Systematic Analysis and Identification of 5-Axis Machining Accuracy

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Abstract

Within this paper an approach will be discussed that capacitates a time reduced method for accuracy identification of 5-axis machines. Based on machine models sensitivity analyses are performed to identify the impact of single axis errors. In combination with a simple measurement procedure the amount of superior axis errors can be estimated. Also the overall accuracy can be identified using this procedure.

1 Introduction

The metrological identification of geometrical axis errors of 5-axis machines still necessitates huge time as well as device related efforts [1]. Consequently the aim is to reduce efforts by identifying metrologically only the superior axis errors. Here superior error means that this error impacts the overall machining accuracy significantly more than others. Besides, in most cases the operator just wants to get quick information about the overall accuracy to decide if more detailed measures are needed. In the following systematic sensitivity analyses of error budgets will be presented. Based on this a metrological procedure will be discussed that capacitates the estimation of the superior errors and the fast identification of the overall accuracy.

2 5-axis machine model

The basis for the sensitivity analyses is a flexible mathematical machine model, which can be adapted to different 5-axis machine types (different axis configurations) [2]. The model represents the transformation of the single axis errors on the overall machining accuracy in consideration of given tool paths. A software tool has been implemented that creates the machine models automatically by entering the axis configuration as well as the relevant geometric and kinematic parameters. Errors are represented according to known standards [3] [4].

3 Sensitivity analyses

To identify the theoretical impact of each single axis error on the overall machining accuracy sensitivity analyses are carried out by two different procedures. The first one is a numerical simulation; the second one is a mathematical differentiation. The results of both procedures correspond, but the use case is different.

3.1 Simulation

For the simulation nominal tool paths and exemplary error data are entered into the model. These paths ensure that all axes will be moved and the complete axes ranges will be considered. The model outputs the relative deviations between nominal and real (due to errors) paths. The simulation is run several times: Each time one error has a constant value and all other errors are zero. Hereby the influence of single errors can be analysed individually. Afterwards the maximum deviation will be identified and normalized to represent the error impact independent of the given error value. The simulation will be done for specific machines. Figure 2 shows that the impact of each single error depends on the axis configuration as well as on the machine size.

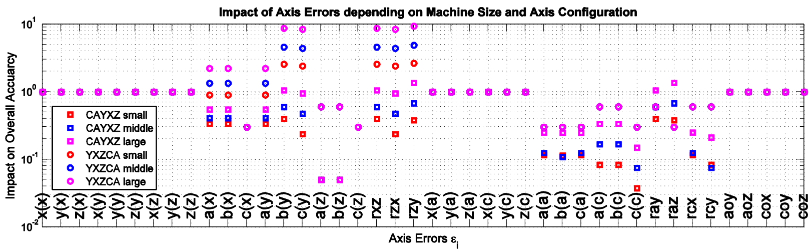

Figure 2: Impact factors of axis errors for different machines (CAYXZ, YXZCA)

3.2 Mathematical differentiation

Within the mathematical differentiation [5] the machine model will be differentiated with respect to the single axis errors by using the Nabla operator according to

$$\vec{\nabla}\delta(x,y,z,a,c,\varepsilon_i,g_j)=\left(\frac{\partial\delta(x,y,z,a,c,\varepsilon_i,g_j)}{\partial\varepsilon_1},\ldots,\frac{\partial\delta(x,y,z,a,c,\varepsilon_i,g_j)}{\partial\varepsilon_n}\right)^T \quad (1)$$

Here δ represents the model, ε_i the single axis errors and g_i the geometrical machine properties. Based on this differentiation the impact of each error depending on specific geometrical properties can be analysed very detailed. As an example figure 3 represents the impact of the A-axis tumbling error of a CAYXZ configuration separated in x-, y- and z-direction depending on the work piece size as well as the position of the C-axis within the machine coordinate system.

