Journal of Machine Engineering, Vol. 10, No. 1, 2010

high speed lapping, linear motor lathe,
mirror-like surface, high quality and productivity

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HIGH SPEED LAPPING FOR MIRROR-LIKE FINISH USING THE LATHE WITH LINEAR MOTOR

Several machines with linear motor have been developed for high productivity. The characteristics of these machines are high speed, high acceleration and deceleration with stable behaviors of feed. Moreover, mirror-like surface is required to add high quality on the most products. In this study, high speed lapping by using the lathe with linear motor was investigated for mirror-like surface. Lapping was performed after turning with the same lathe. Lapping tool consists of a lapping head, a spring and holder on the tool post to assemble the linear motor lathe. The spring is used to supply lapping pressure. Lapping slurry consists of water, PEO (Polyethylene Oxide) and diamond grain. This slurry was supplied between a work piece and lapping head. Then, high speed lapping was performed. During the process, the lapping head temporarily left from work surface in order to catch some new grains and removed some chips. The optimum combination of both the spindle speed and the feed speed was investigated for high quality and productivity experimentally. Surface roughness and form accuracy were measured. It was concluded from the results that (1) Mirror-like surface was obtained by the high speed lapping , and (2) Optimun conditions for efficient high speed lapping was revealed experimentally.

1. INTRODUCTION

Recently, the application of the linear motor [2]&[3] in several machine is well developed in manufacturing industries due to their characteristics of higher acceleration and deceleration of feed with repeatability, and lower machine vibration in compare with ball screw drive. Moreover, the mirror-like surface becomes essential for high quality products of various parts.

In order to fulfil this demand, the research regarding the high speed lapping is carried out. High speed lapping technology by using only linear motor lathe from initial cutting to mirror-like finishing simultaneously was developed.

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In concretely, new lapping tool and lapping slurry applicable for the lathe were developed. The governing factors of the high speed lapping processing were investigated with developed lapping system. Then, the surface roughness improvement and geometrical form accuracy were measured. Finally, high speed lapping algorithm for mirror-like surface on cylindrical outer surface using the lathe with linear motor was revealed experimentally.

2. DEVELOPMENT OF LAPPING SYSTEM TO ASSEMBLE WITH LATHE

2.1. DEVELOPMENT OF LAPPING TOOL

The developed lapping tool is shown in Fig. 1. Lapping tool consists of lapping head, soft long coil spring for generation of lapping pressure and holder to be fitted on the tool post. This tool can be produced with extremely low cost and short time. In order to suppress the chatter vibration, cubic shape lapping head was used. Moreover flat nature of lapping tip can catch and control the grains efficiently for the high speed cylindrical surface lapping. During the lapping process, the lapping head required to maintain the diamond grains strongly to produce the random cutting edge for cutting work surface. Therefore, polypropylene was selected as lapping head material among the various materials such as nylon, felt, wood, copper, steel and etc., for long time and high precision lapping. The process was controlled by the lapping pressure supplied from spring force to the contact area between the lapping head and the work surface. With this arrangement, the lapping pressure could be managed easily. The soft 62 mm long coil spring with spring constant of 1.09 N/mm was used for generate lapping pressure.

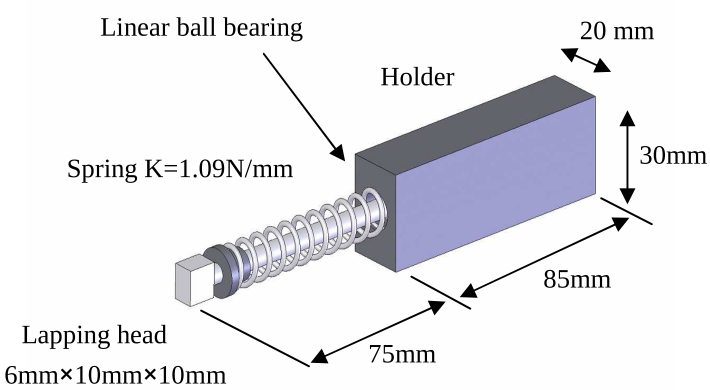


Fig. 1. Schematic view of a lapping tool for mirror-like surface using the lathe with linear motor

2.2. DEVELOPMENT OF LAPPING SLURRY

If the commercially available lapping slurry was used in this cylindrical outer surface lapping, the grain density variation would occur inside the slurry due to spindle rotation.

