

## Ceramic Element Bonding for Piezoelectric Motors

Federal Manufacturing & Technologies

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C. P. Montesana, Project Leader

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## Abstract

This paper briefly describes the methods used to epoxy bond PZT ceramic to stators used in 8-mm piezoelectric motors. It also includes a discussion of the advantages of metallic bonds over epoxy, and beginning work with metallic bonds made by silver diffusion bonding and tin lead soldering.

## Summary

The majority of 8-mm piezoelectric motors had the PZT ceramic element epoxy bonded to the bottom of the stator using a fixture consisting of a delrin post and sleeve arrangement. The post was used to support the stator, and the sleeve aligned the element with the center of the stator. This worked very well at creating good bonds, but required a lot of difficult masking with Kapton tape to keep the epoxy from filling the slots between the stator teeth and away from the attachment area for the electric cables. An alternate fixturing method was developed using an o-ring to both mask off the teeth of the stator and provide centering alignment for the element. Bonding problems, probably due to an insufficient application of epoxy, prevented this method from being used on the CX4 group of motors built. Instead, a "quick and dirty" method was devised for bonding this group of motors by aligning the elements by eye under a microscope and holding the element in place using Kapton tape before bonding to the stator.

Beginning efforts at metallic bonds were investigated. Silver diffusion bonding and tin lead solder bonding were evaluated. Both methods showed promise as a possible improvement to epoxy bonding. Tests were evaluated demonstrating that these methods would depole PZT ceramics with a low Curie temperature, but not cause any depoling of the higher Curie temperature PZT ceramics.

## Discussion

### Scope and Purpose

This paper presents the methods used for epoxy bonding PZT ceramic elements to the bottom of the stators used in 8-mm piezoelectric motors. It also describes the beginning development efforts of silver diffusion bonding and soldering the PZT ceramic rings to the bottom of the stator.

### Activity

### Epoxy Bonding

#### Overview of Epoxy Bonding

The PZT elements were bonded to the stators using Ciba-Geigy Araldite 179 epoxy. This particular version of the Araldite family of epoxies is commonly used for potting of electrical insulators and connectors due to its very low viscosity. This epoxy was chosen because the low viscosity creates a very thin bond thickness. Because the epoxy material has a high amount of damping energy loss, minimizing the epoxy with a thin bond helps to reduce the energy losses in the vibrations that drive the motor. This epoxy is a three-part mixture of resin, hardener, and accelerator that is cured for twelve hours in an oven at 125 degrees Celsius. During this cycle, the viscosity becomes so low that the adhesive flows and covers practically everything with a very thin coating of epoxy. In most instances, the slots machined into the stator to form the teeth were masked to prevent the epoxy from collecting into and filling in the slots. The sputtered gold plating on top of the element was masked to prevent the epoxy from contaminating the area for attaching the electrical leads used to drive the motor. Before bonding, the stators and PZT elements were ultrasonically cleaned in a solution of heated Dirl Lum in deionized water. The stators were then plasma cleaned. The bonding was then performed at a class 100 capability clean bench.

#### Bonding Using Delrin Centering Fixture and Kapton to Mask Stator

The majority of elements bonded to stators for 8-mm piezoelectric motors were bonded using a two-piece delrin fixture. This fixture consisted of a post for supporting the stator and a sleeve that slipped over the post. The close fit between the top of the sleeve and the stator acts to center the element with respect to the stator during bonding. The slots between the teeth of the stator were masked off by first fastening the stator (teeth down) to the post using a #0-80 screw, and then wrapping the post and stator teeth with 0.002-inch thick Kapton tape. Figure 1 is an illustration of the stator fastened to the post. Figure 2 is a cross-sectioned view of the stator attached to the post with the Kapton tape masking.



Figure 1. Stator Attached to Bonding Post

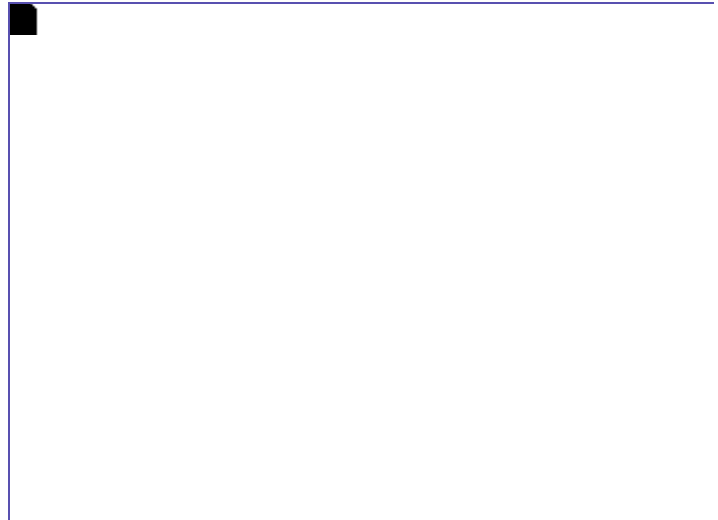


Figure 2. Cross Section of Stator on Bonding Post

After masking the stator teeth with Kapton tape, the screw was removed, and a 0.234-inch diameter circular piece of Kapton tape (cut out using a shim stock punch set) was used to mask off the top of the inside web area of the stator. Another circular Kapton mask with a 0.313-inch outside diameter and a 0.188-inch inside diameter hole was cut out using the punch set. This mask was carefully aligned under a microscope and placed on top of the PZT element to mask off the top surface of the element. The alignment sleeve was then placed over the post, and the epoxy applied to the bonding surfaces on the bottom of the stator and PZT element. Figure 3 is a cross-sectioned view of the masked stator and PZT element placed on the stator within the centering sleeve. Figure 4 is a cross-sectioned view showing the addition of a silicone rubber pad placed on top of the PZT ring during bonding. A weight of 1.25 pounds was placed on top of the silicone rubber pad, before the unit was placed in the oven for bonding.



