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Simulation Based Parameterization for Process Monitoring of Machining Operations

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Abstract

Process monitoring can prevent machine and tool failure in metal-cutting. A successful process monitoring of cutting processes depends on reliable monitoring limits for the process. In industrial applications these limits have to be generated in a learning phase during a ramp-up process. In order to enable process monitoring for single batch production without a learning phase, this paper describes a simulation based approach for generating reference data to set process limits.
As a foundation for calculation of monitoring limits a position-based process simulation has to be established. In a first step an approach of modeling material removal is evaluated to check whether it fits the application for parameterizing the process monitoring. In this context the potentials of a process simulation for calculating process limits are clarified. Additionally the quality of data generated by this kind of simulation is discussed. In a second step a method is described to implement machine properties by a virtual machine tool within a simulation of material removal. For that purpose a method to use actual data of axis position and tool within the simulation of material removal is necessary. With these data a way-based simulation of material removal can generate reference parameters for monitoring limits instead of using data from a learning phase during the ramp-up process. By using position data of a virtual machine tool a reliable source for the actual position of all axes enables the position-based simulation to perform material removal in a more accurate way.

Selection and peer review under responsibility of Professor Roberto Teti

Keywords Monitoring; Simulation; Material Remova; Toolpathl

1. Introduction

Process monitoring of machine tools is an established method used within automated batch production. A suitable process monitoring can ensure process stability and availability of production facilities [1, 2, 3]. Common practice for referencing the process monitoring is to measure machine signals during the production of the first parts of a batch. Thus a reference curve for ideal process characteristics can be generated. Any deviations of the signals in further production of the batch can be used to identify process failure.

Signal based process monitoring can be classified in three essential steps. These are data acquisition, signal processing and decision-making [4]. The fundaments to make a decision about interrupting a monitored process is a comparison of measured in-process signals and a reference curve generated from measured signals from manufacturing of the first pieces in a batch. A common approach for this kind of process monitoring is an analysis of measured internal digital drive signals, e. g. spindle current [5].

For a process monitoring that is suitable to monitor a single part production without any reference generated by a teaching phase, a precise process simulation for referencing the monitoring systems has to be established. In this paper a concept for referencing process monitoring with a process simulation will be explained as well as a first validation of this concept regarding challenges of calculating material removal and generating signal-alike reference data.

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2. Basic Concept

Nomenclature

V_c	volume cut in an increment of the material removal simulation
l_{nd}	length of removed part of dexel number *n* in direction *d*
d_x,d_y,d_z	distance between dexels in x, y or z-direction
$n_{cut,d}$	number of removed dexel in dexel-direction *d*

2.1. Teachless Monitoring

The approach to reference process monitoring with a process simulation uses G-code to generate a tool path. This enables a virtual parameterization of reference data by a simulation of material removal. The resulting reference data is furthermore used in a process monitoring system to recognize errors and process failure in manufacturing on machine tools by comparison of measured machine signals (figure 1).

Focus of this research is on improving the simulation of material removal and creating a technology based model to simulate data in a way that process monitoring can be referenced. For this aim there are two main challenges to solve:

- Synchronicity of reference data and measured signals of the process
- Simulated data that is comparable to measured signals

The synchronicity is crucial to avoid false alarms in process monitoring as is the comparability of reference data and measured signals.

Furthermore a calibration of the simulated data will be inevitable to enable a comparison of measured signals and simulation results. Thus, a technological coefficient, dependent on workpiece and tool setup, will be necessary to calibrate the simulated reference data, similar to cutting force coefficients in cutting force models. There are two different ways to calculate this technological coefficient. One is to calculate the coefficient by analyzing data of previous process monitoring for similar cutting geometries with the same tool and workpiece material. The other method is to use the first few seconds of the monitored process in single part manufacturing for calibration of the reference data. In that case the assumption has to be made that the initial seconds in cutting are without any errors or process failure.

For now two different operations for evaluating the approach of teachless process monitoring are chosen: turning and milling on a turning/milling center.

2.2. Path-based simulation of material removal

Simple virtual NC-controllers used for tool path generation and thus to calculate tool movement in scientific simulations of material removal usually do not emulate machine control or machine dynamics. Hence, in this research a new approach to create way-based reference data with a simulation of material removal is developed. Using tool position data calculated by a virtual machine tool like a machine simulation offers the chance to generate tool and machine movement that is very close to the real tool and machine movement.

