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Application of Capacitor Microphones and Magnetic Pickups to the Tuning and Trouble Shooting of Microelectronic Ultrasonic Bonding Equipment

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Application of Capacitor Microphones and Magnetic Pickups to the Tuning and Trouble Shooting of Microelectronic Ultrasonic Bonding Equipment

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G. G. Harman and H. K. Kessler

ABSTRACT

Microelectronic ultrasonic wire bonding equipment typically welds wires to integrated circuits at frequencies between 50 and 65 kHz. Mechanical vibrations at these frequencies are difficult to measure directly and malfunctions of the system may not be recognized. Two different methods of measuring these vibrations are described. The first method involves use of a capacitor microphone and a tapered tip, and the second method use of a small magnetic pickup. Procedures are given for establishing a specific ultrasonic vibration amplitude, tuning the ultrasonic system to resonance, and diagnosing both mechanical and electrical problems in wire bonding equipment. Although these techniques and procedures were developed for ultrasonic wire bonding equipment, they are applicable to other ultrasonic welding systems of lead attachment, such as flip-chip, beam lead and spider bonding.

Key Words: Capacitor microphone; flip-chip; magnetic pickup; microelectronic interconnections; spider bonding; ultrasonic bonding; wire bonding.

1. *INTRODUCTION*

Numerous problems exist in the ultrasonic systems used for bonding wire to integrated circuits. Many of these problems have been characterized and discussed in detail [1]. The object of this report is to summarize these observations and to describe techniques and procedures which have been devised to tune and trouble-shoot ultrasonic wire bonding machines in a production environment. New material, updated techniques, and information from previous reports are included here.

Most of the diagnostic work described previously was performed using small capacitor microphones. These units, having either 1/4 in. or 1/8 in. diameter diaphragms, can be obtained with frequency responses to 100 kHz or higher.* They have been used to measure the mechanical

* Such units are available from B & K Instruments, Inc.; Cleveland, Ohio. Any other microphone with a similar high frequency response can be used as well.

Q of ultrasonic transducer-tool combinations, to plot the 60 kHz mechanical vibrations along bonding tools, to trouble-shoot bonding machines for bearing defects, to tune ultrasonic transducers to their mechanical resonance, and to reestablish the vibration amplitude of bonding tools. Recently magnetic pickups have been used successfully for the latter two purposes.[†]

Section 2 describes capacitor microphones, a method of fabricating acoustical tapers, and general ultrasonic techniques. Those who already have such equipment may wish to go directly to Section 3, which gives procedures and techniques for tuning and trouble-shooting wire bonding equipment. Section 4 describes ways in which inexpensive magnetic pickups can be used to trouble-shoot and tune bonding equipment.

The measurement methods and techniques described were developed for ultrasonic wire bonding equipment. However, the procedures are applicable, with little modification, to other ultrasonic systems of lead or die attachment, such as flip-chip, spider, and beam lead bonding.

[†] Such units are available from Electro Products Laboratories, Inc., Chicago, Illinois. Other magnetic units may serve the purpose just as well but were not available during this work.

2. *CAPACITOR MICROPHONE*

A capacitor microphone, without any additions, modifications, or amplification of its output, can be used to tune ultrasonic wire or flip-chip bonding machine transducers to their mechanical resonance. A 1/4 in. or 1/8 in. diameter microphone produces a substantial output voltage (approximately 0.1 V) when brought close to the vibrating tool or transducer horn end. However, the movement of a person's hand or any other object within several inches of the microphone may disrupt the standing wave pattern and change the output amplitude. If such motion is avoided, and the background noise level is not high, the mechanical resonance frequency of the system may be obtained. However, it is generally necessary to obtain considerably more information than the mechanical resonance alone. In order to trouble-shoot and to reestablish vibration amplitude of ultrasonic wire bonding equipment it is essential to improve the spatial resolution of the microphone.

2.1. *Microphone Acoustical Taper:* Capacitor microphones with diaphragms of 1/4 in. or 1/8 in. diameter normally detect incident sound from relatively large angles. However, when measuring parameters of wire bonding systems it is desirable to measure the sound pressure emitted only from the tip of a bonding tool, an area of approximately 50 to 100×10^{-6} sq. in. In order to do this, the entrance to the microphone must be constricted by some means such as a conical tip.

The design of a tapered conical tip for focusing sound into the microphone is subject to many practical constraints and uncertainties. Generally, the volume of the cone should be kept as small as practical in order to minimize standing waves. Ideally, the cone is constructed of thin-walled steel. However, almost any continuously tapered material may be used. For example, it is completely adequate to construct a cone that has the necessary physical dimensions required for making the measurement and then insert appropriate damping material to eliminate standing waves. A simple and satisfactory cone may be constructed by wrapping several layers of aluminum foil around a tapered mandrel, such as the end of a sharpened pencil. Even the plastic cone from the end of a tube of silicone rubber can be used.

In order to constrict the opening as well as to protect the small end of the cone from damage caused by physical contact with hard objects, such as tungsten carbide bonding tools, the cone is usually coated with a rubber-like material. The technique for doing this is as follows: The lightly greased tip of a sewing needle or pin is extended through the hole in the small end of the cone. The outside of the cone is coated with a layer of self-leveling silicone or urethane rubber and positioned with the small end pointed downward. This causes the rubber to coat the pin as well as the cone. After polymerization of the rubber, the needle is retracted and the tip of the rubber sheath is cut off,

