# Teachless Process Monitoring for Single Part Production

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**Summary**: For automated batch production with machine tools process monitoring is essential to secure process stability and quality of the product. Referencing the monitoring usually happens during ramp-up of the process by measuring different signals of the machine. In order to provide process monitoring for single part production, reference data has to be generated without having a chance to teach the monitoring with real process data. A way to circumvent this is to use a process simulation of material removal to reference process monitoring. This approach enables calculation of signal-alike reference data based on the NC-path for a workpiece. Hence an autonomous control for manufacturing single parts is possible.

This paper describes a concept to generate reference data for process monitoring via a way-based simulation of the process. For this purpose a method to use a control and machine-based simulation coupled with a dexel-based simulation of material removal is described. The comparison of results of the simulation with measured signals of a real process gives a first validation of the basic concept.

**Keywords: Machine Tool, Monitoring, Simulation, Material Removal.**

## 1. General

Process Monitoring is in many cases used for batch production on machine tools to ensure process stability and availability of production facilities [1, 2, 3]. In general the design of process monitoring systems is classified in data acquisition, signal processing and decision-making [4]. Besides the application of additional sensors internal signal sources of the machine tool are used for data acquisition due to low costs, robustness and high reliability [5]. For an application of tool wear monitoring internal digital drive signals are suitable [6].

Signal based methods of monitoring have to fit the regarding process and require a preceding teaching phase. Hence, this methods can be effectively used only in batch production [7]. If there is only a single part production, teaching phase has to be substituted as well as referencing the process monitoring is not possible. Furthermore there are no existing methods to parameterize a process monitoring for single part manufacturing with reasonable effort.

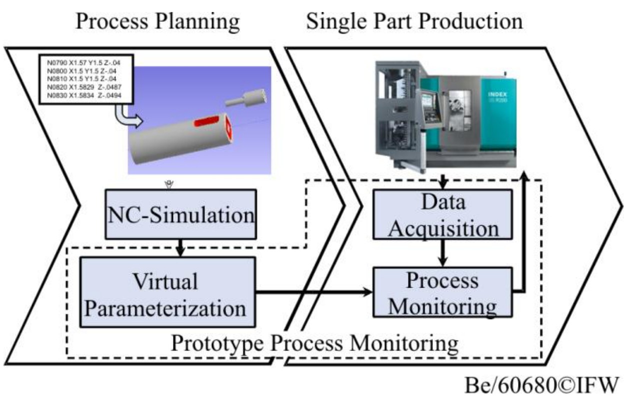



**Figure 1**. Teachless process monitoring for single part production.

To surpass this, referencing of the process can be done by a process simulation. By that a stable and secure process can be accomplished for single part manufacturing.

At the IFW a method is researched to combine process simulation for referencing and signal-based process monitoring to enable teachless process monitoring for single part production (figure 1). A way-based simulation of material removal in combination with a NC-based virtual machine model is used to generate knowledge about basic process characteristics and process data. By that, data in correlation to the signals measured by the monitoring system can be generated. These include specific limits for process monitoring and error characteristics. To increase the robustness and acceptance in industrial manufacturing control internal and working space externally sensor signals are used for data acquisition. Methods for robust reconstruction of the process characteristics are used in further research to increase the quality of these signal sources.

Below the basic concept of this approach and first results are presented.

## 2. Concept

Focus of this research is on way-based simulation of material removal. Common practice in material removal simulation is to use a virtual NC-controller for generating an incremental tool path. This approach does not cover specific limitations and characteristics of machine control and machine dynamics. Virtual machine tools like “Vericut” or machine tool manufacturer’s machine simulation nowadays are able to emulate machine control and machine specific characteristics. Hence the NC-based path generated by those tools gives precise way-based data of tool position. That kind of NC-based simulation realizes a geometry-based, control-based and time-based approach of process simulation but neglects many technological aspects of material removal.

Integration of the tool and axis position within a scientific simulation of material removal offers the possibility to calculate referencing data for process monitoring (figure 2). By that a synchronization of simulation and process monitoring can be established in further research.

