

APPLICATION NOTES

THUNDER®

Thunder is a revolutionary device that is a member of a family of products known as "smart" materials. These materials are most commonly used in actuators, sensors, and acoustic sound generators. Based on a NASA invention and only commercially available through FACE International Corporation, Thunder is a unique, extremely rugged and highly adaptable member of the "smart" materials group of products. The name Thunder is an acronym for Thin Layer Unimorph Ferroelectric Driver and Sensor. This means that Thunder is a ferroelectric device made of multiple layers of material, typically stainless steel, aluminum and PZT piezoceramic. The individual material layers are held together in a "sandwich-like" package using a NASA patented high temperature polyimide adhesive called LaRC™-SI. The bonding strength of the adhesive induces a "pre-stress or pre-load" in the device and enables Thunder to have exceptional ruggedness and performance capability.

SUMMARY OF PIEZOELECTRICITY

PZT Piezoceramic and piezoelectricity

Piezoelectricity is derived from a Greek word that means "pressure electricity." This describes a phenomenon that occurs in a certain class of naturally occurring crystalline materials such as quartz, Rochelle salt and tourmaline. Piezoelectricity simply means that these materials change their geometry or dimensions when an electrical charge (voltage) is applied to them, and conversely, they produce an electrical charge (voltage) when mechanical pressure is applied to them. However, these materials exhibit such a small amount of this very useful behavior that other materials have been created with improved piezoelectric properties. Piezoelectric ceramics with improved piezoelectric properties are often made of polycrystalline ferroelectric materials such as BaTiO3 and Lead Zirconate Titanate (PZT).

Piezoceramic material is composed of randomly oriented crystals or grains, each having one or possibly a few domains. With the domain dipoles randomly oriented, the material is isotropic and does not exhibit the piezoelectric effect. By applying electrodes to the ceramic and a strong dc electric field (poling), the dipoles will tend to align themselves parallel to the direction of the electric field, so that the material will have a permanent residual polarization. The material is then considered to be anisotropic because of the increased number of aligned dipoles. The number of domains that can align their dipoles in ceramic materials such as piezoceramics is less than that found in single crystal materials, but enough of the dipoles do align to allow the material to become piezoelectric. After the poling process, the material has a residual polarization, which means the domains will proportionally increase their alignment with an applied voltage. The result is a change of the geometric dimensions (expansion, contraction) of the PZT material with an applied voltage.

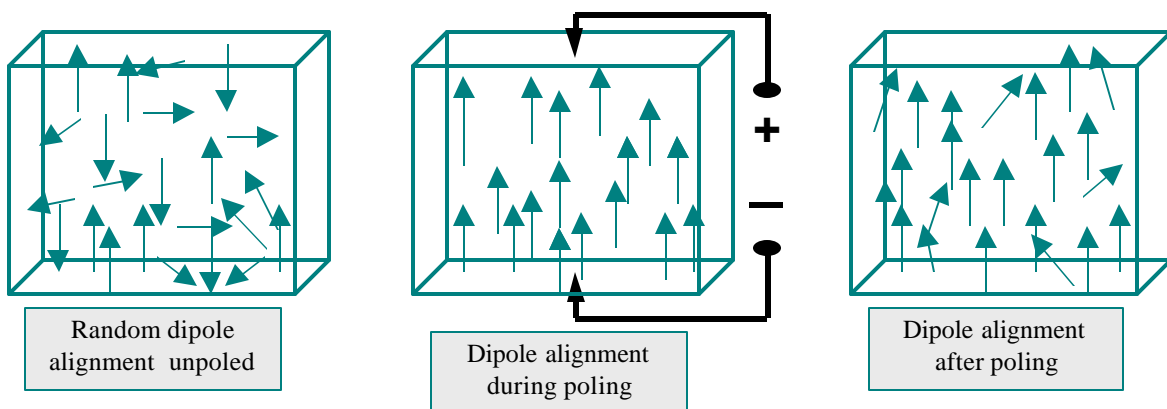


Figure 1. Dipole alignment in piezoelectric material

THUNDER CONSTRUCTION

At the heart of every Thunder device is a PZT piezoceramic wafer which enables Thunder to act as either a sensor or transmitter/actuator, or both. Recall that the piezoelectric theory states that when stressed mechanically, PZT generates an electric charge (sensor), and when a piezoceramic material is stressed electrically by a voltage, the result is a geometric change in dimension (actuator).