Figure 3. Cross Section of Bonding Setup



Figure 4. Cross Section Including Silicone Pad

This method worked well at creating good thin bonds. Measurements of cross-sectioned bonded stators showed the thickness of the epoxy bond to be about the same thickness of the sputtered gold plating itself (one to three microns). Although this method was very successful at building a lot of motors, the masking method was very tedious, and the centering system was very inflexible. The centering sleeve had to be made large enough to handle the PZT ring elements at their largest outside diameter (within the manufacturing tolerances). This meant that when the PZT elements were at the low end of the manufacturing tolerance, they would fit loosely within the centering fixture and be poorly centered.

#### Bonding Using O-ring for Centering Element and to Mask Stator

Another method for bonding PZT elements used an o-ring for both centering and masking. This fixturing consisted of a round Teflon platform, shim washers, a round brass weight, a silicone sponge rubber pad, and a center pin used to guide the weight down upon the rubber pad to load the element. Figure 5 is a cross-sectioned view of a ring being bonded using the fixture. Figure 6 is a close-up cross-sectioned view of the stator within the o-ring sitting on the shim within the counterbore of the Teflon platform. (The guide pin, sponge rubber pad, and brass weight are not shown.)

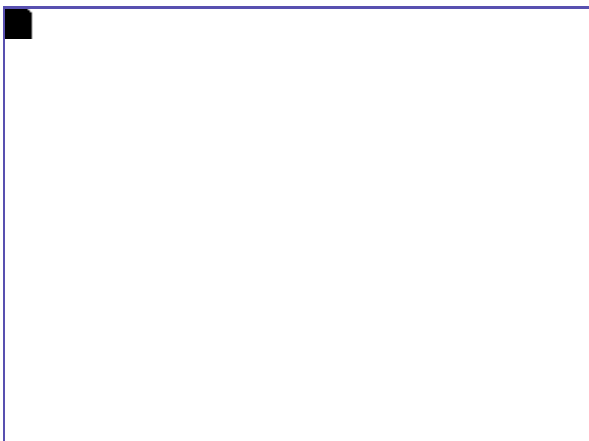


Figure 5. Cross Section of Stator Being Bonded

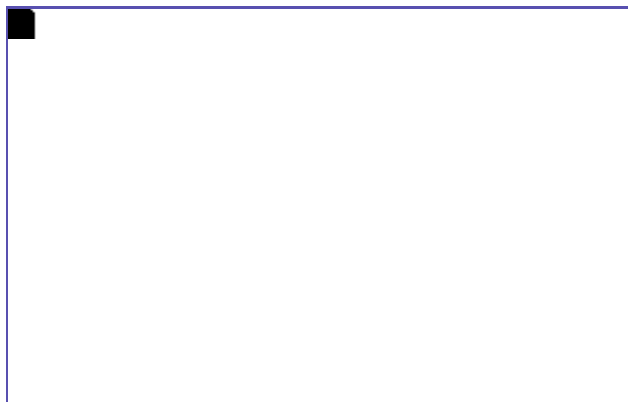


Figure 6. Close-up Cross Section of Parts in Fixture

The o-ring, when placed onto the outside diameter of the stator, seals the teeth of the stator from the epoxy and forms a circular ring for centering the element. Changing the stackup of shim washers under the stator raises or lowers the bonding surface of the stator with respect to the o-ring. This changes the clearance between the PZT element and the o-ring, to accommodate the size of the element. Using this method allows the PZT element to be accurately centered with the stator as long as the outside diameter of the element is kept within its tolerances to be as big as the stator or slightly larger. Figures 7 and 8 are close-up cross-sectional views of the change in clearance between element and o-ring with a change in the shim washers below the stator.



Figure 7. Large Clearance Between O-ring and Element



Figure 8. Small Clearance Between O-ring and Element

The o-rings were ultrasonically cleaned with Dirl Lum to eliminate any mold release on the surface of the o-ring from contaminating the epoxy bond joint. Viton and Buna-N o-rings were cleaned and tested by slipping the o-ring onto a 0.313-inch diameter steel rod and then applying the epoxy against the rod and o-ring interface. As was hoped, the epoxy did not bond well to either o-ring material, and the Viton was chosen because it separated more easily from the epoxy to steel interface. The delrin posts from the previous bonding fixture were used to hold the stator while slipping the o-ring onto the stator. The electrostatic charges on the o-ring made it susceptible to gathering any dust particles and needed to be kept very clean to prevent contaminating the bond joint. The delrin posts and sleeves from the previous bonding fixture were also modified to make it much easier to apply the mask to the top of the element. The Kapton tape mask was placed onto the post sticky side up, the sleeve was then placed onto the post, and the element was dropped onto the mask with tweezers and centered by the sleeve. Although the stators bonded using this method looked very good, there were areas that didn't bond, and the elements came loose from the stators. Based on these failures, and the need to bond motors for the CX4 development group, this method was abandoned, and the elements were bonded by simply using a strip of Kapton tape to mask and hold down the element. Although more investigation is needed to be sure, it is believed that the joints failed simply because not enough epoxy was applied to the bond surface. In order to minimize the amount of epoxy used, a smaller than typical amount was applied. It is believed

that the thinning of the epoxy in the oven allowed too much to flow out and "starved" the bonding joint in some places and that the clean dry o-rings may have wicked away some of the epoxy.