The concept of coupling the data from simulation of material removal and process monitoring includes comparing reference data of the simulation and signal-based data of monitoring. This data is basically in correlation to process forces and enables recognition of process errors. In a first step process characteristics are identified in the way-based simulation which can be used during the process to trigger different states of process monitoring. For example in a pocket milling process path length of roughing process, plunging and changes in depth of cut are recognizable in the simulation results.

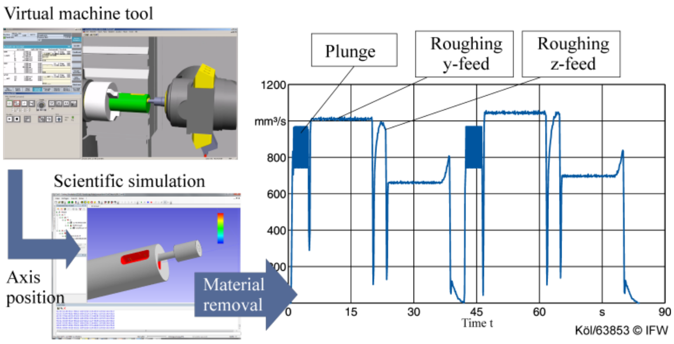
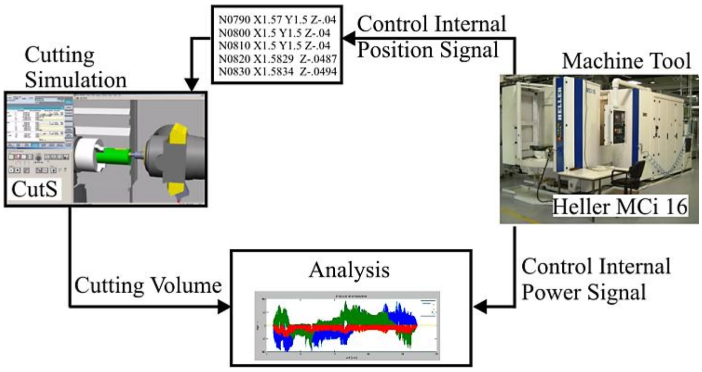



**Figure 2.** Simulation of material removal based on axis position.

In a second step the raw simulation data can be calculated to generate values correlated to signals that can be measured during the process by monitoring systems. For that a model based on the type of material removal simulation is necessary. First results in process simulation have been established by using a dexel-based approach within the simulation tool “CutS” developed at the IFW [8]. This works well for simulation of milling processes. The final process to evaluate the results of this approach will be a combined milling and lathing process. Especially the simulation of lathing processes can create challenges in simulating material removal via a dexel based model. This is due to the necessity to either rotate the dexels or simulate the tool rotating around the workpiece in small increments which will cause variances in the calculated material removal rate. This will be looked at in further research.

## 3. Measurement results

A first comparison of simulated material removal and measured signal gives a basic idea of the monitoring concept (figure 3). The path used in the simulation is based on axis position data measured on machine control during the roughing process. Due to inconsistencies in the data output of axis positions there are errors in material removal that lead to simulation increments with no removal directly followed by an increment with double removal rate while the measured feed rate is constant. Nevertheless 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).




| | |
|---|---|
| Machine Tool | Heller MCi 16 |
| Process | Pocket Milling |
| Spindle Speed | n = 10.000 $min^{-1}$ |
| Feed | f = 1500 mm/min |
| Cutting Depth | $a_P$ = 10 mm |
| Milling Tool | Solid Carbide (D = 6 mm; z = 2) |

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**Figure 3.** Test setup.

In this pocket milling process the change of the feed direction is recognizable as well as the duration of straight path segments. This duration recognizably increases if a circular center to edge strategy is used. Hence further research can establish a way-based simulation of material removal to correlate with measured signals of a production process on a machine tool.