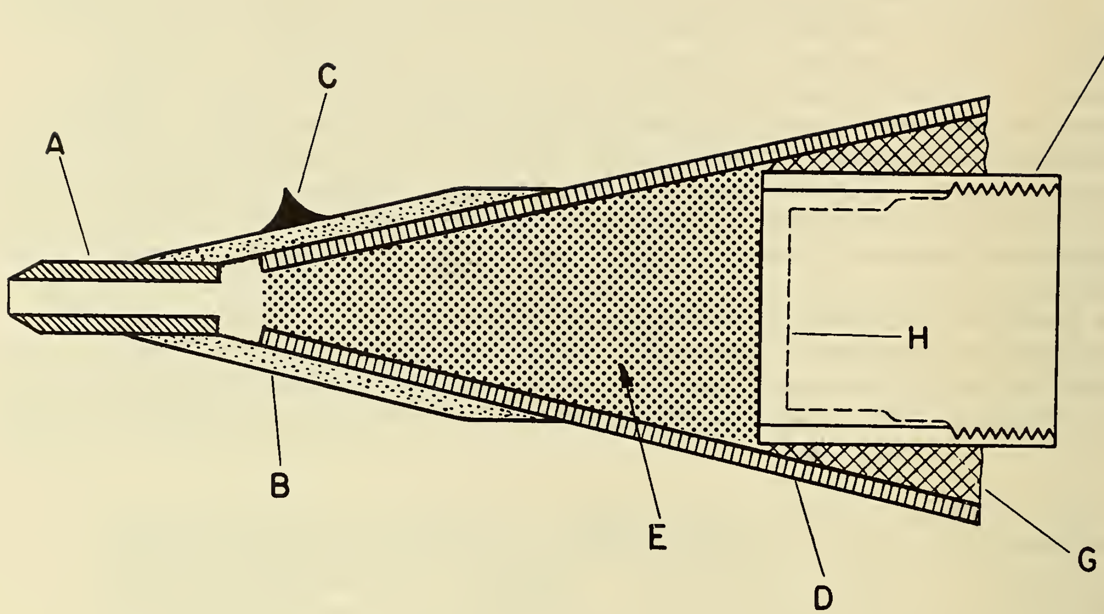

Fig. 1. Cross-sectional view of a high-resolution extension tip for the capacitor microphone.

A: Section of hypodermic needle. This can be made from size #20 to 30 but most units were made from #27 or 29 needles.

B: Self-leveling silicone rubber coating

C: Red or black silicone rubber dot for reproducible orientation of A with respect to the bonding tool

D: Steel or aluminum cone

E: Cotton or open-pore plastic foam damping material with low reflection of the ultrasonic signal

F: Stainless steel threaded sleeve (typically made from a microphone protective grid)

G: Epoxy or silicone rubber bond between the sleeve, F, and the aluminum cone, D. (This bond must be tight or stray signals can enter the microphone from the rear.)

H: Dotted lines indicate position of microphone exposing the small needle hole. A threaded metal sleeve that screws onto the microphone is bonded on the large end of the cone. The cone is screwed onto the microphone and is now ready to be used for simple measurements, such as peak tuning the mechanical resonance of a bonding tool.

2.1.1. *High-Resolution Taper:* If reproducible amplitude measurements are required, a small length (approx. 0.05 in.) of a hypodermic needle, typically in the size range of No. 20 to 29 is inserted and bonded into the needle hole; silicone primer is essential for good bonding to the stainless steel needle. For maximum signal strength and reproducibility this needle must lie straight along the axis of the cone.

The cross section of such a high-resolution microphone taper is shown in Fig. 1. The total extension in front of the microphone is about 1/2 in. to 3/4 in. for a 1/4 in. diameter microphone and about 3/8 in. for a 1/8 in. diameter microphone. These dimensions are not critical. The acoustical pickup area is defined by the hole in the hollow needle, A, which is typically chosen to be from 0.004 to 0.015 in. in diameter. The smaller diameter is more suitable for studying the vibration modes of a bonding tool. The stainless steel mounting sleeve, F, should not protrude more than approximately 0.040 in. past the diaphragm of the microphone or standing waves may occur. A colored dot of silicone rubber, C, may be applied to the cone to maintain a specific orientation of the tip, A, with respect to the bonding tool. With use, the steel tip may wear preferentially, and changing its orientation could produce a sudden change in the microphone output.

Bonding tool motion is generally studied at a fixed frequency, therefore the microphone-taper system need not have a flat frequency response. However, in order to determine the mechanical Q of a transducer, the frequency must be varied over a range of 4 or 5 kHz, and it becomes necessary to eliminate any standing waves over this range. This is done by adding a damping material, E, which should extend to within about 0.04 in. of the diaphragm.

2.1.2. *Specialized Cones and Tips:* Microphone tapered tips made in the manner described above provide essentially complete rejection of all ultrasonic signals not entering through the entrance hole. (When this hole is positioned a few mils or less from a vibrating surface, there is freedom from standing waves or reflections from nearby objects.) Ultrasonic sound waves are prevented from reaching the microphone diaphragm primarily by reflection from the outer surface of the cone. Audible sound, particularly if it contains low frequency components, may be transmitted through the cone walls. A simple, high-pass R-C filter can be placed at the output of the microphone and preamplifier to eliminate such background interference. The exact component values are chosen

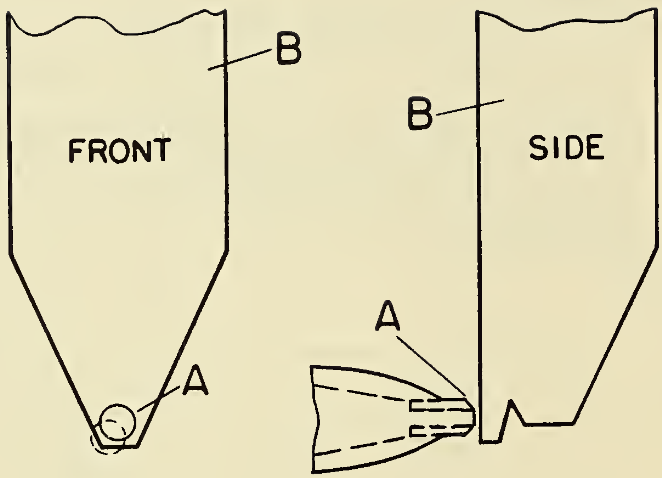

Fig. 2. Positioning of the microphone tip on the bonding tool. (A) is the hollow steel needle. (B) is the bottom section of an ultrasonic bonding tool. The solid circle (front view) is the typical position for measuring vibration amplitude. The dotted circle represents the position of the microphone tip when examining looseness in the transducer mount bearings of the bonding machine (see Section 3.4).

to be compatible with the output impedance of the preamplifier.†

Many specialized cones and tips have been designed. In one case the hypodermic needle (A, Fig. 1) was seated at right angles to the cone axis so that the microphone could be placed at the side of the bonding tool and horn. In another case, a tip was made in which the entrance to the cone was sealed with a thin layer of high-performance silicone rubber. The minimum pick-up area was a 0.02 in. diameter circle. In operation, the tip was pressed directly against the tool or horn. A good signal (50 to 100 mV)* was produced and the tip did not mechanically load the transducer noticeably. However, the signal amplitude increased somewhat with increased pressure of the tip against the tool due to improved piston action of the rubber.

