A Skill Transfer Method for Manual Machine Tool Operation Utilizing Cutting Sound

Takashi Kawashimo[1], Noriaki Sato[2], Daisuke Doyo[1], Michiko Anse[1], and Tsutomu Tabe[1]

[1] Aoyama Gakuin University 5-10-1 Fuchinobe, Sagamihara-shi, Kanagawa, 229-8558, Japan
a5705030@cc.aoyama.ac.jp
{doyo,anse,tabe}@ise.aoyama.ac.jp
[2] Murata Manufacturing Co., Ltd 1-10-1 Higashikoutari, Nagaokakyo-shi, Kyoto, 617-8555, Japan
sato_noriaki@murata.co.jp

Abstract. This study focuses on the inheritance of skills that has faced difficulties through the years in Japan. Sensorimotor knowledge, which is hard to be described by words alone, is often seen in technical skills in a manufacturing environment in Japan. Interpreting sensorimotor knowledge as formal knowledge, attempts have been made to impart technical skills but have faced barriers particularly in lathe processing due to no visual check of finished quality being allowed. Thus, this study suggested training on the inheritance of skills utilizing the level of cutting sound generated in process. Novice workers served as experimental subjects for an experiment to verify the effectiveness of proposed training.

1 Introduction

Japan is rapidly graying in recent years, which has wielded an influence on manufacturing industry. In 2007, baby boomers including skilled workers who anchored a high-growth period in Japan have reached the retirement zone, and this phenomenon has raised the issues of "the inheritance of skills" that many of manufacturers are groping for an avenue to hand down proficient skills to the generations. Upon enforcement of the amended Law concerning Stabilization of Employment of Older Persons, the manufacturers have taken preventive measures including the postponement of the employment period and the acquisition of skilled retirees from other companies to stem the outflow of technical skills temporarily. The measures, however, provide no fundamental solution, and it is still in need of instituting essential measures for skill inheritance.

Manufacturing Research [1] indicates that "machining and assembling" are processes in the course of manufacturing where skill inheritance issues are likely to manifest themselves. This study examines the inheritance of skills in lathe processing, Manual Machine Tool Operation, which is a major process in "machining and assembling."

Intended for novice and skilled workers, a field hearing as a pilot study was conducted in a medical precision equipment manufacturing plant on the subject of issues

M.J. Smith and G. Salvendy (Eds.): Human Interface, Part I, HCII 2009, LNCS 5617, pp. 77–86, 2009.
© Springer-Verlag Berlin Heidelberg 2009

in the inheritance of skills in lathe processing. Preliminary findings showed that visual observation of a contact between a cutting tool and an object during precise and quick lathe processing was difficult and that a question as to what could be information for making a decision had arisen among novice workers. In their answers, skilled workers relied on their sensations in the hand and cutting sound for judgment. Their judgment criteria such as sensations in the hand and cutting sound are classified as sensorimotor knowledge that is indescribable. In particular, hand sensory information that skilled workers have will be acquired only after work is conducted on a level with them, which is difficult to get the difference in work level between novice and skilled workers across to novices. There have been earlier studies [2] and [3] on cutting sound, but the analysis of cutting sound has not taken shape and not been applied to the inheritance of skills. Focusing on auditory information, cutting sound generated in lathe processing, this study is to not only analyze cutting sound but devise a method for skill inheritance based on operation analysis so as to facilitate the inheritance. It is also intended to evaluate the possibility of improvement in work through the adoption of the proposed method and cutting sound-based training.

2 Lathe Processing and Cutting Sound

2.1 Sound Structure and Analysis Method

Lathe processing is defined as a machining operation that a rotating cylindrical object is turned and slotted with a cutting tool.

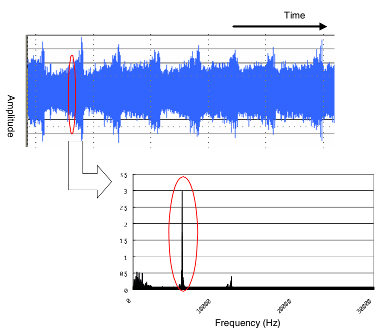

Fig. 1. FFT Separation of Frequency Components

The cutting tool operates interlocked with the lever and handle (this movement is hereinafter referred to as feed motion, the rate of feed motion as a feed speed, and the movement of the cutting tool as a feed rate), and cutting sound is produced by turning the object. Feed speed increases and decreases proportionately with a pushing force on the lever or rotating force on the handle, and variations in feed speed achieve a change in pitch of cutting sound.