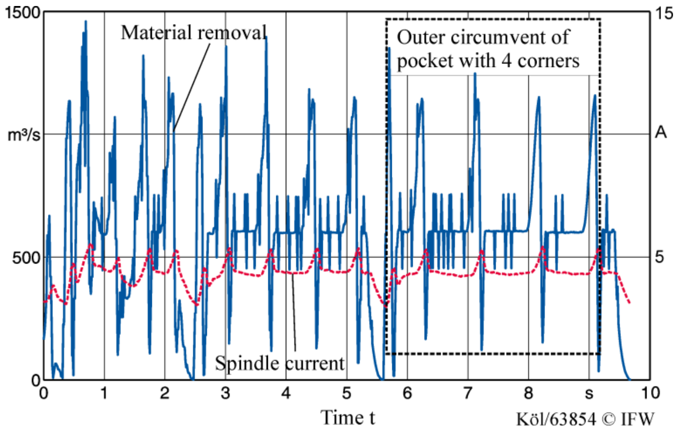


**Figure 4.** Simulation of material removal and signal of spindle current.

In detail the comparison of measured signals and simulated data verifies that the basic concept of teachless monitoring is able to generate eligible results. During the roughing process as illustrated here, there is an anomaly in the current signal. An anomaly like that could indicate some sort of process error. In this case, reference data to compare the measured signals with is necessary to decide whether to stop, change or continue the process. With the simulated material removal a similar anomaly at that same segment with linear movement can be identified (figure 5). 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. This illustrates the basic principle of referencing the process monitoring with simulation data.

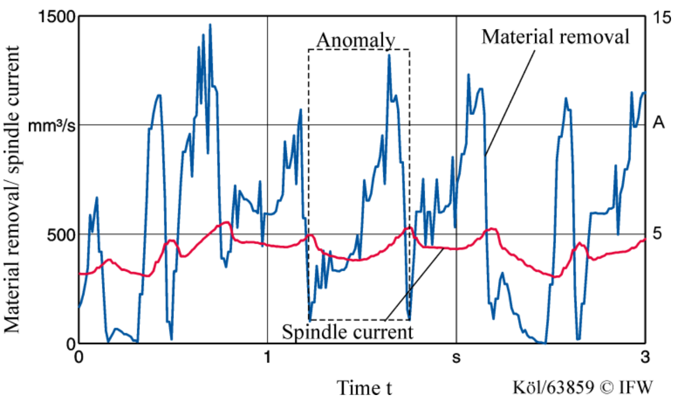


**Figure 5.** Anomaly in measured signals is represented by simulation data.

### 3. Conclusion and further research

In this presented research a way-based material removal simulation of pocket milling process is accomplished with NC-code-based as well as measured axis position data and compared with control internal spindle current signals to test the approach for teachless process monitoring in single part production. On the basis of the used dexel-based model different process characteristics are clearly visible. With the given time and way synchronicity the simulated material removal and the measured power signals are well correlating.

In further research different simulation models for material removal will be investigated for extended analysis of material removal. The aim is to generate reference process factors as well as to decrease simulation-based inaccuracies. Therefore milling and lathing processes will be simulated. Further researches focus on the data acquisition to receive actual process sensitive signals in high quality. Next to control internal signals working space externally in combination with reconstruction methods to filter the drive dynamics are investigated. The detailed concept for further research is shown in figure 6.

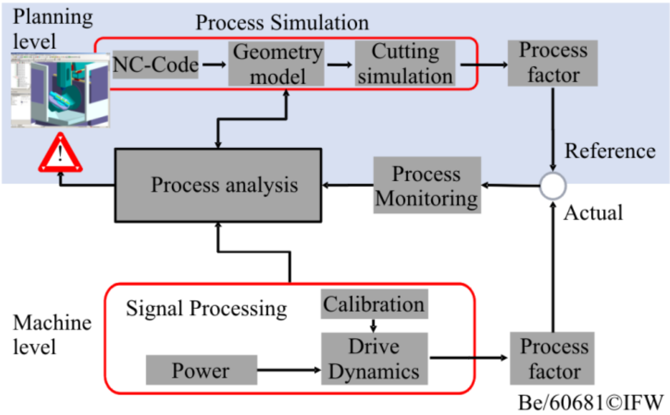


**Figure 6.** Detailed concept for further research.

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