Manufacturing

Thunder is a layered composite in which individual materials are layered on top of each other to form a "sandwich." In a "standard" Thunder configuration found in Face's inventory of devices, the bottom layer is stainless steel followed by an adhesive, usually a NASA invention and trade marked material called LaRCTM-SI, PZT, more LaRCTM-SI and finally aluminum on top. The entire assembly is placed into an autoclave for processing. During the autoclave cycle the "sandwich" is heated and squeezed, allowed to cook and then cooled to room temperature. During the cool down cycle, the different individual materials' thermal coefficients of expansion rates begin to work against one another. However, the strength of the adhesive bond holds everything together. The result is a "pre-stress" internal to the individual layers that results in the characteristic bend or curvature of the final product.

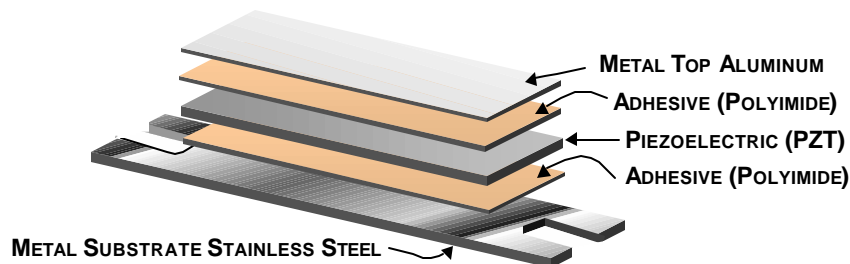


Figure 2. Thunder construction

What makes Thunder work?

Bonding. The bond between layers is essential because it makes possible the induced pre-stress. The adhesive, LaRCTM-SI, is a high temperature thermoplastic polyimide developed and patented by NASA's Langley Research Center. This bonding material holds the Thunder layers together despite the high internal stresses that are created during the manufacturing process.

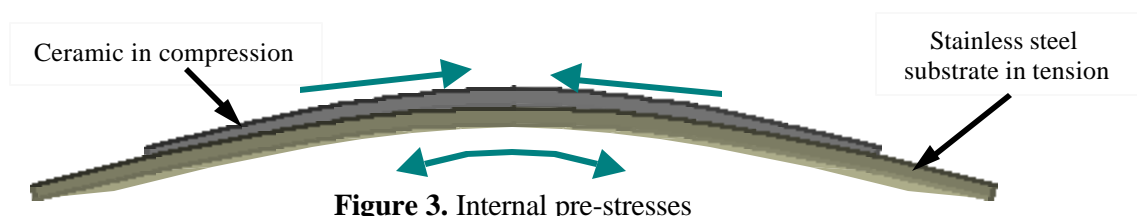


Figure 3. Internal pre-stresses

Internal stress state. As a result of the manufacturing process, the substrate, which is bonded to the piezoceramic, acts to keep the ceramic in compression and is itself continuously in tension. This pre-stress allows Thunder to be deflected far more than standard piezoceramics without cracking. The pre-stress also yields Thunder's unique, natural "pumping" motion. This motion occurs as the device flattens and then arches during polarity shifts of the applied voltage. This stress is one of the reasons why Thunder is constantly being considered as a solution for applications where traditional piezoceramic benders or stacks are limited. Incidentally, it is this high internal stress state that makes Thunder so robust.



