Dudley's Element Paper

A Compilation of Ideas to Promote the Highest Quality of Element Installation Practice

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Prologue

A few ideas to help you better understand concepts about resistive elements

Element Stretch Your new elements arrive in what is called a closed coil, that is, each coil is touching the next coil (see fig. 4a.) a result of the manufacturing process. There are several reasons for stretching your new element: a) for letting the heat out of the coils; b) for fitting the element to the kiln; & c) if you don't, the electricity can arc across the touching loops and burn the element out. A good rule of thumb is to have a minimum distance of 3 to 5 diameters of wire distance between coils. Thus for 15 or 16 gauge wire this translates into roughly 1/4" spacing. There is no maximum distance. The coils can be stretched straight with no harm done. In fact, it is a common practice in Japan to pin straight wire elements all around the interior of the kiln. We use coils to condense this process and put the elements in grooves or on rods, but this is only a Western kiln practice, not universal.

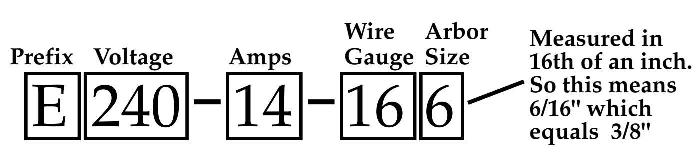
Resistance These elements are made of resistance wire. The raw material is extruded into wire and then measured for electrical resistance– so each spool of wire is somewhat different. Elements made from 2 different source melts could be substantially different in terms of weight and length, maybe as much as 2%. That said, both would have the same electrical properties though visibly different.

Your Electrical Voltage Your voltage can be an issue. Measure it. Don't just assume it is 240 VAC just because that sounds right. Here's a recent example: I made elements for a guy who said he had 240 volts. He had a standard sized kiln 42" x 27" x 18" (almost 12 cubic feet). The walls were made of 2-1/2" soft brick with 2" of blanket. This kind of kiln generally needs 600 watts per cubic foot (see fig. 22) or a power need of 7087.5 watts. I recommended a pair of standard elements, the E240-14-166 which fits nicely in grooved brick construction. Each of these elements produces 3360 watts for a total of 6720 watts, just slightly shy of the mark. In real numbers it is 5% less than ideal, but these numbers have a good deal of slack in them and in terms of performance it might mean the kiln would take 32 minutes to get to temperature rather than 28 minutes and for the rest of the day you would notice no difference. But that's not what happened. The kiln took 3 and a half hours to get to temperature. UG! So of course I got a call. "Why are your elements not working?" So I keep some records and I look up the design information. That all looked fine. Then he said maintenance thought he had 208 volts. I suggested he test the voltage. A day later he calls with the information that he has 200 VAC. This is a 16.6% drop in voltage. The problem was even more magnified. The element does not change: it stays the same length and has the same resistance (17.14 Ohms), but at 200 volts it only delivers 2333.33 watts and the pair of elements put out 4667 Watts which is 34.15% off from our ideal amount of power. They were lucky the kiln got to temperature at all! The answer is to install another element, somehow, like suspending it from the ceiling, but the kiln definitely needs more power.

If this same scenario is reversed, like to install elements designed for 208 volts and actually put 240 volts or even 250 volts on them, the results can be pretty devastating. It is not so much dangerous as it is damaging to the elements as they will be way too hot and will most likely burn out within a short time. So the point here is to test your voltage. This is vital information. There are many multi-use meters on the market. Purchase an amp meter (see fig. 21) which reads both amps and volts.

Schematic of your element installation If you are uncertain about how the elements are to be installed, request an electrical schematic for your elements. We will be happy to supply you with this information.

Write the element model number on your kiln wall with Magic Marker From your invoice copy the element name next to your kiln's power supply. Then when something goes wrong and you have to replace elements all you need is this number. This saves a lot of time and trouble.



Installing Your New Elements

The first order of business for making a successful installation is to make a full scall drawing of the element path. I often use chalk on the studio floor. To illustrate: figure 1 is a front loader kiln with the element grooves cut in the insulated fire brick (IFB) walls. Figure 2 is the information I would draw with chalk on the floor or on cardboard, full scale. I recommend only measuring the horizontal runs because the vertical sections are simply a few inches of uncoiled wire.

Element Path in a Front Loader Oven

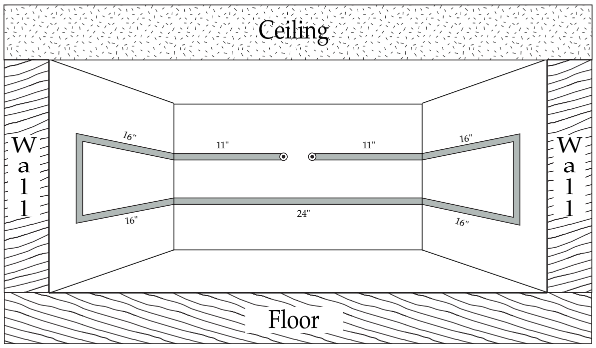


fig. 1 A typical front loader annealer oven. The element grooves are placed on the back and side walls. The element leads go through the center back to the power supply.

Diagram of the Element Path

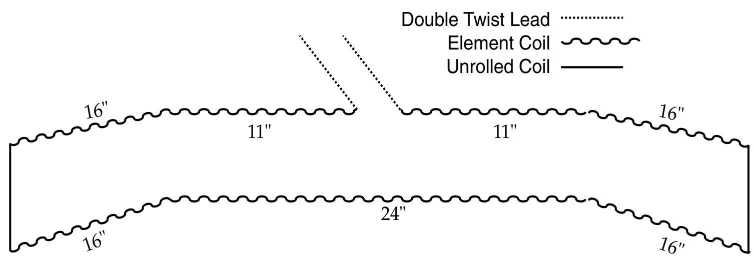


fig. 2 This is the plan for the element path. The element coils are placed on the horizontal runs. The vertical sections are single wire unrolled coil sections.

Add up the total length of the horizontal path. In our example above this would be 11 + 16 + 16 + 24 + 16 + 16 + 11 = 110 inches. Pull element to this length, see figure 3.

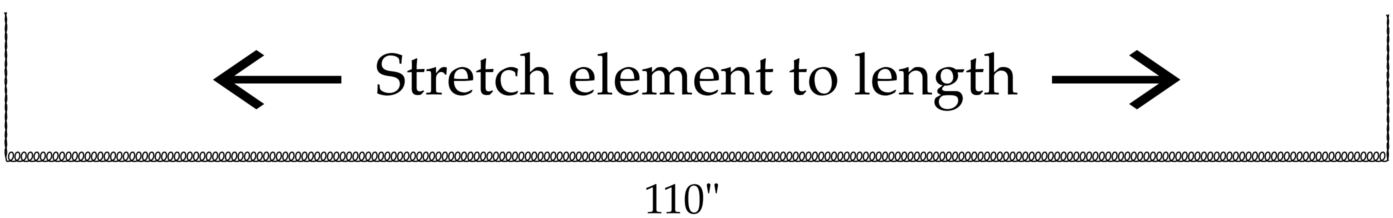


Fig. 3 This is the stretched element, pulled to the appropriate length as determined in the plan shown in figure 2.

To accomplish this stretch make a mark on the floor with masking tape or chalk at 110 inches. With the help of an assistant on the far end of the element each of you hold the double twist lead in one hand and the last coil with a pliers as shown in the photo, figure 4b. Pull until the stretch is accomplished.

The wrapping of an element puts a lot of stress into the wire and sometimes the elements will stretch in an uneven manner. To compress a coil section insert a rod (metal or wood) into the center of the element coils. Now you can adjust the distribution of the spacing quite easily. The object is to have even spacing between coils throughout the entire element and for it to lay at the correct length to the 110" mark on the floor.

