Research Article

ISSN 2639-9466

Nanotechnology & Applications

Dynamic Analyses of Damping Alloy Sleeves for Boring

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Received: 25 October 2018; Accepted: 29 November 2018

Citation: Yuto Horigome, Fumihito Sakurai, Shinichi Nishida. Dynamic Analyses of Damping Alloy Sleeves for Boring. Nano Tech Appl. 2018; 1(2): 1-4.

ABSTRACT

Since the overhang of the boring bar is large in the boring process using the NC lathe, the vibration of the boring bar is often a problem. It is necessary to reduce the tool vibration because surface roughness and tool life are greatly affected by the tool vibration. In this study, the application of damping alloy for the NC lathe sleeve was proposed. The characteristic of damping alloy is absorb vibration by transforming dynamic energy of the vibration into heat energy. A cutting experiment was operated by using the new type sleeve made of only damping alloy and the traditional type sleeve made of steel. The results such as vibration, surface roughness and tool life are compared between the both tools. The tool vibration became small and the tool life became long with new type sleeve compared to the traditional type sleeve. However the surface roughness became large by using new type sleeve. It is supposed that the rigid of new type sleeve is smaller than that of traditional type sleeve.

Therefore, the composite sleeve that was combined with damping alloy and steel was developed for improving the rigidity. As a result, the tool vibration using the composite sleeve indicated one fifth and the surface roughness became half compared to the steel sleeve. The vibration analysis based on this experimental results was studied to clarify the vibration mechanism. The modal analysis was operated with the structural analysis software by using 3D models. And the FFT analysis was operated by the vibration data. As a result, it was revealed that the natural frequency of cutting tool system with new type sleeve was changed compared to the traditional system. And it was revealed that the bending mode frequency was closed to the twist mode frequency.

Keywords
Damping alloy, Boring, Sleeve, FFT analysis, Modal analysis.

Introduction
In recent years, the boring process with the lathe is increasing. Machining by the lathe is able to short time by continuous machining of outer diameter cutting and inner diameter cutting. However, when the overhang amount of the tool become too large at boring with the NC lathe, the tool vibration often become a problem at boring. The surface roughness are increased and tool life are decreased by the large tool vibration. Therefore, it is necessary to reduce the tool vibration at boring process with NC lathe [1,2].

In this study, Twin-deformation-type damping alloy that causes internal friction with twin deformation when vibration is added was used [3]. The characteristic of damping alloy is absorbing vibration by transforming dynamic energy of the vibration into heat energy. The application method of this alloy to the cutting system has not been clarified. In this paper, this alloy was applied to sleeve for improving surface roughness and tool life. Experimental results, FFT analysis and modal analysis were combined to investigate optimum cutting condition when applied damping alloy.

Experimental Equipment
Table 1 shows the mechanical properties of the damping alloy. Fig. 1 shows the application method of the damping alloy. The photograph shows the case using the φ20 boring tool. The damping alloy was applied to the sleeve that grips the boring tool. Figure 2 shows the 3D model of φ20 composite sleeve. The composite sleeve is a sleeve combining steel and damping alloy. This sleeve has a double structure for securing rigidity, and screw coupling is used for expansion of the contact area. Daido Steel Co., Ltd. provided damping alloy and sleeve. Currently, production is over. Figure 3 shows the acceleration pickup which detects vibration. In the case of the φ20 boring tool, it was attached to the back end of the boring tool. In the case of the φ10 boring tool, it was attached to the tool rest because it cannot be attached to the boring tool. Figure

4 shows the surface roughness measurement position. Arithmetic average roughness in the feed direction was measured. Figure 5 shows the tool's flank wear amount.

Young's modulus [GPa]	Poisson's ratio	Proof strength 0.2% [MPa]	Tensile strength [MPa]
80	0.301	265	530

Table1: Mechanical properties of damping alloy.

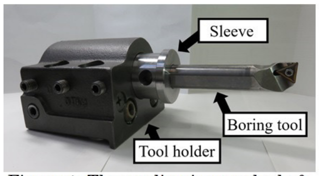

Figure 1: The application method of the damping alloy.

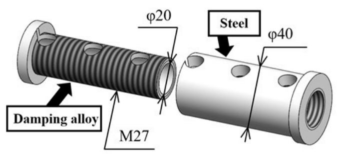

Figure 2: The 3D model of φ20 composite sleeve.

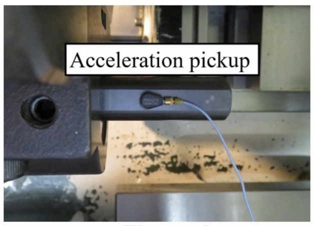

Figure 3: The acceleration pickup (the φ20 boring) tool.

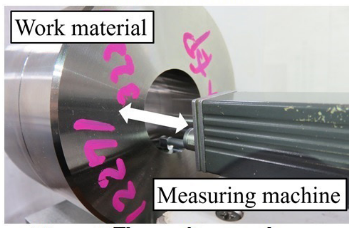

Figure 4: The surface roughness measurement.

