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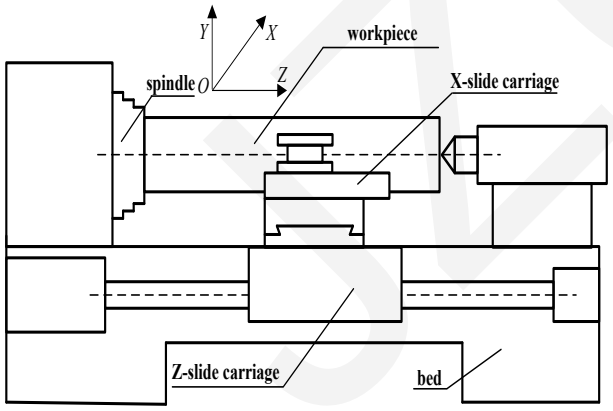
The Effects of Geometric and Spindle Errors on the Quality of End Turning Surface

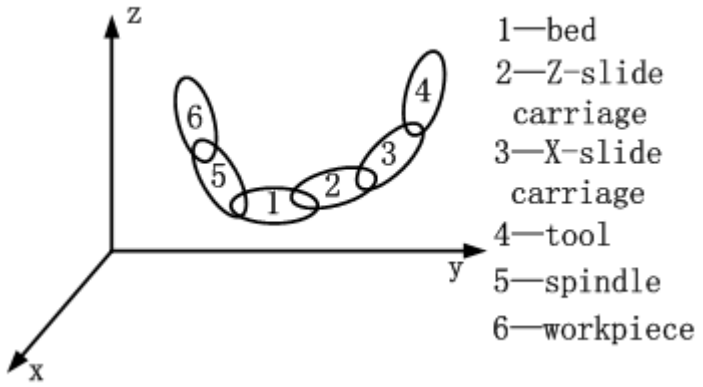
Key words: Surface quality, Geometric errors, Spindle errors, Homogeneous transformation matrix (HTM), Principal component analysis (PCA), End turning surface

Details in errors analysis are discussed under following sections:

- Integrated Volumetric Errors Model
- Homogeneous transformation matrix(HTM)
- Surface Topography Model of End Turning
- Simulation Experiments and Numerical Analysis
- Methods to find the principal volumetric error components



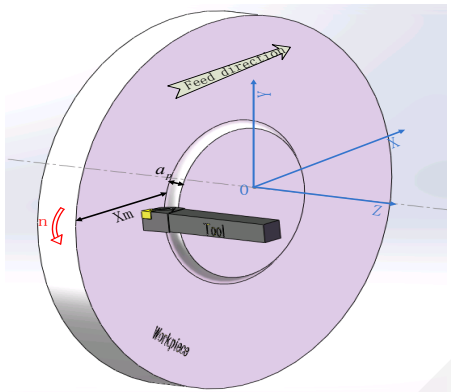
Lathe structure



Topology of lathe

Integrated Volumetric Errors Model of Lathe

An integrated error model for lathe based on rigid body kinematics and homogeneous transformation matrix (HTM) was developed.



Turning process

Table 1 Geometric error components of lathe*

Error type	Axis X	Axis Z	Spindle
Displacement error	$\delta_x(x)$	$\delta_x(z)$	$\delta_x(\theta)$
	$\delta_y(x)$	$\delta_y(z)$	$\delta_y(\theta)$
	$\delta_z(x)$	$\delta_z(z)$	$\delta_z(\theta)$
Angular error	$\varepsilon_x(x)$	$\varepsilon_x(z)$	$\varepsilon_x(\theta)$
	$\varepsilon_y(x)$	$\varepsilon_y(z)$	$\varepsilon_y(\theta)$
	$\varepsilon_z(x)$	$\varepsilon_z(z)$	$\varepsilon_z(\theta)$
Squareness error		η_{xz}	

