Introduction of Products

Machine Tool Monitoring System Komtas

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Against the backdrop of labor shortages and a decline in the number of skilled technicians at manufacturing sites, there is a growing demand for labor saving and unmanned operation. We are working on solving the problem.

This time, we have developed a monitoring system, "Komtas", which can visualize the machining status to reduce defective products, which is one of the issues at the manufacturing site.

Key Words: *Processing sites, Machining center, Machine tool, Monitoring system, Tools, Breakage, Damage, Machining abnormality, Machine abnormality*

1. Introduction

In the processing sites of the manufacturing industry, machining centers are used for machining of parts including engine parts (**Fig. 1**). Machining center is a machine tool which is composed of three orthogonal axes (X, Y, Z axes) for the machining feed and is capable of various machining works by mounting tools required for making holes and surface machining such as a drill, a reamer or a milling cutter on the main spindle and rotating the main spindle for cutting work, with automatically replacing the tool mounted on the main spindle by using the tool replacing device called "magazine" (**Fig. 2**, **Fig. 3**).

Fig. 1 Machining center (horizontal type)

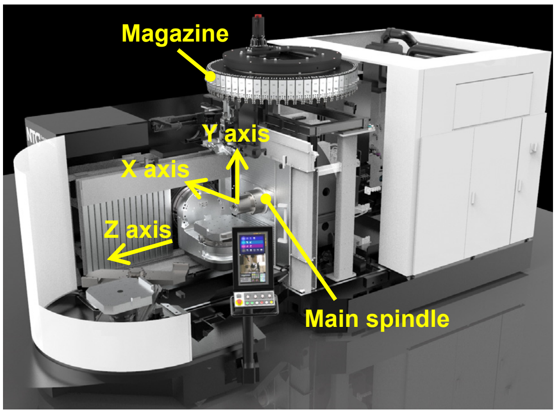

Fig. 2 Structure of machining center (horizontal type)

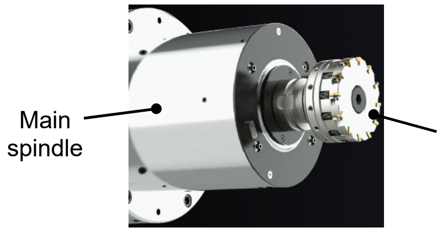

Fig. 3 Main spindle and tool

In machining by a machining center, the cutting edge of a tool occasionally gets damaged (chipped) with a high cutting load (**Fig. 4**). When the machining is continued without noticing the damage of the tool, various losses including shipping of defective products, disposal of the tool, and a damage of the machining center are caused.

It is possible to reduce the losses by conducting preventive measures such as regular replacement of the tool with its number of times of machining use and regular quality check of the work in process. But, it has a problem that tools still usable are replaced to waste the expense and the working time for the tool.

Fig. 4 Damaged cutting edge of a tool (chip)

2. Overview of Komtas

For this problem, we thought that collecting the data in the machining and real time monitoring of damages, abnormal changes and wear of the tools are effective to reduce defective products and unnecessary tool replacement, and has developed Komtas.

Komtas is the edge device which is connected to the machining center with the Ethernet cable to collect the motor information and any analog sensor data in each machining process and is the system to detect machining abnormality caused by a sudden change of the tool's state without fail by "visualization", "analysis", and "judgment" (**Fig. 5**).