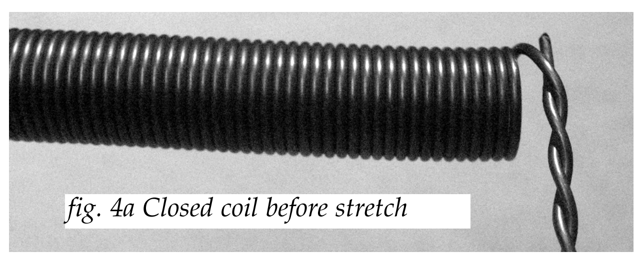


fig. 4a Closed coil before stretch

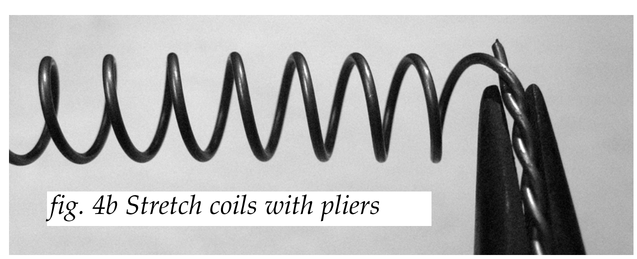


fig. 4b Stretch coils with pliers

The next part of our project is to measure and bend the element to fit the exact parameters as set out in our design as shown in figure 2. It is quite useful to do this work on a large desktop or shop table. Make your measured bends at 25 or 30 degrees (see figure 5, below) instead of 90 degrees, a kind of marking out of the fit. When you have finished this layout work move the element into the kiln and begin fitting it to the grooves. Here you will finish the bends to 90 degrees and stretch or compress coil sections to fit the grooves as needed. Once the element is tightly fitted in place it must be secured in the groove.

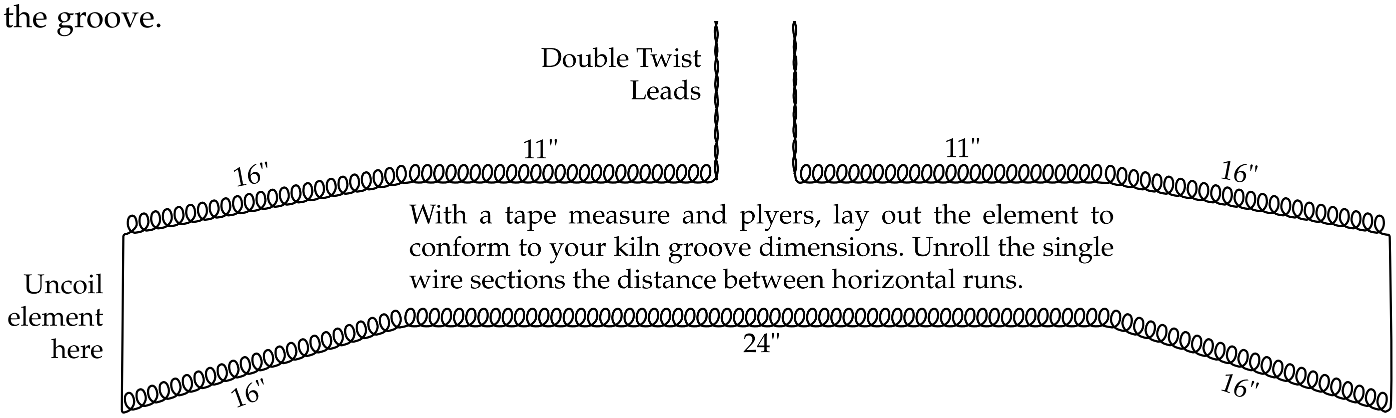


Fig. 5 Measuring and marking off the coiled element.

Securing Elements in Grooves

If you were to just plug in your nice new element we have struggled to install in the kiln, within a few minutes or at most a few hours the element will move around like a writhing snake and it will be completely out of its groove dangling dangerously in the kiln waiting to snap you out of a lethargic daze. The age old solution to this problem is to pin the element in the groove. Each kind of soft brick has its own qualities meaning the softer the brick the easier it will be to pin. The idea is to bend a 15 or 16 gauge piece of Kanthal wire to look like a hair pin as shown in figure 6. This then gets hooked over a coil loop and pushed into the soft brick. The element needs to be pinned every three or four inches along the groove. This system is somewhat permanent, but it will require some maintenance because as has already been mentioned the element does want to writhe. With each heat-up and cool down, the forces of expansion and contraction are hard at work putting pressure on this pin system. Occasionally a pin will ride up and the element will pop out of the groove. This means that every few weeks you should give your kiln element an inspection and reset any pins that are riding up.

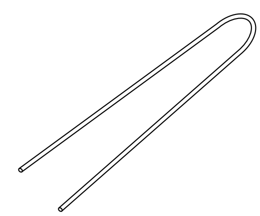


Fig. 6 The Kanthal wire hairpin for securing elements coils in soft brick grooves.

Working on an element that has been previously fired to a hot temperature presents its own set of problems. Kanthal type elements once fired tend to become brittle so when resetting pins be especially cautious as you cannot just bend and push the cold element back into the groove. I have a pet kiln that I have used for many many years which has the pinned element system. At least once a year I have to adjust the elements which will begin to pop out of the grooves. The trick is to heat the Kanthal type elements to a red heat at which point you can do anything you want with them. So I turn the kiln on and when the element gets nicely hot I use a pair of long wooden sticks to push the element to shape. The wood sticks must be dry and at least two feet long as this provides sufficient electrical insulation and protection from possible electric shock.

If I have an especially tricky area I unplug the kiln and use a small plumbers torch to get a small section of coils hot so I can adjust the shape using pliers and a screwdriver. Re-pin the coils if required. If you have a problem area where the pins continually loosen try using a little mortar on the pin and pin hole. Be sure to clean the mortar off of the element. You can also use Z-wash to set the pins.

Pinning elements in grooves is a long standing technique. The beauty of it is the low tech, anyone can do it, appeal. On the scale of ten it rates about 6 for perfection. As already mentioned it has flaws as the element will, over time, pop out of the groove and so this requires some maintenance. There are more permanent solutions. For grooved brick the best method is to hold the element in place using fused silica rod in the center of the element with metal or fused silica pins used to hold the rod and element coils stationary. This system rates about 9. Using the fused silica rod down the center of the element coil guarantees the element will never pop out of the groove. The main drawback is it is just a little bit more difficult to install and it makes the installation a little more expensive.

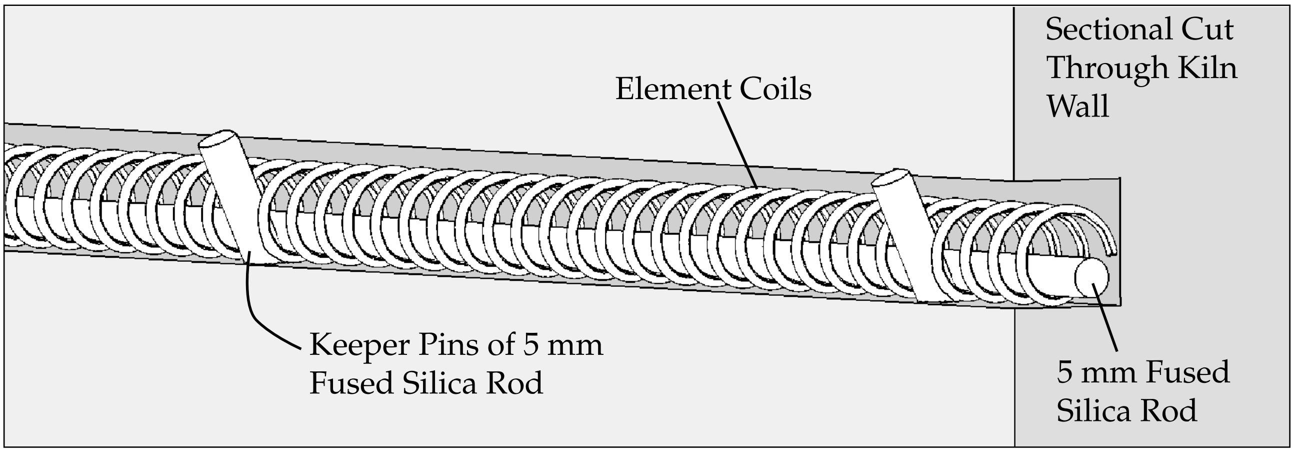


Fig. 7 This shows a most effective element holding system, the fused silica keeper rod which holds the element in position in the open groove. This is a permanent solution which will need little or no maintenance. Insert the keeper pins every 3 or 4 inches to keep the element from crawling.

