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ON COUNTER MEASURE OF VIBRATION FOR MACHINE USING ALKALINE WATER WITH POLYMER

In the 21st century, as it is important to produce the products with high accuracy, high quality and eco-friendly, the most of manufacturers need several daring plans, unique ideas and new technologies. For example, in machine tool technology, restraint of vibration on the machine tool was required for high accuracy and quality, and several countermeasures using costly equipment and large quantity of electrical energy were used for the restraint, however those countermeasures are not enough. Therefore a countermeasure of vibration for machine tool using alkaline water with polymer was developed and evaluated. Polyethylene oxide was used for the polymer because of the low cost and the safety for health. Relationship between the mixed polymer in the alkaline water and the damping ratio were firstly investigated. And the optimum percentage of the polymer was decided for restraint of vibration on a machine tool. Then the damper structures using alkaline water with polymer were development, and the three dampers were set for restraint of vibration in the small machine tool; those are the support units, the vise and the head stock. Each damper was evaluated regarding noise and vibration on the machine tool and surface roughness on a work piece in the experiment. It is concluded from the results that; (1) the optimum percentage of the polymer for the damper was 6 wt%, (2) the damper structures using alkaline water with polymer were very effective for restraint of both noise and vibration on the machine tool and smoothly surface on the work piece.

1. INTRODUCTION

In this paper, new technology for improvements of noise and vibration on a machine tool was developed and evaluated. A small machine was used for the research and strong alkaline water [1] mixed with polymer was added in some parts of the machine. First, the relationship between the characteristics of damping and the weight ratio of the strong alkaline water with polymer was investigated in order to determine the optimum specification to be used as a damper in the machine tool. Next, these dampers were applied in three places of the small machine tool; spindle head, vise and support point. And the

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noise and the vibration characteristics were measure and evaluated for the effectiveness in the industry. Then this damper was lastly evaluated in real cutting.

The purpose of this research is to develop and evaluate techniques for improvements of noise and vibration on several machine tools in order to get an optimum cutting condition with the environment-friendly. The accuracy, quality and productivity can be obtained easier and low cost by the new techniques. The reach of this research is to investigate, to analyze and to evaluate the use of strong alkaline water with polymer PEO [2] as a damper for reducing vibration in a small milling machine and real cutting.

2. EVALUATION OF STRONG ALKALINE WATER

In factories, the use of water in machine tools is small. Because the steel parts or some machine elements have corrosion in water. However, when the pH of the strong alkaline water exceeds pH 12.5, the steel parts will not be corrode by it. Also lately in order to eliminate bacteria and prevent the growth of microorganisms, it has been used as a cleaning agent in wide areas. Here, corrosion resistance of several machine elements in the alkaline water is revealed in the experiment. Specifications of the device used for making the strong alkaline water are shown in the Table 1. As shown in the specifications, with a small generator is possible to produce strong alkaline water of pH 12.5 very easily. According to the field of corrosion engineering, in an equilibrium state when the logarithm value of metal ion concentration (mol/ℓ) is lower than -6, the metal will not be corroded. Therefore, related to the corrosion properties of strong alkaline water in the case of steel it will be necessary alkaline water with pH 10 or more for not being corroded. Therefore, the nickel and nickel-based alloy aren’t chemically corroded on the range from pH 8.5 to pH 13.0. Titanium and titanium-based alloy aren’t chemically corroded below pH 13.0. From here, a tool of titanium-based alloy or nickel-based alloy can use in strong alkaline water with Ph 10.0~13.0, and it is effect for reducing the thermal effects in the tool. The properties

Table 1. Specification of the system for making strong alkaline water

Method of generation	Closed generation type
Value of pH	pH 12.5
Quantity of generation	10 ℓ/h
Voltage & Power	Voltage & Power
Size	495W×430D×1100H

Table 2. Condition of corrosion test

Medium in the vessel	Strong alkaline water (pH 12.5)
Ambient conditions	Room temp.: 20±1℃, Humidity: 60%
Period	Two months

Table 3. The results of the materials tested in strong alkaline water with pH12.5 (for two month)

Work piece materials	Condition inside strong alkaline water	**Tool materials**	Condition inside strong alkaline water
Ti (pure)	○	High speed tool	○
		Carbide (S30T, T725X)	○
Ti6Al4V	○	Cermet (NS530)	○
		Ceramics (LX11)	○
Inconel 718	○	CBN (KBN525)	○
		Diamond (DA2200)	○
Steel (S45C)	○	**Coating materials of tool**	○
Aluminum	×	TiN	○
Copper 	Changed to dark brown 	TiC	○
		DLC	○
Brass 	Changed to dark green 	TiAlN	×
		TiAlCr	×

Symbol : ○ = No change, × = Corrode

of these materials in alkaline water against corrosion were confirmed in the experiments. Condition of corrosion test is shown in the Table 2. These materials were left in alkaline water in a room with constant temperature of 20 ± 1ºC and a humidity of 60% during two months. The alkaline water was replaced once a week for maintaining the pH 12.5.

Results of the corrosion test in strong alkaline water with pH 12.5 are shown in Table 3. In addition to pure titanium, titanium alloys, and nickel-based alloys, was also tested in work-piece as steel (S45C), aluminium, copper, brass; also in tools like high speed steel tools, carbide, cermet, ceramics, CBN and diamond; finally in coating materials of tool like TiN, TiC, DLC, TiAlN and TiAlCr. Metals such as aluminium, aluminium alloys, copper, non-copper alloy after the two months in strong alkaline water presented corrosion. As is shown in the Table 3, the color of the metal like copper and brass changed in a darker color. In the other hand, steel, titanium alloys, nickel alloys did not presented corrosion being immersed in strong alkaline water, so is possible to think in using this method for cutting.

