

## 4-Axis CNC Machine Tool for Relief Grinding Sphere Gear Hob

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### Abstract

*a new 4-axis machine tool, which is used for relief grind of sphere gears hob including spherical hob, elliptic hob and arc surface hob, is developed. The principle of relief machining of spherical hob is introduced first. Transmitting system, numerical system and some key techniques are then introduced. The machine tool can be reconfigured in machining of arc worms and spatial cams beside of machining of spherical hob. Four forms of the machine tool for machining different workpiece are also introduced.*

**Key Words:** Numerical control machine tools, Gear hob, Relief grind machine tools, reconstructed

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### 1. Introduction

Sphere hob is a new kind of gear cutting tool in which are sphere basic shape including spherical hob, elliptic hob and arc surface hob. Spherical hob is a kind of often used sphere hobs, and can be used to machine great internal gears with exact envelope gear tooth profile [1, 2].

But because of its complex shapes, spherical hob can not be machined with present machine tools, and therefore it is hob with approximate tooth profile, that is used in engineering. Spherical hob is only a concept hob for a long time, and great internal gears can only be machined with hobs with approximate tooth profile [3- 5].

In 80' years last century, small module spherical gear hob was developed by professor AINOURA Masato and his team and spherical hob became practical from theory [6- 8], but nor proper machine tools for machining great module spherical hob [9-11]. Based on previous researching, a new 4-axis numerical control machine tool for sphere hob relief grinding is developed by authors of the paper.

The machine tool can also be used in machining of arc worms, spatial cams and traditional hobs beside of machining of sphere hobs. The machine tool can be reconfigured for machining different workpiece, and development of the machine tools will make great progress in utility of the new gear cutting tools.

### 2. Principle of relief grinding of sphere gear hob

As shown in Figure1, four motion elements are included in feed motion of relief grinding of spherical hob, which are rotation feeding of spherical hob around its own axis, circular feeding of grinding wheel around the center of hob, radial and tangent feedings of grinding wheel. Relation between the elements are that when the hob rotates a round, the grinding wheel feeds an angle pitch along the B axis, and that the hob rotates a teeth, the grinding wheel feeds one time along radial of the hob(for radial relief grinding) or along tangent of the hob(for tangent relief grinding). Clearance angle of top edge for radial relief grinding is:

$$\tan \alpha_{\beta} = \frac{K \cdot Z_k}{\pi d_{a0}} \quad (1)$$

Here,  $K$ : amount of relief,  $Z_k$ : groove number of hob,  $d_{a0}$ : outer radius of hob,  $\alpha_{\beta}$ : top edge clearance angle of hob, generally,  $\alpha_{\beta} = 12^{\circ} \sim 15^{\circ}$

Normal clearance angle of side edge from relief grinding is:

$$\tan \alpha_n = \frac{K_e Z_k}{\pi \cdot d_0} \tan \alpha_0 \quad (2)$$

Here:  $d_0$ : pitch circle radius of hob,  $K_e$ : amount of relief for side edge,  $\alpha_0$ : teeth angle of a point on cutting edge.

