# 초음파 절단기에 의한 유리 절단면의 상태에 관한 실험적 검토

# Experimental Study on Cutting State of Glass by Ultrasonic Scriber

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## 요 약

본 논문은 초음파를 이용한 유리 절단기를 개발하고 실험적으로 최적의 구동 주파수를 조사하였으며 유리 절단기의 효과에 대하여 검토하였다. 효과를 분석하기 위해 유리 절단기 시스템의 이론적 모델을 제시하였다. 그리고 시스템에서 최대 가속도 진폭의 주파수를 이론적으로 구하였다. 주어진 시료에 대해 절단면의 최대 깊이를 실험적으로 조사하였으며 사용한 시료는 석영유리(200mm(L)×30mm(W)×3mm(T))로 일정 가속도 진폭으로 모든 주파수에 대해 초음파 진동자를 구동하였다. 적정한 구동 주파수의 효과를 실험적으로 검토한 결과, 유리판에서 메디안 크랙의 깊이를 최대화하는 최적 주파수는 18.35kHz로 나타났다. 이러한 결과는 이론적 모델로 제시한 시스템의 계산 결과와 매우 일치하였다.

## Abstract

In an ultrasonic glass scriber, the effect of ultrasonic vibration and its optimum driving frequency were investigated experimentally. To investigate the optimum ultrasonic frequency theoretically, the vibration model of the ultrasonic scriber is assumed. The frequency for maximum amplitude of acceleration is obtained theoretically. To investigate the depth of cutting edge corresponding the each frequency. The quartz glass plate specimen with a dimension of 200mm(L)×30mm(W)×3mm(T) is selected. The ultrasonic transducer is operated by the constant acceleration amplitude for the every frequency. The maximum crack depth was generated when the driving frequency was 18.35kHz. These results were in good agreement with those of the calculated model theoretically.

***Key words*** : Glass, Scribing, Ultrasonic, Vibration, Crack

## I. Introduction

Recently, the demand for large-scale display increases in television sets, personal computers, etc. as the information industry develops. In production process of the display, it is necessary to cut a glass plate with high cutting speed and orthogonality in cutting cross sections. It was difficult to solve those problems in the conventional process, which was able to control only the speed and the pressure of cutting tool. However, if high pressure is applied to a scribing wheel to make a deep median crack vertically, the high speed scribing with high pressure would make much lateral cracks in the surface of the glass plate horizontally. To overcome these problems, many researches have studied on the ultrasonic glass scriber[1-2]. However, because the cutting mechanism had not been investigated enough, the driving frequency had been decided according to the engineer's experience.

In this paper, to analyze the mechanism of the ultrasonic scribing for cutting a glass plate, an

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ultrasonic scriber was designed and the cutting state of the glass was examined. For theoretical investigation, a model with forced vibration was suggested.

## II. Theory

When a force is applied to the surface of a glass plate vertically, a median crack is generated in direction of the force. In this case, even if the force keeps on, the median crack is not increased, and the excessive energy generates the lateral crack horizontally[3]. Applying periodical forces by an ultrasonic transducer, unnecessary lateral cracks due to the excessive energy can be prevented. To investigate the optimum ultrasonic frequency theoretically, the vibration model of the ultrasonic scriber is assumed as shown.

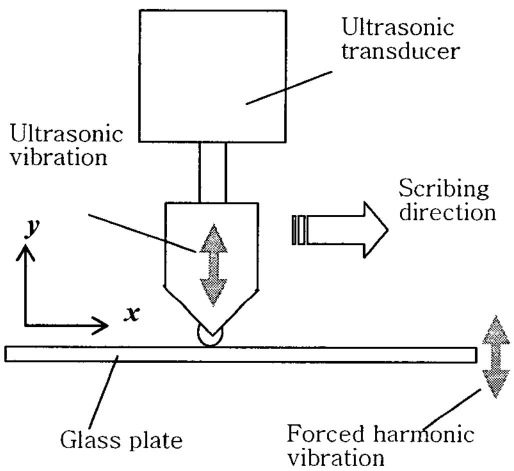


Fig. 1. Forced harmonic vibration model of ultrasonic glass scribing system

In Fig. 1, the motion of glass plate is assumed as the forced harmonic vibration moves in y-direction. Therefore, equation of motion for the displacement of y can be derived from Eq. (1) as follows[4];