3. EVALUATION OF DAMPING RATIO AND AMOUNT OF POLYMER TO MIX

Here the strong alkaline water was mixed with the polymer PEO (Polyethylene oxide) and was investigated for improvement of the damping ratio in the experiments. Alkaline water pH12.5 with polymer was used for the research. The polymer used was Poly Ethylene Oxide (PEO). This is a non-ionic polymer with a molecular weight ranging from 150,000 to 10 million. It has good properties has coagulation, blinding effect, thickening, and friction reduction, as good soluble with water. One of the reasons why the PEO was selected as material for regarding vibration was its high viscosity when is dissolved.

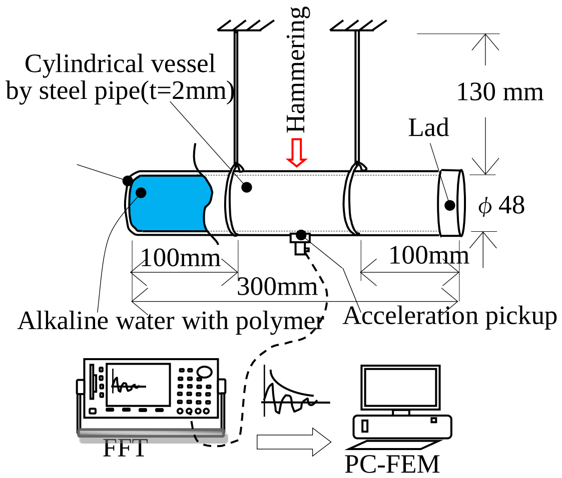


Fig. 1. Experimental setup for measuring damping ratio (Alkaline water with polymer is poured in the cylindrical vessel and it is sealed up by the lad, then damping ratio at 1st mode is measured)

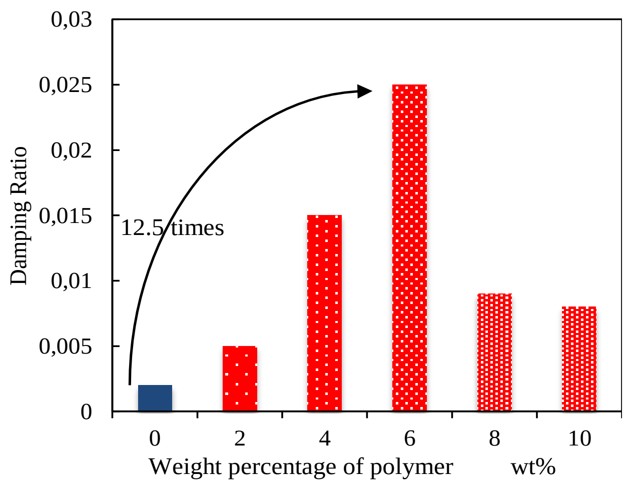


Fig. 2. Relationship between the weight percentage of the concluded polymer and the damping ratio (These damping ratios are values at 1st mode)

After the preparation of the mix of alkaline water and polymer, the setup for the experiment was prepared. Schematic view of experimental setup for measuring the damping ratio of alkaline water with polymer is shown in the Fig. 1. The setup was consisted of a steel pipe with length ℓ = 300 mm and thickness t = 2mm, the one was filled with the mix of alkaline water with polymer PEO and then hanged with a wire of ℓ=130mm in $\ell/3$ from both end sides of the pipe. The pipe is hanged on one-thirds of length and damping ratio at 1st mode is measured. The pipe was excited with an impact hammer in $\ell/2$ and the vibration response was measured with an acceleration pickup that was setup in the opposite site from where it was impacted. The damping ratio was calculated by logarithmic decrement of excitation response, but because the measured vibration comes not only from the mix, but also from the steel pipe, it was necessary to do an analysis using FEM to get the damping of only the alkaline water with polymer PEO. In this process the curves obtained in the experiment and the simulation were compared by fitting (The model of the pipe and the alkaline water with polymer are firstly made, and these vibration behaviors are calculated by the time history response analysis of FEM. At that time, damping ratios of alkaline water with polymer for input data are successively changed. When the result of the time history response analysis became same to the result of the experiment, the damping ratio of alkaline water with polymer is adopted for its property). While the polymer is added to the water, the density of this one increases. Following this, in the simulation the density of water was modified in order to fit the experimental results.

In Fig. 2, it can be appreciated how the damping ratio was increased while polymer PEO concentration was increasing in around 12.5 times. However, when the polymer PEO concentration passed the 6wt%, the damping ratio decreased. In this point, the damping ratio has reached a steady-state value when the polymer concentration exceeds 6wt%. Because there are the domain of viscoelasticity at over polymer concentration 6wt% and its behaviour was restrained. PEO was chosen for this polymer, because it is cheap, moreover, safe and harmless for the human body.

4. APPLICATION OF DAMPING MATERIAL OBTAINED BY STRONG ALKALINE WATER WITH POLYMER PEO IN A SMALL MILLING MACHINE

Recently, space-saving and light weight are required for machine tools, but also ensuring the static and dynamic stiffness of the machine structure by reinforcing it with ribs [3] and with advanced materials [4],[5]. Further, an effective countermeasure for vibration damping is necessary to identify the suitable main parts [6], and we used the strong alkaline water with polymer as a damping material in several machines. It was firstly used in the small machine tool and work-piece part near origin of the large vibration.

Specifications of the small machine tool used are shown in the Table 4. The small milling machine MODELA MDX-20 is an extremely compact computer controlled of size of 476.8×381.6×30mm.

Schematic view of the small milling machine and the parts where the strong alkaline water with polymer was applied is shown in the Fig. 3. The applied places were (1) spindle housing, (2) vise and (3) support points. Each of the applying parts has three different size of vessel with different capacity of amount of damping material. Using strong alkaline water with 6wt% polymer PEO on each of the three countermeasures, the noise characteristics, vibration characteristics and surface roughness of the work-piece were analyzed and evaluate theirs effectiveness.

