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Modeling of Thin Wall-Parts Deflection During High Speed Milling

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Abstract: The machining of thin wall parts remains a challenge in industry especially at High Cutting Speeds. In this paper the static deflection of thin walled parts during Dry High Speed Machining was studied. The problem was solved using the finite element method. The material removal during the cutting process was simulated using standard packages in ANSYS. The new introduced method is based on parameterized work piece geometry that was updated continuously during the cutting operation. A purely geometric criterion was chosen to initiate material removal. The cutting forces were estimated using a predictive cutting force model including material constitutive equation. The cutting forces were distributed uniformly in the tool-work piece contact zone. Full immersion peripheral end milling tests were performed for different cutting conditions. The model generated the work piece static displacements during the cutting process. The proposed method is found to be easier and more rapid than existing methods in the literature.

Keywords: Dry High Speed Milling; End milling; thin walled part; FEM

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1 INTRODUCTION

Dry High Speed Machining is a promoting technology for future industry encouraging sustainable machining processes. Dry High Speed Machining (DHSM) is an environmental friendly process, less expensive than dry machining process (Khettabi et al. 2007). If the cutting conditions are correctly chosen, than the DHSM can ameliorate the work piece surface error (Shen,G. 2003) and reduce the dimensional errors (Kaufeldand et al. 2001).

The most challenging problem for Dry High Speed Machining is the selection of optimum cutting conditions (Radeluscu,R. 1993). Excessive heating of the tool and the work piece cause work piece distortion and short tool life. Work piece distortion and short tool life are the challenging problems faced when cutting fluid are not used during the cutting process (Shen,G. 2003).

When the machined parts have thin sections, the cited problems become worse. The part rigidity decrease associated with acting cutting forces, cause the part deflection. The rigidity change is due to the material removal during the cutting process. (Budak, E. et al. 1994) studied the deflection of thin walled parts using the finite element method. Authors investigated the effect of the machined part thickness on cutting forces and surface error. Different work piece thicknesses were considered for simulations and experimental studies. The cutting forces were generated using a mechanistic force model. The thermal effects were neglected during the study of (Budak, E. et al. 1994). However the model validation was performed using dry milling tests. (Tsai,J. et al. 1999) used the same method developed by (Budak, E. et al. 1994). but a tool geometry with non cylindrical section was considered. (Budak, E. et al. 1994) and (Tsai,J. et al. 1999) and did not consider the work piece geometry change during the cutting process.

(He et al. 2003) studied the effect of thickness variation during the milling process of a thin walled pocket. The four walls of the part were assigned different thickness. The released simulations demonstrated that the deflection was larger in the operation-end than in its beginning. The simulations results were not validated experimentally during the study of (He et al. 2003).

(Mounayri et al. 1998) studied the tool and the work piece deflection during end milling process for low cutting speeds of aluminium (30m/min to 60 m/min). The material removal effect is take into account using an automatic mesh generation program. (Ratchev et al. 2004, 2005) presented a closed loop model to predict thin walled part deflection during end milling operations. The model is based on continuous update of the work piece geometry and an update of the cutting forces. The cutting forces were predicted using a FEM model of an orthogonal cutting process. The transformation from orthogonal to oblique cutting was necessary. A new algorithm based on the voxel approach was developed to simulate the material removal during the cutting process.

The most challenging step during the FEM simulation of the cutting process is the material removal step. Two approaches were proposed in the literature. The double node method (Shin, Y. et al. 1999) and the thin layer method (Nga, E. et al. 2002). With one of these two methods a separation criterion is to be fixed. The separation criterion can be a geometrical criterion or a physical criterion (stress, plastic strain, temperature…etc). These methods are time consuming for during the programming step and the running step. Furthermore the cited methods can be applied to simple geometries only.

An alternative approach is developed in this study. The new method is based on the parametric approach combined with the finite element method. The work piece geometry is modelled as parameterized geometry that is updated continuously. The estimated static displacements are used to update the cutting force calculation. The cutting force prediction is generated by a new force model including a constitutive equation, appropriated for Dry High speed Machining. The paper remainder is organised as follows: In section 2 the model description is presented. In section 3 results are presented and discussed. The paper is concluded with a summary of the study and a prospectus of further activities.

2 MODEL DESCRIPTION

The work piece used for simulation tests has a parallelepiped shape with a weak initial wall thickness (12 mm). Half peripheral immersion will deeply cause a decrease of the part section from 12 mm to 2.5 mm. The material removal affects the work piece rigidity. In this study the influence of the change of work piece rigidity during the cutting operation will be investigated. A variable work piece geometry during the cutting operation will helps to investigate the effect of rigidity decrease on static work piece displacements.