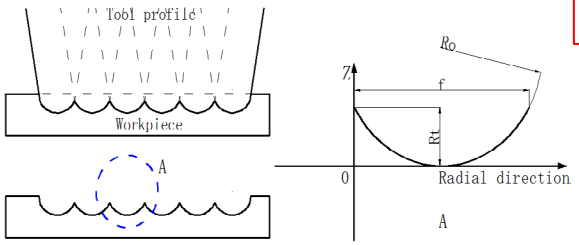
$$\begin{cases} \Delta x = [\delta_x(x)+\delta_x(z)]\cos\theta + [(x-R)\varepsilon_z(z)+\delta_y(x)+\delta_y(z)]\sin\theta \\ \qquad\quad -\delta_x(\theta)\cos\theta - \delta_y(\theta)\sin\theta \\ \Delta y = -[\delta_x(x)+\delta_x(z)]\sin\theta + [(x-R)\varepsilon_z(z)+\delta_y(x)+\delta_y(z)]\cos\theta \\ \qquad\quad +\delta_x(\theta)\sin\theta - \delta_y(\theta)\cos\theta \\ \Delta z = (x-R)\varepsilon_y(\theta) - (x-R)\varepsilon_y(z) + \delta_z(x) - x\eta_{xz} + \delta_z(z) - \delta_z(\theta) \end{cases}$$

Integrated Volumetric Errors Model of Lathe

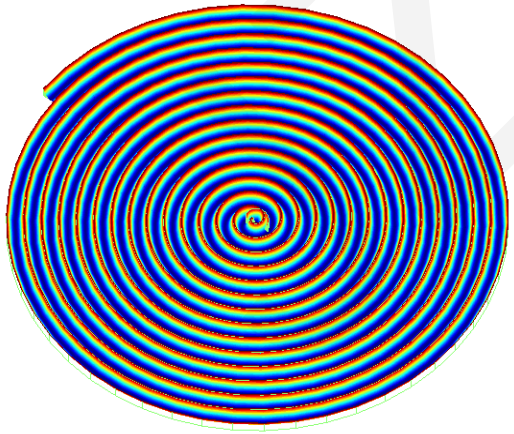
Surface Topography Model of End Turning

The ideal model without considering the effect of volumetric errors is established first. Then by mapping machine errors onto the ideal surface, an complete end turning surface topography model is presented.