Schematic view of the experimental set-up for measuring noise and vibration was shown in Fig. 4. Being installed the three countermeasures in the milling machine (1) spindle housing, (2) vise and (3) support points and added the damping material, first the noise attenuation degree was measured. The sound level meter was installed at 300 mm away and at 150mm height from the small milling machine and measured the noise during processes. At that time the background noise was of 36~44dB. During the noise check, the spindle was rotating at 6500min^{-1}, and measured in idling state.

Table 4. Specification of the small milling machine used for evaluation and its photograph

Machine size	476.8mm（W）× 381.6mm（D）× 305m（H）
Weight	13.7 Kg
Max. operation area	203mm (X) ×152.4mm (Y) × 60.5mm (Z)
Spindle speed	6500 rpm
Feed rate	0.1 to 15 mm/sec
Acceptable material	Wood, plaster, resin, aluminum (A5052 according to JIS), brass, resin (modelling wax, styrene form, chemical wood)
Acceptable tool	Endmill, Drill

MODELA MDX-20

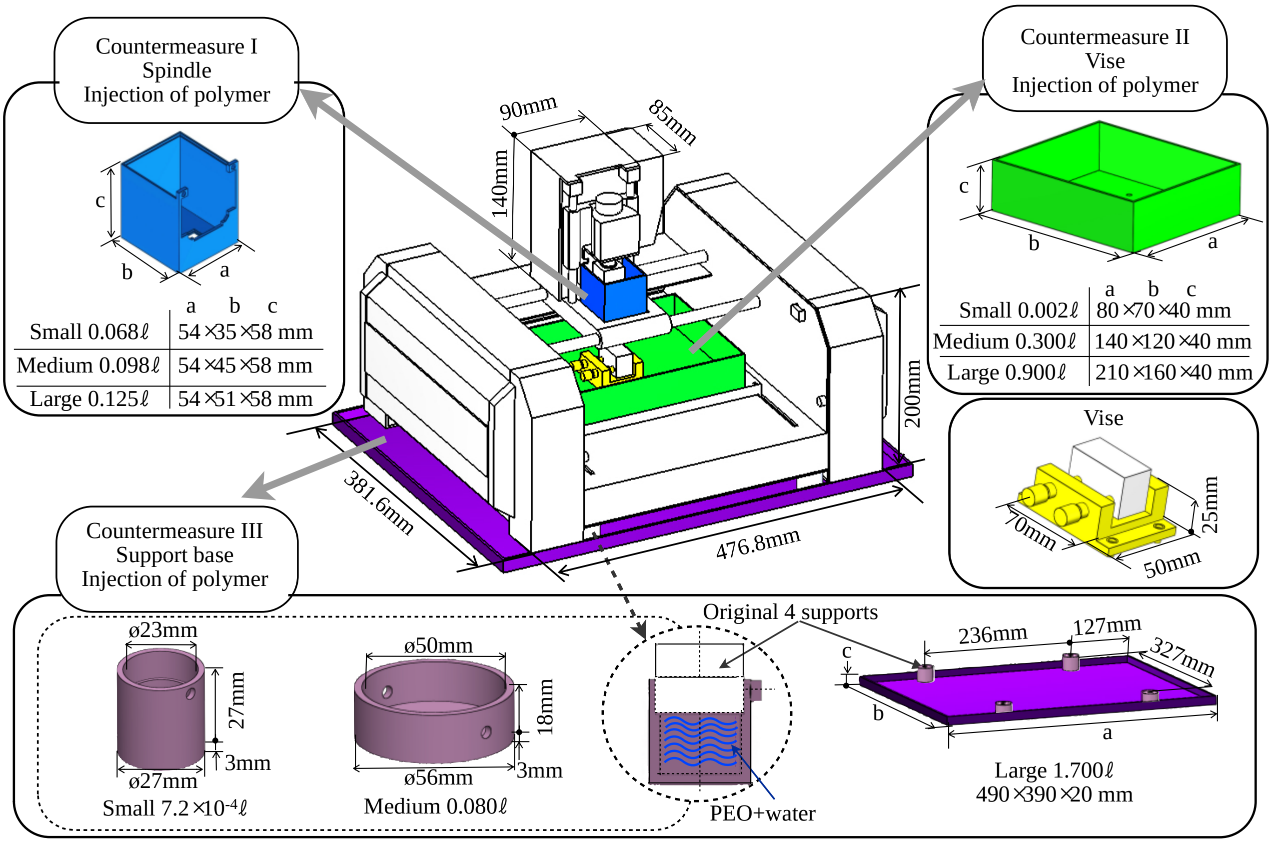


Fig. 3. Schematic view of the small milling machine with 3 countermeasures for noise and vibration

Results of the noise were shown in Fig. 5. When the amount of strong alkaline water with polymer is incremented, the reduction effect of noise is bigger. As is shown in the graph, the use of the damping material was effectively to reduce the noise. Because the processing point was far from the support base, it was not effectively for reducing noise. When the three countermeasures (spindle head, vise and support base) were used with the damping material, the noise reduction was effective of about 6dB. In addition, was also revealed that for noise reduction, the small vessel with the strong alkaline water with polymer can also be applied for this purpose.

