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Experimental Evaluation on Machining Errors in Milling with Different Helix Angle End Mills
밀링에서 부등각 엔드밀의 가공오차에 관한 실험적 고찰

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<요 약>

이 연구는 밀링가공시 채터진동을 억제하기 위하여 부등각 엔드밀(나선각이 서로 다른 엔드밀)을 사용하여 절삭가공을 수행한 후, 그 가공특성을 고찰한 것으로 가공표면의 기하학적 오차를 일반적으로 사용하는 등각 엔드밀에 의한 값과 실험에 의해 비교·검토한 결과, 두 엔드밀 모두 가공표면의 기하학적 오차는 유사함 나타내고 있으나, 부등각 엔드밀의 절대오차는 등각 엔드밀 보다 더 적은 경향을 나타내고 있다. 이들의 오차는 상향절삭보다 하향절삭 가공했을 때가 더 큰 것으로 나타났다. 더구나, 등각 엔드밀과 부등각 엔드밀과의 절대오차가 다르게 나타난 것은 밀링가공시 사용한 절삭날 인선에 의하여 완전히 의존되어지며, 또한, 다른 나선각에 의해 기인된 각각의 절삭날에 대한 절삭날당 이송비의 변화에 의한 원인이라는 것을 명백히 알 수 있었다

Key Words : Different helix angle end mills, Feed rate, Machining errors, Cutting forces, elastic deformation.

1. Introduction

It is known that using different helix angle end mills in machining, the variation of cutting area under machining decreases and the machining state becomes stable[1]. From such a viewpoint, the different helix angle end mills are widely used to avoid the occurrence of chatter vibrations in machine shop at present. However, since their engage angles of successive cutting edges are not uniform, the geometric interference state between tool and workpiece differs from the case when using the conventional end mills and it is anticipated that the different machining errors take place. In this study, as the first step to clarify the machining characteristics of the different helix angle end mills, the difference of machining errors between different helix angle and conventional end mills is experimentally compared and discussed.

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2. Experimental Equipments and Methods

In order to compare the machining characteristics of two types of end mills, the end mills shown in Fig.1 are utilized for experiments. In the different helix angle end mills used in this study, the engage angles at the nose part and the helix angles of successive cutting edges are different. Hence the engage angle α decreases and β increases with the increase of the distance of cutting position from the nose of the end mill L. This causes the geometric difference of