Although the same lapping condition was used, it was difficult to obtain the mirror like surface. Considering from several factors, it is required to ensure that surface roughness, brightness and condition of the mirror-like surface need to be uniform. Up to this point, the new lapping slurry applicable for lathe is required. Therefore, the new lapping slurry from another recent study [1] was applied. Table 1 shows the specifications of the lapping slurry used. This slurry is the mixture of diamond grains 4 wt% concentration embedded into the water base solution made of 2.0 wt% of PEO (Polyethylene Oxide). Then, the condition of lapping slurry with different spindle speed on the linear motor lathe was investigated. In this experiment, bigger size alumina powder #220 with similar concentration was used instead of diamond. To dye alumina powder into green, permanent marker was used. Diamond grains which will use in actual lapping processing are #400~500, # 1200 and, #2500 respectively. Ideally, if the aluminum grains neither drop nor scatter, the diamond grains actually used would also be applicable. The experimental results of conditions of the lapping slurry with different spindle speed were shown in Fig. 2. Lapping slurry dropped from work piece at spindle stop. However the spindle rotation was in the range between 20~700 min^{-1}, the lapping slurry well attained the condition without dropping and scattering. Moreover grain distribution inside the lapping slurry was stabled between this range regardless of the effect of both centrifugal and gravitational force. Therefore, the diamond grain (#400~500, #1200, #2500) inside the lapping slurry supplied on the work piece could also maintained uniform even the spindle speed was varying between 20~700 min^{-1}.

Table 1 Specifications of lapping slurry

Mixture ratio of solvent	Water : PEO = 98 : 2 wt%		
Viscosity	158 Pa. s (at 0.1 rps)		
Shearing stress	15.8 Pa (at 0.1 rps)		
Size of diamond	#400~500	#1200	#2500
Concentration of diamond in slurry	4.0 wt%	4.0 wt%	4.0 wt%

Scatter of Slurry	○	○	○	○	×	×	×	×
Uneven of Grain	○	○	○	○	○	○	×	×
Drop of slurry	×	○	○	○	○	○	○	○
Spindle revolution(min^{-1})	0	20	300	700	710	800	820	1000

Fig. 2. Conditions of lapping slurry during revolution of spindle on the lathe

2.3. DELOPMENT OF LAPPING METHOD AND LINEAR MOTOR LATHE USED IN THE EXPERIMENT

The specifications of the linear motor lathe and photograph is shown in Tab.2 and Fig. 3 respectively. The quill type spindle head stock with linear turret table move along with Z axial direction. Multiple tool post can be installed on table based on the X axial direction. Linear thread cutting operation is capable with higher positioning accuracy of Z axis. In compare with conventional lathe, the feed speed on the Z direction is dramatically high. Therefore, lapping direction on the outer cylindrical work surface can be vary from vertical to nearly horizontal by setting the suitable combination of the spindle and the feed speed.

Only linear motor lathe can perform this operation. The schematic explanation of the lapping method is shown in Fig. 4. The developed lapping tool was mounted on the tool post of the linear motor lathe. The work piece was fitted on the main spindle collect chuck and the lapping slurry was dropped on it. Diamond grain in the lapping slurry was picked up onto the lapping head at position (P) by applying the X axial tool feed. Then, combination of spindle speed and feed speed on Z direction generated the relative speed between the work surface and lapping head. By that way, lapping speed was provided.

Table 2 Specifications of the lathe with linear motor

Items of specification		New lathe with linear motor
Head stock	Max. spindle speed (min^{-1})	10000
	Power of main motor (kW)	1.0/2.64
	Stroke on Z direction (mm)	200
	Max. acceleration on Z direction (m/s^2)	12.1 (1.23G)
	Max. speed on Z direction (m/min)	90
	Max. load on Z direction (N)	1674
	Positioning accuracy of Z (μm)	0.3
Carriage	Stroke on X direction (mm)	195
	Max. acceleration on X direction (m/s^2)	19.6 (2.0G)
	Max. speed on X direction (m/min)	110
	Max. load on X direction (N)	1674
	Positioning accuracy of X (μm)	0.5
	Table size (mm)	410×80×434
Bed	Size (mm)	720×498×1300
	Weight (kg)	1518
Weight of the lathe (kg)		2664
Type of CNC		Mitsubishi M700

