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LAPPING SYSTEM FOR IMPROVEMENT OF GEOMETRICAL ACCURACY USING LATHE MACHINE

The geometrical accuracy of the products are essential for high quality and interchangeability. Lapping processing is mostly using for final improvement of geometrical accuracy. Geometrical accuracy includes cylindricity, circularity and straightness. In this paper, lapping processing using a normal lathe was investigated for improvement of geometrical accuracy. Firstly, normal turning process is taken and then, the lapping process is performed using the same lathe. The lapping tool consists of a lapping head made of polypropylene (PP), a coil spring for supplying lapping pressure and holder for fitting on tool post. Lapping slurry is composed by mixing water, PEO (Polyethylene Oxide) and diamond grain. This lapping slurry is supplied between the work piece and the lapping head during lapping processing. The lapping head is made to contact and leave from work piece in regular intervals for catching new grains and removing chips. The optimum lapping condition was invesigated for high productivity and high accuracy by experiments. It is concluded from the results that; (1) The geometrical accuracy were improved by using developed lapping system with ordinary lathe machine. (2) The optimum lapping condition was revealed experimentally. (3) The surface roughness and dimensional accuracy are also improved using this developed lapping system.

1. INTRODUCTION

Recently, the products with high quality and accuracy are well demanded and the production technology and machine tools for those products are also being investigated. Especially, for the case of producing cylindrical shape products, it is necessary to undergoes many step of processing with various kinds of machines such as lathe turning, grinding, polishing processes and taking long processing time. The authors have been already revealed for the lapping system for mirror like cylindrical surface processing [1] and the development of lapping slurry for using with lathe machine [2].

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Therefore, in this research, the cutting technology for improving both geometrical accuracy and productivity with using only an ordinary lathe turning machine starting from turning process to lapping finishing process with one chucking. In concretely, the lapping system and the lapping slurry which has been already developed by researchers are modified and then the improvement of geometrical accuracy and the optimum processing conditions for both dimensional accuracy and surface roughness are investigated. Finally, the lapping technology for improving geometrical accuracy with using only ordinary lathe machine is revealed. Here, the improvement of the geometrical accuracy can also be achieved by using grinding processing after lathe turning or ultra fine finishing lathe machine. However, the objective of this research is made to be achieved improved geometrical accuracy using only ordinary lathe machine with advantages of faster, easier and economy.

2. LAPPING SYSTEM FOR USING ON ORDINARY LATHE MACHINE

2.1. DEVELOPMENT OF LAPPING TOOL

The developed lapping tool is as shown in Fig. 1. Lapping tool consists of lapping head made of polypropylene (PP), coil spring for supplying lapping pressure and holder. The PP material is chosen for lapping head for its characteristic of maintaining the diamond lapping grains during lapping processing and durable functioning likes grinding stone. A soft coil spring of 78 mm long with spring constant 1.09 N/mm is used for supplying lapping pressure. This arrangement is aim to recover and improve the effects of low accuracy of the lathe machine and tool setup. The lapping tool is made to be easy adjustment for lengths and easy replacement of different stiffness of springs to investigate the optimum lapping condition. Moreover, the tool axis is made to be able to adjust the initial compression force of the spring to control the best lapping pressure.

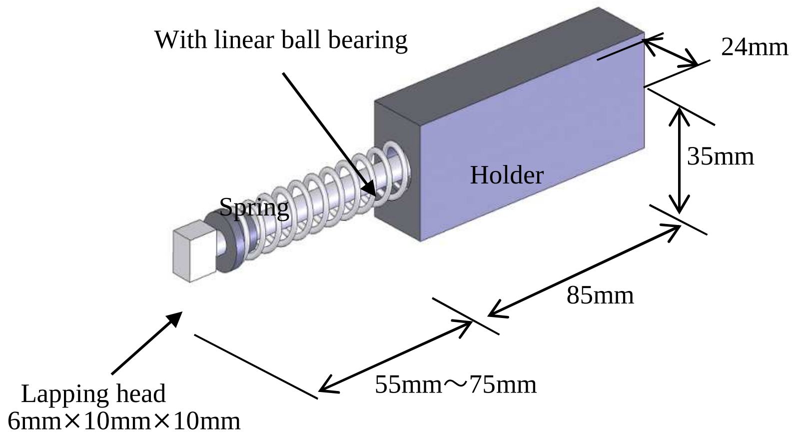


Fig. 1. Schematic view of the lapping tool for improvement of several deviations of form

2.2. DEVELOPMENT OF LAPPING SLURRY

The lapping slurry from the marketplace may have grain density variation inside the slurry during the spindle rotation and it is difficult to obtain mirror like surface even using same lapping condition. Considering the interchangeable parts manufacturing, it is required to ensure that surface roughness, brightness and condition of the mirror-like surface are needed to be uniform. Therefore, the new lapping slurry, which is applicable for lathe is developed by researchers [2], by putting diamond powder into the mixture of polyethylene oxide (PEO_{-8}) and water. Those authors used diamond grain size of (#400~500, #1200, #2500). However, in this research, we intended to use only ordinary lathe and its overall accuracy is also originally lower. Therefore, we thought the diamond grain sizes of (#800, #200, #325) are suitable for applying on ordinary lathe and this will also increase productivity.