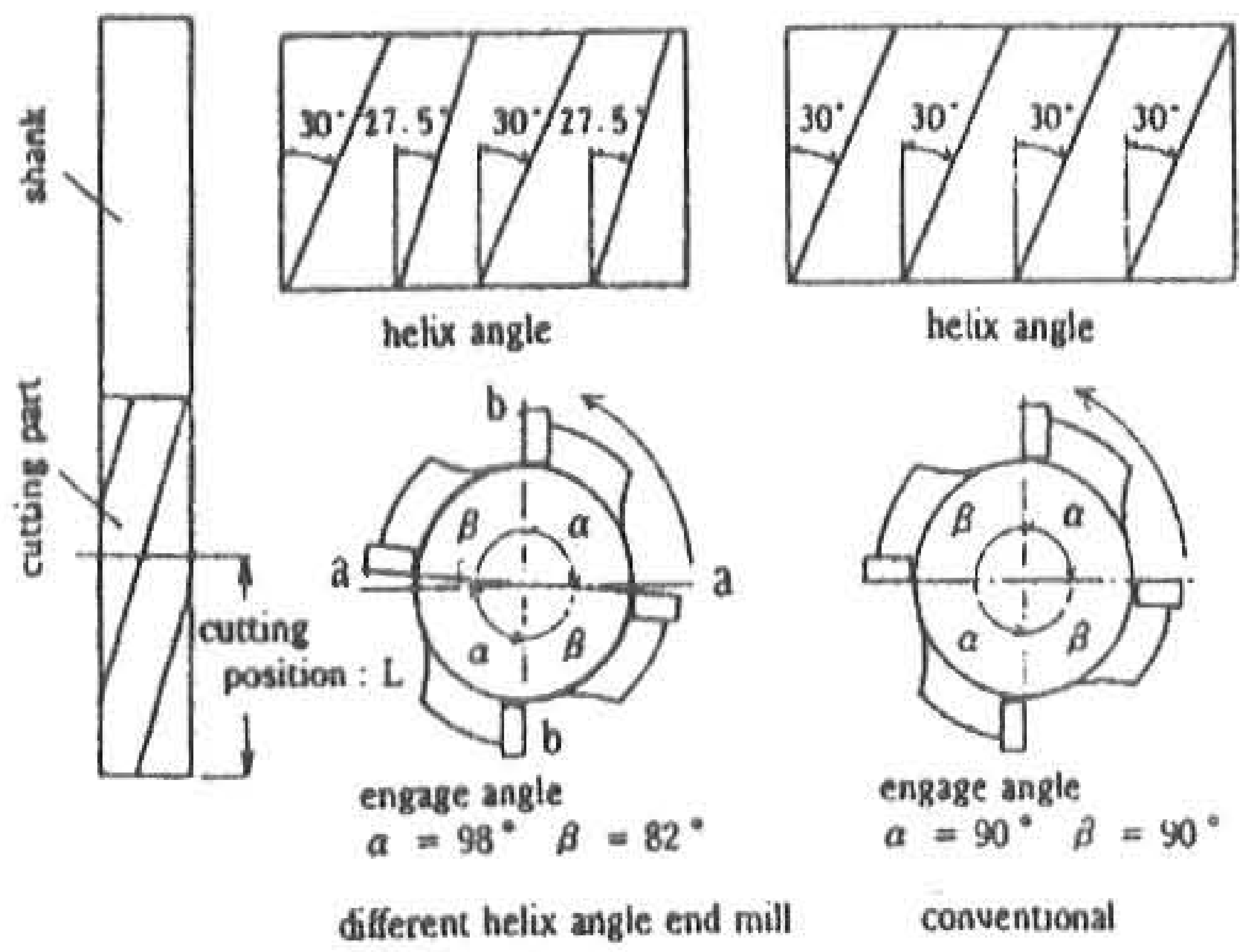

Fig.1 Utilized end mills

Table 1 Machining conditions

Workpiece	SS41
Number of revolution	200, 400 min^{-1}
Cutting speed	209.3, 418.7 mm/sec
Width of cut	10 mm
Depth of cut	1, 3 mm
Feed rate	35, 120 mm/min
Cutting directions	Down-cut, Up-cut
Dry cutting	

interference states between tool and workpiece depending on the cutting position.

In the machining tests, a vertical milling machine MHNC-40S produced by Makino Seiki Co. is used and the edge of workpiece loaded on a dynamometer 9257A by Kistler Co. is machined in peripheral milling as shown in Fig.2 From the viewpoint to monitor the difference between two types of end mills, the machining conditions shown in Table 1 are selected as the number of simultaneous acting cutting edge is one.

As shown in Fig.3, the machining errors are measured at nine points in every 1 mm successively with on electric micrometer located on the spindle head and the data are transmitted to a personal computer.

3. Comparison of Machining Errors

Measured results of the machining errors in down-cutting and up-cutting under the condition that the machining position L=12 mm are shown in Fig.4. In down-cutting, the positive machining errors, that is residual stock removal, take place and its amount

