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Design of the Nonlinear Pin Rubber Forming Equipment Integrating the Functions of Extruding, Dewatering, Drying & Expanding

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Abstract: The top priority of car-tire suppliers is to improve wetland grip force of the using tires, reduce the rolling resistance and the rolling noise of tires. It is urgent for the tire industry to research and develop high-performance tires to solve the above problems. They must use the high-performance synthetic rubber and auxiliary rubber to develop the most advanced manufacturing technologies and equipment. Silica, a kind of important tire auxiliary rubber, can significantly reduce the rolling resistance of tires, improve the grip force and properties resistant to ice, wetness or slippery of tires. In this paper, based on the conventional tire rubber forming technologies of extrusion, dewatering, drying and expanding, a study is made on the conical screw, the dewatering barrel, the drying barrel, the pin layout scheme, the expanding die head, cutter and the control system. The nonlinear pin rubber forming equipment integrating the functions of extrusion, dewatering, drying and expanding is designed and applied to tire auxiliary rubber forming. The experiment shows that the forming device can realize the one-step forming, with high forming efficiency, low cost and less labor.

Keywords: Pin extruder, Tire auxiliary rubber, Integral forming, Expansion, Dewatering, Drying, Expanding.

1. Introduction

Recently, with the increase of car amounts and rapid development of the highways, more efforts should be made to improve the safety of tires as such problems as tire blowing-up because of heat on the highway, the grip or wearing resistance of tires in harsh conditions, rolling resistance and duration of the tires, and these problem have become more and more serious. The first priority should be given to improve the wetland grip force of tires and lessen their rolling resistance and rolling noise. It is urgent for the tire industry to research and develop high-performance tires to solve such problems. For the purpose of manufacturing high-performance tires, the manufacturers should develop high-performance synthetic rubber and auxiliary rubber, enhance the security of tires, and they must develop high-performance materials, the most advanced manufacturing technology and equipment [1, 2].

Silica, an important tire auxiliary rubber, can significantly reduce the rolling resistance of tires and improve their grip, ant-icing and anti-wet-skidding capacity when it is used for manufacturing tread rubber. Because of high cost, Chinese tire enterprises rarely apply silica auxiliary rubber in tire production. If so, auxiliary rubber is just added directly without any expansion auxiliary, so the effect is greatly limited. At present, the tire rubber forming technology in China mainly includes extruding-dewatering, drying-expanding segment forming. An extruding-dewatering machine and drying-expanding machine are required for the production which is low productivity and high costs. There is much improvement space in the development of expanding equipment for tire auxiliary rubber. This paper is aimed to explore the integral forming technology for silica extrusion, drying, watering and expanding, and design a kind of nonlinear pin rubber integral forming equipment for extrusion, drying, watering and expanding. As a result, one-step forming can be achieved by just one set of such equipment, which is characterized by high forming efficiency, less energy consumption, low cost, small occupation area and less labor. It fills the gap in tire auxiliary rubber forming.

The application of extrusion technology for producing dewatering, drying and expanding equipment has a long history. As early as in the 1970s, extruders were applied in the rubber industry in Britain. In early 1960s, Anderson Corporation in the UK invented an expander applicable for processing oil raw materials. In the mid 1980s, they invented an annular gap expander which attracted much attention to people who were from the developed countries in Europe or the USA (They put much emphasis on feed hygiene and safety). The annular gap expander was very popular with high-end users in the feed industry. In recent years, they also launched an OEE Carle extruder, the die head of which is mounted in a hydraulic piston, totally different from the traditional extruders. The die head can freely stretch out or into the mouth of the extruder through accurate controlling in the process of operation. The die head can be dismantled or replaced effectively through hydraulic pressure. Compared with ordinary extruders, the extruder is easier to operate because it is easy to start and can rapidly release pressure in case of material blocking. The cutter head is equipped with a separate driving device, so the cutter head can keep in the original position when the die head is replaced. The machine is also equipped with a friction disc and a container with vapor interlayer. The empty die can start without adding any water when production begins, resulting in less waste of materials. The new technology of the Wenger Corporation in single or twin screw extruders is that the spiral components of the machine were designed with mixed spiral protrusion which can endure greater shear force and hybrid force. The homogeneous spiral components have improved mixing effects [3-6]. It is reported that the Q-88-8C-18 screw dewatering extruder manufactured by the French Oil Mill in the USA is the largest dewatering extruder overseas. The Q-88-8C-18 screw dewatering extruder is mainly composed of the following three components: screw, cylinder cage-shaped shell and cone. The screw shaft and output shaft of the reducer are linked together by flexible coupling [7].