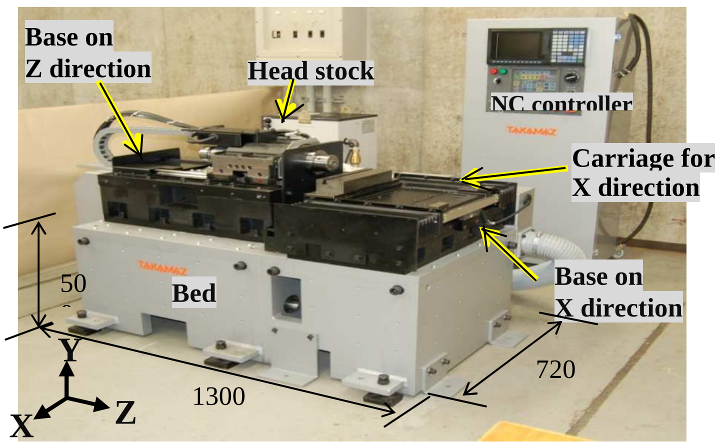


Fig. 3. Photograph of the lathe with linear motor

The lapping process was carried out on the work surface by the diamond grains on the lapping head. During the process, new diamond grains was catch repetitively with regular intervals by X axial tool feed for stable lapping. This is similar effect likes dressing of grinding. For this fact, the proposed high speed lapping process regards the lapping head as the grinding stone which is capable of continuous grinding process with dressing and cleaning. Then, the lapping process was repeated continuously as described in the Fig. 4.

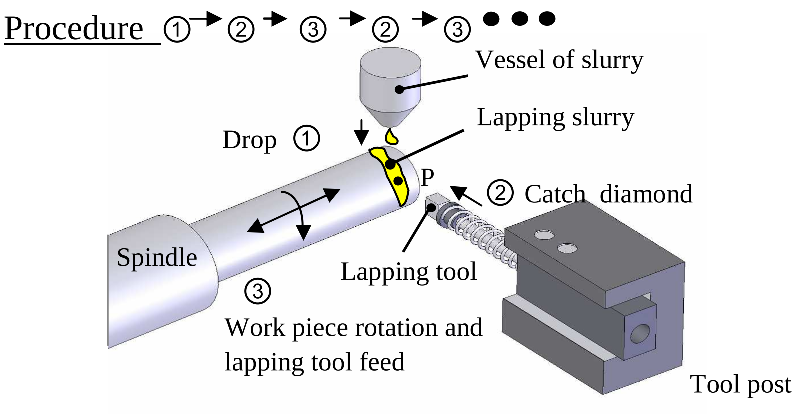


Fig. 4. Schematic view of lapping method using the lathe with linear motor

3. INVESTIGATION OF THE GOVERNING FACTORS FOR LAPPING PROCESS

3.1. LAPPING PRESSURE TO PICK UP THE DIAMOND GRAINS

The relationship between the number of received diamond on the lapping head with different lapping pressure is shown in Fig. 5. The 18mm diameter (roughness Rz = 2.5μm) cemented carbide (JIS V10) work piece was used in this experiment. The lapping slurry (Table 1) of 3 mℓ was dropped on work surface while spindle was rotating.

After being applied force to new lapping head, it was pulled apart from the work piece and the number of diamond grain deposited on the lapping head was counted with microscope. It was found that the lower spindle speed had higher tendency for deposition of diamond grains on the lapping head. Hence , 20 min^{-1} (lowest spindle speed for the uniform grain distribution) was selecteted as the spindle speed for pick up the diamond grains. The three diamond grains sizes of #400~500, #1200 and #2500 were used for this experiment. According to the results, every size of diamond grains deposited on the lapping head was maintained stable and saturated at lapping pressure of 50 MPa and more. Hence, the lapping pressure of 50 MPa was taken as the limited pressure for catching the diamond grains. If the concentration of diamond grains in the lapping slurry was changed, these results will also be changed. The concentration of diamond grain for the lapping process will describe in section 3.2.