Target operation in this study is slotting an 80-mm-dia SUS304 stainless steel bar 0.1mm.

Sound falls into two types, “pure sound” and “complex sound”, and sound that is usually heard is classified as complex sound. The frequency analysis is a test to examine what type of pure sound is contained in complex sound producing multifrequency and sound pressure. As with the dispersion of sunlight into a seven-color light pattern by a prism, FFT (Fast Fourier Transform) analysis allows sound to be split into frequency elements (Figure 1).

In this study, FFT analysis of data on cutting sound that is split every 0.1 second is carried out to detect the frequency of the maximum amplitude spectrum (except that of a motor) and create time-series data on the frequency (hereinafter referred to as a cutting sound chart) for analyzing cutting sound.

2.2 Graduated Lathe

A graduated lathe offers easy check of a feed rate. Slotting is defined as a combination of making a zero adjustment to a contact between the cutting tool and object and moving the cutting tool until the graduation mark indicates 0.1mm. An experiment was conducted with the utilization of a lathe with a stopper that curbed excessive slotting more than a specified amount, assuming that no error is observed in the depth of slot. The experiment was to analyze subject’s feed motion based on time-series data (hereinafter referred to as a feed rate chart) that was derived and created from a video of graduation marks taped during the experiment.

2.3 Cutting Sound Chart and Feed Rate Chart in Target Operations

The examples of the cutting sound and feed rate charts of FFT-analyzed slotting are presented in graphical form in Figure 2. Frequencies rise at the instant when the cutting tool comes into contact with the object (I: hereinafter referred to as a rise segment) and remain relatively stable until the object is slotted for the specified amount and the cutting tool starts being moved back (II: hereinafter referred to as a stable segment). Also, frequencies fall upon restoring the cutting tool to its original position (III: hereinafter referred to as a fall segment).

Chatter vibrations are created if too low or too high feed speed is observed in the rise segment or stable segment. Chatter vibration describes actual motion of the cutting tool associated with the resistance produced by the tool cutting the object. A cutting tool vibration develops a type of wave-patterned flaw in the surface of the object, which causes deterioration in quality. The cutting tool is to be used while it is vibrating in a wide range if low feed speed is obtained, which causes large chatter vibrations and forms a large wave-patterned flaw in the cut surface. In contrast, the tool is to be used while it is vibrating in a narrow range if high feed speed is obtained, which causes small chatter vibrations. If feed speed is excessively high, however, the cutting tool vibrates concomitantly with the scattering of an impulsive force developed on contact between the cutting tool and the object in other directions, which creates chatter vibrations. Thus, these findings suggest that the cutting tool be operated at appropriate speed. “Appropriate feed speed” varies with the type of machine, cutting tool, and object, and it is what only skilled workers are capable of acquiring from practical experience.

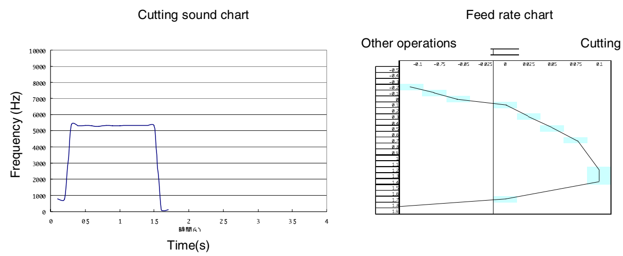

Fig. 2. Cutting Sound Chart and Feed Rate Chart in Slotting

The feed rate chart in Figure 2 shows a segment in which no fluctuations were generated in graduation marks at the tail end of the stable segment. This is a phenomenon which occurs at the instant when the handle is stopped once a slot reaches a specified depth. A momentary stoppage of the handle permits the cutting tool to be secured that keeps the shape (depth) of a slot on a spirally-cut surface even. A long stoppage of the handle, however, causes the cutting tool to develop chatter vibrations involving a high-pitched sound.

2.4 Characteristic Values of Cutting Sound during Slotting

Characteristic values for the analysis of data on cutting sound produced during target operation are comprised of the followings: “rise time”, “stable time”, “fall time”, “maximum frequency”, and “instability index.” The characteristic values are described below.

