The Research Status and Analysis of Melt Spinning Pack

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Abstract: The article briefly describes the importance of the spinning pack that is the core component of the melt spinning equipment. The current processing technology of the spinning pack is described in detail. Based on the structural optimization design of the spinning pack, a sorting study was performed. Finally, the development direction of the spinning pack is pointed out in the light of the production demand in recent years.

1 INTRODUCTION

According to the statistics, the output of chemical fiber in China has been ranked first in the world since 1998. In 2015, the output of chemical fiber in China was 48.43 million tons with year-on-year growth of 12 percent which accounting for 73% of the world's total chemical fiber production. The output of polyester filaments was 36.81 million tons, an increase of 9% year-on-year, which is still the main driving force for the growth of the fiber market. In 2016, China's chemical fiber production reached 49.44 million tons, accounting for 70% of the global total. The "13th Five-Year Development Plan for Chemical Fibre Industry" formulated by the China Chemical Fibre Industry Association pointed out that it is expected that by the end of the "Thirteenth Five-Year Plan", China's chemical fiber production will reach 55 million tons per year1.

The core process of chemical fiber production is spinning. The commonly used spinning methods are classified into two types: melt spinning and solution spinning. As the world's public awareness of environmental protection has increased, international regulations on solvent-polluting environments for chemical production have become more stringent, and solution spinning will face severe environmental challenges. Melt spinning is more adaptable to the requirements of the new situation. The technology uses no solvents, waste water, and simple equipment, saves investment, and has the lowest production cost. It is the most economical and most competitive technology. Therefore, many of the original manufacturers that used solution spinning have adopted the melting method recently, and the melt spinning technology has also achieved rapid development2.

In the melt spinning process, the spinning pack, also known as the spinning nozzle, is referred to as the heart of the melt spinning process. It finely filters out mechanical impurity and gel particles doped inside the melt, and evenly and thoroughly mixes the melt. Under a certain pressure of the assembly, the fibers are stably and uniformly spun out from the microcellular of the spinneret. Therefore, spinning pack has a direct impact on the spinnability and performance of the fiber. More and more attention has been paid to the research on the processing quality and structural design optimization of spinning pack.

2 RESEARCH STATUS OF SPINNING PACK PROCESSING TECHNOLOGY

The spinneret is the core of the spinning pack whose function is to accurately spray the spinning solution through microcellular in the spinneret to spray out the fiber bundle with a certain thickness and fine texture3. As the parent of new synthetic fibers, its quality is an important condition for ensuring the quality of finished fibers and good spinning process4. Therefore, the processing technology level

of the spinning pack is reflected in the processing quality of the spinneret.

In the spinneret processing, foreign advanced production technology and management technology are still ahead of domestic companies, but domestic companies are also catching up.

Kasen Corporation is well-known in the world for the design and manufacture of spinnerets, especially for the development of differentiated fibers such as profiled and bi-component composites, which has a very high market share. The company's newly introduced spinneret controls the holes' precision to within 1μm, making it possible to produce round holes or profiled holes with diameters from 0.01mm to 0.1mm.

Table 1: The accuracy of round hole.

Diameter of hole(ϕ)	L/D	Hole diameter accuracy		Accuracy of L	
		Special	Standard	Special	Standard
φ0.03~0.5	1/1~5/1	±0.001	±0.002	±0.01	±0.02
φ0.5~1.0	1/1~10/1	±0.001	±0.002	±0.01	±0.02
φ1.0~2.0	1/1~25/1	±0.003	±0.005	±0.02	±0.05

Since 1930, Nippon Nozzle has succeeded in realizing the localization of man-made chemical fiber in Japan, Nippon Nozzle is a leading manufacturer of spinnerets for chemical fiber manufacturing. The processing precision of spinnerets for melt spinning pack is shown in Table 1 and Table 2.

Table 2: The accuracy of profiled hole.

