Development of a Safety Simulator for Lathe Turning

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This paper deals with the development of a desktop safety simulator ("simulator") to ensure safe lathe turning ("cutting"). The revolving center for supporting work in the cutting plays an important role of holding the work against come-off and fly-off, though the revolving center is inclined to be avoided partly because its usage is bothersome. One of the possible worst cases due to no use of the revolving center is that a fatal accident is caused by the work come-off and fly-off. The necessity of using the revolving center depends on the protrusion length of the work from the chuck. However, the judgment of such necessity is too difficult to make for those who are not familiar with the cutting.

In view of the above, this study intends to conduct experiments of risky work come-off and fly-off in order to clarify the conditions of the work come-off and fly-off and reflect the experimental data in the configuration of the simulator. To the configured simulator, the cutting conditions are inputted. Then, the simulator simulates the cutting on a PC screen. If any of the inputted cutting conditions is judged dangerous, the work vigorously comes off and flies off, and "WORK FLIED" is displayed on the PC screen. Since this simulation is run on the PC screen, the operator can safely learn how the work comes off and flies off. This study is to develop such a simulator for use in safety education that can be operated as if playing a game with no worry about injury.

Keywords: Lathe Turning, Safe Operation, Simulator

1. Introduction

In the cutting field, the NC (numeric control) operation is programed. Before the cutting starts, the safety guard forcibly closes against the access to the motion space to form a safety structure. An NC lathe is one of the lathes of safety structure to ensure safety against fatal accidents due to operator's being caught up or work come-off and fly-off. In fact, however, there are quite a few cases where work comes off from the chuck and flies off due to inappropriate conditions of the cutting. The NC program is designed by proficient technicians who are familiar with the cutting. To master the cutting, general-purpose lathes are indispensable. The general-purpose lathe has no safety guard, so that the operator can freely access to dangerous spaces to raise the working efficiency. However, this induces risks as seen in annual reports of accidents caused by general-purpose lathes.

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Among all troubles, work come-off and fly-off occasionally may incur fatal accidents, and even if injury is not accompanied, cause a massive loss, such as product defects and machine breakage, and is more than close call for operators.

The operation of general-purpose lathes requires a lot of intuition and knack backed up by longstanding experience and proficiency, and, therefore, they say it takes an operator as long as ten years to be able to skillfully operate general-purpose lathes. For this reason, it is difficult for inexperienced operators, who cannot judge the necessity of using the revolving center to support the work or the extent of risk in the setup operation, to master lathe operation.

In this paper, for the purpose of avoiding serious risk, such as work come-off and fly-off, in the three-jaw chucking operation for general-purpose lathes, the authors conduct experiments of the cutting accompanied by work come-off and fly-off, analyze the possible cases of work come-off and fly-off and the degree of their influence, and, based on the analysis data, develop and fabricate a "safety simulator cutting on lathes for use in safety education."

When an inexperienced operator or the like operates general-purpose lathe, he/she inputs various cutting data, such as cutting depth, to the simulator, and simulates the cutting on the PC screen. If any of the inputted cutting conditions is defective, the work vigorously comes off and flies off, and "WORK FLIED" is displayed on the PC screen, urging the re-setting of the cutting conditions.

It is expected that every operator will able to instinctively learn the marginal conditions of work come-off and fly-off through the simulator, and thereby prevent accidents and disasters. In this paper, the work material used is only S45C, various experiments are repeated, and the development of tools for the simulator and their effectiveness are verified.

The fabrication of the simulator was roughly divided into two fields－the creation of basic data, and the development of software based on the basic data. The software development was carried out by information experts.

Fig.1 General-purpose center lathe

Lathe: A type of machine tools, which is designed for revolving and cutting work with a cutting tool called "byte." It covers various, most basic machining, including convex cutting, boring, drilling, threading and cutting-off.

2. Work Samples and Experimental System

For the experiments, a general-purpose center lathe (WASINO LEO-80A) and a three-jaw chuck of 230mm in outside diameter (KITAGAWA KA-6) are used. In the experiments, the cutting is limited to the outside diameter portions. The work material is S45C (HB210), which is most frequently used by students for practical training, etc. The work is prepared in three different diameters of 60mn, 80m and 100mm, three different lengths of 150mm, 160mm and 170mm, and three different chucking lengths of 10mm, 20mm and 30mm. The protrusion length from the chuck is fixed to 140mm. Since experimenting work come-off and fly-off is extremely risky, a measure should be taken to prevent it during the experimentation. For this purpose, an experimental system as shown in Fig. 2 is fabricated, a hole (right circular cone) is made in the work with a center drill, and the revolving center is locked in such a way that it is at a distance of approx. 1mm from the vertex of the hole in the work. If the work comes off and flies off during the cutting, the work displaces and comes to contact the revolving center, and revolves accordingly. The revolution at that time is detected by a reflective sensor mounted above the revolving center, and alerted by the lamp lighting and the buzzer sounding. This structure is schematically depicted in Fig. 3. Also, the cutting resistance is measured to create the data, which is indispensable to configure the simulator, as shown in Fig. 4. As a dynamometer, Kistler Dynamometer is used.