- Rise time .This is defined as time in the rise segment. Long rise time denotes that the cutting tool is touching the object slowly that may cause chatter vibrations.
- Stable time .This is defined as time in the stable segment. Long stable time denotes that the cutting tool is producing slow feed motion that may cause chatter vibrations.
- Fall time. This is defined as time in the fall segment. The cutting tool may develop deflections if it is returned slowly to its original position in the fall segment. Quick return is desirable.
- Maximum frequency. This is defined as the maximum frequency detected in the progression of cutting sound. The maximum frequency increases with increase in feed speed, and it decreases with decrease in feed speed. The handle causes an increase in the maximum frequency if it is rotated with undue force in the stable segment. Operation becomes unstable if performed with undue force, which may lead to inconsistent quality.
- Instability index Lathe processing requires the constant-speed turning of the handle as a basis. Variations in frequencies in the stable segment will be minimized if the handle is turned with a uniform speed. The standard deviation of frequencies in the stable segment for each trial run is defined as an instability index so as to evaluate the stability of the operating handle movement performed by subjects.

The standard deviation of the above-listed characteristic values is used as a means of judging that constant and stable lathe processing is gained each time in several attempts.

3 Experiment

3.1 Experimental Procedure

The verification experiment was carried out on one skilled worker and two novice workers as experimental subjects, according to the following procedure.

1. As a present data analysis, each subject performed slotting five times consecutively. Cutting sound was recorded, and handle graduation marks were videotaped.
2. The novices received explanations on that different feed motion would result in a difference in the waveform of cutting sound as an outcome of cutting, according to the cutting sound chart and feed rate chart. Given an explanation for differences in feed motion and cutting sound between the novices and a skilled worker, the novices received 30-minutes of training by comparing cutting sound produced by them to that produced by the skilled worker, which allows them to establish criteria to judge cutting sound during work.
3. The two novice workers performed slotting five times consecutively after training to evaluate achievements of training. As with the present data analysis, cutting sound was recorded, and handle graduation marks were videotaped.

Roland EDIROL R-09 IC recorder was used for recording cutting sound, and Dell Precision470 XEON3.6GHz computer was used for conducting FFT analysis.

3.2 Experimental Results and Discussion

Figure 3 shows the characteristic values of cutting sound created by the subjects, and Figure 4 gives the examples of the cutting sound chart and feed rate chart.

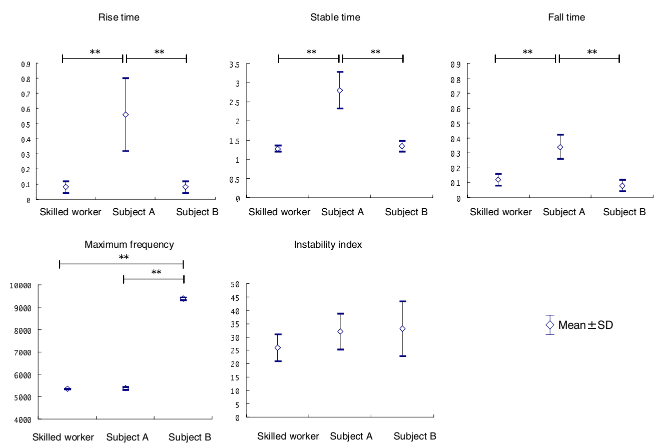

Fig. 3. Characteristic Values of Subjects

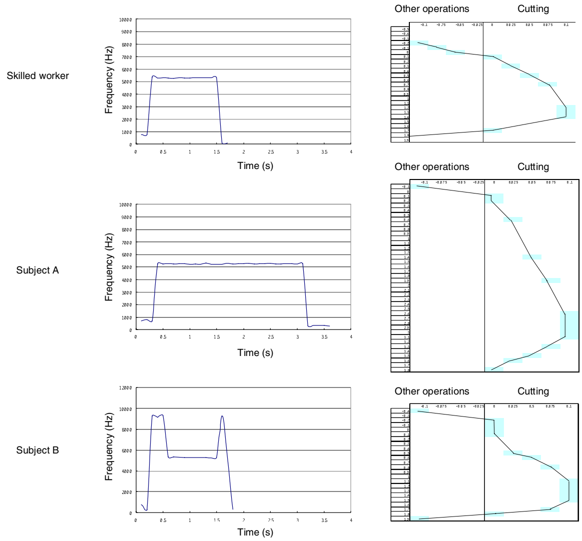

Fig. 4. Examples of Individual Cutting Sound Charts and Feed Rate Charts

The skilled worker's work was characterized by the fact that he moved the cutting tool off the object and then started cutting at initial rate. Frequencies reached the maximum (approx. 5300Hz) at the beginning of the stable segment and made a smooth progression over a stable frequency band ranging between 5200 and 5300Hz. The rise time and fall time was recorded the average of 0.1 second each, and the stable time was recorded that of 1.3 seconds. The feed rate chart testifies that the skilled worker commenced a slow adjustment once the graduation mark reached 0.075 to bring the rate close to a desired value.