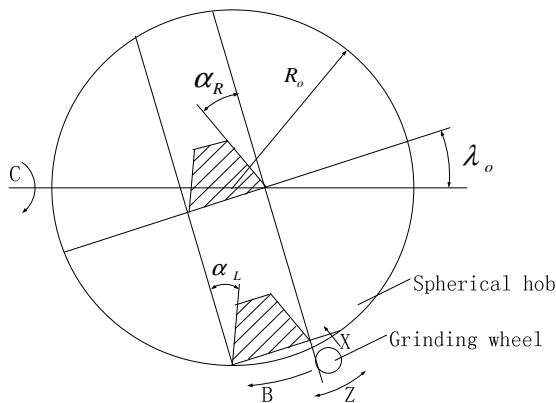


Figure 1. Feed motion of relief grinding of spherical hob

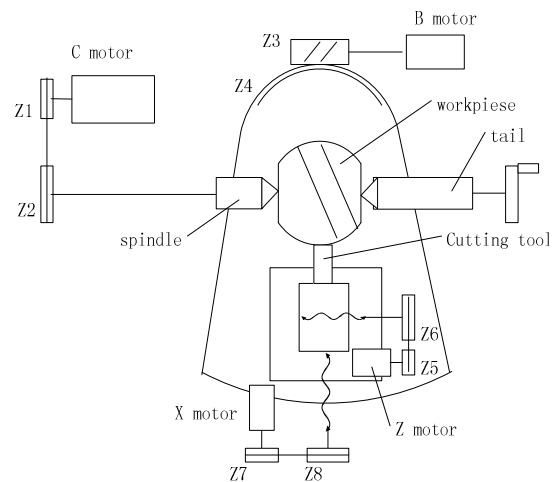


Figure 2. Transmission system of machine tool

### 3. Design of structure of the machine tool

Transmitting system of the machine tool. According to the requirement for relief grinding machining, transmitting system of the machine tool as Figure 2 is designed, in which 4 servo motors are used to drive the movements needed in relief grinding. oscillating feed of grinding head in B axis is driven by a servo motor through worm gear transmission, feeds in C axis, X axis and Z axis are driven by other three servo motors through synchronous belt and ball screw transmission respectively. The machine tool is reformed from a CA6140 lathe.

Reconfiguration of the machine tool. In order to expand the machining ability, reconfigurable design is adapted in the machine tool. After simple adjustment, elliptic hob and arc surface hob can also be machined in the machine tool. The method of adjustment is shown in Figure 3.

- (1) When machining spherical hob, oscillating center of grinding head is on the spindle line of machine tool, shown in Figure 3.(a).
- (2) When machining elliptic hob, oscillating center of grinding head is not on the spindle line of machine tool, by using screw bolt under the adjust-arc-plane adjusting its position. The ellipsoid can be thick or thin depending on which side of spindle line the oscillating center is at, shown in Figure 3.(b) and Figure 3.(c).
- (3) When machining arc surface hob, it is needed that adjust-arc-plate is returned  $180^\circ$  and grinding head is moved to other side of ball screw. Through adjusting position of worm, it can be make sure that distance between the oscillating center and the spindle of machine tool is equal to the center distance of machined worm couple, as shown in Figure 3.(d).

In engineering, the components with sphere as their basic shape are often encountered, such as spatial cams, arc surface worm, and sphere link, which can all be machined in the machine tool. Main advantageous of machine tool is that steady cutting angle can be maintained in machining so the higher precision will be gotten than that in general 3 axis machine tool.

