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Structure Design of Spindle Speed Increaser for Machining Center

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Abstract. In order to increase the speed of existing machine tools, a kind of speed increasing device is needed. In this paper, a spindle speed increaser using gear drive is designed for the machining center. The speed increaser which can be matched with BT40 interface of machine tools uses planetary gear as the transmission scheme. Its structure is relatively simple which input port directly connected to the machining center's spindle whose speed is increased and transmitted to the tool end by planetary gear. Finally, the purpose of improving the speed of machining center without changing its structure is realized.

1. Introduction

Manufacturing industry is not only the main body and pillar of the national economy, but also the foundation and prosperity of a nation. At present, machinery manufacturing industry faces enormous opportunities and challenges. CNC machine tools is the main device of the equipment manufacturing industry and its technical development level represents the development level of a national manufacturing industry [1]. There are a lot of machine tools in our country, whose total energy consumption is huge, but the effective energy utilization is low [2]. Nowadays, the demand for the precision of the product is getting higher and higher, but the existing machine tools often fail to meet the requirements. Thus, it needs more efficient and higher accuracy machining equipment. How to use the existing machine tools for processing special parts has become a major problem in machinery manufacturing industry. One of the main solution to solve this problem is to increase the speed of machine tools.

Spindle speed increaser, also known as a speed-increasing shank, is a device that increases speed of machine tools [3]. The advent of the spindle speed increaser enabled the speed of many older machine tools raised, so that higher surface quality of parts could be machined.

In this paper, a spindle speed increaser for machining center is designed by using the existing advanced technology and mechanical design methods synthetically. The overall structure of transmission scheme is identified, calculated and strength is checked.

2. Transmission design for spindle speed increaser

Gear mechanism is one of the most widely used driving mechanism which transfer the motion and power between any two axes in the space through the direct contact among the gear tooth profiles.

Gear mechanism also has the advantages of large transmission power, high transmission efficiency, accurate transmission ratio, long service life, reliable work and so on [4]. Therefore, gear mechanism is adopted to design the speed increaser. The schematic diagram of spindle speed increaser for machining center is shown in Figure 1.

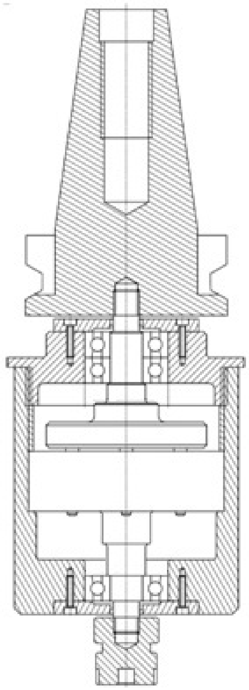

Figure 1. Schematic diagram of spindle speed increaser.

2.1. Design requirements

The design object is vertical machining center XH714G whose maximum rotated speed is 8000 r/min, tool interface is BT40, motor is produced by Siemens and its power is 9.5 kW. The required output speed is about 24000 r/min.

2.2. Design of drive type of the spindle speed increaser

As the spindle speed increaser is designed for the machining center, it needs to satisfy the conditions of high driving efficiency, smaller volume and can run smoothly on the machine tools spindle. In the gear transmission, the planetary gear has advantages of small size, high transmission efficiency, large drive ratio and smooth motion [4]. It is clearly that the planetary gear meets all the demands of the speed increaser. Therefore, the 2Z-X (A) drive type of NGW is suitable and chosen for this design as Figure 2 shown.

Figure 3 is the transmission sketch of the speed increaser. The planet carrier 'x' is the input of the gear-type spindle speed increaser and its revolution drive the planet 'c' rotated. At the same time, the center wheel 'a' which is the output of the speed increaser is also revolved and is connected to the cutting tool. In this planetary gear mechanism, the outer gear ring 'b' is fixed.

Based on the given condition, the gear parameters are chosen and calculated. They are z_a=25, z_c=14 and z_b=53. The transmission ratio is i_{xa}^{b} =0.3205.

