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Removal of Dust on Flat Board by Device of Focusing Ultrasonic Waves

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Abstract

The rapid advancements in various current technologies and the constant trend in miniaturizing of components have created a need for higher cleanliness levels. Dust on the surface of IC components often affects their functions. Sometimes, it may damage the component. Therefore, the technology is necessary to remove effectively dust. In the present study, a vibration system, composed of a bolt-clamped Langevin transducer and a disc, was employed to study the effect of dust removal experimentally. When a flat board with calcium carbonate powder was irradiated by this focusing ultrasonic wave, the powder was diffused and removed completely. The experimental result indicates that: the higher input voltage of transducer, the higher removal efficiency.

1. INTRODUCTION

The rapid advancements in various current technologies and the constant trend in miniaturizing of components have created a need for higher cleanliness levels. Dust on the surface of IC components often affects their functions. Sometimes, it may damage the component. Therefore, it is necessary to remove dust.

In a traditional ultrasonic cleaning system, parts are usually cleaned in a solution which is followed by a process of drying. It is different from the traditional cleaning system that the method proposed in the present study will remove dust without cleaning liquid. A vibration system, composed of a bolt-clamped Langevin transducer and a disc, is employed to study the possibility of dust removal without cleaning in liquid experimentally. In the experiment, a disc is exited in a flexural vibration. And, ultrasonic sound waves are focused by a focused ultrasonic device. The focused ultrasonic irradiates to a flat board with dust.

To tune the system and obtain a high intensity focused ultrasonic, the vibration system and the focused ultrasonic device are designed though theoretical calculation. A prototype is fabricated and its characteristics (angle of radiation, vibration velocity and sound pressure) are measured.

Calcium carbonate powder with a particle size of 7μm is employed as dust which is sprinkled on a flat board. It was verified that dust can be removed when the flat board was irradiated by the focused ultrasonic wave.

2. PRINCIPLE

A vibration system (shown in Fig. 1) is employed in the experiment [2]. It consists of a bolt-clamped Langevin transducer (BLT), a horn, and a disc. The resonance frequency of the BLT is 28.0 kHz.

The connection between the BLT and the horn of the vibration system was strongly tightened, so that the interfaces were in as much contact with each other. Moreover, the horn and the disc were fastened tightly by a bolt.

When the BLT is subjected to a longitudinal vibration, this vibration is amplified by a stepped horn and transmits into the disc. Because a mode conversion is occurred at the interface between the disc and the horn, the disc is vibrated in a flexural vibration mode.

Moreover, a focused ultrasonic device was fabricated as shown in Fig. 2. This device consists of reflecting planes and the vibration system. These reflective planes work as an “acoustic lens” which focuses ultrasonic wave and radiates from the opening of the device.

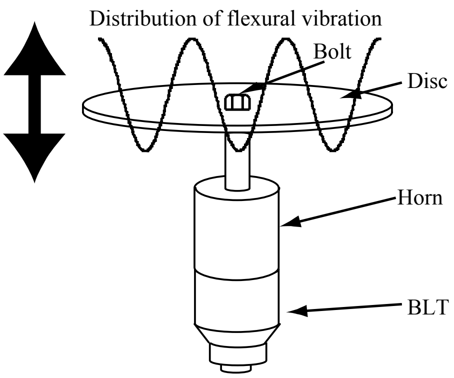

Figure 1. Vibration system.

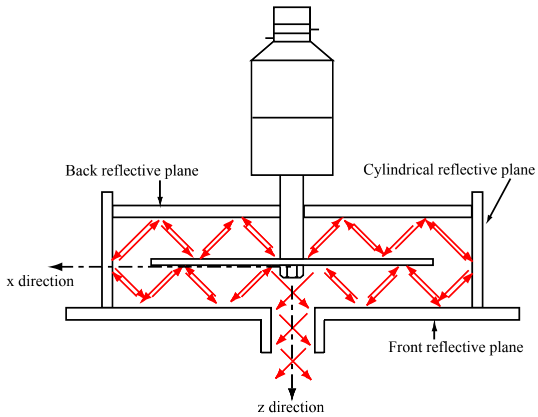

Figure 2. Focused ultrasonic device.

