euspen's 19th International Conference & Exhibition, Bilbao, ES, June 2019
www.euspen.eu

Monitoring of cutting state in micro milling of lithium niobate

Kenji Shimana[1], Tetsuya Oshige[1], Shinichi Yoshimitsu[1], Yuya Kobaru[1] and Eiji Kondo [2]

[1]*National Institute of Technology, Kagoshima College, Japan*
[2]*Graduate School of Science and Engineering, Kagoshima University, Japan*

shimana@kagoshima-ct.ac.jp

Abstract
In recent years, microfabrication by using a small diameter end mill has been used widely in manufacturing process of optical components and semiconductor because high speed machining by using a small diameter end-mill has been put into practical use. Therefore, since the effect of cutting edge on the machining accuracy is very large, it is very important to detect the state of small diameter end mill in real time. However, since the size of the cutting phenomenon using the small diameter end mill is very small, it is difficult to detect the state of tool. On the other hand, single crystal lithium niobate ($LiNbO_3$), has been widely used for the laser elements, piezoelectric elements, surface acoustic wave elements in recent years. A liquid delivery system using surface acoustic wave (SAW) generated from $LiNbO_3$ as a micropump can transport a trace amount of liquid with high accuracy. However, it is necessary to process the groove with smooth bottom surface and without chipping on edge portions in order to fabricate a device utilizing the SAW characteristics of $LiNbO_3$. However, $LiNbO_3$ is a brittle material with strong crystallographic effect. $LiNbO_3$ must be machined as the ductile-mode cutting without brittle cracks. The purpose of this study is to propose an effective method for monitoring the cutting state of $LiNbO_3$ in real time. For this purpose, cutting tests were performed in order to investigate the effective parameters for monitoring the cutting state in micro milling of Z-cut $LiNbO_3$. As a result, it was found in the experiments that the strong crystallographic orientation effect was observed on the machined surface. Furthermore, the crystallographic effect of $LiNbO_3$ affects the cutting force. Consequently, the cutting force can be used as an effective parameter for monitoring the cutting state in micro milling of $LiNbO_3$.

Keywords : Lithium Niobate, Monitoring, Cutting Force, End Mill

1. Introduction

Microfabrication techniques are indispensable to manufacturing small parts of the tablet-type device, the cellular phone, and so on. In recent years, microfabrication using small-diameter end mills has been used widely in the manufacture of optical components and semiconductors as high-speed machining using small-diameter end mills has increasingly been put to practical use.

Single crystal lithium niobite ($LiNbO_3$) has been widely applied in surface acoustic wave (SAW) in recent years because it has superior physical, optical and electronic properties. However, $LiNbO_3$ is difficult to machine because it is a hard and brittle material. In addition, final fracture can easily occur once-cracking occur. Therefore, $LiNbO_3$ must be machined using ductile-mode cutting to prevent brittle cracks. Many researchers have tried to clarify the effectiveness of micromachining of $LiNbO_3$ [1,2]. In ductile-mode cutting of $LiNbO_3$, the cutting thickness per cutter must be very small. Therefore, the feed rate must be very low. Consequently, it is important to monitor the cutting state during micro milling of $LiNbO_3$. Relations between specific cutting energy and cutting parameters have also been reported [3].

The purpose of this study was to develop an effective method for real-time monitoring of the cutting state in end milling of $LiNbO_3$. To this end, cutting tests were performed to identify parameters that are useful in monitoring the cutting state in micro milling of $LiNbO_3$.

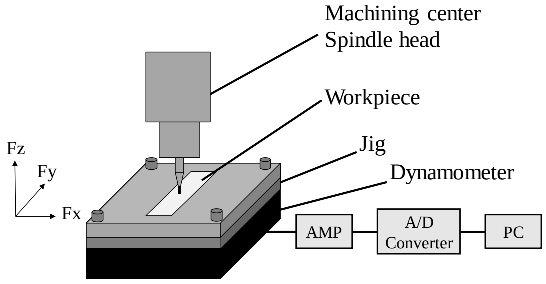

Figure 1. Experimental appratus

2. Experimental procedure

The experimental apparatus used in this study is shown in Fig. 1. Cutting tests were performed using a vertical machining centre. Each end mill was mounted in such a way that the eccentricity of the end mill would be 1 µm or less, as measured using a dial gauge. The cutting conditions are listed in Table 1. In the cutting tests, the groove on the workpiece was formed by a milling cutter moving horizontally.