Curvature. The characteristic bent shape of Thunder occurs from the device attempting to relieve its high internal stress state. Thunder's radius of curvature depends on the type and thickness of its constituent materials, the length of the device and the type of adhesive used. The curvature is a unique feature to Thunder and is predictable and repeatable. Though inherent in all Thunder devices, the curvature of some models is sometimes very slight and barely visible.

Extreme rugged design. As result of the manufacturing process, the basic piezoceramic material is strengthen and protected by the internal pre-stresses and through the metallic top and bottom layers. The metallic layers not only act as a suit of armor to protect the ceramic but also providing a place for electrical connection.

PRINCIPLES OF THUNDER OPERATION

Motion vs. applied voltage

When zero voltage is present at the electrodes of a standard Thunder device, the piezoceramic material is in a pre-stressed compressive state. At the same time, the substrate is actually in a tensile state as described previously.

When positive voltage is applied across the electrodes of a Thunder device, the piezoceramic is geometrically allowed to "shrink, " reducing the internal compression. This causes the stainless steel substrate to flatten and the Thunder to move downward.

Conversely, when negative voltage is applied across the electrodes of a Thunder device, the piezoceramic is electrically excited and geometrically "grows" in size. Since it is bonded to the stainless steel substrate, the substrate is made to arch to accommodate the ceramic's increased length. This causes Thunder to move upward.

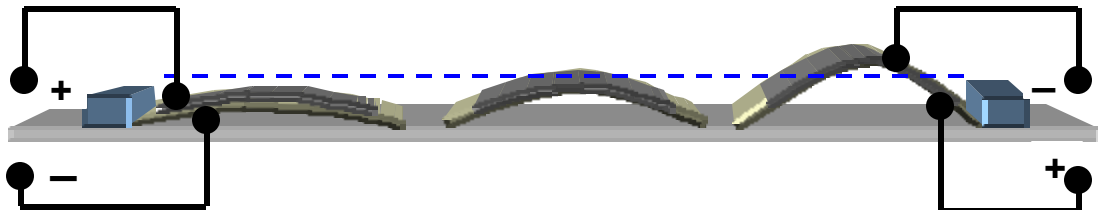


Figure 4. Thunder motion while simply supported

TYPICAL CONFIGURATIONS FOR PIEZO ACTUATORS

One of the exciting things about piezoceramic technology is that useable mechanical and electrical energy is generated from a lightweight, low power and versatile material. As an actuator, the mechanical deformation can perform work. This is done by using the natural movement of the ceramic to vibrate or move in step increments. These movements usually are accomplished by using the actuator as a simple bender, a simple beam or a multilayered stack.

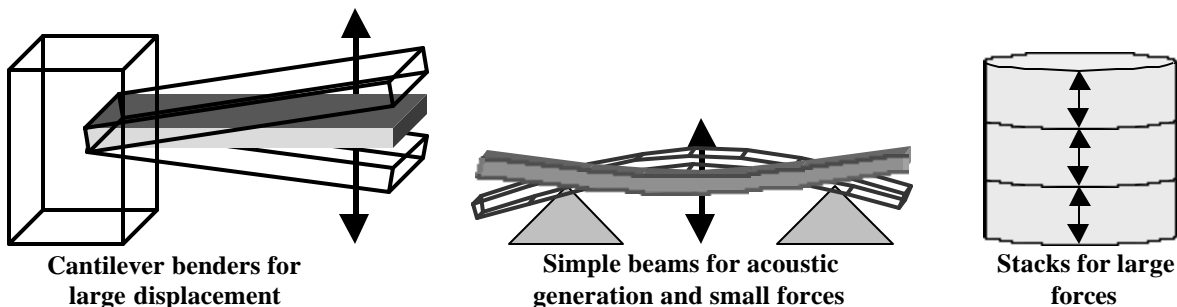


Figure 5. Typical piezo actuator configurations

Thunder configurations.