The hypodermic needle tip is customarily seated in rubber to protect the needle entrance hole against accidental deformation which may occur if the bonding tool is struck too hard. However, if such accidents can be avoided, as for instance in a laboratory setup, then the needle can be rigidly bonded with epoxy or soldered in position at the end of the cone. Such a procedure is simpler than the silicone rubber method described earlier.

2.2. *Various Measurement Techniques:* For studying the vibration along the entire length of a bonding tool [1], an amplitude reproducibility of about ±5 percent is essential to obtain meaningful results. This is achieved in the following manner: Both the source transducer and the microphone are held in rigid mounts, and the microphone is moved with a micrometer stage. In a given position, the steel tip of the microphone is advanced until it just touches the bottom of the vibrating tool as shown in Fig. 2. The instant of contact is clearly evident because "hash" appears on the oscilloscope display of the microphone

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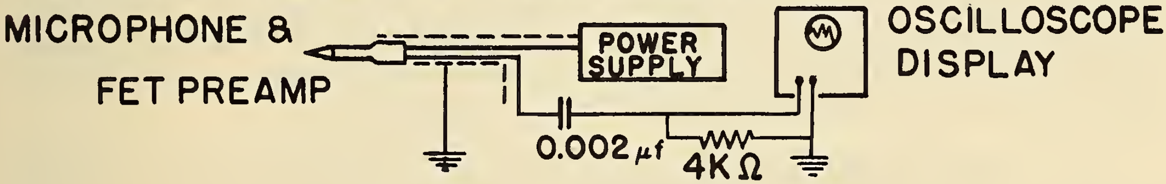
† A simple high pass filter, consisting of a 0.002 μF capacitor and a 4 kΩ resistor, can be inserted between the microphone preamplifier and the oscilloscope to eliminate audible sound.



* Normally the output of the capacitor microphone is amplified by a 10X FET amplifier before it is fed into a meter or oscilloscope. The typical microphone output voltages given in this report are those from the FET amplifier. An oscilloscope with a 5 mV/cm sensitivity is preferred over a meter for measurements on bonding machines because the waveshape display can reveal problems such as loose bonding tools, transducer-mount interactions, etc.

output. Then the tip is carefully retracted until the "hash" just disappears and a clear sine wave appears. A reproducible signal (20 to 30 mV) is obtained with this technique. This is the technique normally used to measure the vibration amplitude of a bonding tool (Section 3.3).

There is an alternative method of obtaining amplitude reproducibility with a hypodermic-needle-tipped cone that involves actual contact with the vibrating tool. This method works best with a low mass, solid or hollow needle (No. 29 or higher number hypodermic needle or equivalent), and with bonding tool tip amplitudes less than about 50 microinches peak to peak displacement. Under these conditions the microphone tip is advanced until it contacts the bonding tool. This first produces an audible noise as well as "hash" on the oscilloscope display. The tip is further advanced until the "hash" disappears and a large (∿ 50 mV) sinusoidal signal appears on the oscilloscope. This signal is quite reproducible and further advancement of the tip produces only slight amplitude changes. Under these conditions the steel tip actually contacts the bonding tool and is vibrated by it at the 60 kHz rate. The tip does not noticeably load or detune the transducer. For the contacting technique to be successful, it is essential that the steel tip be seated directly along the axis of the cone. If not, the needle will ride off to one side of the vibrating bonding tool. In general, reproducible amplitude measurements are easier to make with this technique than with the non-contacting method described above.

Information about "sideways" vibration modes of the bonding tool can be obtained using the microphone as a detector. In this case the system is tuned to its characteristic resonance with the microphone in front of the tool. The microphone is then rotated 90 deg to the side of the tool, and the system is retuned to a new maximum, if one exists. Sideways modes of the tool with amplitudes up to one fourth that of the main resonant amplitude have been observed as close as 250 Hz away from the main resonant frequency. With a given transducer, these sideways characteristics depend on the length of the tool extension, the characteristics of the individual tool, and the tightness of the tool set screw. It is necessary to compare resonance curves from the front of the tool to those taken at the side. Because of the asymmetrical tool shape in order to recognize weaker sideways modes, for practical purposes, such weak modes would appear to have little effect on bonding.

2.3. *Acoustical Properties of Materials at 60 kHz:* Simple arrangements of the microphone and transducer horn may be used to determine with precision suitable for these studies, the reflection or absorption of plastic foams or other materials in the frequency range of interest (see Fig. 3). For reflectivity measurements, place the microphone with its diaphragm exposed beside the transducer horn and pointed in the same direction. The microphone and transducer should be placed parallel to each other and about 3/8 in. apart, with the microphone adjusted so that its diaphragm is in a standing wave node of the 60 kHz transducer generated sound. Place the sample to be tested so that a flat area is facing the microphone and transducer. Any reflected sound will be detected by the microphone. A large signal output indicates a highly reflective material. For measurements of transmission through materials which are not highly reflective, place the microphone in front of, and pointed toward the transducer horn, and place the sample between the two. The decrease in microphone output is related to the absorption.

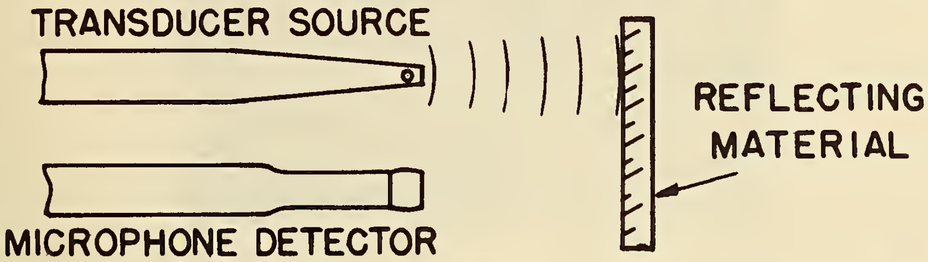


Fig. 3. Location of equipment for a simple ultrasonic sound reflection measurement.

Most materials, such as paper, metal foil, rubber, and plastic foams are highly reflective to 60 kHz sound waves. However, darkroom felt, soft paper tissues, cotton, and a very few open-pore plastic foams have little reflection. A single layer of black darkroom felt was found to absorb about half of the energy of a 60 kHz sound wave with almost no reflection. Two layers of this material, used to line a bench-top anechoic chamber, were sufficient to reduce 60 kHz signal reflections to a negligible level. One open-pore plastic foam which had essentially no reflection was found to have moderate absorption. This material was used to damp standing waves inside high resolution microphone tips (E in Fig. 1). The length of the foam inside the cone was adjusted to absorb about 50 percent of the 60 kHz sound energy, the calculated absorption required to sufficiently damp a standing wave in the tapered tip.