Table 1. Specification of lapping slurry

Mixing ratio of solvents	Water : PEO = 96 : 4 wt%		
Viscosity	530 Pa･s (at 0.1 rps)		
Shearing stress	53 Pa (at 0.1 rps)		
Sizes of diamond grain	#80	#200	#325
Concentration of diamond grains inside slurry	10.0 wt%	10.0 wt%	10.0 wt%

Scattering of slurry	○	○	○	○	○	×	×
Variation of diamond gains concentration inside slurry	×	○	○	○	○	○	○
Dropping of slurry	×	○	○	○	○	○	○
Spindle speed min^{-1}	0	83	155	270	560	1030	1800

Fig. 2. Condition of lapping slurry during revolution of spindle (Diameter of work piece = 18 mm)

Table 1 shows the specifications of the lapping slurry used. The percentage of PEO_{-8} is increased up to 4 wt% for sufficient viscosity of the lapping slurry so that the diamond grains could not be scattered during lapping processing. If the percent of PEO_{-8} becomes larger than this value, there occurs the variation in density of diamond grains in the slurry. Then, the percentage of diamond grains inside slurry is also increased for higher productivity till reach 10.0 wt%. There also exhibit when the percentage of diamond grains exceed this value, the excess of diamond grains cause the scratches on the work surface resulting lower surface quality.

The conditions of lapping slurry on the revolving workpiece are determined by preliminary experiments. The lapping slurry is put on a workpiece of 18 mm diameter revolving with various spindle speeds and the conditions are observed. Fig. 2 shows the observed conditions of the lapping slurry. It can be seen that the lapping slurry was kept maintain without dropping or scattering and also no variation of diamond grains in the range of spindle revolution between 83 ~ 560min^{-1}.

3.2. THE EXPLANATION OF LAPPING METHOD

Fig. 3 shows the schematic view of the lapping system and procedure of lapping. The lapping tool in Fig 1 is fitted on the tool post of an ordinary lathe machine and the lapping procedure is arranged as follow. (1) The lapping slurry is dropped on to the work surface, (2) Picking up the diamond grains from the slurry to the lapping head, (3) the lapping processing is commenced with the relative movement between work piece and lapping head by the revolution of spindle and feed speed along Z axis of the machine. The lapping head and work piece are separated intermittently during lapping processing for dressing and cleaning. The investigation of the optimum lapping conditions by selecting lapping pressure, spring stiffness, spindle speed and feed speed on Z axis are influencing factors in this research.

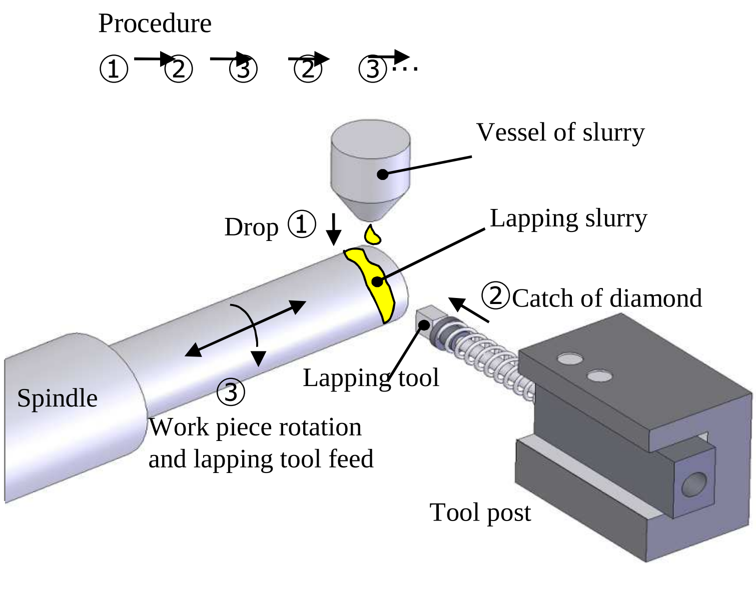


Fig. 3. Schematic view of lapping method

3. COMPARISON OF LAPPING PROCESS AND GRINDING PROCESS

For the evaluation of the accuracy, processing time and effectiveness of the proposed lapping method, the experiments are taken comparing with the conventional grinding process. Table 2 shows the processing condition for each process.