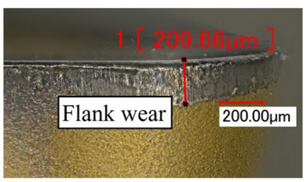

Figure 5: The tool wear measurement.

Effectiveness of Damping Alloy

Experimental conditions

Boling process was carried out using φ20 boring tool. Three sleeves, that the commercially available sleeve made of only steel, the sleeve made of only damping alloy and the composite sleeve, were compared. The tool overhang amount was 100 mm (L/D ratio = 5). The L/D ratio is the ratio of the overhang amount and the tool diameter. The cutting speed was 100 m/min, the depth of cut was 1 mm, and the feed rate was 0.05 mm/rev. The work material was SKD61 (outer diameter 100 mm, inner diameter 30 mm).

Experimental Results and Discussion

Table 2 shows measurement results of vibration acceleration, surface roughness and tool wear. Compared to the sleeve made of only steel, the sleeve made of damping alloy did not show a large reduction in vibration. But the composite sleeve drastically reduced the vibration. Damping alloy has lower Young's modulus and lower rigidity than steel. Therefore, the surface roughness increased when the damping alloy sleeve was used. It is considered that the surface roughness was reduced when using the composite sleeve in order to reduce the vibration by the damping alloy and to maintain the rigidity by the steel. The smaller the vibration acceleration was, the smaller the tool wear was.

Sleeve	Vibration acceleration [m/s^2]	Surface roughness [µm]	Tool wear [µm]
Steel	282	0.63	257
Damping alloy	236	1.68	252
Composite	58	0.28	210

Table 2: Measurement results.

Figure 6 shows vibration waveforms of cutting with the sleeve made of only steel and Figure 7 shows the vibration waveform of cutting with the composite sleeve. The growl was confirmed in the vibration waveform of cutting with the composite sleeve. This is thought to be caused by the slight difference in the natural frequency of the steel and the damping alloy because the damping alloy reduced the vibration energy of the large resonance phenomenon. As a result, it is presumed that the vibration is canceled by mutual interference of vibration at different eigenvalues, and the vibration acceleration becomes small when using the composite sleeve.

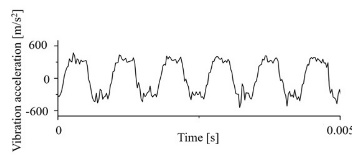

Figure 6: Vibration waveforms of cutting with the steel sleeve.

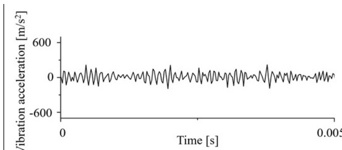

Figure 7: Vibration waveforms of cutting with the composite sleeve.

Figure 8 shows the results of FFT analysis of the vibration when using the steel sleeve and the composite sleeve. The composite sleeve suppressed the vibration in the low frequency range and peaks transited to high frequency ranges (10 kHz and 20 kHz). The resonance phenomenon that occurred in the low frequency range was dispersed over a wide frequency band, it was possible to greatly reduce the vibration.

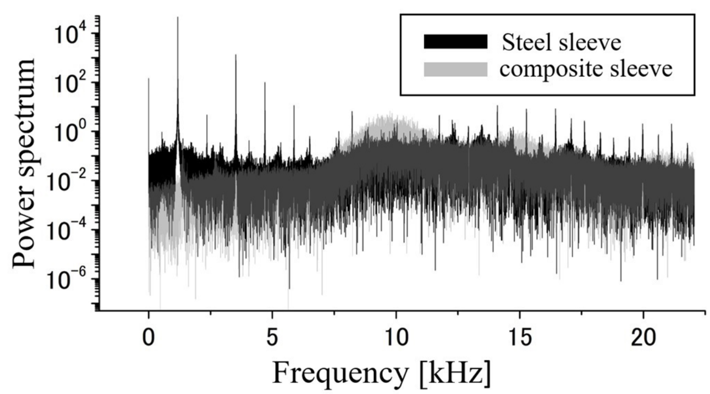

Figure 8: The FFT analysis

Simple models of boring tools, sleeves and tool holders were created using 3D-CAD software SolidWorks, and the modal analysis was performed. Figure 9 and Table 3 show the analysis results. As in the FFT analysis results, the vibration in the first mode of the composite sleeve was higher than that of the sleeve made of only steel. The primary natural frequency of the composite sleeve became close to the secondary. Also, the value of the fourth order became close to the fifth order. Therefore, it is considered that the vibration acceleration of the composite sleeve became small because the natural frequency changed due to two vibrations with different mode shapes. In the each sleeve, there are twist mode shape with a natural frequency of 9 kHz or more.

