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Study on Performance of Integral Impeller Stiffness Based on Five-axis Machining System

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Abstract

Integrated stiffness characteristics of machine tool, cutters in various postures and distribution of impeller blade will affect the machining system in processing impeller with complex and thin-wall sculpture surface, and have further effect on machining accuracy of blade. Base on the theories of multi-body small deformation, the point of transfer matrix and the Jacobi matrix, the integrated stiffness model of machining system is established by space force ellipsoid in 3D particular to 5-axis NC machining center. The force ellipsoid method is used to analyze the effect of machine tool joints, cutter and joint of tool holder/cutter on the integrated stiffness field of machining system. And then, the integrated stiffness field distribution of impeller blade in cutting plane is analyzed. Finally, this theoretical model can be effectively optimized path of machining of integral impeller, which is tested by optimization experiments of working table posture.

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Keywords: impeller; complex surfaces; five-axis machining; force ellipsoid; stiffness field

1. Introduction

Nowadays, with the development of sophisticated manufacturing technologies, impeller-type parts are widely used in energy field, defense industry and aerospace field. Due to the sculptured surface of impeller blade, multiple-spindle NC machining center and intelligent CNC machining are necessarily used in machining impeller-type parts. Because of the complex structure of multiple-spindle NC machining center, cutter and worktable of NC machining center in various postures will affect the performance of the integrated stiffness of the machining system and kinematic chain gets longer from workpiece movement space to cutter movement space [1]. Deformations of cutter, tool holder/tool coupling section and machining center joints transfer through kinematic chain to tool nose. These deformations are amplified in transfer process and have further effect on the integrated stiffness of the machining system. Overcut or cutter relieving emerge if lack of stiffness of the machining system particularly to high speed milling, which have effect on machining precision and cause machining errors [2, 3, 4]. In addition, the performance of the integrated stiffness of the machining system also affect sculpture surface profile precision, which have further effect on the corrosion resistance, abrasion resistance and ability of resist fatigue [5]. Therefore, it is particularly important to establish the integrated stiffness model considering certain impeller, machining system and kinematic chain.

In recent years, the research on multi-body system stiffness model by foreign scholars have made some progress for dealing with problems of numerical control machine dynamics. Budak [6, 7] regarded cutter as cantilever structure to compute stiffness matrix of cutters, which was used to estimate workpiece machining errors caused by cutter deformation. C.Gosselin [8, 9] et al. considering of the rigidity of machine transmission parts, the Jacobian matrix between the workpiece coordinate system and machine transmission parts coordinate system was established, and established the model of integrated stiffness of the machining system based on the principle of virtual work. Wan Min [10] considering of the machining errors caused by the deformation of cutter and workpiece, the finite element

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analysis and calculation were carried out for the deformation of the cutter relative to the arbitrary sampling point of the workpiece in Flank Milling, and the results were used to compensate for the distortion error. The above scholars have calculated and analyzed the integrated stiffness characteristics of the machining system, however, the influence of cutter, worktable posture and workpiece cutting point on the integrated stiffness of machining system is not considered.

Domestic scholars have also done numerous studies about the stiffness field of machining system. Liang Ruijun et al. [11] considering of the integrated machining system of machine tool, cutter and workpiece, dynamic stiffness performance of the system was extracted by experiments for weak rigidity of thin-walled parts and cutters in multi-axis NC machining. Liu Haitao et al. [12] considering of the stiffness performance of machine tool and cutter, the multi-body dynamics finite element model and the generalized stiffness function of the four axis machining center were established, and the dynamic stiffness of the system was obtained by analyzing the generalized dynamic stiffness field function. Peng Fangyu et al. [13, 14] established closed-loop stiffness model for seven-five axis machine and five-axis machine and analyzed integrated stiffness characteristic by force ellipsoid in 3D space. Position and posture of cutter and tool path were optimized, but the influence of workpiece sculpture profile on the integrated stiffness model of machining system was not considered in analysis.

The stiffness matrix of key points on blades are established for open impeller in this paper. Then, kinematic chain model of impeller particular to five-axis machining system is established and solve the coordinate transformation matrix to obtain the theoretical model of integrated stiffness field. Finally, based on force ellipsoid model, the integrated stiffness performance of key points on blades are analyzed, which is guidance to optimize the feed path and processing parameters for machining blades of impeller.

2. Stiffness matrix of key points on open impeller blade

The machined open impeller blades are shown in Fig. 1. According to the structural characteristics of the closed impeller, the five axis vertical machining center UCP Mikron 710 was selected for processing, as shown in Fig. 2.

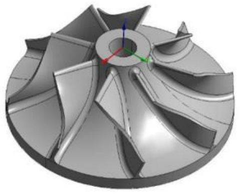


Fig.1 3D model of open impeller

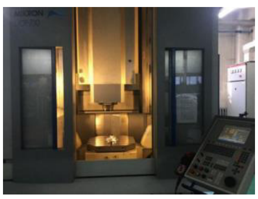
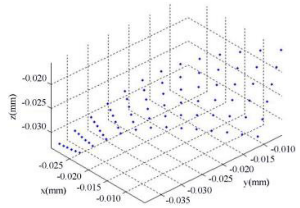
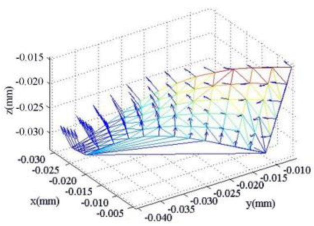


Fig.2 Mikron UCP 710

Because of multiple surface in the integral impeller, the model of impeller is complex, global analysis will cause large number of controlling point sample. Complex grid affects the efficiency of finite element analysis. So finite element analysis is analyzed only against certain impeller blade while ensuring of the surface reconstruction precision. Based on bending moment principle, the impeller blade is sampled by using the method of adaptive sampling [15]. Sampling points are more denser in the range which changes of surface curvature become more violent based on change laws of surface curvature, and vice versa. Setting of 78 sampling points on the surface of open impeller blade are shown in Fig. 3(a). Then these sampling points are reconstructed by using of NURBS interpolation principle. The reconstruction surface as research object, normal vector of sampling points are calculated, and the results are shown in Fig. 3(b).



(a) Model of adaptive sampling



(b) Normal vector of sampling points

Fig.3 Sampling model and normal vector of blade surface

The axis of the impeller is generally located at the center of the table. So in order to be closer to the actual processing situation, when the finite element model is established, it is not based on the geometric center ofthe blade, but the axis of the impeller is set as the base coordinate of the blade, namely the coordinate system of workpiece (CSW). According to a certain sampling point of the blade,the 6 directions of the unit load are applied to the point,namely. Deformation from 6 directions, X, Y, Z, θ_x, θ_y, θ_z are caculated in each unit load. The force or torque applied tothe other five directions of i, respectively, and the final deformation matrix is obtained. Due to the analysis is carried out under the CSW, the deformation matrix is the sampling point flexibility matrix in the CSW. The stiffness matrix of the sampling point i can be obtained from the inverse matrix of the flexibility matrix. Similarly, flexibility matrix of all points areobtained, then, sampling point receptance matrix database are established and thesampling point coordinates and flexibility matrix are saved. In necessary, based on the inverse matrix of theflexibility matrix, the stiffness matrix of the sampling point is obatained.

3. Modeling of integrated stiffness field

According to the motion relationship between the motion axis and the motion joint of machining center Mikron UCP 710, the model of the kinematic chain was established. The processing center has five kinkage axes, which are recorded