Width	L/D	Width accuracy		Hole diameter accuracy	
		Special	Standard	Special	Standard
0.045W ~0.08W	1/1~4/1	±0.001	±0.002	±0.01	±0.02
0.08W ~0.11W	1/1~5/1	±0.001	±0.003	±0.01	±0.02

Enka Technica is the world's leading manufacturer of spinneret manufacturing, offering a full range of spinnerets and spinning pack for the melt spinning process. The average value of the spinning holes tolerance of the product is less than 0.001mm, and the minimum diameter of the spinning hole is less than 0.05mm.

Table 3: The accuracy of ordinaryspinneret.

D	L/D	Tolerance of D		Tolerance of L	
		Special	Precision	Special	Standard
φ0.04~0.10	≤1.00	±0.001	±0.002	±0.01	±0.02
φ0.11~0.20	≤3.00	±0.001	±0.002	±0.01	±0.02
φ0.21~0.50	≤5.00	±0.001	±0.002	±0.01	±0.02
φ0.51~1.00	≤8.00	±0.002	±0.004	±0.02	±0.04

Table 4: The accuracy of profiledspinneret.

W	L	Tolerance of leaf width		Tolerance of leaf length		Tolerance of hole length	
		Special	Precision	Special	Standard	Special	Standard
0.04~0.06	≤5.00w	±0.002	±0.003	±0.015	±0.025	±0.02	±0.03
0.06~0.10	≤10.00w	±0.002	±0.003	±0.015	±0.025	±0.02	±0.03
0.10~0.20	≤20.00w	±0.002	±0.003	±0.015	±0.025	±0.02	±0.03
≥0.20	≤30.00w	±0.002	±0.003	±0.015	±0.025	±0.02	±0.03

Changzhou Spinning Precision Machinery Co., Ltd. is a state-controlled, Sino-Hong Kong joint venture high-tech enterprise engaged in the professional production of spinnerets, and has made achievements in the development of varieties and improvement of production capacity. Polyester spinneret design and manufacturing technology is at the leading position in the country. The precision of spinneret of its melt spinning pack is shown in Table 3 and Table 4.

Beijing Chonglee Machine Spinning Plate Co., Ltd. is one of the earliest manufacturers to develop and produce spinnerets in China, and is also one of the manufacturers participating in the formulation of spinneret standards. The spinnerets used in various melt spinning, compound spinning, melt-blown spinning and other equipment produced by the company are spread all over the country and exported to Russia, Iran, India and other countries. The company now has an annual processing capacity of 3.5~500 million holes.

After decades of hard development, we can see from the above table that the gap between the accuracy of domestic spinnerets and foreign production is gradually narrowing. At present, Changzhou Spinning Precision Machinery Co., Ltd. and Beijing Chonglee Spinning Machine Co., Ltd. have become the main force in the production of spinning components in China.

3 RESEARCHSTATUS OF STRUCTURAL DESIGN OF SPINNING PACK

The structure and dimensions of the spinning pack are determined by the spinning process route, the size of the supporting winder, the size of the spinneret, the fastening method, the feeding method, and the installation method. There are two ways to fasten the bolts: the bolts are screw tightening and the bolts are self-bring fastened. There are two types of feeding methods: upper loading and side feeding. There are two installation methods: top loading and bottom loading.

As the core component of spinning equipment, many innovative designs or improvements of spinning pack are based on certain practical applications of production. These innovative work have further improved the quality and yield of spun fiber. The following three directions will be introduced in detail.

3.1 Research on Optimization Design of Component Filtering Structure

The filter part is an important part of the spinning pack. The role is to remove the mechanical impurities of the polymer melt and form a certain melt pressure, so that the melt is evenly mixed to form a good melt stream. When the filtering effect of the component is not good, the melt is likely to form a plugging hole at the spinneret and cannot be normally spun. Generally, the filter media of the component is mostly composed of different proportions of metal sand or coarse-grained sea sand and metal filter meshes, and there are also combinations of several metal meshes with different mesh numbers.