### Bonding Using Kapton Tape to Mask and Hold Down Element

Due to the problems with the motors bonded with the o-ring fixture, the CX4 group of motors needed to be bonded another way. Instead of going back to the previous delrin fixturing, a method was tried where a long piece of Kapton tape was placed across the top of the element to mask the element and hold it in place for bonding. A machined round brass weight used for the o-ring bonding method was used as a base. Two strips of Kapton tape were used to hold down a third piece of Kapton tape placed sticky side up on the brass base. The stator was then placed teeth down onto the sticky side of the tape attached to the base. Using tweezers, the PZT ring element was then dropped with the segmented side down onto the sticky side of another piece of Kapton tape. The bonding surfaces of the element and the stator were then brush-coated with the epoxy. The element was aligned by eye under a microscope and then placed down onto the stator. The top piece of Kapton tape was pulled tight and attached to the brass base, to hold the element in place while masking the top side of the element. The brass weight with the stator and element attached was then turned upside down and placed with the brass on top, and the stator and element sitting on a ground flat surface placed in the oven. With this method, the slots between the teeth of the stator were not masked, because when it was turned over and placed into the oven, gravity acted to keep the epoxy from filling the slots between the teeth. More epoxy was used with this method than the o-ring method, and all of the bonds were good. This observation led to the belief that the problems encountered with the o-ring method may have been due to a lack of enough epoxy. Although this method was easy to use and made good bonds, it wasn't easy to get good, consistent centering of the element to the stator. Five of the seven motors bonded this way were as well centered as the motors bonded using the previous methods. The other two were off by as much as 0.005 inch. Visually centering the element under the microscope is made difficult because the liquid epoxy blurs the edges of the stator and element.

### Metallic Bonding

#### Overview of Metallic Bonding

Silver diffusion bonding and solder bonding were investigated as metallic bonding methods for attaching PZT elements to stators. The performance advantages of a metallic bond are that the metals normally have less damping energy loss and higher strength than the epoxy bonds. Another key advantage of a metallic bond for weapons usage is the elimination of the long-term life concerns of the organic epoxy bond. A further advantage to the metallic bonds is that the process is much cleaner with regards to eliminating the need for masking off areas from epoxy. A disadvantage to metallic bonding is that some of the PZT ceramics will experience depoling when subjected to the elevated temperatures and/or clamping pressures required for a metallic bond. Diffusion bonding requires both elevated temperature and clamping pressure. Soldering requires elevated temperature and slight pressure to hold the parts together as the solder is reflowed. Some PZT ceramics such as EC-76 from the EDO Corporation have such a low Curie temperature (190 degrees Celsius) that they will depole under either the diffusion bonding or soldering environments. Testing showed that other PZT ceramics (with Curie temperatures above 300 degrees Celsius), such as the Fuji hard PZT used on the CX4 group of motors and EC-67 PZT from EDO, survived the diffusion bonding and soldering environments without depoling. These ceramics were subjected to a temperature, pressure, and time environment of 200 degrees Celsius and 850 pounds per square inch for 30 minutes to simulate diffusion bonding. They were then subjected to an environment of 260 degrees Celsius and 50 pounds per square inch for 3 minutes to simulate soldering.

Before and after measurements of the piezoelectric strain coefficients and capacitance proved that these temperatures and pressures did not affect the poling of these ceramics.

### Beginning Development of Silver Diffusion Bonding

Samples of PZT ceramic elements were diffusion bonded to 8-mm stators in 1995. These samples were sputter coated with an adhesion layer of chrome and then about 3.5 microns of silver. They were placed in a light vacuum environment of less than 0.1 Torr and subjected to temperatures and pressures from 250 to 350 degrees Celsius and 4000-6000 pounds per square inch for times varying from 30 to 60 minutes. These bonded stators were then cross-sectioned. The bonding process made very good bonds at the high contact points, but did not bond elsewhere. It was clear from this experiment that a good silver diffusion bond was possible, but the surfaces would need to be flatter.

In 1997 an experiment was run using milder temperatures and pressures to eliminate depoling of the PZT ceramic. 17-mm disks of 0.022-inch thick PZT ceramic and 0.008-inch thick stainless steel were lapped and their surface flatness measured with a profilometer to be less than 0.5 micron. The PZT and stainless steel surfaces were sputter coated with a chrome adhesion layer and then 3.5 microns of silver. Five samples were bonded as shown in Table 1. All samples were bonded at 200 degrees Celsius.

Table 1. Silver Diffusion Bonding Experiment

Sample Number	Configuration	Load (pounds/square inch)	Time (minutes)
1	PZT bonded to PZT	1421	15
2	PZT bonded to metal	568	15
3	PZT bonded to metal	284	30
4	PZT bonded to metal	853	15
5	PZT bonded to metal	853	30

All five samples were ultrasonically tested, and all showed good-looking consistent bonds in the ultrasonic imaging. Samples one and five had the best looking bonds. One probable explanation for the apparent higher bond quality of sample number one is that the lapping process was able to get the PZT more flat than the stainless steel, and it consists of two PZT disks bonded together. Another explanation is the higher clamping pressure used. The probable explanation for the apparent high bond quality of the last sample is that the fixturing used to apply the clamping pressure to these disks was lapped before sample number five was bonded. This probably resulted in a more consistent loading of the sample.

