LARGE CAPACITY ULTRASONIC COMPLEX VIBRATION SOURCES USING MULTIPLE TRANSDUCERS INTEGRATED USING A CIRCULAR VIBRATION DISK

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ABSTRACT
Large capacity ultrasonic complex vibration sources 20, 27 and 40 kHz with four to eight ultrasonic transducers integrated using a longitudinal and a transverse vibration disk were developed. Longitudinal vibration disk for 27 kHz system is one-wavelength in its diameter with six ultrasonic transducers installed along the outer circumference of the disk, and the outer diameter of the system is about 600 mm. Four to eight ultrasonic transducers are installed normally along a loop circle position symmetrically in the transverse vibration disk (2, 1) or (1, 1) mode. A complex transverse vibration catenoidal or stepped horn with a welding tip is installed in the central position of the disks. The transducers are driven in 90 or 120 degrees vibration phase difference using two to three driving 500 W power amplifier systems and almost circular loci are obtained. Vibration amplitude of a 20 kHz complex vibration source with a disk 134 mm in diameter is 15 μm (peak-to-zero value) at driving voltage 70 Vrms. Welding specimens of 1.0- to 2.0-mm-thick aluminum, aluminum alloy and copper plates were welded with strength almost equal to the material. Maximum weld strengths per welded spot were about 2500 N.

INTRODUCTION
Various large capacity ultrasonic complex vibration sources for high power applications of ultrasounds were developed. Configurations of large capacity ultrasonic complex vibration sources of 20 and 27 kHz with four to six bolt-clamped Langevin type piezoelectric ceramic (PZT) longitudinal transducers (BLTs) integrated using longitudinal and transverse vibration disks for ultrasonic welding are described in this paper. Longitudinal vibration disk for 27 kHz system is one-wavelength in its diameter with six BLT transducers installed along the outer circumference of the disk, and the outer diameter of the system is about 600 mm. To obtain smaller diameter vibration sources of 27 and 20 kHz, four to six BLT transducers are installed normally along a loop circle position symmetrically in one side of the transverse vibration disk (2, 1) or (1, 1) mode. A complex transverse vibration catenoidal or stepped horns with a welding tip are installed in the central position of the disks. The transducers are driven in 90 or 120 degrees vibration phase difference using two to three driving 500 W power amplifier systems and almost circular loci are obtained.

CONFIGURATIONS OF LARGE CAPACITY ULTRASONIC COMPLEX VIBRATION SOURCES
27 kHz complex vibration source with six BLT transducers integrated using a longitudinal vibration disk
Figure 1 (1) shows configuration of a 27 kHz ultrasonic complex vibration source with six BLT transducers which are integrated using a one wave-length longitudinal vibration circular disk (aluminum alloy). Six driving longitudinal vibration systems with BLT transducers which have normal and reverse polarity PZT stacks are installed in outer circumference of the circular disk. Catenoidal horn with a welding tip (stainless steel) is installed in the longitudinal vibration loop position at the center of the disk using a connecting bolt and driven transversally. Stepped horn with a flange (stainless steel) for supporting the system is installed in the other side of the disk using a connecting bolt.
27 kHz complex vibration source with six BLT transducers integrated using a (2, 1) mode transverse vibration disk
Figure 1 (2) shows configuration of a 27 kHz ultrasonic complex vibration source with six BLT transducers integrated using a (2, 1) mode transverse vibration circular disk (aluminum alloy). Six driving longitudinal vibration systems with BLT transducers which have normal and reverse polarity PZT stacks are installed along circular loop position in one side of the disk. Catenoidal horn with a welding tip is installed in the transverse vibration nodal position in the other side at the center of the disk and driven transversally by slant of transverse nodal position.