Element Creep

Because I have worked in the element replacement business over a long time I get to see the cumulative effects of natural wear and tear on elements. I get to see how they die and what kills them. For the most part it is a phenomena I call "element creep." I first noticed this in my toaster oven element which crapped out on me after many years of making happy toast. This was an encased element, a fused silica tube with a regular element coil running down the middle. I had noticed that it had been getting hotter and hotter on the ends and cooler in the middle. Then one day I just had cold frozen bread. It was time to fix the toaster. On a closer examination when I pulled the element out of the tube (figure 8) I saw a pretty well deformed cluster of packed coils in both ends with a fairly spindly spread of coils in the middle. The coil clusters were somewhat fused together like arc welded. It was like an archaeological find, only it was nasty looking. I could see pretty clearly what had gone on.

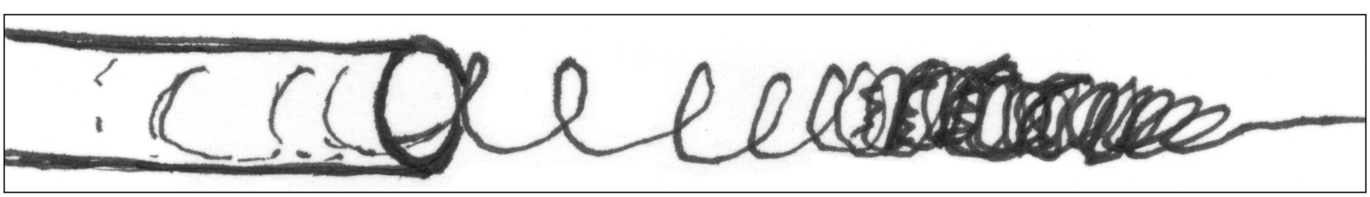


Fig. 8 Over time the forces of expansion and contraction will push an element to pack itself against whatever restraints are present. In the case of this toaster element there were no restraints throughout the length of the tube so the coils packed into the ends of the fused silica tube and at one moment they fused together by arced electricity.

The same forces are at work on an element that is suspended on a rod, like suspended in mid air. It will take time, but slowly and incrementally the element will creep up against its restraints, like the donuts that hold it in place. So if you initially have a nicely spaced element, in a few years you may have a potential problem. But there are ways of combating this problem and that is of making small restraints along the whole element path. In the case of our element installation in figure 5 if you place the restraints, the pins, every three inches that is plenty good. If you put them every 9 or 10 inches, in time you will have coil clusters and big problems.

Some installment systems are immune to this creep problem, specifically the donut and rod system against fiberfrax. Here the rod holds the element straight and puts even pressure on the element coils as they are pressed gently against the fiberfrax surface. Each coil is held in position and they don't move over time as shown to the right in figure 9. And there is one other system that is virtually free of the element creep problem and that is the simple donut system which is great for use on annealers up to possibly the low slumping temperature range. Here the donut is used to position the element at intervals of 2 to 6 inches depending on the temperature range you are going to. For greater stability use a heavier gauge element coil (like 15 gauge) and set the donuts every 2 or three inches. This will eliminate most of the element sag and there will be virtually no element movement horizontally.

Element with Ceramic Rod Installation

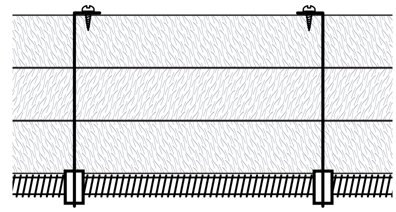


Fig. 9 The donut and rod system used against a fiberfrax wall provides great ability to hold each coil in place on the rod thus eliminating "element creep."

One of the hardest installations is placing the element/rod system against fiberboard or frax board, any stiff material that is less soft than fiberfrax. The rigid board makes it hard to get the element drawn into contact with the board to provide the necessary friction against the coils to protect against "element creep." It is possible to recess the donuts by cutting little grooves. That would allow for more element contact with the fiber wall but not everything is straight: the board is not always perfectly straight and even if it were the extruded support rods we sell have as much as 3/8" deflection. This is not a problem if it is a simple curve which can fit flat against a surface, but the rod deflection can be compound, i. e., curving in two directions. The solution with these installations is to put daubs of z-putty every few inches along the rod (see figure 10). This keeps the element from creeping along and moving out of position. You can be as careful as you want with this application or you can be cavalier. I have not used this directly overhead, only in wall installations.

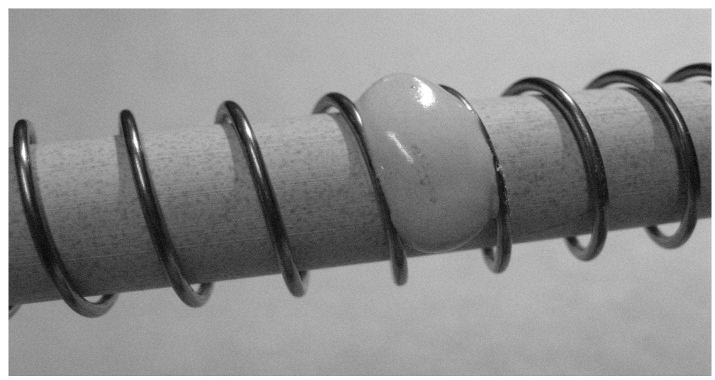


Fig. 10 This is the daubing technique which is used to position the element on the ceramic rods. With daubs placed every two to three inches the problem of element creep is eliminated

Joppa Glassworks sells a small z-kit for making this z-putty and for doing very small repairs on element runs and kiln interiors. Please inquire. Also little baggies of Sairset to do the same work.

Now for a simple story. I had a fellow named John Bozarth as a sculpture teacher my sophomore year at RISD, 1964. We were doing bronze busts or at least doing the modeling for this experience. One day he shared with me how a friend of his would do his low tech burnout using an electric element which he embedded into the ludo mold. Once this was dried in the sun or oven enough he would plug in the element and watch it first melt out the wax and then burn out the carbon. When it was sufficiently clean he would unplug it and turn it over and pour in the bronze.

So that little idea let me know these elements could be embedded and over my career I have covered over elements with a variety of materials including clay mortars, several kinds of castables, and the zircon-silica paste just mentioned above as z-putty. Covering them is the easy part and from my experience they have lasted just fine and not really suffered from this abuse. This is all to justify the unusual application in figure 10, the zircon daubing. And so a word of advise on how to mix the material. The z-putty kit has two parts: a powder called "zircon" which is zirconium-silicate, and a liquid called colloidal silica. You only mix what you need at any given time. For the daubing just mix a couple of teaspoons of powder with a tiny amount of liquid to get a heavy paste. With a brush paint a drop of slurry (a thinner mixture of liquid to powder) where you are going to put the daub. With your finger tips place a small daub about the size of a large grain of rice on the drip. That's it. You can daub up several feet of this per minute.

If you are concerned that at a latter date you might want to remove the daubs, make the mix a little weaker by adding some water (25%) to the colloidal silica liquid used to make the paste. Since this has never been an issue for me I haven't explored the exact percentages of water to colloidal silica. If you keep adding water, that is upping the percentage of water to colloidal silica, you will get to a point where the material you are daubing on can be blown away with your breath when dry. So if you get to that point you know you have gone too far. For daubing I have only used the straight mix as it comes in the kit. If you ever have to replace an element, you will have to face this problem of hard to remove daubs. The bottom line is the material put on at full strength can be sanded down and removed. For me I think of this issue in reverse terms: by using the daubing I am making a more permanent installation, one that is greatly beneficial to the long life of the element. In this light I recommend daubing.

