ULTRASONIC COMPLEX VIBRATION SYSTEMS AND VARIOUS APPLICATIONS OF HIGH POWER ULTRASONICS

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ABSTRACT

Ultrasonics complex vibrations with two- or three-dimensional vibration locus are effective for various applications. Various high-frequency and complex-vibration systems have been proposed and studied. The applications include ultrasonic direct welding of LSI, semiconductor chips without adhesive or solder, ultrasonic seam welding of thin metal plates, ultrasonic welding of thick metal specimens such as an automobile body and also ultrasonic motors, etc.

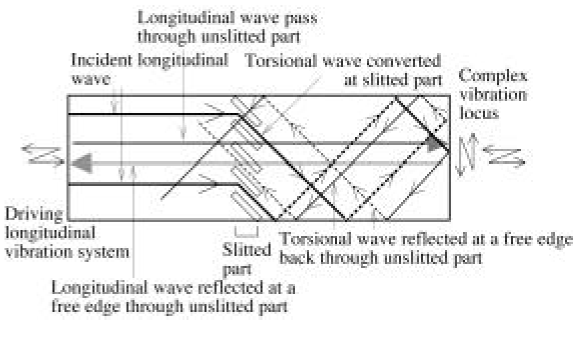
INTRODUCTION

Ultrasonics complex vibrations with two- or three-dimensional vibration locus are effective for various applications. Complex vibration systems using a longitudinal-torsional vibration converter with diagonally slitted parts and a complex transverse vibration source driven by multiple longitudinal driving systems have been proposed and studied. Applications of the complex vibration systems include ultrasonic direct welding of LSI, semiconductor chips without any adhesive and solder, ultrasonic seam welding of aluminum, copper plates for heat exchanger or heat sink, ultrasonic welding of thick metal specimens such as an automobile body, etc. Various high-frequency and complex-vibration systems have been proposed and shown effective for various applications. Using the complex vibration welding system, the welded area and weld strength become larger and more uniform than those obtained by a conventional linear vibration system. Thick metal plate specimens can be welded continuously with uniform weld strength independent to welding positions and directions using the complex vibration systems[1][2]. Furthermore, the converters are applied to ultrasonic motors.

ULTRASONIC COMPLEX VIBRATION CONVERTER WITH DIAGONAL SLITS

Principle of longitudinal to torsional vibration converter

The principle of one-dimensional cylindrical longitudinal to torsional vibration converter is shown in Figure 1. The converter has a slitted part along its circumference surface. Diagonal slits are only partially cut at the circumference surface of the cylinder while the inner cylindrical part remains unslitted. Slit angle is decided about 45 degrees (principal stress direction of torsional vibration). The converter is driven using only a longitudinal vibration source. The incident longitudinal wave is partially converted to a torsional wave at the diagonally slitted part and reflected at a free edge and returned through an unslitted area. The other part of the incident longitudinal wave progresses and is reflected at a free edge of the converter through the unslitted area. Longitudinal and torsional waves are coupled at the free edge and the edge part vibrates elliptically or circularly at the frequencies where the phase difference between these vibrations is about 90 degrees. The resonance frequencies of longitudinal and torsional vibrations must be different to obtain elliptical or circular loci. Figures 2(1) and (2) show the complex converter installed in a 27 kHz longitudinal vibration system with a stepped horn for increasing vibration velocity.



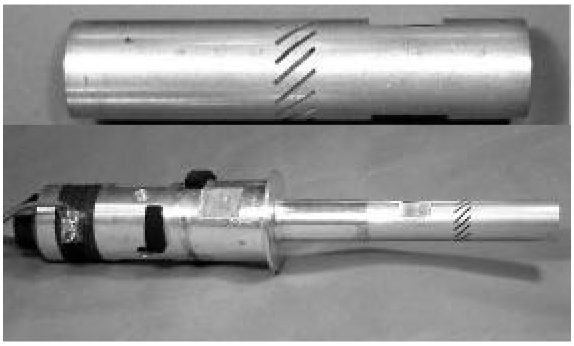
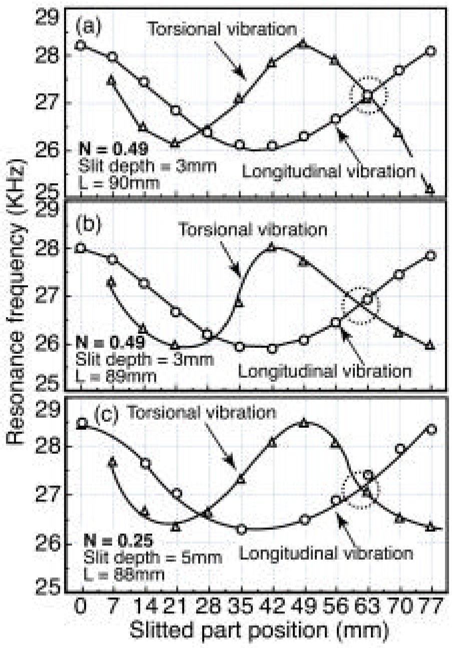


