Study of Operating Characteristic of Stepping Motor Driven Sub-packaging Screw

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Abstract. During the operation process of a stepping motor driven screw, the dynamic operating performance in real-time, the frequent starts and stops, quick response and other aspects are important prerequisites for the reliable and stable operation of the screw filling machine. As a basis, PLC control of stepping motor driven screw sub-package system was introduced. Then starting from stepping motor torque-frequency characteristic, the effects of running speed control during screw split charging, best starting frequency and the maximum operating frequency of a stepping motor on the screw operating characteristic and measurement accuracy were analyzed.

Introduction

There are two kinds of powder sub-packaging ways in pharmaceutical production: screw type and air flow type. Screw metering and packing is a normal method for powder or fine particle materials in pharmaceutical production. It is based on the spiral groove of the screw as the metering cavity, the material is loaded into the container by intermittent rotation, and the drive screw rotation is often used stepping motor. The main parameters and indicators include step angle, torque-frequency characteristics, the time of up and down-frequency and stepping accuracy. This research is based on the screw dispenser controlled by PLC, and analyzes the operating characteristics of the metering screw driven by the stepping motor in the technological process of “stepping turntable stop-screw intermittently dispensing”.

Block Diagram of Sub-Packaging Screw Driven Stepping Motor Based on PLC

Stepping motor is a digital-angle converter, which is to transform electrical pulse signal into the corresponding angular displacement or linear displacement\cite{1}. Stepping motor can control the position and speed without feedback (open loop position), and high precision, good reliability, easy to use and low cost, so in modern industrial production, it is the main control component in process control and instrumentation, widely used in positioning systems and other areas of automation and control. PLC (Programmable Logic Controller) is a widely used new controller in the field of industrial control, which uses a typical computer architecture is based on sequential controller and computer controller developed. PLC has the functions of simple programming intuition, high reliability, low requirement on the environment, rich logic control, arithmetic operation, analog quantity processing and communication networking. The various external switching signals, analog signals, sensor detection signal can be used for its input variables, and as a kind of output variable to carry on each kind of control to the peripheral equipment after the logical operation and processing of the CPU\cite{2,3}. PLC as the control system core controls the stepping motor driven screw, with simple system, easy to control, accurate speed and positioning, small load difference, low cost and so on. The block diagram that PLC control of stepping motor driven screw sub-packaging system shown in Fig. 1.
As the figure shows, we can control core of the system to communicate and set the sub-packaging system's parameters by Display and Operating System and PLC. Control signals will be issued after PLC receives and deals with the relevant input signal, so that the stepping machine drives the stepping motor with the pulse signal, and the screw to work.

Analysis on the Motion Characteristics of Sub-packaging Screw

Sub-packaging screw rotation requires two conditions: first is to drive the stepping turntable of the glass bottle rotates into accurate location. Secondly, there is a glass bottle in the turntable positioning groove. However, the screw is driven by stepping motor, so the stepping motor starts or not depends on whether the control system gives it "turntable in place" and "a glass bottle" commands, which is the basis to achieve the coordination of screw and turntable. As for the effect of the operating characteristics of the metering screw rotation on the sub-packaging and accuracy depends on start-stop characteristics and operation characteristics of stepping motor. In fact, in the stepping motor driving screw running process, the good dynamic performance of PLC control system is an important prerequisite for reliable and stable work, especially in real-time, frequent start and stop, fast response and so on. Therefore, it is necessary to analyze the dynamic characteristics of the stepping motor torque-frequency characteristics, acceleration or deceleration curves and pulse frequency. Besides it is important to study their impacts on the operating characteristics of the screw packing.

Torque-frequency Characteristic of Stepping Motor

As a implementation of digital-analog conversion elements in a digital control system, entering a pulse signal, the stepping motor will rotate an angle and step forward. The displacement and speed are respectively proportional to the number of pulses and the pulse frequency of the input motor, and the proportional relation will not change due to voltage, environmental conditions and other fluctuations in the range of load capacity[4]. Therefore, you can control the stepping motor’s speed and achieve rapidly start-stop or reverse if you control the pulse frequency of stepping motor. The stepping motor will produce the maximum output torque in the static state, and the motor torque will decrease when the input pulse frequency increases. Therefore, the starting of stepping motor from the start to accelerate the maximum speed is the process of pulse frequency from the starting frequency to the maximum operating frequency, that is, the motor output torque from large to small changes in the process. The relation between the output torque and the input pulse frequency is called the torque-frequency characteristic of the stepping motor.

