RESEARCH AND SYSTEM DEVELOPMENT OF TOOL BREAKAGE DETECTION IN PRODUCTION LINE

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Tool breakage detection is very important for automated production line. However, the traditional way of using the sensor to detect the tool breakage has brought great inconvenience1 to the implementation. In this paper, the relationship between tool breakage, motor current and NC program sequence is studied and the correlation model is established. Then, the tool breakage detection method is given and the software system is developed. Finally, the above system has been tested in FANUC numerical control machine tool, which proved that the method is feasible.

Keywords: tool breakage detection, NC program, software system

1. Introduction

Tool breakage on-line detection is a key technology to ensure the quality of products and improve the efficiency of batch production line. There are a lot of tool breakage detection methods, including direct method and indirect method [1-3].The former includes laser measurement, optical measurement, visual processing and other methods [4-8].The latter includes cutting force monitoring, spindle power monitoring, vibration monitoring and acoustic emission monitoring, etc[9-11].

Direct method requires the installation of sensors, resulting in higher costs. Therefore, the indirect monitoring method has become a research focus in the field of tool breakage detection in batch production line [12].

There are some commercial tool breakage detection systems. For example, ARTIS tool breakage monitoring system is a monitoring and control system to monitor machine status, such as the tool breakage, spindle collision in the process of the machine tool processing. And the United States BK Mikro tool breakage monitoring system with a mechanical monitoring probe perceives tool state

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changes and rapid feedbacks tool state information. But most of them is only applicable to the laboratory, few stable and reliable for commercial tool monitoring, so there is an urgent need to develop stable and reliable products to meet the actual requirements of production.

The current tool breakage detection system generally requires external sensors, which is installed in the surface of work piece or the tool. And it severely limits the scope of application of the system. In order to solve the above problems, this paper studied CNC machine tool breakage detection of batch production line, and developed new tool breakage on-line breakage detection, which used built-in sensor of CNC machine tool to obtain cutting tool monitoring signal.

2. Tool breakage detection mechanism

In the process of machine tool cutting, when the tool is damaged, the changes of cutting edge state will lead to the changes of the cutting torque, resulting in machine tool spindle power changes, so the tool condition can be detected by monitoring spindle power. The current load of machine tool spindle is more sensitive to tool breakage, which can avoid the interference of chip and vibration in environment. Therefore, it is an ideal monitoring signal for cutting tool breakage detection in production practice [13-16].

In batch processing, the power signal of the spindle of the NC machine tool has the characteristics of periodicity on the time axis due to the same processing parameters [7]. According to the above characteristics, the power information of the NC machine tool can be acquired in real time and compared with a set of standard machining power signals, so as to achieve the purpose of tool breakage detection.

3. Design of tool breakage on-line detection system

Tool breakage detection system includes four modules: signal acquisition module, learning module, on-line monitoring module and warning module. Signal acquisition module is mainly used to collect and monitor all kinds of information. The learning module is mainly used to store the power standard data of the main shaft when the new tool is processed, and the corresponding limit threshold value can be set. The online monitoring module can monitor the change of the current load of the main shaft in real-time, and determine whether it is beyond the corresponding threshold value. In the monitoring process, when the current power is beyond the set threshold value, the warning module would work to produce the corresponding protective action for the machine tool.

a. Self-learning method of tool breakage detection

Self-learning method of cutting tool state monitoring, is in mass production, first with a standard tool for machining a work piece, then save in the process of machine tool spindle current load changes, and gives the corresponding set. In the actual machining process, the system will be real-time acquisition of the main current load situation and the standard load trend identification and comparison, if the mutual relationship is very low, it shows that the tool breakage [9]. The process is shown in Fig. 1.