Fig.1. One-dimensional longitudinal to torsional vibration converter with diagonal slits

Fig.2. (1) Complex vibration converter
(2) Complex vibration system

Vibration Characteristics of the Longitudinal-Torsional Converter

The relationships between slitted position and longitudinal and torsional resonance frequencies of the converter calculated by equivalent electrical transmission line method are shown in Fig.3. The value N (shown in Fig.3) is the ratio of transmission impedance of the slitted part to the uniform part of the converter. The dimensions of the converter (aluminum alloy: JISA7075B) are 20 mm in diameter and are varied from 80 mm to 92 mm in length. The dimensions of slits are 0.5 mm in width, 10 mm in length, and 3 mm and 5 mm in depth. For determining these transmission impedances of uniform and slitted parts, the sound velocities of longitudinal and torsional vibration of the converter were calculated using measured values of longitudinal and torsional resonance frequencies of the converter. These resonance frequencies are measured by small piezoelectric ceramic sensors, which are installed at a free edge surface and normal to the circumference of the converter. There are two positions along the converter where the calculated values of longitudinal and torsional resonance frequencies become the same (Fig.3). Figure 4 shows vibration loci at a free edge of the converter made form aluminum alloy installed in a longitudinal vibration system. The calculated values of the length, slitted part position indicated in the figures by dotted circles in the cases of the transmission ratio N = 0.49 and 0.25 are used to product the converters (aluminum alloy). The vibration loci are measured using two laser Doppler vibrometers whose transmission characteristics are adjusted to be the same. Figure 4 shows vibration loci of the longitudinal-torsional vibration converter of N = 0.49 and 0.2. The measured vibration loci of the converters at the free edge are elliptical near to circular.



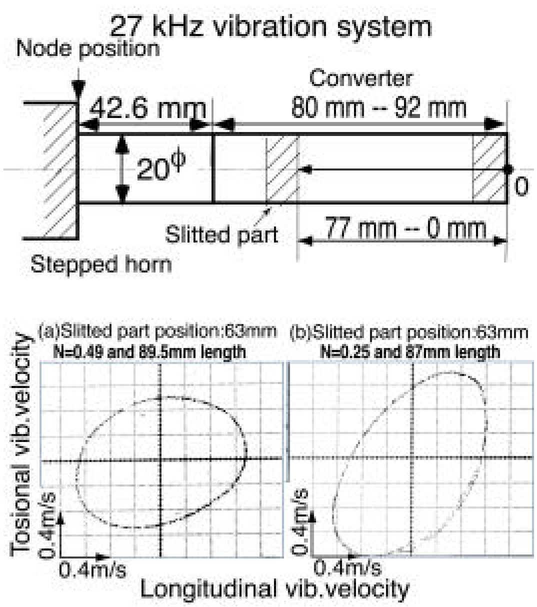


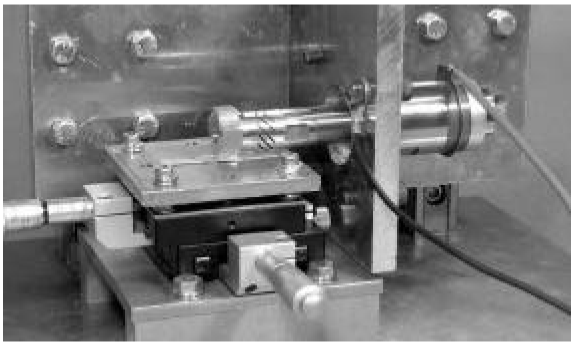
Fig.3. Relationship between slitted part position and calculated longitudinal and torsional resonance frequencies. N = 0.49 and 0.25.

Fig.4. Vibration loci at the free edge of the converters.