Table 1 Cutting conditions

Workpiece		$LiNbO_3$
Tool	Type	Cemented Carbide Square-end mill
	Diameter [mm]	0.3
	Number of flutes	2
	Overhang [mm]	15
Rotational speed N [min^{-1}]		10000
Feed rate f [mm/min]		0.3
Inclination angle [deg]		90
Axial Depth of cut [µm]		5

The workpiece was made of polished Z-cut $LiNbO_3$ plate 1 mm in thickness. The workpiece was attached in such a way that the inclination of the workpiece was 1 µm or less, as measured using a dial gauge. The cutting conditions were determined in preliminary cutting tests. The cutting thickness at the moment when the machined surface is generated on the side surface of the groove, is very small as 1 nm or less. Therefore, it is considered that no cracks occur on the machined surface.

The cutting tests were performed without using coolant. The cutting forces F_x, F_y, and F_z were measured with a dynamometer, as shown in Fig. 1. The dynamometer was a piezoelectric quartz force transducer affixed to a table. The cutting forces were transmitted to a personal computer via an A/D converter board every 50 µs. The machined surface of the lithium niobate were observed using a digital micro-scope.

3. Experimental results

Figure 2 shows the definition of crystal orientation of $LiNbO_3$ and feed direction of tool. The feed direction $[\bar{2}\ 1\ 1\ 0]$ was defined as 0°.

Figure 3 shows the photograph of the finished surface. The smooth machined surface was obtained at feed directions of 30°, 90° and 150°. On the other hand, the machined surface with fine brittle fracture was observed at the edge of the groove at feed directions of 0°, 60°, 120° and 180°.

Figure 4 shows details of the cutting force F_t. F_t is the principal cutting force obtained from equation (1):

$$\begin{pmatrix} dF_x(\theta) \\ dF_y(\theta) \end{pmatrix} = \begin{pmatrix} -\cos\theta & -\sin\theta \\ \sin\theta & -\cos\theta \end{pmatrix} \begin{pmatrix} dF_t(\theta) \\ dF_r(\theta) \end{pmatrix} \qquad (1)$$

where F_x and F_y is the forces along the feed and normal directions respectively, F_r is the thrust force, with θ as the rotation angle of the flute [4]. The cutting process by two flutes can be seen at feed directions of 30° and 90°. On the other hand, components different from the cutting process by two flutes can be seen at feed directions of 0° and 60°.

Figure 5 shows the spectrum of the cutting force. The amplitude of the spectrum at a frequency of approximately 333 Hz shows a peak value at feed directions of 30° and 90°. This frequency is considered to be approximately equal to twice the rotational speed of the spindle because the end mill has two flutes. On the other hand, the amplitude of the spectrum at frequency of 500 Hz or 833 Hz shows a peak value at feed directions of 0° and 60°. Although, this frequency is considered to be due to fine brittle fracture of $LiNbO_3$, it is necessary to investigate further in the future.

4. Conclusions

The strong crystallographic orientation effect was observed on the machined surface in micro milling of lithium niobate. Furthermore, the crystallographic effect of $LiNbO_3$ affects the cutting force. The possibility of monitoring the machining state by the cutting force in micro milling of $LiNbO_3$ could shown in this paper.

References

[1] OKUDA K., et al.. Machining of micro groove of lithium niobite by planer-type cuting with diamond tool for fabrication of SAW device. *Proc. of the 14h Euspen Int. Conf.* 2014.

[2] TAKIZAWA R., et al.. Lithium niobite ridged waveguides with smooth vertical sidewlls fabricated by an ultra-precision cutting method. *Opt. Express* 214; **22**-22: pp. 27733-27738.

