# HIGH-FREQUENCY AND COMPLEX VIBRATION ULTRASONIC WIRE BONDING SYSTEMS

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**ABSTRACT** High-frequency and complex vibration ultrasonic wire bonding systems are proposed and their welding characteristics are studied. Ultrasonic wire bonding is used widely for joining thin connecting wire of various electronic devices including IC or LSI. Conventional bonding systems use vibration frequency of 40 or 60 kHz and linear vibration welding tips. Complex vibration welding tip which vibrates in elliptical to circular or rectangular to square in the same or different frequency is effective to join welding specimens in shorter welding time and under smaller vibration amplitude, and furthermore high-frequency systems such as 90, 120, 190 kHz are also significantly effective. High-frequency and complex vibration welding system of 90, 120 and 190 kHz are designed. Welding characteristics of these systems are found very superior than a conventional system. Welding specimens of aluminum wire of 0.1 mm diameter are joined successfully.

## 1. INTRODUCTION

Welding characteristics of ultrasonic wire bonding using 60 kHz, 90 kHz, 120 kHz and 190 kHz welding tips which vibrate in linear to elliptical or circular loci are studied. A conventional wire bonding system usually has a welding tip of 40 kHz or 60 kHz frequency which vibrates in a linear locus. Vibration loci of complex systems are controlled from linear to elliptical or circular by regulating vibration phase difference of the driving vibration systems.

Welding specimens used are 0.1-mm-diameter aluminum wires and 1.0-mm-thick copper plates. These welding specimens are welded successfully by the welding equipment which controls the shapes of the welding tip vibration loci and has higher vibration frequency[2-10]. The required vibration amplitudes of these complex system are about one-half to one-third and required weld times are shorter than those for conventional systems using a welding tip which has only vibration system and a linear vibration locus[7-10]. The required vibration velocity of the 90 kHz bonding system is about half that of the 60 kHz system, and required vibration velocity of the 120 kHz system is smaller than that of 90 kHz system and furthermore required velocity of the 190 kHz system is smaller than that of 120 kHz. The deformations of the welded specimens at adequate welding conditions are almost same even if the welding tip vibration locus is altered or the vibration frequency used is changed from 60 kHz to 190 kHz in the case where the same wire specimens are used.

## 2. ULTRASONIC COMPLEX VIBRATION WIRE BONDING SYSTEMS AND WELDING SPECIMENS

### 2.1 *Ultrasonic wire bonding systems of 60, 90, 120 and 190 kHz*

Ultrasonic welding systems used are complex vibration systems of 60, 90, 120 and 190 kHz frequency.

The complex ultrasonic vibration welding system consists of a complex transverse vibration rod driven by two longitudinal vibration systems of the same frequency of 60 kHz, 90 kHz, 120 or 190 kHz and a welding frame with a static clamping pressure source.

Figure 1 shows a 190 kHz complex vibration bonding system. The welding tip is driven in two directions at right angles to each other in its sectional plane through quarter-wavelength transverse vibration rods which prevent mutual interference between the two longitudinal driving systems. These vibration systems are driven simultaneously by independent controllers and amplifiers, and welding tip vibration locus shape and direction are controlled from linear, elliptical to circular by regulating the vibration amplitude and phase difference of two driving systems.

The dimensions of vibration systems of 60 kHz, and 90 kHz used are 15 mm in diameter and 1.0 in longitudinal wavelength. The dimensions of vibration system of 120 kHz used are 8 mm diameter and 1.5 in longitudinal wavelength.

The 190 kHz vibration system consists of two piezoelectric ceramic (lead-zircon-titanate; PZT) disks of 8 mm diameter and 1.5 mm thickness, and 1.5 wavelength longitudinal vibration system of 7 mm diameter with a transverse vibration welding of tip of 1.2 mm diameter.

Figure 2 shows free admittance loops of two 190 kHz vibration systems used under no-load conditions. The difference of resonance frequencies of these systems are 39 Hz which is about 0.02% of resonance frequency. The quality factors of these vibration systems are 203 to 280 and these amplitudes of motional admittance at the resonance frequency are 5.5 and 6.0 mS. These vibration systems used have almost same vibration characteristics. Vibration amplitude is measured by ring-type magnetic vibration detectors installed at a loop position of the transducers[1].