3. CHARACTERISTICS OF VIBRATION SYSTEM

3.1 Admittance characteristics

The admittance is the ratio of the current to the voltage. Using the force-voltage analogy, it corresponds to the ratio of the vibration velocity to the force. In other words, it indicates the ease of the flow of an electric current, and it is also equivalent to the reciprocal of the impedance, which is equal to resistance.

When the driving frequency reaches the value near resonance frequency, the admittance will reach a maximum. Therefore, resonance frequency can be deduced from an admittance curve.

An impedance analyzer is used to measure the admittance of vibration system. The result is shown in Fig. 3. It shows that admittance reaches a maximum near 23.0 kHz, i.e. the resonance frequency of the vibration system is 23.0 kHz.

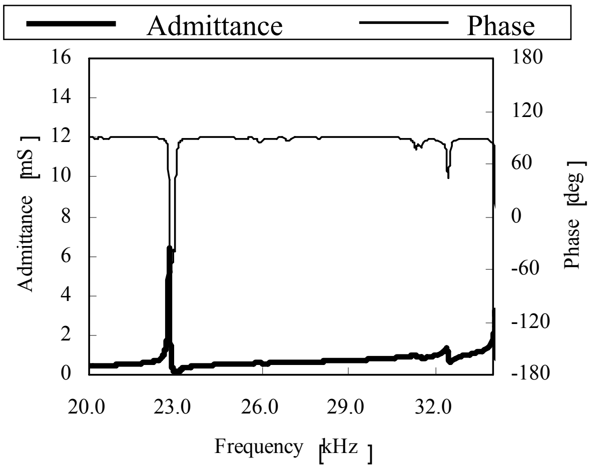

Figure 3. Admittance of vibration system

3.2 Distribution of vibration velocity

For the displacement can not be measured directly, vibration velocity and its phase are often employed to analyze the vibration mode of a vibration system. The Laser doppler vibrometer was used to measure the vibration velocity [2]. In this measurement, the disc is excited at its central point.

The measurement method of vibration velocity is shown in Fig. 4. Vibration speed of 36 test-points were measured in a diametrical direction at intervals of 3mm. 16 groups of data were measured along the circumferential direction at intervals of 22.5 degree. The results are shown in Fig.5. The vibration velocities are expressed using absolute values. If the vibration velocity is represented by a negative value when the phase is shifted by 180 degree, the vibration curve could be approximated by a sine function. Thus, it is verified that the disc vibrates at the flexural vibration mode as we expected.

Because there is a hole in the centre of the disc, the vibration velocity of this area was not measured. The wavelength in the centre part of the disc was longer than elsewhere, because the horn was jointed in this area. Except the area which the horn occupied, the distribution of the vibration velocity is equal to the wavelength of the flexural vibration.