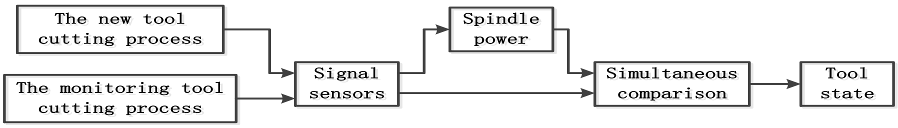


Fig. 1. Self-learning monitoring process

The method requires the repeatability of the machining process, including the work piece blank, cutting tool, cutting dosage and so on. In the mass production, the above conditions are basically unchanged, so the method is mainly applicable to batch production. The principle of self-learning method is to compare the process data and standard process data, which requires the data synchronization in the time domain, and the realization of the synchronization, is the key to the self-learning monitoring method.

b. Function design of tool breakage detection system

The structure of self-learning tool breakage detection system is shown in figure 2. The cutting state of the tool is reflected by the change of the current load of the spindle, and the synchronization of the load change data is reflected by the execution of the program. The above information is read directly from the numerical control system through the FOCAS2 interface. Monitoring module will collect real-time data, and according to the corresponding rules to determine the state of the tool, if the damage is detected, then give the corresponding alarm. When the system detects the tool breakage signal, the system sends out a trigger signal to the machine tool numerical control system, causes the numerical control machine tool feed to stop, and prevented the cutting tool and the work piece further contact.

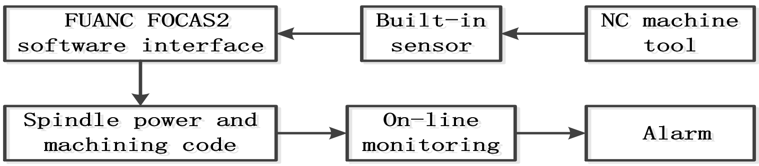


Fig. 2. Structure of monitoring system

c. The signal acquisition module

Generally, CNC machine tools have built-in sensors. Commonly used built-in sensors generally include the detection of the speed of the pulse encoder, the detection of the position of the photoelectric encoder and the detection of the current load of the Holzer sensor and so on. Based on the FOCAS2 interface, this paper develops a visual C++ software system, which can capture the speed of each axis, the current load of each axis and the current processing procedures, and so on. The real-time acquisition of the signal frequency can reach 40HZ, can meet the requirements of real-time tool breakage detection. Signal acquisition process is shown in Fig. 3.

