Design of Special Lathe for Taper Turning Slender Shaft

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Abstract. Based on the analysis of the machining process characteristics for special slender shaft work-piece, considering the increase in taper turning efficiency and accuracy, a new clamping scheme for machining both ends of slender shaft is put forward, which also includes using pulling tail-stock instead of traditional pushing, using follow-manipulator instead of follow-rest. Following the clamping scheme, the dual drive device, the tail-stock with pulling device and the manipulators are designed, then the parts are integrated into the special lathe for taper turning slender shaft.

Keywords: slender shaft; special lathe; dual main drive; clamping; manipulator.

1. Introduction
In general, the axis parts with the ratio of length to diameter (L/D) greater than 20 are called slender shaft. The shape of slender shaft is not complicated, but it has the poor rigidity. In the turning, because of lateral cutting force, gravity, cutting heat and other factors, process vibration and bending deformation occur easily, which cause the shape error of taper, drum or saddle [1-3]. Though the technique of error compensation [4,5] can solve the problem, but the error rule must be known, which is difficult to achieve precisely, and it is not often used in application. So turning the slender shaft is a difficult processing problem all along.

The front gripping with chuck and rear pushing with lathe center are often used for slender shaft turning. But the clamping scheme especially rear pushing often increases the bending of the work-piece. Studies [6,7] have shown that holding and pulling work-piece could be appropriate to reduce bending deformation in turning, so the pulling plan and device are proposed in the clamping scheme of the special lathe. In order to enhance the rigidity of slender shaft work-piece, the tool follow-rest or center rest is often used [8,9]. Considering taper turning and automatically control requirement, the manipulator is employed in the special lathe, instead of follow-rest, it also play the role of enhancement of processing stiffness.

When both ends of slender shaft need to be machined, the traditional lathe with one powder head usually needs clamping twice and cutting twice, causing low efficiency in mass production. In this paper, a kind of lathe with dual driver for synchronous turning slender shaft is put forward to improve the producing efficiency.

2. Specific Process Requirement
Here special machining is required, which is the original stick (material 55CrSiA) for making the damping spring of truck, the production is massive. The length range of stick is 2000 mm to 3000 mm, the diameter range is 8 mm to 14 mm, and which is the typical slender shaft. A type of slender shafts is shown in figure 1. The total length of the work-piece is 2800 mm, the middle section with 1200 mm and two ends with 50 mm are equal diameter segments, and have no processing need. The variable
diameter segments with 750 mm on both sides of the middle section need to be machined, and the maximum diameter is 13.6 mm with tolerance ±0.1 mm, the minimum diameter is 8.3 mm with ±0.1, the taper is about 0.2 degrees. The characteristics is that the machining length is large, the diameter is small. Taper machining cause the cutting volume changing constantly in the process, so the cutting force is constantly changing, which increases the machining difficult and the unstable possibility.

![Figure 1. Slender shaft (unit: mm)](image)

### 3. Clamping Scheme Development
Generally the traditional machining method of the special slender shaft work-piece is turning by universal NC-lathe, as shown in figure 2. The machining process is clamping work-piece, turning one end, disassembling and changing direction, clamping again, turning the other end. Two times of clamping and cutting are needed, so the efficiency is low.

![Figure 2. Traditional machining method and machined product](image)

In above machining process, the model of the clamping method is shown in figure 3, the middle section gripped with three-jaw chuck, one end pushed with the lathe center and auxiliary support with follow-rest is proposed. According to the stability theory of pressure bar, pushing influence at the lathe centre will increase the instability and bending deformation of the slender shaft. In addition, because the diameter of taper turning segment in work-piece is changing, if the rigid follow-rest is pre-adjusted
to fit the maximum diameter, the role of the rigidity enhancement is disappeared when tool-rest turns to the smaller diameter position. So the machining accuracy is difficult to guarantee, some unacceptable products occur.