$$\frac{\partial^2 y}{\partial^2 t}+\frac{\alpha}{m}\frac{\partial y}{\partial t}+\frac{c}{m}y=\frac{F_0}{m}\cos wt \qquad (1)$$

In this equation, the amplitude of external force due to the ultrasonic transducer is $F_0$, and angular frequency of the ultrasonic vibration is $\omega$, and m, c, and $\alpha$, are mass, elastic constant, and damping coefficient of the glass, respectively. To investigate the vertical force applied to the glass plate for various driving frequencies, the y-component of acceleration was obtained from Eq. (2) as follows;

$$a_y=A(\omega)\cos(\omega t-\phi) \qquad (2)$$

where,

$$A(\omega)=\frac{\omega^2 F_0/m}{\sqrt{(\frac{c}{m}-\omega^2)^2+(\frac{\alpha}{m})^2\omega^2}} \qquad (3)$$

From the Eq. (3), the frequency for maximum amplitude of the acceleration is obtained as following Eq. (4).

$$f_r=\frac{1}{2\pi}\sqrt{\frac{c}{m}-\frac{1}{2}(\frac{\alpha}{m})^2} \qquad (4)$$

## III. Experiment and Results

An ultrasonic glass scriber was manufactured for experiment as shown in Fig. 2.

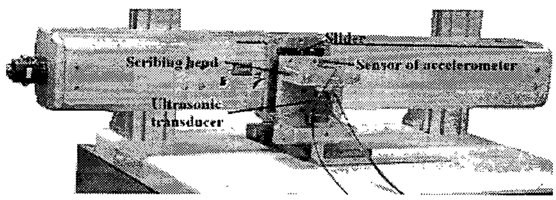


Fig. 2. .Photograph of ultrasonic glass scribing system

In Fig. 2, the scribing head with an ultrasonic transducer can freely slide along to y-axis. Therefore, the head presses the glass by its own weight. The moving speed of the head to x-direction was controlled by servomotor. The construction of scribing head is shown in Fig. 3.

In Fig. 3, The scribing head is inserted on the bottom of a Langevin-type ultrasonic transducer. The sensor of accelerometer was placed on the top of the head mass of the transducer. The head mass was fixed by a screw with point tip. The experimental setup is shown in Fig. 4. The amplified electric signal drives the ultrasonic transducer fixed on the scribing head, and the transducer makes the scribing wheel of the head vibrate. The wheel is rolling on the glass as the scribing head moves along the x-direction.