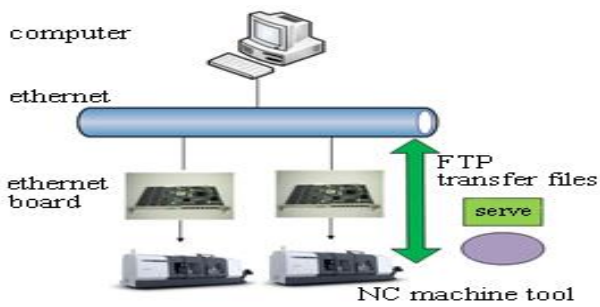


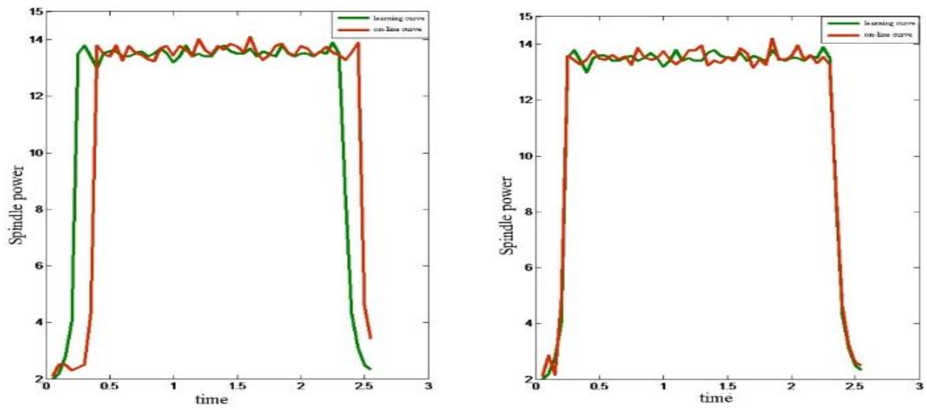
Fig. 3. Signal acquisition process

d. Self-learning module and on-line monitoring module

This paper adopts the analysis of NC program code, to realize the segmentation monitoring and data synchronization in the learning and monitoring module. A process of NC machining program contains NC code of multiple working step. Each working step contains the cutting process code and the non-cutting process code. When NC program is written, each working step are defined procedure number, working step, tool number and blade number. In addition, Empty code #29=1is written before the start of the working step code, and empty code #29=0 is written later of the end of the working step code. As a result, a normal NC program is divided into a lot of segments by #29=1 and #29=0. The code expresses cutting process in between of #29=1 and #29=0, otherwise the non-cutting process. The above process is the process of NC code analyzing according to the working step to obtain an obviously, differentiation between cutting process and non-cutting process. Tool breakage monitoring monitors cutting process to improve monitoring efficiency. The NC code segment analysis process is shown in Fig. 4.

Fig. 4. The NC code segment analysis

The comparison of learning data with on-line monitoring data is one of the key technologies to realize the self-learning tool breakage monitoring. Self-learning tool breakage monitoring requirements the comparison under the same conditions, as is shown in Fig. 5.



(a) Asynchronous contrast (b) Synchronous contrast

Fig. 5. Comparison between learning curve and monitoring curve

In the learning phase, monitoring system reads the currently executing code name and the line numbers. When read #29=1, system begins to read and save the spindle power. When read #29=0, system stops read spindle power and saves working step number and tool number. Then system continues to read NC code, the logic is the same, when read to#29=1 and #29=0. The algorithm of learning process is shown in Fig. 6.

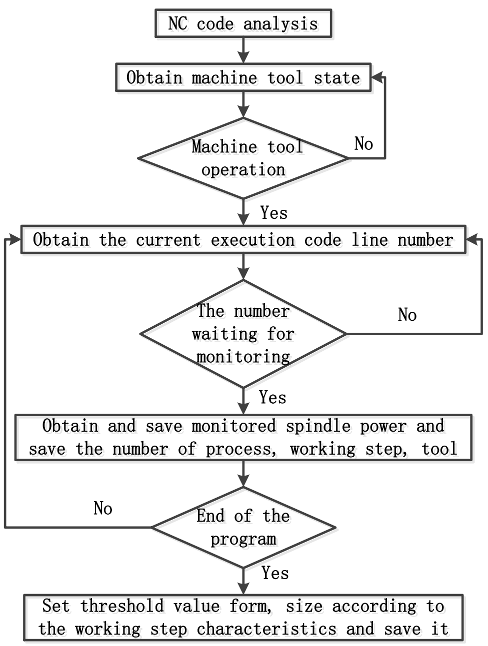


Fig. 6. The learning process algorithm

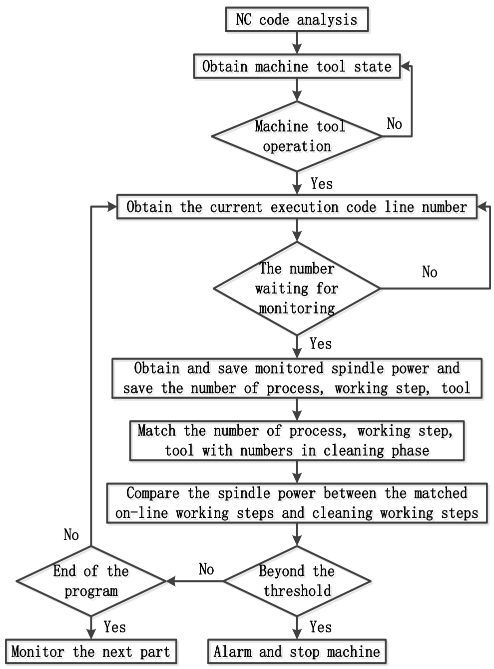


Fig. 7. The monitoring process algorithm

Threshold setting method and threshold value setting directly influent the effect of the self-learning tool breakage monitoring. Threshold setting forms divide into linear threshold and curve threshold. The former is suitable for rough machining, and the latter is suitable for semi finishing and finishing machining. If threshold value setting is too small, monitoring system response is too sensitive to prone to false alarms. Conversely, some tool breakage may be missing alarm. The paper puts forward a method to set different threshold based on working step, setting large threshold in the rough machining and setting small threshold in semi finishing and finish machining. This method is more reasonable to set threshold value.