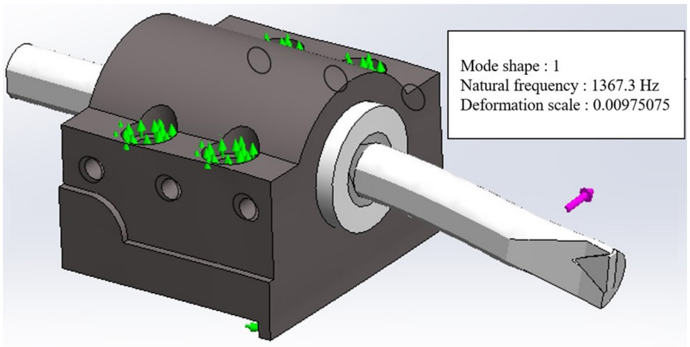

Figure 9: The modal analysis result.

the peak value (primary mode). P-value is the probability of taking an extreme value. For all factors, p-value is less than 5%, so it can be said as significant. Since the contribution rate of the depth of cut is the highest, it is considered that this factor has a large influence on the frequency transition. The cutting speed and the feed rate contribution are small. Figure 10 shows the influence of the frequency transition of the depth of cut. It was found that the frequency shifts to the lower frequency as the depth of cut is larger. It is thought that the vibration of the tool is disturbed because the cutting force increases due to an increase in the depth of cut.

Cutting condition	P-value [%]	Contribution rate
Cutting speed	4.48	4.44
Cutting amount	7.31×10^(-4)	72.68
Feed	3.71	4.94

Table 4: Result of variance analysis.

Mode	**Steel**		**Damping alloy**		**Composite**	
	Natural frequency [Hz]	**Mode shape**	**Natural frequency [Hz]**	**Mode shape**	**Natural frequency [Hz]**	**Mode shape**
1	1320	Dorsal	1267	Dorsal	1367	Dorsal
2	1569	Main	1512	Main	1470	Main
3	2083	Dorsal	2034	Dorsal	2055	Dorsal
4	2875	Dorsal	2708	Dorsal	3418	Dorsal
5	3994	Main	3907	Main	3656	Main

Table 3: Modal analysis result. Dorsal: Dorsal force direction Main : Main force direction.

From the results of the FFT analysis and the modal analysis, the natural frequency of the composite sleeve shifted to the higher frequency side than that of the sleeve made of only steel, so that the vibration in the resonance frequency range became smaller with. The vibration mode of the resonance of the compound sleeve is considered to have transited from the bending mode to the torsion mode.

Optimum Cutting Condition

Experimental conditions

From Section 3, it is considered that the natural frequency affects the vibration during cutting. Therefore, we will clarify the frequency transition due to the change in cutting conditions. The straight turning process experiment was carried out using φ20 boring tool. Because the tool often causes chipping in boring process. In previous research, the tendency of vibration of the straight turning process and the boring process was equal. The same composite sleeve (outer diameter 40 mm, inner diameter 20 mm) as in Section 3 was used. In order to efficiently analyze the relevant ratio of each factor, experimental design was used (L9 orthogonal table). The cutting speed was 60, 80, 100 m/min. The depth of cut was 0.5, 1, 1.5 mm. The feed rate was 0.05, 0.1, 0.2 mm/rev. Table.4 shows the assignment of each level. The work material was SUS 304, and it was designated as a collaborative research destination. The tendency of vibration of the work material is equal to SKD61. The repetition number is two.

Experimental Results and Discussion

Table 4 shows the result of variance analysis of the frequency of

Influence of Tool Protrusion Amount

Experimental conditions

The overhang amount of the tool become large at boring process with the NC lathe. Therefore, we confirmed the influence of the vibration acceleration due to the change in the tool’s overhang amount. The φ10 boring tool was used to make the vibration of the tool stand out. In order to change the overhang amount, the L/D ratio was set to 3, 4, 5, and 6. The cutting speed was 100 m/min, the depth of cut was 0.5 mm, and the feed rate was 0.1 mm /rev. The work material is SUS304.

Experimental Results and Discussion

Figure 11 shows the vibration acceleration at each L/D ratio. Initially, as the tool's overhang amount is larger, the tool bends and the tool cutting edge sway, so the vibration acceleration supposed to be larger. However, the vibration acceleration with the L/D ratio of 6 was the smallest. Fig.12 shows the FFT analysis results of the vibration when the L/D ratios are 3 and 4. Fig. Three peaks appeared in each sleeve (E.g. between 6 kHz and 8 kHz when L/D = 3). As the L/D ratio increased, the tendency of peak values to be dispersed was confirmed. Table 5 shows the modal analysis results of the simple models of each L/D ratio using SolidWorks. As the L/D ratio increases, the natural frequency of the primary mode decreases. Moreover, it can be confirmed that the first to fifth order mode shapes are shifted to the low frequency side. It is conceivable that the rigidity of the cutting system has decreased. Therefore, since the eigenvalues are dispersed and the vibration in the resonance frequency range becomes smaller, it is considered that the vibration acceleration becomes smaller.

Conclusion

In this study, we confirmed the effectiveness of the damping alloy for improvement of processing accuracy. In addition, optimum processing conditions and application method were discussed. Summary is below.

The composite sleeve was effective for vibration reduction.

The depth of cut most affected the frequency transition.

When it was made the specific tool's overhang amount, the tool vibration reduced.

Acknowledgment

This work was supported by the subsidy of National Institute of Technology, Gunma College. The damping alloy used by an experiment was offered than Daido Steel Co., Ltd.

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