The initial and intermediate work piece geometries were meshed using the same elements type (solid 185). This element type is used for 3-D modelling of solid structure and thin plates. The solid element 185 is defined by eight nodes having each three degrees of freedom. The three degrees of freedom are translations in the nodal directions x, y and z. Rotational degrees of freedom are not needed for the present problem. The meshed geometry of the initial and final work piece geometry are presented in figure 1 . In the beginning of the end milling operation the work piece geometry has 1500 elements with 2250 nodes. In the end of the cutting operation the work piece meshing has 1100 elements with 1800 nodes. During all the machining operation the work piece bottom was encastred, all other surfaces were free. A predictive force model appropriate for DHSM that was developed by authors in an other study (Zaghbani, I. et al. 2007) is used to generate the cutting force profile for given cutting conditions. A sample of the cutting forces is presented in figure 2.

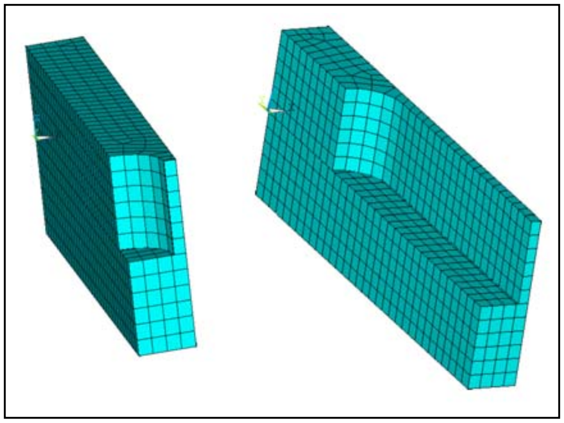

Figure 1 *The initial and final work piece geometry meshed with solid elements*

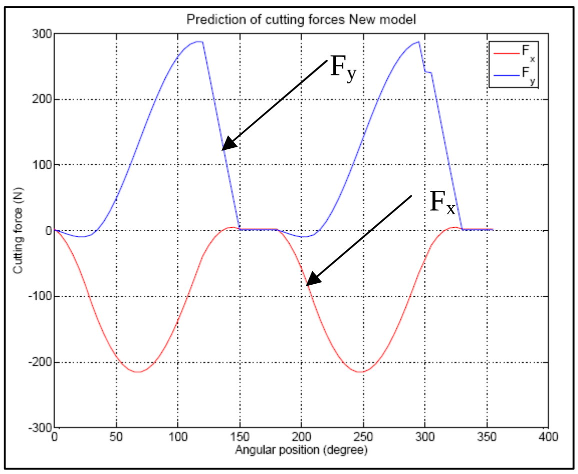

Figure 2 *A sample of cutting forces generated using a new model developed by* (Zaghbani,I. et al.2007)

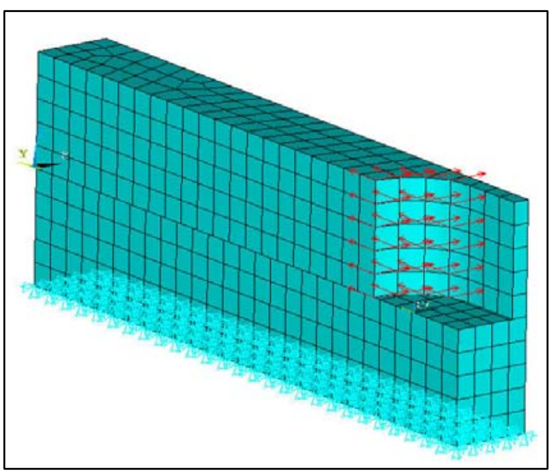

Figure 3 *Boundary conditions and applied cutting forces in the contact zone, some force vectors (in red) are null*

The most important problem during end milling pf thin walled parts is the decrease of the machined part rigidity. The rigidity decrease, associated with the cutting force acting on the tool lead to the static deflection of the machined part. The static deflection causes dimensional and

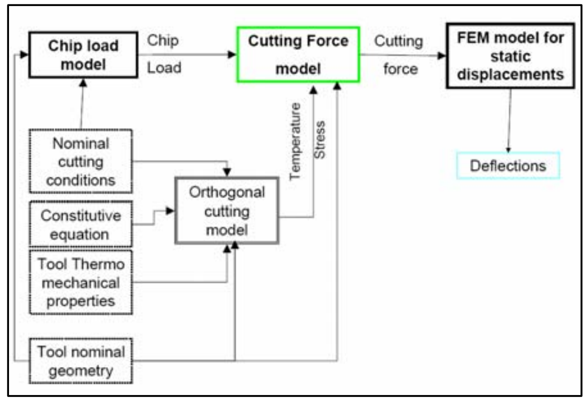

Figure 4 *The open loop static displacements model*

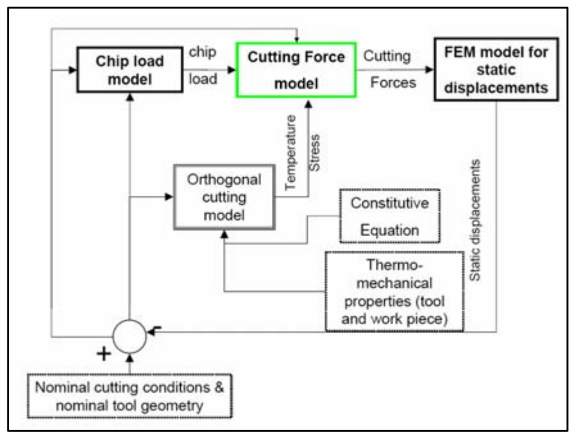

Figure 5 *The closed loop static displacements model*

form errors. To study the influence of rigidity decrease parameterized work piece geometry is studied. Two models are tested

- The open loop static displacements model. The diagram in figure 4 explains this first approach
- The closed loop static displacements model. The diagram in figure 5 explains this second approach.