Ideal surface

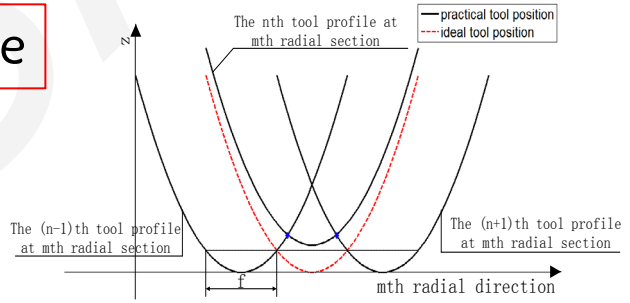


Ideal turning surface profile in the radial direction

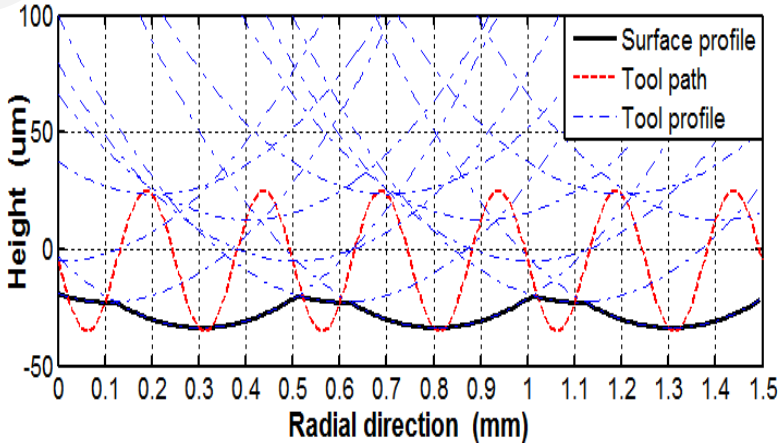


The ideal turning surface

real surface



The trim between the tool tip in radial direction



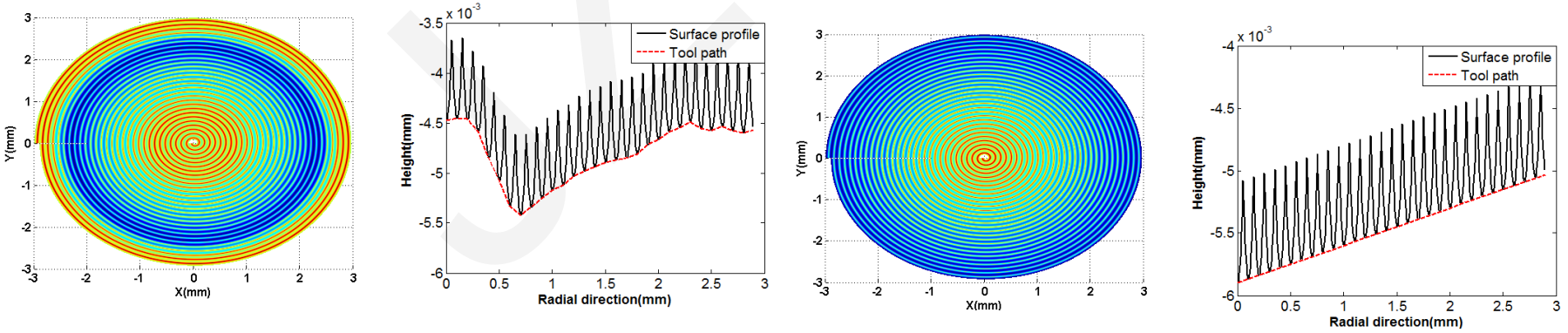
Surface profile in the radial direction with tool interference

Surface Topography Model of End Turning

A series of experiments are conducted under various error conditions to intuitively reveal the impact of the volumetric errors on the topography of the end turning surface.

Table 2 Simulation plan under different error conditions

Case no.	n (r/min)	f (mm/rev)	R_0 (mm)	$\delta_z(x)$ (coefficient)	$\varepsilon_y(\theta)$ (rad)	$\varepsilon_y(z)$ (rad)	η_{xz} (rad)	Amplitude of $\delta_z(\theta)$ (μm)	Frequency of $\delta_z(\theta)$ (Hz)
a	1200	0.1	1.554	1×	0	0	0	0	0
b	1200	0.1	1.554	0×	0.0003	0	0	0	0
c	1200	0.1	1.554	0×	0	0.0003	0	0	0
d	1200	0.1	1.554	0×	0	0	0.0003	0	0
e	1200	0.1	1.554	0×	0	0	0	0.4	40
f	1200	0.1	1.554	0×	0	0	0	0.4	42
g	1200	0.1	1.554	0×	0	0	0	0.4	38
h	1200	0.1	1.554	1×	0.0003	0.0003	0.0003	0.4	60