The Wire Keeper

In terms of making permanent, non-moving element installations there are a couple of other tricks and techniques that are useful. The illustration in figure 11 shows two main ideas that are a great aid to element stability. First is to position the "thru tubes" shown as #1 behind the end of the rods symbolized by the dotted line. This assures the element will not wiggle its way off the end of the rod over time. The daubing technique mentioned above is used on both ends of the rods. This is proba-

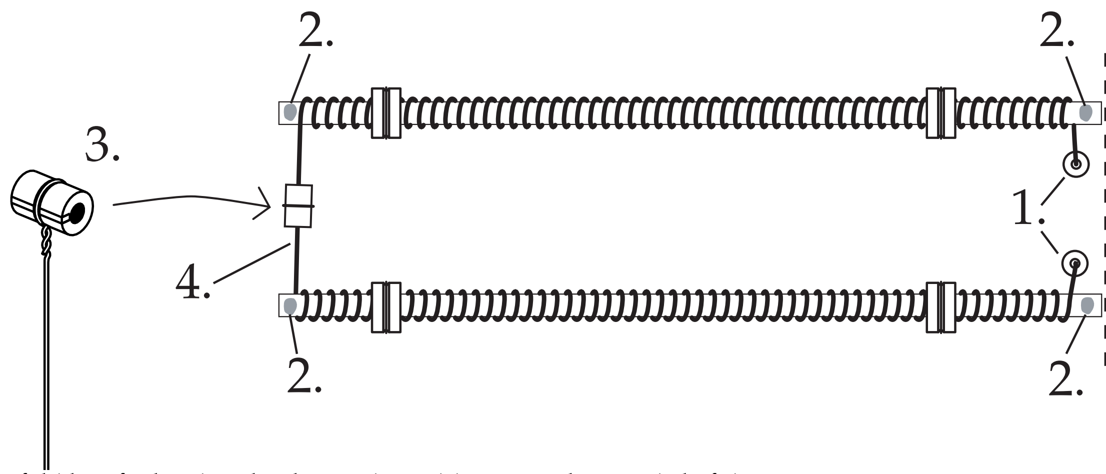
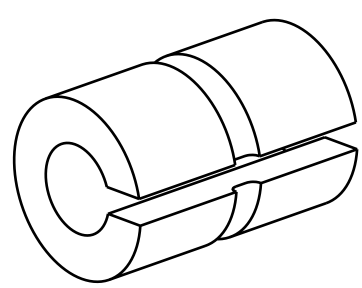


fig. 11 Useful ideas for keeping the element in position over a long period of time.

bly overkill especially if this were on a frax wall installation.But I recommend this bit of overprotection. Item #3 is special insulator made from a 3/4" section of cordierite rod and is used to position the vertical wires and hold them in place (fig. 12 on the next page show the manufacturing sequence of this useful item). By placing this wire keeper behind the end of the rods (see position #4) this keeper assures the coils will not eventually come off the end of the rods. I make my own wire keepers using a standard diamond saw with a thin blade. The cordierite rod material used to make these keepers is available from Joppa Glassworks. Inc. These are also offered for sale from Joppa Glassworks, Inc. as a kind of package. There is a package of Sairset mortar (3 Tablespoons) $6.00, "one cut" wire keepers, as shown in this image to the right at 3.50 each, and wire for attaching the keepers at 35¢ per foot.



"One cut" wire keepers, a new idea for keeping elements in position.

Making the Wire Keeper

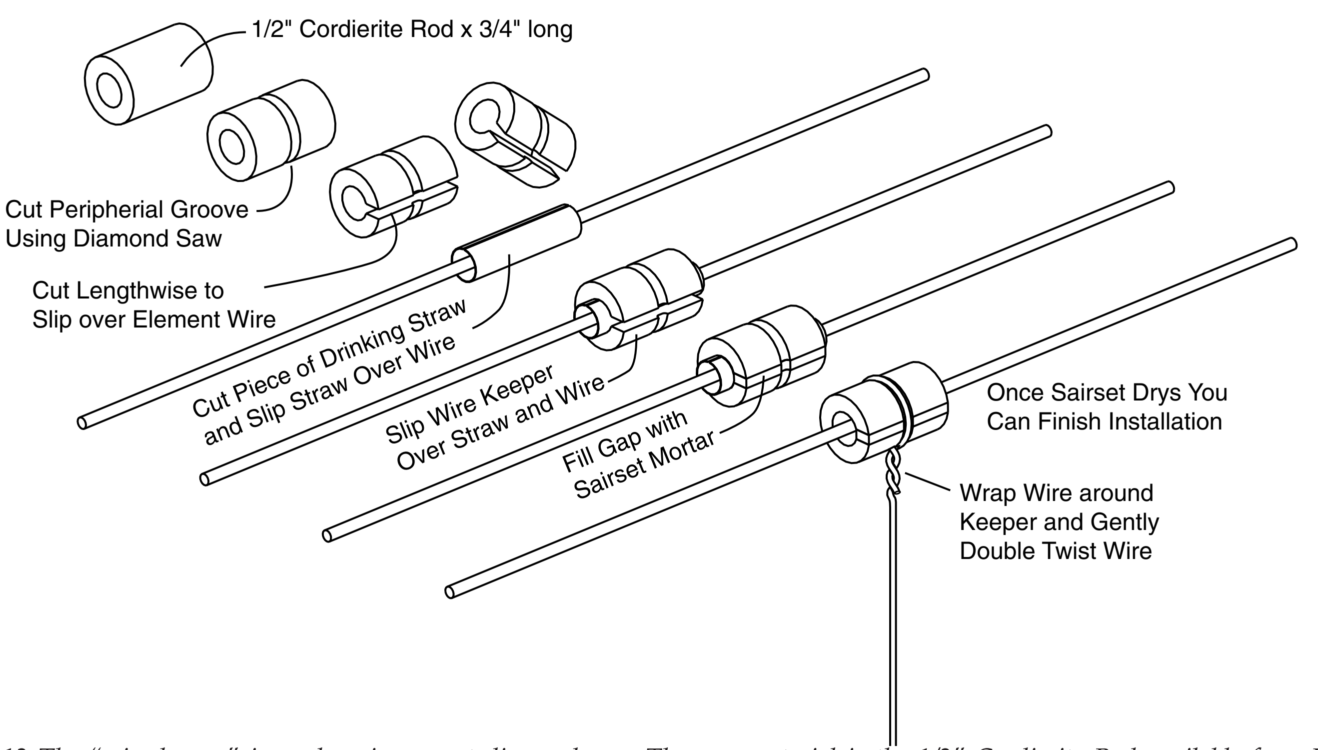
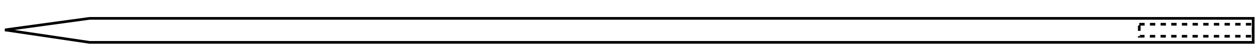


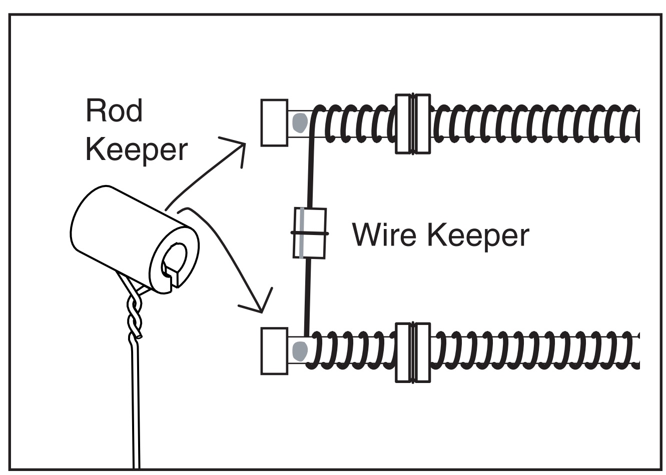
fig. 12 The "wire keeper" is made using a wet diamond saw. The raw material is the 1/2" Cordierite Rod available from Joppa Glassworks, Inc. (12.65 per 30.5" or you can purchase partial rods if available). I use an open blade 10 inch disk diamond blade, solid rim, which rotates in a bed of water. It is all freehand work. The nice thing is it doesn't take many to complete an element installation.

Before you install the element, lay all the parts out and measure out the element path and stretch the element to fit. Unroll sections going from one run to the other. Wire up the donuts and cut the rod lengths so there are 1/2" end areas for applying daubing. Make a paper pattern which shows where the holes will be drilled to install the donuts, thru-tubes, and "wire keepers". By using a threading needle which is made from 1/8" brass, shown below, you will be able to accurately install the components where they should be. You drill an 1/8" hole in the shell and poke the threading needle



through the fiber insulation, then reverse the direction of the needle and poke the donut wire into the hole end of the needle and push it back through the hole in the frax to the outside of the kiln where the end of the wire can be roughly bent over to keep the donut in approximate position. When everything looks right begin snugging up the parts.

There is one other part that might be of use to you: this would be a "rod keeper" to limit the movement of the main rods that support the elements. By installing one of these at each end of the element support rods it assures there will be no horizontal movement of this component. This would be most useful on frax board doors where the continual lifting and closing might cause loosening of the components. This piece is made by two saw cuts into the ends of a small section of 1/2" cordierite rod material.



Good Element Layout

For each type of kiln there is probably a preferred element layout. For example if you are slumping or fusing the typical wisdom is to have top heat so we place the elements in the ceiling and have the work relatively close to the heat. If you are annealing blown work you want easy access and reliability and if you are casting you want to be able to heat your mold to casting temperature evenly, top and bottom. Here are a few sketches illustrating these points with comments.