When metal sand or sea sand is used as a filtering material, in addition to collecting impurities in the melt, their sharp parts can divide the gelled part of the polymer melt and reduce the melt viscosity. However, the local porosity between sand grains is also changing under the pressure of the components. When the voidage increases, the filtration performance decreases, and when the voidage decreases, the pressure of the assembly increases, shortening the life cycle of the assembly. At the same time, varying porosity leads to uneven polymer melt flow and inconsistent filament number so that the quality of fiber will be affected. The Chinese patent has adopted different number of annular filter columns for the melt filtration between the spinneret plate and the cover plate, which overcomes the influence of the voidage change of the sand filter, shortens the residence time of the polyester melt in the module, and prolongs the time.

The service life of the spinning assembly increases the quality and spinnability of the tow and reduces production costs.

In view of the drawbacks of the single sand, the Chinese patent overcomes the defects by layering the filter sand. The filtering part is optimized to be a coarse filter sand layer on the upper layer and a fine filter sand layer on the lower layer. The spinning melt is filtered through two layers of filter sand. The u level accuracy melt is obtained, thereby extending the service life of the spinning assembly and ensuring the quality of each monofilament.

In recent years, there have been more and more studies on alternative sands. Japan TMT's patents use a polygonal section metal short fiber filter as part of the filter section. The filter also has the function of refining the gel-like portion of the molten polymer as the granular filter material. The advantage is that the volume of the spinning pack can be reduced several times, and the internal structure of the module is more compact. However, attention should be paid to the fact that the position of the spinning pack and the position of the blower cooling device must be adjusted after the filter section becomes smaller. However, the filling space for this type of assembly is relatively large and the retention time becomes longer. In addition, deterioration caused by heat aging is liable to occur, which is a main cause of yarn breakage and uneven yarn quality.

3.2 Research on Assembly Structure Design of Spinning Pack

The traditional spinning pack is the assembly of spinnerets and other components into the interior of the assembly cavity, and then bolted and connected to ensure the overall tightness of the spinning assembly. The spinning assembly is then placed in a spinning box with heating and heat retention effect for spinning process. However, this assembly method is time-consuming and labour some. At the same time, in order to ensure good sealing of the spinning pack, the spinning pack must be disassembled and cleaned frequently, which is inconvenient. Therefore, many new ideas emerged gradually in the assembly effect.

Zhiqiang Xuan5studied the spinning pack's use and operating conditions and designed a crimp spinning assembly. The spinning pack has good

overall rigidity, high precision, stable performance and reasonable pressure design within the spinning pack. The design completely eliminates the problem of slurry leakage from spinning pack, and is particularly suitable for the production of large short fibers. It solves the problems of current thread components that are vulnerable to threading and inconvenient to operate, and reduces manufacturing and use costs.

Chinese Patent discards traditional spinning assembly type that put the spinneret, distribution plate, filter sand cup into the spinning pack housing in sequence. Instead, the above components are designed into three major parts. In the premise of guaranteeing that the feed port and the distribution plate are not disassembled, the spinneret can be replaced quickly and conveniently, facilitating the replacement of spinning species and the spinning test. The design of the structure is simple and the working efficiency is high with less heat loss.

When the melt is directly spinning, the number of spinning stations is usually more and the spinning box has a certain size so that it is inconvenient to switch between spinning types. Chinese patent provides a spinning pack which sheathed the outside of the spin pack body for melt spinning of fine denier filaments. The overall size of this spinning pack coincides with the outer diameter of the coarse denier spinning pack, so that the original coarse denier production line can be easily converted into a fine denier production line. Then it avoided various problems such as unstable production and poor physical properties due to the large gap between the fine denier filament spinning pack and the coarse denier filament spinning pack cavity.

Chinese patent provides a new spinning pack without housing, locking ring, and gasket. All the contained parts are locked together by bolts to complete the assembly and fixation of the entire spinning pack. The assembly eliminates the need to fix the built-in parts such as the housing, which saves materials, reduces processing costs, facilitates assembly, and lowers maintenance costs. In addition, leakage can be found in time to avoid the occurrence of bad products.

3.3 Research on Spinneret Special Treatment

Spinneret is the core of spinning pack. The melt is finally extruded through a spinneret to form primary fibers, which are then solidified by cooling to form a filament. The effect of spinneret on the fiber forming process is extremely important. Therefore, the special treatment of the spinneret can directly increase the surface quality of the inner hole of the spinning pack and improve the quality of the spun fiber.