In the on-line monitoring phase, the monitoring system reads the current execution program name and code. Firstly, the system judges if the current execution program name is same as learning phase program name. If it is same, system reads the current execution code. When reads #29=1, the system began to read the execution code and spindle power, and collected working step number, tool number. Then matches the numbers with learning phase numbers, and system compares on-line collected spindle power with learning power point and determines the on-line spindle power whether exceeds the threshold. When read #29=0, the system doesn’t read code until the end of the whole process. The algorithm of monitoring process is shown in Figure 7.

4. Development of tool breakage monitoring system

Tool breakage on-line monitoring system mainly consists of an industrial computer, MOXA industrial switch(Figure8), and a display. Industrial computer is the core of the monitoring system, which integrates the monitoring software system.

Fig. 8. MOXA industrial switch

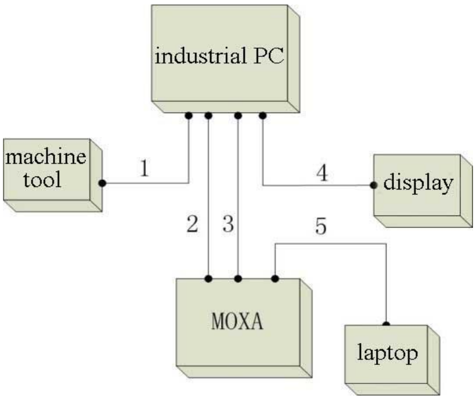


Fig. 9. The communication structure of the monitoring system

MOXA industrial switch is mainly to complete the data transmission, the monitor is to display the monitoring interface and operate the terminal. The specific communication structure of the monitoring system is shown in Figure 9: Its line connection is shown in Figure 10:

Fig. 10. Monitoring system's line connection

According to self-learning tool breakage monitoring principle and algorithm description above, tool breakage monitoring system is developed using Visual C++ and SQL SERVER, realizing tool breakage on-line monitoring function of automatic production line mass production. The main structure of the monitoringsystem is shown in Figure 11:

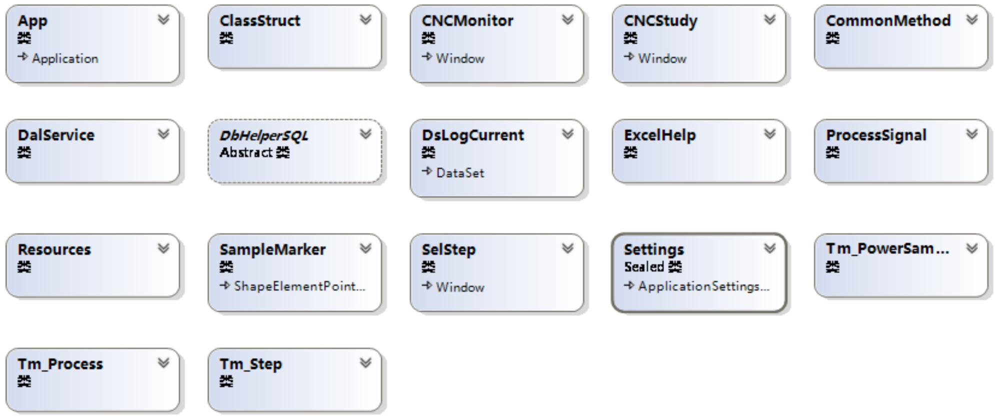
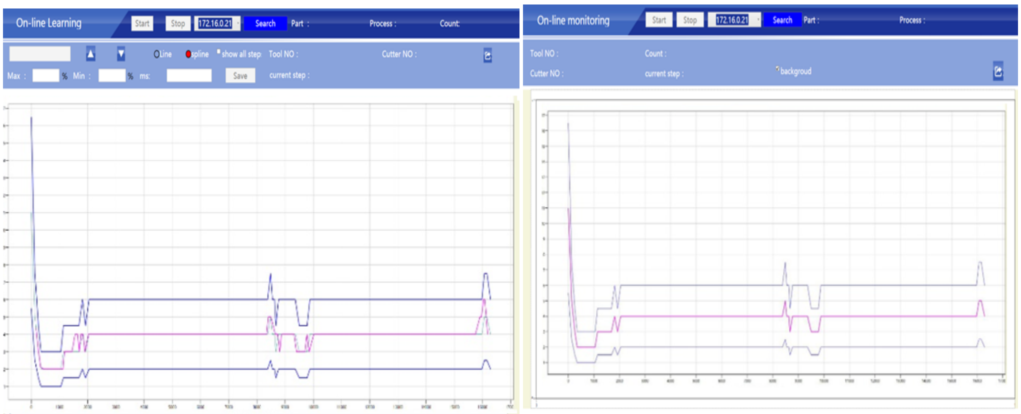


