Analysis of cutting parameters in point machining of parts with complex shape

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Abstract

This paper presents developed SW module in the postprocessor, which is designed to backward analysis of CAM milling toolpath. The module is designed to analyze multi-axis finishing machining of complex shape parts with milling cutters with a circular cutting edge. In CAM, the milling cutter diameter is entered by a constant value of the maximum cutting diameter, but moving of the contact point between the milling cutter and the work piece, the actual cutting diameter changes over the machining cycle. By conventionally entering of the constant diameter into CAM, required technological cutting parameters are not adhered in some cases, and thus the resulting quality and productivity are not achieved. This developed SW tool is implemented directly into the postprocessor for generating NC programs. This Analysis Module designed as a tool for technologists and for CNC programators to visualize and to optimize the machining process with respect to adhere cutting parameters.

1. Introduction

Thanks to the constant need to generate production on CNC (Computer Numerical Control) of machine tools, there is a growing demand not only for the machine itself, but also for the chosen technology and tool. The optimization of the production process leads to shortening production times, lowering the energy intensity, reducing total costs, improving the accuracy and quality of the surface of the manufactured parts. This paper is therefore focused on optimization in CAM (Computer Aided Manufacturing) software and postprocessing. The main aim of this paper is to design supporting analysis module for solving adjustment of technological conditions in CN (Numerical Control) programs for CNC machine tools to guarantee correct technological conditions in machining, leading to productive and efficient machining. The paper is focus on making the machining process more efficient due to the adherence of the prescribed technological parameters

The research found that the main optimization interventions in the machining process due to the observation of the technological parameters is the variable feed rate (F) along with the intelligent generation of tool paths. Tool paths are generated in such a way to avoid overloading of the tool in cut with a large current removal of the material. Additionally, some advanced features modify the toolpaths with respect to the maximum time of the tool in cut, i.e. with low-pass crossing without effect. Tracks of tools due to keeping a constant wrap angle are generated as a different modifications of the trochoid or morphing spirals. In these paths, the tool is machined with a significantly larger depth of chip action against the working width, i.e., RDOC >> ADOC. This ratio is mainly appli-cable to hard-machining materials, or to parts where precision is primarily concerned with the effort to minimize internal strain after machining. Gene-rally, optimization features in CAM software have a number of drawbacks, such as frequent neglect of the shape of the tool, or the ability to use only 2.5D roughing. Optimizing machining functions are also addressed by many companies and scientists around the world. Many methods, algorithms, and software have been developed, focusing on various options of optimization, [1] [2]. It is important to note few optimizations are commonly used in current NC programming options. The reason is the complexity of the operation of the superstructure optimization functions, but also the problematic implementation into the production environment. This paper deals with the creation of a user friendly analysing module designed to subsequently optimize the tool paths in the multi-axis machining of the complex parts in terms of observing the prescribed technological parameters.

2. Analysis module

During machining with a circular cutting edge of the tool, especially in finishing operations when the depletion of material is minimal, i.e. intersecting the ball cutting part of tool, when the actual diameter on the tool is changing. Usually, during programming CNC machines, the maximum diameter of the cutter part of the milling tool is entered. It does not always respect the prescribed cutting parameters of the technologist (cutting diameter´s tool is changing).

When programming tool paths for multi-axis machining, the programmer has the option of selecting a tool axis vector relative to a given point on the surface,

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thus having direct influence on compliance with the cutting conditions. The tool axis vector is chosen depending on the workpiece, with a view to avoiding collisions in the states.

2.1. Cutting parameters

The spindle speed (S) is calculated from the surface cutting speed (Vc). Surface cutting speed is the relative speed between the tool and the work piece. The surface cutting speed value is given by the tool manufacturer. Calculation of spindle speeds is based on the formula (1) [3].

$$V_c = \frac{S*D*\pi}{1000} \quad [m/min] \tag{1}$$

The feed rate (F) is the product of shift on the feed per tooth Fz (greatly affect the quality of the resulting surface), the number of the teeth of the cutter (z) and the spindle speed (S). The feed rate size calculation is based on the formula (2) [3].