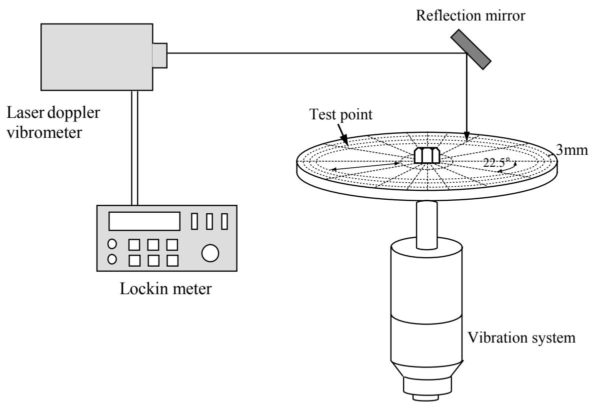

Figure 4. Measurement of vibration velocity

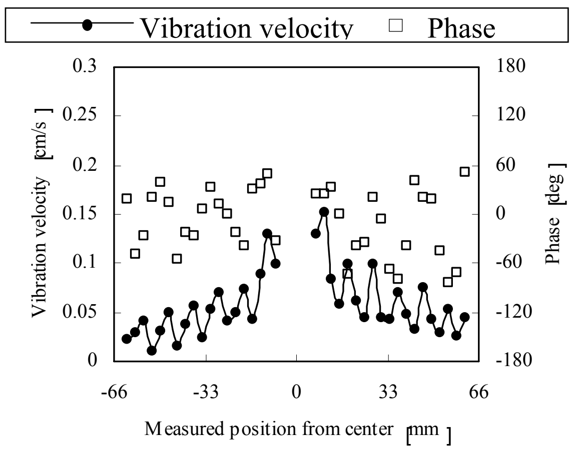

Figure 5. Distribution of vibration velocity

3.3 Directivity of the vibration system

In order to verify the directivity of the vibration system, it is necessary to measure the sound pressure irradiated from the disc. When the order of the mode of vibration increases, the radiation angle becomes like cone-shape which has several lobes [3].

A hydrophone and the dual microphone supply are employed to measure the sound pressure irradiated from the disc. The diagram of the experimental setup is shown in Fig. 6.

The driving frequency was 22.3 kHz, which is the resonance frequency of the vibration system, and the input voltage was 100V and the input power was 4W.

The measurement method of sound pressure is shown in Fig. 6. Sound pressure of X-Z plane was measured along a semi-circle with radius of 120mm at intervals of 5 degrees. The result is shown in Fig. 7. It can be found from Fig. 7 that the directivity of this system is very clear. There exist several sublobes at angle of 40 degree and 60 degree. This angle is termed as angle of radiation in the present research. In the following section, when the distance between the disc and the front and back reflective plane is calculated, the angle of radiation is selected 40 degree for convenience.

As mentioned above, the resonance frequency of the vibration system was 23.0 kHz. But, the driving frequency of the vibration system was 22.3 kHz in the experiment. The reason is that the resonance frequency is measured using small signal, while driving frequency is measured with a higher input voltage. This error is caused by the nonlinearity of PZT.

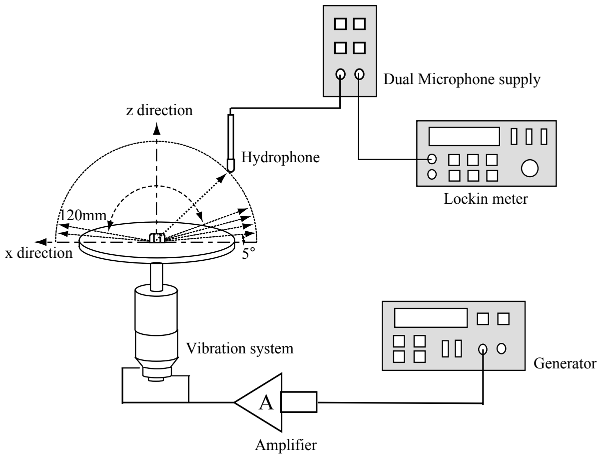

Figure 6. Measurement of sound pressure

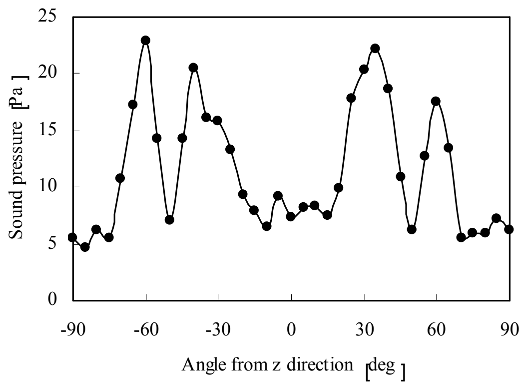

Figure 7. Distribution of sound pressure

4. CHARACTRISTICS OF THE FOCUSED ULTRASONIC DEVICE

4.1 Prototype of the focused ultrasonic device

4.1.1 Material of reflective plane

The reflectivity γ can be calculated from Eq. (1), when sound wave is reflected between the reflective plane and air.

$$\gamma = \frac{Z_2 - Z_1}{Z_1 + Z_2} \tag{1}$$

where Z_1 ($=\rho_1 c_1$) and Z_2 ($=\rho_2 c_2$) are the acoustic impedance of air and the reflective plane, respectively.