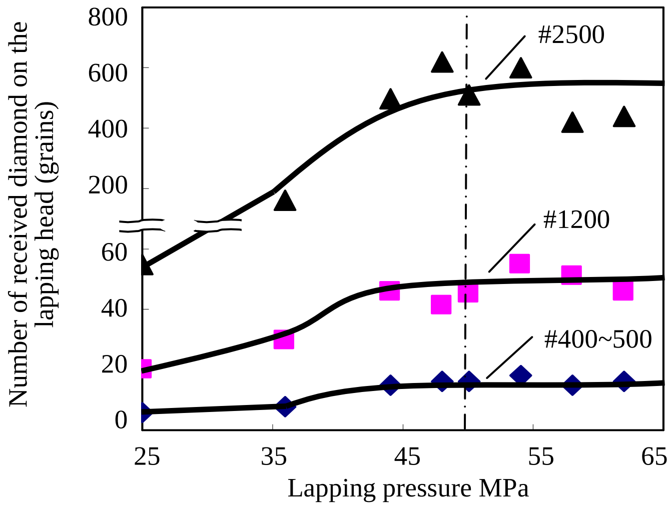


Fig. 5. Relationship between number of the received diamond on the lapping head with different lapping pressure

3.2. CONCENTRATION OF DIAMOND GRAINS IN THE LAPPING SLURRY FOR DIAMOND CATCHING

With the same experimental setup, the relationship between the number of diamond grains deposited on the lapping head with different diamond concentration in slurry was investigated. It was considered that higher concentration of diamond inside the lapping slurry would achieve faster processing rate. However, the objective of this section is to make clear the relationship between the diamond grain concentration and the number of deposited diamond grains on the lapping head. Therefore the study of diamond grains concentration was beyond of this research. The lapping pressure was taken as 50 MPa in accordance from the result of section 3.1. The result of the experiment was shown in Fig. 6.

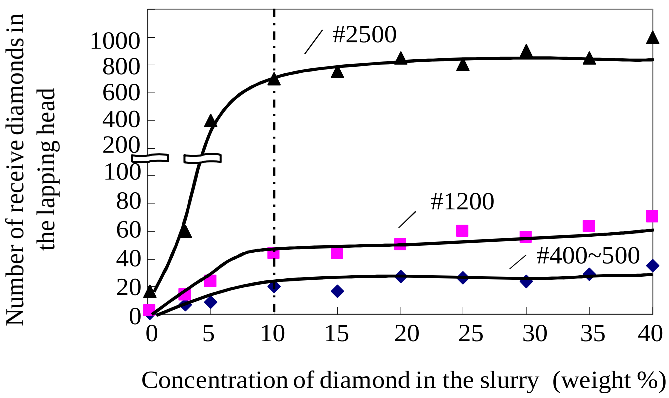


Fig. 6. Relationship between numbers of received diamonds on the lapping head and concentration of diamonds in lapping slurry

It was clear from the result that diamond concentration of the lapping slurry increased, the initially deposited diamond grains on the lapping head also increased. However, diamond concentration exceeds 10% (by weight), the number of deposited diamond became saturated. Therefore, diamond concentration of 10wt% was taken as the mixing limit. It was possible to reduce the lapping processing time by increasing the diamond conecntration. However the excessive diamond grains concentration will produce unplesent result for good surface finish.

3.3. LAPPING PRESSURE AND LAPPING SPEED FOR RETAINING OF DIAMOND GRAINS

It is essential to maintain the diamond grains effectively on the lapping head during the lapping process. For this purpose, the suitable lapping pressure and lapping speed for retaining of diamond grains was investigated. The sechametic explanation of experimental set up is shown in Fig. 7. CNC milling machine was used in the experiment to find out the stable lapping speed. The inverted miscroscope was mounted on the table of CNC milling machine. Lapping tool was rubbed on the cemented carbide (V10) which was immersed in the lapping slurry. Lapping pressure of 30MPa was applied for catching diamond and the number of grains deposited on the lapping head position (A) was counted. After data was recorded, lapping head was rubed on work surface for 10mm stroke length under various lapping pressure of 5MPa, 30MPa and 60MPa respectively.