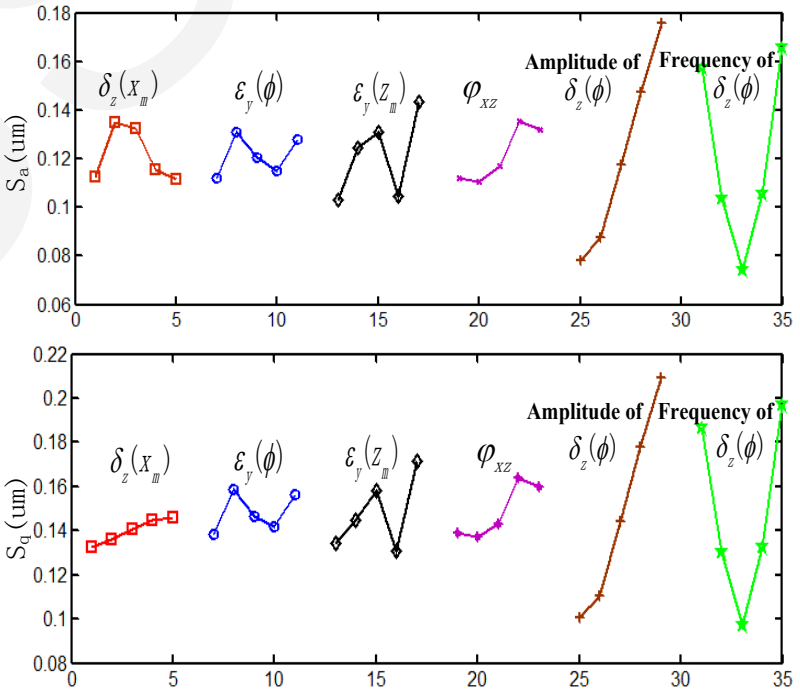
Simulated turning surface under different error conditions according to the parameters listed in Table 2

Simulation Experiments and Numerical Analysis

Various simulations were conducted to analyze the combined effect of the geometric and spindle errors on the surface roughness under different .

Table 3 The 25 repetitions of the experiment

Exp. No.	$\delta_z(x)$	$\varepsilon_y(\theta)$ (10^{-4}rad)	$\varepsilon_y(z)$ (10^{-4}rad)	η_{xz} (10^{-4}rad)	Amplitude of $\delta_z(\theta)$ (μm)	Frequency of $\delta_z(\theta)$ (Hz)	Results S_a(μm)	Results S_q(μm)
1	1	1	1	1	0.1	18	0.069	0.084
2	1	2	2	2	0.2	19	0.071	0.087
3	1	3	3	3	0.3	20	0.058	0.072
4	1	4	4	4	0.4	21	0.113	0.137
5	1	5	5	5	0.5	22	0.251	0.284
6	2	1	2	3	0.4	22	0.203	0.233
7	2	2	3	4	0.5	18	0.251	0.286
8	2	3	4	5	0.1	19	0.067	0.084
9	2	4	5	1	0.2	20	0.061	0.076
10	2	5	1	2	0.3	21	0.093	0.116
11	3	1	3	5	0.2	21	0.086	0.109
12	3	2	4	1	0.3	22	0.157	0.187
13	3	3	5	2	0.4	18	0.205	0.237
14	3	4	1	3	0.5	19	0.140	0.171
15	3	5	2	4	0.1	20	0.074	0.096
16	4	1	4	2	0.5	20	0.086	0.115
17	4	2	5	3	0.1	21	0.084	0.109
18	4	3	1	4	0.2	22	0.121	0.150
19	4	4	3	5	0.3	18	0.163	0.195
20	4	5	2	1	0.4	19	0.123	0.156
21	5	1	5	4	0.3	19	0.117	0.152
22	5	2	1	5	0.4	20	0.093	0.126
23	5	3	2	1	0.5	21	0.151	0.191
24	5	4	3	2	0.1	22	0.098	0.130
25	5	5	4	3	0.2	18	0.099	0.131



The computation results of S_a and S_q for different factors

Conclusions

- Using rigid body kinematics and homogeneous transformation matrix (HTM), an integrated volumetric errors model applied to the lathe has been developed, which has taken into account the impact of spindle motion errors
- Developing the turning surface topography model with consideration of geometric and spindle errors, and then predict the end turning surface topography for a given error condition
- Analyzing the effect of machine tool geometric and spindle errors on the quality of end turning surface
- Principal component analysis (PCA) is used to find the principal error

Simulation experiment results showed a clear dependency between the machine errors and the value of surface roughness. This will give the direction to improve the surface quality.