[3] SHIZUKA H., et al.. A study on the ductile mode cutting of lithium niobate. *Adv. Mater. Res.* 2010; **126**-128: pp. 246-251.

[4] KANG I.S., et al.. A mechanistic model of cutting force in the micro end milling process. *J. Mater. Process Tech.* 2007; **180**: pp. 250-255.

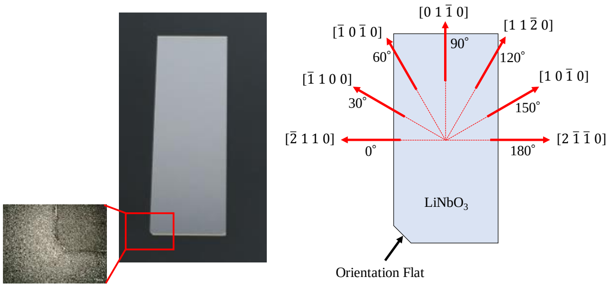

Figure 2. Crystal orientation of $LiNbO_3$ and feed direction

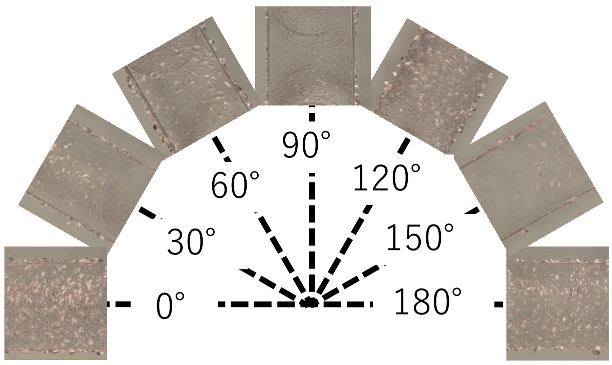

Figure 3. Photographs of the finished surface

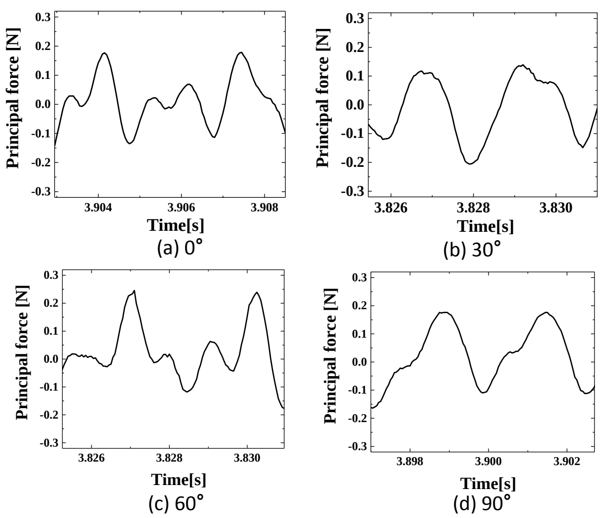

Figure 4. Details of cutting force F_t

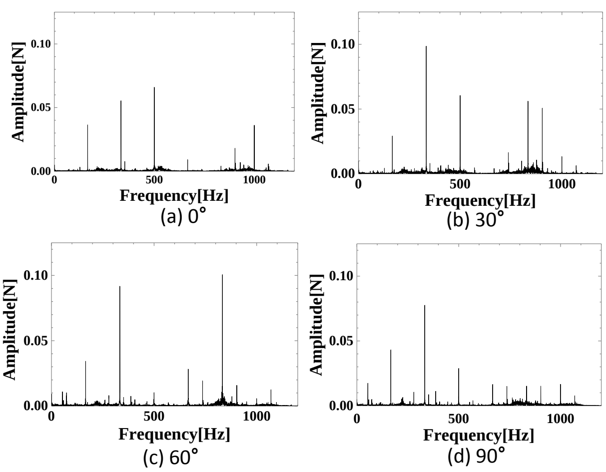

Figure 5. Spectrum of cutting force