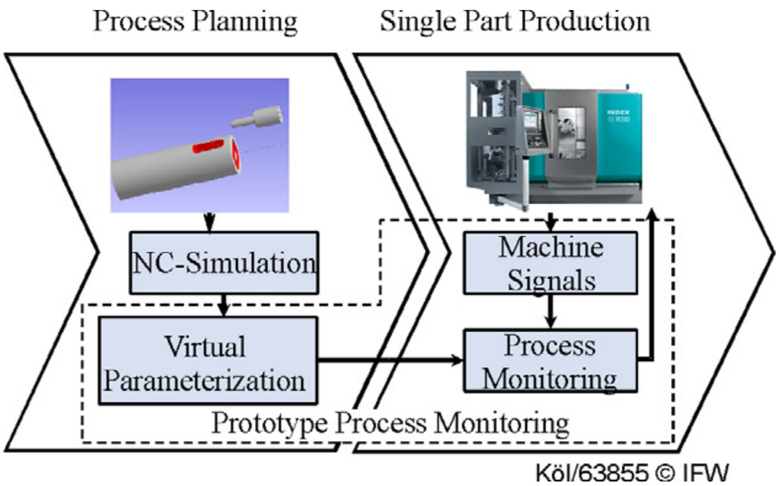

Fig. 1. Basic concept of teachless process monitoring

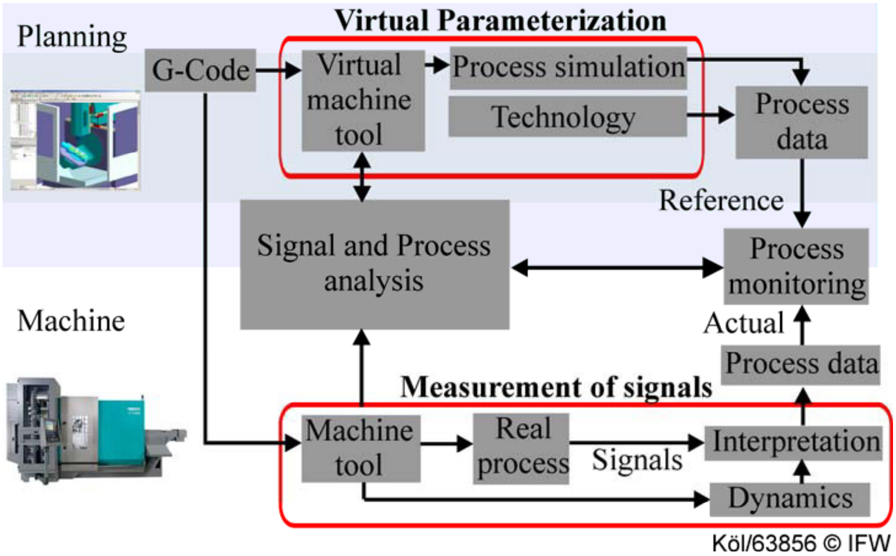

Fig. 2. Detailed concept of teachless process monitoring

The movement calculated from the axis position values for each simulation increment is the basis for calculating the material removal from one position to the next. Analyzing the material removal as pure cutting volume information in a first step gives process data for validating the approach for referencing process monitoring in this research. Further research will provide a model to generate signal-alike data based on geometrical tool engagement which is the technological part of the virtual parameterization (figure 2).

Traditional cutting force models are based on actual geometrical tool engagement. Hence, the tool engagement can give information about the actual state of the process which correlates with signals like spindle current. Thus a model based on tool engagement is able to generate signal-alike reference data for process monitoring.

To validate this concept of process simulation an analysis of first simulation results has been conducted. The results for a dexel-based model with varying dexel-density are presented in the following chapter. Dexel-based geometry models are in general able to give a volumetric description of a workpiece and calculate tool engagement for different applications, e. g. virtual prototyping [6, 7].

3. Simulation results

The first simulation test was made for a pocket milling process with a spiral inward to outward path. The tool movement was controlled by the simple NC-Controller of the process simulation as accuracy in timing of the tool movement was not necessary for this first validation. Within the simulation of material removal the removed material for each step of the simulation was calculated. For that purpose the following equation was used:

$$V_{cut} = \frac{d_y d_z \sum_{i=0}^{n_{cut,x}} l_{ix} + d_x d_z \sum_{j=0}^{n_{cut,y}} l_{jy} + d_x d_y \sum_{k=0}^{n_{cut,z}} l_{kz}}{3} \quad (1)$$

For each Cartesian direction the recently removed dexel are summed up and multiplied with a virtual volume based on the distance between those dexel. To get the cutting volume the mean value for three directions is calculated.

The dexel density as well as how many dexel are cut per increment makes a noticeable difference in the quality of simulation results (figure 3). Running the simulation with larger increments results in more dexel cut per increment. This leads to higher quality in the simulation result as the dexel-based calculation of the cutting volume is more precise the more dexel are cut within one increment. Hence, by choosing a density of the dexel fields that suits the increments of the simulated path significant simulation results for the calculated material removal are possible while maintaining a high quantity of information generated by the simulation.