The developed countries in Europe and America, such as the USA, the UK, Germany and Japan, have long dominated in manufacturing the forming equipment for extruding, dewatering, drying and expanding rubber. They have realized the integration of drying, expanding, extrusion technologies, and have developed relevant integrated machine with excellent performance and reliability. American FRENCH Company is a supplier specializing in the production of rubber dewatering extruder. The dewatering extruders applied in the assembly line which can process 50, 000 tons of rubber per year in Daqing Petrochemical Company were manufactured by American FRENCH Company. The working principle of a dewatering extruder is as follows: rubber particles containing 35 %-50 % of water which generate from the second vibration dewatering screen are conveyed to the mouth of the dewatering extruder by the screw drive. In the conveying process, the water in the wet materials is extruded out from the cage-shaped gaps of the shell of the dewatering extruder. As a result, the water content of the materials at the mouth of the dewatering extruder drops to 8 %-12 %. The dewatered materials are extruded out by the cone, and conveyed to the drying expander (M-304) for expanding and drying processing. The water content of the materials at the mouth of the dewatering extruder can be controlled by adjusting the openness of the cone [8-10]. China was later than most developed countries in Europe and America in manufacturing equipment for rubber extruding, dewatering, drying and expanding, so there is a big gap in this aspect between China and developed countries in Europe and America. It is generally hard to realize process integration and relevant process theories, and equipment still remains to be further studied. At present, only Dalian Tiansheng General Machinery Co., Ltd under MESNAC has successfully tested whole-line forming equipments for manufacturing isoprene rubber [11].

2. Conical Screw Design

If the traditional technologies of extrusion, dehydration, drying, expanding are integrated together, screws are required to provide sufficient back pressure to ensure the follow-up process have enough pressure for expansion forming. Conical screw is shown in Fig. 1, in this paper, the high-speed conical screw is designed to solve the above problem, while the problem of transmitting pressure is solved by the two projects of improving the screw speed and the conical screw design. The project of high-speed

conical screws has brought new difficulties to the design and manufacture of screws. Considering the problem of rubber leakage caused by high speed screws, the lead of traditional conical screw was optimized. This problem can be effectively solved with the project of small lead design.

The major processing materials for the products in this paper are tire rubber and its auxiliary rubber which cause more serious wearing of the crews than ordinary plastic or chemical fiber raw materials. In addition, the screw speed can be as high up to 250 rpm, about as 4 times as that of an ordinary plastic & chemical fiber machine. The faster speed wills promote the wearing of the screws. With regard to the wear problem of screw in the process of high-speed forming, this work adopts the project of sectional-type screw design. The screws are conical design and the nickel double metal coating technology is adopted to ensure the wear-resistance of products. Because of the insufficient hardness of traditional nitriding process and its limited resistance to high temperature and corrosion, the coating technology is adopted. Thus the traditional screw nitriding steel 38CrMoAl is no longer used. The hardness of the hardened layer of the double metal screw is HRC55-62, while its depth is 1.5-2.0 mm. The base adopts stainless steel 316L (Its chemical composition is shown in Table 1 and mechanical properties in Table 2) resistant to high temperature and corrosion. The selected material for the hardened layer is Ni60 (Its chemical composition is shown in Table 3) with better self-fluxing nature and excellent comprehensive performance including resistance to wearing, corrosion, high temperature and oxidation. The SDK die steel resistant to wearing and high temperature is selected for the screw head, which is undergone quenching heat treatment. Meanwhile, the screw edge of the barrel is coated with double metal, as effectively ensures the wear resistance and the reliability of the equipment.

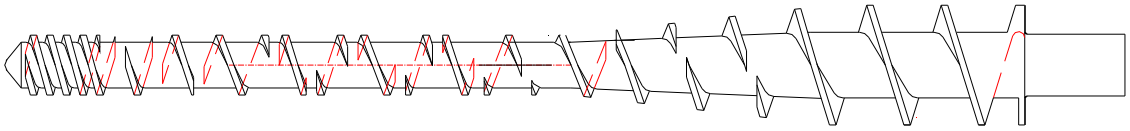

Fig. 1. Conical screw.

Table 1. 316L Chemical composition.

Material	Chemical composition %							
	C	Si	Mn	P	S	Ni	Cr	Mo
316L	≤0.03	≤1	≤2	≤0.035	≤0.03	10-14	16-18	2-3

Table 2. 316L Mechanical properties.

Material	Density g/cm^3	Melting point °C	Yield strength MPa	Tensile strength MPa
316L	7.93	1375-1450C	170	485

Table 3. Ni60 Chemical composition.

