Application of variable frequency drive permanent magnet synchronous motor in plastic extruder

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Abstract: This article primarily focuses on the transmission system of plastic extruders, utilizing frequency converters to drive permanent magnet synchronous motors. It elaborates on the advantages of permanent magnet synchronous motors over conventional three-phase asynchronous motors, including high efficiency, high power factor, large starting torque, high precision, wide speed range, simple structure, and small size. Additionally, through parameter optimization and adjustment of the Toshiba frequency converter VF-AS3, the operational efficiency of the permanent magnet synchronous motor is enhanced, thereby assisting customers in reducing costs, conserving energy, and ensuring smooth operation of the extruder.

Key words: extruder; permanent magnet synchronous motor; frequency converter; energy saving

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0 Introduction

In plastic extrusion molding equipment, the plastic extruder is commonly referred to as the host machine, while the subsequent equipment, the plastic extrusion molding machine, is known as the auxiliary machine. The driving part of the plastic extruder typically consists of an electric motor, a reducer, and bearings (see Figure 1). In the past, electric motors were mainly DC-regulated. With the continuous development of AC technology, AC frequency converters have replaced DC regulation, saving a significant amount of energy for the country. However, this is far from enough. With the introduction of new national standards, aiming to achieve carbon peak by 2025 and carbon neutrality by 2050, reducing energy consumption has become an important indicator. Statistics show that 65% of the electric energy is actually used in motors. Given the high power of plastic extruder motors and customers' high requirements for motor efficiency, it is necessary for us to have better choices for extruder motors.

1 Drive system of plastic extruder

1.1 Requirements of plastic extruder for drive motor

As shown in Figure 1, a plastic extruder is a material processing equipment that relies on the pressure and shear force generated by the rotation of the screw to enable the material to be fully plasticized and evenly mixed, and then extruded through the die head mold. Extruders can be basically divided into two categories: single-screw extruders and twin-screw extruders. These two types of extruders have basically the same requirements for the driving motor, which are generally as follows:

(1) The starting torque is large. The working characteristics of the extruder determine that the motor must be capable of heavy-load starting, and the low-frequency output torque of the frequency converter should be powerful and have high overload capacity.

(2) The debugging performance is good. The extruder

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needs to discharge material evenly and adapt to products of different specifications, which requires high speed regulation accuracy and a wide range to meet the speed regulation requirements under various working conditions.

(3) The characteristic curve should be stiff. It is necessary to ensure that the extruder speed remains basically unaffected by load changes, so as not to affect efficiency.

(4) Easy to install and operate. From a design perspective, considering the high power of the extruder motor, the smaller the motor size, the better. This necessitates easy installation, simple operation, and flexible control.

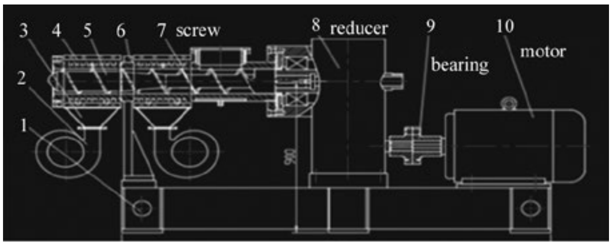

Figure 1 Assembly drawing of extruder

1.2 Composition of drive system

In response to the requirements of extruders for drive performance and the new national standards for reducing energy consumption, as shown in Figure 2, we propose to replace the current variable frequency speed regulation scheme using three-phase asynchronous motors with a combination of a frequency converter and a permanent magnet synchronous motor. This not only improves the performance of the extruder, but also saves a significant amount of electricity for customers, as permanent magnet synchronous motors are more energy-efficient than the commonly used three-phase asynchronous motors.

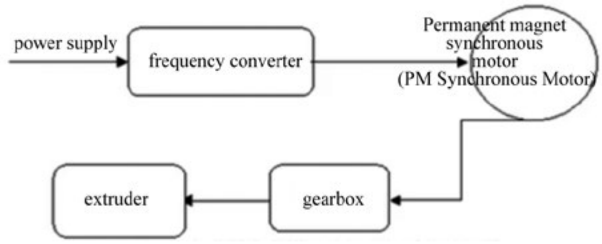

Figure 2 Block diagram of variable frequency drive permanent magnet synchronous motor

2 Introduction to permanent magnet synchronous motors and motor selection

2.1 Structure of permanent magnet synchronous motor

The basic structural composition of a permanent magnet synchronous motor is shown in Figure 3.

