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The research status of key problems of experimental equipment for tube hydroforming

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Abstract: Tube hydroforming technology is an advanced manufacturing technology adapted to lightweight structure. The technology has the advantages of low production cost, high material utilization rate and light part quality. Forming equipment is the basis for implementing the technology, the performance of the equipment greatly affects the product quality. However, the key problems affecting the performance of the equipment include: loading path, axial feeding and sealing method, etc. The article is for the purpose of key question carrying on the system combing with the discussion. Among them, several hydraulic pressure control methods are summarized, the influence of different loading path on tube hydroforming is shown, A loading method that axial stress - circumferential stress is always proportional in the forming process is proposed. Meanwhile, the control method of axial feed is summarized, it is expressed that axial feeding can improve tube forming ability. Besides, five kinds of common pipe sealing methods were compared, the reliable and effective sealing structure is summarized.

1. Introduction

Tube hydroforming technology is a kind of plastic forming technology for producing thin-walled metal components with complex sections. This technology has the characteristics of low production cost, high material utilization, light weight of parts and high rigidity. The technology can realize component structure integration and lightweight manufacturing. It has been widely used in aviation, automobile, home appliances and other fields [1]. It has been widely used in aviation, automobile, home appliances and other fields. The process of this technology is: The tube fitting of a certain length is put into the die and high-pressure liquid is injected into the tube, at the same time, axial force is provided at both ends of the tube to make the tube deform and fill the die cavity. According to the

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above forming principle, it is necessary to solve the problems of high-pressure fluid, axial feeding, sealing technique and so on. Scholars at home and abroad have found that different loading paths have different effects on tube hydroforming performance. Axial feeding will improve the forming effect. Leakage is the "common fault" of the hydraulic system, and good sealing is the guarantee of the system [2]. This article summarizes the recent development of tube hydroforming technology in loading path, axial feeding and sealing method is reviewed. The development and application of forming equipment at home and abroad are discussed, and the future development trend of tube hydroforming is prospected.

2. Loading paths

During tube hydroforming, the liquid should be flushed into the inner cavity of the tube while the die is closed, the production and control of liquid pressure will directly affect the forming effect of tube. The loading path refers to the relationship between the hydraulic pressure and the axial feed during forming. Scholars at home and abroad have put forward such methods as broken line loading, pulsating loading and impact loading. In 2005, Imaninejad et al. [3] conducted the bulging experiment on A6063 circular tube with diameter of 38mm, wall thickness of 3.81mm and length of 200mm by using a press with polyline loading method. The results show that the effect of this loading method on the uniformity of tube wall thickness is not obvious, but it can effectively improve the sticking of tube. In 2001, Rikimaru et al. [4] adopted the pulsating loading mode, which can improve the hydroforming performance of tubes, the research shows that the pulsating loading mode can make better use of wrinkles to improve the tube forming. In 2017, Ngaile et al. [5] provided high-pressure liquid through supercharger, the liquid pressure transformation is realized by the proportional valve, the pressure sensor detects the pressure in real time, converts the simulation signal into digital signal and transmits it to PLC for logic operation and outputs the controllable liquid pressure curve. In 2011, Lin [6] was adjusted by PID controller and then acted on the pilot proportional solenoid relief valve. The relief valve regulated the pressure to realize the unloading of the low-pressure chamber of the booster cylinder. In this way, the output pressure gradually increases according to the pulsation of the set curve, this system use PID control system, but most of the debugging use the empirical method, and the ratio, integral, differential three parameters set too dependent on the field debugging. In 2007, K. Mori et al. [7] et al. Used servo punch to generate pulsating hydraulic pressure for pulsating hydroforming, Compared with the non-pulsating hydroforming, it is found that under the condition of pulsating hydroforming, there will be micro wrinkles in the process of tube forming, and the wrinkles have the characteristics of repeated generation and disappearance, which makes the wall thickness of tube deformation area change more evenly, Therefore, it is believed that pulsating hydraulic pressure is helpful to improve the forming performance of tube. In 2014, Huang cm et al. [8] applied the impact force to the liquid with a punch, and carried out the research on the impact hydroforming, this technology has been applied in the field of automobile and aviation industry because of its fast forming speed, high forming quality and low cost. It is proved that the folding line loading can improve the film sticking property of tubes, wrinkle can be used to improve formability under pulsating loading, impact loading can improve production efficiency.