The acoustic impedance of air is extremely smaller compared with that of acrylic material. Therefore, the reflectivity of sound wave is more than 99% when the reflective plane is acrylic plane.

From above calculation, it was found that the thickness of the reflective plane has not influence on reflectivity. In this study, the thickness of the reflective pane is 3mm.

4.1.2 Distance between the disc and the reflective plane

Ultrasonic wave is reflected among the disc, the front reflective plane, the back reflective plane and the cylindrical reflective plane and was focused at the focal point. To improve the intensity of ultrasonic wave at the focal point, the distance between the disc and the reflective plane should be calculated carefully. The distance between the disc and the reflective plane *d* should obey the following equation.

$$d = \frac{m \bullet \lambda_a}{2\cos\theta} = \frac{m \bullet c}{2f \bullet \cos\theta} \tag{2}$$

where λ_a, θ, c and f are the wavelength of sound wave in the air, the angle of radiation, sound velocity in the air and the driving frequency, respectively. It should be noted that the parameter m is an arbitrary integer to describe the periodicity of sound wave. In this calculation, the angle of radiation and the driving frequency are 40 degree and 22.3 kHz, respectively. Table 1 indicates several value of the distance. When m=1, d=10mm is the fundamental distance.

Table 1. Distance between the disc and the front and back reflective plane.

m	Distance between disc and the front and back reflective plane [mm]
1	9.69
2	19.37
3	29.06
4	38.74

4.1.3 Dimension of the focused ultrasonic device

Because the angle of radiation is 40 degree, for simplicity, it can be thought that the ultrasonic energy is emitted from the central of disc with an angle of 40 degree. The transmission route of the radiation sound wave is shown in Fig.8. The position of the focal point can be calculated by the following equation.

$$p = \frac{4r_2 - 2r_4 + 2r_1}{\tan 40°} - \{(n + k + 3)h_2 + (m + k + 4)h_3 + 2\} \tag{3}$$

where r_1, r_2, r_3, r_4, h_2, and, h_3 are the radius of opening in front reflective plane, the inner-radius of cylindrical reflective plane, the radius of disc, the smaller radius of horn, the distance between the disc and the front reflective plane and the distance between the disc and the back reflective plane, respectively. And n, m, l, and k are integers.

Homoplastically, h_3 can be calculated in the same way. According to the above result and the convenience of design, h_2 and h_3 are the integral multiple of the fundamental distance.

Substitution of r_3=66(mm) and r_4=7(mm) into Eq. (3), we can obtain the following result as shown in Table 2. And h_1 and t are the height of the opening of front reflective plane and the thickness of reflective plane, respectively.

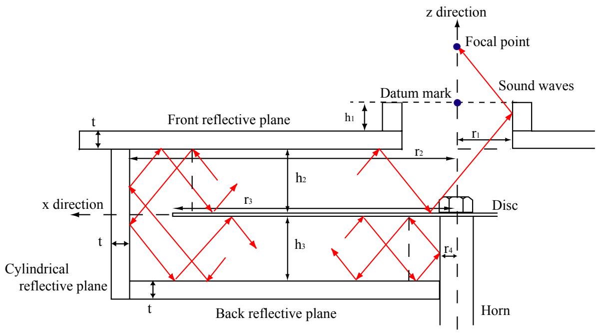

Figure 8. Transmission route of sound.