The work piece is a ϕ18 mm diameter S45C material with effective length 20 mm. The turning cutting conditions taken for initial cutting are same for both lapping and grinding processes as 2(a) in the Table 2.

Fig. 4(a) and (b) shows the results for improvement of geometrical accuracy and their comparison between lapping and grinding processes respectively. In Fig. 4(a), as it is impossible to measure geometrical accuracy during lapping processing, the multiple work pieces are taken with changing the lapping time and the combined results for continuous processing are shown here. Here, only diamond grain size of #80 is used and lapping condition is just directly applied from the references previously explained [1]. This condition

Table 2. Cutting condition

(a) Turning using the engine Lathe				(b) Grinding	
Cutting	Spindle speed min^{-1}		270	Wheel speed min^{-1}	2420
	Feed speed mm/rev		0.1	Wheel diameter mm	340
Lapping	Lapping Pressure	Catching diamond	10MPa (spindle stop)	Grinding speed m/min	2585
		For lapping	4MPa	Grinding depth mm	0.002
	Lapping slurry	Specification	See table 1		
		Size of diamond	#80		
	Spindle speed min^{-1}		83		
	Feed speed mm/rev		0.1		

is not yet the optimum condition in this step. The results of the lapping process become improve till 6 min from starting and there is no more improvement after 6 min. Moreover, the processing accuracy becomes 5μm during 6 min lapping time and it can be said that this research is effective for lapping with simple and faster method. Regarding to the grinding process, it takes 25 min for rough grinding of whole work surface and 15 min for finish grinding. Normally, total 40 min is taken for grinding a single product with same dimension. Grinding process takes much longer time and the overall accuracy also better than lapping method. For this experiment, only one size of diamond grain is used and the improvements of the accuracy also have limitation for this step. Therefore, in the next step, multiple sizes of diamond grains will be used and the improvement of the processing accuracy will be investigated.

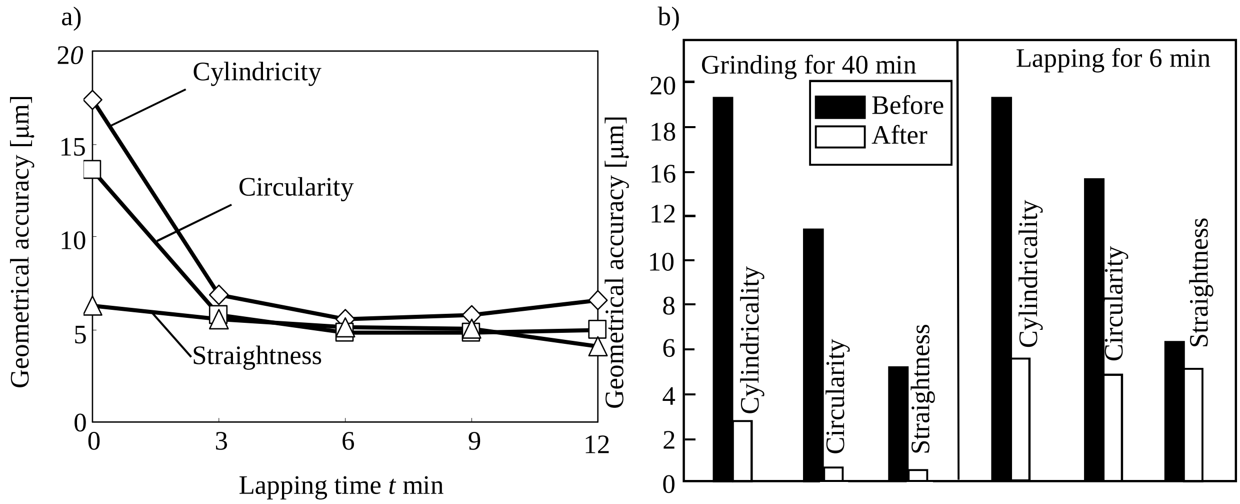


Fig. 4. Comparision of each machining processes, a) relationship between lapping time and deviation of form, b) comparision of grinding and lapping

4. OPTIMUM LAPPING CONDITION FOR IMPROVEMENT OF GEOMETRICAL ACCURACY

4.1. CONSIDERATION OF FUNDAMENTAL FOR IMPROVEMENT OF GEOMETRICAL ACCURACY

Fig. 5 shows the schematic of mechanism for improvement of processing accuracy by using proposed lapping system. In the preceding turning step, the accuracy of the lathe machine, eccentric error of spindle revolution and work piece center, centrifugal force, cutting force and vibration of the machine effects largely on the cylindricality, circularity and straightness of the work piece. Those affects are needed to eliminate in the succeeding lapping process for improving product accuracy. Thus, the structure of the lapping tool is considered and constructed as shown in Fig. 5. In Fig. 5(a), the change in the relative distance between work piece and lapping tool effects on the lapping pressure and lapping volume. For example, the larger distance between work piece and lapping tool (as in part A) will decrease lapping pressure and lapping volume will also decreased. In the opposite, the shorter distance between work piece and lapping tool (as in part B) the lapping pressure will be increased and the lapping volume becomes increased. In this method, the coil spring at lapping tool can expend freely till the lapping pressure become zero and thus the variation in circularity of the work piece could also become nearly zero. This mechanism effects for improving circularity even in the case of eccentric revolution of spindle and work piece. Similarly, in Fig. 5(b), as the lapping tool going from part D to E along Z axis, the relative distance between work piece and lapping tool become larger and the lapping pressure and lapping volume also decrease. The final lapping surface line will become line *L* in the figure.