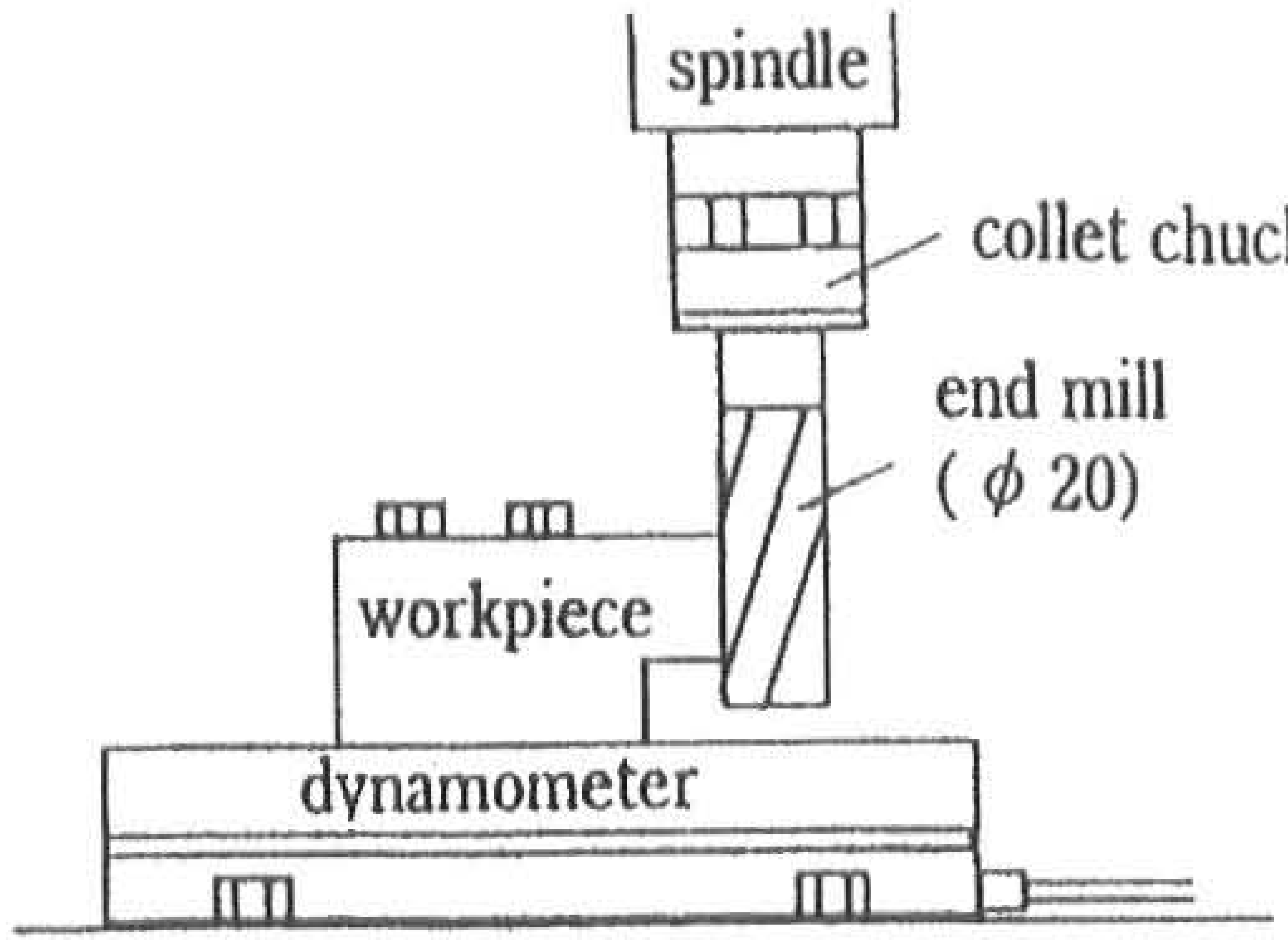

Fig.2 Machining setup

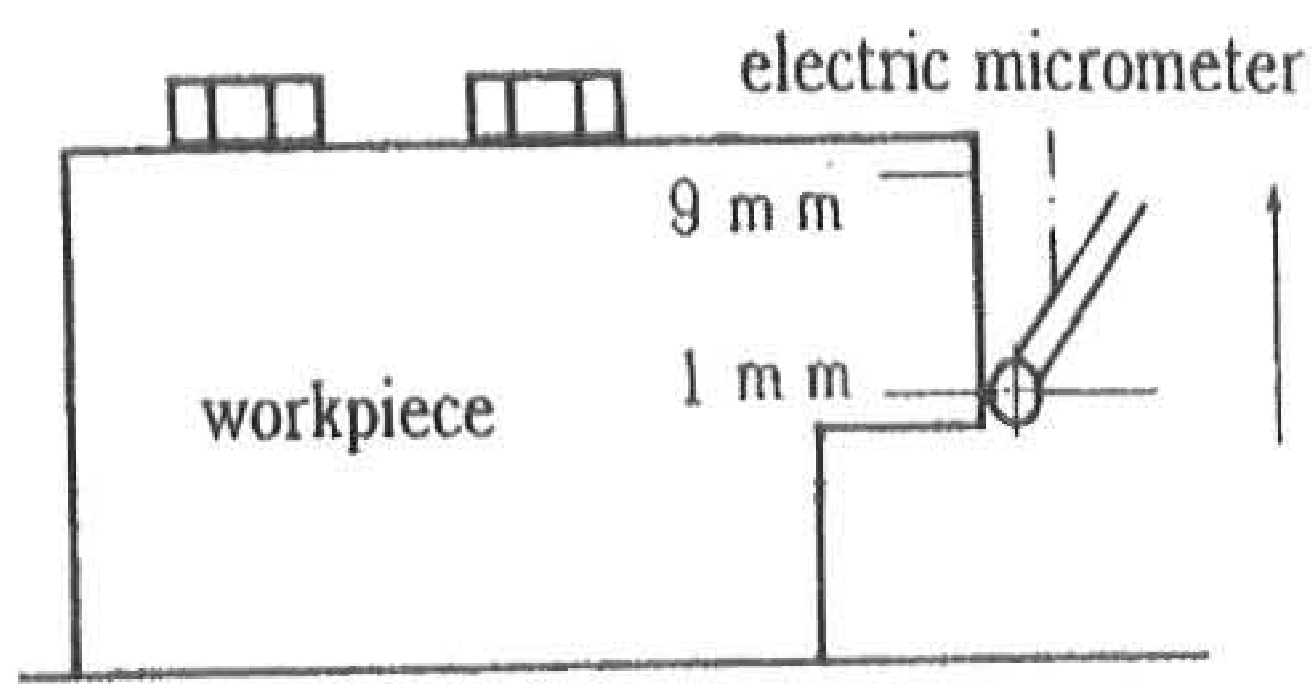

Fig.3 Error measuring method

increases from the top to the bottom of workpiece. These errors are caused by the elastic deformation of spindle system, which consists of spindle, collect chuck and end mill, due to the cutting force taking place in the opposite direction of depth of cut. In up-cutting, the negative machining error, that is excessive stock removal, take place. The error amounts slightly decrease from the point h=9mm to h=6mm and tends to increase from h=6mm to h=1mm. In this