Table 2. Size of the device of focusing ultrasonic waves

Radius in opening of front reflective plane	r_1	15 [mm]	15 [mm]
Inner-radius of cylindrical reflective plane	r_2	72 [mm]	72 [mm]
Radius of disc	r_3	66 [mm]	66 [mm]
Radius of horn	r_4	7 [mm]	7 [mm]
Height of opening of front reflective plane	h_1	15 [mm]	15 [mm]
Distance between the disc and the front reflective plane	h_2	20 [mm]	20 [mm]
Distance between the disc and the back reflective plane	h_3	20 [mm]	10 [mm]
Thickness of reflective plane	t	3 [mm]	3 [mm]
Distance between disc and focal point	p	40.29 [mm]	40.29 [mm]

4.2 Characteristics of sound pressure of the focused ultrasonic device

The hydrophone and the dual microphone supply were employed to measure sound pressure. The diagram of the experimental setup is shown in Fig. 9 [4]. The sound pressure of the following two groups of parameters was measured: (h_2=20mm, h_3=20mm) and (h_2=20mm, h_3=10mm). The input power was 4W.

The result is shown Fig. 10. This figure shows that the sound pressure of parameter of (h_2=20mm, h_3=10mm) is higher than that of parameter of (h_2=20mm, h_3=20mm). In the case of (h_2=20mm, h_3=10mm), sound pressure is 1700Pa at the distance of 30mm from the disc.

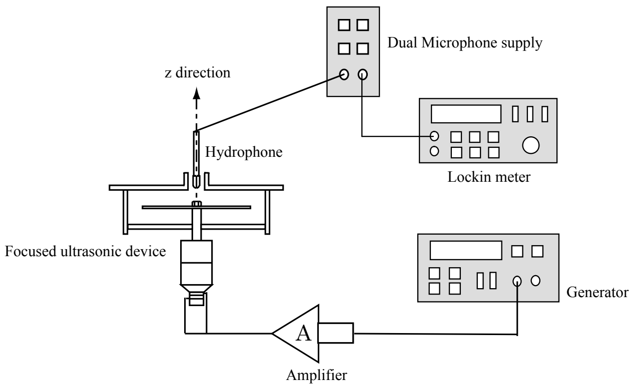

Figure 9. Measurement of sound pressure

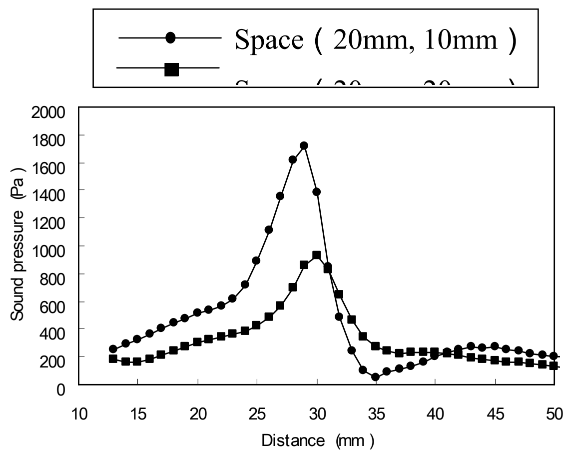

Figure 10. Distribution of sound pressure along z direction

5. EXPERIMENT OF DUST REMOVAL

5.1 Experimental equipment

The vibrations of the system might not be transmitted through the disc effectively when positions other than the node point of the vibrations are supported. Because the horn is designed in half-wave vibration mode and the vibration speed of node plane is zero, the horn is supported at its node plane.

5.2 Experimental results and discussion

5.2.1 Input power and rate of removal

The relationship between the input power and the rate of removal is shown in Fig. 11. This figure shows that the higher input power is, the higher the rate of removal is. The rate of removal is about 90% when the input power is over 4W. That is to say, the dust is removed completely. Compared with the result of the experiments without focused ultrasonic device, the focused ultrasonic device has higher removal efficiency.

5.2.2 Distance from the datum mark to the flat board and rate of removal

The relationship between distance from the datum mark to the flat board and the rate of removal is shown in Fig.12. The rate of removal is more than about 90% when the distance from the datum mark to the flat board ranges from 1mm to 6mm. It is difficult to remove the dust without the focused ultrasonic device even the distance is very small.