$$F = F_z * z * S \quad [\frac{mm}{min}] \tag{2}$$

The aim of the optimizations is to keep the surface cutting speed and feed per tooth values as constants during the machining cycle.
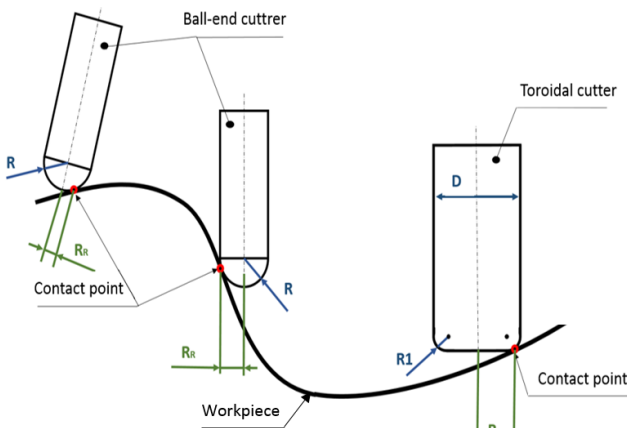
2.2. The goal of analyses module

Fig. 1. *The solved problem of the tool contact with the workpiece*

In Fig. 1 is a solved problem with a schematic for spherical and toroidal tools. The red-painted points determine the point of contact of the tool with the work piece, from which the actual cutting radius RR is further determined. It can be seen from the figure that the actual radius RR is not equal to the radius of the tool R. With a variable diameter of tool, see formula (1) also becomes an unwanted variable value from the spindle speed value. This value has always been the programming of milling CNC machines is considered as a constant. Furthermore, with variable speeds, see formula (2), also from variable speed value becomes the velocity value. It is therefore important to select the vector of the tools on the work surface with

respect to the largest cutting diameter du-ring the machining cycle. For example, surfaces of the turbine are challenging to correctly select ideally the tool axis vectors. There is space for finding of solved analysis module. Based on visualization from the analysis module, it is possible to optimize toolpaths. This optimization is conditioned by the need for knowledge of the point of contact of the tool with the work piece from the CAM software the best in CL data. The analysis function works with the touch point without considering the material after the prefinishing operations. Precondition is a small finishing machining allowance, which is a tenths of a milimeter. Keeping the cutting conditions at the point of contact with the work piece has the greatest effect on the final quality of surface after machining. Therefore, this point is considered as essential for determining the tool diameter, i.e. cutting conditions.

2.3. Calculates the actual tool diameter

In Fig. 2 shows a case of multi-axis machining. To compute the actual diameter we need to use the auxiliary triangle with the vertices in the contact point CP, the center of the ball tool S_c and the point PP constructed by the intersection of the direction of the tool´s axis vector and the normal vector to the axis of the tool passing through the contact point CP. The distance between the SC and CP points is always equal to the radius of the ball tool. The distance between the point CP and P_P is the current rotation radius R_r on which the cutting speed vector is located, and is therefore the actual cutting radius of the tool, also called the actual cutting radius. The angle β that forms the tool axis $\vec{e}$ and the basic vector $\vec{k}$ is called the leading angle.
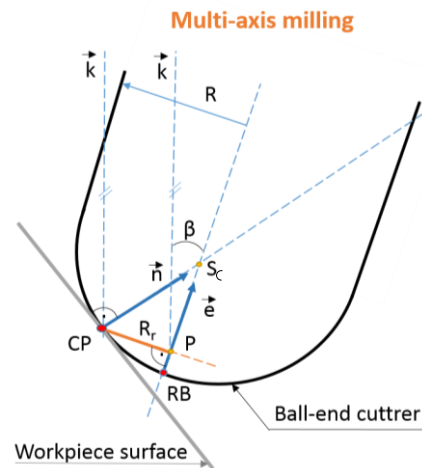

Fig. 2. *Calculating the actual tool diameter from contact of the tool with the workpiece*

In Fig. 3 is a separated triangle with the vertices FC, SC, CP for calculating the required angle γ angle for subsequent calculation of the actual cutting radius, respectively diameter. Angle α is obtained from the CL data as the deflection of the direction of the vector normal machining surface (at the contact point) from the axis Z, i.e.

