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Analysis on Large Deformation Compensation Method for Grinding Machine

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Abstract

The positioning accuracy of computer numerical control machines tools and manufacturing systems is affected by structural deformations, especially for large sized systems. Structural deformations of the machine body are difficult to model and to predict. Researchs for the direct measurement of the amount of deformation and its compensation are farly limited in domestic and overseas, not involved to calculate the amount of deformation compensation. A new method to compensate large deformation caused by self-weight was presented in the paper. First of all, the compensation method is summarized. Then, static force analysis was taken on the large grinding machine through APDL (ANSYS Parameter Design Language). It could automatic extract results and form data files, getting the N points displacement in the working stroke of mechanical arm. Then, the mathematical model and corresponding flat rectangular function were established. The conclusion that the new compensation method is feasible was obtained through the analysis of displacement of N points. Finally, the MATLAB as a tool is used to calculate compensate amount and the accuracy of the proposed method is proved. Practice shows that the error caused by large deformatiion compensation method can meet the requirements of grinding.

***Keywords**: displacement, compensation, APDL*

1. Introduction

As the abrasive belt grinding technique advances, its application range is expanded [1-2]; however, there are still a lot of problems about the large-scale NC grinding equipment in processing of large workpiece. The large NC grinding equipment should have a large structure size for machining large workpieces, but the larger structure size will cause a large deformation due to its own weight, so this will make it difficult to achieve precision control for the NC grinding equipment, and the machining accuracy of abrasive ble grinding machine is reduced.

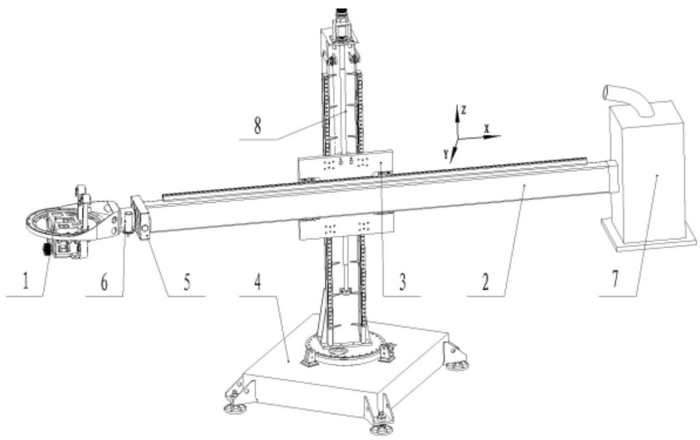

Figure 1. The Structure of Large-scale NC Grinding Equipment

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The large-size NC equipment involved in this paper is a certain type rasp machine, as shown in Figure 1, grinding 1 head, 2 crossbeam, 3 cross slide, 4 base frame, 5 paralleltranslation mechanism, 6 Rotating Mechanism, 7 suction mechanism, 8 the vertical column. When the crossbeam move from the intermediate piont to the other end, its own weight caused by the large torque will lead to a large deformation of crossbeam due to the heavy weight of high-power abrasive belt grinding head devices. When its 2 and 3 is in the extreme position, the amount of deformation reached 34mm, so it affects seriously the control accuracy and polishing precision. In the process of grinding, there are the phenomenons of grinding too much or too little, grinding surface quality poor, and even burning workpiece.

Structural deformations of the machine body are difficult to model and to predict. The usual approach is a model-based prediction of structural deformations, which is followed by a compensation of positioning errors. Reference [3-4] illustrates a different approach in active error compensation, which exploits a new measurement system able to provide real-time measurement of the displacement field of a given structural component, without any model about its dynamic/thermal structural behavior. In references [5], the strategy of evaluation and compensation method utilize coordinates measuring machine (CMM) as a master gauge because of its accuracy so that machine operator devote himself to machining and estimator of accuracy dedicate in measurement.In respect of structural deformation forecasting, support vector regression trained by particle swarm optimization algorithm is applied to structural deformation prediction in References [6], and the comparison of the forecasting results of structural deformation between PSO-SVR and SVR indicates that the forecasting performance of structural deformation of PSO-SVR is better than that of SVR. In order to enhance the positioning accuracy, a composite sensor has been designed and tested, which allows direct and continuous measurement of geometrical deformations on machine structural elements in References [7].

Therefore, researchs for the direct measurement of the amount of deformation and its compensation are farly limited in domestic and overseas, not involved to calculate the amount of deformation compensation [8-16]. This paper presents a new method for the compensation of large deformation in order to achieve precise positioning.

2. Present the Large-deformation Compensation Method

As Figure 2 is shown, A1 for A point before the deformation of the position, A2 for A point after deformation position. Therefore, if make A point to A2 point position, A1 point position is the only one.