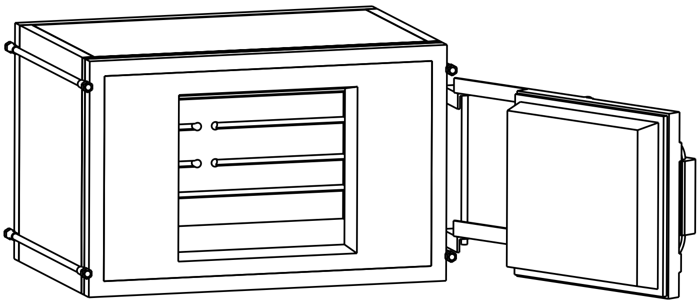


Fig. 13 The Front Loading Annealer. This is a great kiln for the ease of placing hot blown work into it and it anneals ok, but because it is heated from three sides instead of four, it is not good for casting where you want even heat from all sides. Typical dimensions would be 32″ wide by 24″ deep by 20″ high (8.9 cubic feet). This would require 2 elements of the standard configuration E240-14-156. Power this from a 35 amp breaker, 240VAC. The element path can run all the way across the back and up to both sides as shown or you could have them go from the middle to one side and back to the middle. The advantage to using the longer path is better heat distribution.

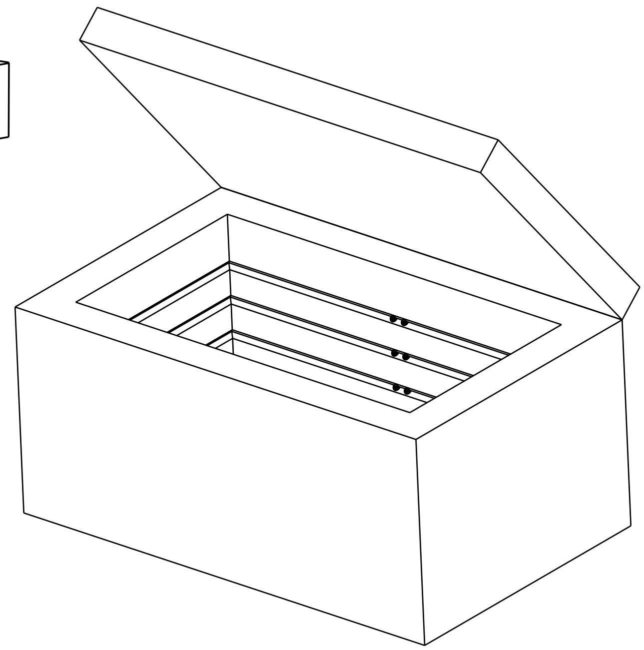


Fig. 14 This is your typical coffin kiln, great for casting to 1650°F and also makes a terrific top loading annealer. These can be large to small in size, but usually it measures something like 45″ wide, by 27″ front to back, by 24″ tall. Wall is made of 2.5″ IFB with 2″ backing of fiberfrax. This is a 17 cf. kiln, as shown, and if it were just used for annealing three standard elements of the E240-14-156 configuration would be adequate. However, if you want to cast in this kiln plan on at least 5 of the E240-14-156 elements with a 100 amp dedicated power supply. If you want to cast in a kiln similar to this and you only have 50 amps available whittle down the size to something like 27″ wide x 24″ deep x 22.5″ high which is an 8.4 cubic foot casting kiln.

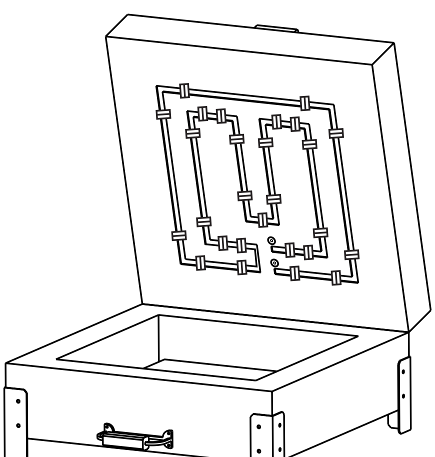


Fig. 15 This is a small slumper/fuser kiln, a.k.a. the Betsy Kiln from Chapter 20, page 99 of ***A Glassblower's Companion****. This kiln is fired with a single 240 volt element (E240-13-168) and is suspended on 1/2″ ceramic rods with #8 donuts. The element is fairly close to the work and that is why the element path is shown meandering over the entire surface which is an attempt to equalize the heat distribution. If there were a little more distance between the work and the elements I might choose to run the elements horizontally and uncoil between rows as shown in figure 16 to the right.*

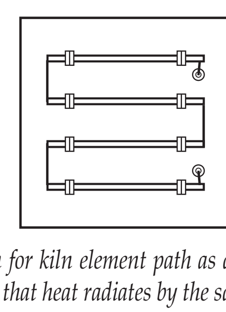


Fig. 16 Alternate pattern for kiln element path as discussed in fig 15. If you use this pattern keep in mind that heat radiates by the square of the distance. Place the elements above the work farther than the elements are spaced apart. This allows the temperature to be more even across the casting/slumping surface.

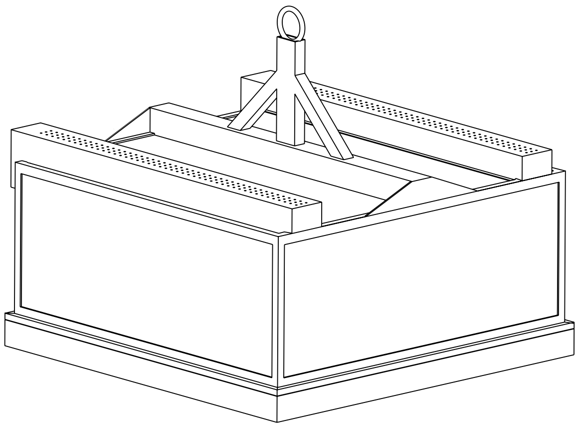


Fig. 17 The large lift top kiln. Most of these kilns begin at about 60 cubic feet and we have helped customers with kilns as large as 250 cubic feet. Some are fired with elements just in the top while others are fired with at least some power in or under the floor.

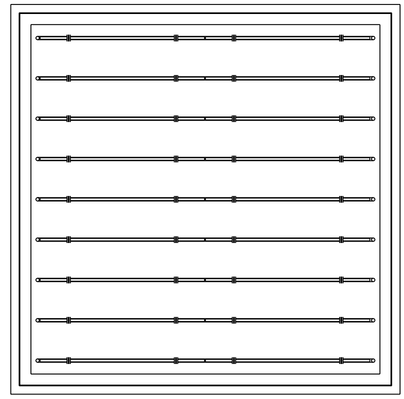


Fig. 18 The element pattern in the lid of the large lift top kiln. The most simple approach is to run the elements in rows across the top. The lid height from the casting floor varies from nine to twenty inches depending on your specific needs and goals.

Limits of Kanthal-type elements:

As the price of gas has recently moved into higher ground a great number of glassmakers have tried to circumvent the cost of melting glass by switching to electric which is more heavily regulated and slower to rise in cost. Before this time, most glassmakers' electric use was limited to modest temperature ranges for annealing (950˚F) and slumping/casting (1650˚F) max. Now they want electric furnaces to go to 2350˚F. I get several calls a month where folks want to convert an old kiln to melt glass in. There are several problems with this approach. First, 2350˚F is the top temperature for Kanthal type elements. At that temperature the life expectancy of an element is about an hour. At 2300˚F the average Kanthal element might last 8 hours. At 2200 you might get a few weeks and at 2150˚F you might get several months.

To complicate the issue, most installations of Kanthal type elements are in grooved brick. This is a kind of kiln within a kiln. Please look at the blowup image of an element in a groove, figure 19. This illustrates a range of temperatures within the kiln and within the groove. The temperature within the groove is our problem spot because for the kiln to reach 2150˚F the temperature within the groove is very likely going to be considerably higher, maybe even 200 degrees higher. It is kinda like the old fuse idea where if the temperature goes above a certain amount, POW! That's when you need to install another element. What you have is a perfect system for burning up Kanthal type elements.