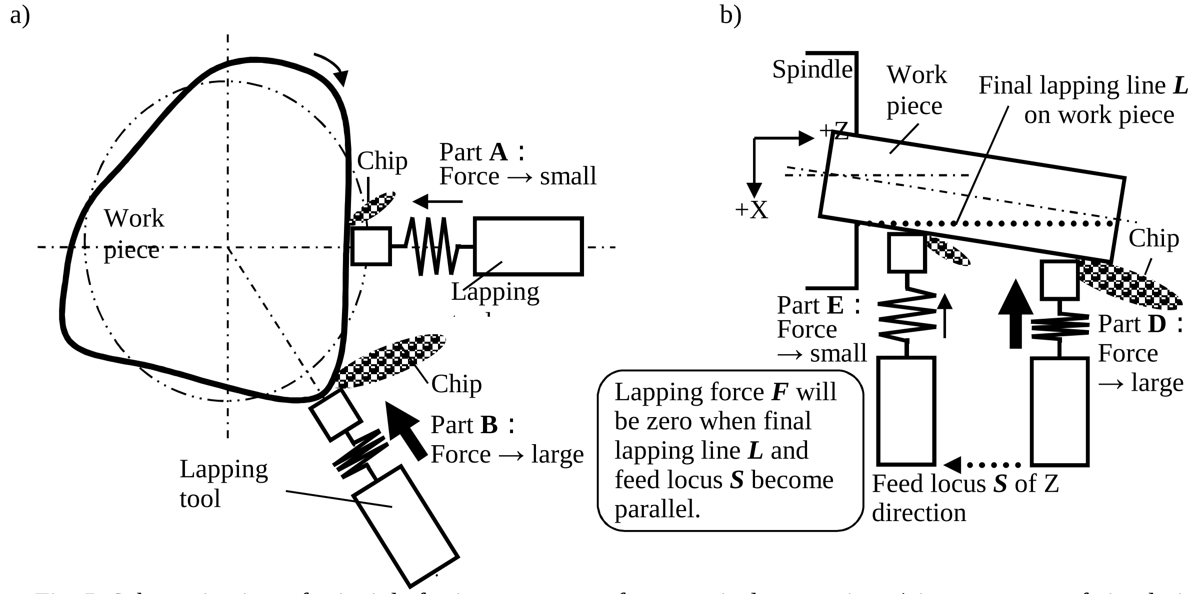


Fig. 5. Schematic view of principle for improvement of geometrical accuracies: a) improvement of circularity, b) improvement of both cylindricity and straightness

Therefore, there exist large influences by the revolution center of the work piece on cylindricality, the feed path of lapping tool along Z axis (line S) on the line *L* and the straightness of the feed path on the straightness of work piece respectively. Therefore, the accuracy of cylindricality and the straightness from the preceding turning process can be made improved in the succeeding lapping process. Moreover, the lapping pressure being used is relatively very small to that of cutting force in the turning process. Therefore, there is not much impact to deformation of work piece and thus the geometrical accuracy is improved more. The contact area between lapping head and work piece is also very short resulting less effect of vibration. Moreover, the cutting condition in the turning process is defined depending on the type of tool and work piece material. The machine vibration is unavoidable in this stage. However, in the succeeding lapping process, it is possible to select lapping condition to increase productivity as well as to avoid the resonance frequency of the machine easily. Therefore, the proposed lapping method is applicable for improvement of geometrical accuracy of the products.