At times it is desired to temporarily couple ultrasonic energy from a transducer or tool to various ceramic or semiconductor accelerometers. This can be done successfully with putty-like silicone materials.* The putty is pressed against the transducer and the detector is pressed into the putty.

* Dow Corning Silastic 55U uncured silicon resin, or XC-20982 bouncing putty are both satisfactory 60 kHz sound-coupling agents for temporary use. Other materials may serve the purpose, but were not available for testing.

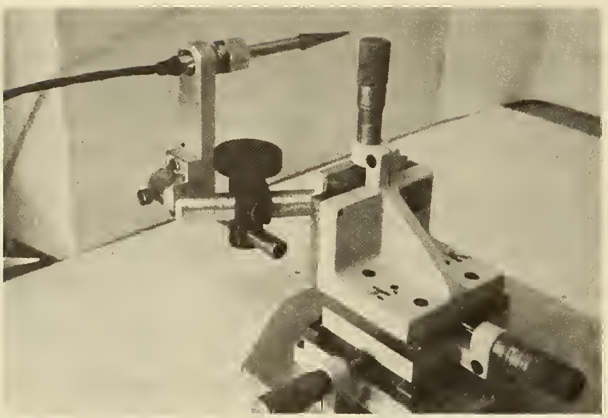
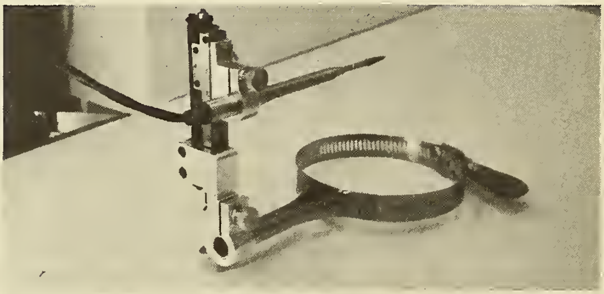


Fig. 4. Adjustable fixture in which the microphone is held by an x-y-z positioner. In use, this fixture is placed on the bonding machine to the left or right of the workstage. The microphone is moved to the bonding tool or transducer by adjusting the micrometers. The picture displays a microphone with a tapered steel tip.

5(A)



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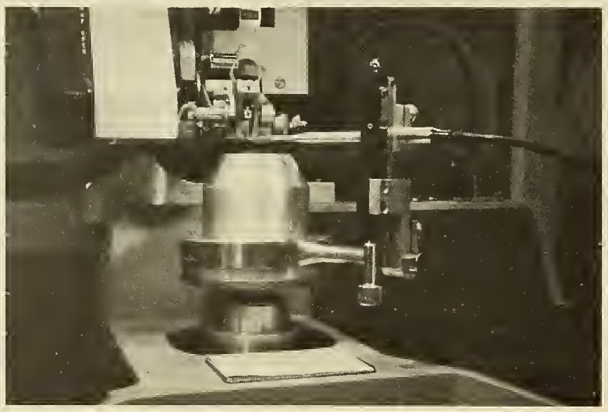

Fig. 5. (A) A simple fixture that is made to clamp directly on the bonding machine workstage. The x and y movements are obtained by using the bonding machine chessman positioner. The z movement is made from an inexpensive microscope graduated mechanical stage and is adjusted with the knob at the bottom of the positioner. This knob is more clearly shown in Fig. 5(B). This picture displays a 1/8 in. microphone with a tapered steel tip. (B) The same fixture as in 5(A) mounted on a bonding machine workstage.

3. *PROCEDURE FOR REESTABLISHING VIBRATION AMPLITUDE, TUNING, AND DIAGNOSING TROUBLES IN ULTRASONIC WIRE BONDING MACHINES, USING A CAPACITOR MICROPHONE*

3.1. *Introduction:* Generally a bonding schedule is established empirically for each different integrated circuit or transistor package to be bonded.† A general procedure has been developed for using a microphone or magnetic pickup (see Section 4) to tune the ultrasonic system and to reestablish the previous 60 kHz vibration amplitude of the bonding tool tip, in order to maintain the same satisfactory bonding schedule after changing tools. Mechanical looseness at such points as the transducer-mount pivot-bearings can be detected with the microphone. The relative mechanical stability of various parts of the bonding machine can also be determined.

3.2. *Mounting Fixture:* In order to use a capacitor microphone for tuning and trouble-shooting an ultrasonic wire bonding machine, a suitable holding fixture must be designed. Figure 4 shows one that was designed to rest on the bonding machine base. Another fixture is shown in Fig. 5a and mounted in position on a bonding machine, in Fig. 5b. Many other designs are possible. In general, however, a fixture of the type shown in Fig. 5 is advantageous because, as will be discussed below, it permits measurements of mechanical looseness and spurious motion of the transducer mount with respect to the work stage that holds the device to be bonded.

3.3. *Tune-up Procedure and Reestablishment of Vibration Amplitude:* The following procedure should be considered as a general guideline for tuning ultrasonic bonding machines. Variations of this procedure may be desirable for tuning particular machines or in special circumstances. It is desirable to keep day-to-day records of bonding parameters as a means of determining long-term deviations from the bonding schedule. For maximum reproducibility, microphone measurements must be made each time with the bonding machine in the same part of its cycle, usually the "start" or "reset" position. The entire procedure should take only a minute or so longer than is normally required to change a bonding tool and retune the power supply.

(1) Position the microphone on the bonding machine as shown in Fig. 5b. Adjust the high resolution tip of the microphone so that the top of the needle-like end tip is positioned about 0.02 in. above the bottom of the bonding tool as shown in Fig. 2. After an appropriate warm-up time, turn on the test switch of the ultrasonic power supply and hold it on for a <u>short</u> time (preferably not

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† A discussion of the checkout procedure and measures of bond reproducibility used at NBS is given in NBS Tech. Note 560, pp. 32-33 [1].

over one or two minutes) with, if necessary, a rubber band or other mechanical means. Advance the microphone tip until it lightly touches the vibrating bonding needle and "hash" appears on the oscilloscope. Then back it off until it just barely clears the needle. The "hash" disappears and a clear 60-kHz sine wave signal is seen. (An alternative contacting procedure which may also be used is described in Section 2.2.)