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3. Axial feeding

According to the theory of plastic forming, plastic flow occurs when materials are deformed, this theory has been widely used in THF, by applying axial force to both ends of the tube, the material flows to the bulging area. It can avoid the fracture of the bulging area due to the thin deformation wall thickness, relieve the tensile stress of the tube in the bulging area, and effectively improve the forming performance. If the material is not replenished in time, the tube wall will become thinner and fracture. Excessive feeding can cause wrinkling of the tube. Therefore, the precise control of axial feeding is very important. In 2006, Li et al. [9] analysis the relationship between the internal pressure and the axial load based on the plasticity theory, put forward the method of controlling the axial feed and optimized the load mode. It is proved by simulation and experiment that axial feeding can improve tube forming effect. In 2017, Ken-ichi et al. [10] performed bulging analysis on C1220-H and SUS304 tubes with a diameter of 0.5mm and a wall thickness of 0.1mm. It is concluded that SUS304 has better formability than C1220-H. However, the use of gear propulsion to provide axial movement, feed accuracy is lower, and the comparability of the final experimental results will be reduced. The structure is shown in Figure 1. In 2007, Hartl et al [11]. Used the spindle gear driven by gear to provide axial force to carry out the hydroforming of small tubes. In 2017, Dai [12] conducted experiments on 304 tube with diameter of 2mm and wall thickness of 0.3mm, it is found that axial feeding can also improve the formability. The power source is provided by the stepping motor, and the feeding quantity is precisely controlled, which effectively improves the feeding accuracy. However, due to the length of the tube is 50mm, the span of the bulging area is 5mm, the guide area is 22.5MM long, and the friction force is too large. The tube in the guide area will have a large compression strain, which will reduce the actual material entering the bulging area, and the wall thickness will be excessively thinned and cracked. Therefore, the length of the guide area should be reduced appropriately. It is proved that precise control of axial feeding can improve the formability of tube.

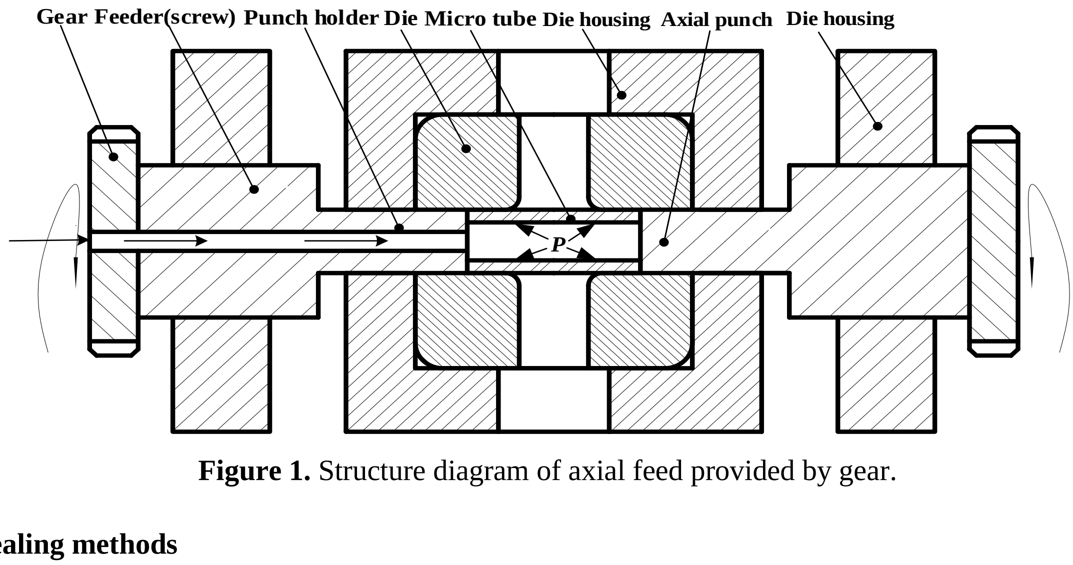

Figure 1. Structure diagram of axial feed provided by gear.

4. Sealing methods

During the tube hydroforming process, leakage will seriously affect the forming quality. Serious external leakage will affect the working performance of the hydraulic pump and the stability of the actuator. Internal leakage will cause the system not to work properly. In 2010, Qin et al. [13] summarized the sealing methods commonly used in THF. The structure is shown in Figure 2. Figure 2 (c) and (d) have shown poor wear resistance in actual production, as shown in Figure 2 (b), the tapered

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punch shows good sealing and wear resistance, but the material can't be put into the bulging zone, in the actual mass production, it is proved that the appropriate punch design in Figure 2 (a). The wear here is mainly due to the sharp angle around the contact area between the punch and the pipe end, When the punch contacts the end of the tube, this angle is pressed into the front of the tube to form a seal. In 2012, Lungershausen et al. [14] avoided the difficulty of machining the sealing groove, and ensure the sealing effect, the structure is shown in Figure 3. At the same time, the problems of difficult processing, demoulding and sealing are solved. It can be seen that the traditional conical structure can be used in the hydroforming of micro tubes. In 2013, Ngaile et al. [15] successfully avoided the difficult problem of micro pipe sealing, they developed a floating die set, the structure is shown in Figure 4. The punch, die and feed system are submerged in the high-pressure liquid chamber, the outer surface of the tube is coated with Teflon, successful completion of T-shaped Y-shaped hydroforming. It provides a new scheme for micro tube hydroforming. Reasonable sealing method can solve the problems of system leakage and demoulding.