4.2. THE OPTIMUM CONDITION REGARDING LAPPING PRESSURE AND SPRING CONSTANT

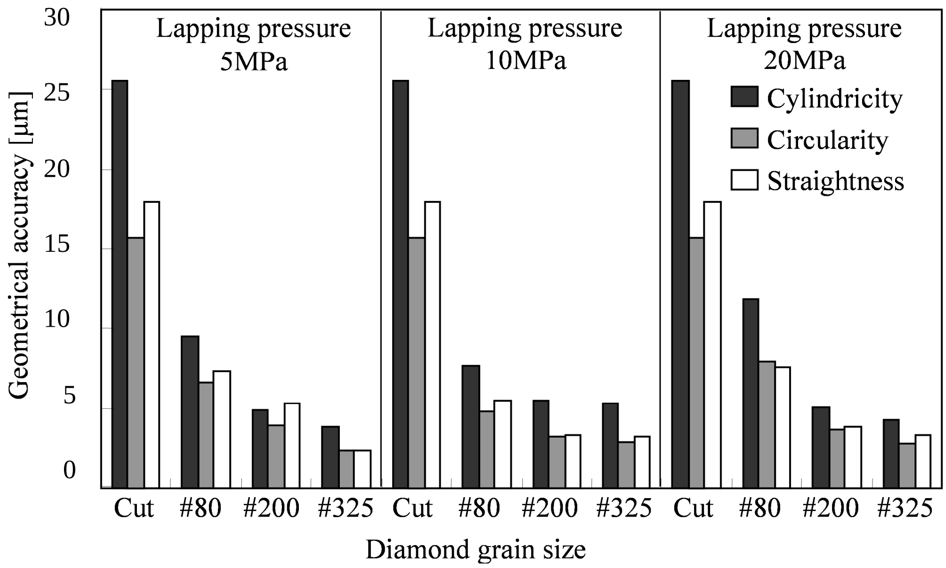
Lapping pressure influences on the productivity. In addition, the spring stiffness of lapping tool also affects the rate of improvement of geometrical accuracy. Thus, the effect of lapping pressure and spring stiffness on the improvement rate of geometrical accuracy is investigated here. Table 3 shows the lapping conditions taken in the experiment.

Table 3 Lapping condition

Material of work piece		S45C
Lapping area		φ18×20 mm
Lapping slurry		See table 1
Lapping pressure for amount catting diamond		10MPa (spindle speed 0 min^{-1})
Fig.6(a)	Lapping pressure	5, 10, 20 MPa
	Spring stiffness	1N/mm
	Spindle speed	270 min^{-1}
	Feed speed	0.1 mm/rev
Fig.6(b)	Spring stiffness	1, 9,27,33,53 N/mm
	Spindle speed	270 min^{-1}
	Feed speed	0.1 mm/rev
Fig.7(a)	Spindle speed	83, 270, 560 min^{-1}
	Feed speed	0.1 mm/rev
Fig.7(b)	Feed speed	0.1, 0.55, 1.1 mm/rev

Fig. 6(a) and (b) show the experimental results for geometrical accuracy with changing lapping pressure and spring stiffness respectively. For evaluating the effect of lapping pressure, lapping tool with lower spring stiffness 1.09 N/mm (same as in the research done

a)



b)

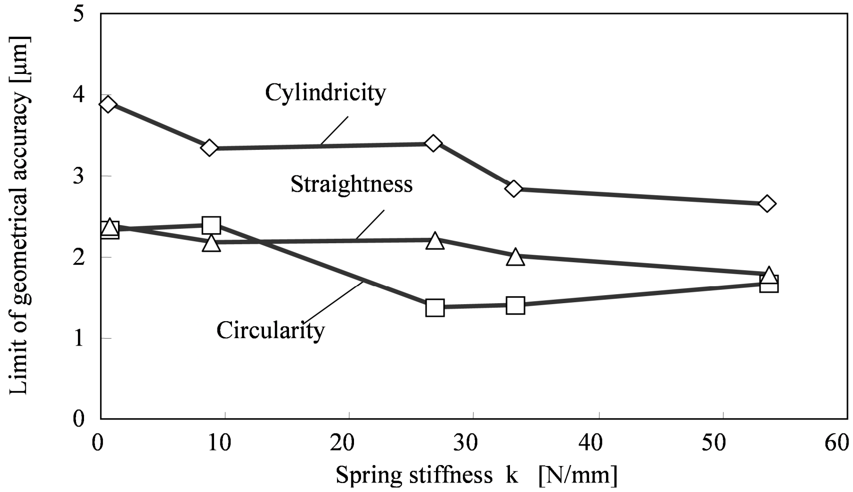


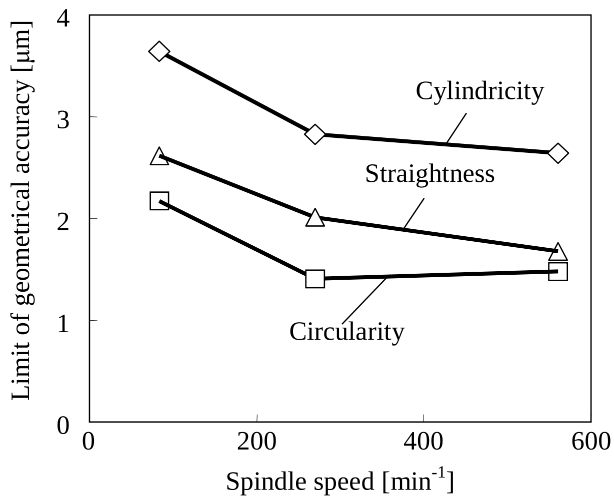
Fig. 6. Influence of lapping pressuere and spring stiffness on geometrical accuracy: (a) lapping pressure, (b) spring stiffness