Fig. 11. The main structure of the monitoring system

In learning phase, the system stores spindle power data in the process of processing, according to the analysis process, completion the learning process of a part.

At first, threshold setting needs to choose a form from linear threshold and curve threshold. Using the curve threshold method, the upper limit of curve threshold equals maximum power value setting percentage in learning sample plus the every moment power, and the lower limit is equal to the every moment power minus minimum power value setting percentage in learning sample. Using the linear threshold method, the upper limit of curve threshold equals maximum power value in learning sample plus maximum power value setting percentage, and the lower limit is equal to minimum power value in learning sample minus minimum power value setting percentage. After all the working steps complete learning process, each working step is set a different threshold size.

When on-line monitoring, the system reads the current spindle power and simultaneously compares it with learning samples to judge the spindle power whether is beyond the threshold limit. If exceeded, the monitoring system alarms, and NC machine tool stops feed. The interface of tool breakage on-line monitoring system is shown in Figure 12.

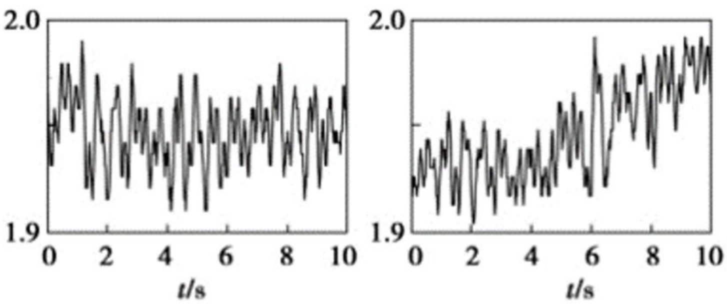


(a)on-line learning (b)on-line monitoring

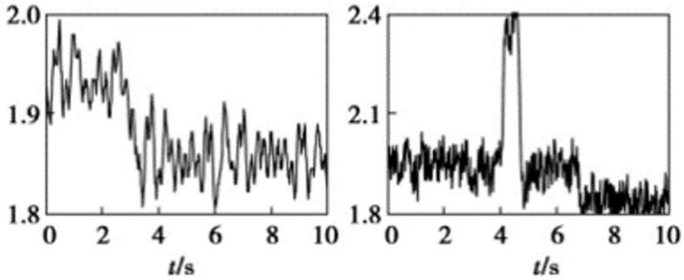
Fig. 12. The main interface

5. The application testing

Test method is shown in the following figure 13, figure (a) the power signal map when the normal processing, figure (b) the power signal map when tool rake face severe wear lead to the damage of the blade and cutting power continues to increase, graph (c) the power signal map when tool occurred brittle fracture lead to reduce power; graph (d) the power signal map when the rake and flank occurred severe wear lead to fracture of the tool.



(a) (b)



(c) (d)

Fig. 13. The power signal map

The test main simulates the two cases of figure (c) and figure (b). Specific use of the standard parts for test is shown in Figure 14.