Face has designed several standard Thunder configurations and maintains these in inventory. There is one circular and five rectangular models that vary in dimensions from approximately 3"x 2" to 0.88"x0.38." Each piece has different component thicknesses and voltage limitations but is made of the same materials – stainless steel bottom, PZT and aluminum top. Rectangular pieces have tabs on either end with slots for mounting; the round piece has a small apron of stainless outside the ceramic circumference. Detailed specifications and performance is provided in other documents available from Face International.

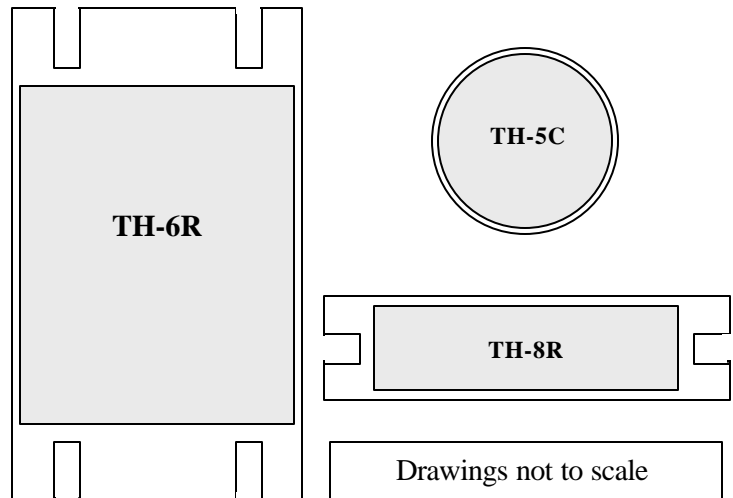


Figure 6. Basic Thunder configurations

DESIGN CONSIDERATIONS FOR THUNDER

Cantilever mounting.

When used in the cantilever position as a bender for applications in the fields of switching, flow control, positioning or pointing, Thunder actuators should be firmly clamped or fastened at one end using the tabs made in the substrate material. Slots in the tabs are not mandatory but are provided for ease of mounting. Avoid securing the device by means of the piezoceramic. As a rule of thumb, the aluminum top layer can be considered as the geometric limits of the piezoceramic. The extreme deflection capability of Thunder may cause stress at the mounting point, so be sure to secure or fasten Thunder at least .015 to .025 inches away from the edge of the ceramic.

Displacement measurements. Thunder deflection is measured in the cantilevered beam mount by placing a laser beam on the far edge of the ceramic, not the edge of the bottom substrate. This is because the length of the substrate can vary depending on customer needs. Naturally, a longer substrate will amplify the tip displacement; by measuring deflection from the edge of the ceramic, a true measurement of deflection is provided to the customer.

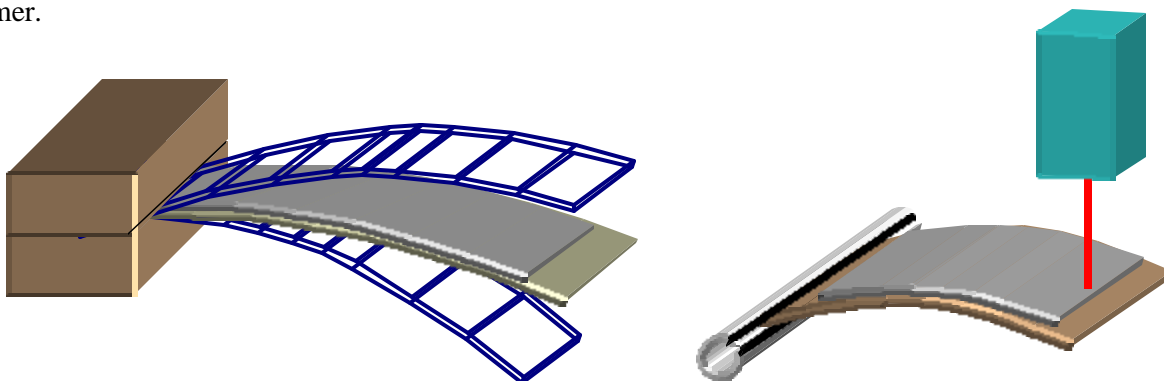


Figure 7. Cantilever mount and displacement measurements

Force. Cantilever mounts are not very effective for maximizing the ability to act against the weight or mass of an object. The strength of the beam in this configuration limits the amount of force that can be moved.