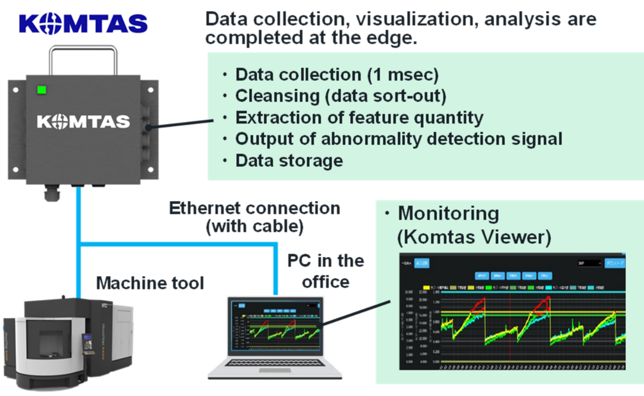

Fig. 5 Overview of the system

2.1 Hardware specifications

The enclosure of Komtas has the appearance shown in **Fig. 6**. It has bolt fixture holes and a magnet sheet on the back as it is assumed to be installed on the side of the cover or the door of the control panel of the machining center.

Data 8ch can be input from the machining center with the control equipment (NC). Also, analog data 8ch from various sensors can be input at the same time (**Table 1**).

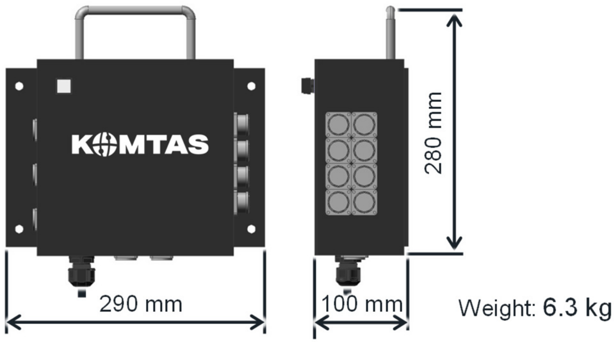

Fig. 6 Appearance of Komtas

Table 1 Hardware specifications

NC data input	Number of input channels	8ch
	Sampling frequency	1 kHz
Analog data input	Number of input channels	8ch
	Input range	± 10 V
	Resolution	16 bit
	Sampling frequency	1 kHz
Interface	HDMI	1 port
	USB3. 0 Type A	2 ports
	USB3. 1 Type C	1 port
	LAN 10/100/1000	1 port
	Connection target	FANUC's CNC i series
Power supply	Input voltage	100 to 240 VAC

2.2 Software specification

Komtas has the software functions necessary for detecting tool wear and machining abnormality.

(1) High-speed data collection
- Data necessary for the analysis (NC data/sensor data) is acquired in 1 msec cycle

(2) Automatic cleansing
- Disturbing information such as acceleration and deceleration of the motor is eliminated to sort out the data of the field to be monitored

(3) Extraction of optimal feature quantity
- Thousands of time-series data are transformed into one feature quantity
- Exclusive formulas to catch a damage of the cutting edge of the tool (chip) are provided in addition to general statistical quantity

(4) Real-time visualization and abnormality detection
- The value of the feature quantity is plotted to visualize the feature data for easy grasp by the user
- A threshold value can be set for NG judgment

(5) Output of abnormality detection signal
- A signal is output to the machining center when the threshold value is exceeded

(6) Data storage
- Collected data can be stored for about 6 months *1
- Comparison of data in the past and that at present is possible.

*1: It is depending on the amount of acquired data

3. Major Features

3.1 High-speed data collection

For catching an abnormal phenomenon of tool's cutting edge occurring in the machining center without fail, data collection with a cycle of 1 sec or less is necessary (**Fig. 7**).

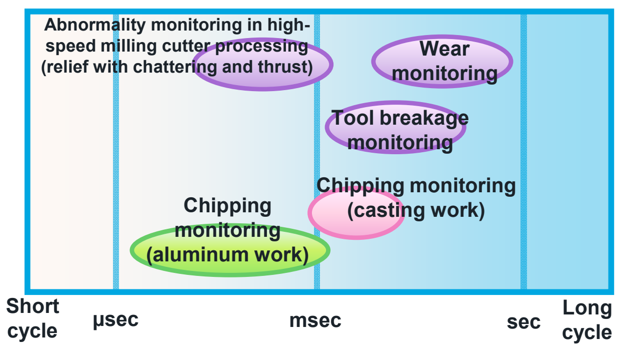

Fig. 7 Examples of cutting phenomena occurring in the machining center

Komtas can collect the data of the motor load information with a higher-speed cycle of 1 msec (1 kHz) to catch a subtle change in the machining or a change of the state of each blade of a multiple-cutting-edge tool such as a milling cutter.