COMPLEX VIBRATION SYSTEMS FOR ULTRASONIC MICRO WELDING

Configuration of Ultrasonic Micro Welding System with a Complex Vibration Converter

Configurations of 40 kHz and 100 kHz complex vibration systems are shown in Fig.5 and Fig.6. The systems consist of a one-dimensional longitudinal-torsional vibration converter, a stepped horn with a supporting flange and a bolt-clamped Langevin type PZT longitudinal transducer (BLT) of 30 mm in diameter. The 100 kHz vibration converter has a slitted part (slit number: 12, slit angle: 45 degrees, slit width: 0.5 mm, length: 10 mm, depth: 2.2 mm) adjacent to a longitudinal nodal position. Four welding tips are made at the free end of the complex vibration converters of 16 mm diameter. Welding tip area is 3 mm square to 10 mm square. Fig.

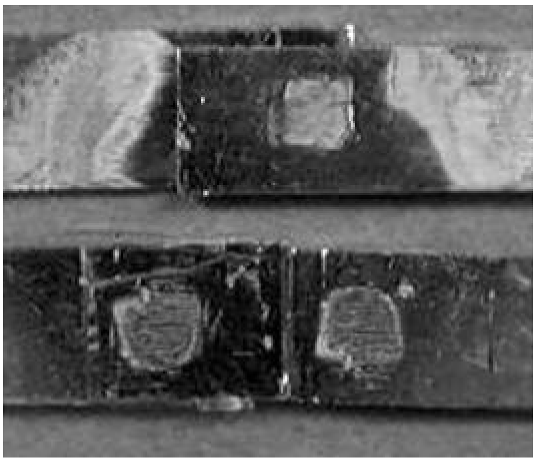


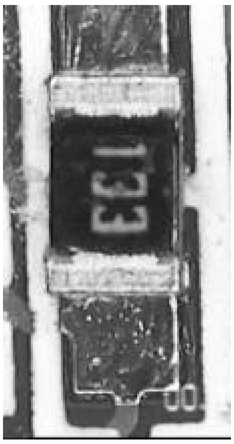
5. 40 kHz complex vibration welding system with a complex vibration converter.

Fig. 6. 100 kHz complex vibration system and longitudinal-torsional vibration converter.

Welding Characteristics of Complex Vibration System and Welded Samples

Welded conditions of 0.3-mm and 1.0-mm-thick aluminum plates welded using the 100 kHz system with a complex vibration converter (Fig.6) are shown in Fig. 7. Figure 8 shows welded condition of a tip resistance element (1.0 mm x 1.2 mm) welded to solder coated baseboard using an 80 kHz complex vibration system. Using a conventional low-frequency linear-vibration welding system, solder is very difficult material to weld. Figure 9 shows a ceramic package (3.8 mm x 8 mm) directly sealed with a KOVAR plate using a 40 kHz complex vibration system.





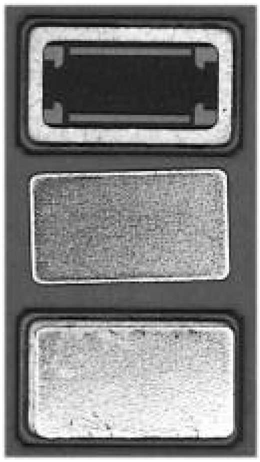


Fig. 7. Aluminum plates welded by 100 kHz. Fig. 8. Tip element. Fig. 9. Ceramic package.

COMPLEX VIBRATION SYSTEM FOR ULTRASONIC CONTINUOUS SEAM WELDING

Configuration of Ultrasonic Complex Vibration Seam Welding System and Vibration Locus

Configuration of 27 kHz and 19 kHz complex vibration seam welding system installed in rotating equipments is shown in Figs. 10 and 11. The rotating complex vibration disk is driven by a longitudinal vibration system through a one-dimensional longitudinal-torsional vibration converter with diagonal slits.

The 27 kHz longitudinal converter (SUS304B, 20 mm in diameter) has a slitted vibration converting part with twelve slits of 0.5 mm width, 10 mm length and 2.2 mm depth. The 19 kHz longitudinal-torsional vibration converter (SUS304B: 40 mm in diameter) has a slitted vibration converting part with twelve slits of 0.5 mm width, 20 mm length at an angle of 45 degrees and 2.0 mm depth. Lapped welding plate specimens are clamped between a welding tip and an anvil, and the welding part is shifted in the direction parallel to the welding table by rotating the vibration system and shifting the table. The vibration systems were driven by a 1 kW static induction transistor power amplifier.

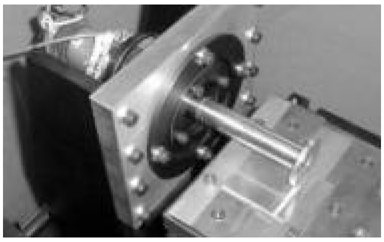


Fig. 10. 27 kHz complex vibration seam welding system.

