Documentation of tool wear dataset of NUAA_Ideahouse

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1. Introduction

This dataset is used for i) analyzing the influence of process information on monitoring signals under the same tool wear state through signal processing methods; ii) training and testing models of tool monitoring and tool wear prediction especially for cutting conditions with large variations including cutting parameters, material and geometry of cutting tools, and workpiece materials, and also cutting conditions with continuous changes. This data set includes monitoring signals collected from machining process of sidewalls and closed pockets. The sidewall machining belongs to the cutting process with fixed cutting conditions; the closed pocket machining belongs to the cutting process of continuously varying cutting conditions for the reason that the tool path of closed pocket includes line, arc, full cutting and non-full cutting. Although cutting parameters are given fixed in the arc tool path area, the actual cutting parameters (such as feed, cutting width) are constantly changing due to the change of cutting geometry.

2. Equipment and materials

The equipment and materials used for tool monitoring data acquisition include DMU™ 80P douBLOCK machining center, endmills, titanium alloy workpiece, superalloy workpiece, PCB™ acceleration sensor, NI™ data acquisition box, Spike™ sensory tool holder, Sinico™ microscope.

Table 1 Various cutting tools and workpiece material

Serial number	Tool specification	Tool material	Quantity	Workpiece material
1	12*75*R1	Solid carbide	69	Titanium alloy (TC4)
2	16*100*R1		1	
3	20*100*R1		1	
4	12*75*R1		1	Superalloy
5	12*86*R1	High speed steel	1	Titanium alloy(TC4)

*Note: tool specifications: tool diameter * tool length * tool tip chamfer.*

3. Tool monitoring data acquisition

Two experimental methods are used here: i) Control variates, each group of experiment only changes one machining parameter, which can be used to analyze the influence of corresponding machining parameter on the monitoring signals; ii) Orthogonal experiment, different levels of any two factors are combined once, so that a full factor experiment can be carried out.

3.1 Experimental set for analyzing factors sensitive to machining parameters

The experiment of cutting sidewall in titanium alloy worpiece is divided into three groups: variable axial depth of cut, variable feed per tooth, and variable spindle speed, and the tool path is shown in Fig. 1.

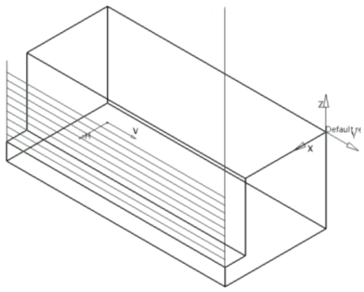

Fig. 1. Tool path for machining sidewall

3.1.1 Variable axial cutting depth

In this group, 20 solid carbide cutting tools with the same specification (12*75*R1) and the same wear state are used for each experiment. Only the axial cutting depth changes, and other cutting conditions are fixed. The experimental details are shown in Table 2.

Table 2 Experiments of variable axial cutting depth

No.	fz (mm/r)	n (r/min)	ap (mm)	ae (mm)	Tool material	Workpiece material
1	0.03	1200	1	3.0		
2	0.03	1200	2	3.0		
3	0.03	1200	3	3.0		
4	0.03	1200	4	3.0		
5	0.03	1200	5	3.0	Solid carbide	TC4
6	0.03	1200	6	3.0		
7	0.03	1200	7	3.0		
8	0.03	1200	8	3.0		
9	0.03	1200	9	3.0		

10	0.03	1200	10	3.0		
11	0.03	1200	11	3.0		
12	0.03	1200	12	3.0		
13	0.03	1200	13	3.0		
14	0.03	1200	14	3.0		
15	0.03	1200	15	3.0		
16	0.03	1200	16	3.0		
17	0.03	1200	17	3.0		
18	0.03	1200	18	3.0		
19	0.03	1200	19	3.0		
20	0.03	1200	20	3.0		

Note: fz: feed per tooth; n: spindle speed; ap: axial cutting depth; ae: radial cutting depth.

The tool monitoring signals under different axial cutting depths are saved in the files named with corresponding No., all of the data in this group are in the folder of ".\Data collection of cutting parameters \Variable axial cutting depths".