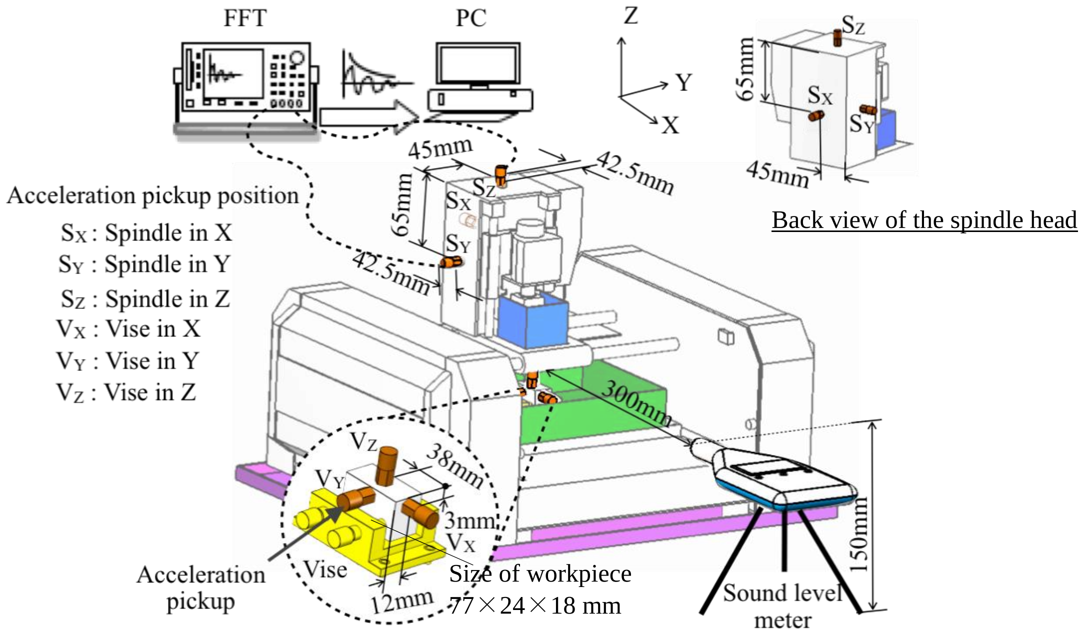


Fig. 4. Schematic view of the set up for experiment regarding noise and vibration

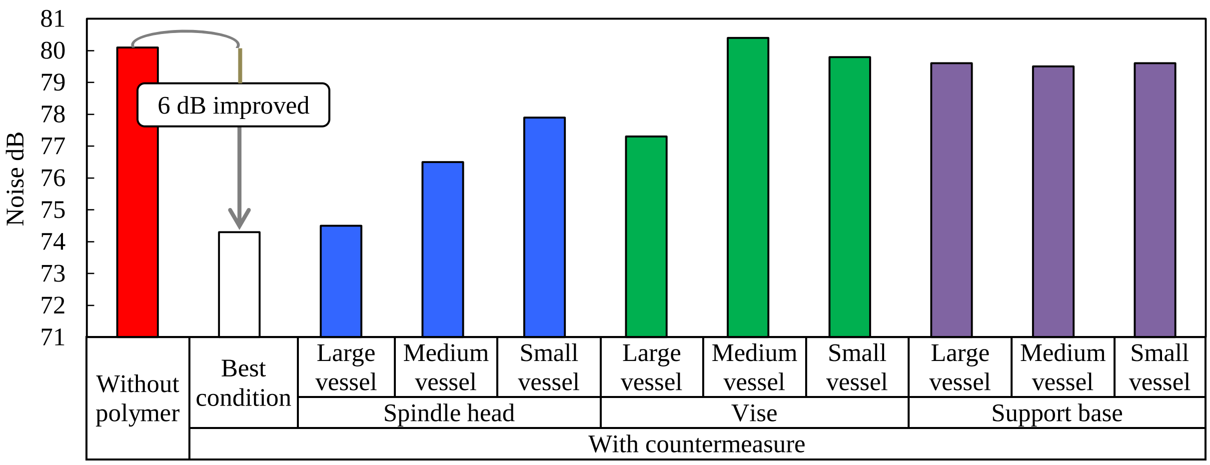
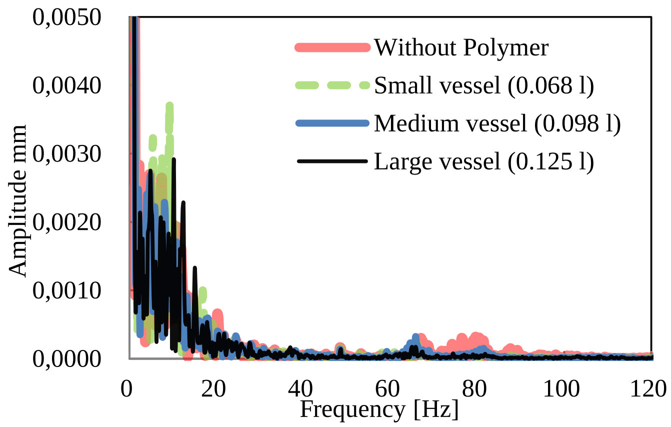


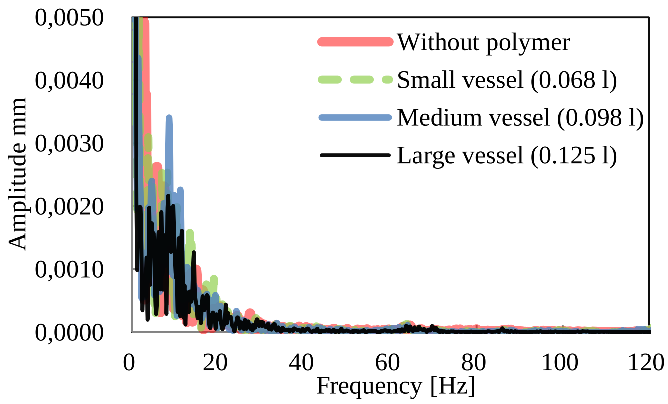
Fig. 5. Relationship between the noise and the four countermeasures

As in this section, the same setup parameters were done for the experiment. The vibration amplitude of the vise was measured in X, Y and Z direction. Schematic view of the vibration setup is also shown in Fig. 4. Spindle was rotating at 6500min^{-1} in idling state. Measurement for vibration was performed from 0Hz to 200Hz because of consideration for surface roughness on the work-piece. And vibrations from 0Hz to 120 were only shown in Fig. 6, 7, 8 and 9 because of large amplitudes.