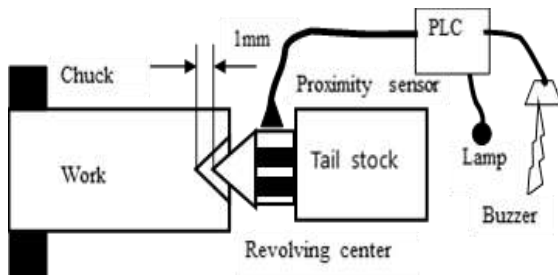Fig.2 Experiment of work come-off and fly-off detection

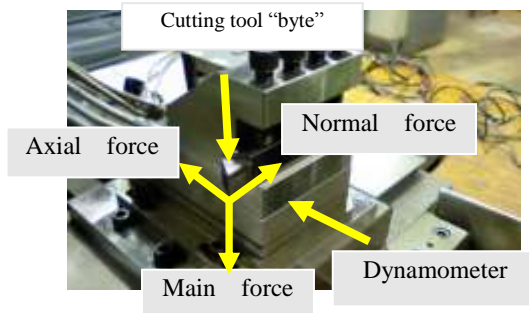Fig.3 Experimental system for work come-off and fly-off detection

Fig.4 Measurement system for cutting force

3. Experimental Conditions and Evaluation Cases

The external turning tool used for the experimentation is of such specifications as the upper take angle of 5°, the back clearance angle of 5°, the tool material of cermet alloy, and the chip breaker of triangular tip for throwaway at the rake angle of 10°. Table 1 shows the experimental conditions. The chucking torque shows the turning torque of the chuck handle. When the work is tightened by the chuck handle, chucking force is generated. The chucking torque, at which the operators tighten the work in person, is different from the chucking force. Based on the reports of investigation made on 44 male and female students, the obtained chucking torques are classified into three groups of 110 (N·m), 140 (N·m), and 160 (N·m), which are further divided for better feeling and recognition into three intensity levels of "Weak," "Medium" and "Strong." Three evaluation cases are set: (1) Normal cutting, (2) cutting accompanied by work come-off and fly-off, and ③ cutting accompanied by work sinking into the chuck. The actual work setting state is shown in Fig. 5.

Table.1 Experimental conditions (Dry cutting)

Chucking torque	Weak（110N·m）	Medium（140N·m）	Strong（160N·m）
Chucking force	244×100(N)	305×100(N)	366×100(N)
Cutting speed	114,116,126(m/min)	114,116,126(m/min)	114,116,126(m/min)
Chucking length	10(mm)	20(mm)	30(mm)
Cutting depth (D)	2(mm)	4(mm)	6(mm)
Cutting velocity	0.21(mm/rev)	0.25(mm/rev)	0.32,（ mm/rev)
Work diameter	60(mm)～100(mm)	60(mm)～100(mm)	60(mm)～100(mm)

Fig.5 Three-jaw chuck

4. Relation between Chucking Force and Chucking Torque

Since the chucking torque is reflected in the chucking force when the chuck handle is turned, the relation between the chucking torque and the checking force should be obtained. The measuring system for the turning torque of the chuck handle, which is an important component of the simulator, is designed and fabricated by using a strain gauge and a PLC for simplicity. The torque measuring system is calibrated to adjust the torque by using a torque wrench available in the market, and the chucking torques of 44 male and female students are obtained. Thereby, the effective range of the tightening torques with the upper and lower limits is determined.

Then, the chucking force generated by the tightening torques is obtained, and the relation between the chucking

handle turning torque and the work chucking force is obtained. This is an important measurement experiment for grasping the calculative relation of the work come-off from the chuck, and the force required for the work sinking into the chuck.

As shown in Fig. 6, the authors have developed a chucking force measuring system to obtain the relation between the chucking force and the chucking torque.