3.1.2 Variable feed per tooth

In this group, 20 solid carbide cutting tools with the same specification (12*75*R1) and the same wear state are used for each experiment. Only the feed per tooth changes, and other cutting conditions are fixed. The experimental details are shown in Table 3.

Table 3 Experiment sets of variable feed per tooth group

No.	**fz (mm/r)**	**n (r/min)**	**ap (mm)**	**ae (mm)**	**Tool material**	**Workpiece material**
1	0.021	1200	2.0	3.0	Solid carbide	TC4
2	0.022	1200	2.0	3.0		
3	0.023	1200	2.0	3.0		
4	0.024	1200	2.0	3.0		
5	0.025	1200	2.0	3.0		
6	0.026	1200	2.0	3.0		
7	0.027	1200	2.0	3.0		
8	0.028	1200	2.0	3.0		
9	0.029	1200	2.0	3.0		
10	0.030	1200	2.0	3.0		
11	0.031	1200	2.0	3.0		
12	0.032	1200	2.0	3.0		

13	0.033	1200	2.0	3.0		
14	0.034	1200	2.0	3.0		
15	0.035	1200	2.0	3.0		
16	0.036	1200	2.0	3.0		
17	0.037	1200	2.0	3.0		
18	0.038	1200	2.0	3.0		
19	0.039	1200	2.0	3.0		
20	0.040	1200	2.0	3.0		

The tool monitoring signals under different feed per tooth are stored in the files named with corresponding No., all of the data in this group are in the folder of ".\Data collection of cutting parameters \Variable feed per tooth".

3.1.3 Variable spindle speed

In this group, 20 solid carbide cutting tools with the same specification (12*75*R1) and the same wear state are used for each experiment. Only the spindle speed changes, and other cutting conditions are fixed. The experimental details are shown in Table 4.

Table 4 Experiment sets of variable spindle speed group

No.	fz (mm/r)	n (r/min)	ap (mm)	ae (mm)	Tool material	Workpiece material
1	0.04	820	2.0	3.0	Solid carbide	TC4
2	0.04	840	2.0	3.0		
3	0.04	860	2.0	3.0		
4	0.04	880	2.0	3.0		
5	0.04	900	2.0	3.0		
6	0.04	920	2.0	3.0		
7	0.04	940	2.0	3.0		
8	0.04	960	2.0	3.0		
9	0.04	980	2.0	3.0		
10	0.04	1000	2.0	3.0		
11	0.04	1020	2.0	3.0		
12	0.04	1040	2.0	3.0		
13	0.04	1060	2.0	3.0		
14	0.04	1080	2.0	3.0		
15	0.04	1100	2.0	3.0		
16	0.04	1120	2.0	3.0		

17	0.04	1140	2.0	3.0		
18	0.04	1160	2.0	3.0		
19	0.04	1180	2.0	3.0		
20	0.04	1200	2.0	3.0		

The tool monitoring signals under different feed per tooth are stored in the files named with corresponding No., all of the data in this group are in the folder of ".\Data collection of cutting parameters \Variable spindle speed".

3.2 Experimental set for model training and testing

This part includes 9 orthogonal experiments. 9 solid carbide endmills of 12*75*R1 are used to machine the pocket of titanium alloy (TC4) worpiece, using circling toolpath from inside to outside. The tool path is shown in Fig. 2.

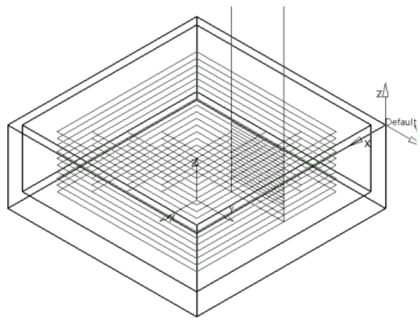

Fig. 2 Tool path for machining pocket feature

The orthogonal experiment was designed with 3 factors and 3 levels (W1-W9). Reasonable machining parameters, shown in Table 5, were selected to ensure the tool state is normal. The other four experiments (W10-W13) were designed for different tools or workpiece materials with corresponding cutting parameters, as shown in Table 6.