Both silver diffusion bonding experiments demonstrated the ability to create good metallic bonds wherever good contact is obtained between the two surfaces. They also demonstrated how critical the flatness of the samples and the fixturing is to the ability to obtain good bonding throughout the sample. With a very flat sample, the second experiment and the environment testing suggest that good silver diffusion bonds could be developed at low enough temperatures and clamping pressures to prevent

depoling of the PZT ceramic.

### Beginning Development of Tin Lead Soldering

An evaluation was performed to determine the feasibility of tin lead soldering the PZT elements to the stator. An advantage of soldering is that the samples do not need to be lapped as flat as with diffusion bonding. In order to get a bond thickness comparable to the thickness of the epoxy bonds, a method was needed for applying a very thin layer of solder. Tin lead solder plating was chosen as the method for applying such a thin solder layer. Samples were made of both stainless steel and phosphor bronze stators. The stators were plated with about 50-100 microinches of nickel and then about 100-300 microinches of eutectic tin lead solder. The solder was not reflowed after plating. Two types of metal coatings sputtered on top of the gold were tried to provide a good interface layer for tin lead soldering. These coatings consisted of either nickel or platinum. The platinum coating was sputtered with thin adhesion layer coatings of chrome and then gold before the platinum. The nickel coating was sputtered with a thin adhesion layer of chrome before the nickel. The water-soluble flux used was Superior Supersafe Number 30 Flux by the Superior Flux and Manufacturing Company, Cleveland, Ohio. The flux was applied to the plated solder on the bottom of the stator and to the nickel or platinum metalization on the PZT element. The element was held against the stator by sandwiching it in between the stator to be bonded and another stator and lightly clamping the parts together with a nut and screw through the center hole of both stators. The stators were then placed on an alumina substrate with the plated solder on top (to allow gravity to help the plated solder to contact the metalization on the PZT ring). A Sikama Falcon 5X5 Conductive Reflow system by Sikama International Inc. Santa Barbara, CA, was used to reflow the solder. This system is a conductive belt reflow system with five separate settable heating zones. This allows the part temperature to be ramped up and then ramped back down. The temperature settings, in degrees Celsius from the beginning of the cycle to the end, were 92, 256, 210, 240, and 186. The 256-degree second stage was set up so high to supply the most preheat, before settling into the next two stages for reflowing the solder. The belt speed was set at 12 inches per minute. The temperatures used for reflow are based on a melting temperature of eutectic tin lead solder of 183 degrees Celsius and a rule of thumb that to promote good wetting of the solder joint, the reflow temperature should be about 56 degrees Celsius above the melting temperature.<sup>1</sup> Also, the melting point of the solder is at this temperature only if the plating composition is exactly eutectic. Any slight variation in plating composition will raise the melting temperature. Six samples were soldered, three phosphor bronze and three stainless steel stators. The elements consisted of three platinum and three nickel coated samples. All six samples were cross-sectioned after soldering. For a preliminary evaluation, the results were promising. There didn't seem to be any significant difference in bond quality due to the metalization or the stator material used. The solder thickness was about the same thickness as the epoxy bond thickness. The solder appeared to have wet the metalization very well. Two of the cross-sectioned samples appeared to be free of any voids in the solder, while the rest had at least a few voids. Although it would be very difficult to eliminate all voids from this type of solder bond, the size and number of voids allowable in the bond would need to be evaluated, with possible process changes to minimize voids. Figures 9 and 10 are pictures of typical cross-sectioned solder joints created in this evaluation.