20 kHz complex vibration source with four BLT transducers integrated using a (1, 1) mode transverse vibration disk
Figure 1 (3) shows configuration of a 20 kHz ultrasonic complex vibration source with four BLT transducers integrated using a (1, 1) mode transverse vibration circular disk (stainless steel). The complex vibration source consists of a catenoidal complex transverse horn with a welding tip (stainless steel), and a (1, 1) mode complex transverse vibration disk (stainless steel) with four driving longitudinal vibration systems that are installed normally in the disk. Longitudinal vibration driving system pair (A) consists of two stepped catenoidal horns, and 40-mm-diameter BLT transducers of normal and reverse polarity. The other driving system pair (B) consists of two catenoidal horns, half wavelength vibration rod and BLT transducers of normal and reverse polarity. Half wave-length vibration rods are required for installing four driving systems in rather small space of the (1, 1) mode disk, and for preventing the electrodes of BLT transducers and metal vibration systems touch and short-circuit each other. Dimensions of the disk are 112 mm in diameter and 25 mm in thickness. The vibration source is supported using four steel rods installed in outer nodal line of the complex transverse vibration disk.

The dimensions of the disks are determined using calculations of the frequency equation and FEM method (ANSIS).

Figure 1. -(1) 27 kHz ultrasonic complex vibration source with six BLT transducers integrated using a one wave-length longitudinal vibration disk.
(2) 27 kHz ultrasonic complex vibration source with six bolt-clamped Langevin type longitudinal transducers integrated using a (2, 1) mode transverse vibration disk.
(3) 20 kHz ultrasonic complex vibration source with four bolt-clamped Langevin type longitudinal transducers integrated using a (1, 1) mode transverse vibration disk.

Transverse vibration modes of the circular disks
Figure 2 shows transverse vibration modes of the circular disks. (2, 1) or (1, 1) transverse vibration modes have two or one transverse node circles and one nodal line. Four or six driving longitudinal vibration systems are installed symmetrically along transverse vibration loop positions. Two vibration systems installed opposite side of the disk are driven in anti-phase mode corresponding to the transverse vibration distributions (vibration system pair). Two or three driving system pairs are driven simultaneously in phase difference of 90 or 120 degrees using two or three power amplifiers. The vibration mode of the disk rotates as the driving
systems are driven simultaneously and the stepped or catenoidal horn installed in the central position of the disk is driven transversally and the welding tip vibrates in circular locus.

Figure 2. -(1) (2, 1) and (2) (1, 1) transverse vibration modes of the circular disks.

Driving system for a complex vibration source
Block diagram for driving the complex vibration sources with six BLT transducers shown in figure 3. Two driving longitudinal system are installed opposite side of the disk and driven in anti-phase vibration mode. This two or three driving system pairs are installed in the disks, and driven in 90 or 120 degrees vibration phase difference using an arbitrary waveform generator with multiple phase outputs and two or three 500 W SIT (static induction transistor) power amplifiers. Almost circular vibration loci are obtained at the welding tips of these vibration systems.

Figure 3. -Driving system for a complex vibration source with six BLT transducers

VIBRATION CHARACTERISTICS OF THE ULTRASONIC COMPLEX VIBRATION SOURCES
Vibration distributions of the complex vibration sources
Figure 4 shows transverse vibration distributions along the diameter of (1) (2, 1) and (2) (1, 1) mode circular disks measured using a laser Doppler vibrometer. Measured vibration distributions show (2, 1) and (1, 1) mode transverse vibrations.
Figure 5 shows transverse vibration distributions along stepped and catenoidal transverse vibration horns with a complex vibration welding tip installed in (2, 1) and (1, 1) transverse vibration disks shown in Figures 1 (2), and (3). Transverse vibration amplitude increases at stepped parts and catenoidal part of the horns and the vibration transforming ratios 5 to 7 are obtained.

Vibration loci of the complex welding tips
Vibration locus of the complex welding tip is measured using two laser Doppler vibrometers whose transmission characteristics are adjusted to be same. Figure 6 shows vibration loci of the complex welding tips of the three vibration sources shown in Figures 1 (1), (2) and (3). The complex vibration sources are driven using three or two driving longitudinal vibration system
pairs in vibration phase difference 120 or 90 degrees using an arbitrary waveform generator and three or two 500 W SIT power amplifiers. Vibration locus is measured using two laser Doppler vibrometers. Almost circular loci are obtained in these welding tips.