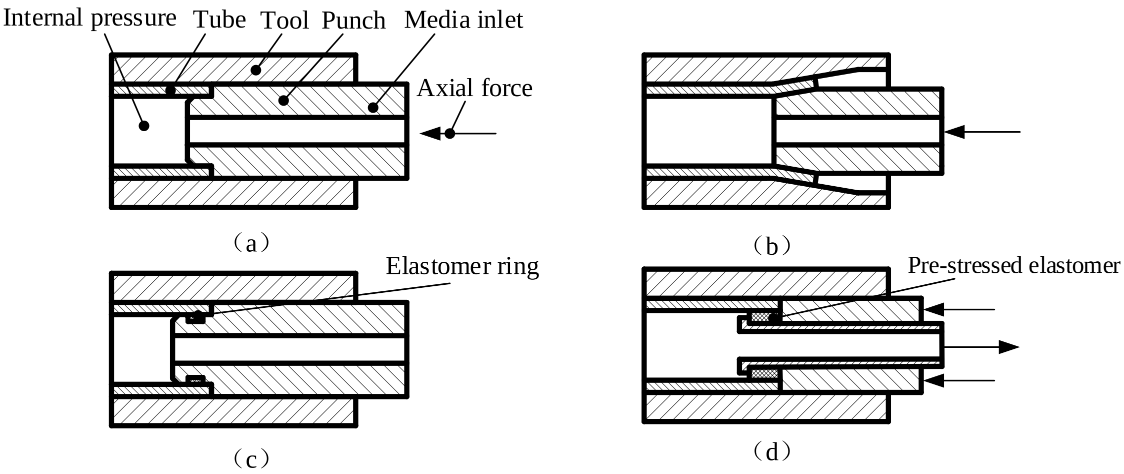

Figure 2. Common sealing principle.

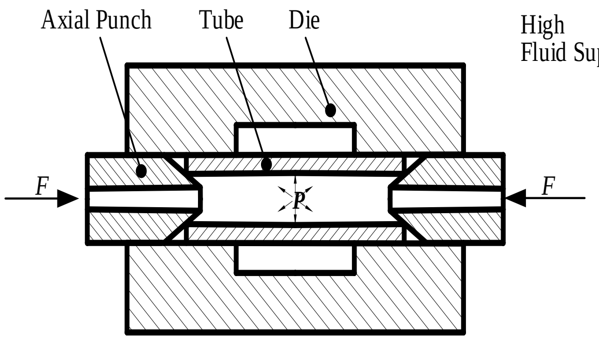

Figure 3. Sealing structure of conical punch.

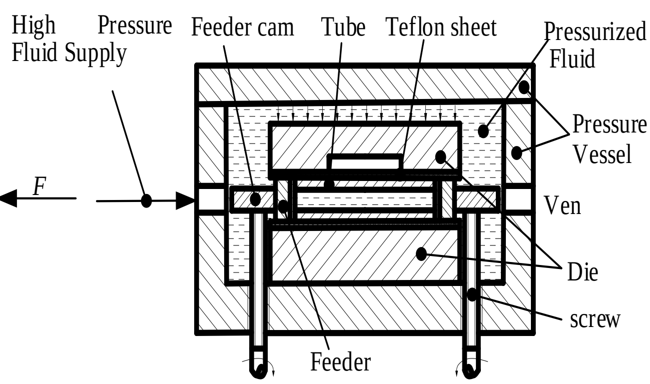

Figure 4. Structure of the floating die.

5. Conclusion

This article mainly introduces the key problems of the tube hydroforming experimental equipment in three aspects: loading path, axial replenishment and sealing method. This article be aimed at broken line loading, pulsating loading and impact loading respectively. Pulsating loading can make use of wrinkling to improve the forming performance of tube. Impact loading can greatly improve production

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efficiency. Based on the above loading method, a proportional loading method is proposed: The axial stress is always proportional to the circumferential stress at the highest point of expansion, this loading path can be used to predict the deformation characteristics, it has a good guiding effect on actual production. It has been proved by scholars that the controllable feed rate can significantly improve the axial feeding, use servo motor can improve the accuracy of control. The structure of punch seriously affects the sealing of hydraulic system, it has been proved by scholars' practice: Conical structure can achieve good sealing, and easy to process, convenient to take off the die, At the same time, this kind of structure can be applied to micro pipe.

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