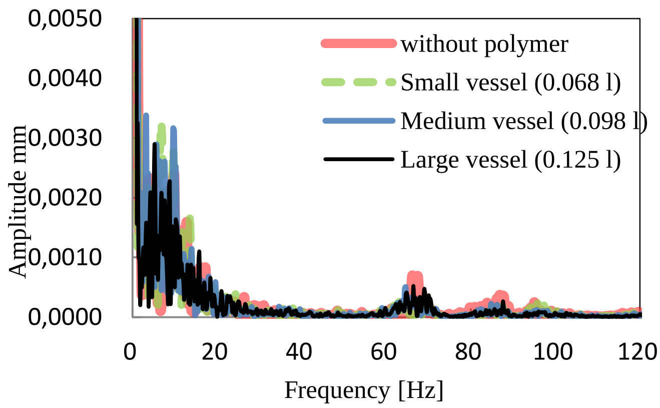
Result of the measurement of the frequency response in the spindle head with only the countermeasure of the spindle head is shown in Fig. 6, while Fig. 7 shows the frequency response in the vise with only the countermeasure of the spindle head. In this experiment the spindle was the only one running, the table is without running. In Fig. 6 the vibration in the spindle head was reduced, while the damping material was settled in the spindle head.



(a) X direction using acceleration pickup S_X

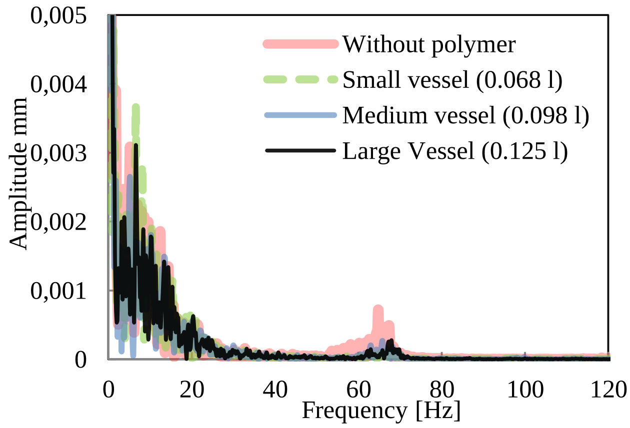


(b) Y direction using acceleration pickup S_Y

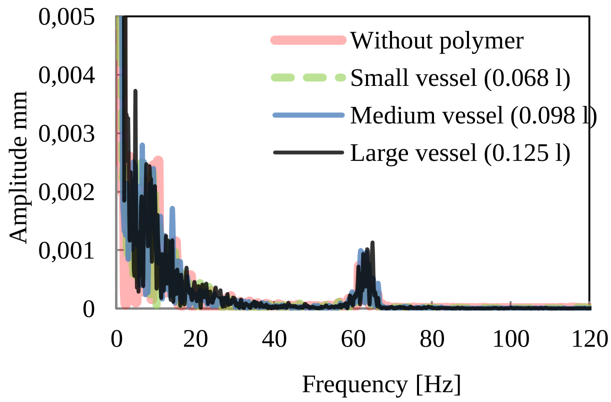


(c) Z direction using acceleration pickup S_Z

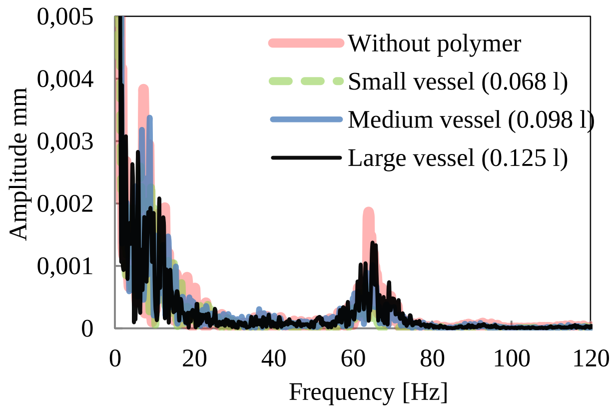
Fig. 6. Frequency response in the spindle head with only the countermeasure of the spindle head



