

## MEASURING THE ACCURACY OF PRODUCING FREE-FORM SURFACES WITH THE USE OF THE COORDINATE MEASURING METHOD

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**Abstract:** The present paper presents a method of determining errors in processing complex-shape surfaces produced with the use of a CNC machine tool. In order to achieve this, the whole process of making a three-dimensional object was performed, from creating a CAD model to generating a processing programme for a CNC machine tool and producing the actual object. The obtained surface was measured with a Brown & Sharpe Mistral coordinate measuring machine with the use of a Renishaw TP200 measuring probe.

### 1. INTRODUCTION

Nowadays, expectations concerning the quality and accuracy of producing goods are higher and higher, which makes different companies invest in research aiming at increasing these aspects of a production process more and more often. Additionally, because of a rapid growth in computer science, the possibilities of generating and actually producing complex geometry surfaces have increased substantially (Choi et al., 2007; Surazhsky et al., 2001). Some three-dimensional objects are of such complex shapes that measuring them with the use of conventional measuring methods is inefficient or even impossible, and that is why more advanced measuring methods need to be applied in accuracy inspection (Ainsworth et al., 2000). One of these methods is undoubtedly the coordinate measuring method which is especially widely used in the automotive, aircraft, or shipbuilding industries, e.g. in producing injection moulds (Weckenmann et al., 2001).

Due to the fact that coordinate measuring machines are more and more popular, it is necessary to develop the right methods of accuracy inspection of produced objects, especially in the case of objects described with complex-shape surfaces (Cheung et al., 2007; Li et al., 2004). Such measurements may be performed with the use of the surface scanning method on the basis of an already existing CAD model.

### 2. DESCRIPTION OF THE TEST STAND AND PREPARATIONS FOR MEASURING

The test stand (Fig. 1), in which the process of determining the errors in processing the shape object was performed, consists of the following elements:

- a Hartford OMNIS1020 milling centre, in which the object under research was produced;
- a DEA (Brown & Sharpe) MISTRAL coordinate measuring machine – used for measuring the accuracy of the obtained surface;

- a PC class computer integrated with a machine tool and a coordinate measuring machine;
- SolidWorks, MasterCAM, PC DMIS CAD++ software.

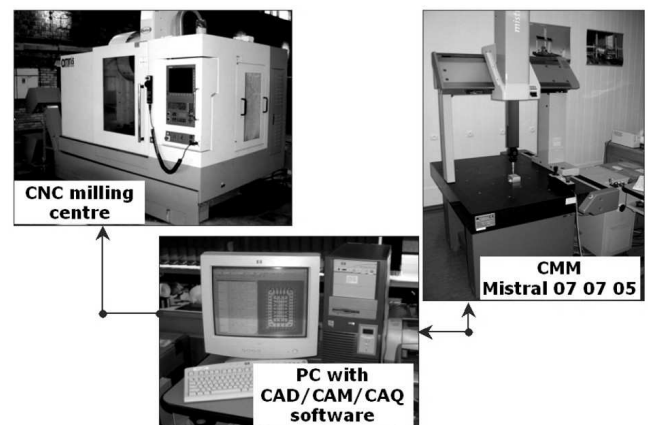
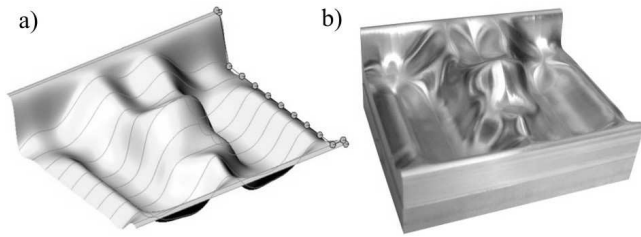


Fig. 1. The test stand

The list below is the order of preparations for measuring:

- creating a geometric model of a complex-shape object in a CAD system (Fig. 2a);
- generating a processing programme for a CNC machine tool – the obtained surface patch was saved in the IGES (\*.igs) format and then imported to the MasterCAM system. Using this software, the surfaces to be processed were indicated, and the parameters necessary for carrying out the production process were defined. The final stage of the experiment performed in this system was generating by the postprocessor a processing programme ‘understandable’ to the control system of the given machine tool (the iTNC 530 Heidenhain control system in this case);
- producing the object with a CNC machine tool – the machining was performed with the OMNIS 1020 milling centre with the use of a ball nose end mill of 12 mm in diameter (Fig. 2b).