Material	Chemical composition %						Density g/cm^3	Hardness HRC	Melting point °C
	C	Cr	B	Si	Fe	Ni			
Ni60	0.6-1.0	14-17	2.5-4.5	3-4.5	≤15	Balance	7.5284	55-62	1027

3. Design of Dewatering Barrel

Dewatering barrel and screw are combined to complete such functions as melting, extrusion, dewatering and back pressure establishing. There is a great deal of water in the auxiliary rubber materials of tires. Most of them are dewatered via the extrusion function of barrel and screw. The dewatering barrel is a core component of equipments for rubber finishing.

As shown in Fig. 2, since the dewatering barrel cannot complete such functions as melting, extrusion, dewatering and back pressure establishing without combining with the conical screw, the project of conical structure design also is used for the dewatering barrel. The common rubber extruders include hot-feed extruders, cold-feed extruders and pin extruders. Because of the requirements for dewatering and back pressure function, the structure of pin extruder is adopted in this work. Sever column pins are mounted in the barrel, which greatly improves the plasticizing property of rubber, the compactness of extruded products and the quantity of extrusion. Besides, the excreation temperature is so low that low-temperature extrusion can be realized. It

also has such advantages as good self-cleaning, convenient rubber replacement and meeting the requirements of various production processes.

Just like the high-speed conical screw, there is also high temperature, high pressure and serious wearing for dewatering barrel in operation. The wearing problem of barrel can be solved through adopting the structure design that a sleeve is added inside the barrel. The service life of dewatering barrel can be extended by replacing sleeves of barrels. However, the integral forming equipment designed in this paper is only produced in small batches, so the whole barrel design should be adopted due to the potential after-sale problems. The screw edge, which is processed by wire cutting, is mounted on the circumferential plane inside the dewatering barrel to improve the shearing force of the barrel. As to the problem of barrel wear, double metal coating is used on the screw edge of dewatering barrel.

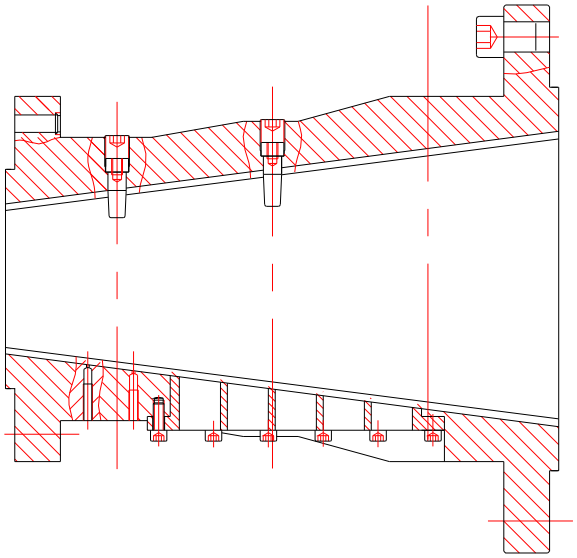

Fig. 2. Dewatering barrel.

4. Development of Component for Drying and Expanding

There mains some water in the auxiliary rubber after the majority of the water in the materials are removed through extrusion and dewatering of screw. The remaining water is hard to remove just by mechanical technology, so it must be realized by the drying component. For the purpose of simplifying the process and structure, component for drying and expanding must be combined together.

4.1. Design of Drying Barrel

The drying function of drying parts is mainly realized by the method of heating the rubber melts. When the rubber melts are heated to a certain degree, water and other small molecular substances are gasified and separated out through screw edge of the barrel. Because the main functions of drying parts are drying and expanding, the barrel is designed with traditional cylindrical structure and also adopted the integral structure and double metal coating.

Different from the traditional plastic, chemical fiber raw materials, auxiliary rubber for tires is more sensitive to temperature. As a result, too high temperature may result in rubber burning. The barrel must be heated by appropriate thermal media instead of the traditional method of resistance wire direct heating.

The regular thermal media are oil and water, because drying barrel needs gasifying water molecules, the heating temperature is not high enough in the case of water as a medium. Thus, oil is used as a medium of heating in the present work. As far as structure, the oil grooves, screw edge and pin holes are arranged to stagger each other. For the ease of machining, the oil grooves adopts the structure of straight grooves and is processed by wire cutting. In order to realize continuous heating, oil grooves are circular-closed structure, and the circulation of oil grooves is realized by linking the oil grooves to the barrel channel. To facilitate the oil flow and temperature control, the barrel is designed into two sections. There is a bigger lead angle in the drying barrel to facilitate the installation and debugging of screws.