Simple Beam.

When used as a simple beam to generate force or create "pumping motion" for applications in flow control, positioning, vibration damping, or on-off control, Thunder actuators should be secured at both ends. One end should be completely fixed while the other end is free, or more free, to move. Rigidly fixing both ends of the Thunder device will seriously prevent the full use of its capabilities. As explained before, Thunder devices have a radius of curvature, and the larger the device, the larger the dome height or pre-stressed curvature. Due to this shape, the ends of the Thunder extend and retract, so it is important that at least one end be allowed to move. The amount of "pre-loading" on the fixed end can seriously reduce performance.

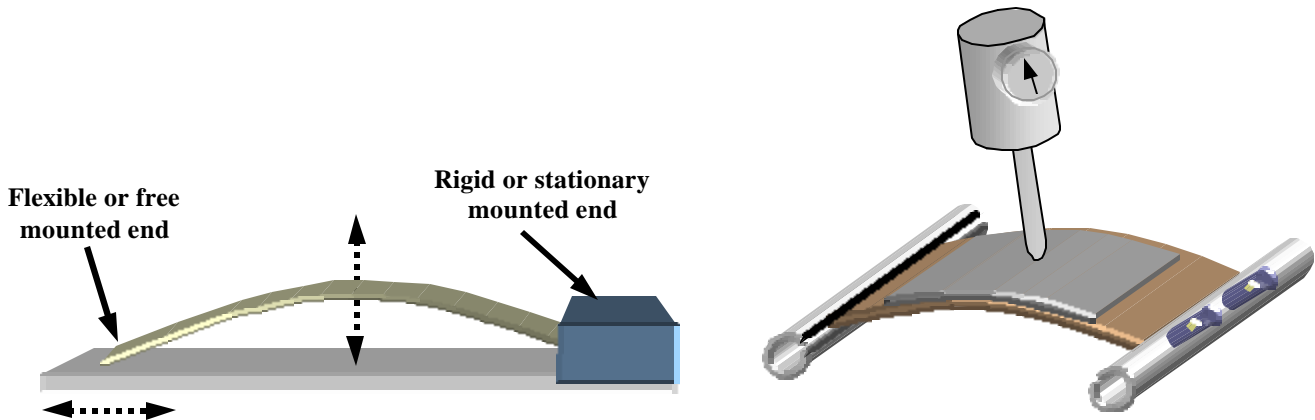


Figure 8. Simply supported mount and force measurement

Force measurement. Thunder force is measured in the simply supported mount by placing a force gage against the center of the Thunder element while it is energized. Force can be used in two ways. The up and down motion of the Thunder can be used to lift a weight or mass. The disadvantage is that the force is bearing on the ceramic and over time could reduce reliability. A second method is to use the force exerted by the change in effective length of the device. This method is better for the ceramic but the amount of displacement is much less than available with the up and down pumping motion of the device.

Additionally, a Thunder device will move farther and is "more powerful" when moving in the "flattened" or down direction than in the up direction. This occurs because the voltage limits are twice as large (e.g. 60 volts/mil of ceramic thickness instead of -30 volts/mil) for positively applied voltages.

Displacement measurement. Displacement is measured similarly to the cantilever mount except the laser beam is directed at the top of the Thunder arch, in the same location as the force gage. Data given in the specification tables are total movement from the maximum up position to the flattest position.