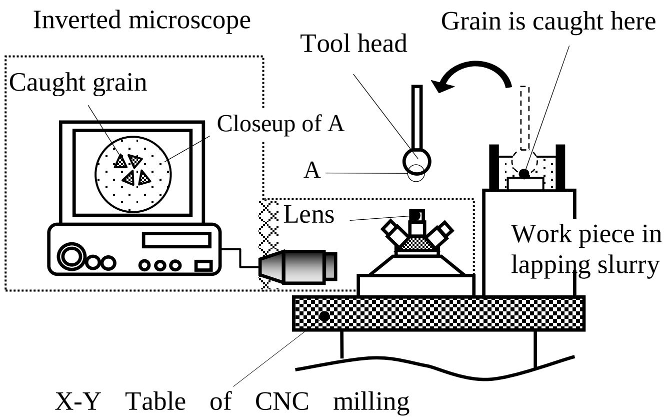
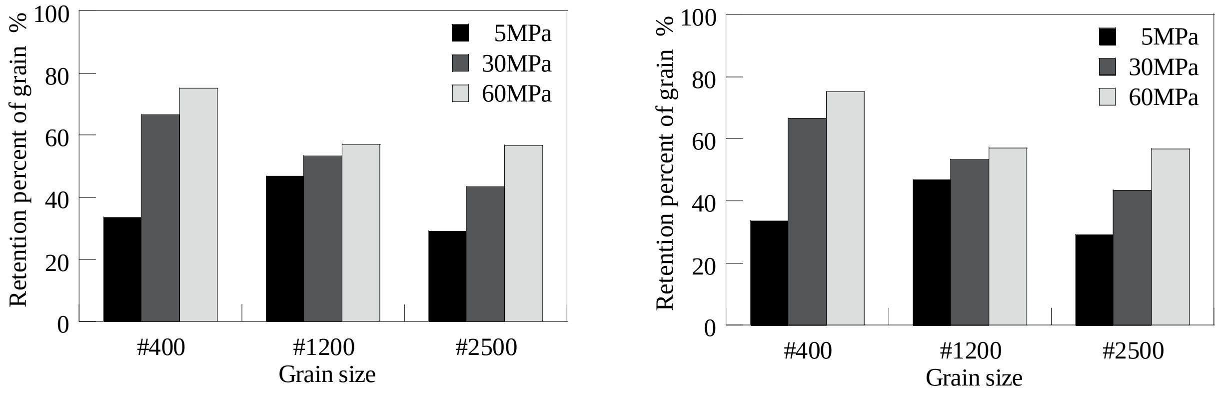


Fig.7. Measurement setup for number of grain on the tool head

The lapping speed was set to be 500 and 3000 mm/min. The retaining percent of grains after one stroke was calculated. [(Number of remained grains after process ÷ number of initially caught grains) ×100]. The experiment was conducted with every diamonds grain sizes of #400-500，#1200 and #2500. The experiment results with lapping speed of (a) 500 mm/min and (b) 3000 mm/min are shown in Fig. 8. In the investigated range of the lapping speed of 500 and 3000mm/min, the consistency was observed.

Moreover, the retaining percent of every grain size in both lapping speed was satisfy



(a) Lapping speed: 500 mm/min

(b) Lapping speed: 3000 mm/min

Fig. 8. Relationship between the lapping conditions and the retaining percent of grains

with 50~80% at 60MPa. At lower lapping pressure of 5MPa, the retaining percent reduced to 30% at both lapping speed. From this result, it was required to increase the lapping pressure for effective lapping processing with lower diamond grains dropped out from lapping head. However, it was required to consider that increasing of lapping pressure more than desirable value would result poor surface finish. Obviously, it was possible to obtain the higher retaining percent for the material with lower cutting resistance than cemented carbide which was used in experiment.

4. MIRROR- LIKE SURFACE FINISH TECHNOLOGY BY HIGH SPEED LAPPING

4.1. EVALUATION OF THE IMPROVEMENT OF SURFACE ROUGHNESS

In this experiment, three different work materials of Brass, medium carbon steel (JIS S45C) and cemented carbide (V10) were used. Three diamond grains sizes of #400~500, #1200 and #2500 were used accordance with the surface roughness improvement. In order to reduce the effect of machining vibration on the work surface, lapping pressure was reduced to 4MPa during the lapping process. Three lapping track patterns were proposed for mirror-like surface processing. Fig. 10 shows the development of lapping track on work surface. Lapping direction starts from same moving path with previous turning track on work surface. At first, lapping tool perform only one way path (see Fig. 10(a)). Next, lapping tool moved go and back with symmetrical path on work surface (see Fig. 10(b)). The lapping tool track performed orthogonal to each other for go and back direction. (see Fig. 10(c)). The better result was obtained by the orthogonal lapping method (c). Therefore lapping method (c) was used for the mirror-like surface processing. Lapping process was carried out by using the developed lapping system and the lapping conditions stated in Table 3. The relationship between surface roughness improvements with lapping time is shown in

Fig. 9. Surface roughness value Rz (maximum high) of all work material became under 0.1µm after lapping of 65~75min. It was confirmed that the developed system was capable of mirror- like surface finish.