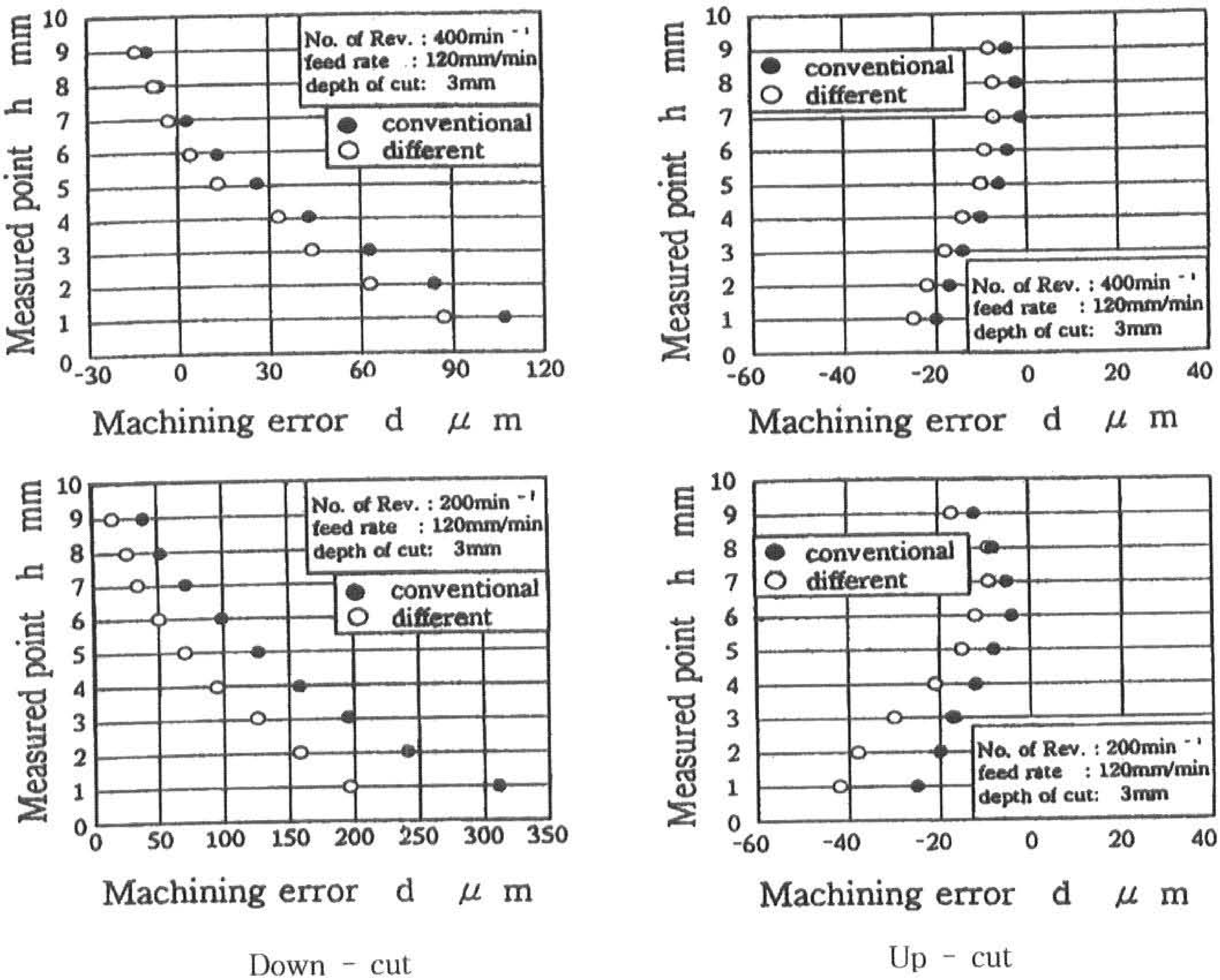

Fig.4 Measured machining errors

case, since the cutting direction is opposite to the down-cutting, the cutting-force directs to the workpiece side. Consequently, another type of machining errors occur. The mechanisms of the occurrence of these two types of machining errors in conventional end mills are analyzed in detail by Fujii and others[2], and they have reported the similar tendency with the results shown in Fig.4. Comparing the machining errors with the conventional and different helix angle end mills shown in Fig.4, the tendencies of both cases are similar and the absolute amounts of machining errors increase with the decrease of spindle revolution speed.

However, absolute amounts of errors are different between two types of end mills. In down-cutting, these amounts with different helix angle end mills are smaller then the case of conventional end mills. On the other hand, the amounts with different helix angle end mills are larger in up-cutting. Furthermore, the different of absolute amounts between two types of end mills in down-cutting is larger than them in up-cutting. So that, it can be considered that the effect of different helix angle typically appears in down-cutting rather than in up-cutting. Taking into account these tendencies, the effect of different helix angle in down-cutting will be considered in detail in follows.

In the Machining with conventional end mills, the feed rates per edge are constant, in cases shown in Fig.4 0.075mm and 0.150mm, and the interference state of each edge is uniform. Consequently, the machining forces and the elastic deformations are constant. On the other hand, in case of different helix angle end mills, the feed rate per successive edges are changed depending on the machining position L. For example, at the point L=3 mm corresponding to the measuring point h=1 mm in Fig.4, the engaging angles are α =97.3 ° and β=82.7 ° and the feed rate of cutter a is 0.081 mm and of b is 0.069 mm. Two dimensional interference state between successive tools and workpiece is schematically shown in Fig.5. In the case of cutting edge a of which locus is shown with broken line, the feed rate of cutting edge is large and the residual stock removal due to the elastic deformation becomes large. While, in the case of next cutting edge b, shown with alternate long and short dash line, the feed rate is smaller and the residual stock removal developed by cutting edge a may be removed.