Subject A's work showed that frequencies in the stable segment made a gradual progression over a stable frequency band ranging between 5250 and 5230Hz, which was an inconsistent shift, and a high frequency was obtained at the end of the stable segment. The average rise time was 0.5 seconds, the average fall time was 0.3 seconds, and the average stable time was 2.8 seconds, which demonstrated longer overall operation time than the skilled worker.

In Subject B's work, a 9000-Hz high-pitched sound was produced at the end of the rise segment and remained in a frequency band ranging between 5250 and 5300Hz in the stable segment. The same high-pitched sound was again produced at the beginning of the fall segment. The rise time and fall time was recorded the average of 0.1 second each, and the stable time was recorded that of 1.3 seconds.

Differences between skilled worker and Subject A

As to the rise segment, Subject A started gradual feed motion with respect to 0 on the graduation mark, while the skilled worker rotated the handle backward by generating an initial rate. The cutting tool that Subject A was holding was slightly touching the bar while he was making sure of 0 on the graduation mark, which resulted in longer rise time as compared with the skilled worker.

In the stable segment, Subject A performed feed motion a little at a time at approx. a third of the speed that the skilled worker took, which caused the stable time to be longer than that the skilled worker obtained. These findings inferred that Subject A exercised considerable care in work operations. In Subject A's work, low feed speed was obtained that caused large chatter vibrations. A large wave-patterned flaw in the cut surface of the object was observed under a microscope.

As with the skilled worker, it is believed that a worker is capable of quick rotating of the handle after moving the cutting tool off the object and commencing cutting at initial rate, which deliver stable frequencies in the stable segment.

- While the skilled worker rotated the handle upon loosening his hold of it in the fall segment, Subject A was trying to restore the handle once before actually rotating it. Also, his gradual restoring of the handle developed rattles of the cutting tool and rasp (wide-ranging frequency components). These findings showed that the handle was required to be jerked back at the moment when it was loosened.
- A large standard deviation subdivided into the rise time, stable time, fall time, and maximum frequency was observed in Subject A, which could be interpreted as inconsistent feed motion every time attributed to slow operation.

Differences between skilled worker and Subject B

Although the findings revealed that Subject B's and the skilled worker's work was similar in operation time and motion, a 9000-Hz high-pitched sound was developed at the end of the rise segment in Subject B's work. This is a phenomenon which is caused by undue force on feed motion. As with Subject A, Subject B started feed motion with respect to 0 on the graduation mark but rotational speed of the handle was much faster. A probable cause of handle rotation with undue force may be that Subject B was bearing down the cutting tool against high resistance generated on contact between the tool and the object. Also, Subject B's quick work allowed a small standard deviation in the rise time, stable time, and fall time. However, inconsistent exerting of a force every time caused a large standard deviation of maximum frequency.

These findings inferred that Subject B was unable to control the handle due to undue force. Therefore, for Subject B to start cutting at initial rate as with the skilled worker will be a solution to the problems of bearing down and high-pitched sound.

As with Subject A, Subject B was also trying to loosen and restore the handle once before rotating it. Then, Subject B rotated the handle with force rattling the cutting tool, which developed a 9000-Hz high-pitched sound at the beginning of the fall segment.

3.3 Instructions

The following instructions were provided to Subject A and Subject B using the cutting sound chart and feed rate chart based on the results of the above analysis, and 30-minute training followed.

Subject A

Commence cutting at initial rate.

- To ensure stable cutting with constant feed motion
- To reduce the rise segment

Gain a threefold speedup to enhance feed motion

- To improve wiggly feed motion
- To accelerate operation time
- To maintain a frequency band in the stable segment constant

Loosen the hand and handle at the same time.

- To reduce the fall segment and have the cutting tool free of vibrations

Subject B

Commence cutting at initial rate.

- To remove undue force
- To maintain a frequency band in the stable segment constant by adjusting the force of feed motion

When securing the handle, restore the handle immediately when a high-pitched sound arises.