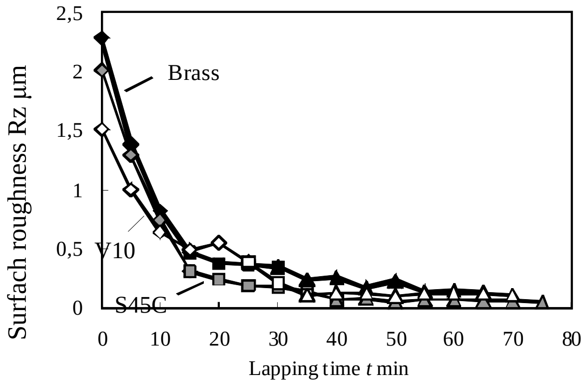


Fig. 9. Relationship between improvement of surafce roughness and lapping time

Table 3. Lapping conditions for mirror-like surface

Lapping slurry		**See Table 1**		
Lapping pressure	For catching diamond	10MPa (spindle speed 20/min)		
	For lapping	4MPa		
Lapping speed		3000 mm/min		
Spindle speed		53 , 3 min^{-1}		
Feed speed		0.1 , 900 mm/rev (Both ways)		
Work pieces		**S45C**	**V10**	**Brass**
Lapping time (min)	#400-500 ,.	15	25	15
	#1200 ,.	25	10	20
	#2500 ,.	35	35	30
Total time (min)		75	70	65

4.2. CONSIDERATION FOR REDUCTION OF LAPPING TIME

For high quality and productivity, algorithm for efficient lapping time was investigated. S45C was used as work material in this experiment. The effect of lapping angle on previous cutting line was investigated by using orthogonal lapping. Lapping angle variation combined with orthogonal lapping method was explained in Fig. 10 (d).In this method, the angle between the previous turning direction and first lapping direction was changed to 0°,10°, 20° and 30° respectively. Then, the possibility of surface roughness improvement speed and limit surface roughness by different lapping angle were examined. During the process, the orthogonal lapping was followed accordance with the angle variation from turning track. The results outcome from the experiments was shown in Fig. 11. It was cleared that 20° lapping angle was the fastest for surface roughness improvement speed. However, 0° lapping angle the best for the view point of limit surface roughness. According to the result shown in Fig. 11, new algorithm for high productivity mirror-like surface was developed by using multiple lapping angle combination.

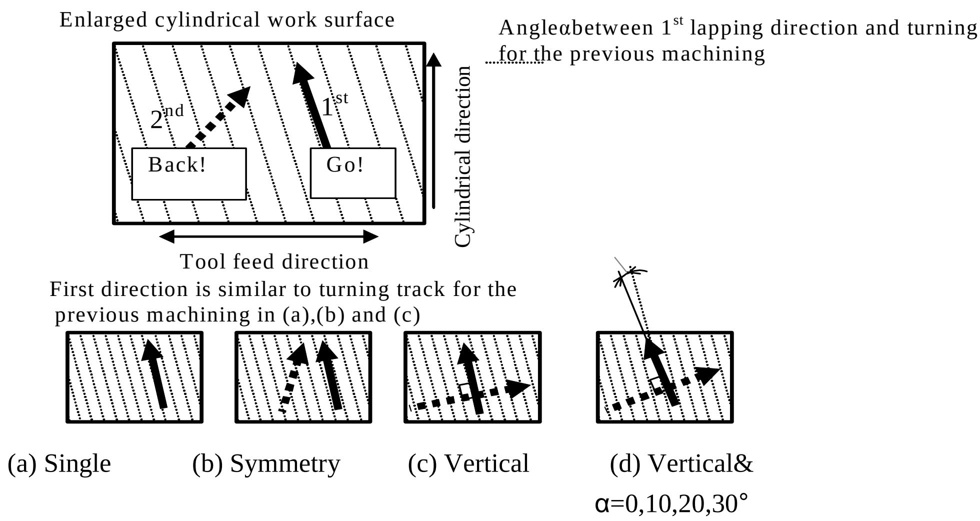
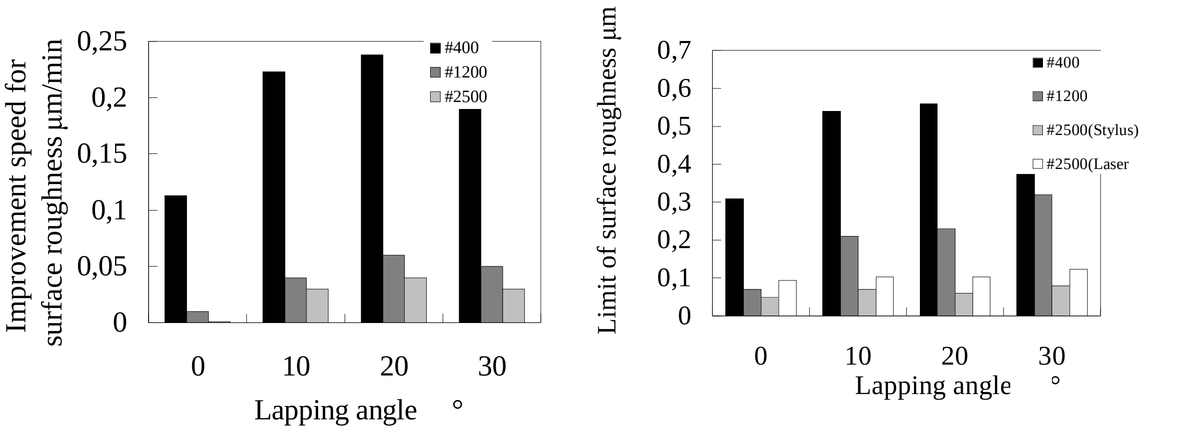