4.2. Optimization of Pin Layout Scheme

The melts are directly output from the die via the barrel of expanding and drying. Then the expansion of rubber materials is realized by the sudden release of pressure. However, only one-time release of pressure is difficult to realize full expansion of all the rubber materials. Obviously, it influences the expanding rate, therefore some corresponding expanding functions should also be increased based on the drying component, and it needs pressure release one more.

The conventional rubber forming machines are mainly in isometric pin layout, playing the major role of shearing the melts. Only a few manufacturers have adopted the scheme of geometric linear layout to arrange the pins, so as to increase the back pressure in addition to shear melts. As shown in Fig. 3, in the present work, the nonlinear scheme is adopted to arrange the pins, which is neither equidistant nor disproportionate.

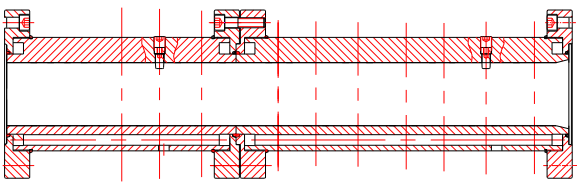

Fig. 3. Diagram of pin layout.

As a result, besides the above-mentioned functions, the pins have an added function of pressure release. The pressure can be repeatedly established and released in the drying and expanding process of auxiliary rubber melts. This can effectively enhance the expanding and the compression property of products.

4.3. Design of Expanding Die

The outlet of expanding die has an important influence on the specifications and expanding effects of products. The following points must be considered in design of expanding die.

1) Convenience.

The die should be easy to clean and replace.

2) Flexibility.

Flexibility should be considered in design of die head. Many products with different specifications and properties can be manufactured by changing dies based on different conditions and requirements of customers. Therefore, the die should be designed with replaceable flexibility.

The die is of cylindrical structure, with a via hole in the middle to make the melts flowing out of the die. The via hole is cut with the drilling technology and is designed in a series to meet the different needs of customers. The die head made of stainless steel is to improve its property of corrosion resistance.

4.4. Design of Cutter

The main function of the cutter is to cut the auxiliary rubber extruded out by the die. The quantity, layout and cutting speed of the cutters determine the size and specifications of products. The cutters are made of stainless steel, which can improve corrosion resistance. The scheme of two-cutter symmetrical layout is adopted in this paper. The stepless-speed stepping motor is applied to deal with products with different sizes.

5. Development of Control System

The present work aims at developing nonlinear pin rubber integral forming equipment for extruding, dewatering, drying and expanding, and utilizing the equipment to process tire auxiliary rubber. As mentioned before, the tire auxiliary rubber is sensitive to temperature. The melts must be heated for the requirement of drying. Therefore the temperature must be under closed loop control. In this paper, PLC with excellent electromagnetic compatibility is used as the control system, which is mainly responsible for controlling the speeds of the main motor and of the cutter motor, and also for controlling the pressure and temperatures of the melts. The 220 KW three-phase asynchronous motor is used as the main motor. The speed is adjusted via frequency control technology. In this paper, a reducer is still provided to guarantee the output torque and power in various working conditions.

In addition, this work adopts the design scheme of the gear pump. At the extruding stage, the gear pump is mounted on the extruder to get stable and balanced rubber with high output and low temperature plasticization. The gear pump is driven by an independent motor, which can effectively overcome effect of the pressure pulsation and flow fluctuation from preceding step. The pressure pulsation at the outlet of the gear pump can be controlled within 1 %. What's more, the output flow can be improved on the forming line, and the time for material shear and dwell within the extruder can be reduced. In this way, the technical bottleneck problem that flow fluctuation and pressure are difficult to control effectively and continuously can be solved fundamentally in the extrusion process. Thus, productivity and quality of products will be greatly improved.

The assembly drawing for integral forming equipment is shown in Fig. 4.

6. Experimental Verification

6.1. Experimental Conditions

Experimental equipment: JS120-110325 extruder (As shown in Fig. 5) manufactured by Zhoushan Dongbin Rubber Machinery Screw Co. Ltd.

Screw diameter: Φ150-Φ300;

Screw material: SDK die steel;

Nickel-based bimetal screw with the base of 316L stainless steel and the material for the hardness layer Ni60;

Motor power: 185 KW;

Screw speed: 100 rpm;

Forming rubber material: SiO_2.