Figure 9. Soldered PZT Element to Stator Without Voids in Solder

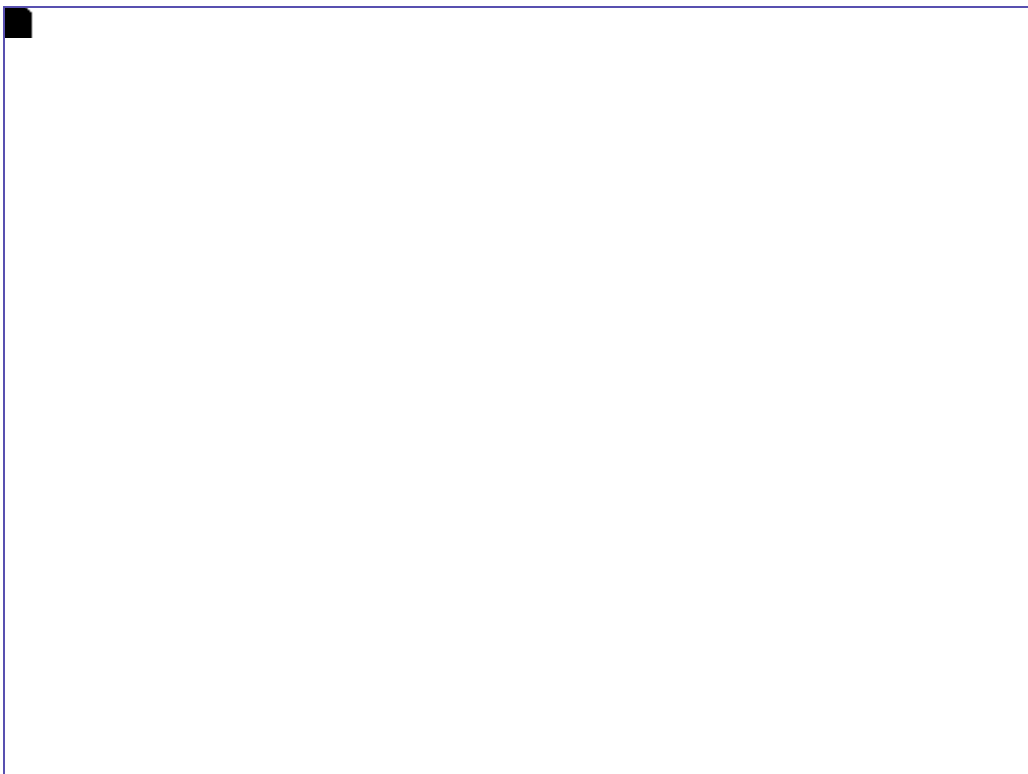


Figure 10. Soldered PZT Element to Stator With Voids in Solder

Accomplishments

Methods were developed for epoxy bonding the PZT ceramic elements to the stators of 8-mm piezoelectric motors. These methods, and the epoxy used, allowed the bond thickness to be about the same as the thickness of the sputtered metalization. These thin bonds minimize the energy losses due to damping in the vibration used to drive the motors. Evaluations were performed of metallic bonds made by silver diffusion bonding and tin lead soldering. Both methods were promising first steps toward creating stronger bonds with less damping energy losses and with better long-term life characteristics than epoxy.

#### Future Work

Work in the future should focus on the two methods of metallic bonding and methods for making the bonding process easier to manufacture. Alignment and fixturing methods would need to be addressed for bonding in a production environment. Performance testing to compare the operation of motors made using epoxy and metallic bonds should be done.

#### Reference

1H. Manko, *Solders and Soldering*, McGraw-Hill, New York, NY, pp. 53-56, 1979.

#### Appendix A

##### Bonding Process Instructions for Using Delrin Post and Sleeve Fixture

##### USM Motor Bond Process

The following steps are used in the preparation and bonding of components that comprise a stator assembly for the piezoelectric motor.

#### Bond Process

##### 1. Stator Preparation (Stainless Steel)

- 1.
2. Cleaning process:

- 1.

## 2. Ultra-Sonic Aqueous Cleaning:

1. Mix Dirl Lum at 20 to 30 grams per liter of DI (deionized) water.
2. Use a heated tank set to 45-50 degrees C.
3. Arrange parts in a non-metallic holder that will keep the parts from touching each other during the cleaning process.
4. Place parts into the tank and ultra-sonically clean for 5-10 minutes.
5. Remove parts from the detergent bath and rinse in DI water to remove the bulk of the detergent.
6. Rinse in ultra-sonic cascade rinse of DI water dwelling 15-30 seconds in each well.
7. Gently blow dry the parts using dry nitrogen or clean, filtered dry air.
8. Do not handle clean parts with bare hands.

### • Plasma Cleaning:

1. Place parts to be cleaned onto a glass mesh (shelf) in the plasma chamber. Suspend parts, that can be hung on wire, in the center of the chamber. This will allow the flow inside the chamber to move across the entire part.
2. Select reaction gas, Zero Air or Oxygen for stainless steel stators, and assure that the valve at the bottle is opened all the way.
3. Turn the reaction gas on. Adjust the regulator for a flow of approximately 7 psi.
4. Turn on the vacuum. Pull vacuum on the chamber to .2 torr or less.
5. Adjust the reaction gas **flow control** for a reading of .8 torr on the vacuum gage.
6. Set the RF power level to **50 watts**.
7. Wait 10 seconds to allow the gas to enter the chamber then turn on the **RF power**.
8. Adjust "tuning" to achieve a minimum **Reflected** power reading.
9. Cycle for 15 minutes.
10. Turn off the RF power.
11. Turn off the reaction gas.
12. Wait 15 seconds to allow the vacuum to remove the reaction gases.
13. Turn off the vacuum (not the pump).
- 14.
15. Slowly purge the chamber.
- 16.
17. Do not handle the clean parts with bare hands. Place them in a plasma cleaned container or wrap in plasma cleaned foil.

### • Fixture Assembly:

1. In a clean bench, invert a stator (teeth down) and assemble it to a bonding post using a screw to hold it firmly to the post.
2. Using Kapton tape, wrap the stator and post to mask the spaces between the teeth. Apply two layers of tape. The tape should be positioned just high enough to cover the spaces. Press the tape against the stator to remove any gaps or bubbles.
3. Make sure that the tape is not allowed to come in contact with the bond surface. The tape adhesive will contaminate the surface and ruin the bond.
4. Remove the screw from the top and mask the inside area of the stator with Kapton tape.
5. Place the outer fixture cylinder over the stator and post. Gently slide it down into place. Use a vacuum tool to remove any debris that may be on the bonding surface of the stator.
6. Repeat until all of the stators are on the bond fixture. Leave the assemblies in the clean bench.

- PZT Element Preparation:

1. Using a microscope, visually inspect the bonding surface for raised metal such as comets, scratches, and etc. Carefully remove any contaminant using a clean knife or tweezers. Avoid scratching the surface as this only creates more raised metal areas.
2. In a clean bench, soak the element in **high purity** acetone for 2 minutes, rinse with **high purity** isopropyl alcohol. Place on a lint free wipe to allow evaporation of the alcohol.
3. Using Kapton tape, carefully mask the area for wire attachment.
4. Make sure that the tape does not contact the bonding surface of the element. The adhesive on the tape will contaminate the surface and ruin the bond in this area.
5. Trim the Kapton from the outer diameter to flush with the edge. Leave a small Kapton tab on the inside diameter for handling during epoxy application.
6. Place prepared elements in a clean container or on a lint free wipe inside the clean bench.

