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MACHINING ERROR SOURCES CLASIFICATION FOR MACHINE TOOLS

BY

TEODOR EMIL MIRCEA*

"Gheorghe Asachi" Technical University of Iaşi,
Faculty of Machine Manufacturing and Industrial Management

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Abstract. This paper proposes a clasification of the main types of machining errors by their impact on the accuracy of the machined part, difficulty to detect the error type in order to try to compensate it, type of error and main types of electrical measurement systems used to detect it. The structured way of presenting the main types of errors and their characteristics make this paper a usefull guideline for any reasearcher which studys one/multiple types of machining errors and their impact in production.

Key words: machining errors, measurement system, geometric errors, thermal errors, electrical measurement.

1. Introduction

The accuracy of machine tools is a factor which affects the quality of manufactured products and can be considered one of the most important considerations for any manufacturer. The performance of any machine tool is constrained by the errors built in the machine (e.g., assembly error) or occurring on a periodic basis on the account of different causes, like change in room temperature, external vibrations and cutting forces. A large number of studies

*Corresponding author; *e-mail:* teodormircea@yahoo.com

have been conducted to identify, predict and compensate these errors in order to improve machining accuracy.

This paper reviews these studies, identifies and classifies the main error sources in machining process and makes a classification of these sources in accordance with their influence on the part precision and difficulty of detecting the error type.

2. Machine Tool Accuracy and Errors Sources

2.1. Common General Error Sources

The accuracy of a machine can be formulated as the deviation in the path of the tool cutting tip in relation with the theoretically established path value, with specified tolerance.

The extent of this path deviation in a machine gives a measure of its accuracy. The accuracy is defined as the degree of conformance of a finished part with the imposed dimensional and geometrical specifications prescribed in the technical documentation.

Factors affecting the total volumetric accuracy of a machine tool and their relationships are given below in Figure 1 (inspired from (Ramesh *et al.*, 2000a) and (Samir & Tunde, 2012) and updated). These include four main sources of errors:

- Geometric errors;
- Thermal induced errors;
- Load (cutting forces) induced errors;
- Other types of errors.

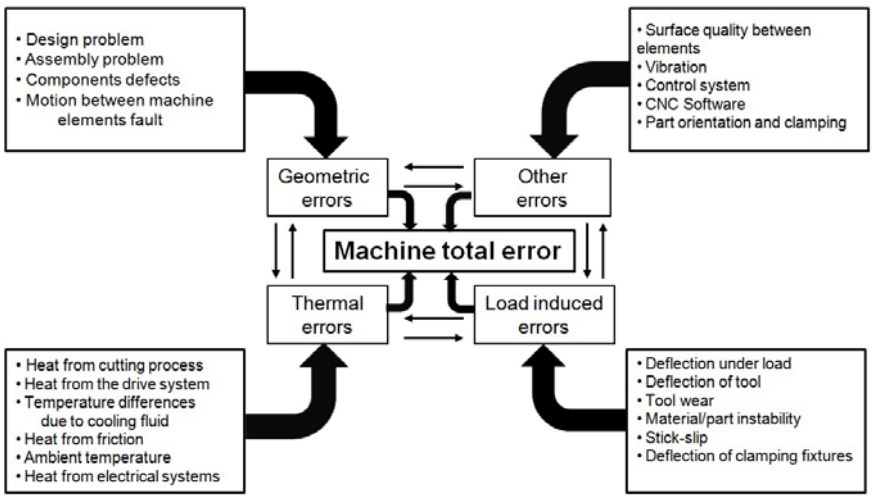

Fig. 1 − The main sources of machining errors and their interaction during a machining process.

2.2. Classification of Error Sources and Degree of Detection

Analyzing the various types of errors, their characteristics can be classified into systematic and random error as presented in Table 1.

Systematic errors are those errors that occur in the same way at every measurement and cannot be discovered by examining the result of measurements. Causes of systematic errors are usually known and can be predicted. They possess constant relative magnitude and constant sign and correction can be applied. Random errors, in comparison with systematic ones present some variability in both magnitude and sign (Slocum, 1992), and are affected by measurement system, variation in operating and environmental conditions, measurement procedure and technique. All main categories of errors in machine tools possess systematic and random components as shown in Table 1.