Figure 3 Composition of permanent magnet synchronous motor

As can be seen from Figure 3, the stator, bearing, frame, and other parts of a permanent magnet synchronous motor are basically the same as those of a variable frequency motor, but its rotor is composed of magnetic steel, replacing the silicon steel sheets of ordinary motors.

The material of magnetic steel is permanent magnetic material (magnetite), and currently, sintered neodymium-iron-boron permanent magnetic material is mainly used. It has the following characteristics:

(1) It boasts extremely high magnetic properties and is known as the "Magnetic King";

(2) It has very high anti-demagnetization ability;

(3) It can be processed into various shapes;

(4) It is a kind of anisotropic material;

(5) Devices utilizing neodymium iron boron exhibit excellent energy-saving effects;

(6) Devices utilizing neodymium-iron-boron can achieve miniaturization.

2.2 Advantages of permanent magnet synchronous motors

2.2.1 High efficiency and high power factor

After embedding permanent magnets in the rotor, permanent magnet synchronous motors rely on the permanent magnets to establish the rotor magnetic field. During normal operation, the rotor and stator magnetic fields operate synchronously, with no induced current in the rotor and no rotor resistance loss. This alone can improve the motor efficiency by 5% to 10%. Due to the absence of induced current excitation in the rotor of permanent magnet motors, the stator windings exhibit almost pure resistive load, resulting in a motor power factor close to 1. As shown in Figure 4, on the right is a permanent magnet synchronous motor, where the secondary copper loss is clearly zero. Therefore, the power loss is significantly reduced, approximately to 60% of that of ordinary motors.

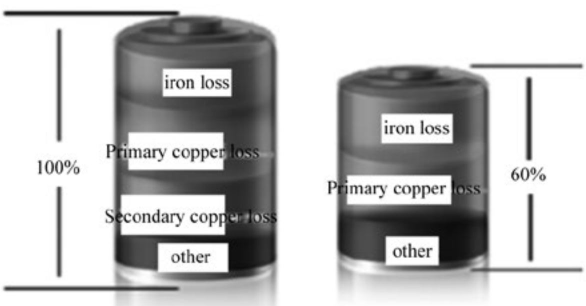

Figure 4 Comparison of losses between permanent magnet synchronous motors and asynchronous motors

2.2.2 High starting torque and high overload capacity

The starting torque and overload capacity of permanent magnet synchronous motors are both one power level higher than those of ordinary motors. The ratio of the maximum starting torque to the rated starting torque can reach 3.6 times, whereas for ordinary motors, it is only 1.6 times. This is a very important characteristic for extruder drives, which require a large starting torque.

2.2.3 High precision and wide range

The variable frequency control system of permanent magnet synchronous motors can ensure the motor speed accuracy to reach 0.1% to 0.01% without the need for closed-loop control. In this paper, a high-precision frequency converter is used, which can achieve a speed regulation accuracy of 0.01% under open-loop control, and the adjustment range can reach 100%. This is very important for extruders, as it offers high accuracy and simple control.

2.2.4 Smaller size and lighter weight

When selecting between permanent magnet synchronous motors and conventional variable frequency motors, it can be observed that for motors of the same power, the frame size of permanent magnet synchronous motors is smaller. The analysis is as follows:

(1) The power factor of a permanent magnet synchronous motor is not limited by the number of poles. With the permission of the motor's supporting system, the number of poles of the motor can be designed to be higher, and the corresponding motor size can be made smaller.

(2) With the increase in motor efficiency, the corresponding loss decreases, and the temperature rise of the motor reduces. Therefore, under the condition of using the same insulation level, the motor can be designed to be smaller in size.

(3) The flexibility of the motor structure allows for the elimination of many ineffective parts within the motor, such as winding ends and rotor end rings, resulting in a smaller corresponding volume.

This design, featuring smaller size and lighter weight for the same power output, is highly suitable for extruder design and installation. Additionally, it offers greater cost-effectiveness in the selection of reducers, resulting in significant cost savings.

