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General stiffness model for five-axis CNC machining

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ABSTRACT: Five-axis CNC machining has become an important method for processing thin-walled parts. However, compared with the traditional three-axis machine system, the tool path planning becomes more difficult especially in high-speed and accuracy machining process. In this paper, taking into consideration the rigidity establishes a general stiffness model in order to increase the surface quality, restrain the chatter of the machine and provide a reference for tool path planning. The model considerate the comprehensive impact of the tool posture, tool overhang length, transmission axis of the machine and the parts, in which the finite element method and the principal of virtual-work are applied.

Keywords: five-axis CNC, tool path planning, general stiffness

I. INTRODUCTION

With the rapid development of the aerospace, national defense,vehicle and other industries. Thin-walled parts consisted of cut surfaces, Composite surfaceand popular complex curved surface has been widely used such as propeller, integral impeller and so on. Manufacturing levels of these products related to the level of the national economy and national security.At the same time,it also represents the core competitiveness of the national manufacturing.

Efficient processing of the thin-walled parts, however,becomes a major problem. Nowadays five-axisCNC machining replacing the traditional three-axis machining has become an important means of processing. Compared with the traditionalthree-axis machine, five-axis CNC machining adds two rotating shafts so that the machine tool can be rotated in any direction in space.In this way, we can achieve the main advantages of the five-axis CNC machining. First,we can adjust the tool orientation to ensure the tool can be better matched with the surface of parts in order to obtain effective cutting width and improve cutting efficiency. Second,adjustment of the tool orientationcan avoid interference of tool and part. Third, appropriate tool orientation can reduce the overhang of the tool, thereby enhancing the overall stiffness of the machine. In addition, appropriate tool orientation can control contact area of tool and part. Therefore, it can reduce cutting forces and tool wear, improve the surface quality.In fact, there are also many difficulties coming up with the axis CNC machining. On the one hand, compared with traditional three-axis CNC system, the five-axismachining has more shafts which increases the flexibility of the whole system but decrease the stiffness. On the other hand, in the machine coordinates, the tool movement is more complicated, it increases the difficulty of the tool path planning. Currently, the study of the five-axis CNC mainly focused on three dimension: path planning, geometry - mechanics simulation and dynamic simulation.

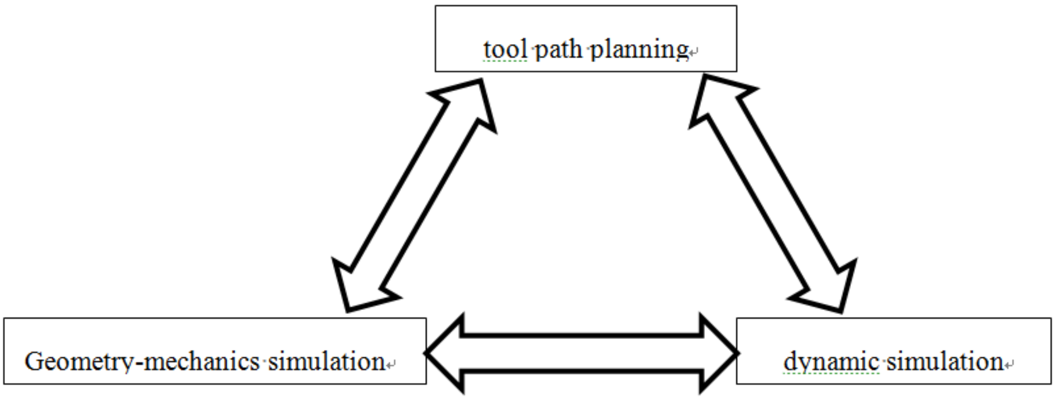


Fig.1 the key issues of the five-axis CNC machining

II. Tool Path Planning Research Status

Tool path planning is an important research field of five-axis CNC machining. Howerer,currently research still largely remains in the geometric planning. It aims to reduce overlap and path interval. But if we only think about the geometry characteristic,the dynamic characteristics of tool path trajectory will be negelected.

In fact, the rigidity characteristic of five-axis machine tools has a direct effect on machining performances. Therefore, during machining planning process of five-axis machinetools, we should not only focus on the geometry characteristic of workpiece surface, but also take into account the rigidity characteristic and motion capacity of the five-axis machine.So the tool path planning must be integrated into the geometry, kinematics, and dynamics characteristic.