Fig. 10. Development of lapping track on enlarged work surface



a) Improvement speed for surface roughness b) Improvement speed for surface roughness

Fig. 11. Relationship between improvement of surafce roughness and lapping angle

Optimumng lopping conditions with new algorithm is shown in Table 4. Fig. 12 shows the relationship of surface roughness improvement with lapping time under new lapping conditions. In contrast to old method, the new method was possible to reduce lapping time by one-third. The limit surface roughness and improvement speed will be changed from Fig. 11 by increasing the lapping pressure. Additionally, there will be an influence on the result depending on work material, rigidity of lapping tool and machine vibration during lapping. However, it can expect that the cemented carbide and brass will also be able to shorten the lapping time with similar method.

Table 4. Lapping conditions with new algorithm

Lapping conditions		New (Fig.10 (d))	Old (Fig.9)
1st	Grain size	#400	#400
	Angle □	20°	0°
	Lapping time	5 min	15 min
2nd	Grain size	#400	#1200
	Angle □	0°	0°
	Lapping time	5 min	25 min
3rd	Grain size	#1200	#2500
	Angle □	20°	0°
	Lapping time	5min	35 min
4th	Grain size	#2500	
	Angle □	20°	
	Lapping time	10 min	
Total lapping time		25 min	75 min

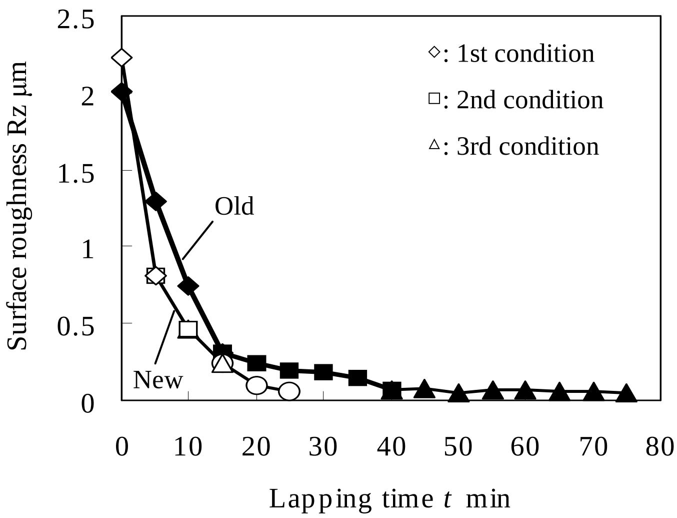


Fig. 12. Improvement of lapping time

4.3. EVALUATION OF GEOMETRICAL FORM ACCURACY OF DEVELOPED LAPPING PROCESS

To evaluate the geometrical form accuracy of developed lapping system, the following experiment was conducted. In this experiment S45C was used. The process conditions were taken as in Table 4. The form accuracy improvement were measured periodically and evaluated. Fig. 13 shows the relationship between the improvement of deviation of form and lapping time.