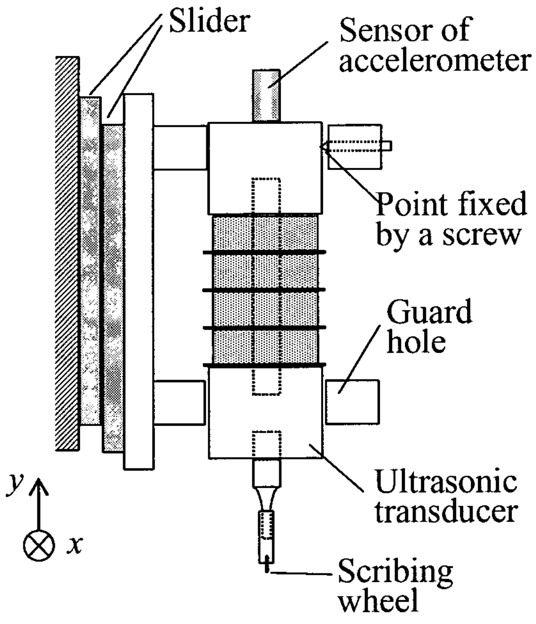


Fig. 3. Construction of scribing head

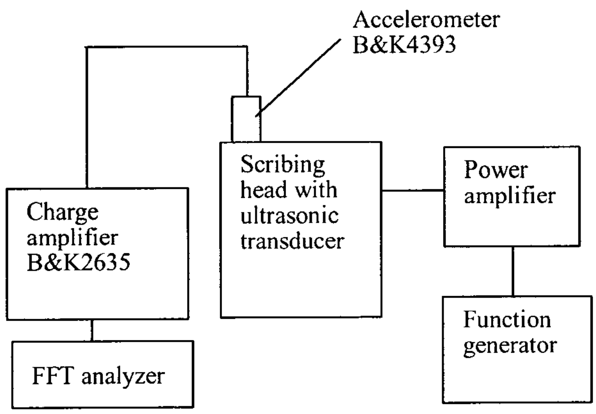


Fig. 4. Experimental setup

The acceleration amplitude in the transducer was measured as shown in Fig. 5 when the ultrasonic transducer was driven by a constant input voltage. In this result, the data in range of 30kHz~50kHz have error bars because the sensitivity of accelerometer is unstable in the frequency range. From the results, five frequencies for efficient driving of the transducer were chosen as follows;

$$f_1 = 6.12kHz,\quad f_2 = 14.30kHz,$$

$$f_3 = 18.35kHz,\quad f_4 = 26.28kHz,$$

$$f_5 = 42.64kHz$$

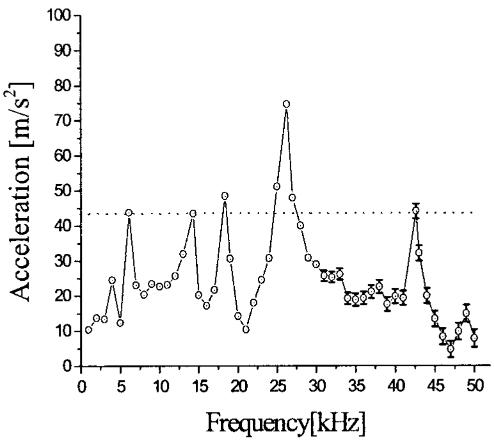


Fig. 5. Acceleration amplitude according to the driving frequency

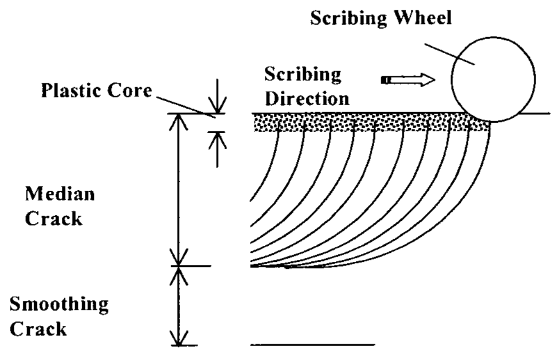


Fig. 6. Schematic illustration of scribing process

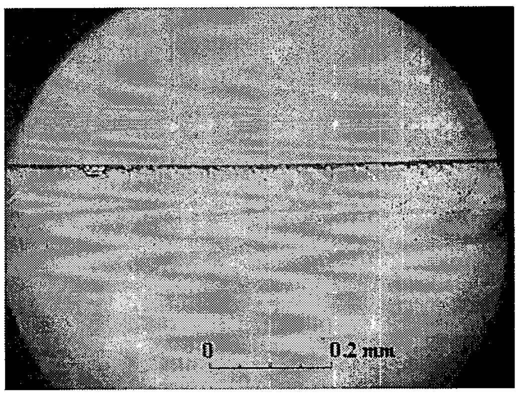


Fig. 7. Photograph of scribing cross section with 50 magnification

For every driving frequency, the input voltage was controlled so that the acceleration amplitude became the constant value of $43.3m/s^2$, which was presented by dot line in Fig. 5. The cracks made by scribing are consisted of plastic core, median crack, smoothing crack, and lateral crack as shown in Fig. 6. First three of them are formed in the perpendicular direction to the surface of the glass plate. As an example, a photograph of the cracks is shown in Fig. 7, which were generated when driving frequency was 26.28kHz, and scribing speed was 400mm/s. It can be confirmed that the interval between circular arcs in the median crack was same to wavelength of the driving signals.