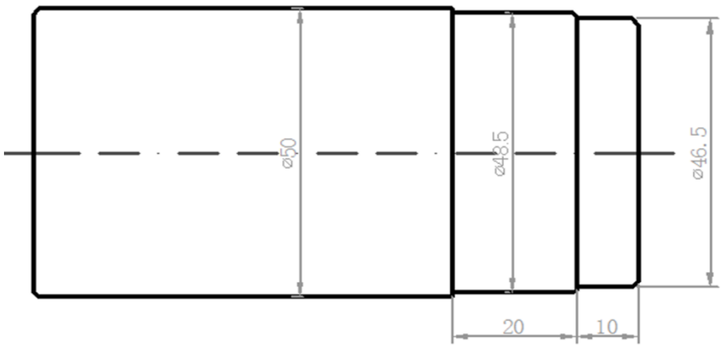


Fig. 14. The standard parts of test

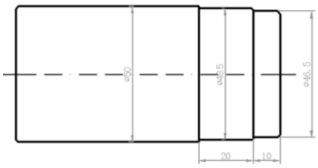
Test environment is test machine tools, as shown in Figure 15.

Fig. 15. The test machine tools

The processing technology of standard partsis follows in Table 1.

Table 1.

The processing technology of standard parts

<table>
<tr><td colspan="3" rowspan="2">The machining process card</td><td colspan="3">Part drawing number</td><td colspan="2">-</td></tr>
<tr><td colspan="3">Part name</td><td colspan="2">Test workpiece</td></tr>
<tr><td colspan="3" rowspan="8">
</td><td colspan="2">Blank type</td><td>Blank size</td><td colspan="2">Process name</td></tr>
<tr><td colspan="2">Sticks</td><td>∅50×100</td><td colspan="2">Rough turning-Finish turning cylindrical</td></tr>
<tr><td colspan="2">Material</td><td>Equipment name</td><td colspan="2">Equipment model</td></tr>
<tr><td colspan="2">45#</td><td>Horizontal lathe</td><td colspan="2">A5-T2</td></tr>
<tr><td colspan="2">Fixture number</td><td>Fixture name</td><td colspan="2">Cutting fluid</td></tr>
<tr><td colspan="2">-</td><td>Three jaw chuck</td><td colspan="2">-</td></tr>
</table>

<table>
<tr><td rowspan="2">Work step</td><td rowspan="2">Step content</td><td rowspan="2">Tooling</td><td>Speed of mainshaft</td><td>Cutting speed</td><td>Feed amount</td><td>Cutting depth</td><td rowspan="2">Number of feed</td></tr>
<tr><td>r/min</td><td>m/min</td><td>mm/r</td><td>mm</td></tr>
<tr><td>1</td><td>Rough turning cylindrical</td><td>Carbide turning tool R1.6</td><td>600</td><td>300</td><td>0.5</td><td>1</td><td>1</td></tr>
<tr><td>2</td><td>Semi-finished turning cylindrical</td><td>Carbide turning toolR0.8</td><td>600</td><td>210</td><td>0.35</td><td>0.4</td><td>1</td></tr>
<tr><td>3</td><td>Finish turning cylindrical</td><td>Carbide turning toolR0.8</td><td>900</td><td>225</td><td>0.25</td><td>0.1</td><td>1</td></tr>
</table>

Contrast test pieces are as follows:

The test sample 1 (Figure 16) is corresponding the tool breakage a, to simulate the situation of increasing cutting power.

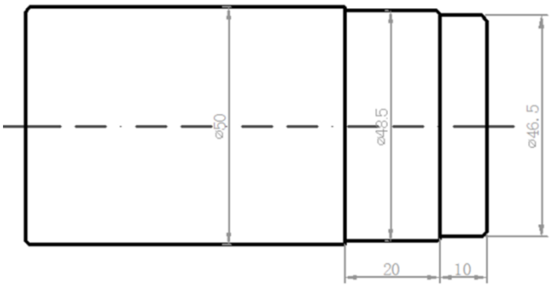


Fig. 16. The test sample 1

The test sample 2 (Figure 17) is corresponding the tool breakage b, to simulate the situation of decreasing cutting power.