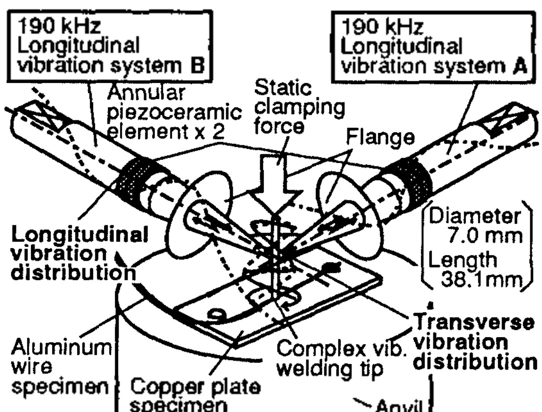


Fig. 1 Arrangement of the same frequency complex vibration wire bonding system of 190 kHz.

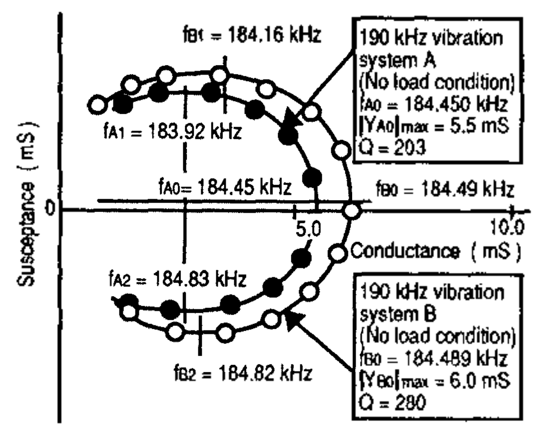


Fig. 2 Free admittance loops of 190 kHz complex vibration systems for ultrasonic wire bonding without power factor compensating inductance.

## 2.2 *Welding specimens*

Welding specimens used are 0.1-mm-diameter aluminum wires (tensile strength=60 gf) and 1.0-mm-thick copper plates. The copper plates are cleaned and degreased by trichloroethylene and diluted hydrochloric acid.

Weld strength measured is the maximum force required to break the specimen wire or welding surface in a direction perpendicular to the welding surface.

# 3. WELDING CHARACTERISTICS OF 60 kHz, 90 kHz, 120 kHz AND 190 kHz LINEAR AND COMPLEX VIBRATION WIRE BONDING SYSTEMS

## 3.1 *Welding conditions of 60 kHz, 90 kHz and 120 kHz linear and circular vibration welding tips*

The relationship between linear velocity of 60 kHz, 90 kHz and 120 kHz welding tips and weld strength of 0.1-mm-diameter aluminum wire specimen is shown in Fig.3. The direction of the linear vibration welding tip is set parallel to the specimen wire length. Welding tip vibration velocity is altered to about 1.0 m/s (peak-to-zero value), which is equal to vibration amplitudes of 1.77 μm for 90 kHz and 1.33 μm for 120 kHz. Welding time used is 0.1 s and welding tip champing force is 300 gf. The required vibration velocities for sufficient weld strength are about 0.8 m/s at the frequency of 90 kHz and 0.4 m/s at 120 kHz and furthermore 0.3 m/s in the case of 120 kHz circular vibration locus. The required vibration velocity of 120 kHz of linear and circular loci becomes about half to one third that of 90 kHz. It was shown already by the authors that the required velocity of 90 kHz is smaller than that of 60 kHz which is about 1.4 times that of 90 kHz[7].