Thunder stack configurations

I want more force -- spoon configuration. In a simple multi-layer or "spoon" arrangement, the individual strength of each Thunder element within a stack is additive. In other words, if one Thunder can lift a 1 pound weight, then a stack of 5 Thunder elements would be capable of lifting 5 pounds. Naturally, this is not exactly proportional, but the rule of thumb will help when designing stacks for larger load requirements. This stacking method does not provide any additional displacement capability.

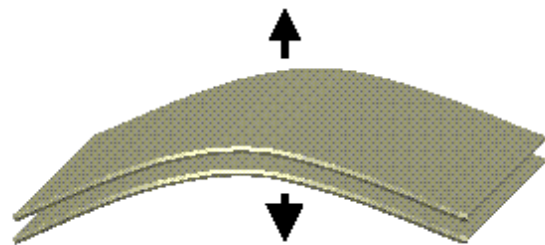


Figure 9. Spoon stack



Insulation. Be sure to take into consideration proper electrical insulation between devices when stacking Thunder elements. If the devices are kept far enough apart, an air-gap can be created that acts as an insulator. However, if a layer of material is required, the actuator will be more efficient if the material offers less friction, such as Teflon, by having a surface that will allow for the Thunder devices to slide against each other.

I want more displacement -- clamshell configuration. Another option is a "clamshell" arrangement, which allows for increases in displacement with essentially no change in force capabilities. This design is a natural for pumping, squeezing, gripping or switching applications. The rule of thumb for the stack arrangement is that the individual displacements of each Thunder element within a stack is additive. There is no change in force capabilities.

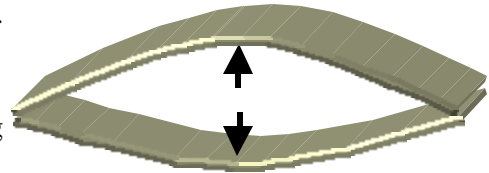


Figure 10. Clamshell stack

Insulation. Thunder used in clamshell applications may not require electrical insulation between the devices. This is because the devices will be contacting each other at the substrate only, thus sharing a common ground. However, the devices will be moving at the edges so a layer of material may be required to ensure a frictionless surface. Again a material like Teflon has a surface that will allow for the Thunder devices to slide against each other. Holding the two edges together in a mount to maximize movement without restricting motion is a significant aspect of this design.

APPLICATION ENGINEERING

How should I apply a load ?

When applying a load to the surface of the Thunder device, do not concentrate the majority of the load at any one point. It is preferred that the load be distributed evenly over as much of the Thunder surface as possible. Though Thunder is remarkably rugged, point loading can still cause potential problems to occur.

What if one Thunder device doesn't provide what I need?

If a Thunder device is unable to meet design requirements, individual Thunder element performance can be amplified through innovative design of several factors that influence performance. Face International can meet special needs in a number of different ways. For instance, the basic materials and processes used to make individual Thunder elements can be changed to modify performance. Or, because of Thunder's unique design and shape, multiple Thunder elements can be used to achieve the needed results. There are several stacking configurations that can be used to magnify certain performance characteristics.

Deflection and force measurements

Typically, piezoelectric bending actuator performance is specified in terms of its **free deflection** and **blocked force** capabilities. Free deflection refers to displacement at a given voltage level without any external load. For a given input voltage, blocked force refers to the force exerted at a specific point that prevents the actuator from moving. Additionally, **force and displacement measurements** are typically specified under quasi-static conditions. This means the actuator is operating well below its first resonant frequency. If an application requires the actuator to operate at higher frequencies, the output performance (i.e. force and displacement) of the device will need to be determined for that loading condition.

It is important to know that all of our performance data for Thunder is measured not calculated or estimated. This provides the customer with a good source for comparative data when using the device at customer locations.