Fig.6 shows the interference state indown-cutting. Cutting edge starts to interfere with the bottom point A and progresses topoints B and C,

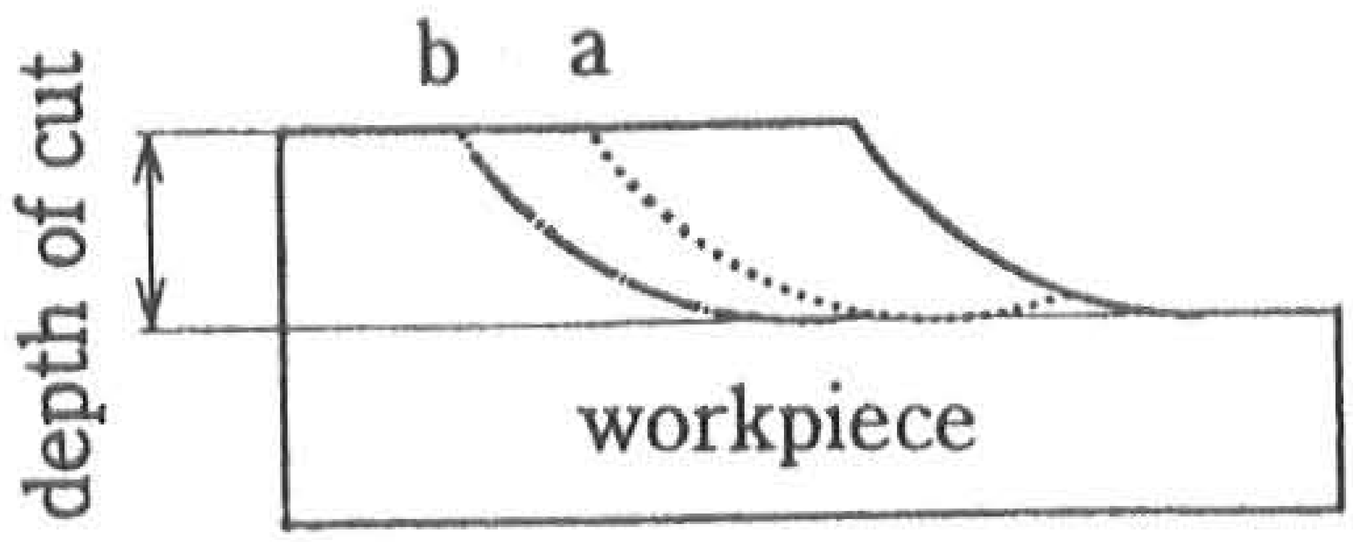

Fig.5 Schematical 2 dimensional interface state

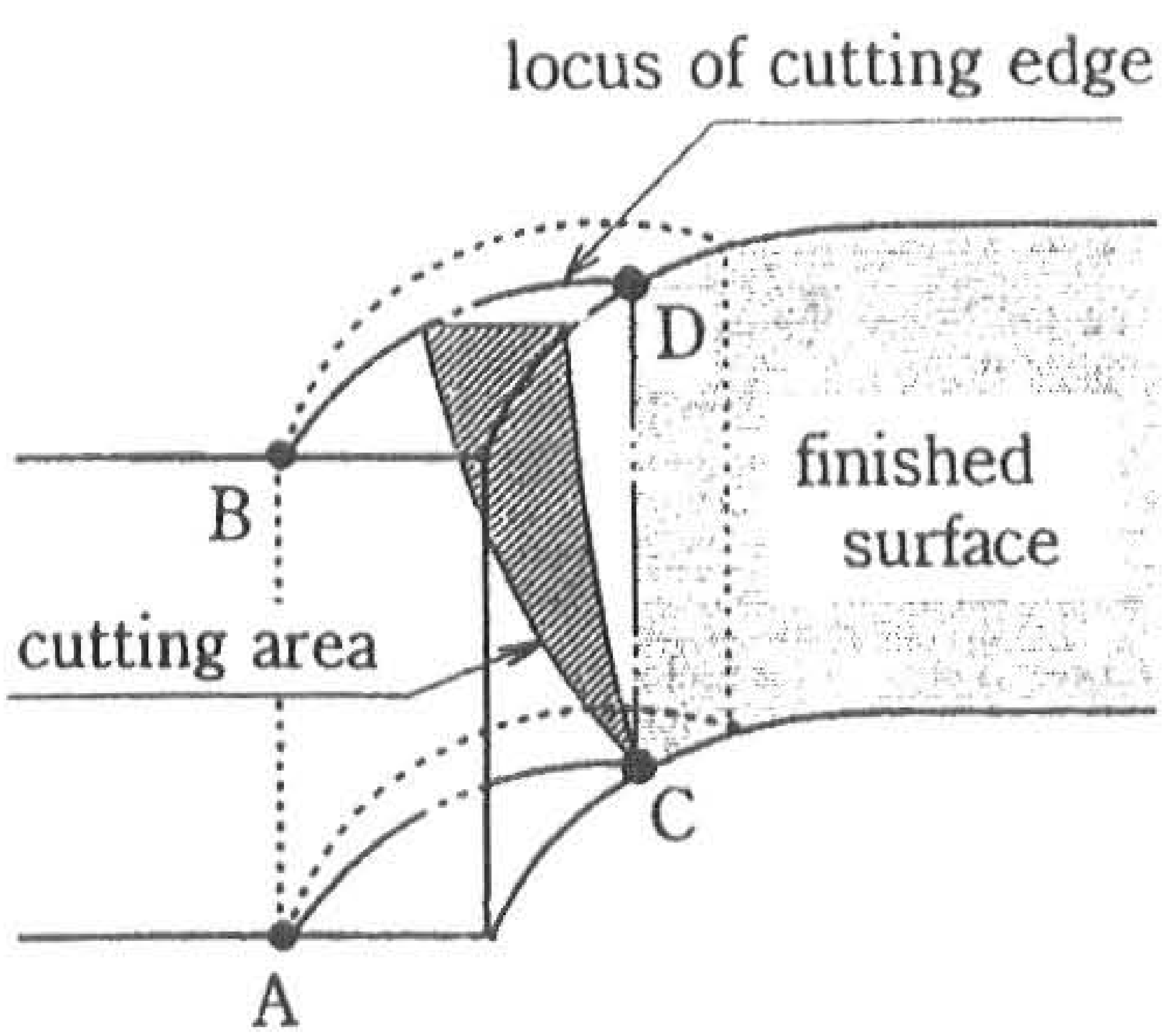

Fig.6 Interference state in down-cutting

while the cutting edge starts to be released from the point C to D. Hatched area shows the cutting area in this cutting process. As shown in figure, the cutting area of cutting tool gradually increases from the point A to the peak and decreases to zero at the point D. A measured example of the cutting forces in the normal direction to finished surface in down-cutting with different helix angle end mill is shown in Fig.7. The machining conditions are also shown in this figure. In Fig.7 it is known that the cutting force gradually increases to the peak and decreases to zero. The process of cutting force deviation shown in this figure corresponds to the changing process of cutting area in Fig.6. In Fig.7, a boundary line between the area of removed as chip and the area remained as finished surface is shown. This line corresponds to the line between two points C and D in Fig.6. Since the tool starts removing from workpiece when the cutting force intersects with this line, it can be considered that the amount of cutting force after this intersecting point directly affect on the machining errors finallyremained in finished workpiece surface.