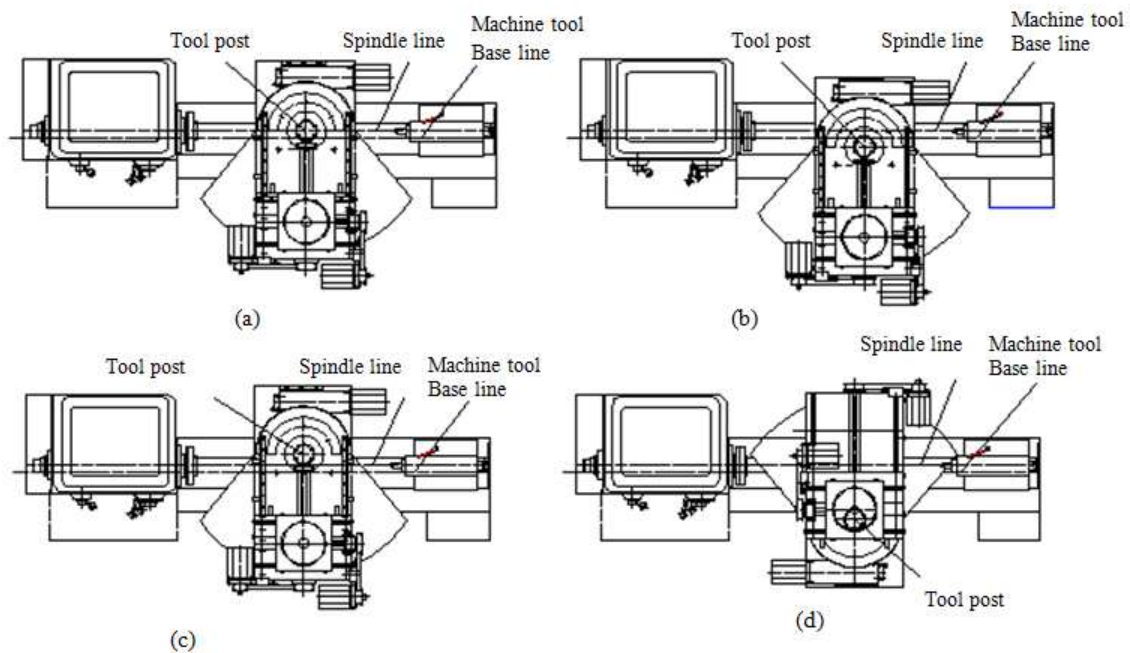


Figure 3. Reconfiguration of machine tool

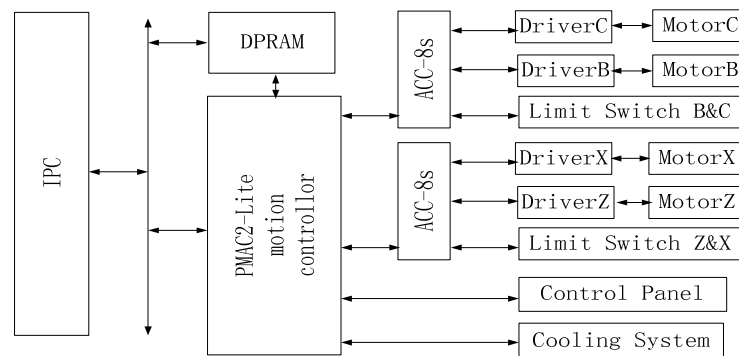


Figure 4. Hardware system of NC system

## 4. Design of numerical control system

### 4.1. Hardware of the system

Open architecture, composed of PC and PMAC motion controller, is adopted in numerical system of the machine tool[12]. Shown in Figure 4, industrial PC communicates with PMAC motion controller through PCI bus and double port RAM, and PMAC motion controller controls 4 servo motors through two ACC-8s connectors, therefore all feed motions can be realized. PMAC controller has another 16 pins connector, through which control panel, cooling system and other electrical components can be connected to the controller. Character of the system is its open architecture, some control modules can be integrated into the system according to the requirement of user. For example, CAD/CAM module can be integrated into the system to simplify the programming of workpiece, and grinding force adaption control module can be integrated into the system, to keep grinding force steady and get higher machining precision.

The prototype of the machine tool is shown in Figure 5, it is proved that positioning precision in main cutting directions is 0.005mm, after adjusting mechanical and electrical system carefully. The precision is enough in machining AA grade hobs, which is most comment used in engineering.

#### 4.2. Software of the system

Software of CNC system is shown in Figure 5, which is developed with Visual C++ 6.0 at windows platform. Main function models of the system are introduced as following:

- (1) Initialization model: When CNC system starting, initialization is conducted automatically, which include interfaces enable, system memory setting, communication port setting, and system document download.
- (2) parameters setting: System parameters are setting with this model, diagnosing of system is also be conduted in this model.
- (3) machining display: Machining status are displaid at screen of CNC system, including coordinate of grinding wheel, cutting amounts.
- (4) software control panel: Main operations are performed with soft contrl panel. Clicking the soft buttons on screen, creponding functions are cundusted, just liking pressing the buteens on panel.