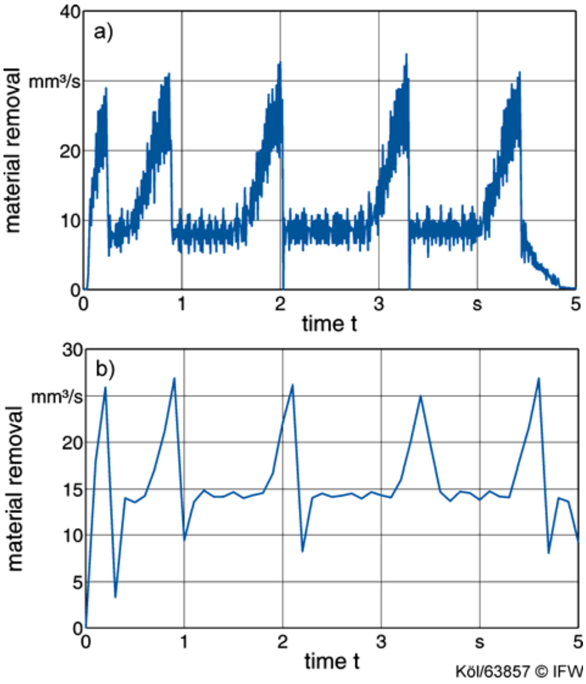

Fig. 3. (a) few dexel cut per increment; (b) few increments concludes to more dexel cut

4. Comparison with measured signals

To synchronize simulation results with measured results a different concept has been used. The path used for comparison is based on axis position data of the machine control. These measured axis positions for spiral pocket milling enables a time-scaled comparison of the measured spindle current during the roughing process with the simulated material removal (figure 4).

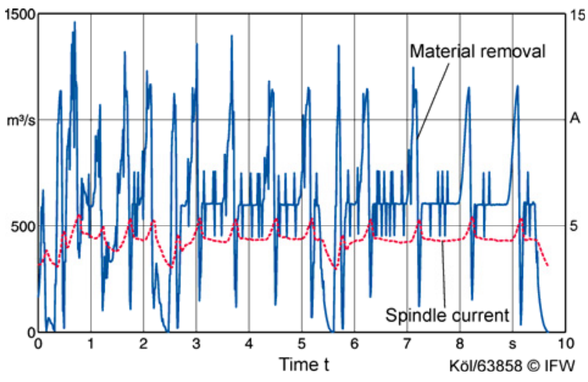

Fig. 4. Comparison of simulated material removal and measured spindle current

In this comparison the basic process characteristics are recognizable in the simulation of material removal and path direction change in the corners of the pockets is visible in both the simulated data as well as the measured data (figure 4).

One part of the measured signals and simulated data shows that the basic concept of teachless monitoring is able to generate eligible results. At the second change in path direction during roughing as illustrated here, there is an anomaly in the current signal. During a running process this could indicate some sort of process error, if there is no reference data to compare the measured signals with. In this test case the simulated material removal gives a similar anomaly at that segment with linear movement. Hence, the anomaly in the signal is not based on an error of the process but on a change of tool engagement during the process (figure 5). This illustrates the basic principle of referencing a process monitoring by simulation.

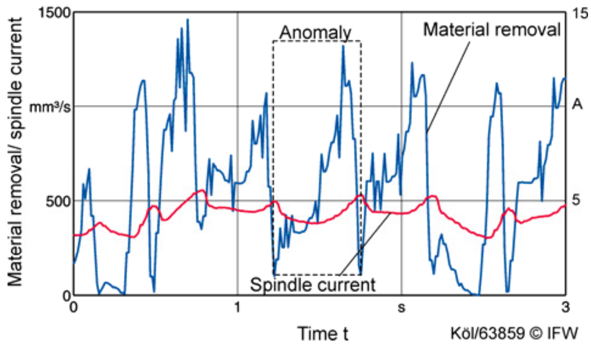

Fig. 5. Local anomaly in current signal is represented in simulated reference data

5. Path data from virtual machine tool

The concept of using axis-position data generated by a virtual machine tool developed and parameterized by the machine tool's manufacturer was tested with a milling reference process on a turning-milling center. The path for the simulation of material removal was interpreted by the control-based axis position of the virtual machine tool simulation. Hence, the tool engagement and thereby the incrementally removed material could be calculated (figure 6).

The process characteristic for a roughing operation is clearly recognizable. For analyzing the plunging operation the dexel should be set denser than in the first experiment as the quality of simulation results for this operation is still comparably low and thus not sufficient to reference process monitoring.