The monitoring signals were collected by multiple sensors, and the tool wear values were measured by electron microscope (Sinico^{TM}XK-T600, calibration accuracy: 0.01mm) after the machining process of each pocket layer. In many tool failure forms, flank wear is very common, and it affects the tool diameter, which has a significant impact on the shape and position accuracy of the part. So the maximum width of the flank wear land (VB^{max}) was selected according to ISO standards. The tool life is deemed as exhausted when VB^{max} reaches 0.3mm.

Table 5 Details of orthogonal experiment

No.	fz (mm/r)	n (r/min)	ap (mm)	Tool material	Workpiece material
W1	0.045	1750	2.5	Solid carbide	TC4
W2	0.045	1800	3		
W3	0.045	1850	3.5		

W4	0.05	1750	3		
W5	0.05	1800	3.5		
W6	0.05	1850	2.5		
W7	0.055	1750	3.5		
W8	0.055	1800	2.5		
W9	0.055	1850	3		

Table 6 Details of the extended experiments

No.	Tool specification	Tool material	fz (mm/r)	n (r/min)	ap (mm)	Workpiece material
W10_D16	16*100*R1	Solid carbide	0.06	2200	6	TC4
W11_D20	20*100*R1		0.07	1300	8	
W12_High speed steel	12*86*R1	High speed	0.08	500	3	
W13_ Superalloy	12*75*R1	Solid carbide	0.07	1200	4	Superalloy

The tool monitoring signals are saved in the files named with corresponding No., all of the data in this group are in the folder of ".\ Data collection of machining pocket".

The signals of non-cutting path are removed. In order to change the cutting condition as well as the tool wear rate, the actual spindle speed in W10_D16 varied from 1300 r/min to 2200 r/min, and the actual spindle speed in W13_Superalloy varied from 900 r/min to 1400 r/min. The corresponding fz changed as well.

The collected tool wear labels were saved in the file ".\ machining pocket\Tool wear label.csv", where the edge-*j* is the tool wear of the *j*-th cutting edge, and the *n*th row under a certain cutting condition is the label corresponding to the monitoring signal file named as "*n*.csv". Since each file saves a phase of the monitoring signals, the tool wear is measured once for each layer, one label for a specific "*n*".csv file, and specific tool wear values during a period needs to be interpolated between two adjacent inspected labels. The kinds of monitoring signals can be selected according to the requirement in actual situation.

3.3 Data acquisition

The synchronous acquisition software is used to collect tool monitoring signals in the machining process, including signals such as cutting force, vibration, spindle current and power. The monitoring signal acquisition experiment set is shown in Fig.3, and the signal acquisition flowchart is shown in Fig. 4. The sampling frequency of each sensor is shown in Table 7, which are selected considering the cutting speed and spindle speed in our experiments. Synchronous acquisition software ensures that the sampling frequency of each signal source is consistent at 300

Hz, so the amount of different signal data saved is the same, the time information of the monitoring signal can be calculated by the sampling frequency after the synchronization of each signal source.

Fig. 3 Monitoring signal acquisition experiment

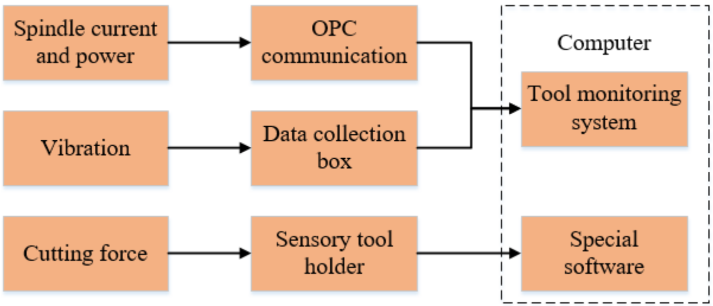

Fig. 4 Flow chart of monitoring signal acquisition

Table 7 Different signal acquisition equipment and sampling frequency

Signal category	**Acquisition equipment**	**Sample frequency(/Hz)**
Spindle current and power	PLC	300
Vibration	PCB^{TM}-W356B11	400
Cutting force	Spike^{TM} sensory tool holder	600