Furthermore, in order to narrow down the work fly-off extent and reduce the number of experiments, finite element analysis is made concurrently, and experiments are conducted to investigate the relation among the chuck handle turning torque, the chucking force and the work fly-off based on the experimentally obtained basic data. For analysis, the contact analysis of the finite element analysis is made by using analysis software "ANSYS." Fig. 7 shows the finite element analysis made in the investigative experiments.
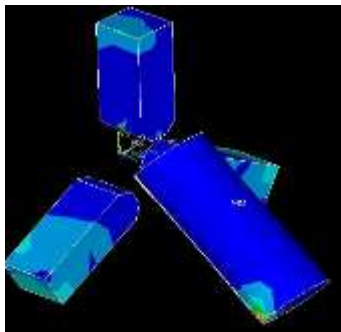

Fig.6 Measuring system for chucking force

Fig.7 Finite element analysis

5. Experimental Results and Their Considerations

5.1 Results of evaluation of work come-off and fly-off specific to work diameter and cutting area, and their considerations

Figs. 8, 9 and 10 show the chucking lengths, the cutting areas, the work diameters, the chucking torques, and the work come-off and fly-off limits. Fig. 8 shows the work come-off and fly-off limits of the shortest chucking length of 10mm. The largest cutting area at the chucking torque of 110 (N・m) for the work diameter of 100mm is $0.32mm^2$ (feed velocity 0.32mm/rev × cutting depth 1mm). In contrast, at the chucking torques of 140 (N・m) and 160 (N・m), the work up to 100mm in diameter can be cut up to the largest cutting area of $0.5mm^2$ (feed velocity 0.25mm/rev × cutting depth 2mm). In Fig. 9, at the chucking length of 20mm, where the largest cutting area is on the same tendency as the

case with the chucking length of 10mm, the work of 80mm and 100mm in diameter can be cut up to $0.5mm^2$ (feed velocity 0.25mm/rev × cutting depth 2mm). For the work of 60mm in diameter, at the chucking torque of 160 (N・m), an infinitesimally small increase of $0.1mm^2$ is shown from the case at the chucking torque of 110 (N・m). Fig. 10 shows the data at the longest chucking length of 30mm. At the chucking toques of 140 (N・m) and 160 (N・m), the work can be cut up to $0.5mm^2$ for all diameters (feed velocity 0.25mm/rev × cutting depth 2mm). From these results, the chucking torque should be 140 (N・m) and 160 (N・m) or more to achieve stable cutting. On the other hand, compared with the work diameter of 60mm, the work diameter of 100mm tends to be larger in cutting area and less frequent in the occurrence of work come-off and fly-off. The cutting torque is indicated as $T = Ft・D/2$ (Ft is the main component force), which shows the reverse trend here because the larger the diameter becomes, the larger the cutting torque facilitates the occurrence of work come-off and fly-off. Since the cutting resistance remains in the same range under the same conditions, on the chucking side as well, the larger diameter (radius × chucking torque) is more influential than the cutting torque, which seems to be substantially related to the roundness of the work holding portion of the three-jaw chuck. This is an assignment to be dealt with. Fig. 11 shows a scene of the experiment.
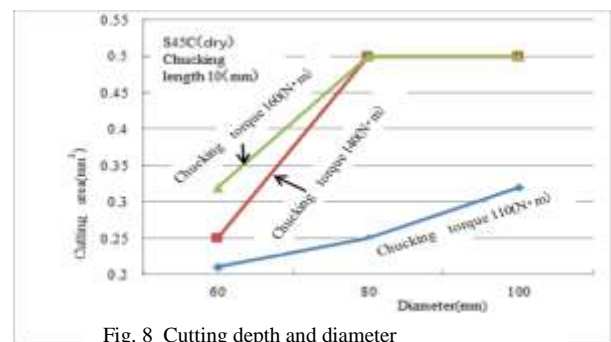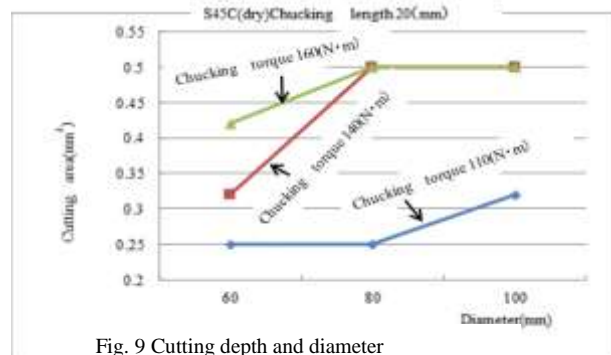