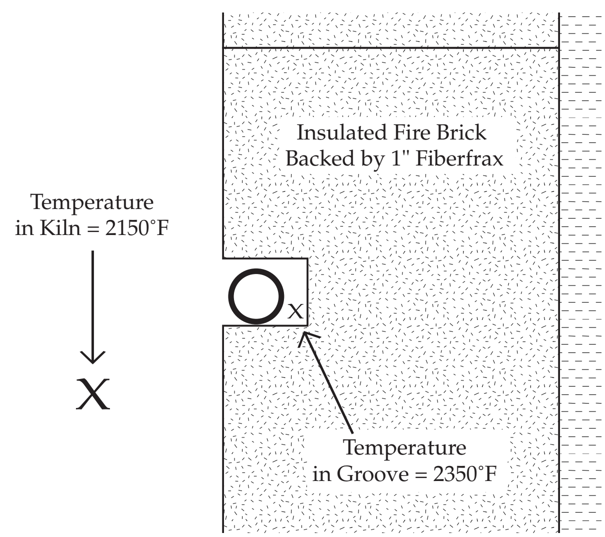


Fig. 19 Grooved brick element channel shows the obvious fact that at high temperatures the groove will be hotter than the kiln, after all this is the source of the heat.

So what's the answer? There is no terrific answer, period. But there are things you can do to get some high temperatures out of Kanthal-type elements:

1. Keep your temperature to a maximum of 2150˚F
2. Open top of groove to let more of the heat out (see figure 20)
3. In a furnace situation wash your cullet and warm it before charging to make fewer bubbles
4. Maybe go to a lower melting glass
5. Use thicker wire for the elements with lower amperage per element. This might save you a few days on the replacement schedule, but that is not the real culprit; it's the heat.

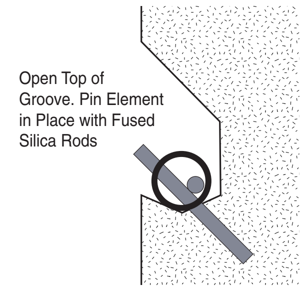


Fig. 20 An open Groove would let more of the heat out

Other Options:

Of course there are other solutions for electric, but I don't sell them. There is much experimentation in the field. Probably the most knowledgeable guy, Steve Stadelman, has come and gone from the glass furnace business. So what to do? Well, there are the Wet Dog Furnaces that start at $37,000.00 for a 400 pound furnace. Or look up Pete Vanderlaan with http://talk.craftweb.com. It is my humble opinion that electric glass melting furnaces are not comparable to gas fired furnaces. They don't work that well and it leaves disgruntled customers. Well, as a fuel source it makes sense if you are near the Grand Coulee Dam, where the rates might be cheaper, but in the middle of New Hampshire it is SOL.

The Efficiencies of Electric

And there is the efficiency issue. I know of one Vermont glass facility that has free electric which comes with the rent. The juice is generated on the property. That's a terrific deal. But it's just one odd studio situation. Maybe you too can fall into such a sweet deal. These guys have experimented with several types of heating elements and use three phase silicon carbide elements for the main furnace, a free standing pot furnace. These require a transformer. The other approach is the moly-disilicate heating elements that Stadelman used, and they require quite a bit of electrical gear and some sophisticated electrical knowledge to piece it all together. But the piece of the puzzle that interests me is the real source for most of the electrical power that is generated in our country- coal, oil and gas.

I live just a few miles from the Bow, NH, electrical generating facility. My brother, Dr. Melbourne F. Giberson, is a power transmission specialist and he travels the world over keeping stations like this alive and functioning. He took me on a tour of this plant a few months back and the one thing that impressed me is the raw fact that this plant burns 4000 tons of coal every 24 hours. That's 8,000,000 pounds of coal a day. So when someone in NH turns on his little electric melter he gets quiet, clean heat in the shop, but the smoke and sulphur and CO2 are down at Bow slowly blowing out toward the coast and toward Europe. This is part of the hidden costs of electricity. With this downside hidden, electricity is frequently considered to be "GREEN" and a buffer to the fluctuations of natural gas, who's costs remains a wild card. Who would have predicted the precipitous drop in the cost of natural gas in the last three years or that the price of gasoline in April of 2015 would be $2.15 per gallon (two completely different issues). Now electricity is neither seen as "green" or cheap.

The efficiency of converting coal to electricity is somewhere around 38% and on top of that, depending on the distance, there is a loss in transmission of 3-5%. So the carbon footprint is pretty big. These are the physical facts about electric power. Glassmaker and equipment designer Charles Correll sent me a calculation comparing his gas recuperator-glassmelter to an electromelt on high. It turns out the electromelt system is responsible for producing 2.5 times as much CO2 as is his gas furnace melting the same amount of glass. This is exactly my point: electric is electric. Don't confuse it with electric is green, because it ain't. To be perfectly clear: Electric power is one of the greatest sources of pollution: sulphur, raw carbon, mercury, carbon dioxide, etc. But the beauty of electricity is its cleanliness where you use it in your shop. And it appeals to the technically oriented mind as there's a science to it. In the next pages we will explore the formulas that help us calculate the right amount of heat your kiln needs to do its work and how to connect your kiln to the greater power grid.

Computing your power needs: Ohm's Law

$$I = E/R$$

Where:
I = Amps; E = Volts; R = Ohms

This is the formula we all encounter in 8th grade science and wonder why me? It seemed then like maybe an appendix. Now we actually have a use for this nifty little ditty. And you get to use some of that algebra you put into your pocket. Let's use some real numbers. We have a 240 volt kiln with one element that is 17.14 Ohm's. How many Amps will this kiln draw? (ans. 14 Amps). At one time or another most craftspersons pick up a used or even new Volt meter that has an Ohm meter component. So you hook the two leads to the ends of an element and take a reading. You get wildly divergent reports. I've never seen an Ohm meter work right. The part of this device that usually works great is the volt meter. Use it. Set it to the correct range and take a reading on your power supply. Most people call me and say, "I need a 220 volt element." Turns out when they do the reading it says "240."

So, what if it actually read 208 Volts and you have this same kiln with its 17.14 Ohm element attached to that? When we run the numbers it now will draw less power, 12.14 Amps. To see how dramatically different these two solutions are we need another formula, the calculations of Watts:

Watts = Amps x Volts

Watts are the units of energy we consume. One thousand watts is a kilowatt, the units of power we pay for on our electrical bill. The cost of a kilowatt can vary quite widely from state to state, but let's say the cost is 12¢ per kilowatt hour (KWH). You have a 50 watt light bulb you burn as an outside light for 4 hours every night. How much will that cost at the end of 28 days? (ans..67¢) Now back to the real issue with our element in the previous paragraph. The kiln that is powered with 240 volts is going to be a lot more peppy than the one powered by 208 volts even though they both have the same element.

In situation #1 the amps are 14 and the volts are 240 so we compute:

Watts = 240 x 14 = 3360 Watts

In situation #2 the amps are 12.14 and the volts are 208 so we compute:

Watts = 208 x 12.14 = 2525 Watts

This is the same kiln with the same element but with different voltages and the results are strikingly different, about 25% less power even though the voltage is only 13.3% less.

With Ohm's Law and this watts equation we can work with electrical ideas and begin to formulate the power needs of our kiln designs. To heat a kiln to a certain temperature requires the input of power (watts) into the kiln space. The insulation of the kiln restricts the flow of the energy out of the kiln and over time the temperature increases. As a rule of thumb the hotter a kiln gets, the greater the heat loss through the insulation so that at some point the heat loss and the power input equal each other; that's the point the kiln will get no hotter. I was curious about what was going on but I didn't want to go back to school, like engineering school, to get the long version. My approach to power requirements is empirical. To better understand what was going on I bought an amp meter (see figure 21) to measure the amount of power kilns and other shop equipment use.

Fig. 21 The amp meter is an accurate and easy to use piece of shop equipment. By clamping around one of the insulated power leads you get a reading of amperes drawn.

So early in my career with amp meter in hand I measured twenty five kilns which I knew functioned well and I calculated their size and wattage input and condensed this information into the chart shown in figure 22, below. [By the way, I still use the same amp meter today some 40 years later. It is an important tool for understanding electrical use and electrical functionality in your shop and I recommend every craftsperson have one.]