Transmission efficiency of the speed increaser is:

$$\psi^x = \psi_{ma}^x + \psi_{mb}^x + \psi_n^x = 0.0228 + 0.0107 + 0.1 = 0.1335 \quad (1)$$

$$\eta_{xa}^b = 1 - \frac{p}{p+1}\psi^x = 1 - \frac{2.12}{3.12} \times 0.1335 = 90.93\% \quad (2)$$

It is easy to see the transmission efficiency of the speed increaser is high and enough to meet the demand.

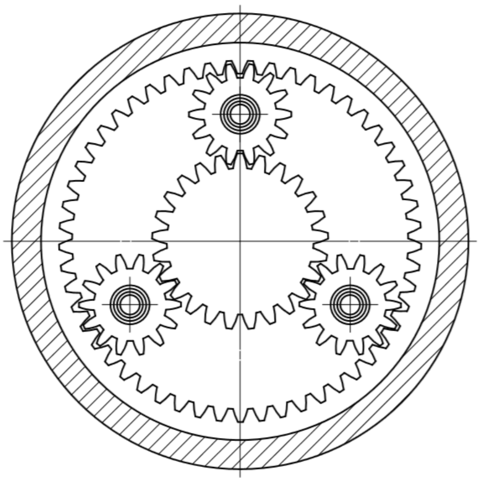

Figure 2. Transmission profile.

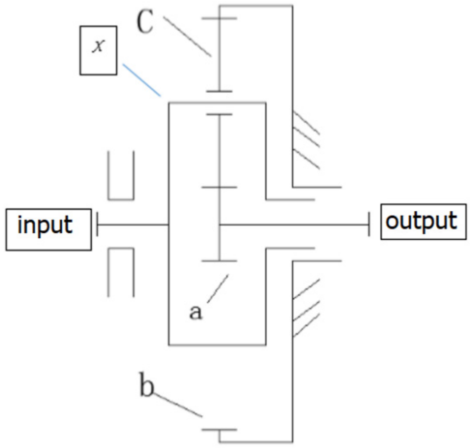

Figure 3. Transmission sketch of the speed increaser.

2.3. Gear check

Determine the root stress of external meshing:

$$\sigma_{Fc} = \frac{F_t}{bm_n} Y_{Fa} Y_{Sa} Y_{\varepsilon_{a-c}} Y_{\beta_{a-c}} K_A K_V K_{F\beta} K_{F\alpha} K_{Fp} = 159.03\ \text{MPa} \tag{3}$$

$$\sigma_{Fa} = \frac{F_t}{bm_n} Y_{Fa} Y_{Sa} Y_{\varepsilon_{a-c}} Y_{\beta_{a-c}} K_A K_V K_{F\beta} K_{F\alpha} K_{Fp} = 148.49\ \text{MPa} \tag{4}$$

Take the root stress σ_{F1} =160MPa.

Determine the allowable root stress of external meshing:

$$\sigma_{FP1} = \frac{\sigma_{F\lim} Y_{ST} Y_{NT}}{S_{F\min}} Y_{\delta relT} Y_{RrelT} Y_X = 348.88\ \text{MPa} \tag{5}$$

$\sigma_{F1} < \sigma_{FP1}$, therefore, external meshing gear pairs meet the root bending conditions.

Determine the tooth root stress of internal meshing:

$$\sigma_{Fb} = \frac{F_t}{bm_n} Y_{Fa2} Y_{Sa2} Y_{\varepsilon_{a-c}} Y_{\beta_{a-c}} K_A K_V K_{F\beta} K_{F\alpha} K_{Fp} = 121.39\ \text{MPa} \tag{6}$$

From (3), it is known σ_{Fc}=159.03MPa, select σ_{F2}=160MPa.