With the develompent of domestic CNC machining centers and high - grade CNC machine and other hardware devices, some deep-seated problems around high-speed CNC machining will be gradually revealed. The most obvious is the contradiction between the high-speed machining CNC machine tools and traditional processing methods.Less stiffness model considerate from kinetic, and they are independent of each other, espacially the studying of five-axis high-speed machining [1].

HUANG et al[2-3]use the finite element method to calculate the general machine stiffness, first,estaltish finite element model for each of the key components, and then using the substructure method compute the general stiffness method of the whole machine ;WANG et al[4-5]according to the principle of virtual work, first create stiffness model machine components subsystems, and finally using the linear superposition principle calculate the general stiffness of the machine;GOSSELIN et al[6-7]taking into account the weak rigidity,build Jacobi matrix according to the differential displacement mapping relationship between local transmission parts coordinate system and the workpiece coordinate system,and then using the principle of virtual work creates the general stiffness model;BUDAK er al[8-9]think that tool's weak rigidity is negligible, they calculate the cantilever stiffness characteristics of tool using a simplified model.RATCHEV et al[10-12] analysis the weak rigidity of workpiece and tool ,calculate the deformation that tool relative to any control point on the parts,and then use the simulation results for deformation error compensation.

The above scholars put forward the corresponding stiffness model, but these models have certain limitations and isolate from each other, there is no analysis of the contact of various parts, establish the general stiffness model. In this paper,fully consider the main impact factors of the general system stiffness characteristic, including the tool pose, tool overhang length, rigidity of the machine transmission parts, workpiece stiffness characteristics, and ultimately establish a general stiffness modelof five-axis machining system by Minimum deformation theory.

III. General stiffness of five-axis machine tool

The main objective of general stiffness model is to establish general stiffnessformulation for the multi-axis machine tool [13]. In traditional studies machine axis and its jointdeformation, the tool postureand tool overhang length is considerde separaerly. As mentioned previously, we need take full account of the intrinsic link between the various parts.

3.1Tool posture and tool overhang length

Priorresearchers have attempted to research tool path planning subjected to both geometry and physicsconstrains. But all of these researches haven't referredto tool posture control, that is, tool posture planning is still based on geometry constrain[14]. Duringmachining process, even although feedrate, vertical depth-of-cut and crossfeed is uniform, obviouslythe machine rigidity changes along with the change of tool posture. In order to improve product machining chatter need to be restrained by controllingthe machine rigidity along cutting feed direction, that is, by controlling tool posture to make themachine rigidity suitable for cutting process[15].At the same time, tool posture can also decrease the tool overhang length which is the main influence of the tool stiffness. The first job we need to do is select a suitable tool postureto make the machine rigidity suitable in order to restrain machine chatter and improve product quality. In this research, we first select some control point on the sculptured surface. The number of control points depends on how accurate the sculptured surface will be. The density of the control points is determined by the surface curvature of thesculptured surface.Next, using the force ellipsoid we can determine what kind of tool position and orientation can get the maximum localstiffness index. (Fig 2 is an example of force ellipsoid.)Once the maximum local stiffness indexis calculated, optimum tool posture at this control point can be selected for machining complexsurface.Then we can select the tool posture at each control points according to the maximum local stiffness index. Finally, subsection interpolation can be applied to determine tool posture atdiscrete points between two nearby control points.

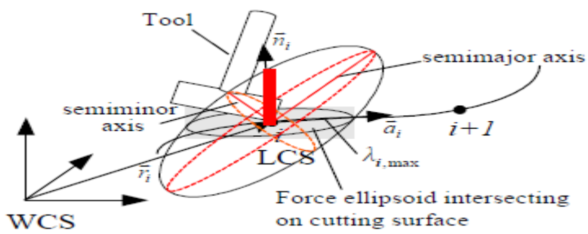


Fig.2 three-dimension ellipsoid schematic diagram

Once getting the tool path and tool posture, we can use the Simulation Software very cut 6.2 to calculate the overhang length of the tool for the reason that shorter overhang length can help us get greater rigidity.