by authors [1]) is used. It is observed that both the accuracy improvement rate and accuracy results are the best in using lapping pressure 5MPa. This is due to the vibration of themachine is very small as the lapping pressure is lower. In the case of changing spring stiffness, the best accuracy improvement rate and accuracy results are found while using spring with 33 N/mm. This is due to the effect that while the spring stiffness becomes higher, the metal removing rate also increases as the lapping pressure becomes higher and hence increased in lapping volume. The results for geometrical accuracy become worse using spring stiffness exceeding this value because of larger variation of lapping pressure deviated from optimum value 5MPa. This large variation occurs even in small change of spring length due to higher spring stiffness.

4.3. THE OPTIMUM CONDITION FOR SPINDLE SPEED AND FEED SPEED

The results of the improvement of geometrical accuracy for corresponding spindle speed and the feed speed are shown in Fig. 7(a) and (b) respectively. The spindle speed does not only effect on the improvement of geometrical accuracy, it also causes the machine vibration including resonance frequency. Therefore, with the consideration for both reducing the effects of vibration and increasing the productivity, higher spindle speed should be selected. In the experiment, it is observed that the spindle speed 560 min^{-1} gives maximum effective improvement of geometrical accuracy. Here, this value of spindle speed is only the specific characteristic of the lathe used in this study. For the case of using other machines, it is needed to take preliminary experiment for lowest vibration. Regarding to the feed speed, although there already revealed higher lapping rate and accuracy improvement rate by arranging lapping speed and lapping direction in the research paper [1], there is no much affect in this research due to different accuracy of the machine.

a)



b)

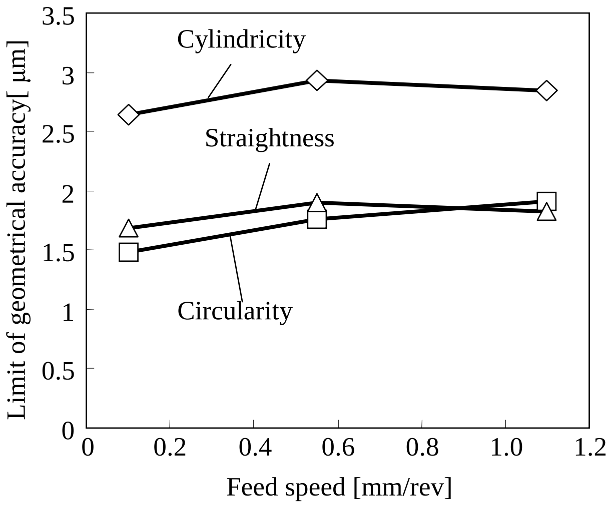


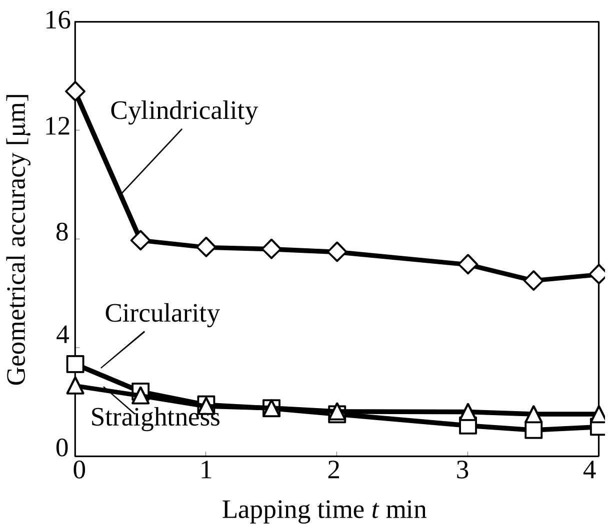
Fig. 7 Influence of spindle speed and feed speed on improvement of geometrical accuracy: (a) spindle speed, (b) feed speed