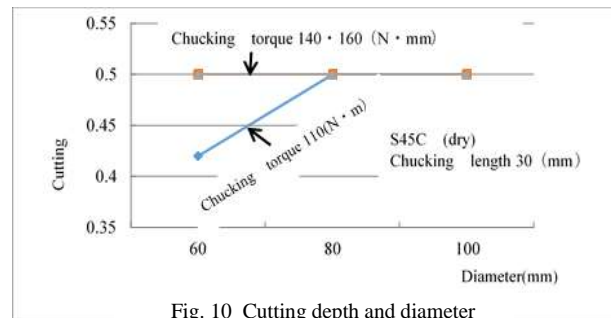Fig. 8 Cutting depth and diameter

Fig. 9 Cutting depth and diameter

Fig. 10 Cutting depth and diameter

Fig. 11 Work come-off and fly-off experiment

5.2 Composition of the safety simulator for lathe turning

The operating environment used for the software development is as follows:

OS: Windows XP

Development language: Java, Java3D, Java Communications API (serial communication)

UI: Swing (to ensure the same layout regardless of OS)

Java was used as a development language. Java can be used for OS of any environment (e.g., Macintosh, Linux), while VB and C++ are easier for creating GUI (graphical user interface) but applicable only to Windows. At first, 3D creation was tried by using OpenGL, but switched to Java3D because no class was available to column creation.
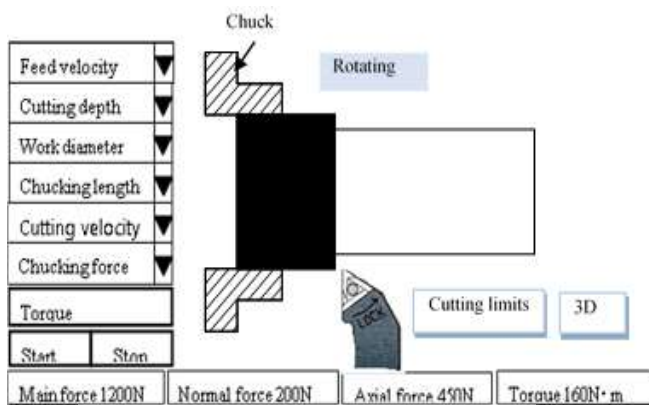

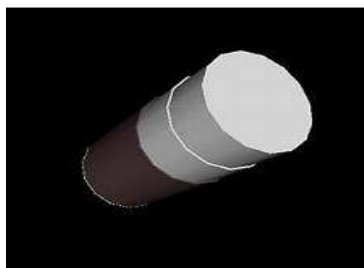Fig.12 Safety simulator for lathe turning
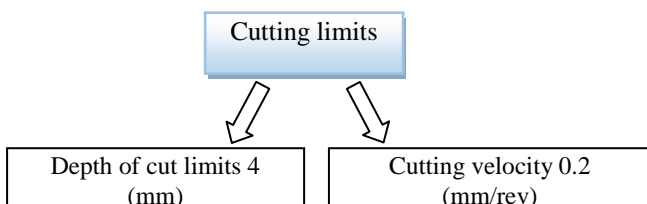

Fig.13 3D display screen

Fig.14 Cutting depth limit 4

Work come-off and fly-off experiments are conducted on the work of 60mm, 80mm and 100mm in diameter to obtain the relation among the cutting area, the chucking length and the chucking torque. Fig. 12 shows the screen of the "safety simulator for lathe turning" for use in safety education, which was developed based on the experimental results. This software was developed by using Java with various experimental data incorporated in it for judging danger. If the safety limits are exceeded, the occurrence of work come-off and fly-off is displayed, and the simulation is interrupted. In Fig. 13, the entire 3D image of the work cut in the simulation is turned around to show in animation.

To simulate the cutting, firstly, the operator selectively inputs the intensity level of the chucking torque from among "Weak," "Medium" and "Strong." In order for the operator to enable this input, he/she should grasp his/her chucking torque beforehand. Each operator is requested to measure his/her chucking torque with the chuck handle turning torque measuring equipment described in Section 4 and grasp his/her chucking torque. Then, the operator inputs the feed velocity, the cutting depth, the work diameter, the chucking length and the cutting velocity from the respective control select boxes, and presses the START button to start the cutting operation. At that time, three component forces of the then cutting resistance (main component force, thrust component force, feed component force) are displayed. If the selected cutting conditions are not satisfied, "WORK FLIED" is displayed. Fig. 14 shows the "cutting limits" button provided in the final response to the cutting limit value. The maximum cutting depth and the maximum feed velocity, which are permitted under the selected conditions, are displayed. When these maximum values are not exceeded, the cutting operation is safe with no work come-off and fly-off.