- Epoxy Mix:

1. Carefully measure the appropriate amount of each component into one mixing cup as follows:  
Ciba Geigy Araldite epoxy

1. CY 179 10 parts by weight (pbw)
2. HY 906 13 pbw
3. DY 062 0.1 pbw

- Mix by hand for 2 minutes making sure to incorporate all of the components.
- Deaerate the epoxy. Place the mixture into a vacuum chamber and pull a vacuum until the foamy bubbles have collapsed, continue under vacuum for another 5 minutes. You may have to regulate the vacuum throttle to keep the mixture from boiling over.
- Close the vacuum valve and **Slowly** (to prevent tipping of the container) release the vacuum in the chamber.

- 

- Epoxy Application

1. Using a small clean brush, apply epoxy to the bond area on one of the stators. Use gentle strokes to remove any air bubbles from the surface.
2. Using the reflection of the scope light, inspect for debris or air bubbles in the epoxy. If noted, use another brush to remove the debris, then reapply epoxy to the area.
3. With tweezers, grasp the tape tab and pick up an element to be bonded. Apply a thin layer of epoxy to the bonding surface of the element.
4. Examine the applied epoxy for bubbles or debris. Use a brush to remove any suspects and reapply epoxy to the element.
5. Holding the element by the tape tab, turn it over and gently place it onto the stator. If required, maintain proper element alignment to the stator.
6. Once the element has come into contact with the stator, do not remove or disturb it. This will cause air to become trapped between the surfaces and will create voids in the bond layer. If this does happen, reapply epoxy to both surfaces and reassemble.
7. Repeat this process until all of the stators and elements are complete.

- Epoxy Cure

1. Place a red rubber pad on top of each element. Assure that the pad fits within the inside diameter

of the outer cylinder of the fixture and rests fully on top of the element.

2. Place the fixture on a flat rigid plate in an **ambient** oven.
3. Center a flat five-pound weight on top of the entire fixture coming to rest on the red rubber pads.
4. Set temperature controls to 125 degrees C.
5. Cure at 125 C for 12 hours minimum.
6. Leave the assemblies in the oven until it has cooled to ambient (2-3 hours). This will avoid thermal shock to the elements.

- Post Bond Assembly Clean-up

1. Carefully remove the stator assembly from the bond fixture. Twist the inner post to break the excess epoxy prior to lifting off the outer cylinder of the fixture. This lessens the chipping on the edge of PZT element.
2. Remove the masking tape.
3. Use a knife to remove large excess epoxy deposits from the o.d. of the stator.
4. Use a Dremel tool with a mini point (silicon carbide impregnated rubber) to remove any remaining epoxy and tape adhesive. This same tool can be used on the inside diameter of the stator if needed.
5. Rinse the Stator assembly with alcohol and gently wipe it dry or blow dry with nitrogen.

## Appendix B

### Bonding Process Instructions for Using O-ring Fixture

#### Bonding PZT Elements to Stators Using O-ring Fixture

#### Problems with Bonding of CX4 Motors

The group of piezoelectric motors known as the CX4 motors experienced some form of bonding problem. After the bonding process, the stator and element looked very good. The bond line between the stator and element was very thin, with good contact between the stator and element. The problem was that there were large areas that were unbonded, even though the ring was in intimate contact with the stator in these areas. At this point, further investigation will need to be done to determine the cause of these bonding problems, and whether or not these problems are due to changes created by using the new o-ring bonding process.

#### Overview of Changes to Bonding Process

This is a new process for bonding a PZT element to an 8-mm piezoelectric motor stator using an o-ring bonding fixture. This method makes use of a 7-mm inside diameter by 2-mm wide Viton o-ring which fits around the outside diameter of the stator. The o-ring acts as an outside collar to center the element while sealing the outside of the stator and preventing epoxy from getting on the teeth.

The Teflon base of the bonding fixture should have the right stackup of shim washers to position the bottom of the stator at the right height with respect to the o-ring. If the shim stackup is correct, there will be about 0.003 inches total movement of the element within the o-ring (for a concentricity of plus or minus 0.0015). If the bottom of the stator sits too high with respect to the o-ring, there will be too much clearance, and the element will not be centered precisely. If the bottom of the stator sits too low with respect to the o-ring, the element will drag on the inside of the o-ring and not sit flatly on the bonding surface at the bottom of the stator.

To place the o-ring on the stator, the stator is attached by a screw to the delrin post, and the o-ring is pushed up the post and onto the stator. As the o-ring is pushed up the delrin post, it gathers up any microscopic debris that lies on the post. Because of this, the delrin post is inspected along its length and wiped down with an alcohol soaked wipe if necessary. To prevent contamination from any debris that is statically clinging to gloves, the o-ring is not touched with the gloves, and a delrin sleeve is used to push the o-ring up onto the stator.

The stator is then set over the counterbore on the Teflon base and tweezers are used to push against the center of the stator and seat it against the shim washers. At this point, the o-ring will still have a lot of twist in it that causes it to roll in, as the center of the stator is pushed down with tweezers. To relax this twist, the center of the stator is held down with one set of tweezers, while a second pair of tweezers is used to "bump" it off of contact with the stator in places all around the stator. When doing this, care must be taken to ensure that the bonding surface on the bottom of the stator is not scratched.