(2) Observe and record the 60-kHz sine wave amplitude as read from an oscilloscope. This is a very important step that permits the reestablishment of this amplitude at the end of the tune-up procedure.

(3) If the bonding tool is to be changed or adjusted, do so at this time. Move the microphone to the side without changing its vertical height and remove the old tool. Insert the new tool to the measured extension and tighten the set screw with a torque wrench to its recommended torque.

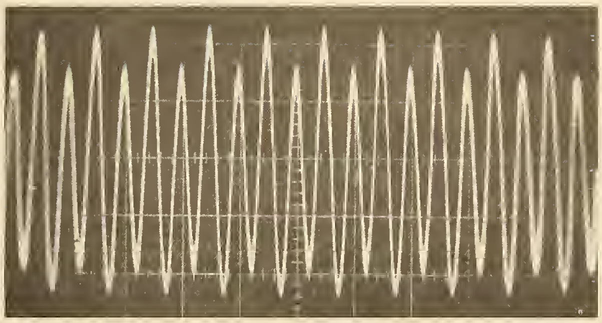
(4) Reposition the microphone as in (1).

(5) Peak tune the frequency on the power supply to produce maximum vibration amplitude of the tool. (It is preferred that an oscilloscope be used as the indicator rather than a meter, so that the output waveshape can be carefully observed for asymmetries similar to those shown in Fig. 6 and described in Section 3.4.) Quickly turn the power control from zero to maximum on the scale (Hi or Lo) normally used in bonding. If any waveshape asymmetries exist or if the amplitude does not increase linearly, tighten the set screw to its recommended torque, replace the tool, or both. If the waveshape still does not return to a pure sine wave and the ultrasonic amplitude does not increase linearly with power, then there is a problem in the power supply, the transducer, or its mount. The latter condition often can be improved by tightening the mount screw, moving the position of the transducer in its mount, etc.

(6) After tuning according to step (5) if the measured vibration amplitude does not return to within 10 or 15 percent of the value recorded in step (2), then readjust the power control to return the amplitude to this value. This is the most important single step in these instructions! The bonding machine is now ready to resume the same bonding schedule established previous to step (1).

(7) The transducer is temperature sensitive; thus if a high intensity illuminator burns out or if there are other

6(A)



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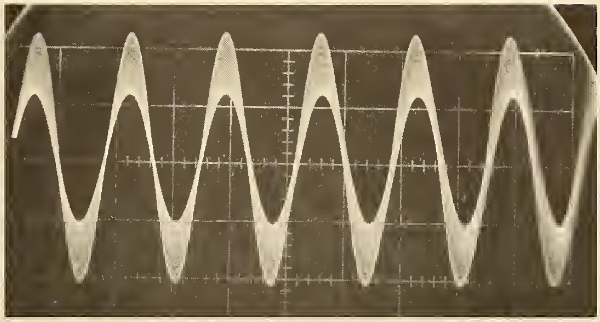

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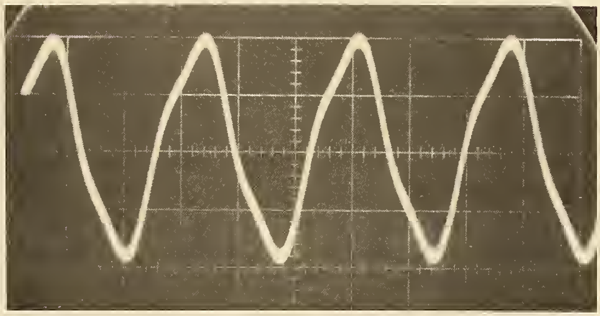


Fig. 6. Non-sinusoidal wave forms obtained with a capacitor microphone resulting from problems in the ultrasonic system. Similar results are obtained using the magnetic pickups. The power settings were relatively low, typical of those used for bonding 1 mil wire. (A) This wave form results from a transducer mount resonance in which the mount absorbs power at half the excitation rate (30 kHz rate when the transducer is driven at 60 kHz). The normal waveform should be a symmetrical sinewave. (B) An unusual waveshape that was observed only within a narrow power range. The distortion ceased when the bonding tool set screw was tightened past its recommended torque. The problem did not reoccur with a new tool. (C) Distorted waveshape resulting from a worn bonding-tool set-screw. The screw was replaced and properly torqued, the waveshape became sinusoidal and the amplitude increased by a factor of two.

The above wave forms are considered to be representative. In other cases the same waveshape may be symptomatic of a different problem. The important point is that any non-sinusoidal waveshape represents a problem.

reasons to suspect significant temperature change, tune the system as above when the new equilibrium has been established.

3.4. *General Trouble Shooting Methods:* Several transducer-mount interactions and transducer tool problems have been discussed previously [2]. One problem was a change of transducer resonance frequency as a function of power. Several ultrasonic power supply manufacturers specify meter tuning of their equipment at much higher power levels than are generally used for microelectronic wire bonding. In many cases the power supply meter will never indicate the peak mechanical resonance. Even if it does, the resonance frequency may be power sensitive, and the unit will not be properly tuned when it is used at normal power levels. This situation can be quickly diagnosed with a microphone. First tune the bonder at the specified conditions. Then lower the power to that of the normal bonding range and retune according to step (5) in Section 3.3. If the lower-power resonance frequency is different from the higher power one, then a transducer-tool interaction, a transducer-mount interaction, or a faulty transducer is indicated. The tool should be changed to eliminate the possibility of transducer-tool problems. After this, a verification of these problems can be obtained by measuring the microphone (or magnetic pickup) output versus power control setting of the ultrasonic power supply. The curve should be approximately linear. If it saturates, decreases at high power, or requires continual peak tuning, then transducer and/or mount problems exist.

A further indication of trouble can frequently be seen by a nonlinearity in the oscilloscope wave shape display of the microphone output during the linearity test or after changing the tool. Three such nonsinusoidal patterns are shown in Fig. 6. In general, all problems that cause non-linear wave forms increase in severity as the power is increased. A bonding machine-transducer combination may be linear and perform well for bonding 1 mil wire ($\lesssim$ 1 watt of power), but show severe distortion, tool amplitude loading, etc., when used to bond thick wire at $\sim$ 5 watts or greater. A transducer-mount interaction can often be corrected by tightening the mount screw and/or by adjusting the transducer slightly backward or forward in its mount. If this does not help, then the problem is most likely in the transducer, which should be changed. The transducer mounts on some older bonding machines may have been inadequately designed and even changing the transducer will not help.