from the basic vector $\vec{k}$. In the same way, angle β is diverted, the tool axis vector offset from the axis Z. Subsequently, the angle γ is the third angle of the triangle from the two known angles α and β. The actual tool diameter is calculated based on the properties of a rectangular triangle PP, SC, CP. The resulting formula for actual calculation of the actual Dr diameter is given in formula (3).

$$D_r = 2 * R_r = 2 * sin(\gamma) * R \quad [mm], \quad (3)$$
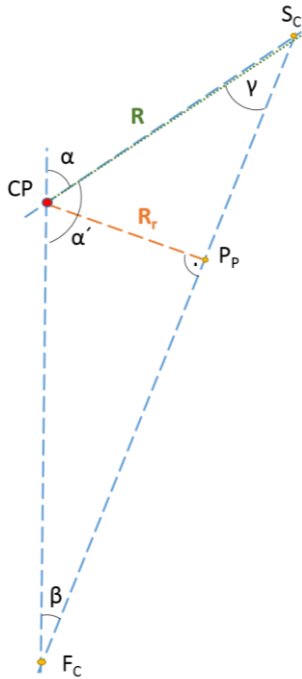$$\gamma = (180 - (180 - |\alpha|) - |\beta|) \quad [°]$$

Fig. 3. *Ttriangle for calculating the actual tool diameter*

2.4. Integrating the analysis module into postprocessor

The CAM software Siemens NX with Postbuilder - Development environment [4] was chosen to implement the analysis module. The analysis module is integrated into the postprocessor. The module backs up the CL data file. This new CL data file is generated based on the calculated values. This module visualizes the tool diameter of the instrument tool in the CAM, Fig. 4.
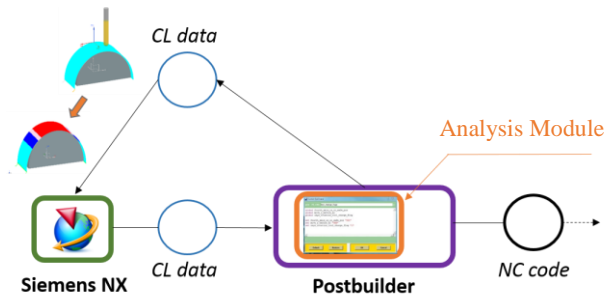

Fig. 4. *An analysing module operating with the point of contact of the tool with the workpiece*

3. Results and Discussion

Based on the analysis module, it is possible to subsequently optimize the machining process. From the knowledge of the actual cutting tool diameter and the visualization, it is possible to optimize the machining process by three main options. The first option is to change the tool axis vectors to the machined surface while preparing the toolpaths in the CAM to move the contact point on the tool as close as possible to the maximum tool diameter. The second optimization option is reducing the feed rate depending on the current tool diameter. This optimization is based on the analysis module algorithm. The last form of optimization can be the principle of active spindle speed control and feed rate depending on the actual cutting tool diameter. The last form of optimization can be the principle of active spindle speed control and feed rate speed depending on the actual cutting tool diameter. This optimization belongs to more demanding optimizations and is protected by patent (PV 2017-403). This optimization allows you to achieve time savings under the technological conditions (with decreasing cutting tool diameter spindle speed increases along with feed rate). This optimization is also based on the same algorithm used by the analysis module. To verify functionality, the analysis module was used in the turbine design (finishing machining of the blades).
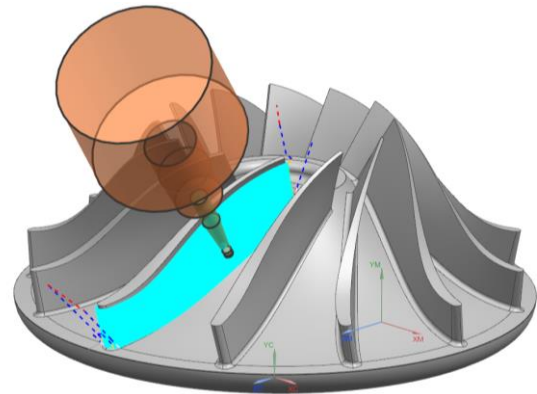