A fixture was made to make masking the top of the element with Kapton tape easier. A punch set is used to make a washer shaped piece of Kapton tape with an outside diameter of 5/16 inch and inside diameter of 3/16 inch. This washer shaped mask is then placed sticky side up on a delrin post and a delrin sleeve is lowered over the post. The element is then placed within the sleeve onto the Kapton tape mask.

Each Teflon base has its own brass weight used to apply pressure during bonding. A 1/16-inch thick washer shaped piece of silicone sponge rubber is placed on top of the ring, and the brass weight slides down a 0.060-inch removable center pin and onto the sponge rubber.

## Step by Step Bonding Instructions:

### Bond Process

1. Ultrasonic Aqueous Cleaning of Stator (Stainless Steel)
  1. Mix Dirl Lum at 20 to 30 grams per liter of DI (deionized) water.
  2. Use a heated tank set to 45-50 degrees C.
  3. Arrange parts in a non-metallic holder that will keep the parts from touching each other during the

cleaning process.

4. Place parts into the tank and ultra-sonically clean for 5-10 minutes.
5. Remove parts from the detergent bath and rinse in flowing DI water to remove the bulk of the detergent.
6. Rinse in ultrasonic cascade rinse of 115°F DI water dwelling 15-30 seconds in each of three tanks.
7. Gently blow dry the parts using dry nitrogen or clean, filtered dry air.
8. Dry in nitrogen purged, HEPA filtered convection oven set at 220°F for 15 minutes minimum.
9. Do not handle clean parts with bare hands.

- Plasma Cleaning of Stator (Stainless Steel):

1. Place parts to be cleaned onto a glass mesh (shelf) in the plasma chamber. Suspend parts, that can be hung on wire, in the center of the chamber. This will allow the flow inside the chamber to move across the entire part.
2. Select reaction gas, Zero Air or Oxygen for stainless steel stators, and assure that the valve at the bottle is opened all the way.
3. Turn the reaction gas on. Adjust the regulator for a flow of approximately 7 psi.
4. Turn on the vacuum pump and power on switches. Set the RF power level to 50 watts.
5. Press the start button.
6. As the plasma chamber begins to glow, adjust "tuning" to achieve a minimum reflected power reading on the status display readout.
7. Cycle for 15 minutes.
8. Press the stop button.
9. Turn off the vacuum pump and power.
- 10.
11. Do not handle the clean parts with bare hands. Place them in a plasma cleaned container or wrap in plasma cleaned foil.

- Stator Preparation:

1. Clean o-rings using the same processes performed in section 1 above. Handle o-rings only with clean tweezers, and seal o-rings in nylon bag.
2. In a clean bench, inspect the length of a delrin post and the bore of the delrin sleeve for any debris, and wipe down with an isopropyl alcohol soaked lint free wipe if necessary.
3. With tweezers, hold the delrin post on its end, with the tapered end up.
4. Pick up an o-ring with tweezers and drop onto the tapered end of the delrin post and use the delrin sleeve to push the o-ring about  $\frac{3}{4}$  the way down the delrin post.
5. Invert a stator (teeth down) and assemble it to a delrin post using a screw to hold it firmly to the post. Care must be taken to prevent the screwdriver from slipping and scratching the bond surface.
6. Using the delrin sleeve, push the o-ring up onto the stator.
7. Mask off the web area of the stator with a small washer shaped piece of Kapton tape. Make sure that the tape is not allowed to come in contact with the bond surface. The tape adhesive will contaminate the surface and ruin the bond.
8. Carefully remove the screw from the delrin post, and touching the o-ring only at the outer diameter, lift the stator off of the delrin post.
- 9.
10. Set the stator over the counterbore on the Teflon base and press with tweezers on the center of the stator until it seats against the shim washers.

11. Remove the twist out of the o-ring by holding down on the center of the stator with one set of tweezers while moving around the stator with another pair of tweezers, and "bumping" the o-ring off of contact with the stator. "Bump" the o-ring by pushing against the inside diameter of the o-ring with the point of the tweezers, being careful not to scratch the bonding surface.
12. Check that the twist has been removed from the o-ring by watching to see if it rolls inward when pushing down on the center of the stator with a pair of tweezers.
13. Using a microscope, visually inspect the bonding surface for raised metal such as comets and scratches. Carefully remove any contaminant using a clean knife or tweezers, or dry brush. Avoid scratching the surface as this only creates more raised metal areas. If the bonding surface has any raised metal, do not bond to the stator.

- PZT Element Preparation:

1. In a clean bench, soak the element in **high purity** acetone for 2 minutes, rinse with **high purity** isopropyl alcohol. Place on a lint free wipe to allow evaporation of the alcohol.
2. A special delrin post and delrin sleeve are used for aligning the Kapton tape used to mask off the top of the element. These pieces are marked with notches cut around the circumference. The delrin sleeve has two notches, with the bottom of the delrin sleeve being the end with the widest notch. The delrin post is wrapped with Kapton tape to fit tightly and off center within the sleeve. Place the sleeve all the way down onto the delrin post and position the post and sleeve such that the zero clearance area between sleeve and post is at the six o'clock position. Remove the sleeve.
3. Place a washer shaped piece of Kapton tape sticky side up on the delrin post. Put the sleeve back on the post, but do not push it all the way down.
4. Position the element on a clean lint free wipe with the critical area to be masked on the bottom at the six o'clock position.
5. Pick up the element with tweezers and position it onto the Kapton tape on the delrin post, by lining up the areas at the six o'clock position and then dropping the ring onto the tape.
6. Carefully push the sleeve down all the way, centering up the element on the Kapton tape. Very carefully touch spots around the element with tweezers to make sure it is in contact with the Kapton tape.
7. Lift off the delrin sleeve and carefully remove the masked element from the delrin post by sliding a scalpel blade between the Kapton tape and the delrin post. Work the scalpel around the circumference of the post.
8. Place prepared elements in a clean container or on a lint free wipe inside the clean bench.