Only a portion of possible ultrasonic wire bonding problems are the result of electrical or ultrasonic system defects. Some problems are related to wire inhomogeneities, substrate metallization defects, worn or dirty bonding machine cams, etc., and are not within the scope of this paper. Other difficulties have a purely mechanical origin and are related to poor alignment or looseness of parts within the bonding machine. These require a sensitive displacement measuring device for diagnosis. The output of a microphone (having a high resolution tip and mounted on

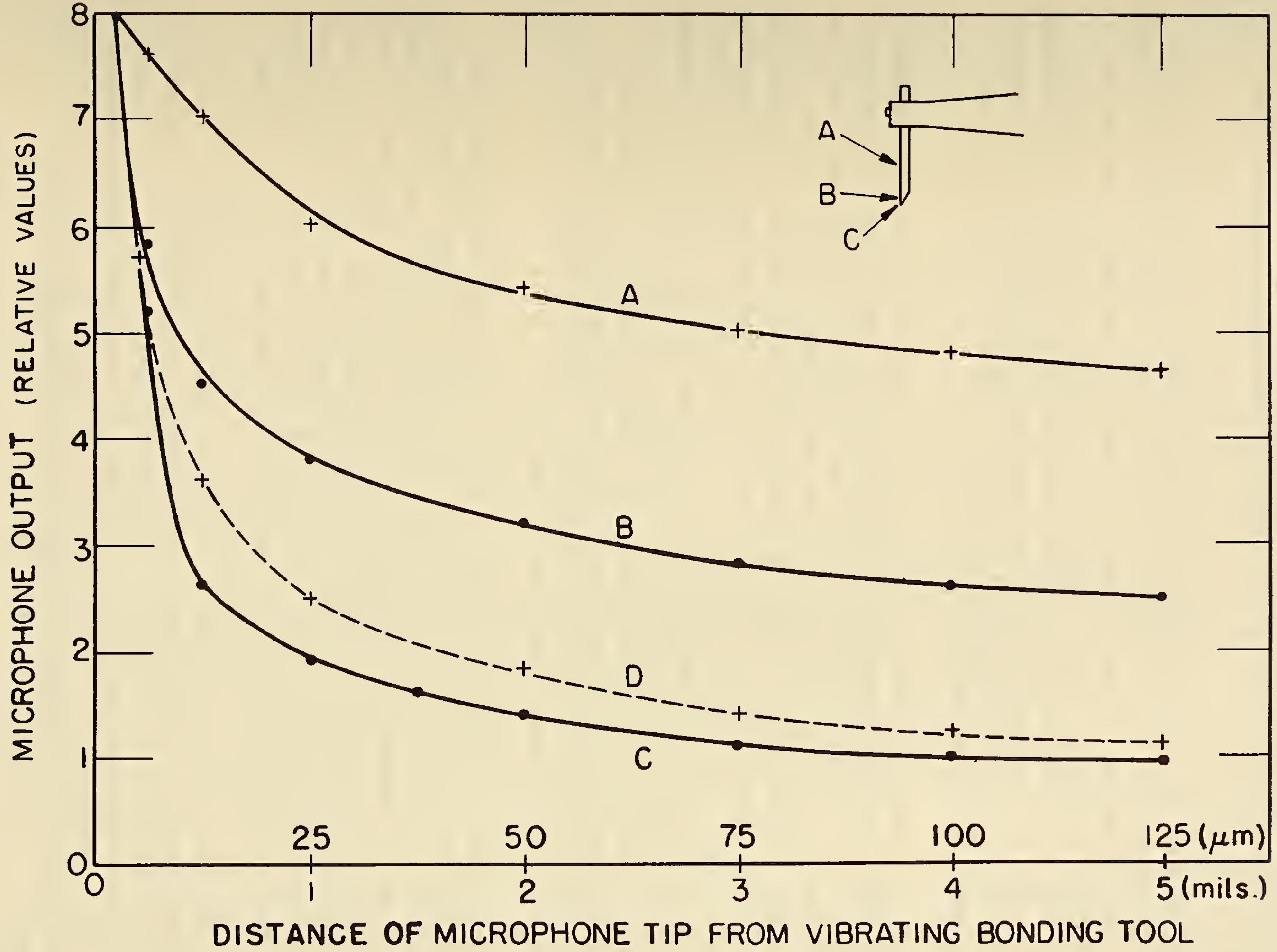


Fig. 7 Microphone output amplitude vs distance from a vibrating bonding tool. (A) Microphone tip is in front of the wide part of a tool, approximately half way between the tip and the transducer. (B) Microphone tip is 0.035 in. above bottom of the tool. (C) Microphone tip is 0.005 in. above bottom of tool. (D) Theoretical plot of amplitude decrease from a sound pressure point source.

the machine as in Fig. 5b) is very sensitive to its distance from a source such as the vibrating bonding tool. It can, therefore, be used to diagnose many purely mechanical problems. As can be seen from Fig. 7, displacements of less than 0.001 in. can result in microphone output amplitude changes of one or two inches on a 60-kHz oscilloscope display pattern. This represents a practical displacement magnification greater than 1000.

The microphone output voltage decreases rapidly with distance from a sound pressure source, the vibrating bonding tool. Therefore, as shown in Fig. 7, large changes in amplitude can result from small changes in location of the microphone with respect to the tool, within the range 0.0001 to 0.001 in. The output is also sensitive to the angle of approach to the tool. The signal amplitude can decrease by a factor of two with a variation of ±3 deg from normal to the tool. Therefore care must be taken in alignment of the microphone and tool.

Mechanical looseness due to wear or poor adjustment in the transducer-mount pivots and other associated parts of the mechanism can easily be detected. To do this, the tip of the microphone is moved partially to one side of the bonding needle as shown above by the dotted circle, A, in Fig. 2. The transducer or other suspected part is tapped or pushed on one side and then the other. The front end of the transducer should then be lifted up ∿ ¼ in. or so and released. A very large resulting change in microphone output or in particular, a failure of the microphone output to return to its initial value after either of these motions ceases, is an indication of mechanical looseness. If such looseness is observed then the pivot bearings or other associated parts should be adjusted according to the manufacturers specifications. The microphone should be used to check the progress of such adjustments.