## 3.2 *Welding conditions of 120 kHz and 190 kHz linear vibration welding tips*

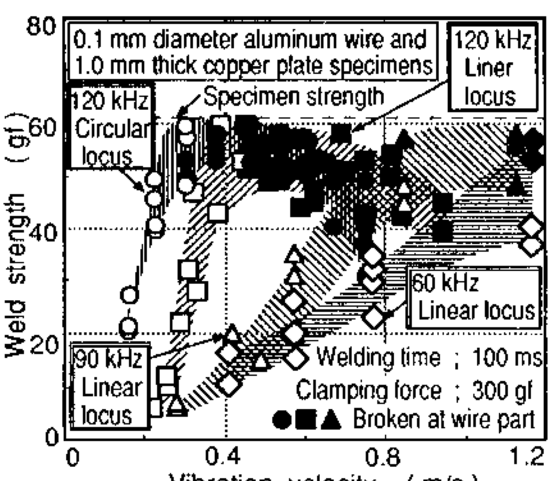


**Fig. 3 Relationship between vibraion velocity and weld strength of aluminum wire of 0.1 mm diameter welded by 60 kHz, 90 kHz and 120 kHz welding tips of linear vibration locus and a 120 kHz welding tip of circular vibration loci.**

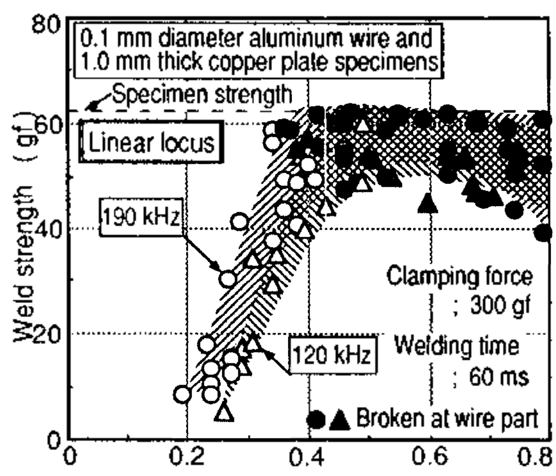


**Fig. 4 Relationship between vibration velocity and weld strength of aluminum wire of 0.1 mm diameter welded by 120 kHz and 190 kHz welding tips of linear vibration locus.**

Various values of weld strength obtained by linear vibration welding tips are shown in Fig.4. Vibration velocities perpendicular to the specimen length direction of 120 and 190 kHz are altered to 0.8 m/s (vibration amplitude of 120 kHz and 190 kHz =1.06 μm and 0.67 μm). The direction of the linear vibration welding tip is set parallel to the specimen wire length. Welding time and clamping force are the same in all cases. The required vibration velocity parallel to the specimen of 190 kHz is smaller by about 30 % that of 120 kHz. The vibration amplitude of 190 kHz is smaller than that of 120 kHz, i.e., 50 % of 120 kHz.

## 3.3 *Required welding time of 120 kHz and 190 kHz linear vibration welding tips*

Various values of weld strength obtained by linear vibration welding tips of 120 kHz and 190 kHz are shown in Fig.5. Vibration velocities perpendicular to the specimen length direction of 120 and 190 kHz are fixed at 0.45 m/s (vibration amplitude=0.6 μm) and 0.42 m/s (0.45 μm). Welding time is changed to 100 ms and clamping force is the same in these cases. The required welding time of a 190 kHz linear vibration welding tip for sufficient weld strength is one-third that of 120 kHz in this case of about same vibration velocity. The amplitude of displacement is required for driving the weldment effectively giving enough mutual vibration velocity between the welding surfaces overcoming the roughness of welding surface and the shear vibration loss of the wire specimens. From the results of Fig.14, the 190 kHz bonding system has enough amplitudes of vibration displacement and velocity for successful bonding.

## 3.4 *Required welding time of 190 kHz linear and circular vibration welding tips*

Various values of weld strength obtained by linear and circular vibration welding tips of 190 kHz are shown in Fig.6. Vibration velocities perpendicular to the specimen length direction of 190 kHz are fixed at 0.45 m/s (vibration amplitude=0.6 μm) and 0.42 m/s (0.45