Watts needed per cubic foot of kiln space

(Chart to calculate the overall heat requirements for a kiln)

Sample wall material→		(4.5" IFB)	(2.5" IFB + 1" Frax)	(3" Frax)
Use	Degrees F	"Ins Value" = 19	"Ins Value" = 25	"Ins Value" = 42
↓	↓	(Watts per cubic foot= wpcf)		
Annealing	950	900 wpcf	700 wpcf	500 wpcf
Pick-up	1150	1000 wpcf	825 wpcf	650 wpcf
Slump	1500	1500 wpcf	1200 wpcf	900 wpcf
Casting	1650	1650 wpcf	1325 wpcf	1000 wpcf
Pottery	2250	2000 wpcf	1800 wpcf	1600 wpcf

Fig. 22 Watts per cubic foot of kiln space

The variable in the use of this information has to do with kiln size, because actually heat loss is conducted through a stratified material, in either a ceiling, wall, floor or door. It is easiest to imagine this at some static temperature point, say 1000 degrees on the hot side of a wall. As the temperature system stabilizes the outside will reach a steady temperature, too. You would say of this system that it is loosing heat at the same rate that you are putting heat into the system. The heat loss is calculated in watts per square inch of surface. If you have an equal thickness of insulation, say 2" around a kiln space, you can calculate the volume of kiln space to exterior surface and find that a small kiln will have a greater surface to interior volume than a large kiln (see fig. 23 to the right). I've simplified this idea: if a kiln is over 25 cubic feet you can almost halve these numbers and if it is less than one cubic foot you can double it. (*For more information on this issue please read pages 100 & 101 of A Glassblower's Companion, first ed.*)

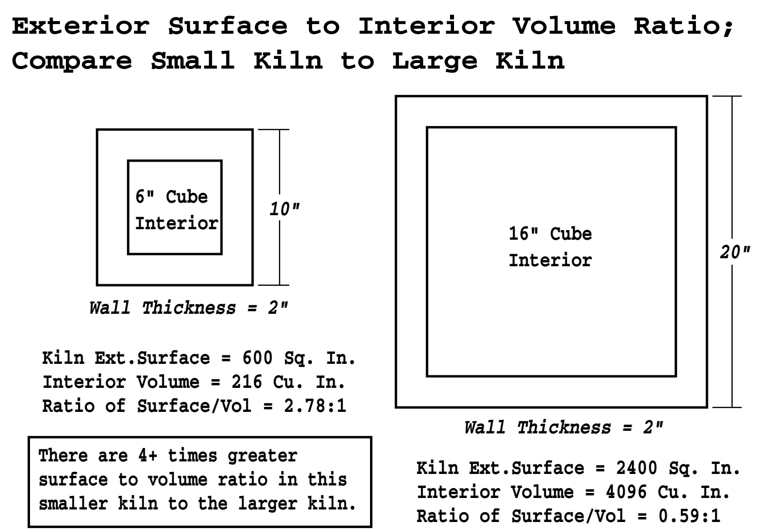


Fig. 23 Images illustrate the Ratio of Surface to Volume in small to large kilns. Small kilns require more heat per cubic inch for kiln to attain same temperature as larger kilns

Matching a kiln to a kiln site

When considering a kiln site the first questions to ask are what are the power constraints? How many amps are available? Single phase or three phase? And what is the voltage? Then ask how large a kiln will this support? I usually get to apply this all in reverse. First the customer tells me he wants to build maybe a 50 cubic foot kiln (120 inches x 80 inches x 9 inches). It has a soft brick base and frax top and sides. He wants to go to 1600˚ F. and has single phase, 60 Amps available for the project. You do the math and you will begin to see the problem. This is one of the large kilns referred to in the preceding paragraph. I've found the right amount of power for this design to be about 550 watts per cubic foot. Multiply 550 x 50 = 27500 Watts. Divide that by the voltage and you get the amps required to produce this much power (27500 ÷ 240 = 114.58 Amps). Ouch! The phone grows quiet. The Solution: get more power or build a smaller kiln.

Without being too technical you now have a method to estimate what your power requirements will be. If you buy and use an amp meter you can balance the loads in your shop. You are now on your way to a happy electrical environment. [FYI, there are other approaches to this power calculations business. If you want something more precise you can search out heat calculation programs on the internet, but I almost never use them.] I have found the best predictor of success is success itself. If you make a kiln exactly like another kiln in all aspects it will perform the same. This is the basis for the chart in figure 22 which I have successfully used for many years.

There is one more piece of equipment I use called a continuity tester, cost about $1.99. It has a little bulb which lights up if you touch one end to neutral/ground and the other to a hot 120 volt source. The light will double in brightness if you touch each end to 240 volt power source. This has remained an invaluable tool in troubleshooting kiln electrical problems like broken elements, malfunctioning switches, etc.

A word of caution: Just be really careful when troubleshooting your power supply problems and disconnect as soon as possible to avoid shock!

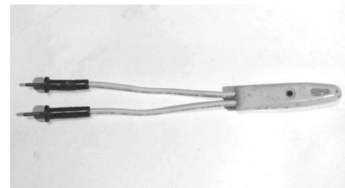


Fig. 24 Continuity tester, an essential and inexpensive ($1.99) testing tool for the craftsperson.

Hooking up the power

Up to now we have dealt with the actual placement of the element in the kiln, how to stretch and pin it and how to limit its possible movement within its support structure. But a good element placement has other important considerations, specifically making a safe and electrically sound connection to the power supply. In the modern shop the main power resides in the breaker box. For the sake of efficiency having enough power is important as there is nothing quite as depressing or wasteful as waiting hopelessly for a kiln or furnace to lug along not able to reach temperature. That is wasted energy. There is another concern when dealing with electricity called the 85% rule: here you want the supply side to be 15% more robust than your actual needs. For example if your kiln needs 85 amps it should be fed using a 100 amp breaker and wire capable of carrying 100 amps. This additional information does not help our customer who wanted to build the 50 cubic foot kiln because now by applying the 85% rule he needs 134 amps of power.

To the right in figure 25 is a wire chart to determine the size of wire which is appropriate to use. An example: you have a kiln with four elements and each element draws 12 amps. The elements draw 48 amps in total. The kiln is within a few feet of the breaker box so distance is not an issue. Apply the 85% rule: Divide 48 by 85% and multiply the result by 100 (48/.85 x 100 = 56.47). So we need wire that will carry at least 56.47 amps. Our chart suggests we use #4 AWG copper wire. With this information we can begin to wire the kiln. Bring the power to a manual power throw box that is fused at 60 amps. This resides next to the kiln. The power goes from the throw box to a mercury relay switch at the base of the connection board. When the mercury relay switch is activated the power will go from it to the connectors on the marinite connection board and on through the elements. A drawing follows:

For Single Conductors in Free Air

Gauge Wire AWG	Diameter in mills	Rubber Insulation Amperes	Bare Conductor Amperes
14	64.1	15	20
12	80.8	20	30
10	101.9	25	35
8	128.5	35	50
6	162.0	50	70
4	204.3	70	90
2	257.6	90	125
1	289.3	100	150
0	325.0	125	200
00	364.8	150	225
000	409.6	175	275
0000	460	225	325

1 mill = 0.001 inch.

Fig. 25 Wire gauge for Carrying Capacity of Copper Wires

Source:Handbook of Chemistry and Physics, 37th ed. 1956. Chemical Rubber Pub., Cleveland.