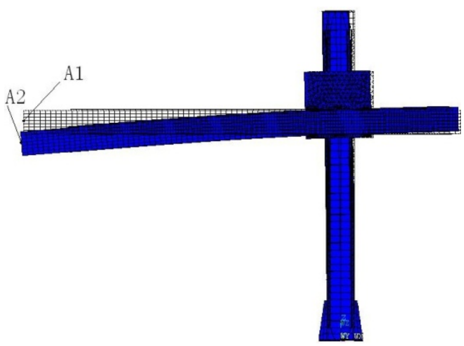

Figure 2. The Location of the Before and After Deformation

To realize this method, steps are as follows: First of all, the deformations of the grinding machine in space N different positions and posture are computed, taking computering the deformation of the grinding machine in the plane in this paper as an example, and then the shape function is established, to Calculate the amount of compensation by interpolation method. Finally, the amount of compensation is introduced into the control program, so that the compensation of large deformation can be realized.

3. The Displacement Amount Solving and Data Analysis

ANSYS orders is organized by Ansys Parametric Design Language (APDL) to compile parameterized user program,to realize parameterization modeling, apply parametric load acquiring solution, solve the displacement amount, automatic extract solving result, and generate data files as well as results display after parametric process [17-20].

The emphasis of this paper is to introduce the method for the compensation of large deformation, so the modeling process and simplification in ANSYS is not discussed in detail. The model of grinding machine in ANSYS, is show in Figure 3：

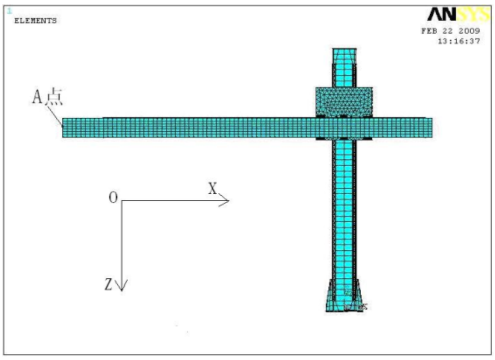

Figure 3. The Simplified Diagram of in FEM

The solving procedure：First step, make the cross slide 3 in the extreme position of the above, and the crossbeam in the leftmost position. The second step, the crossbeam moves right every 0.2m until the rightmost position. The third step, make the crossbeam and cross slide move down 0.2m, then calculate the displacement amount of the point A in this position by static analysis. The fourth step, the crossbeam move left (the negative direction of x-axis) 0.2m each time until the limit position of the left. The fifth step, the crossbeam and cross slide move down 0.2m; the last step, it repeat the first step to the fifth step until the cross slide in the limit position. Meanwhile, Ansys software do static analysis in every move, and the value of the point A in the X and Z direction displacement are calculated. The mobile process of point A in Figure 3.

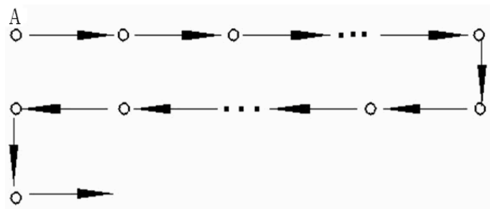

Figure 4. The Mobile Process of Point A

The data obtained by Ansys shows: (1) the displacement data of the node in each row (or column) is decreasing in Figure 4, as shown in Figure 5 and 6 ("X-coordinate" and "Z coordinate" are same as the coordinates in Figure 2); (2) The array obtained by subtracting the Z-direction displacement amounts of two adjacent nodes in any row or column is decreasing, as shown in Figure 7 and 8 (the vertical direction represents the values obtained by subtracting the displacement amounts of two adjacent nodes in row or column, the transverse digital n is the nth obtained by subtracting the displacement amount of the node in the n+1th from the displacement amount of the node in the nth); (3) In any row or column in Figure 4, the array achieved by subtracting the X-direction displacement value of two adjacent nodes is not obvious on degression, as a result of the small displacement amount of the X-direction (⩤0.165mm).

As shown, this (Figure 5, 6, 7, 8) is consistent with the practical experience.