4.4. THE EVALUATION OF THE GEOMETRICAL IMPROVEMENT

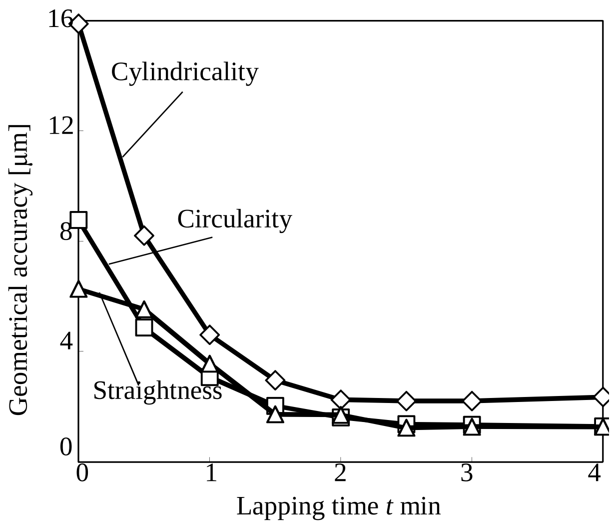
The evaluation of the improvement of geometrical accuracy is done by taking experiments using brass, S45C and carbide materials using optimum lapping condition shown in Table 4, which is obtained from the previous section,. The improvement of the geometrical accuracy is measured periodically and evaluated. Fig. 8 shows the improvement results. Even though the lapping time depends on the hardness of the materials, it is observed that all materials reached the maximum state of improvement during 5 min lapping time. This is 1/8 of the time taken for grinding process which takes 40 min for same dimension of work piece. Cylindricality is observed the most improved. This is due to effectiveness of optimum lapping condition and spring stiffness mentioned in section 4.2.

Table 4. Optimum lapping condition for improvement of each deviation of form

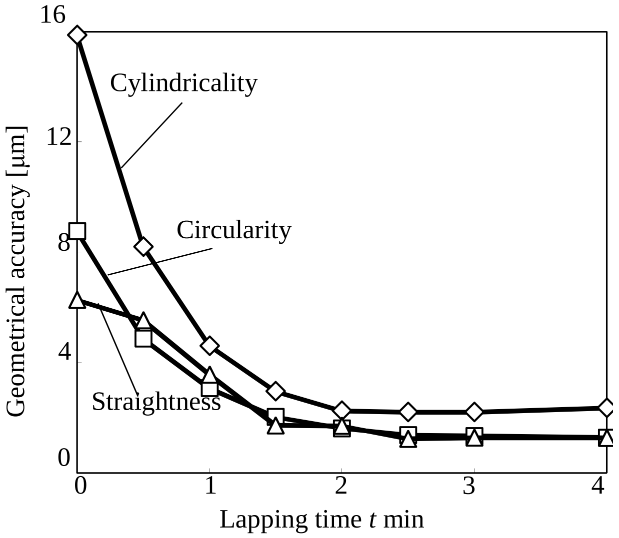
<table>
<tr><td colspan="4">Lapping condition</td></tr>
<tr><td colspan="2">Material of work piece</td><td colspan="2">Brass , S45C , V10</td></tr>
<tr><td colspan="2">Lapping slurry</td><td colspan="2">See table 1</td></tr>
<tr><td rowspan="2">Lapping pressure</td><td>For catching diamond</td><td colspan="2">10MPa
(spindle speed 0 min^{-1})</td></tr>
<tr><td>For lapping</td><td colspan="2">5 M Pa</td></tr>
<tr><td colspan="2">Lapping area</td><td colspan="2">φ18×20 mm</td></tr>
<tr><td colspan="2">Spring stiffness</td><td colspan="2">33 N/mm</td></tr>
<tr><td colspan="2">Lapping speed</td><td colspan="2">31667 mm/min</td></tr>
<tr><td colspan="2">Spindle speed</td><td colspan="2">560 min^{-1}</td></tr>
<tr><td colspan="2">Feed speed</td><td colspan="2">0.1 mm/rev</td></tr>
<tr><td colspan="4">Geometrical accuracy of the lathe used</td></tr>
<tr><td colspan="3">Straightness of slide guide</td><td>20µm</td></tr>
<tr><td colspan="3">Whirling of spindle center</td><td>20µm/300mm</td></tr>
<tr><td colspan="2" rowspan="2">Parallelism between spindle centre line and movement of carriage in Z direction</td><td>In vertical surface</td><td>20µm/300mm</td></tr>
<tr><td>In horizontal surface</td><td>15µm/300mm</td></tr>
</table>