The microphone is capable of being used to rapidly determine the relative mechanical stability of the bonding machine base, to which the transistor holding fixture or work stage is mounted, with respect to the transducer mount. Mechanical stability of this system to at least 0.0001 in. for any external shock or vibration introduced during bonding is essential if reproducible bond strength and deformation are to be achieved [3]. A machine stability problem exists if a significant low frequency amplitude modulation is seen on the oscilloscope pattern of the 60-kHz microphone output after the bonding machine housing is lightly struck with the hand. Most modern bonding machines that were tested in this manner displayed such a modulation in some degree or another. One of these machines continued to vibrate with amplitude ∿ 0.001 in. for about two seconds after being so struck. Such motion can also be excited internally by the torque of the programming cam motor, by shocks and vibration transmitted to the machine through the supporting table from an adjacent machine, or by operator movement.

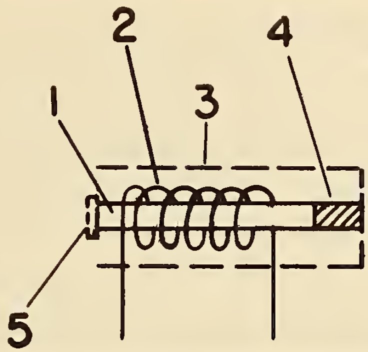
On some machines the work stage is intended to be rotated manually. In practice many operators do not remove their hand from the stage during the actual wire bonding operation. Using the microphone as a displacement gage (clamped in a fixture similar to that shown in Fig. 5), it was found that even a slight hand twitch could move this fixture approximately 0.0005 in. If this happens during bonding, a lift-off or, more dangerously, a weak bond can result. Thus, it is recommended that either the bonding operator remove her hand from the fixture during the actual bonding operation, or that rotation of the holding fixture be accomplished exclusively with an electric motor — a common practice in many machines.

4. *MAGNETIC PICKUPS FOR TUNING AND ESTABLISHING VIBRATION AMPLITUDE OF ULTRASONIC WIRE BONDING EQUIPMENT*

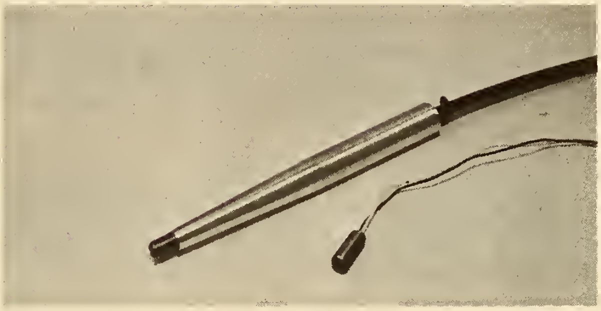
The microphone system described above has been used successfully for the laboratory study of the ultrasonic systems used in wire bonding. It has also been used on semiconductor device assembly lines to tune and trouble shoot ultrasonic wire bonding machines. However, it has several disadvantages. One important drawback is that the precision taper tips necessary for reproducible measurements are difficult to make and are not available commercially at present. Secondly, microphones are relatively expensive, delicate instruments that must be handled with reasonable care by qualified technical personnel in order to prevent damage. Lastly, the microphone and its preamplifier are physically large, 3 to 5 in. long, depending on the particular model chosen. Ideally, a measuring device for assembly line use should be cheap, rugged, and small enough to fit in a simple fixture that can be positioned by the micropositioner of the bonding machine under test.

Consideration of these necessary characteristics led to the reinvestigation of magnetic pickups. It was previously noted in this laboratory [4] that magnetic pickups were sensitive to the vibration of bonding tools. (Davis [5] has independently reported a similar observation.) At that time the magnetic units were being considered for use as in-process bond quality control monitors. However, the physical size of these detectors discouraged an extensive study of their use for that purpose. Interest was revived recently when microphone measurements revealed the importance of properly tuning the ultrasonic system, establishing a specific bonding tool tip amplitude, and examining the waveform of tool vibration. Compared with the microphone, the signal from the magnetic detector is realatively insensitive to its distance from the vibrating tool. This feature makes it easier to use in reestablishing the tool tip vibration amplitude after changing tools or in retuning. (The output is similar to that shown in curve A of Fig. 7.) The electrical output of these pickups is in the range of 10 to 20 mV when measuring typical tool vibration amplitudes used in bonding 1 mil aluminum wire. This represents tool motion in the vicinity of 40- to 80-μin. peak to peak displacement. However, for the same reason, it is less useful than a microphone for investigating the mechanical stability of the bonding machine. The spatial resolution, at the bonding tool, of the presently available magnetic pickups is about 0.05 in., which is adequate for tuning purposes. A typical device has concentric pole pieces as shown in Fig. 8A. The units are approximately ½ in. long and their outside surface is threaded with a 10-32 NF thread as shown in Fig. 8B (see footnote, p. 2). Figure 8B shows two magnetic pickups, one unmounted and the other mounted on the end of an aluminum rod. This rod can be substituted directly for the microphone in either of the fixtures shown in Fig. 4 and 5. They may be mounted on a bonding machine with the same fixtures used for holding microphones (Figs. 4 and 5) as shown in Fig. 8 C. Other smaller, transistor-sized, fixtures are possible. The magnetic pickups are sensitive to stray magnetic fields.

8(A)



8(B)



8(C)

Fig. 8. (A) Construction of a typical magnetic pickup. (1) magnetic-material core, (2) induction coil, (3) magnetic-material case, (4) permanent magnet, (5) thin (0.001 in.) mylar tape film to prevent the vibrating bonding tool from damaging the pickup core. (When applying the film, care must be taken to insure that no air bubbles exist at the tape-pickup interface.)
(B) Photographs of magnetic pickups used for measurements on ultrasonic bonding machines. The small unit is the detector alone, the larger unit shows the detector mounted in a rod that fits in various microphone mounts shown earlier in Fig. 3 and 4.
(C) A magnetic pickup mounted on a bonding machine ready for measuring the bonding tool vibration amplitude.

Thus, if a magnetic chuck is used on the work stage, its field should be shunted. The center pole piece of the pickup should be cleaned occasionally to remove attached magnetic or other particles.