5.3 Application to the NC lathe program

As shown in Fig. 15, the chucking torque (oil pressure gauge) and various conditions are inputted and "Cutting limits" shown in Fig. 14 are displayed in the NC lathe turning operation, and the cutting depth limits and the feed velocity are grasped at the time of NC programing. This prevents the work come-off and fly-off to ensure efficient cutting operation.
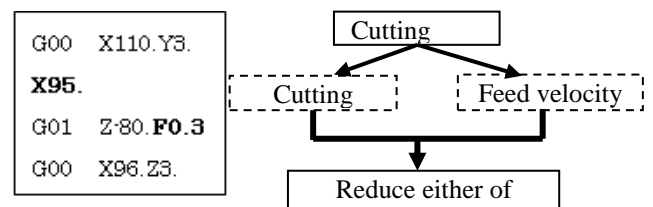
(a) NC program

(b) Selection of conditions to prevent work come-off and fly-off

Fig15 NC program and cutting limit

6. Chucking Torque Adjusting Jig

The chuck handle turning torque, which is related most closely to the work come-off and fly-off, is set in simulation to "Weak: 10 (N・m), Medium: 140 (N・m) and Strong: 160 (N・m)." In actual operation, it requires considerable degree of proficiency and intuition to precisely tighten the work at such chucking torques. To solve this problem, the authors have developed such a "torque adjustment chucking jig" as shown in Fig. 16 that allows everybody to repetitively tighten the work at a constant chucking force. This jig has incorporated a strong spring into three locations in the outer circumstance. At the end of each spring, a steel ball is deposited. The spring force is adjusted according to the chucking torque by the mounted screw. Three jigs are fabricated, one for "Weak," one for "Medium" and the other for "Strong." These jigs are calibrated, and used for chucking. By using these jigs, unevenness in chucking toque varied operator by operator can be eliminated, even chucking torque is ensured regardless of operators, and precise simulation can be realized.

(a) Chucking torque adjusting jig   (b) Replacing the hig

Fig16 Chucking torque adjusting jig

For a person who has never operated a lathe, it is difficult to predict the intensity of rotational energy of the lathe and various risks due to the rotational energy. For this reason, there is no end of lathe accidents, such as being caught, being hit by flying work, and incised wounds.

Among all, accidents caused by flying work due to unaccustomed operation often lead to fatal accidents. They say that it takes many years to make a full-fledged operator. In the course of becoming a proficient operator, every operator should have various dangerous experiences. When a person first tries lathe operation at a practical training site, he/she has little sensitivity to the danger of lathe operation.

The authors have developed the simulator for use in safety education for such beginners, and put the simulator into practical use as a cutting training material for beginners who are not yet ready for starting lathe operation.

Fig. 17 shows a scene of training of lathe operation by using the simulator. Since lathe operation can be learned as if it were a game, the simulator is favorably evaluated by students. A strong point of the simulator is that various conditions obtained through the simulator can be reflected in the practical lathe operation. In fact, since this software was introduced, the students have become more cautious of lathe operation, which has reduced the number of accidents caused by the work come-off and fly-off. Some students carefully repeat tightening, from which the authors presume that the effect of the simulator has begun to exert.

This desktop simulator is useful for inexperienced operators who cannot judge whether or not the work will "come off and fly off."

Fig.17 A scene of training by using the simulator

Many operators, who have been accustomed to lathe operation to a certain extent and can roughly make a judgment of work come-off and fly-off, do not push the work-supporting revolving center at times. This is because they anticipate "botheration" or "troublesomess" about the break of the center drill or the interference of the cutting tool "byte" with the revolving center. This human error may cause fatal accidents. Also, by using the simulator, the operators can learn the limits of the cutting conditions, and the necessity of using the revolving center.

References

[1] Tetsuo Matsuo, Atsuhiko Noda, Yoshiyuki Matsuno, Mitsuji Hino and Hideki Shibahara: Friendly Mechanical Engineering; Morikita Publishing, pp. 104－114., 1998

[2] Hiroshi Nakazawa, Toshiyuki Obikawa et al.: Principle of Production and Processing; JSME, Nikkan Kogyo Shimbun, pp. 103－120., 1998

[3] Toshimichi Moriwaki *et al.*; Design Engineering for Machinery (Basic Edition); JMTBA, pp. 27－44., 1998

[4] Etsuo Marui: Ultraprecision Machining; Corona Publishing, pp. 53－95., 1997

[5] Keizo Sakuma, Katsumasa Saito and Tetsuo Matsuo: Machining Techniques; Asakura Publishing, pp. 5－46., 1984

[6] Japanese Industrial Standards: Disc Springs; JIS B2706：2001

[7] Japan Industrial Safety & Health Association, MHLW: 2015 Indexes of Safety; pp. 2－14., 2015