Figure 8 shows a load of the main spindle motor in the six-blade milling cutter process. When the data is collected with a low-speed cycle of 100 msec, subtle changes cannot be caught (the waveform in orange).

On the other hand, with a high-speed cycle of 1 msec, the variation of the load corresponding to each blade can be caught. We can see that the blade (6) has a low motor load and expect blade chipping or abnormal wear (the waveform in yellow).

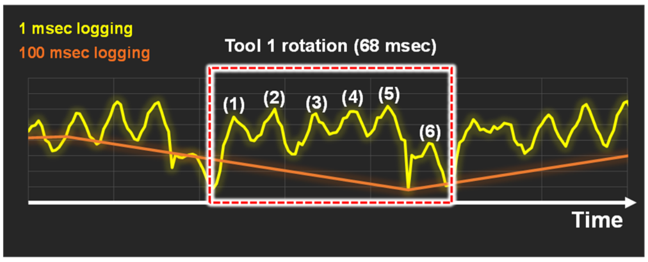

Fig. 8 Load of the main spindle motor of the milling cutter (6 blades)

3.2 Automatic cleansing (data sort-out for analysis)

The amount of data collected with the 1 msec cycle becomes huge, so that its analysis takes a lot of work and time, as well as a heavy calculation load of the computer.

In addition, while the analysis of the machining state requires pure data of the machining only, the collected data contains unnecessary data such as acceleration and deceleration of the motor, which is not appropriate for the analysis.

Komtas can eliminate unnecessary data such as that during acceleration and deceleration of the motor and automatically sort out the data in the machining or that corresponding to a specified abnormality. Besides, by eliminating unnecessary data, the amount of the data can be reduced to lighten the calculation load (**Fig. 9**).

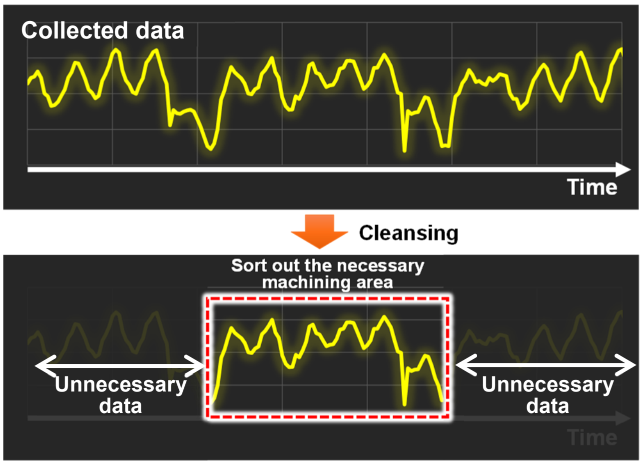

Fig. 9 Automatic cleansing

3.3 Extraction of optimal feature quantity

The data after the cleansing is intermittent and not suitable to be monitored or analyzed by users.

Komtas converts the machining data sorted out to one feature quantity optimal for state monitoring to enable users to easily monitor or analyze the data, by using the formula based on the statistical quantities such as the mean values and standard deviations of the force phenomenon generated in the machining center or the cutting as well as the ideas of frequency processing and quality engineering (**Fig. 10**).

Besides, while the machining data sorted out amounts to several thousands to be difficult to be analyzed at high speed, by the conversion of the data to one feature quantity, the data amount is compressed to enable the data analysis at high speed.

Fig. 10 Thousands of machining data converted to feature quantity (score)

3.4 Easy setting screen requiring no skill

For extraction of an optimal feature quantity, users are required to have special know how. However, Komtas provides the easy setting screen requiring no skill which automatically performs the setting for the extraction of an optimal feature quantity according to the monitor object and the machining conditions the user selected (**Fig. 11**).