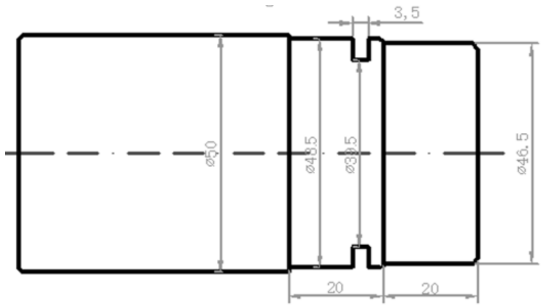


Fig. 17. The test sample 2

The test programs are shown below.

```
O0016
#10=38.5
#9=#10+3.
#11=#10-0.4
#12=#9-0.4
#13=#11-0.1
#14=#12-0.1
N1#30=1
N2#31=1
N3#32=606
N4#33=4
N10G54G21G0
N15G30U0
N20T0601
N40G0Z10.X50.
N90Z-40.
N120G0X55.
N125#29=0
N130Z10.
N135G30U0.
N137M05
N141#30=1
N142#31=2
N143#32=402
N144#33=2
N150T0402
N160G0X50.Z5.
N170M3S600F0.35
N180G0X#11
N186#29=1
N230M05
N241#30=1
N242#31=3
N243#32=402
N244#33=1
N260T0402
N270G0X50.Z5.
N280M3S900F0.25
N290G0X#13
N300#29=1
N310G1Z-20.
N320X#14,C1.
N330Z-40.
N340G0X55.
N350#29=0
```

```
N50M3S600
N57G0X#10
N58#29=1
N60G99F0.5
N70G1Z-20.
N80X#9.
N190G1Z-20.
N192X#12
N194Z-40.
N200G0X55.
N205#29=0
N210Z10.
N220G30U0.
N360G0Z10.
N370G30U0.
N380M05
N400M30
%
```

The field test is shown in figure 18.

Figure 18. The scene processing images

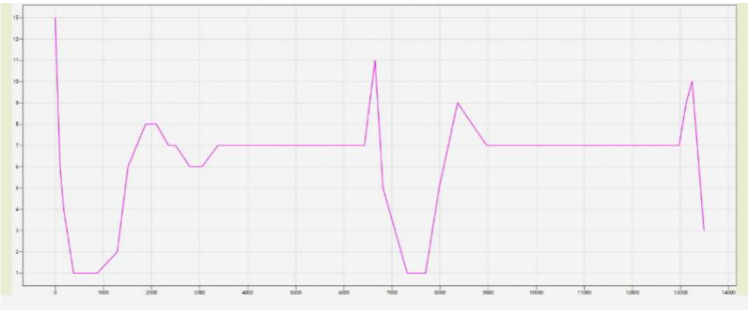
Test data record table is shown in Table 2.

Table 2.

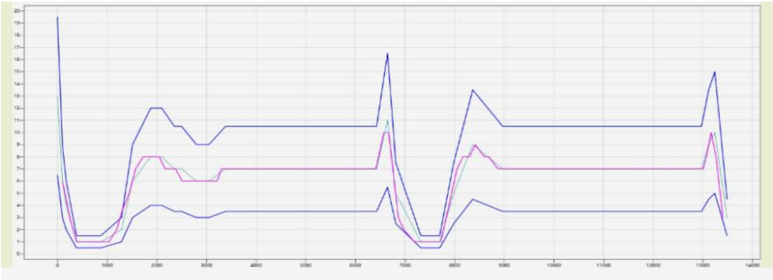
Test data record table

Test-piece	Specimen type	Anticipate result	Achieved the expected results or not
test-piece 1	standard parts	Normal	YES
test-piece 2	standard parts	Normal	YES
test-piece 3	Test piece	alarm	YES
test-piece 4	Test piece	alarm	YES
test-piece 5	Test piece	alarm	YES
test-piece 6	standard parts	Normal	YES
test-piece 7	standard parts	Normal	YES
test-piece 8	Test piece	alarm	YES
test-piece 9	Test piece	alarm	YES
test-piece 10	Test piece	alarm	YES