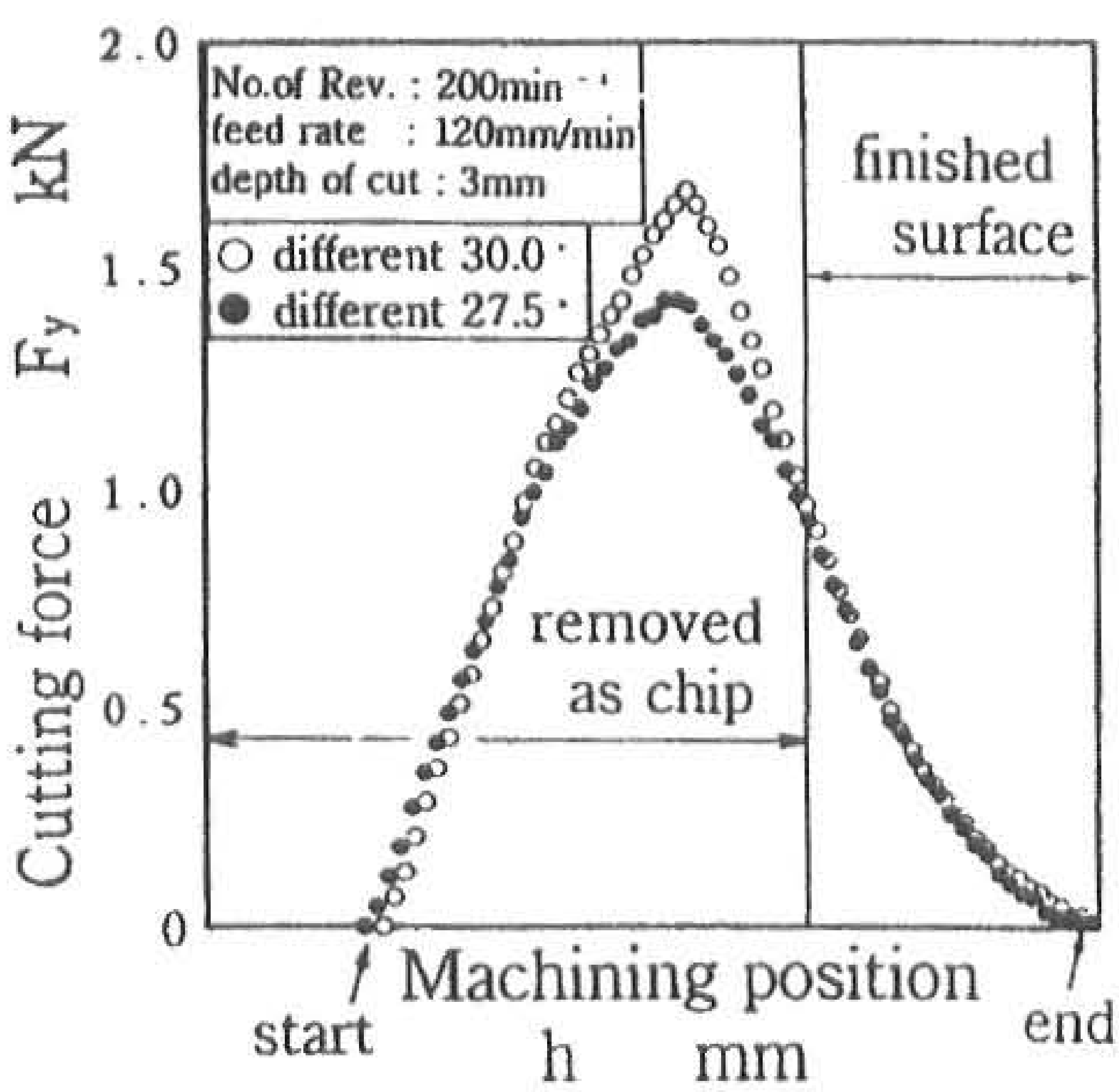

Fig.7 Cutting forces in normal direction

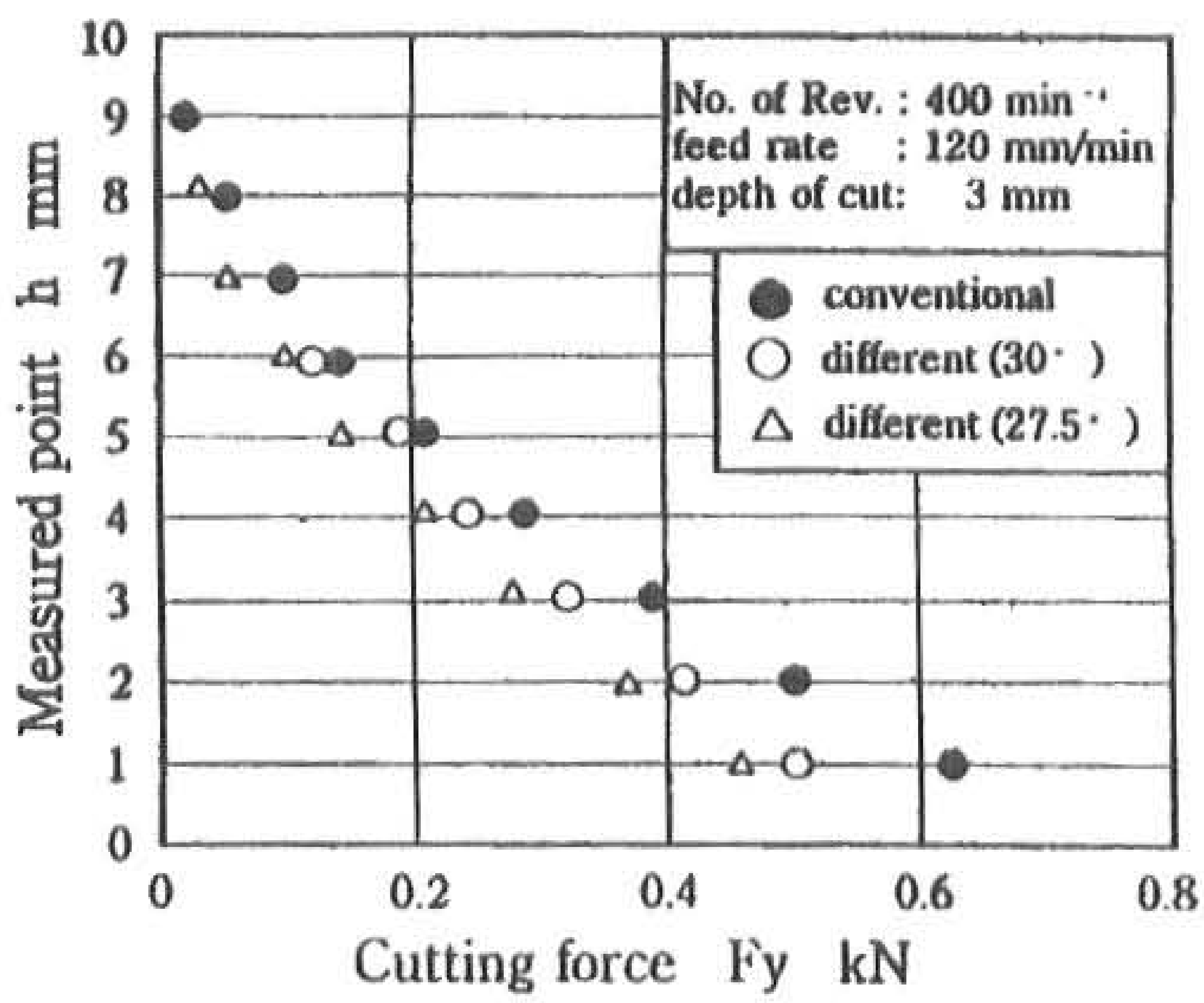

Fig.8 Absolute amounts of cutting forces

From such a viewpoint, the cutting forces corresponding to each measured point are shown in Fig.8. In this figure, the cutting force at measured point h=1 mm is the largest and it decreases form bottom to top points. This tendency coincides with that the cutting area shown in Fig.6 moves from bottom to top and gradually decreases. In Fig.8, the absolute amounts of cutting force with a conventional end mill are the largest and they decrease with cutting edge a to b in different helix angle end mill. Since the cutting force with cutting edge b is smaller than with the conventional cutting edge as shown in this figure, the difference between these two cutting forces causes that the