Fig. 5. *Toolpaths in finishing machining of the turbine*

Toolpaths were optimized based on the visualization of real diameter of the tool on existing toolpaths. On Fig. 6 original toolpaths are visualised (conventional settings of tool axis vector), which were then optimized by technologist based on analysis module. Before optimization the ratio between real and maximal diameter of the tool was from 30% to 82%. After optimization (by selecting more appropriate tool axis vectors on the work surface) change of diameter of the tool was achieved in the interval of 67% to 82% of real ratio compared to the maximal ratio of the tool. Choice of vectors of tool axis is however conditioned by the shape of machined surface, kinematics of the tool and shape of the whole part – in terms of collisions therefore is not always possible to achieve ideal maximum tool cutting diameter on the entire machined surface. The difference between conventional and optimized tool paths in terms of change in actual cutting diameter on machined blades was reduced by 37%. This has greatly improved

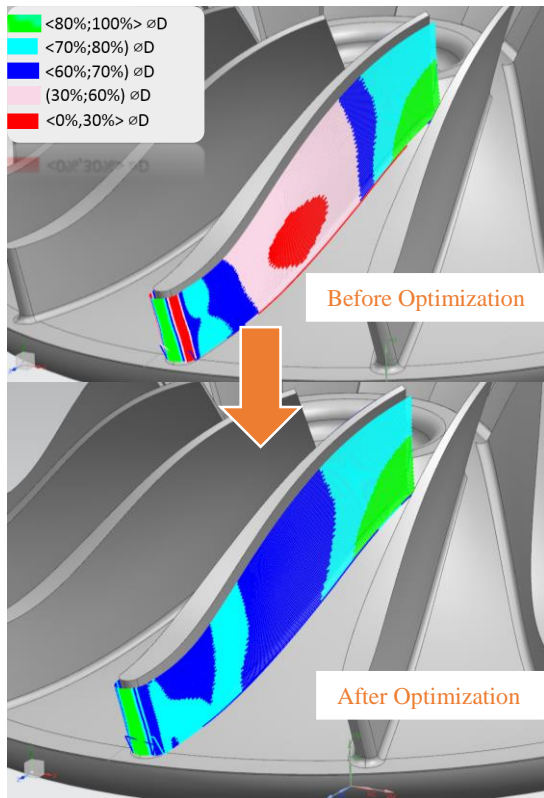the compliance with the technological conditions over the original settings.

Fig. 6. *Color Visualization - optimization based on the Analysis Module*

4. Conclusion

The work deals with the observation of the cutting conditions in multi-axis spot machining with a circular cutting edge tool during finishing the machining process. An analysis module has been designed and created, which is fully integrated into the postprocessor for NC program creation in the CAM Siemens NX. The analysis module generates a new CL data file from the postprocessor, which is used for subsequent visualization in CAM. Using the Analysis Module, it is possible to use visualization of color-visually and visualize the change of the actual cutting tool diameter on existing toolpaths. Based on this visualization, it is possible to optimize the machining process by selecting more suitable tool axis vectors.

Symbols

ADOC	Axial depth of cut (mm)
CP	Tool contact point (-)
D	Diameter of the tool (mm)
D_r	Actual cutting diameter of the tool (mm)
$\vec{e}$	Unit vector in the direction of the tool axis (1)
F	Feed rate (mm/min)
F_c	Point of intersection $\vec{e}$ and $\vec{k}$
F_z	Feed per tooth (mm)
$\vec{k}$	Unit vector in Z direction (1)
$\vec{n}$	Unit vector in normal direction of surface (1)
PP	Point of intersection $\vec{e}$ and RR (-)
R	Radius of the tool (mm)
RB	Coordinate tool reference point (-)
RDOC	Radial depth of cut (mm)
Rr	Actual cutting radius of the tool (mm)
S	Spindle speed (rpm)
S_c	center of the tool (1)
V_c	Surface cutting speed (m/min)
z	Number of teeth (1)
α	Angle between $\vec{k}$ and $\vec{e}$ (°)
α´	Additional angle to angle α to 180° (°)
β	Lead angle (°)
γ	Angle between $\vec{e}$ and $\vec{n}$ (°)

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