(a) X direction using acceleration pickup V_X

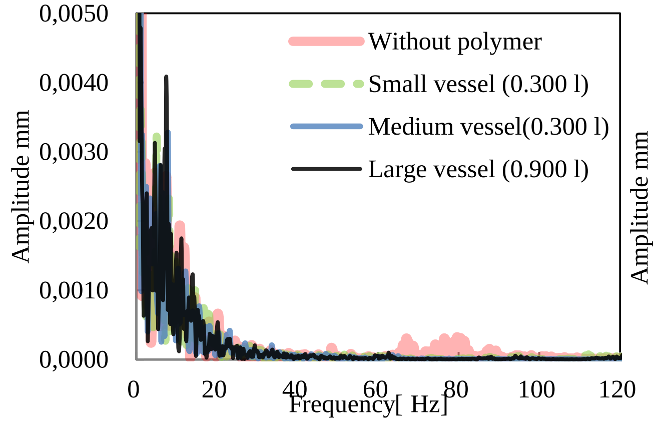


(b) Y direction using acceleration pickup V_Y

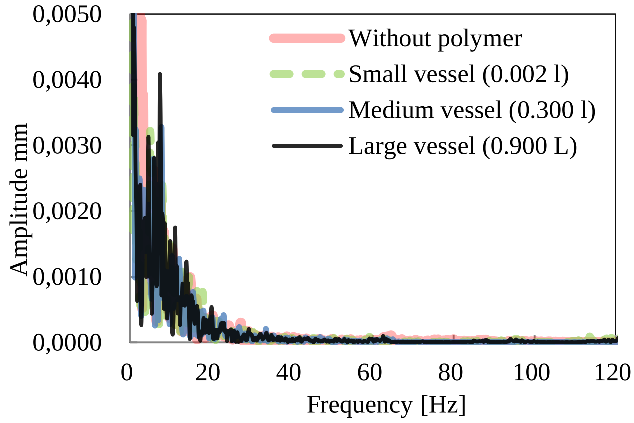


(c) Z direction using acceleration pickup V_Z

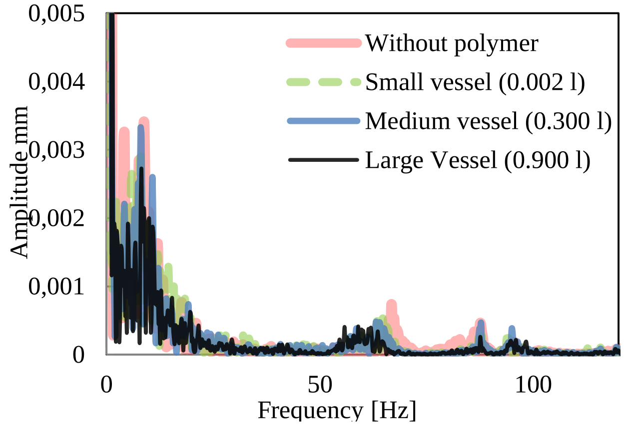
Fig. 7. Frequency response in the vise with only the countermeasure of the spindle head



(a) X direction using acceleration pickup S_X

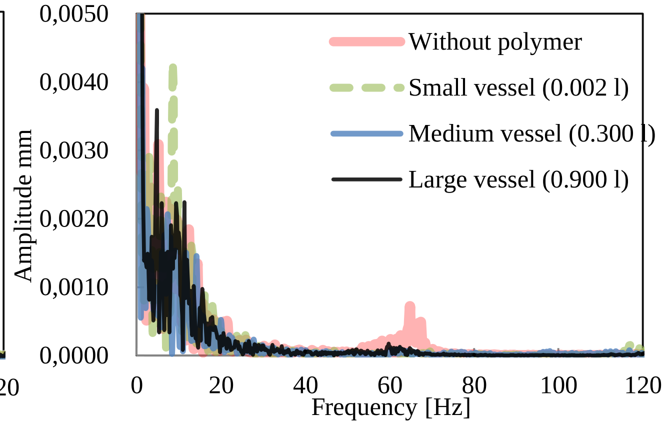


(b) Y direction using acceleration pickup S_Y

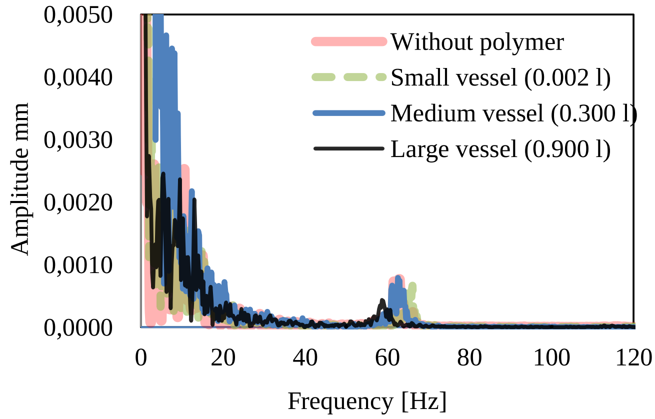


(c) Z direction using acceleration pickup S_Z

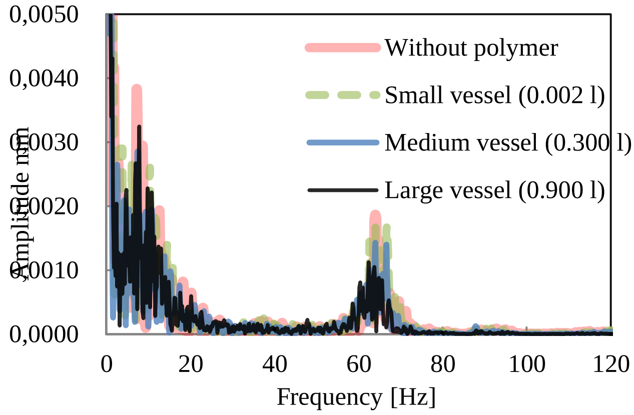
Fig. 8. Frequency response in the spindle head with only the countermeasure of the vise



(a) X direction using acceleration pickup V_X



(b) Y direction using acceleration pickup V_Y



(c) Z direction using acceleration pickup V_Z

Fig. 9. Frequency response in the vise with only the countermeasure of the vise

The damping effect was better when the amount of strong alkaline water with polymer is bigger. Even the injection of alkaline water with polymer is smaller, the density of the mechanical structure increases, amplitude of the vibration becomes smaller because of the damping effect. In Fig. 7, the vibration on the vise was effectively reduced even the mix is in the spindle head.

Result of the measurement of the frequency response in the spindle head with only the countermeasure of the vise is shown in Fig. 8, while Fig. 9 shows the frequency response in the vise with only the countermeasure of the vise. Also in this experiment the spindle is the only one running and vise is without running. Regardless, as is shown in Fig 8, even the countermeasure of vise is away from the spindle head, the vibration of this one was attenuated. It was found that the damping effect of the strong alkaline water with polymer has an effect not only in the countermeasure where is used, but also in the vicinity of it. Because, when the vise was filled with damping material in the table, amplitude of the vibration of the vise was effectively reduced such as Fig. 9. And the damping effect is grater when the amount of mix is bigger.

Countermeasure of support points has very little effects. Therefore the experimental results are omitted in here.