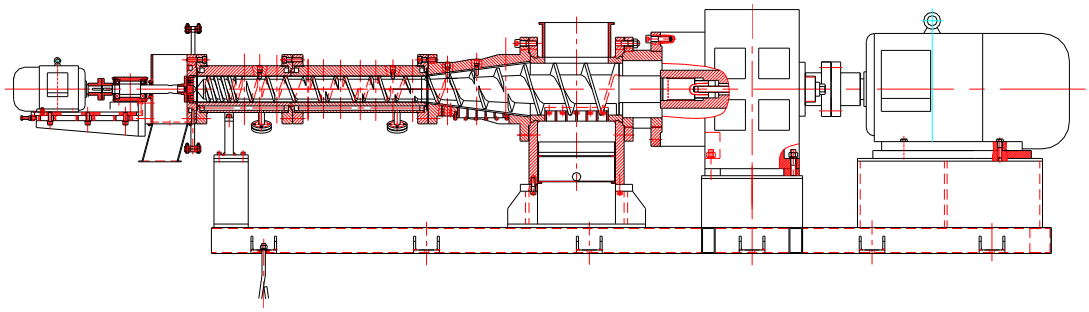

Fig. 4. Assembly drawing of integral forming equipment.

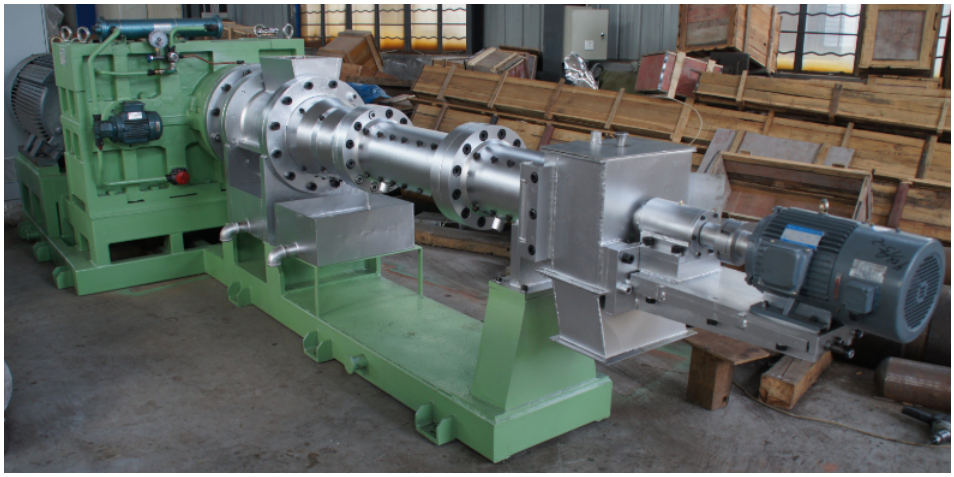

Fig. 5. Integral forming equipment.

6.2. Experimental Results

The experimental results are shown in Table 4.

Table 4. Experimental results.

Items	Results
Yield of dry rubber kg/h	1500
Speed of the cutter/min	1500
The content of water in the rubber material at the mouth of the die head %	25

As shown in Table 4, compared with conventional forming equipment for tire rubber and auxiliary rubber, the integral forming equipment has such advantages as high efficiency and forming quality but a significant decrease in occupied area, labor force, power and cost. In addition, in the whole experiment process, the equipment runs smoothly, the extruder nozzle has normal pressure, and the pressure fluctuation is stable. Neither raw materials nor rubber burning have been found. All these show that the integral forming equipment meet the requirements of the technology.

7. Conclusion

The present design is aimed for manufacturing the nonlinear pin rubber forming equipment for tire auxiliary rubber, which can realize the one-step forming integrating extruding, dewatering, drying, expanding and other functions;

The nonlinear scheme is adopted for pin layout. Compared with the traditional scheme of isometric or geometric linear pin layout, the pins have the function of pressure release in addition to its functions of shearing melts and establishing the back pressure. In this way, the melts of auxiliary rubber can realize repeated pressure formation and release in the drying process, which effectively promotes the expanding properties and compression of products;

The screw of the extruder adopts the scheme of conical screw design, and the problem of back pressure of the integral forming technology is solved by increasing the speed of screw rotation. The scheme of sectional screw design also adopts. The nickel double metal coating technology is applied for the screws while the SDK die steel resistant to high temperature and wearing is used for manufacturing the screw head to ensure the wear resistance;

The dewatering barrel adopts a conical structure, while the drying barrel adopts the sectional cylindrical structure design. Both the dewatering barrel and the drying barrel use double metal coating to improve their wear resistance;

A gear pump is mounted at the extrusion stage of the extruder. The gear pump is driven by an independent motor, which can effectively decrease the pressure and flow fluctuations from preceding step. It can solve the technical bottleneck problem that the pressure and flow fluctuation are difficult to control effectively and continuously in the process.

Acknowledgments

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