Fig. 11. 19 kHz complex vibration seam welding system.

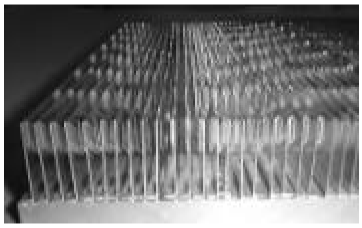


Fig. 12. 300-mm-long aluminum heat sink.

The welding surfaces are driven to vibrate parallel to the welding surface by the rotating disk welding tip and are welded continuously under a static clamping pressure of 15-25% of the specimen strength, by a static pressure source. Welded conditions of 0.5-mm-thick and 300-mm-long aluminum plate welding specimens are shown in Figs.12. A large number of 300-mm-long aluminum plates were welded continuously in parallel directions on a 10.0-mm-thick aluminum base plate by shifting the welding table and rotating the welding tip.

LARGE CAPACITY ULTRASONIC COMPLEX VIBRATION SOURCE

Configuration of Complex Vibration Source and the Vibration Locus

Configuration of a new large capacity complex vibration source is shown in Fig.13. The complex vibration source consists of a complex transverse rod of 40 mm in diameter, a circular disk part of 40 mm in thickness and 220 mm in diameter and six 27 kHz BLT longitudinal vibration transducers of 40 mm in diameter. Six BLT transducers are installed around the circular disk using connecting bolt. Two transducers installed in opposite part are driven longitudinally with the same vibration phase and the transducer pair and the disk part are driven in 2 wavelengths longitudinal vibration mode using a transformer. The center part of the circular disk is the longitudinal to transverse vibration converting part. The center rod vibrates in transverse vibration mode with four transverse vibration nodes at each side.

A block diagram of the driving system is shown in Fig.14. Three transducer pairs are driven simultaneously using three transformers, three 500 W static induction transistor power amplifiers and an oscillator with three output voltages of phase difference 120 degrees.

Figure 15 shows a vibration locus at a free edge of the complex vibration source in the case where three BLT transducer pairs are driven simultaneously. The vibration locus is elliptical due to the difference of the vibration characteristics of the three BLT transducer pairs.

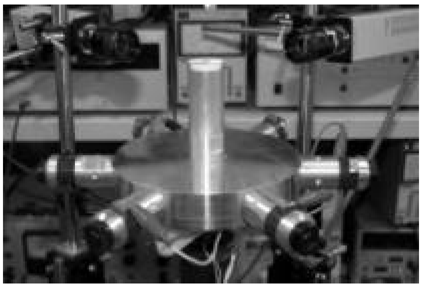


Fig.13. Complex vibration source

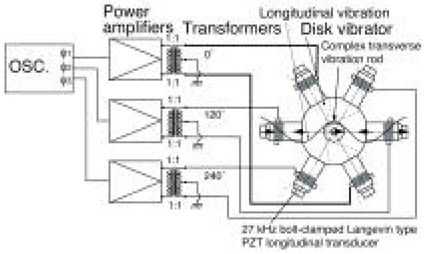


Fig.14. Driving circuit

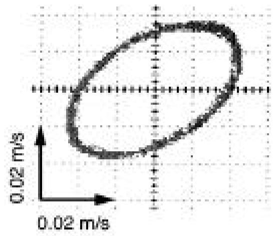


Fig.15. Vibration locus

CONCLUSIONS

Complex vibration systems are effective for various high power applications of ultrasonics especially such as ultrasonic metal welding, ultrasonic wire bonding, various packaging in microelectronics by ultrasonic vibration, ultrasonic plastic welding, various ultrasonic machining and also applicable to ultrasonic motors. Using the complex vibration ultrasonic welding system, the welded area and weld strength become larger and more uniform than those obtained by a conventional linear vibration welding system. Large capacity complex vibration sources with many transducers can be constructed using longitudinal to transverse converters.

REFERENCES

[1] Jiromaru TSUJINO, Tetsugi UEOKA, Koichi HASEGAWA, Yuki FUJITA, Toshiyuki SHIRAKI, Takaaki OKADA and Toshiki TAMURA, New Methods of Ultrasonic Welding of Metal and Plastic Materials (Invited paper), Ultrasonics, Elsevier Science B.V., Vol. **34** (1996), 1996.1, pp.177-185.

[2] Jiromaru TSUJINO: Recent Developments of Ultrasonic Welding, Proceedings of 1995 IEEE International Ultrasonics Symposium (1996) pp.1051-1060.