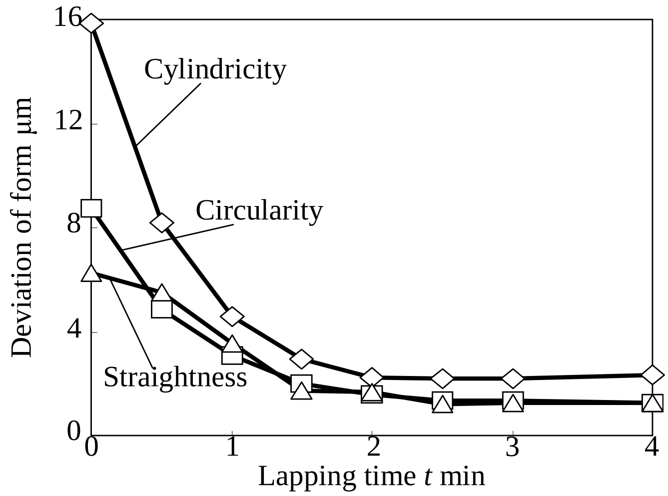


Fig. 13. Improvement of deviation of form with lapping time

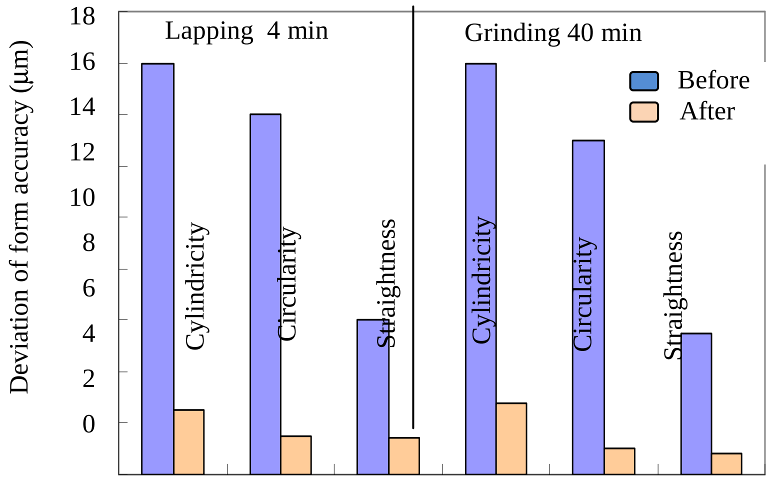


Fig. 14. Comparison of Lapping and grinding for form accuracy

From the results, the improvement of form accuracy were observed remarkably after the lapping time of 4 min with diamond grain size of #400~500. The improvement was not observed after the lapping time of 4 min. It can be considered that, this improvement values will be the processing limit of developed lapping system. Fig. 14 shows the comparison of improvement of deviation of form accuracy between lapping and grinding. For normal grinding process, the rough grinding process took 25 min, and then the finishing grinding process required 15 min for the improvement of form accuracy. Total grinding time of 40 min was essential for normal grinding of single part grinding process. From the result, the developed lapping method can improve the form accuracy within one tenth of grinding process time. It was also confirmed that the developed lapping method was also capable to improve geometrical form accuracy with shorter time.

5. CONCLUSIONS

It is concluded from the results that; (1) The mirror- like surface was possible by developed lapping system. (2) Optimum conditions of efficient high speed lapping for outer cylindrical surface was revealed experimentally.

REFERENCES

[1] IYAMA T., TANABE I., TAKAHASHI T., 2009, Optimization of Lapping Slurry in Automatic Lapping System for Dies with Cemented Carbide and Its Evaluation, (in Japanese)*Transactions of the Japan Society of Mechanical Engineer, Series C*, 75/749/210-215.

[2] KARITA M., 1995, High Performance Technology in Linear Motor (in Japanese), *Journal of the Japan Society for Precision Engineering*, 61/3/347-350.

[3] MIZUNO T., 2001, Machine Tool of Expanding Linear Motor Drive (in Japanese), *The Journal of The Institute of Electrical Engineers of Japan*, 121/9/620-623.