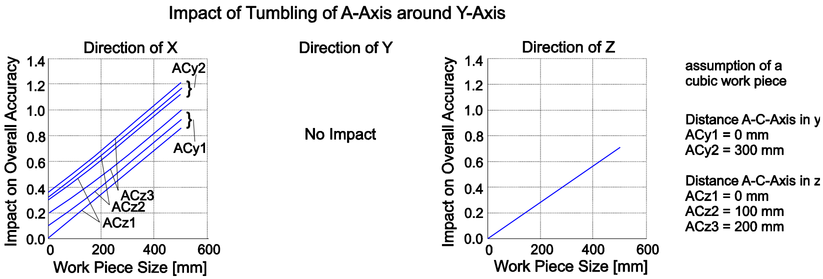

Figure 3: Impact of the A-axis tumbling error of a CAYXZ configuration

4 Concept for fast estimation of geometrical errors

By inverting the 5-axis machine model algorithms can be derived to identify single axis errors based on measured 3D deviations. This requires sufficient measurement data. Suitable metrology devices and procedures were already analysed [6] [7]. The concept taken goes beyond these approaches and considers particularly the results of the sensitivity analysis in order to identify superior axis errors. Figure 4 shows some sections of the focussed measurement concept for a CAYXZ configuration using the 'Chase the Ball' [7] approach. Complete procedure will take around 60 minutes.

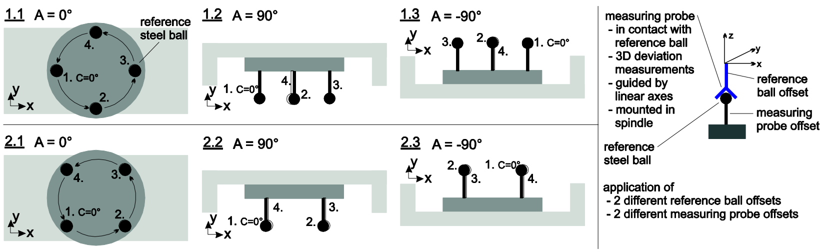

Figure 4: Metrological procedure for error estimation of a CAYXZ configuration

5 Metrological identification of overall machining accuracy

Using the described metrological procedure the identification of the overall machining accuracy is also feasible. Basic approaches were already discussed [8]. By moving all five axes combined along its ranges the captured deviation data contains the impact of all errors in terms of a superposed deviation value. The overall machining accuracy can be identified by determining the maximum value. The practical performance of the testing procedures takes about 20 minutes. Figure 5 shows practical application using the ‘R-Test’ and ‘Double Ball Bar’.

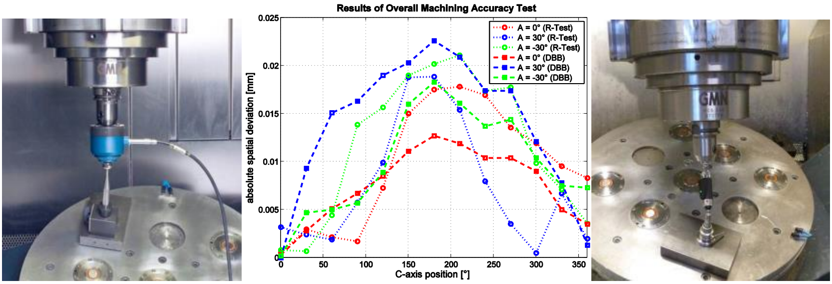

Figure 5: Identification of overall 5-axis machining accuracy

6 Conclusion and Outlook

Superior axis errors depending on axis configuration and machine size can be identified systematically by the described procedure. For the fast estimation of error values a simple measurement approach was presented that also capacitates the quick identification of the overall 5-axis machining accuracy. In next steps the machine models will be inverted to realise the mathematical evaluation algorithms for the error estimation. Later the consideration of thermal influences [9] will be focussed.

Acknowledgement

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