To investigate the depth of cutting edge corresponding the each frequency. The quartz glass plate specimen with a dimension of 200mm(L)×30mm(W)×3mm(T) is selected. The ultrasonic transducer is operated by the constant acceleration amplitude for the every frequency.

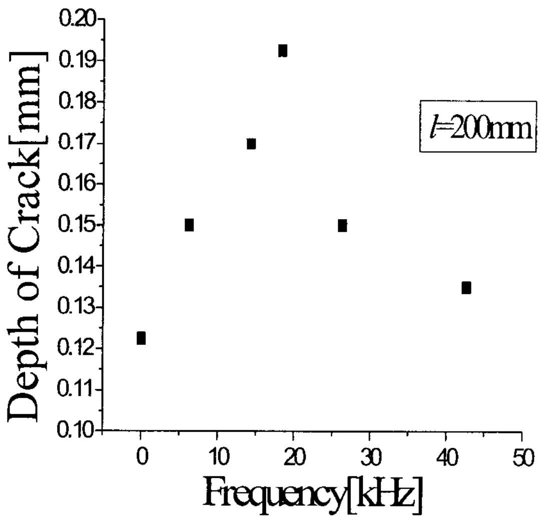


Fig. 8. Depth of crack for various driving frequencies

The results are shown in Fig. 8. In this figure, a data at 0kHz is the value without ultrasonic vibration. The maximum crack depth was generated when the driving frequency was 18.35kHz. The relationship between the depth of crack D(ω) and acceleration of glass plate A(ω) has been reported as following Eq. (5).

$$D(\omega) \propto [A(\omega)]^{4/3} \tag{5}$$

The acceleration of glass plate was calculated as function of driving frequency using Eq. (3) as shown in Fig. 9. It is noted that the tendency of calculated amplitude variation in Fig. 9 agrees well with the experimental results shown in Fig. 8.

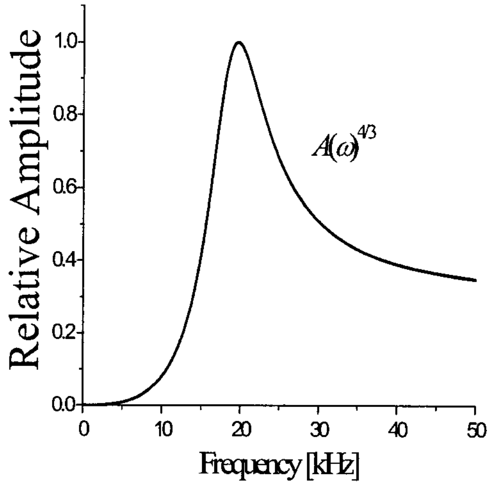


Fig. 9. Theoretical results of acceleration

## IV. Conclusions

To analyze the effect of an ultrasonic vibration in glass scribing, the driving frequency for maximum median crack were investigated experimentally. The results show that the depth of median crack varies ultrasonic frequencies, and the optimum frequency which makes maximum depth of crack was in 17kHz~18kHz for the glass plate with 200mm(L)×30mm(W)×3mm(T). It is confirmed that the deeper median crack is obtained by the scribing with ultrasonic vibration, and the scribed depth strongly depends on the driving frequency. The Eq. (3) for $A(\omega)$ related to the depth can be useful in the design of the scribing equipment with an ultrasonic vibration.

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