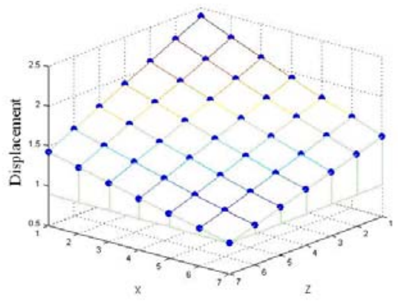

Figure 5. The Displacement of the X-direction (Unit mm)

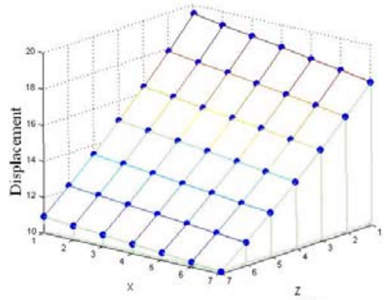

Figure 6. The Displacement of the Z-direction (unit mm)

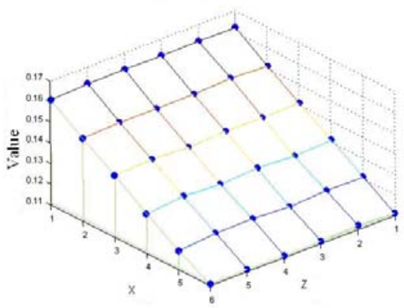

Figure 7. The Value Obtained by Subtracting the X-direction Displacement of Adjacent Nodes (Unit mm)

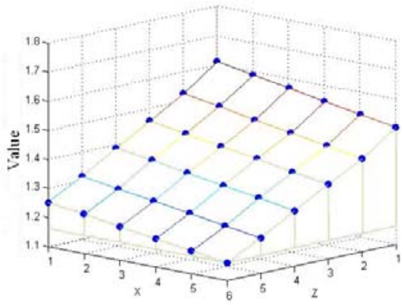

Figure 8. The Value Obtained by Subtracting the Z-direction Displacement of Adjacent Nodes (Unit mm)

4. Shape Function

If each position of the point A is regarded as one node and the displacement amount of the point A is considered as the displacement amount of the node, then these nodes can constitute a rectangle mesh cells. Rectangular unit 4 Angle point for nodes, the center in the origin, the side of the rectangular element is parallel to the X, Z axis. Each node 2 displacement component, so unit were eight degrees of freedom. As shown in Figure 9, circles are nodes.

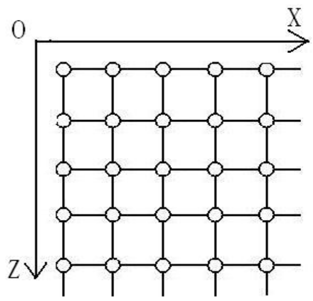

Figure 9. The Element Mesh

Assume that the deformation is continuous in the element, then the displacement amount can be represented by the displacement amount of its node (as shown in formula 1), Displacement has linear change along the unit edge, and the two function change along the other direction. Its displacement model is:

$$\begin{cases} u = a1 + a2 \times x + a3 \times y + a4 \times x \times y \\ v = a5 + a6 \times x + a7 \times y + a8 \times x \times y \end{cases} \quad (1)$$

Where the constant term and the coefficient of one degree term a1, a2, a3, a5, a6, a7 reflect the rigid body displacement and constant strain, so it can meet the necessary condition of convergence; From the theory of finite element, the displacement between the units on common boundary is continuous too,so the entire unit plane are continuous.

Expression of Unit displacement which is through the element nodal displacement is as follows:

$$\begin{cases} u = N_1 u_1 + N_2 u_2 + N_3 u_3 + N_4 u_4 \\ v = N_1 v_1 + N_2 v_2 + N_3 v_3 + N_4 v_4 \end{cases} \quad (2)$$

Where $N_1 \cdots N_4$ are interpolation functions, suppose that $\xi = \frac{x}{a}$, $\eta = \frac{y}{b}$, the expressions can be obtained as:

$$\begin{cases} N_1 = \frac{1}{4}(1+\xi)(1+\eta) \\ N_2 = \frac{1}{4}(1-\xi)(1+\eta) \\ N_3 = \frac{1}{4}(1-\xi)(1-\eta) \\ N_4 = \frac{1}{4}(1+\xi)(1-\eta) \end{cases} \quad (3)$$

5. Compensation Function

The point A should be in the position of A1 before deformation if the point A needs to reach the point A2.Thus, the compensation functions are:

$$\begin{cases} u + A1\_xx = A2\_xx \\ v + A1\_zz = A2\_zz \end{cases} \quad (4)$$

Where A2_xx、A2_zz are the coordinate values of point A in the X-direction and Z-direction after deformation, that is Solved out; and A1_xx、A1_zz the coordinate values of point A in the X-direction and Z-direction before deformation, which is the unknown.

Matlab is a powerful function mathematical tools, which can realize data analysis and numerical calculation. Equations 2, Equation 3 and Equation 4 are synthesized, then solve in one by one unit by MATLAB. Therefore, the compensation quantity u of the x-direction、the compensation quantity v of the z-direction and the coordinate values A1_xx、A2_zz of point A can be solved. The result shows that the solution is the only and effective.