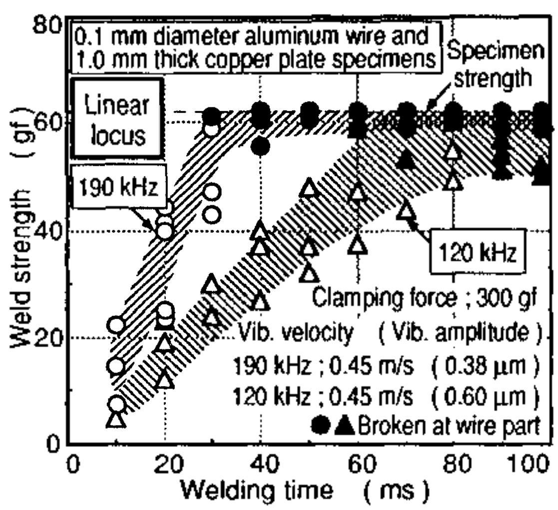


Fig. 5 Relationship between welding time and weld strength of aluminum wire of 0.1 mm diameter welded by 120 kHz and190 kHz welding tips of linear vibration locus.

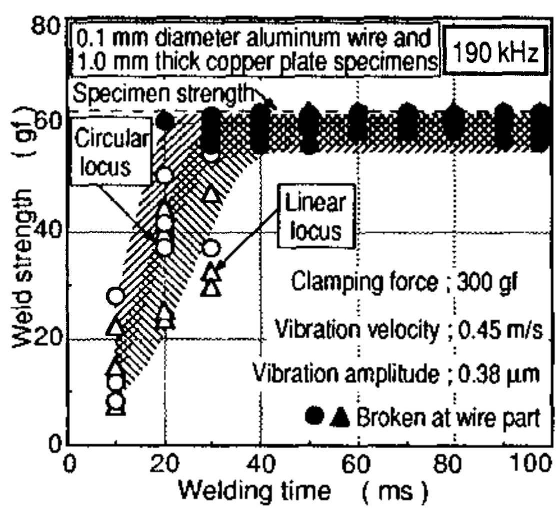


Fig. 6 Relationship between welding time and weld strength of aluminum wire specimens of 0.1 mm diameter welded by a 190 kHz welding tip of linear and circular vibration loci.

μm). Welding time is changed to 100 ms and clamping force is the same in these cases. The required welding time of a 190 kHz linear vibration welding tip for sufficient weld strength is one-third that of 120 kHz in this case of about same vibration velocity. The amplitude of displacement is required for driving the weldment effectively giving enough mutual vibration velocity between the welding surfaces overcoming the roughness of welding surface and the shear vibration loss of the wire specimens. From the results of Fig.6, the 190 kHz bonding system has enough amplitudes of vibration displacement and velocity for successful bonding.

## 4. WELD CONDITIONS OF ALUMINUM WIRE SPECIMENS

### *Relationship between specimen deformation and weld strength*

Figure 7 shows the relationship between weld strength and weldment width of aluminum of 0.1 mm diameter joined by 60 kHz and 190 kHz linear vibration welding tips. The weldment width corresponds to deformation of the wire specimen. Weld strength is maximum over the range where specimen width is 140 % to 180 % of wire specimen diameter. Excessive wire deformation damages specimens and decreases their weld strength. From the results of the measured relationship between specimen width at the weldment (weldment width) and weld strength of aluminum wire specimens of 0.1 mm diameter joined by 90 kHz linear and circular vibration welding tips, weld strength is maximum in the same range in Fig.7 where specimen width is 140 % to 180 % of specimen diameter.

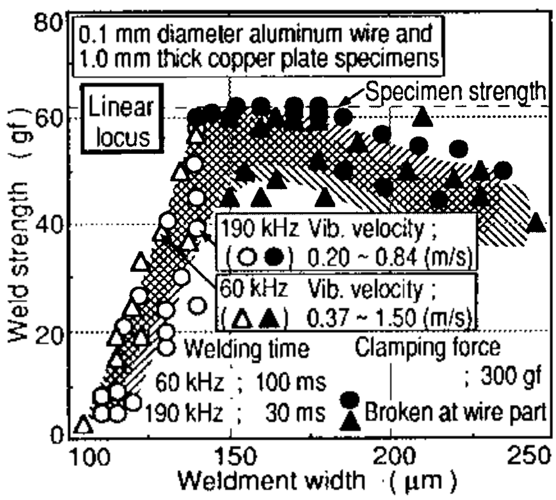


**Fig. 7 Relationship between weldment width and weld strength of aluminum wire specimens welded by 60 kHz and 190 kHz welding tips of linear vibration locus.**

## 5. CONCLUSIONS

Welding characteristics of ultrasonic wire bonding using 60 kHz, 90 kHz, 120 kHz and 190 kHz welding tips were studied. The types of welding equipment used were (1) the same frequency complex vibration wire bonding systems of 60 kHz, 90 kHz, 120 kHz and 190 kHz. Vibration locus of the complex systems were controlled from linear to elliptical or circular.