Speed Control of the Sub-packaging Screw

The operating characteristics of sub-packaging screw will affect its load and accuracy. So if we want to assure the screw dispenser works normally and efficiently, we must ensure the motor will not occur out of synchronization, locked-rotor and overshoot phenomenons when the stepping motor is running at high load. These phenomena are closely related to the variation rule of the stepping motor's running speed, that is, the acceleration and deceleration control curve of the stepping motor.

The acceleration and deceleration curves of stepping motor include uniform acceleration and deceleration curves, exponential acceleration and deceleration curves, S-shaped acceleration and deceleration curves, and parabolic acceleration and deceleration curves. Their dynamic
performances have themselves cons and pros. When driving the metering screw, the working resistance is very small which is mainly used to overcome the friction between screw shaft and support. So, we can choose an enhanced stepping motor with small inertia and good starting characteristics and drive source uses the constant current chopper type modular drive, as a result, it has the specialty of big current to output, high integration, reliable, easy maintenance. In summary, we should choose the uniform acceleration and deceleration curve in order to ensure the stability of the stepping motor operation and take into account the speed of lifting movements. Fig.2 shows a complete track of the sub-packaging process. According to different types of packaging, you can set any computer and modify the stepping motor operating parameters.

As the figure shows, $L_1$ segment is up-frequency operation, $L_2$ segment for uniform speed operation, $L_3$ segment is down-frequency operation. According to the concept of "out-of-step", if the control frequency of $L_1$ rise and $L_3$ decrease is larger than stepping motor's response frequency, the stepping motor will be out of synchronization and even stop the stepping motor. Therefore, it is necessary to correctly control the stepping motor by means of the above-described uniform acceleration and deceleration curve during the screw speed change operation. In general, for the powder with poor fluidity, $L_1$ steps to increase the number of steps, and $L_3$ steps can reduce the number of steps in order to overcome the greater resistance and to ensure that does not lose step. On the contrary, for the powder with good fluidity, we can reduce the number of $L_1$ steps, while increasing the number of steps down $L_3$ because the resistance is small.

In general, the operating frequency of the screw dispenser is set according to the packing amount, and the frequency value is as small as possible, adjusted to send the bottle turntable work without dragging powder. Sometimes, stepping motor can also choose whether to reverse the last step according to need, because for the large viscosity of the powder, plus the reverse is conducive to adhesion in the sub-window on the powder immediately shake off to improve the packing accuracy. Therefore, Set the pulse number of the stepping motor and its frequency parameters can improve the efficiency of the entire packaging system.

The Influence of Pulse Frequency on Screw Operating

In the packaging process of screw, stepping motor can rotate with a fixed angle according to the input of pulse count (step frequency) to obtain a flexible angular displacement control, then getting the rotating speed which is in proportion to this pulse signal’s frequency to ensure accomplishes sub-packaging of a certain amount powder within a rated time. But, when stepping motor speed accelerates and decelerates because of the improper control of pulse frequency, that will make the step motor step-out or overshoot, screw packing accuracy cannot be guaranteed; meanwhile, due to the quickness requirement of screw packaging system, it should improve the packaging speed in the premise of keeping positional accuracy. Therefore, the reasonable pulse frequency of stepping
motor should be researched to ensure the best pulse control plan, making the packaging screw can start and stop rapidly, operating steadily as well as package accurately in the operation process, and in order to improve the working efficiency and measuring accuracy of medicine sub-packaging system.