Table 5. Cutting condition for evaluation regarding surface profile and surface roughness

Cutting speed		20m/min	Workpiece	Material	Chemical wood
Feed speed		0.2mm/s		Density	940kg/m^3
Cutting depth		0.1mm		Hardness	Shore D 72
Spindle speed		6500min^{-1}		Tensile strength	19.6MPa
Tool	Diameter	ϕ 1.0mm		Bending strength	35.3MPa
	Type	End-mill		Compressive strength	61.1MPa
	Material	Carbide		Size	77×24×18mm
Cutting fluid		Nothing			

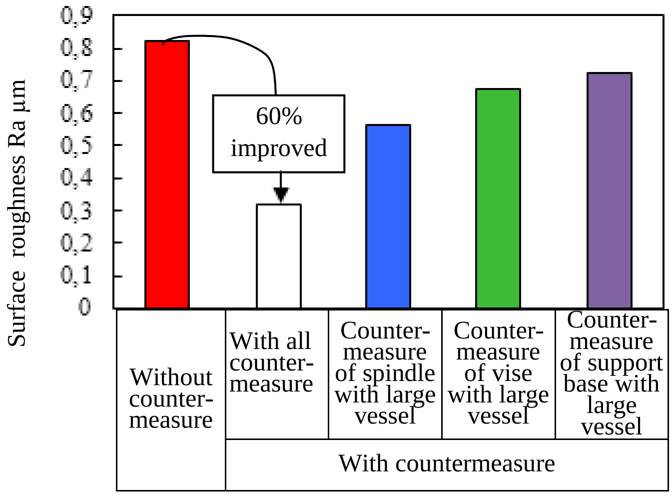


Fig. 10. Surface roughness of the work piece after cutting

Finally, surface of a work-piece was cut by the small milling machine and the surface roughness was measured. For it, the same setup as Fig. 4 was used. The cutting conditions are shown in Table 5. The cutting and measure was executed when the three countermeasure were used. The only the large vessels with the maximum amount of strong alkaline water with polymer was experimented. Results of the measurement of the surface roughness were shown in Fig. 10. The three countermeasures filled with strong alkaline water with polymer had also improved their surface roughness when they were used individually. These results can be cause of the vibration reduction. Finally, when the three countermeasures were used simultaneously the damping effect was better, the surface roughness is also improved by 60% compared with the one without countermeasure.

5. APPLICATION OF DAMPING MATERIAL OBTAINED BY STRONG ALKALINE WATER WITH POLYMER PEO IN A MACHINING CENTER

In here, application of the damping material using strong alkaline water with polymer is evaluated by the experiment. Experimental set-up was shown in Fig. 11 fixed on the NC table.

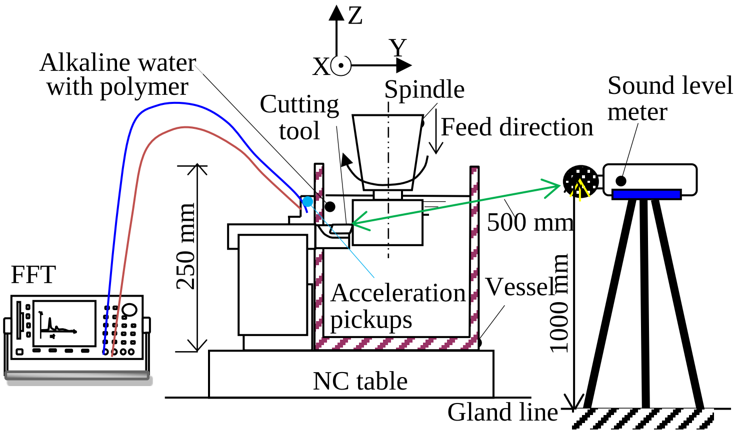
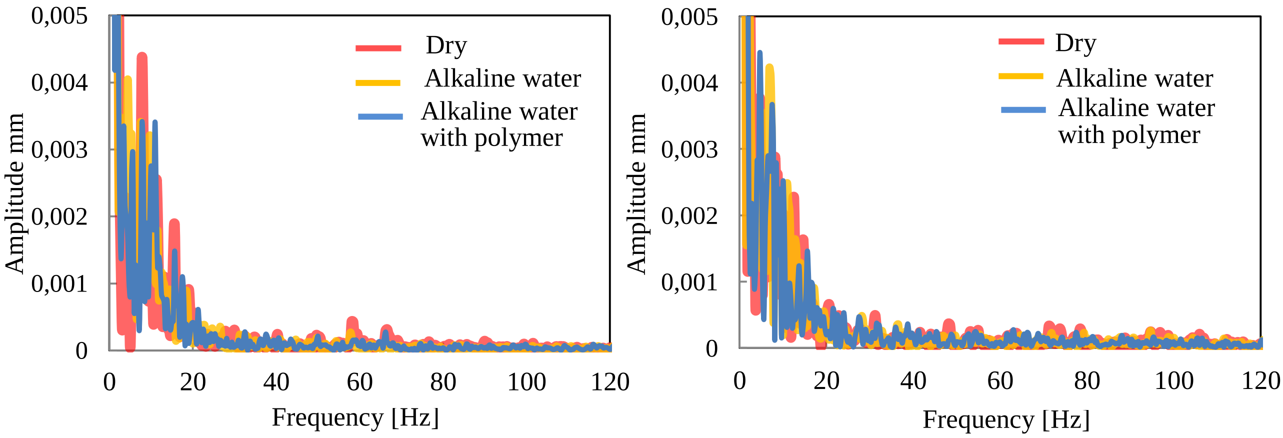


Fig. 11. Experimental set-up for measurement

Table 6. Cutting conditions

	Items	Turning
	Cutting speed	80m/min
	Feed speed	0.25mm/rev
	Width of cut (axial)	—
	Depth of cut (	0.4mm
Work piece	Material	Ti6Al4V
	Specific cutting force	3172N/mm^2
Tool	Material	Coated carbide (S30T)
	Coating	PVD-TiAlN
	Rake angle	5°
	Clearance angle	—