Figure 4. -Measured vibration distributions of (1) (2, 1), and (2) (1, 1) mode circular disks.

Figure 5. -Measured transverse vibration distributions along (1) two stepped and (2) catenoidal horns with a welding tip and side of the disks shown in (1) Fig. 1 (2) and (2) Fig.1 (3).

Figure 6. -Vibration loci of the complex vibration welding tips installed in the vibration sources shown in Figs 1 (1), (2) and (3).

THE ULTRASONIC COMPLEX VIBRATION WELDING EQUIPMENTS

Figure 7 shows the ultrasonic complex vibration welding systems with six BLT transducers integrated using longitudinal and transverse vibration disks which are installed in welding frames with static clamping pressure sources. The complex vibration sources are supported using (1) node supporters installed at stepped part and supporting flange of the stepped horn fixed at the disk, and (2) four supporting vibration rods installed at the nodal area of the disk.
WELDING CHARACTERISTICS OF THE ULTRASONIC COMPLEX VIBRATION WELDING EQUIPMENTS

Various metal plate welding specimens are welded using these welding systems. Figure 8 shows the relationship between vibration amplitude (radius of circular vibration locus) and weld strength of 2.0-mm-thick aluminum alloy plates welded using the 27 kHz complex vibration welding equipment with six BLTs integrated using a longitudinal vibration disk. Li-grease is inserted between the welding surfaces. Static clamping force and welding time are kept at 1176 N and 3.5 s constant. Maximum weld strength 2500 N is obtained.

Figure 9 shows relationship between welding tip vibration amplitude and weld strength of 1.0-mm-thick aluminum and copper plate specimens welded using the 27 kHz ultrasonic complex vibration source with six BLTs integrated using a (2, 1) mode transverse vibration disk. Static clamping force and welding time are kept at 2180 N and 2.5 s constant. Maximum weld strength is about 1000 N which is almost equal to the material strength. Weld strengths obtained are about 1000 N between 1.5 to 2.0 μm and decreases over 2.1 μm range due to vibration fatigue at outer part of the welded area of the specimen. Required vibration amplitudes of the complex vibration for sufficient welding are very small and half to quarter compared with that of a conventional welding equipment using a welding tip with linear vibration locus.

Figures 10 and 11 show SEM photographs of cross sections of 1.2-mm-thick aluminum alloy plates, and 1.0-mm-thick aluminum and copper plates welded using the 27 kHz ultrasonic complex vibration source with six BLTs integrated using a longitudinal vibration disk and a (2, 1) mode transverse vibration disk. The welding surfaces are completely welded without particular structural changes and any defects.

Figure 8. Weld strength of 2.0-mm-thick aluminum alloy plate specimens welded using the 27 kHz ultrasonic complex vibration source with six BLTs integrated using a longitudinal vibration disk.
Figure 9. -Weld strength of 1.0-mm-thick aluminum and copper plate specimens welded using the 27 kHz ultrasonic complex vibration source with six BLTs integrated using a (2, 1) mode transverse vibration disk.

Figure 10. -SEM photograph of cross section of welded aluminum alloy plate specimens.

Figure 11. -SEM photograph of cross section of welded aluminum and copper plate specimens.

CONCLUSIONS
Large capacity ultrasonic complex vibration sources 20, 27 and 40 kHz with four to eight ultrasonic transducers integrated using a longitudinal and a transverse vibration disk were developed. The transducers are driven in 90 or 120 degrees vibration phase difference using two to three driving 500 W power amplifier systems and almost circular loci are obtained. Welding tip vibration amplitude of a 20 kHz vibration source with a (1, 1) mode disk 134 mm in diameter is 15 μm (peak-to-zero value) at driving voltage 70 Vrms. Welding specimens of 1.0- to 2.0-mm-thick aluminum, aluminum alloy and copper plates were welded using the complex vibration welding equipments with strength almost equal to the material. Maximum weld strengths obtained per welded spot were about 2500 N.

References:

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