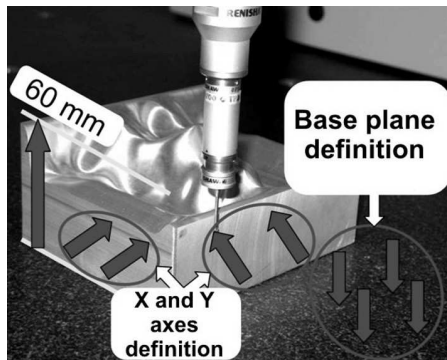


**Fig. 2.** Free surface: a) surface model, b) actual object

After that, the produced object underwent control measuring with a Mistral 07 07 05 coordinate measuring machine.

### 3. MEASURING THE ACCURACY OF FREE SURFACE PRODUCTION

The measuring was performed with a Brown & Sharpe MISTRAL coordinate measuring machine with the use of the PC DMIS CAD++3.6 software into which the model in the form of an IGES file had been imported from the MasterCAM system. A TP200 Renishaw measuring probe equipped with a measuring ball tip with an end of 2 mm in diameter was applied in the process of measuring.



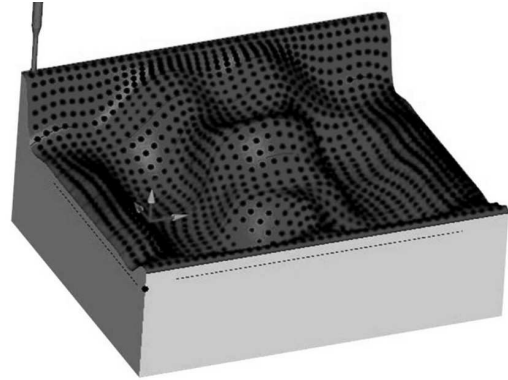
**Fig. 3.** Defining the measured object location in the machine measuring space

In order to perform the experiment, the measuring head had to be defined and calibrated with the use of a calibration ball. After the calibration was finished, the location of the element in the measuring space of the machine was defined (Fig. 3). The characteristic points of the object were selected in the manual control mode. This was the basis on which the coordinate system of the measured object was defined.

Additional attention shall be paid to the fact that the imported CAD model has its own coordinate system and for this reason it was necessary to transfer it to the coordinate system of the measured object, defined in the measuring space.

At the next stage of the experiment, in order to determine the accuracy of producing the shape surface of the processed object, the scanning (patch) method in the so-called UV Scan (offered by PC-DMIS software) mode was applied. This mode includes scanning a surface patch,

which results in obtaining the contact points of the measuring ball tip end and the measured object. The U and V symbols indicate the surface patch parameterisation directions (Piegl et al., 1997). Thus, in selecting the surface, the number of measurement points in the U and V directions has to be defined (in this case  $U=40$ ,  $V=35$ , so measuring at 1400 points was performed accordingly) (Fig. 4).



**Fig. 4.** Location of measurement points on the shape surface

### 4. PROCESSING THE OBTAINED MEASUREMENT RESULTS

In order for the accuracy of producing a free surface of the researched object to be established, the distances between the points located on the surface of the CAD model and the corresponding points obtained in the result of measuring with a coordinate machine have to be determined. The input data for determining processing errors comprises the measurement points coordinates and their corresponding nominal points (from the CAD model). This data might be obtained in two ways:

- through selecting the coordinates from the report generated in the form of a text file by the control software steering the coordinate measuring machine; or
- through generating text files with ready-to-use coordinates of the measurement and nominal points. In this case, the data in the form of an IGES file shall be imported to the do MasterCAM software (into which the modelled surface had previously been input) and these points shall subsequently be projected in the direction normal to the surface (Fig. 5). In this way, the coordinates of the nominal points are obtained.