**The Influence of Optimum Starting Frequency of Stepping Motor**

It is a vital process of stepping motor turns to a stepping angle from a static condition because it is the first step of operation controlled by starting frequency electric pulse signal, which will directly influence the accuracy and stability of follow-up operation steps. In general, the starting frequency limit of stepping system (the corresponding biggest starting speed of stepping motor) is low, but it requires a higher operation speed. If the system starts directly at the required operation speed, it cannot start normally because this speed has exceeded the biggest speed of the starting frequency limit, which will cause the system out of steps and even cannot start. Hence, when the screw starts for packaging, it is important for selecting a proper starting pulse frequency. High frequency will make the stepping motor step out or stall, and low frequency will cause vibration. The best condition is that drive screw’s stepping motor can turn a step angle from static condition to start according to a pulse period within shortest time under the start pulse frequency. In other words, stepping motor should have a reasonable starting frequency, and through it, stepping motor will operates the set step number driving the screw accurately and stably.

Through the kinematics analysis of torque-frequency characteristic of stepping motor, pulse frequency control equation in the starting process, stepping angle and drive system operation equation, it can achieve the mathematics model of stepping motor’s optimal starting frequency, as Eq. 1.

\[
4a202J2fs6+(402J2+4a20JML)fs4+(a2ML2+40JML)fs2-(0.81Mmax2-ML2)=0. \quad (1)
\]

Where: \( fs \) is stepping motor’s starting frequency; \( a \) indicates a dimension of time; \( \theta \) presents stepping motor’s stepping angle, \( J \) is the rotational inertia of drive system; \( M_{max} \) means stepping motor’s maximum static torque; \( M_L \) is load torque. It can be seen that stepping motor’s stepping angle \( \theta \), drive system’s rotational inertia \( J \), load torque \( M_L \) and stepping motor’s biggest static torque \( M_{max} \) are factors that influence stepping motor’s optimal starting frequency. However, in the process of screw packing, screw is directly driven by stepping motor whose drive system’s rotational inertia \( J \) mainly depends on the screw itself with little change; in addition, there is a small resistance when screw pushes powder so the load torque is \( M_L \) small, but it will change according to different medicine. Therefore, the main factor of influencing stepping motor’s best starting frequency depends on stepping motor’s stepping angle \( \theta \) and the biggest static torque \( M_{max} \) namely, stepping motor’s key parameter stepping angle \( \theta \) and biggest static torque \( M_{max} \) will directly influence screw operating characteristics and measuring accuracy through starting frequency \( fs \).

**The Effect of the Maximum Operating Frequency of Stepping Motor**

According to the torque frequency characteristics of the stepping motor, the operating speed and the input pulse speed (frequency) are positive correlation. That is, the faster pulse speed is, the faster stepping motor speed is, while the output torque becomes smaller, the output torque will reach the minimum state at the maximum operating frequency. In fact, under certain load condition, the stepping motor has not only a maximum starting rotational speed, but also a maximum load rotational speed. If the motor runs beyond the maximum load speed, the motor rotor position will be out of the stabilization zone, even the motor will be led to synchronization because of the declining dynamic torque of the motor, the decreasing load capacity, and being unable to overcome the resistance torque, the motor will not drive the load. Therefore, the stepping motor speed should be lower than the maximum load speed in normal operating condition, that is, the operating frequency should be lower than the maximum operating frequency (corresponding to the maximum operating speed of the stepping motor). According to the research data[5,6], the mathematical model of the maximal running frequency \( f_{max} \) of stepping motor is shown as Eq. 2.
According to the above equation, it can be seen that the maximum static torque $M_{max}$ and the load torque $M_L$ of the stepping motor are the factors that affect the maximum operating frequency of the stepping motor. The load torque $M_L$ in the process of screw packing is small. Therefore, the maximum static torque $M_{max}$ of the stepping motor is the main factor affecting the maximum operating frequency of the stepping motor, and will affect the screw running characteristics.

**Summary**

The stepping motor driving screw to metering and packaging based PLC is widely applied in the production of powder injection. This paper that based on the screw packaging machine presents the stepping motor driven screw packaging system based PLC. By analyzing the torque-frequency characteristics of stepping motor, the control of the screw speed, and the pulse frequency of the stepping motor, it is clear that key parameters step angle and maximum static torque of the stepping motor will affect the operating characteristics and measuring accuracy of the screw through the starting frequency and the maximum operating frequency when the screw performs metering and dispensing process. That provides an useful reference for practical application.

**References**


