sampling accuracy and the sampling stability. The schematic diagram of the discretization of the S-curve is shown in Figure 1(a). It can be seen that the running time of each step of the S-curve is the same, and the acceleration and deceleration changes of the S-curve are realized by changing the frequency.

![Figure 1(a). The traditional S-curve](image1)

![Figure 1(b). The Optimized S-curve](image2)

Accurately controlling the sample addition amount of automatic biochemical analyzer is the most important factor to improve the sample addition accuracy, so a sample addition curve that can accurately control plunger displacement is needed. The step size of each step of the traditional S-curve is the same, so the displacement of the plunger pump in each motor step size increases with the increase of the frequency when the stepping motor is started, which leads to the difficulty of quantifying the sample addition amount at the initial stage of the plunger pump start-up. Therefore, an optimized S-curve is designed as shown in the Figure 1(B). It can be seen that the step size of each step of the optimized S-curve decreases with the increase of frequency, which ensures that the plunger pump can push the same displacement in each step of the motor.

3. Organization of the Text
In order to verify the effectiveness of the S-curve, an experimental platform was established. And the start-up of plunger pump of automatic biochemical analyzer only affects the liquid transporting system, so the experimental platform consists of sampling probe, plunger pump, peristaltic pump, flexible tubule and other relevant parts for liquid transportation, as shown in Figure 2.
The operation process of the automatic biochemical analyzer adopts contact sucking sample and non-contact dropping sample. Deionized water was used as system liquid and flushing liquid in the experiment. And since the samples were mostly liquids containing a small amount of organic matters, deionized water was used instead of samples. The whole process consists of cleaning process, sample suction process and sample addition process. Before the sample suction, the sampling probe is flushed through deionized water, then 100ul of air is absorbed to isolate deionized water and samples, and finally 50ul of samples is sucked. During the sample adding operation, the plunger pump pushes 50ul of sample first, and then pushes 50ul of air to promote the discharge of the residual sample at the outlet of the sampling probe (The whole process is shown in Figure 3.)

4. Experimental Results
In order to ensure the accuracy of the sample absorption mass measured in the experimental verification process, it is necessary to remove the influence of the evaporation mass of the sample and the capillary action suction mass on the sample volume. The evaporation mass of the sample is measured by the evaporation rate of the sample in the experimental environment, the capillary action suction mass is measured by measuring the mass difference before and after the sampling probe extends into the sample cup. At the same time, the evaporation mass and the capillary action suction mass were measured 10 times respectively, and the average value was used as experimental data to avoid random errors. (Experimental data are shown in tables 1 and 2).
Table 1. The sample evaporation mass.

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | \( \overline{m_e} \) (ug) |
|---|---|---|---|---|---|---|---|---|---|----|------------------|
|   | 0.3 | 0.4 | 0.3 | 0.2 | 0.4 | 0.2 | 0.3 | 0.2 | 0.3 | 0.4 | 0.27 |

Table 2. The capillary action suction mass

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | \( \overline{m_c} \) (ug) |
|---|---|---|---|---|---|---|---|---|---|----|------------------|
|   | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.13 |

It can be seen that the average evaporation mass of water in each sample suction process under the current experimental environment is 0.27 ug, and the average value of increasing sample mass due to capillary action is 0.13 ul. Taking the average sample evaporation mass and the average capillary suction mass into the Formulas (1) and (2) can obtain the sample suction volume and the sample addition volume.

The suction volume:

\[
V_{su} = \frac{m_{su1} - m_{su2} - m_e - m_c}{\rho_{25^oC}}
\]  

The sample volume:

\[
V_{sa} = \frac{m_{sa1} - m_{sa2}}{\rho_{25^oC}}
\]

\( m_{su1} \) -------- Mass of sample cup before sample suction;
\( m_{su2} \) -------- Mass of sample cup after sample suction;
\( m_e \) -------- Evaporation mass of sample suction process;
\( m_c \) -------- Mass of capillary action suction;
\( \rho_{25^oC} \) -------- Density of water in experimental environment;
\( m_{sa1} \) -------- Mass of sample cup before sample addition;
\( m_{sa2} \) -------- Mass of sample cup after sample addition;
\( \overline{m_e} \) -------- Average sample evaporation mass;
\( \overline{m_c} \) -------- Average capillary suction mass.

According to the above formula, the sample suction volume and sample addition volume of the traditional S-curve and the optimized S-curve are measured respectively, and the measurement is repeated for 20 times. The variation of sample suction coefficient of variation and sample addition coefficient of variation before and after optimization are calculated according to formulas 3 and 4, the comparison of the results before and after optimization is shown in Fig. 4.

The coefficient of variation of suction volume is:

\[
CV_{su} = \frac{S_{su}}{V_{su}} \times 100\%
\]  

The coefficient of variation of sample volume is:

\[
CV_{sa} = \frac{S_{sa}}{V_{sa}} \times 100\%
\]
The coefficient of variation of suction volume: $CV_{su}$

The coefficient of variation of sample volume: $CV_{sa}$

The standard deviation of the suction volume: $S_{su}$

The standard deviation of the sample volume: $S_{sa}$

The average of the suction volume: $\bar{V}_{su}$

The average of the sample volume: $\bar{V}_{sa}$

It can be seen that the optimized start-up curve will reduce $CV_{su}$ from 0.33% to 0.26% and $CV_{sa}$ from 0.51% to 0.39%, which indicates that the optimized S-curve can effectively reduce the discreteness of the sample addition result.

![Comparison of Sample Addition Result of S-Curves Before and After Optimization](image)

**Figure 4.** Comparison of Sample Addition Result of S-Curves Before and After Optimization

5. **Conclusion**

This paper analyzes and optimizes the starting mode of plunger pump of full-automatic biochemical analyzer, and proposes a new type of S-curve based on the traditional S-curve. The new type of curve ensures high precision sample addition by accurately controlling the plunger pump to run the same distance in each step of the stepping motor. After comparing and analyzing the sampling results of the traditional S-curve and the optimized S-curve through the established experimental platform, we found that the optimized curve can effectively reduce the sampling variation coefficient and the sampling variation coefficient. The results show that the optimized S-curve can significantly reduce the discreteness of the sample result, that is, the optimized S-curve can effectively improve the stability of the sample addition result and the sample addition precision of the automatic biochemical analyzer.

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