6. Contrast Verification

Arbitrarily choose eight test points on a straight line, and the methodical error of calculate the amount of deformation between the calculated deformation amount with Matlab and the displacement by Ansys.

Figure 10 and 11 shows that: the error value of the X-direction deformation amount is less than 0.15mm, and the error value of the Z-direction deformation amount is less than 0.25mm.Since this paper is mainly study on the abrasive belt grinder with high-speed and large cutting amount, the contacting pressure between the contact wheel and workpiece can be quite high; the carrier of the abrasive grain of the grinding belt is constituted by the cloth-based or Paper-based material with a certain flexibility. In addition, the rubber contact wheel and the adhesive also have very good elastic effect; Because of the deformation amount of the cloth-based or Paper-based material and contact wheel is large, this method error of calculating the deformation amount satisfy the requirements of the grinding.

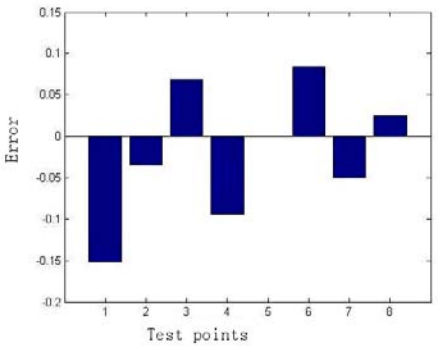

Figure 10. The Error Value of the X-direction Deformation Amount (unit mm)

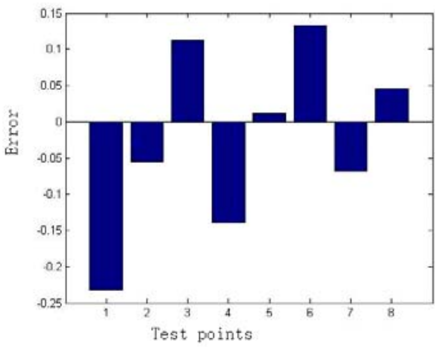

Figure 11. The Error Value of the Z-direction Deformation Amount (unit mm)

7. Conclusion

Due to the large structure size of the large-size grinding equipment, if the stiffness of the grinding equipment increase, its weight will increase too, therefore, the equipment will be particularly ponderosity. Through the large deformation compensation method presented in this paper, calculate the compensation amount in a certain position and posture, and the error is acceptable, and then the compensation amount is introduced into the control program. So this method can be able to compensate for the deformation caused by its own weight. However, due to the finite element analysis has certain error, and needs a number of mesured samples to ensure the correct results of finite element analysis, so this paper proposes the compensation method is suitable for the large deformation.

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References

[1] Huang Yun, Huang Zhi. Modern abrasive belt grinding technology and engineering application. Chongqing: Chongqing university press. 2009.
[2] Huang Yun, Huang Zhi. Development and key technologies of abrasive belt grinding. 2007; (18): 2263-2267.
[3] Bosetti Paolo, Bruschi Stefania. Enhancing positioning accuracy of CNC machine tools by means of direct measurement of deformation. *International Journal of Advanced Manufacturing Technology.* 2012; 18(5): 651-662.
[4] Bosetti Paolo, Bertolazzi Enrico, Bira Francesco, De Cecco Mariolino. *A new direct deformation measurement system to enhance positioning accuracy of machine tools*. 2006 ASME International Mechanical Engineering Congress and Exposition. 2006: 769-777.
[5] Morimoto Yoshitaka, Ichida Yoshio,Ohashi Toshinori, Sato Ryunosuke, Kato Katsuhiko. Study on accuracy compensation of a machining center based on measurement results of machined workpiece measurement and compensation of geometric and dimensional error of three orthogonal axes. *International Journal of Digital Content Technology and its Applications*. 2003; 69(12): 1718-1723.
[6] YIN Zihong, LI yuanfu. Structural Deformation Forecasting Based On Support Vector Regression Trained By Particle Swarm Optimization Algorithm. *AISS: Advances in Information Sciences and Service Sciences*. 2012; 4(5): 130 – 136.
[7] Biral Francesco, Bosetti Paolo, Oboe Roberto, Tondini Francesco. *A new direct deformation sensor for active compensation of positioning errors in large milling machines*. 9th IEEE International Workshop on Advanced Motion Control. 2006: 126-131
[8] Upadrasta M, Peddieson John, Buchanan George R. Elastic compensation simulation of elastic/plastic axisymmetric circular plate bending using a deformation model. International *Journal of Non-Linear Mechanics*. 2006; 44(3): 377-387.