POWERING AND DRIVING THUNDER

Voltage

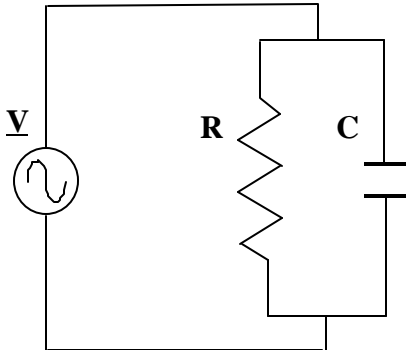
Like any piezoceramic device, Thunder does require high voltage to operate (up to several hundred volts peak to peak), but very low current (milliamps) for maximum performance as an actuator. Thunder has an advantage in deflection and force because of its ability to use larger amounts of voltage to perform work. A standard Thunder device can operate effectively up to +60 V/mil and -30 V/mil of piezoceramic thickness and a maximum peak to peak voltage of 60 V/mil. For example, a Thunder made with 10 mil ceramic can be operated using maximum voltages up to +600 volts and as low as -300 volts as long as the total peak to peak voltage is less than 600 volts.

Frequency

Thunder is capable of operating with dc or ac power, and will provide different performance behaviors with a square, sine, or trapezoid (sawtooth) waveform. When designing with Thunder, an important consideration is the bandwidth or frequency of operation and the effect it has on the overall performance of the actuator. Thunder is a piezoceramic device and should be considered as a capacitive or active load for the power supply. If operated at high frequencies or used to drive maximum loads, Thunder will generate a residual voltage charge. This is not a problem for most power supplies as long as the device is operated below its resonant frequency or is used under moderate loads. Excessive residual charge will generate heat, detrimental to efficient operation.

Power requirements

A critical issue that arises when using piezoelectric actuators is the electric power consumption necessary to drive them. This will depend upon the electrical characteristics of the PZT material, namely the capacitive and resistive behavior of the actuator, which in turn affect their power consumption characteristics. Because the majority of actuator applications occur at low frequency away from the resonance, only the capacitance and the dielectric dissipation of each actuator is considered in the equivalent circuit of the actuator (Figure 11).



$$R = \frac{X_c}{tgj} = \frac{1}{2p \cdot f \cdot C \cdot tgj}$$

Figure 11. Piezoelectric actuator equivalent circuit

Because real power is represented by the dielectric losses (tgj), which are small, an estimate of the power consumed by the actuator can be made using the equation for reactive power of the device with a capacitance C , applied voltage V_{rms} to the actuator, and driven at a vibration frequency f . Thus, the required power for driving n number of actuators will be:

$$Power\ Consumed = 2p \cdot f \cdot V_{rms}^2 \cdot \sum_{i=1}^n C_i$$

My Power Supply Doesn't Give Me What I Need

Many commercially available power supplies can provide adequate voltage, frequency and current for Thunder to operate. However, the unique design of Thunder allows for increased performance with increased voltage levels. Should it be necessary to purchase a power supply to operate Thunder for your application, FACE International Corporation offers two possible solutions.

The Test Driver (TD-1) provides 0 to + 500 Volts and 40 milliamps. The operator can select a 0 to 200 hertz square, sine and trapezoid wave or a DC output waveform. At reduced voltages, it is possible to operate up to 200 Hertz.



The newer Test Driver (TD-2) provides -500 to +500 Volts and 40 milliamps. This supply can also deliver a 0 to 200 hertz sine, square, trapezoid (sawtooth) wave or DC output waveform similar to the TD-1. Both power supplies have a BNC High Voltage monitor connection for use with an oscilloscope.

How Do I Attach My Own Leads ?

When wiring a Thunder device the top of the device is treated as the positive terminal and is usually aluminum. The bottom side is the negative terminal and is usually stainless steel.

There are several options for lead attachments to a Thunder actuator. Temporary electrical leads in the form of conductive copper tape can be used. This allows the designer the ability to locate the leads anywhere on the device. This can be a great benefit when designing and prototyping with Thunder. Once the appropriate location for leads is determined or if a more permanent electrical attachment is required, leads can be soldered to the top and bottom metal layers.