The closed loop model is characterized by a continuous update of the work piece geometry the cutting conditions. For example the static displacement will cause the change of radial depth of cut. The change of the radial depth of cut is not considered in the open loop model. But it is considered in the second model. The closed loop model take a longer timer for running but it is more accurate, however the open model is more rapid than the closed loop model but less accurate.

For both models the tool path was subdivided into many steps. A step corresponds to a program run. The considered instants are considered after radius advance of the tool in the work piece.

3 RESULTS AND DISCUSSION

The deformed shape of the work piece in a tool intermediate position is presented in figure 6. The calculation was performed using the open loop model (left) and using the closed loop model (right)

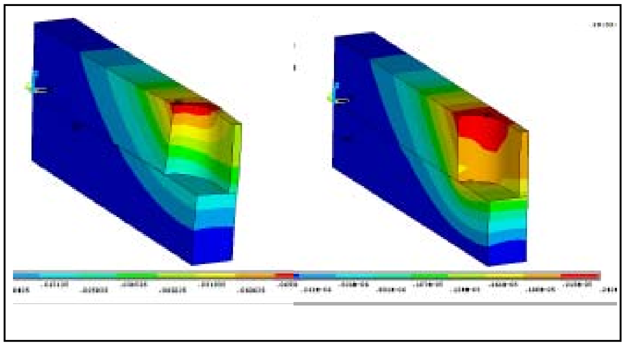

Figure 6 *The deformed shape of the work piece at an intermediate cutting position*

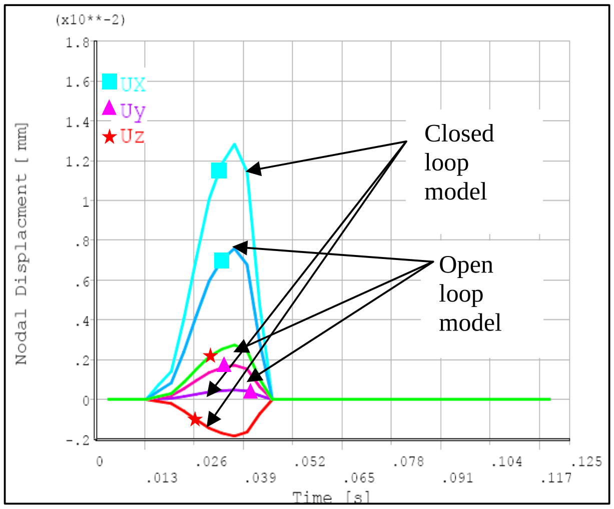

Figure 7 *Comparison of nodal displacements using the open loop model and the closed loop model.*

In figure 6 the simulations results show a higher deflection on the machined part top than on the machined part bottom. This result is available for the two models. This difference is caused the by the cantilever effect. Similar results are found by (He N. et al. 2003, Depince, P. et al. 2006)

Figure 7 illustrates a comparison of the nodal displacements using the open loop model and the closed loop model. For the two cases the displacements in the direction x is the highest. This is explained by the low rigidity in this direction. In the y and z direction the work piece is more rigid, the static displacements are lower. For the case of displacements in the x direction the closed loop model showed higher displacements. This is due to the change in cutting forces. The change in cutting forces was due to the update of cutting conditions.

4 FUTURE WORKS

The presented models generated acceptable results that will be validated experimentally for the Dry High Speed marching process of aluminium thin walled parts. The study of the effects of work piece rigidity change during the cutting process will be investigated. The model will be used for optimizing the cutting conditions. It is possible to get adequate combination of radial and axial depth of cut with the present model. An optimization routine will be added to the model. Using two different programs can result in longer running; one of the future trends is to condensate the algorithm for better efficiency. The model will be used for fixture design and optimization for thin walled parts.

5 CONCLUSION

A new model for simulating the Dry High Speed Machining was developed in this study. An open loop model and a closed loop model were tested. The found results are similar to existing results in literature. The work piece geometry was variable during the cutting process. This approach does not need complicated and slow algorithm for material removal simulation. There was no need for element creation and deletion. The used cutting force model was based on a phenomenological approach appropriated for Dry High Speed Machining, which will help to understand and explain the observed phenomena. Comparatively to other methods the proposed approach is very rapid, the elimination of plasticity calculus from the FEM program reduced the running time. The method is suitable for industrial use.

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