3.2Machine axis and its jointdeformation

After taking into account the tool posture and tool overhang lengthand with the assumption of small deflections, the deflection at the tool tip can be expressed as:

$$\delta_{\mathbf{v}} = (\delta_{v_{1j}} + \delta_{v_{1a}} + \delta_{v_t}) - (\delta_{v_{2j}} + \delta_{v_{2a}}) \quad (1)$$

Where$\delta v1j$, $\delta v1a$, δvt is the deflection at tool tip caused by the tool transmission parts, the flexible axis of Oscillating end and the tool deformation.$\delta v2j$, $\delta v2a$, δvt is the deflection at tool tip caused by the table

transmission parts, the flexible axis of Oscillating end and
According to the principle of virtual work, can get:

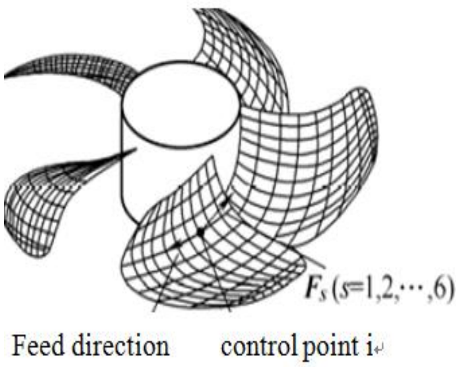
$$\delta \boldsymbol{v} = \mathbf{SF} \quad (2)$$

Where S is compliance matrix of general machine, F is force.

So the work left is how to obtain compliance matrix of the various components. When it comes to the compliance matrix of transmission parts, we only take into account deformation along the transmission direction of transmission parts. We can also use Jacobimatrix to calculate. At the same time, using the point transformationmatrix can calculate the compliance matrix of motion axis. Finally, five-axis machine tool can be considered as a robot havingmulti DOF so that we can get the compliance matrix of tool.

IV. Stiffness of the part

When considering the stiffness of the part, in this research, we use the finite element method. Just as mention above, when we select the tool posture we can get the stiffness index of the part.The finite element method can help to get the stiffness index of every point on the part, though Parts have complex surface and structure. It also need select suitable control point. Fig.3 and Fig .4 is the finite element model and control point selection



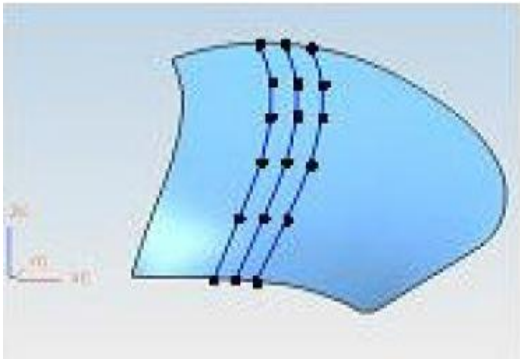


Fig.3 the finite element model Fig.4 control point selection

In this study, can obtain Compliance coefficient at the control point, and the inverse matrix is the corresponding stiffness matrix.Finite element model boundary condition needs to be set according to the holding mode. In Fig.3,F_S according to the order of 1-6 respectively representes F_x, F_y ,F_z, $M_x M_y$ and M_z.Coordinate system is the coordinate system of overall processing system. In calculation process, these unit force are applied to the control point to calculate the corresponding compliance coefficient.

$$S=\{ S_{ij} \} \quad (3)$$

Where S_{ij} is the displacement along the I direction when unit force is applied in the direction j.

After taking all aspects into consideration,we can obtain the stiffness matrix of a five-axis machine according to the minimum deformation theory and deformation superposition principle. It means that general compliance matrix is the sum of the compliance matrices of machine, tool and workpiece. the tool posture and overhang length use the value that mentioned above.

V. Conclusion

One.Considering the impact of five-axis machining tool posture, overhang length, transmission axis, workpiece stiffness characteristics ongeneral stiffness characteristics, using the superposition principle. The general stiffness model is the superposition of every parts.

Two. Determine the tool posture and tool overhang length to get better processability parameters before establishing the stiffness model, and it can also determine the stiffness characteristic of the part.

Three. In tool Path Planning process,geometric factors dynamic factors and physical factors are mutual restraint, mutual influence. Therefore,these three factors need to be further considered and combine with each other.

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