- To have the cutting tool free of vibrations

3.4 Results of Training

Figure 5 shows the characteristic values of cutting sound created by the subjects, and Figure 6 gives the examples of the cutting sound chart and feed rate chart.

Subject A accelerated operation time from 3.8 seconds to 1.4 seconds after training, which shortened the overall operation time. Also, reductions in the rise segment, stable segment, and fall segment were accomplished and the cutting sound chart showed signs of improvement. The result proves that Subject A moved closer to the skilled worker.

Subject B eliminated a 9000-Hz high-pitched sound that had been observed at the end of rise segment and at the beginning of the fall segment before training.

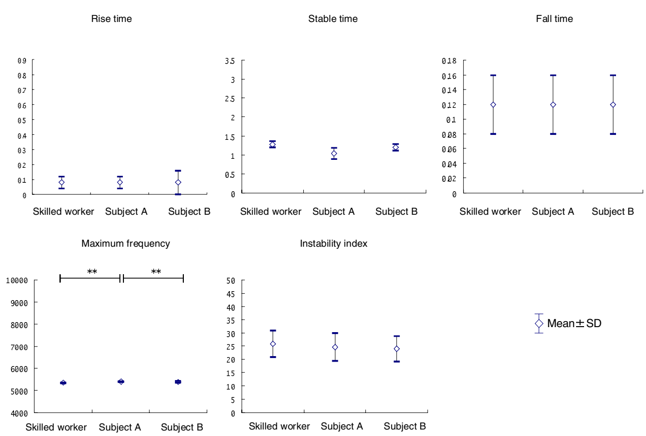

Fig. 5. Characteristic Values of Subjects after Training

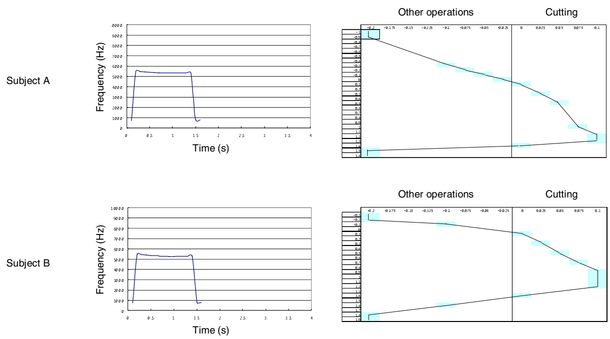

Fig. 6. Examples of Individual Cutting Sound Charts and Feed Rate Charts after Training

Subject A and Subject B attained smaller instability index as well and ensured stable operations while paying attention to cutting sound.

In the fall segment, both subjects became capable of restoring the handles to the 0 position on the graduation mark in 0.1 second upon loosening their hold of them, as with the skilled worker.

The skilled worker checked the cut surface of the subject’s trial samples under a microscope, and the check found their finished quality was much the same as the skilled worker’s.

4 Conclusions and Future Development

This study examined the inheritance of skills with the utilization of cutting sound produced in lathe processing, Manual Machine Tool Operation.

The pilot study ascertained that the extraction of skills was practicable with the use of cutting sound. By analyzing differences in operations according to the cutting sound chart and feed rate chart, this study suggested training on the inheritance of skills utilizing cutting sound developed in skilled worker’s work operation. With two novice workers as subjects, the analysis of cutting sound generated in their slotting process under the same operating conditions was carried out along with the analysis of a feed rate, in accordance with the proposed training, to clarify the differences between the skilled worker and novice workers. The findings of cutting sound data-based training revealed the two novice workers refined their skills that allowed themselves to get close to the level of skilled worker's work.

This study adopted a simple operation, slotting, to conduct an experiment, but it poses a potential problem that it is conceivable that complicated shapes could complexity cutting sound change in process. The potential problem prods verification of the effectiveness of cutting sound data-based training in operations requiring complex changes in cutting sound.

This study still leaves room for future studies on sound type based on discriminability, given the fact that cutting sound varies with the type of materials.

References

1. Monozukuri, N.: Manufacturing Research 2005(10) (2005)
2. Shimizu, R., Shimosaka, H., Ehara, N.: Estimation of Machining Skill Using Cutting Sound. Proceedings of the Japan Society of Mechanical Engineers 1997(2), 159–160 (1997)
3. Suzuki, T., Shimosaka, H., Ehara, N.: Propriety Distinction at Byte Sending Speed Using Cutting Sound. In: Proceedings of the Japan Society of Mechanical Engineers Tohoku Branch, vol. 41, pp. 171–172 (2006)