Obtaining the data makes it possible to calculate the distances between the measurement and the expected (nominal) points. To that end, the error components in each of the three X, Y and Z axes respectively shall first be determined on the basis of the formulae below (Ainsworth et al., 2000):

$$\delta_{xi} = X_{Ri} - X_{Ni} \quad (1)$$

$$\delta_{yi} = Y_{Ri} - Y_{Ni} \quad (2)$$

$$\delta_{zi} = Z_{Ri} - Z_{Ni} \quad (3)$$

where:  $\delta_{xi}$ ,  $\delta_{yi}$ ,  $\delta_{zi}$  – error components in the respective axes;  $X_{Ri}$ ,  $Y_{Ri}$ ,  $Z_{Ri}$  – coordinates of actual points obtained during measuring;  $X_{Ni}$ ,  $Y_{Ni}$ ,  $Z_{Ni}$  – coordinates of nominal points

located on the geometric model surface, corresponding to the measurement points.

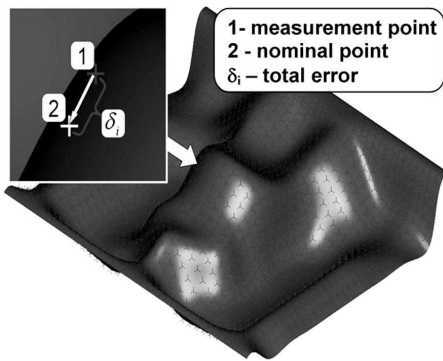


Fig. 5. Projecting the measurement points in the direction  $\delta_i$  normal to the surface

Applying the above components lets us determine the  $\delta_i$  accumulated errors in producing a free surface at the respective measurement points:

$$\delta_i = \sqrt{\delta_{xi}^2 + \delta_{yi}^2 + \delta_{zi}^2} \quad (4)$$

where:  $\delta_i$  – processing accumulated error at a point (Fig. 6)

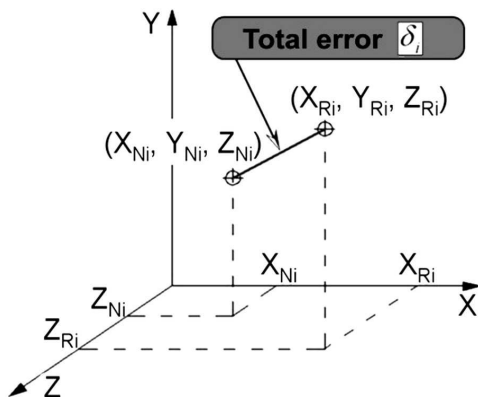


Fig. 6. Graphical interpretation of a  $\delta_i$  processing accumulated error

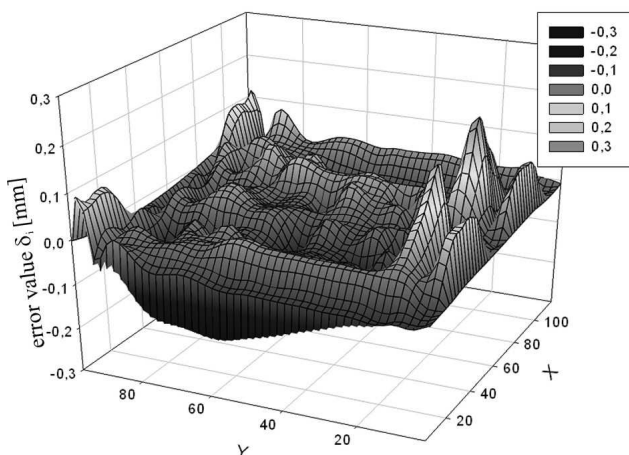


Fig. 7. Error values plot for producing a free surface

On the basis of these errors, a plot presenting the error values at the respective points may be created (Fig. 7).

The plot illustrates errors at 1400 measured points. It can be seen that the inaccuracy of surface producing is significant (max.  $\delta_i = 0,207$  mm). After an initial analysis it is possible to quickly locate the point where the errors occur. The reasons for the errors might have been, among others, shape errors of the machining tool. The obtained processing errors plot may be used in reshaping the geometric model of the object. Such reshaping serves to correct the occurring production errors as well as to generate the corrected processing programme for a numerically controlled milling machine.

## 5. SUMMARY

The present paper describes a method of inspecting the accuracy of producing a complex-shape surface made with the use of a numerically controlled machine tool. The presented method, owing to applying a modern coordinate technique, makes it possible to quickly inspect the accuracy in the process of object producing. On the basis of the measurement results, the values of errors and their locations may be determined. Such information enables us to take some action in order to minimise the occurring inaccuracy. This aim may be achieved for example through reshaping the geometric model of the object and re-generating the CNC machine tool control programme.

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