Abrasive Flow Machining6 referred to as AMF. This is a new process technology for surface polishing and deburring workpieces with fluid viscoelastic materials. Hongfei Zhu7used abrasive flow machining technology to perform micro-hole grinding on spinnerets with large long diameters. The processing error of the shape of the bell mouth did not occur at the orifice of the micro-hole, indicating that the processing effect was better and the surface quality of the micro-hole was improved. However, He did not investigate the influence of spinnerets on the spinning before and after processing while he focused on the process of processing the micro-holes in the spinneret for abrasive flow machining.

Chinese patent covered a nano or sub-nanometer oxide film with a thickness of 0.8 to 28 nm on the surface or inner surface of a spinneret or embedded a 0.1 to 0.25mm thin layer of metal in the spinneret orifice. It not only avoided the degradation of the polymer melt, but also avoided the corrosive substances and impurities of the melt from damaging the inner surface of the spinning hole. And it increased the service life of the spinneret and reduced the scrap rate of the fiber.

4 DEVELOPMENT OF MELT SPINNING PACK

When the melt spinning pack meets the production demands of polyester, polyamide, and polypropylene, with the application of industrialization and experimentation, spinning pack is becoming more diversified in terms of production adaptability and the functions are also more extensive. Based on the current research status, the development of melt spinning pack will have the following characteristics:

4.1 Diversification

During the spinning experiment phase, spinning pack evolved from ordinary component to bi-component and tri-component, while conventional spinning pack evolved to composite, profiled, and composite profiled spinning pack. In industrial production, large-capacity spinning pack are more advantageous, and the large-size spinning packs are

also more plentiful in size and type, such as twin spinning pack and multiple spin packs in one spinning station. As a result, spinning packs will become more diverse as production requirements increase.

4.2 Adaptation

The polymer melt enters the air blowing device after being extruded by the spinning pack. The conventional air blowing device is divided into a side air blowing device and a ring air blowing device, but the air blowing device can automatically adjust the air blowing area or design as the requirement for cooling effect is improved. In the form of an inner ring blow, this allows the spinning pack to be adapted to it, and the spinning pack develops in the direction of adaptation.

4.3 Flexibility

With the continuous improvement of production demand, such as the conversion between coarse denier filament and fine denier filament in melt direct spinning, to enlarge the spinning varieties and specifications produced on the same production line, the spinning pack are required to meet larger production requirements with smaller changes. This makes the components of the internal parts towards the direction of modularity and interchange ability, For example, rapid replace the spinneret to switch spinning varieties, the entire spinning pack are increasingly flexible.

5 CONCLUSIONS

After many years of development, the spinning pack for melt spinning has been relatively mature in terms of design calculation and processing. However, as the production demand increases, spinning components will be further refined in more detail. This article only deals with component processing technology and structure. The optimization design made some summary descriptions, pointed out the future direction of spinning components. It is hoped that this will give some reference to the optimization of spinning pack design and textile industry.

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REFERENCES

1. Lin, B., Zhao, H. 2015. Energy efficiency and conservation in china's chemical fiber industry. *Journal of Cleaner Production*, 103, 345-352.
2. Wang, HP. 2001. Study on Fiber Formation Mechanism in Melt-spinning Process and Development of HMLS Polyester Fibers. *Donghua University*.
3. Chao, Y. 2006. Numerical Analysis of Flowing for High Polymer in Spinning Pack and Optimization the Structural of it.*Donghua University*.
4. Gao, B. 2013.Research on Spinningfor Bottom Hole Automatic Processing.*Donghua University*.
5. Xuan, ZQ. 2010. The Development of a New Type Screw Conjugate Spinpack. *Synthetic Fiber in China*,39(04), 23-26
6. Wu, LS., Li, YZ. 2005. Process of Abrasive Flow Machining. *Diamond& Abrasive Engineering*, (01), 69-74.
7. Zhu, HF., Yang, CC. 2009. Application of Abrasive Flow Technology in Microporous Processing of Spinneret. *Textile Accessories*, 36(01), 27-29.