2.3 Selection of motor

Currently, there are an increasing number of manufacturers capable of producing permanent magnet synchronous motors. Through a comparison of different manufacturers, this article finds that Honeywell's permanent magnet synchronous motors offer high cost-effectiveness. Here, we briefly illustrate the advantages of Honeywell's permanent magnet synchronous motors from the following three aspects:

(1) In terms of rotor design, Honeywell's permanent magnet synchronous motor utilizes embedded high-temperature-resistant rare earth permanent magnets. After undergoing magnetic stabilization treatment and surface chemical treatment, as well as optimized magnetic pole design and simulation verification, the risk of demagnetization is significantly reduced.

(2) Bearing system: Honeywell's permanent magnet

synchronous motors come standard with imported brand bearings across the entire range. For frame sizes 80~160, sealed deep groove ball bearings are standard; for frame sizes 180~355, either lubricable deep groove ball bearings or angular contact ball bearings are standard, with the option to install sealed bearings. To enhance the cantilever force at the drive end, cylindrical bearings can be equipped at the shaft extension end for frame sizes 160~355.

(3) Motor size specification selection: The frame size can be reduced (by 1 to 3 frame sizes for different specifications), which not only improves efficiency but also meets customer requirements regarding motor volume and weight. The standard frame size (consistent with asynchronous motor dimensions) allows for equipment and energy efficiency upgrades for customers with minimal modification to other supporting equipment.

Therefore, this article adopts the Honeywell permanent magnet synchronous motor.

3 Selection and main parameters of frequency converter

3.1 Selection of frequency converter

As introduced in the introduction, the application of AC frequency converters in extruders has become mainstream, and the control and principles of frequency converters will not be discussed in this article. However, there are numerous domestic and foreign brands of frequency converters used in extruders. To choose a frequency converter suitable for permanent magnet synchronous motors, we mainly consider three points: ① high c ost-effectiveness; ② high performance and rich parameters; ③ simple debugging and convenient operation. Through comparative experiments of different brands, Toshiba frequency converters have an absolute advantage. Therefore, this article adopts the Toshiba frequency converter VF-AS3 series.

The VF-AS3 Toshiba frequency converter boasts excellent control capabilities for permanent magnet (PM) synchronous motors, featuring a built-in DC reactor and filter. Additionally, it supports high-speed/real-time network communication via embedded Ethernet, eliminating the need for any additional equipment and meeting the automation requirements of modern IoT and Industry 4.0. This facilitates future remote and networked management. This article primarily discusses the adjustment and parameter setting of Toshiba frequency converters for PM synchronous motors.

3.2 Main parameters of frequency converter

In addition to the parameters on the motor nameplate, the following introduces several important parameters for Toshiba's variable frequency control of permanent magnet synchronous motors:

(1) Open-loop control selects V/F mode: 6, for the control of PM motors;

(2) Automatic tuning selection: 2, automatic tuning upon initiation of command (after execution, it becomes 0);

(3) Current response: 25. To prevent current fluctuations, the current response should be set below 25;

(4) Speed control response: 2. In the case of PM motors, they are more prone to vibration compared to induction motors, so the setting value should be smaller;

(5) PM out-of-step detection frequency: 20%, determination of reversal, stop operation when exceeding 20% of the fundamental frequency;

(6) PM out-of-step detection current level: 75%, set at the variable frequency rated current ratio %, with 75% as the threshold;

(7) PM out-of-step detection time: 0.07 s, out-of-step reversal determination condition, 7 ms trip operation stop;

(8) PM control mode selection: 3, for good decreasing torque control application. Both IPM and SPM motors without saliency can be applied, sometimes with reverse rotation.

4 Permanent magnet synchronous motor standards and energy conservation

4.1 Permanent magnet synchronous motor standards

In 2020, China raised its motor energy efficiency standards, and now the national standards are fully aligned with international standards. The highest level of energy efficiency in the national standards, Level 1, is equivalent to IE5 in the international standards, and so on, as shown in Figure 5. The Honeywell permanent magnet synchronous motor selected in this article is of IE5 standard, Level 1 energy efficiency, which is currently the highest level.