Table 1

Categories of machining errors, severity, detection ration, type of error and electrical measurement device used to detect

Geometric errors				
	Severity	**Difficulty to detect**	**Type of error**	**Device(s) for measurement**
Positioning errors	high	Easy	Systematic	CMM/Laser interferometer
Straightness errors	High	Easy	Systematic	CMM/Laser interferometer
Pitch angular error	Medium	Easy	Systematic	DBB/Laser interferometer
Roll angular error	Medium	Easy	Systematic	Laser interferometer/DBB
Yaw angular error	Medium	Easy	Systematic	DBB
Squareness error between two axes	High	Easy	Systematic	CMM/Laser interferometer/DBB
Reversal error	Medium	Medium	Systematic	-
Spindle radial deviation	Medium	Difficult	Systematic	CMM/DBB
Spindle axial deviation	Medium	Difficult	Systematic	CMM/Laser interferometer
Backlash errors	Medium	Medium	Radom	CMM/Laser interferometer/DBB
Contouring error of each axis	Medium	Easy	Radom	DBB

Hysteresis errors	Low	Difficult	Radom	-
Spindle axial play	Low	Difficult	Radom	CMM
Spindle radial play	Low	Difficult	Radom	CMM
Friction and stick slip motion errors	Low	Difficult	Radom	ZIGLER instruments
Inertia force error while braking/ accelerating	Low	Difficult	Radom	Accelerometer
Machine assembly errors	High	Easy	Radom	CMM/DBB/Laser interferometer
Thermal errors				
Spindle axial growth	High	Difficult	Systematic	CMM/Laser interferometer
Expansion of the lead screw drive	High	Difficult	Systematic	CMM/DBB
Expansion and bending of machine column	High	Difficult	Systematic	CMM/Laser interferometer/DBB
Expansion and bending of machine base	High	Difficult	Systematic	CMM/Laser interferometer/DBB
Spindle radial growth	Low	Difficult	Random	CMM/Laser interferometer
Spindle thermal deflection	Medium	Difficult	Random	CMM/Laser interferometer/DBB
Machined part thermal deflection	High	Difficult	Random	CMM/Laser interferometer
Thermal distortion	High	Difficult	Random	CMM/Laser interferometer/DBB

Load induced errors				
Elastic deflections of part/machine subassemblies	High	Medium	Systematic	CMM/Laser interferometer
Tool wear	Low	Medium	Systematic	CMM/Laser interferometer
Spindle elastic deflection	High	Difficult	Systematic	Tensometric captor/tensometric marks
Vibration	Medium	Difficult	Random	Accelerometer/Vibrometer
Material instability	Medium	Difficult	Random	-
Other errors				
Axes offset errors	High	Easy	Systematic	CMM/Laser interferometer/DBB
Workpiece slippage	Medium	Easy	Random	CMM/Laser interferometer
Workpiece fixturing deformation	Medium	Difficult	Random	Laser interferometer
Mismatch of position	medium	Medium	Systematic	CMM/Laser interferometer/DBB
Instrumentation errors	low	Difficult	Systematic/ Random	-
Servo errors	medium	Difficult	Random	-
Interpolation errors	medium	Difficult	Random	Laser interferometer/DBB

The systematic errors can be easily and permanently compensated by using corrective actions as calibration techniques.

Unfortunately, random errors cannot be permanently compensated due to their random characteristic. They show variations such as amplitude, frequency, static and dynamic response. Thus, it is difficult to model and predict them, thus it is difficult to ensure a precise machining process and a precise semi-finished/finished machined product.

3. Conclusions

While any type of machining error creates at least an interaction with at least another type of machining error, it is important to know the severity and way of presence of each error. This way, it is much easy to choose the right measuring equipment to detect the magnitude of machining error and also to be able to take corrective measures during the machining process but also in advance.

Using the structured table containing the classification of machining errors, presented into this paper and constructed using previous works of other authors but also completed and extended by the present authors of this paper, it is much easy to analyze a machining process performance and judge the severity of its deviations.

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CLASIFICAREA ERORILOR DE PRELUCRARE ALE MAŞINILOR-UNELTE

(Rezumat)

Lucrarea de faţă prezintă, într-un mod sistematizat, principalele tipuri de erori de prelucrare pe maşini-unelte, impactul acestora asupra preciziei semifabricatului prelucrat, modul de manifestare şi mijlocul de măsurare electric utilizat pentru detectarea fiecărei erori in parte. Modul grupat, sub forma tabelară, de prezentare ale celor menţionate mai sus face ca această lucrare să fie un ghid util pentru orice cercetător ce activează în domeniul analizei erorilor de prelucrare ale maşinilor-unelte.