(a) X direction (b) Y direction

Fig. 12. Experimental results for vibration (Spindle speed: 318 [min^{-1}]

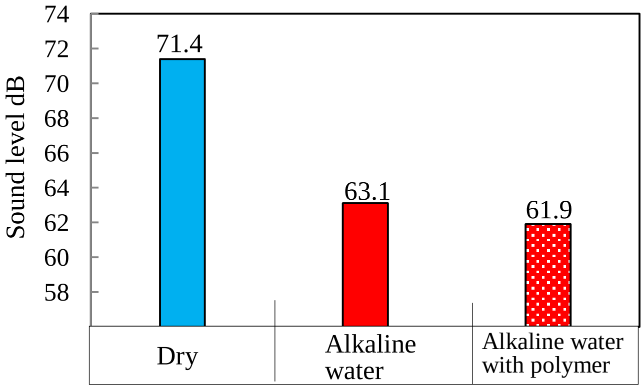


Fig. 13. Experimental results for sound level (Spindle speed: 318min^{-1})

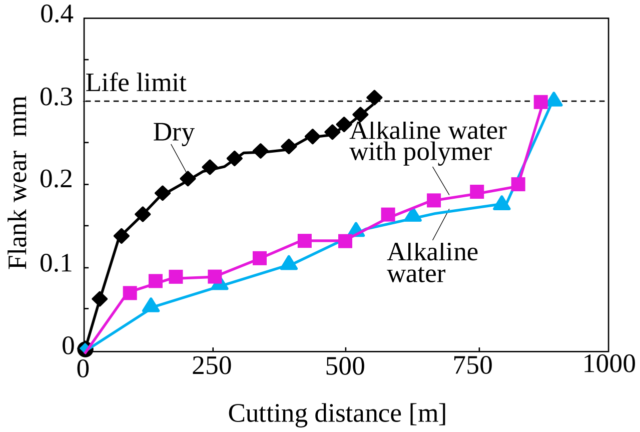


Fig. 14. Experimental results of tool life test

Two acceleration pickups for X and Y directions were fixed on the tool holder and vibrations for X and Y directions were measured by FFT. Noise durin[g cutting was also measured by sound level meter. Cutting condition shown in Table 6 (turning). Difficult to cut material Ti6Al4V was used for evaluation.

According to Fig. 12 the vibration in the tool holder was reduced, while the damping material was settled in the cutting territory. Strong alkaline water with and without polymer were effective for reducing the vibration, respectively. Particularly, in case of the X direction, damping of vibration regarding the machining center using strong alkaline water with polymer was more excellent than one of without polymer. Strong alkaline water with polymer was used at practical manufacturing.

Results of the noise were shown in Fig. 13. At the experiment the background noise was of 45~51dB. Noises of cutting using strong alkaline water with and without polymer were 87 % and 85 % of one of dry cutting, respectively. As it is shown in the graph, the use of the damping material was effectively to reduce the noise. Strong alkaline water with polymer could improve for environment of working.

Fig. 14 shows the result of the tool life experiment. From this result, it can be said that the cutting using strong alkaline water is effective for releasing the cutting heat on the tool during cutting of difficult to cut material Ti6Al4V. Normally, for conventional dry of difficult to cut materials like Ti6Al4V, this cutting condition is not suitable as large cutting heat generation would cause the tool melt and wear easily. Polymer wasn't influence for cooling the tool. Even using this hard cutting condition, the cutting using strong alkaline water with polymer is applicable with soundness. Moreover, the tool used is examined using microscope and no sign of tool damages are exhibited. And the polymer wasn't restrained the cooling function of strong alkaline water with polymer.

6. CONCLUSION

The results of this study are summarized as follows:

(1) Aluminium, aluminium alloy, copper, copper alloys were leaved for two months in strong alkaline water and presented corrosion.
(2) When polymer PEO is mixed to strong alkaline water, the damping ratio becomes bigger. The effect becomes better when increasing the amount of polymer until the content had reached the peak value at 6wt%.
(3) When damping material was used in the three countermeasures (spindle head, vise and support base) individually, the vibration was reduced and the surface roughness was improved. The results of three countermeasures at the same time, was very effective.
(4) To exert the effects of (3) the minimum use of strong alkaline water could be applied to actual machines tools.

REFERENCES

[1] SHIMOHIRA S., 1995, *Material science of corrosion & Corrosion-protection*, Published by Agune Technological Center, 30-32, 255-257, 287-288.

[2] ZUPERL U., CUS, F., 2002, *Optimization of cutting conditions during machining by using neural networks*. International Conference on Flexible Automation and Intelligent Manufacturing, Dresden, Germany, from http://fs-server.unimb.si/si/inst/ips/labod/GUMBI/p-paper-Zuperl-Cus1.pdf

[3] TANABE I., DRUZ J.R.D., INOUE Y., KANEKO Y., 2012, *Development on technique regarding change of resonance frequency on a machine tool*, Transactions of the Japan Society of Mechanical Engineer, Series C, 78/791, 2656-2666.

[4] TANABE I., KATO E., TSUTSUMI M., 2000, *Simulation strategy for using powder composite damper with optimum specification*, Transactions of the Japan Society of Mechanical Engineers, Series C, 66/651, 3785-3790.

[5] TANABE I., WATANABE K., KATO E., 2003, *Countermeasure of vibration for improving availability of laser machine: Effect of powder composite damper*, Transactions of the Japan Society of Mechanical Engineers, Series C, 69/681, 1443-1448.

[6] TANABE I., KANEKO Y., KOBAYASHI D., 2005, *Development of chatter restrained lathe for mirror finished surface*, Transactions of the Japan Society of Mechanical Engineers, Series C, 71/712, 3590-3595.