4.2 Energy conservation

Dalian Sanlei Technology Co., Ltd. has begun using the

IEC60034-01 international standard	GB18613-2020 standard (2020 edition)	GB18613-2012 standard (2012 edition)
IE5	Energy efficiency level 1	
IE4	Energy efficiency level 2	Energy efficiency level 1
IE3	Energy efficiency level 3	Energy efficiency level 2
IE2		Energy efficiency level 3
IE1		

Figure 5 International and domestic standards for motor energy efficiency

drive solution of Toshiba inverter + Honeywell permanent magnet synchronous motor on the SJ-120×38/SJ-90×38 single screw extruder. By testing the same power 315 kW Honeywell permanent magnet synchronous motor (IE5) and three-phase asynchronous inverter motor (IE3), a curve diagram of efficiency, power factor, and load for permanent magnet synchronous motor and asynchronous motor was drawn (see Figure 6). The specific analysis data is shown in table 1.

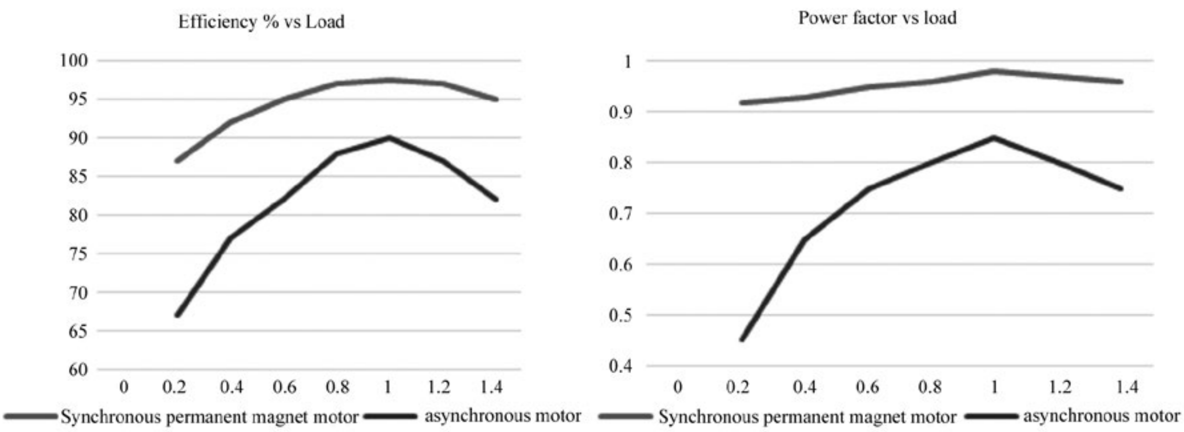

Figure 6 Curve diagram of permanent magnet synchronous motor and asynchronous motor

Table 1 Comparison between permanent magnet synchronous motor and asynchronous motor（1）

Motor category	Economic operation zone	Efficiency has decreased a bit	Power factor at 25% load
Asynchronous motor	60%~100%	35%	Decreased from 0.85 to around 0.5
Permanent magnet synchronous motor	25%~120%	15%	Above 0.9

From Table 1, we can see that in actual economic operations, permanent magnet synchronous motors exhibit significant advantages in terms of efficiency and power factor, with both generally exceeding 90%.

Meanwhile, we monitor energy consumption, and the energy-saving effect is very significant, as shown in Table 2.

Table 2 Comparison between permanent magnet synchronous motor and asynchronous motor（2）

Equipment power	IE5 energy efficiency	IE3 energy efficiency	quantity	Energy saving per hour/kW at 50% to 80% load
315 kW	97.2%	94.6%	1	18

As shown in Table 2, under the condition that the actual operating torque is 50% to 80% of the rated torque (the torque of a typical extruder), the annual calculation is approximately 18 × 8,760 = 157,680 kW.h. The estimated actual cost savings can reach up to 150,000 yuan per year, and the cost of the motor can be recovered after approximately half a year of continuous operation.

5 Conclusion

The application of variable frequency drive permanent magnet synchronous motors in extruders has significant advantages in improving the performance of extruders, compared to current extruder drive schemes. Especially after the country set the goals of carbon peak and carbon neutrality, the use of permanent magnet synchronous motors in plastic extruders is very necessary. Currently, based on customer feedback from on-site usage, customers are very satisfied and the equipment is operating well.