Complex vibration bonding systems used consisted of a complex transverse vibration welding tip and (1) two driving systems at right angles to each other; however, the complex welding tip may be driven using (2) a longitudinal-transverse or (3) a longitudinal-torsional complex vibration system[7].

Welding specimens of 0.1-mm-diameter aluminum wire used were welded successfully by these higher-frequency complex vibration welding equipment of one dimensional configuration.

The required vibration amplitudes of these complex vibration systems were about one-half to one-third and the required welding times are shorter than those of conventional systems using a linear vibration welding tip.

The required vibration velocity of the 90 kHz bonding system was about half that of 60 kHz system, and required vibration velocity of the 120 kHz system is smaller than that of 90 kHz system and furthermore required velocity of the 190 kHz system is smaller than that of 120 kHz system because of the large number of repetitions of vibration stress of the higher-frequency system. The vibration displacement of higher frequency decreases as frequency increases where vibration velocity is kept constant, and certain amplitude of displacement is required corresponding to the roughness of specimen surface for successful welding.

Based on these results, the 190 kHz bonding system had enough vibration displacement amplitude required for driving welding surface effectively overcoming the roughness of welding surface and the shear vibration loss of the wire specimens and higher-frequency and complex vibration bonding systems were found to be adequate for bonding of extremely thin wires of high-density integrated circuits using shorter welding time which is required for increasing integration density of LSI or VSLI devices.

The deformations of the welded specimens at adequate welding conditions are almost same even if the welding tip vibration locus is altered from linear to elliptical, circular or the vibration frequency used is changed from 60 kHz to 190 kHz in the case where the same wire specimens are used. Also, using these methods, the weld strength becomes independent of the difference in the direction between welding tip vibration and wire length[2-9].

## REFERENCES

1) J.Tsujino: Proc. 4th Symp. Ultrasonic Electronics, Tokyo, 1983, Jpn. J. Appl. Phys. 23 (1984) Suppl. 23-1, p.212.

2) J. Tsujino: Proc. IEEE 1987 Ultrasonics Symp. (IEEE, New York, 1988) p. 615

3) J.Tsujino, H. Sugimoto, M. Horikoshi, M. Sakai, H. Ando and T. Negishi: Proc. 8th Symp. Ultrasonic Electronics, Tokyo, 1987, Jpn. J. Appl. Phys. 27 (1988) Suppl. 27-1, p. 186.

4) J. Tsujino: Proc. Ultrasonics Int. 1989 (Butterworths, Guildford, 1990) p. 268.

5) J. Tsujino, H. Furuya and Y. Murayama: Proc. IEEE 1989 Ultrasonics Symp. (IEEE, New York, 1990) p. 1103

6) J. Tsujino, Y. Murayama and H. Furuya: Proc. 10th Symp. Ultrasonics Electronics, Tokyo, 1989, Jpn. J. Appl. Phys. 29 (1990) Suppl. 32-1, P. 173.

7) J. Tsujino, T. Mori, T. Onozato and K. Hasegawa: Jpn. J. Appl. Phys. 32 (1993) P. 2435. part 1, No. 5B

8) J. Tsujino,T. Ueoka, I. Watanabe, Y. Kimura, T. Mori, K. Hasegawa, Y. Fujita, T. Shiraki and M. Motonaga: Proc. IEEE 1993 Ultrasonics Symp. (IEEE, New York, 1990) p. 405.

9) J. Tsujino, T. Mori and K. Hasegawa: Proc. EuPac'94 ( 1st European Conference on Electronic Packaging Technology; 7th Intern. Conf. 'Interconnection Technology in Electronics' ) (1994) p.206.

9) J. Tsujino, T. Mori and K. Hasegawa: Jpn. J. Appl. Phys. 33 (1994) to be published