Determine the allowable root stress of internal meshing:

$$\sigma_{FP2} = \frac{\sigma_{F\lim} Y_{ST} Y_{NT}}{S_{F\min}} Y_{\delta relT} Y_{RrelT} Y_X = 360.64\ \text{MPa} \tag{7}$$

So $\sigma_{F2} < \sigma_{FP2}$, internal meshing gear pair meet the root bending conditions.

3. Design of other main structure

3.1. Design of center gear shaft

Because the designed speed increaser is small in size, in order to increase the strength, the central axis which is the input shaft is designed to gear shaft in a step form.

3.2. Structure Design of Planetary Carrier

Planetary carrier is one of the most important parts of the planetary gear transmission. The planetary gear structure is small, so the single side plate type of planet frame structure is chosen. Since the planetary gear has three planetary wheels, the planet carrier has three small axes to support them. A high quality micro bearing is used to connect the shaft and gear to ensure a longer life.

3.3. Design results

Based on the design requirements and the structure design of the gear-type spindle speed increaser above, the technical parameters of speed increaser are obtained as shown in Table 1. The 3D model and explosion map of speed increaser are shown in Figure 4 and Figure 5, respectively.

Table 1. Technical parameters

Name	Value
Power	9.5 kW
Max. speed	8000 rpm
Max. output speed	24960 rpm
Hilt type	BT40

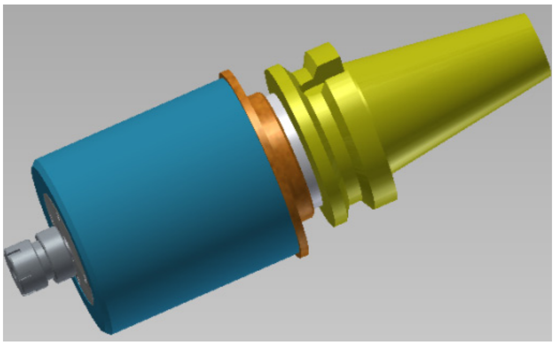

Figure 4. 3D Model of the speed increaser.

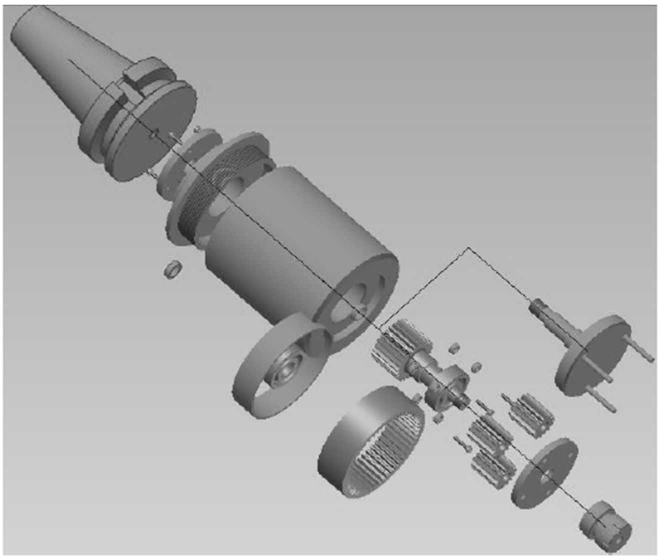

Figure 5. Explosion map of the speed increaser.

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4. Conclusion

Through a series of design calculations, the final designed spindle increaser can meet the expected requirements, and the spindle speed of the machining center can reach 24960 r/min. Meantime, its demands for the machining accuracy of the machine tools are not very high. As long as the interface is the same, most of the machine tools on the market can use this kind of speed increaser at present, which makes the parts processing very convenient. Applying the spindle speed increaser, the speed of the machine tools is increased, which is enough to meet the requirements of most high-precision machining. At the same time, it also can improve the production efficiency, which eliminates the problem of purchasing expensive machine tools for processing high-precision parts.

In general, the designed speed increaser has a higher reliability and service life. It is a spindle speed increaser with high practical performance, which solves the high requirement of the spindle speed in the process of mechanical machining.

Acknowledgments

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