This setting screen is offered based on the know how to extract an optimal feature quantity which was established by repeatedly conducting verification tests for a long period of time.

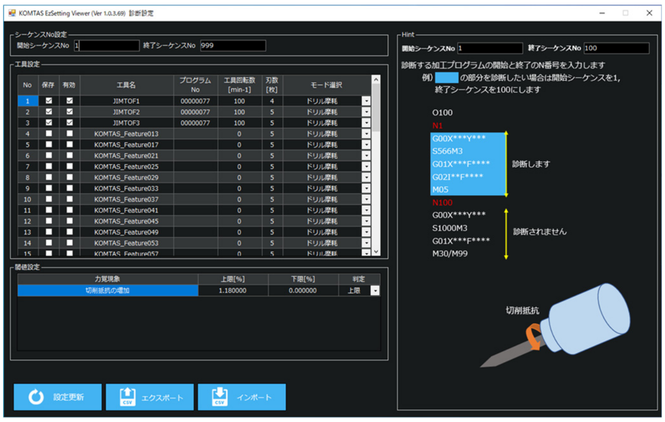

Fig.11 Easy setting screen

3.5 Real-time visualization and abnormality detection

The extracted feature quantity is plotted to the graph with the feature quantity score value on the vertical axis and time on the horizontal axis. The plotted result can be viewed on the monitoring software “Komtas Viewer” (**Fig. 12**).

A threshold to judge the abnormality can be set or be adjusted by the user according to the environment of the worksite. An excess of the threshold value is shown in red to be easily recognized by sight.

By visualizing the feature quantity, a damage and wear of the tool can be monitored in real time to prevent defective products.

Fig. 12 Komtas Viewer

3.6 Comparison and analysis of the data

When there is data exceeding the threshold or that requiring detailed analysis in the feature quantity plotting graph, raw data (data collected with 1 msec cycle) can be used for the comparison and analysis (**Fig. 13**).

This enables abnormality detection by checking a subtle change in the data even for abnormalities which the operator could not find with unusual noise, etc.

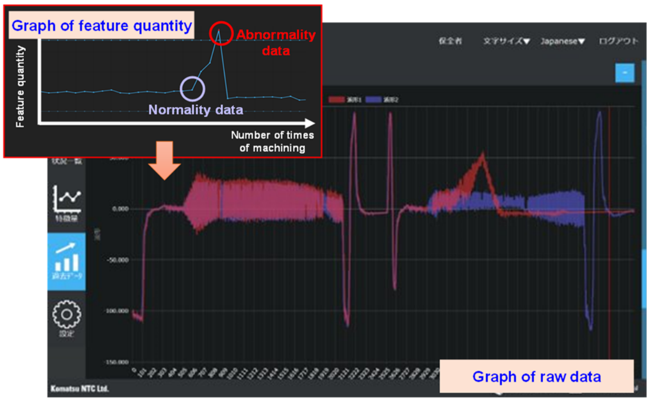

Fig. 13 Comparison in the raw data graph

4. Dedicated applications

We developed three dedicated applications combining five features mentioned above with simplified settings for data collection and feature quantity extraction for easy use by users.

These applications are for the drill and the reamer processes in mass production with iron or cast metal.

4.1 Tool wear monitoring application

It is the application which monitors the cutting quality of the tool in use to enable the use of the tool to its original service life, minimizing expense and replacing work for the tool.

It plots the feature quantity (degree of wear) on the graph for each use of the tool to enable the user to check the feature quantity increasing corresponding to the number of times of the use to use the tool to the end of its service life.

A threshold of the degree of wear can be set to send the information to the user or the machining center when the threshold is exceeded.

Enabling the grasp of the optimal replacing timing of the tools, it is a helpful application for users who have safer settings of the number of times of the use to avoid damages of the tools (**Fig. 14**).