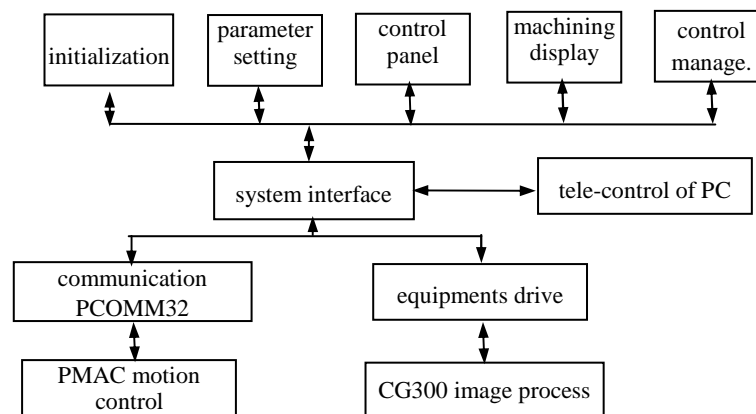


Figure 5. software of CNC system

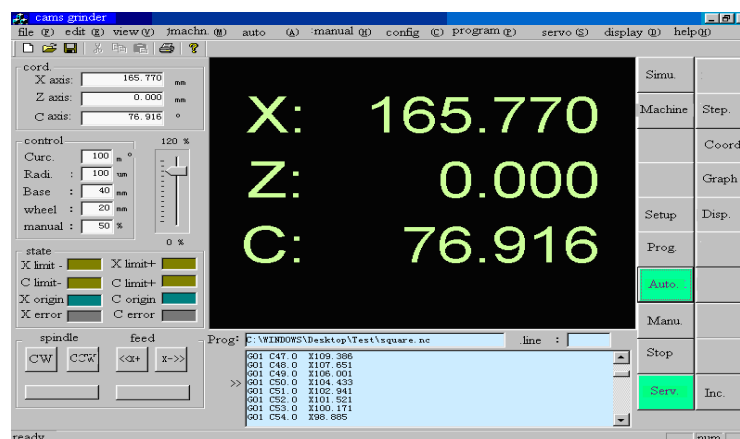


Figure 6. Human-machine interface

Interface of the CNC system is shown in figure 6. There are four sub-windows on screen, software panel and machining status display are in left window, big coordinates of grinding wheel is disolaid in upper middle window, NC program is shown in down middle window, and function selecting buteens are in right window.

Color buttons are designed for software panel, which color will change when it is pressed, therefore status of machine tool is prompted. Class CClrButton is written for the function, in which such functions are packaged as color change of button, color change of word,

shade statue of button. Color change button make the interface more optimal. Machining statue of the machine tool is shown in Figure 7.

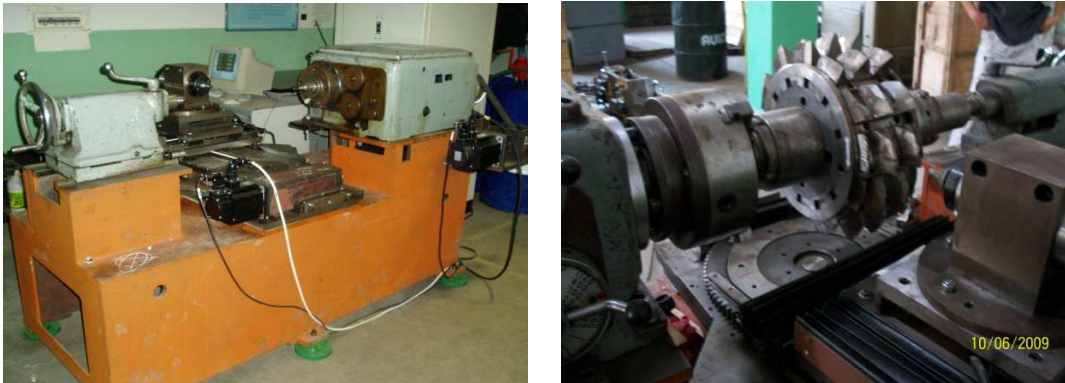


Figure 7. Prototype of NC relief grinding machine tool and machining of sphere hobs

## 5. Conclusions

- (1) Relief cutting and relief grinding of sphere gear cutters, which have sphere basic shape as spherical hob, elliptical hob and arc surface hob, can be realized with NC sphere hobs relief grinding machine tool.
- (2) Parameters and shape of hobs can be adjusted easily and machining precision is enough for AA grade hobs in engineering.
- (3) This machine tool can be used to machine not only sphere hobs but also cylinder hobs and machine parts with sphere as their basic shape, such as spatial cams, arc surface worms and sphere links. Therefore it is a universal machine tool which will be widely used in mechanical manufacturing.

## Acknowledgement

This research is supported by national natural science funding, No. 50675188

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