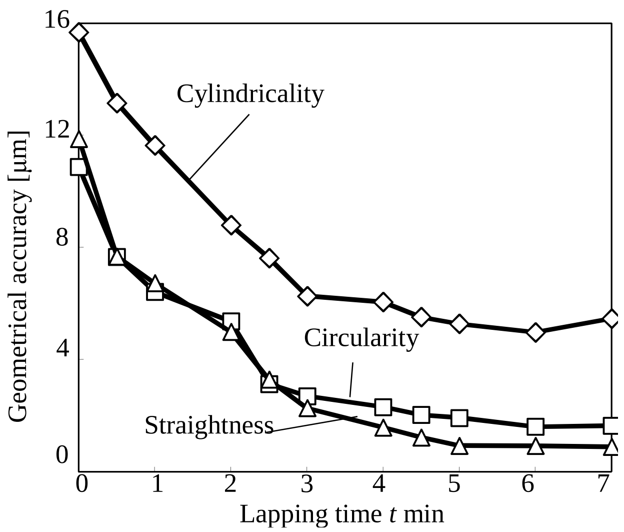
(a) Brass



(a) Geometrical accuracy

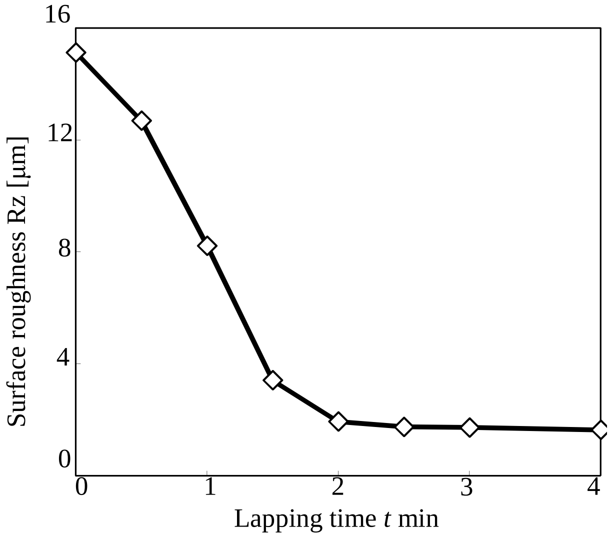


(b) S45C

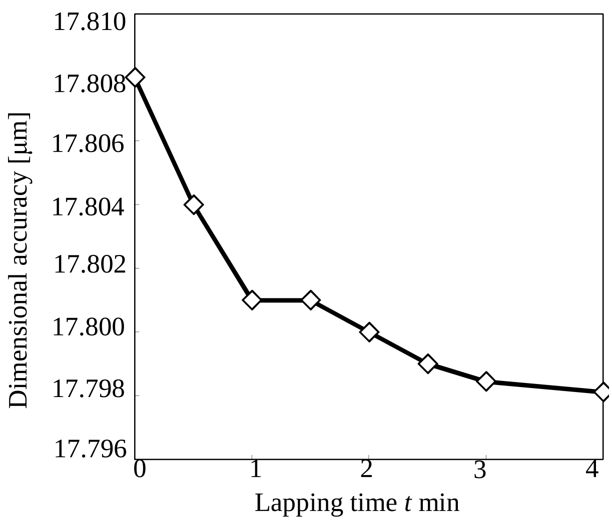


(c) V10

Fig. 8. Relationship between geometrical accuracy and lapping time for various materials



(b) Surface roughness



(c) Dimensional accuracy

Fig. 9. Relationship each processing accuracy and lapping time

Regarding to the circularity and straightness, depending on the work piece material, the geometrical improvement rates are different. V10 exhibit the highest improvement rate.

From these results it can be seen that the improvement of geometrical accuracy is almost straight relation with lapping time and the improvement rate also very fast to reach its maximum state. Therefore, this lapping method is effective for improvement of geometrical accuracy.

5. INVESTIGATION OF SURFACE ROUGHNESS AND DIMENSIONAL ACCURACY

The main objective of this search is to make improvement geometrical accuracy for lapping cylindrical shape work piece using normal lathe machine. However, in general, there also include surface roughness and dimensional accuracy in the meaning of processing accuracy other than geometrical accuracy. Therefore, in this research, the evaluation for surface roughness and dimensional accuracy is carried out by measuring those results of lapping S45C with the lapping condition shown in Table 4.

Fig. 9 shows the relationship between lapping time and geometrical accuracy, surface roughness, dimensional accuracy respectively. The geometrical accuracy is improved first and then the surface roughness is improved. Both conditions are improved with straight line curve in the initial period and then there needed to change the size of diamond. More improvements in both geometrical accuracy and surface roughness are obtained using smaller size of the diamond grains. Regarding to the processing accuracy (dimensional accuracy, geometrical accuracy, surface roughness) to meet with the designated specifications, the following procedures are needed to be arranged. (1) The cutting depth needed for finishing desired geometrical accuracy and roughness is calculated first based on the results of Fig. 8 and Fig. 9 and this thickness is considered to be added in the final dimension of preceding turning process. (2) The desired geometrical accuracy will be decided by succeeding lapping process. (3) The desired roughness will be taken with finishing lapping. (4) The confirmation for the dimensional accuracy will be taken whether it is in the desired range.

5. CONCLUSION

The advantages of this research can be concluded as follow.

(1) The improvement of accuracy for cylindricality, circularity and straightness with using developed lapping method is applicable using ordinary lathe machine.

(2) The optimum lapping condition for improvement of geometrical accuracy is revealed.

(3) The surface roughness improvement and dimensional accuracy is also improved using this lapping method.

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