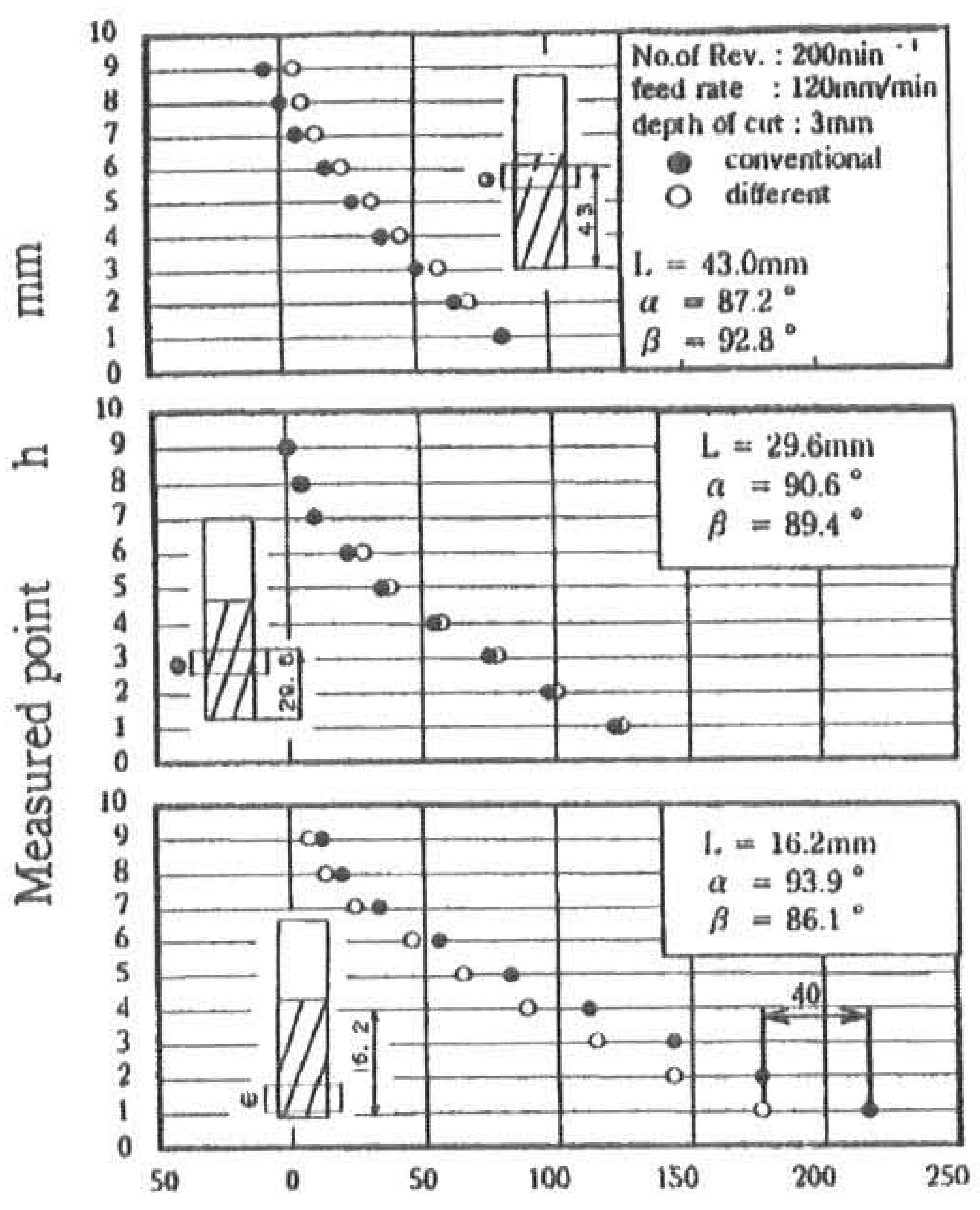

Fig.9 Machining errors in different cutting positions

machining errors with the different helix angle end mills are smaller than the case of the conventional end mill.

Fig.9 shows the machining errors obtained under the conditions L=43.0, 29.6 and 16.2 mm. It can be known that the absolute amounts of cutting errors decrease with the increase of L. This tendency may be caused by that the bulging length of the spindle system from the front bearing decreases with the increase of cutting position L and the static stiffness of spindle system increases. Furthermore, the difference between two engage angles α and β decreases with the increase of L, and the difference between machining errors with conventional and with different helix angle end mill decreases. From the test results shown above, it is known that the metal removal rate varies with the change of the feed rate per cutting edge, the elastic deformation of the spindle system, consisting of spindle, collet chuck and end mill, varies with the cutting force due to the metal removal rate. Consequently, when different helix angle end mill is used in down-cutting, smaller machining errors take place comparing with the conventional end mill.

4. Conclusions

Considering the machining errors occuring in milling operations with different helix angle end mills, the difference of absolute amounts is experimentally compared with the case in conventional end mills. From the test results, it is clarified that the machining errors in down-cutting take place due to the elastic deformation of the spindle system, and that the absolute amounts of machining error between helix angle and conventional end mills occures depending on the difference of feed rate per cutting-edge. In order to clarified these difference quantitatively, a three-dimensional cutting force mechanism depending on the geometrical interference between tool and workpiece shown in Fig.6 have to be analyzed theoretically, and it will be considered in future.

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