The technique for tuning and reestablishing the vibration amplitude of a bonding tool using a magnetic pickup is similar to that described for the microphone in Section 3.3. The only significant difference is in the initial positioning of the detector. Due to its lower resolution, the center core of the magnetic pickup (Fig. 8a) cannot be positioned at the bottom of the tool tip. Instead it is brought close to the tool and about 0.1 in. above its tip and then adjusted vertically downward until the signal amplitude is maximum. This amplitude represents the averaged motion of the lowest vibration loop of the tool. One should be sure that a higher vibration loop is not measured. See the Appendix for vibration pattern of tools. After the measurement, the amplitude is recorded as in Section 3.3 step 2.

Some magnetic pickups have an asymmetrical amplitude response in the horizontal direction. This should be investigated when the pickup is first placed in service. A red mark centered at the maximum response position will allow quick, reproducible, horizontal positioning of the pickup with respect to the tool. After long use the sensitivity of one magnetic pickup decreased suddenly by 30%, presumably due to dropping or other damage to its internal magnet. Therefore, it is desirable to keep a second calibrated pickup available to confirm the cause of any sudden output decrease.

The above procedure should provide a reproducible amplitude within 10 percent when tungsten carbide tools of the same manufacturer are used and a precision between ± 10 and 15 percent when different manufacturers' tools are compared.

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2. Ibid. NBS Tech. Note 520, p. 32-41.

3. Ibid. NBS Tech. Note 527, p. 39 and NBS Tech. Note 555, p. 29.

4. Ibid. NBS Tech. Note 495, p. 25.

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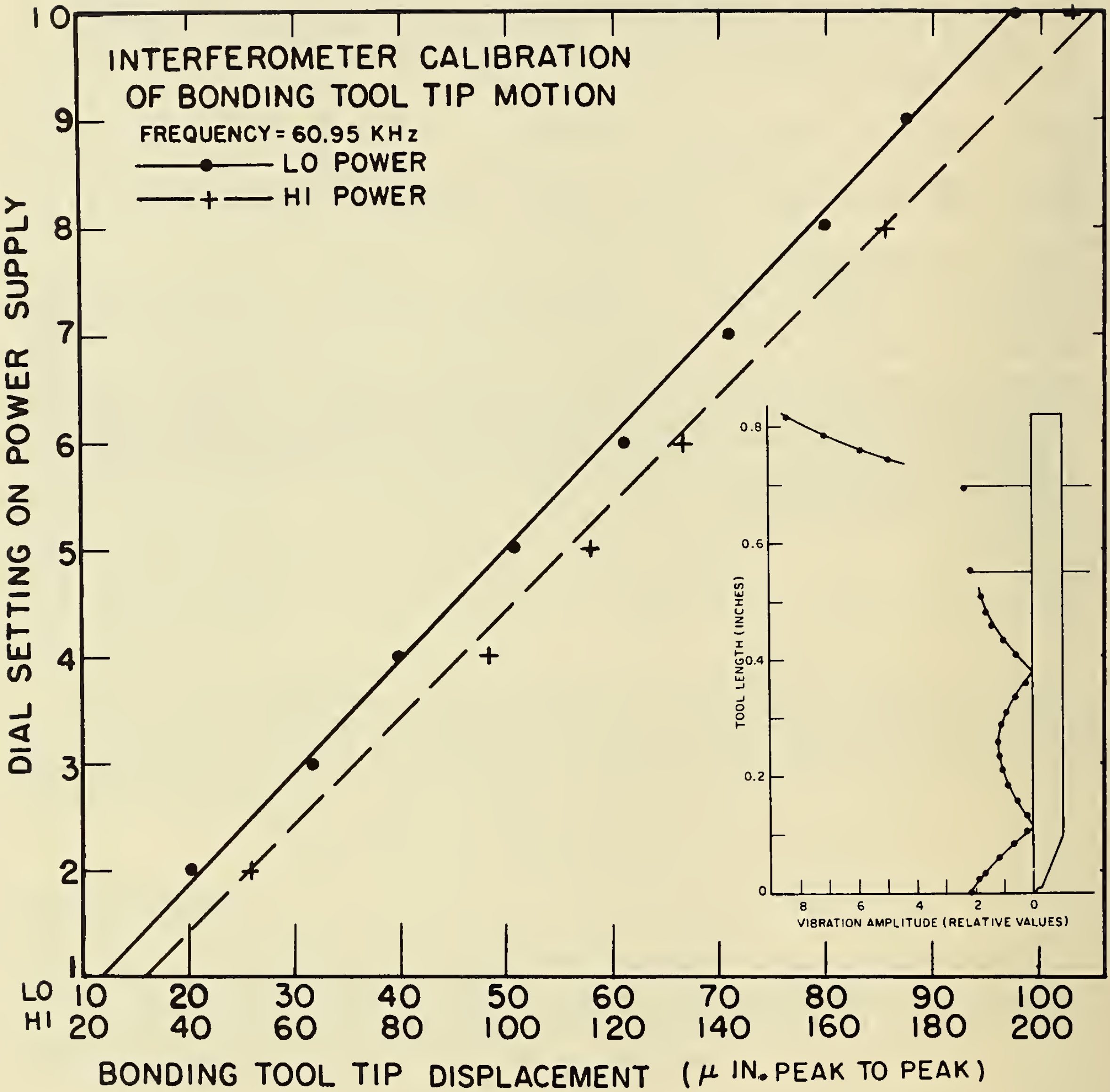

Appendix:

The absolute vibration amplitude curve of a particular 5 watt ultrasonic power supply-transducer-tool combination. The tool vibration mode is shown in the inset. In general, different combinations of components, even from the same manufacturer, can produce significantly different vibration amplitudes. The important point is that the power vs. vibration amplitude curve should be approximately linear. (The measurement technique used to obtain this data was described in NBS Tech. Note. 571, March, 1971.)

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Microelectronic ultrasonic wire bonding equipment typically welds wires to integrated circuits at frequencies between 50 and 65 kHz. Mechanical vibrations at these frequencies are difficult to measure directly and malfunctions of the system may not be recognized. Two different methods of measuring these vibrations are described. The first method involves use of a capacitor microphone and a tapered tip, and the second method use of a small magnetic pickup. Procedures are given for establishing a specific ultrasonic vibration amplitude, tuning the ultrasonic system to resonance, and diagnosing both mechanical and electrical problems in wire bonding equipment. Although these techniques and procedures were developed for ultrasonic wire bonding equipment, they are applicable to other ultrasonic welding systems of lead attachment, such as flip-chip, beam lead and spider bonding.

17. KEY WORDS (Alphabetical order, separated by semicolons)

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