In order to improve the processing efficiency and accuracy, and considering the machining characteristics of the slender shaft, a new processing clamp scheme is put forward, as shown in figure 4. There are two sets of clamping device symmetrically, clamping one time, the work-piece on both ends are machined. So the processing efficiency can be improved greatly. And cutting force both ends of the work-piece is opposite in feeding direction, canceling each other, the stability of machining increases. At the tail-stock, the pulling is adopted instead of pushing to improve the processing rigidity of the slender shaft. Moreover, for the tape turning requirement, follow-manipulator is used as a flexible support instead of rigid follow-rest, and several auxiliary supports using manipulator are proposed to improve the rigidity further. In the machining, the auxiliary support manipulator retracts duly to avoid the feeding tool-rest.

![Figure 4. New clamping scheme](image-url)

4. Structure Design of Special Lathe

According to the special process demand and the new clamping scheme, a special machine tool for synchronizing taper turning on both ends of the slender shaft work-piece is designed. It mainly includes dual main drive device, tail-stock with pulling, auxiliary manipulator, tool holder and discharge device and the base. These parts are integrated with special lathes.

4.1. Dual Main Drive Device

In order to machine both ends of the work-piece synchronously, the dual main drive device is designed, as shown in figure 5. Which is powered by a main motor, and the spindle rotates through the belt transmission. The slender shaft work-piece is clamped by a rotating hydraulic cylinder and a power chuck, so it is easy to realize automatic control. The main drive device is mounted on the slide plate, and can be driven by a linear transmission component (screw-nut) to achieve the relative axial movement, and the relative positions can be changed to adapt to the slender shaft parts of different lengths. When the main drive device moves in axial direction, the spline shaft plays a guiding role.
4.2. Tail-stock Device
Tail-stock pulling device is designed as shown in figure 6, the slender shaft work-piece is clamped and relax by pneumatic collet chuck. The upper cylinder controls the extending and retracting of the pull rod and pneumatic collet device to fit the different length of slender shaft work-piece, and the distance of extending and retracting is limited by adjustable sleeve. In addition, the upper cylinder also plays the role of pulling work-piece. The lower cylinder is connected the slide plate by the piston rod, which can drive the tail-stock to move in the transverse direction, and the aim is to make the space when the slender shaft work-piece is loaded and unloaded.

4.3. Manipulator
In the special lathe, follow-manipulator is proposed instead of follow-rest, and several same manipulators is used as auxiliary support, improving the rigid of slender shaft in the turning. The structure of manipulator is shown in figure 7, and the manipulator has telescopic function and clamping function. The telescopic action is driven by the pneumatic sliding table installed in the mounting seat or tool-rest. And the clamping function is accomplished by the cylinder, the pushing rod,
and two fingers. The finger is jointed with pushing rod and connecting plate, there are rollers in the end of finger to follow the turning of work-piece.

Figure 7. Manipulator

4.4. Special Lathe Integration
Besides the dual main drive device, the tightening tail-stock and the auxiliary support manipulator, the tool carrier and drainage device are designed, and the devices are integrated on the lathe bed as shown in figure 8. In the axial direction of slender shaft, two sets of the same devices is placed symmetrically, and the auxiliary support manipulator is obliquely arranged. The chip room is arranged below the work-piece, and the transportation screw of chip device is installed in the chip room. In the transverse direction, tool feed device are located in the rear of the chip room, so the chip is not easy to fall in the rail of tool feed device. Following the design, special lathe is manufactured and assembled, as shown in figure 9. Next, the special lathe will be tested.

Figure 8. Overall layout of special lathe
5. Conclusions

(1) Considering the processing efficiency of special slender shaft work-piece, a plan of the synchronous turning in both ends is put forward, and then the dual drive device is designed.

(2) From improving the stiffness of work-piece processing, the method of pulling instead of pushing is adopted, then tail-stock tightening device is designed. Follow-manipulator for taper turning replaces follow-rest, and the same manipulator as auxiliary support is used for further improving the stiffness. Several parts are integrated into the special lathe, and now the actual machine is in the stage of assembly. Next time, the test will carry out, and the turning effect of special work-piece will be analyzed in the follow-up study.

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