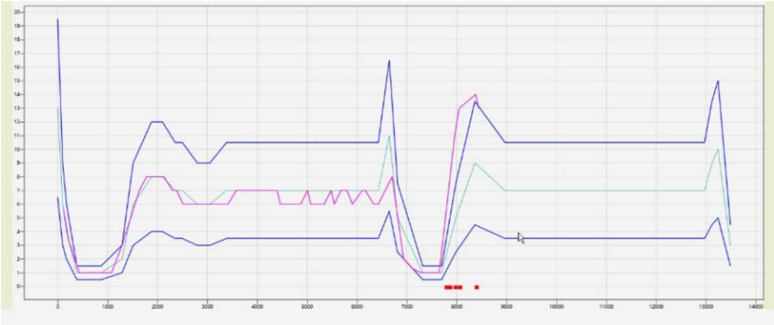
Data chart analysis is shown in Figure 19.



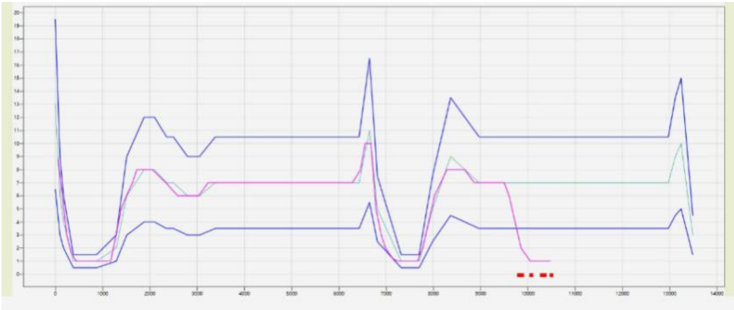
(a) Learning model of standard part



(b) Monitoring mode of standard part



(c) Damage monitoring in high power (test sample 1)



(d) Damage monitoring - low power (test sample 2)

Fig. 19. Data chart analysis

An experiment is done to verify the effect of the monitoring system.

Experimental machine tool is A5-T2 automatic NC machine tool, and CNC operating system is FANUC-0i-mate. Experimental test pieces is Cr40 stepped shaft, and the tool is SANDVIK rough machining turning tool and machining turning tool, cutting tool material for hard alloy. The machining operation contains two working steps. Rough machining tools machine outer circle of the stepped shaft, cutting speed V=200m/min, feed rate f=0.5mm/r, back cutting depthAP=3.5mm, upper and lower thresholds 40%. Finish machining tools machine outer circle of the stepped shaft, cutting speed V=500m/min, feed rate f=0.2mm/r, back cutting depthAP=1.0mm, upper and lower thresholds 25%. Tool breakage occurs randomly, in order to make the tool breakage in machining process, the workpiece is embedded into the hard point. When tool nose meets the hard point, the tool would be broken. In the experiment, the total of test pieces is 50, which 25 test pieces were embedded in hard point in the rough machining process, and 25 test pieces were embedded in the finishing machining process. The former is all monitored by the monitoring system, so the accuracy rate is 100%. The latter is monitored to 24, so the accuracy rate is 98%.

6. Conclusion

This paper develops a tool breakage on-line monitoring system based on API to get tool breakage monitoring signal. This provides a reference for the further research of the state monitoring signal acquisition method of the NC machine tool. The control signal is obtained by using the built-in sensor of the NC machine tool, which solves the problem of the installation of traditional tool breakage monitoring sensors. The cutting process and the non-cutting process are identified by the NC code analysis, which solves the blindness of monitoring the whole machining process to expand the research ideas. The tool breakage monitoring system has been applied in the enterprise, and the practice proves that the monitoring effect is good and reliable.

Acknowledgements

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