SOLDERING RECOMMENDATIONS

When using a standard Thunder with aluminum on top and stainless steel on the bottom, the following basic procedures for soldering to the device are recommended.

Suggested materials

- Multicore, 45D, ALUSOL-D Solder (.028" diameter) for Aluminum superstrate
- Solid core Zinc solder wire (~.0625" diameter) and accompanying liquid flux. Recommend Strong Set Soldering Kit 509 (All-State Welding Product). Possible source local welding supply store.
- LA CO Aluminum Flux Paste. Source: McMaster-Carr, part number 7696A2.
- Regular 60/40 lead tin solder.

Prepare the aluminum top layer by scuffing a small area on the surface using 220 grit sandpaper. DO NOT apply excessive pressure. This can cause a tear in the aluminum. Clean the scuffed area with a cloth moistened with methyl alcohol. This will help assure good solder flow and solid mechanical and electrical contact is made.

Prepare the stainless steel bottom layer for soldering by following the same procedures outlined for the top aluminum layer detailed above.

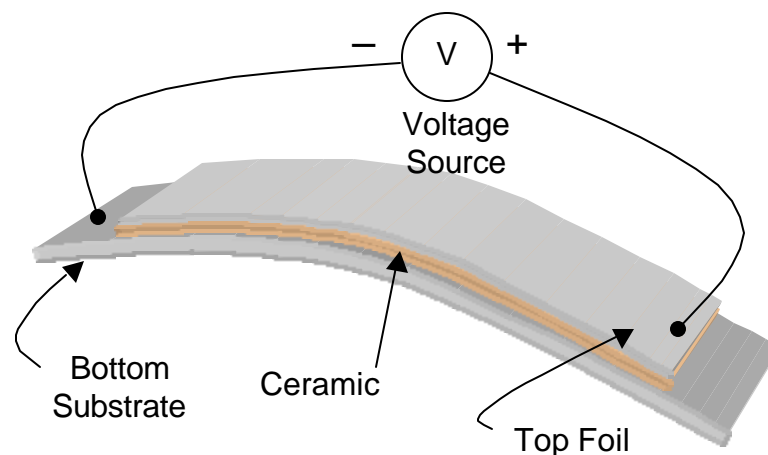


Figure 12. Lead wire attachment



Preparing Solid Core Zinc Wire. The zinc wire that is provided with the Strong Set soldering kit is a solid core variety. It is approximately .0625" in diameter, which is too large to melt with a standard soldering iron. The wire can be made more fit for use by striking it with a hammer to flattened it into a thin foil approximately .007" in thickness. Cut it into thin strips approximately a 1/16 " wide with a pair of scissors. Leave it attached to the wire for easier application.

When applying solder to stainless steel, dip the wire lead into an aluminum flux paste and place a small drop of flux paste onto the surface of the device where connection will be made. Apply a small amount of lead/tin solder to the soldering iron and make the connection.

When applying solder to aluminum, dip the wire lead into No. 509 solder flux. Also apply a small drop of the flux to the scuffed area of the aluminum. Apply Multicore brand Alusol-D solder, with 45D metal that is .028" diameter. If this material is unavailable, use an aluminum/zinc solder

After the leads are attached, apply a small drop of a flexible material like epoxy, hot glue or silicone on the solder joint and any exposed wire. This area may experience the most movement when the device is actuated, and this extra drop of flexible material will act as strain relief to the wire and solder connection.

Should it be determined that soldering is not an option for an application, electrically conductive epoxies also work well for electrical connection to Thunder devices. Direct spring loaded contacts can also be used.

At Face[®] International we strive to provide complete solutions for our customers, and continue aggressively researching new and improved methods for integration of Thunder technology. If you have different or special needs please don't hesitate to ask our technical staff for assistance. We will work closely with you to identify and implement an effective solution for your application.