5.2.3 Surface roughness and rate of removal

The relationship between the surface roughness and the rate of removal is shown in Fig. 13. When the input power is 4W, it can be found that the smoother the surface of the flat board is, the higher rate of removal is.

When the input power was 10W, the rate of removal of all surface roughness was about 90% and the dust was removed almost completely. Only a little calcium carbonate could not be removed, when the surface was bumpy.

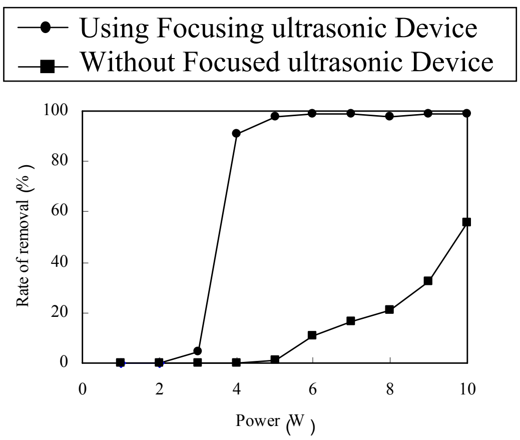

Figure 11. Relationship between input power and rate of removal

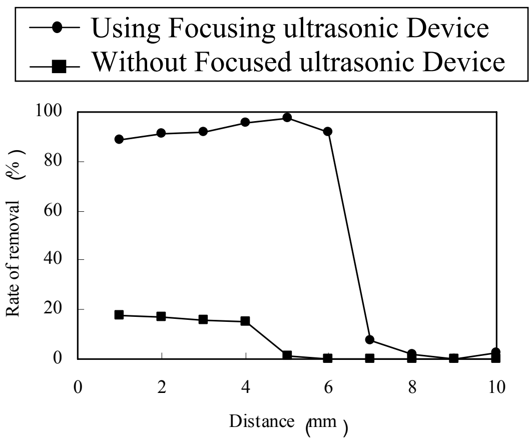

Figure 12. Relationship between distance from the datum mark and rate of removal

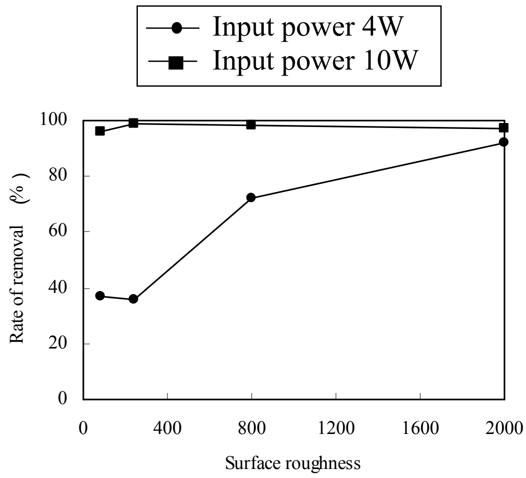

Figure 13. Relationship between surface roughness and rate of removal

6. CONCLUSIONS

To tune the system and obtained a high intensity focused ultrasonic, the vibration system and the focused ultrasonic device were designed though theoretical calculation. A prototype is fabricated and its characteristics (angle of radiation, vibration velocity and sound pressure) were measured.

Relationship between input power and rate of removal shows that the higher input power is, the higher the rate of removal is. The rate of removal is about 90% when the input power is over 4W. That is to say, the dust is removed completely.

Relationship between distance from the datum mark to the flat board and rate of removal shows that the rate of removal is more than about 90% when the distance from the datum mark to the flat board ranges from 1mm to 6mm. It is difficult to remove the dust without the focused ultrasonic device even the distance is very small.

Relationship between surface roughness and rate of removal shows that it can be found that the smoother the surface of the flat board is, the higher rate of removal is.

When the input power was 10W, the rate of removal of all surface roughness was about 90% and the dust was removed almost completely. Only a little calcium carbonate could not be removed, when the surface was bumpy.

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