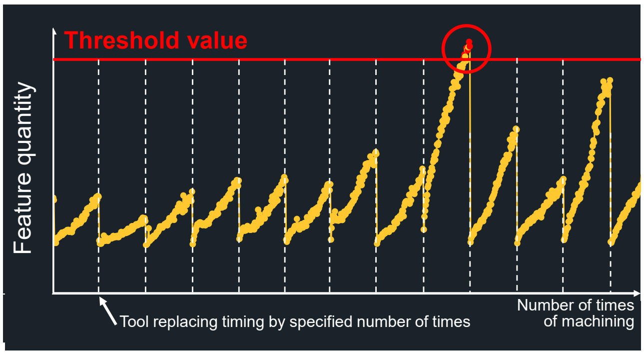

Fig. 14 Example of tool wear monitoring

4.2 Tool damage monitoring application

It is the application which detects a sudden subtle damage (chip) of a tool.

The conventional system for tool damage detection uses the contact-type detection device, being unable to detect a subtle damage (chip) of the tool's cutting edge. It allows the user to continue the machining to have shipping of defective products and a damage of the machining center leading to a long-time production line stop.

This application can grasp the sign of a damage of the tool, enabling easy monitoring of damages by setting the damage threshold to such signs. This prevents shipping of serial defective products and a long-time production line stop (**Fig. 15**).

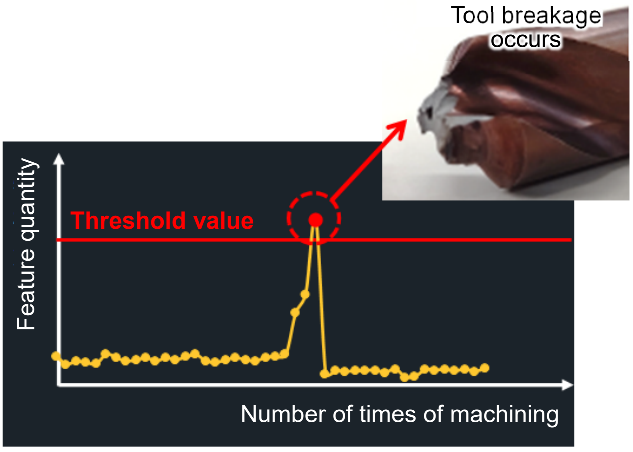

Fig. 15 Example of tool damage monitoring

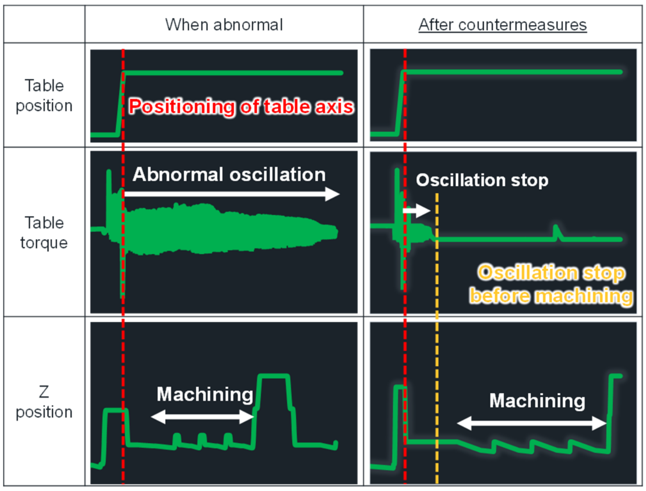

Fig. 16 Machine abnormality and after countermeasure

4.3 Machine diagnosis auxiliary application

It is the application which catches a sign of abnormal deterioration or sudden failure of the parts of the machining center and assists the diagnosis for the necessity of repair. As the user can decide the countermeasure before a failure of the parts, their plan can be maintained.