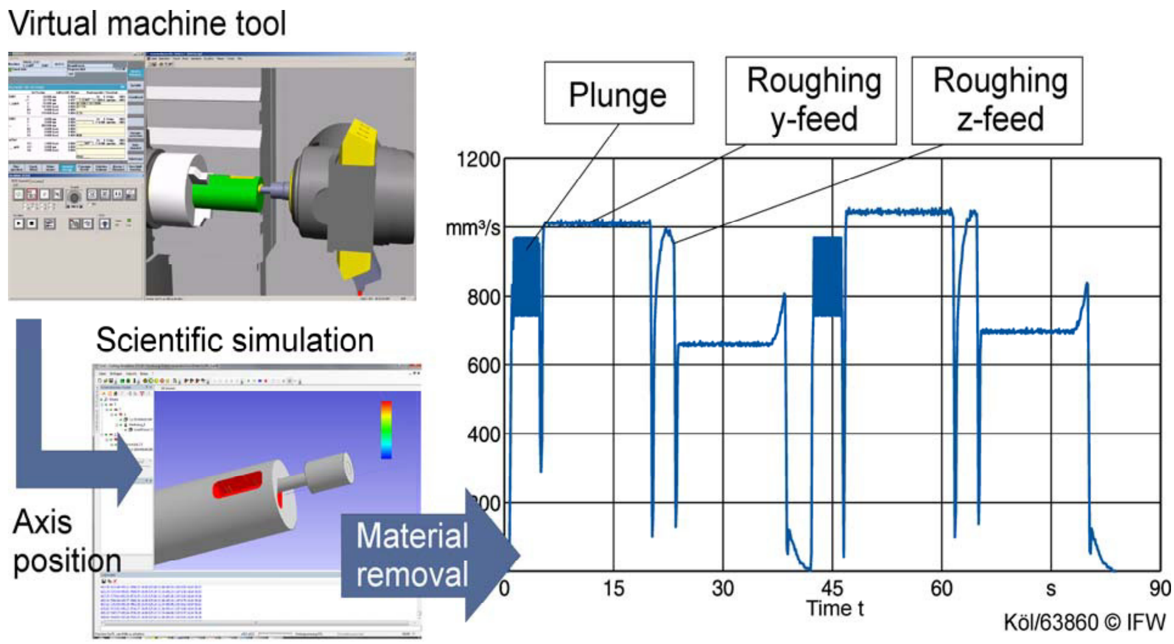

Fig. 6. Path-based material removal simulation from axis position of virtual machine tool

6. Conclusion and further research

Within this paper a concept for teachless referencing of process monitoring by a simulation of material removal has been explained. First simulation and measurement results show that the basic concept is suitable to generate reference data for process monitoring.

For an application of this concept extended analysis of tool engagement in turning operations will be necessary. Thus additional research in finding material removal models suitable for turning processes will be accomplished. Additionally a model has to be researched to generate signal-alike data based on tool engagement. Furthermore a process monitoring system, which combines different machine signals for information about process conditions as well as definition of critical process states, has to be developed to create a functional teachless process monitoring. Thus the aim to generate reference process data and decrease simulation inaccuracies can be accomplished within this research project.

Further research will focus on the data acquisition to receive actual process sensitive signals in high quality. Hence, control internal signals and working space externally measured signals in combination with reconstruction methods to filter the drive dynamics are investigated.

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References

[1] Byrne, G., Dornfeld, D., Inasaki, I., Ketteler, G., König,, W., Teti, R., 1995. Tool Condition Monitoring (TCM) - The Status of Research and Industrial Application, CIRP Annals - Manufacturing Technology, 44, 1995, p. 541.

[2] Teti, R., Jemielniak, K., O’Donnell, G., Dornfeld, D., 2010. Andvanced monitoring of machining operations, CIRP Annals – Manufacturing Technology, 59, 2010, p. 717.

[3] Byrne, G., Dornfeld, D., Denkena, B., 2003. Advancing Cutting Technology, CIRP Annals - Manufacturing Technology, 52, 2003, p. 483.

[4] Reuber, M., 2001. Prozessüberwachung beim Schlichtfräsen von Freiformflächen, Dr.-Ing. Dissertation, RWTH Aachen, Shaker Verlag, 2001.

[5] Brecher, C., Rudolf, T., 2009. Adaptive logging module for monitoring applications using control internal digital drive signals, Production Engineering Research and Development 3, 2009, p. 305.
[6] Ren, Y., Lai-Yuen, S.K., Lee, Y.-S., 2006. Virtual prototyping and manufacturing planning by using tri-dexel models and haptic force feedback, Virtual and Physical Prototyping, 1:1, 2006, p. 3.
[7] Denkena, B., Böß, V., 2009. "Technological NC Simulation for Grinding and Cutting Processes Using CutS," Proceedings of the 12th CIRP Conference on Modelling of Machining Operations, Volume II, May 7-8, 2009, Donostia-San Sebastián, Spain, p. 563.