- Epoxy Mix:

1. Carefully measure the appropriate amount of each component into one mixing cup as follows:  
Ciba Geigy Araldite epoxy

1. CY 179 10 parts by weight (pbw)
2. HY 906 13 pbw
3. DY 062 0.1 pbw

- Mix by hand for 2 minutes making sure to incorporate all of the components.
- Deaerate the epoxy. Place the mixture into a vacuum chamber and pull a vacuum until the foamy bubbles have collapsed, continue under vacuum for another 5 minutes. You may have to regulate the vacuum throttle to keep the mixture from boiling over.
- Close the vacuum valve and **Slowly** (to prevent tipping of the container) release the vacuum in the chamber.

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- Epoxy Application

1. Using a small clean brush, apply epoxy to the bond area on one of the stators. Use gentle strokes to remove any air bubbles from the surface.
2. Using the reflection of the scope light, inspect for debris or air bubbles in the epoxy. If noted, use another brush to remove the debris then reapply epoxy to the area.
3. With tweezers, grasp the tape tab and pick up an element to be bonded. Apply a thin layer of epoxy to the bonding surface of the element.
4. Examine the applied epoxy for bubbles or debris. Use a brush to remove any suspects and reapply epoxy to the element.
5. Holding the element by the tape tab, turn it over and gently place it onto the stator. If required, maintain proper element alignment to the stator.
6. Verify that there is a slight clearance between the o-ring and the outside diameter of the element by bumping the element and looking for a very slight side to side and up and down movement of the element within the o-ring.
7. Once the element has come into contact with the stator, do not remove it. This may cause air to become trapped between the surfaces and create voids in the bond layer. If this does happen, reapply epoxy to both surfaces and reassemble.
8. Repeat this process until all of the stators and elements are complete.

- Epoxy Cure

1. Place a 1/16-inch washer shaped piece of silicone sponge rubber on top of each element. Assure that the pad fits within the inside diameter of the o-ring and rests fully on top of the element.
2. Insert the 0.060-inch center pin into the Teflon base.
3. Place the fixture on a flat rigid plate in an **ambient** oven.
4. Carefully slide the brass weight down the center pin and onto the sponge rubber washer.
5. Set temperature controls to 125 degrees C.
6. Cure at 125 C for 12 hours minimum.
7. Leave the assemblies in the oven until it has cooled to ambient (2-3 hours). This will avoid thermal shock to the elements.

- Post Bond Assembly Clean-up

1. Carefully remove the stator assembly from the bond fixture.
2. Assemble the stator back onto a delrin post using a screw to hold it firmly to the post, and roll the o-ring back down the post to remove it from the stator. Discard the used o-ring.
3. Remove the Kapton tape that masks off the top of the element by using a **sharp** scalpel to make a careful slit upward through the Kapton tape that overhangs the inside diameter of the stator and peeling it around the element.
4. Remove the Kapton tape from the center of the stator.
5. Use a Dremel tool with a mini point (silicon carbide impregnated rubber) to remove any remaining epoxy and tape adhesive if necessary.
6. Rinse the Stator assembly with alcohol and gently wipe it dry or blow dry with nitrogen.

## Appendix C

### Tin Lead Solder Plating Process Instructions

#### Piezo Electric Motor Stators

##### Service Requested:

Nickel and Tin/Lead Plate parts. Requires 0.000050 to 0.000100 inches Nickel and .000100 to .000300 inches Tin/Lead.

Area of stainless steel part = 0.243 sq.in. x 6 = 1.458 sq.in

Area of bronze part = 0.355 sq.in. x 6 = 2.130 sq. in.

For the stainless steel version.....

Process per specification with the exception of substituting Tin/Lead for the Tin plating in paragraph 6.1.10.

Sulfamate plate to a target thickness of 0.000075 inch at a current density of approximately 20ASF (0.034 amps per part).

Amp-min per tube = 0.170

(4 min and 11 seconds at recommended current density) \*\*\*\*\*

Tin-Lead plate to a target thickness of .000200 inches at a current density of approximately 20 ASF (0.034 amps per part).

Solution temperature shall be maintained at 75°to 85°F.

Amp-min per tube = 0.189

(5 min and 35 seconds at recommended current density) \*\*\*\*\*

For the bronze version.....

Process per specification with the exception of adding a Wood's Nickel Strike and matte Sulfamate Nickel plate prior to tin/lead plating in para 6.11.

Wood's nickel strike for 20 to 30 seconds at 3 volts.

Sulfamate plate to a target thickness of 0.000075 inch at a current density of approximately 20ASF (0.049 amps per part).

Amp-min per tube = 0.241  
(5 min and 1 seconds at recommended current density) \*\*\*\*\*

Tin-Lead plate to a target thickness of .000200 inches at a current density of approximately 20 ASF (0.049 amps per part).

Amp-min per tube = 0.276  
(5 min and 35 seconds at recommended current density) \*\*\*\*\*

\*\*\*\*\* Current needs to be increased to allow for added area of wire and hooks used

Additional current = surface area of wire, clips etc. (sq.in.) x 0.139