In the machine diagnosis auxiliary application, the data of the motor load acquired from the axes (main spindle, X, Y, Z axes, etc.) of the machining center is plotted on the graph to show the state as waveforms.

The collected motor load data can be stored for about 6 months (depending on the data storage size). When an abnormality in behavior or sound of the machining center is found, a sign of abnormality can be grasped by comparing the waveforms of the motor load in the normal operation in the past and in the abnormal state.

It allows the user to prepare various measures such as parts replacement and extension of the part's service life (**Fig. 16**).

5. Case of improvement

We introduce an example of user's improvement in extension of service lives (number of times of the use) of tools by utilizing the tool wear monitoring application.

In the user's environment, reamers were used in machining with the setting of number of times of the use for replacement which was shorter than their original service lives for the safety so that they could be replaced before they got damaged. It had a problem of disposal of the tools still usable.

They collected the machining data for several weeks, converted the data to the feature quantity (degree of wear), and analyzed it. Then, they found that a tendency develops as the tool is repeatedly used. In addition, in the comparison between the feature quantities of the tools, the individual variability by tool is considerable (**Fig. 17**).

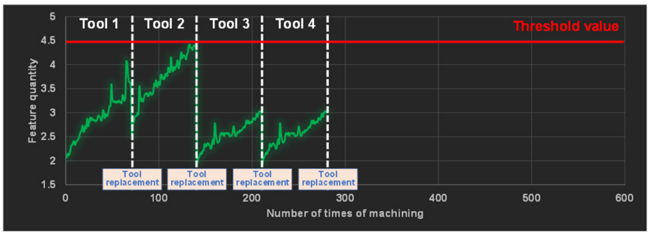

Fig. 17 Feature quantity by tool

Having the maximum value of the feature quantity as the threshold (red line in **Fig. 17**), they conducted tests of continuous use of the tools by extending the conventional setting of number of times of the use and found there was no problem with the extension within the range the feature quantity did not exceed the threshold. By this result, it became possible to use the tools by extending their service lives (number of times of the use) according to their individual variabilities, which led to a 76% extension at maximum compared to those in the conventional use (**Fig. 18**).

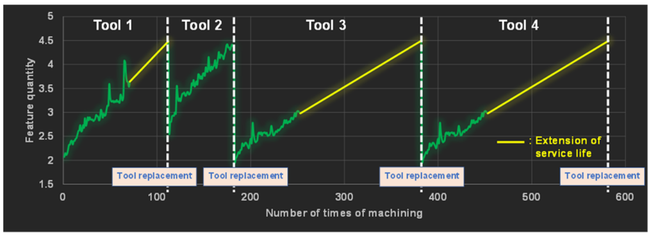

Fig. 18 Extension of the tools' service lives (number of times of the use)

6. Conclusion

At present, we offer the applications for the drill and the reamer processes in the machining of iron and casting materials by machining centers. We will expand the range of the applications to the use in the tapping and the milling processes.

Besides, as processed products of aluminum alloy are dominant in the automobile industry including Komatsu NTC's main customers, the development of the applications meeting such products is essential. Processed products of aluminum alloy are difficult to judge the normal or the abnormal as they do not show a big difference between the normal and the abnormal unlike the case of processed products of iron and casting materials. We will proceed with the study of data necessary for grasp of the state causing abnormality, the selection of sensors necessary for acquiring the data, and the verification of the installation positions for creating the application.

Introduction of the authors

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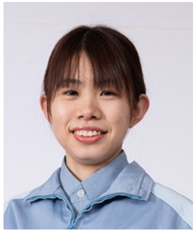

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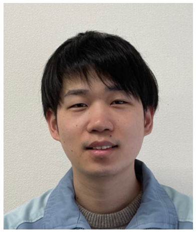

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[A comment from the authors]

We would like to develop the applications in view of the efforts for energy conservation including optimization of the processes in the future, which we believe contributes to the realization of carbon neutrality.