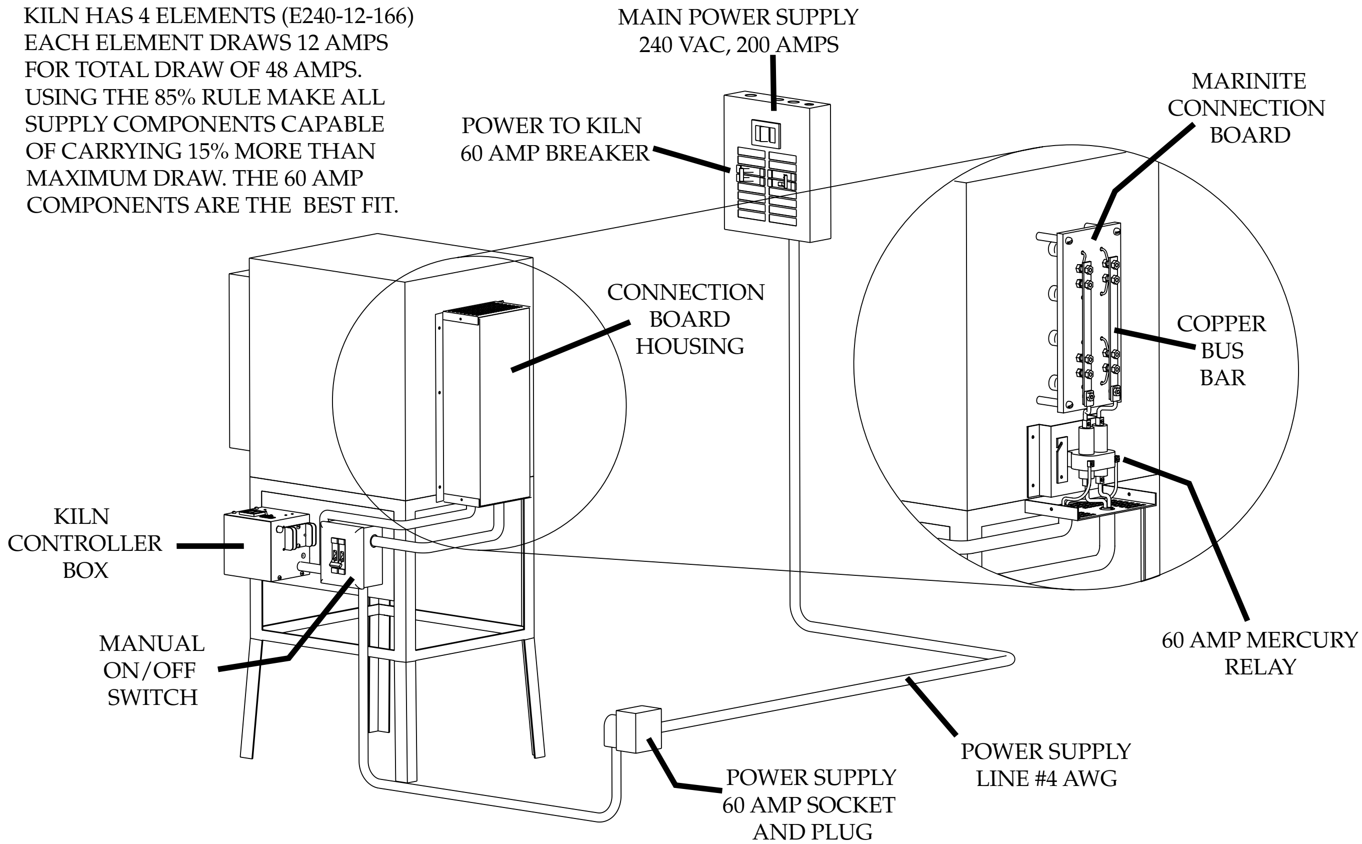


FIG. 26 Power supply components diagram. This diagram shows the important components of a power supply system: Main power is fused at the breaker box. Kiln is monitored with a 60 amp breaker. Power lines travel to kiln site through conduit to a power outlet socket through #4 awg insulated copper wire. The kiln plug attaches to this socket and the power goes to a main on/off manual switch on the side of the kiln, easy to reach for quick disconnect.The main power goes to the input of the 60 amp mercury relay located at the base of the marinite connection board at the back of the kiln. The kiln controller resides at the front of the kiln base where it is easily programmed and monitored for program information and progress. The controller is connected to the mercury relay and controls the temperature by opening and closing this main mercury relay. The power travels from the mercury relay to the elements via the copper bus bars secured to the marinite board. This constitutes a complete power distribution system.

There will always be something more you can add to a power supply, what might be called bells and whistles. The first of these that might be obvious is an open door disconnect switch. This would be wired into the circuit to kill the power to the mercury relay when the door is open. The next would be a kiln over-temperature control. This can be a separate device or you can use the overtemp scheme shown in figure 27 to the right. This overtemp scheme can be locking or floating. A locking system will close down the process if overtemp is reached. A floating system will simply not let the kiln heat above a given temperature. To implement a locking system with the Auber controller you will need to purchase a locking relay (DigiKey #PB472-ND apx. $42.00).

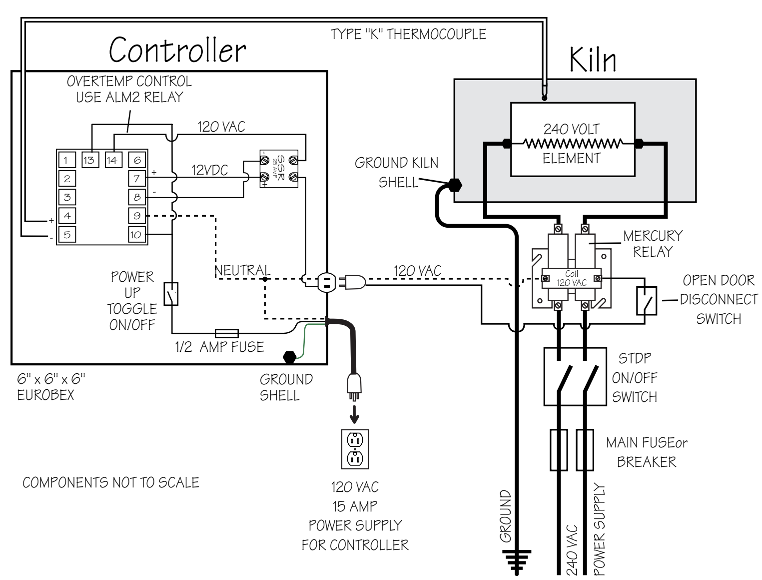


Fig. 27 This is a basic electrical schematic showing the components of a kiln wiring system. This diagram shows the placement of the open door disconnect switch and an over temperature control circuit.

How to connect your power supply to your elements

In the early days of the studio glass movement we made all our connection boards with asbestos cement board, a semi-hard material that is now highly illegal. Marinite board from the 1960s and 70s also had a percent of asbestos, but not now. The marinite board sold by Joppa Glassworks is 100% asbestos free (it is made of calcium silicate), fairly rigid but soft enough so it can be drilled and carved with a knife. It can withstand 1800˚F. and as long as it is dry it is electrically inert. So it makes a good connection board .

Before we begin, I know there are a lot of you who are wondering why go to all the trouble to make a firm connection board when you could just bend over the element leads on the outside of the kiln and attach the power with a split nut connector. Voila! the 25¢ solution. Great for you and for me. I cannot tell you how many people call me after just a few months and say their element burnt up. I say where? They say at the connection. Oh, too bad for you. Now that easy to install system is starting to cost something because the only thing you can do is replace the element. What happens in the split nut arrangement is pretty simple. Every time the element heats up the connection warms up too and it stretches a little (like microns). Nothing actually goes back to its original shape and over time this stretching results in an actual gap, like a loose connection which can produce a micro-spark. With the micro-sparking comes a poorer connection yet, until one day it just arcs like in an arc welder and burns right through the lead. The power lead freed from support can then drop down and short off the shell of the kiln. That's a lot of fireworks for 25¢. The split nut connector is not a good solution.

Sectional View: through lead tube insulators from top looking down

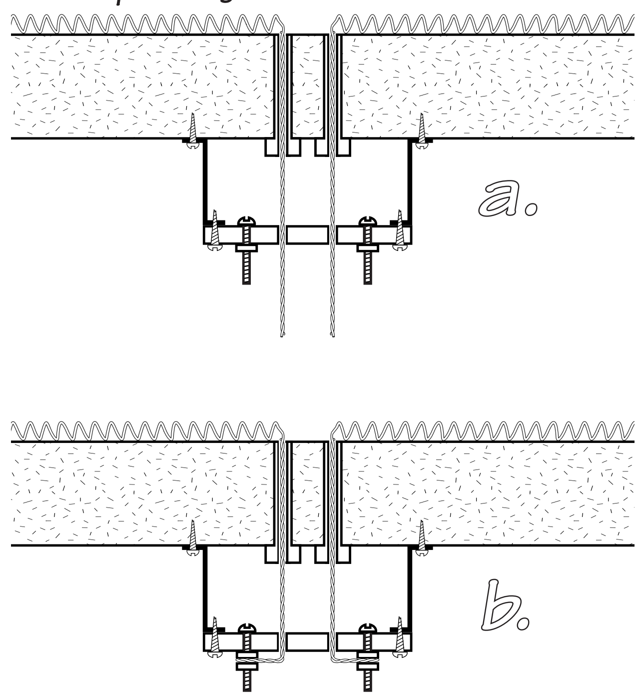


Fig. 28 a and b. In "a" we see the element leads pulled through the insulator tubes and through the marinite board. In "b" we see the leads bent and wrapped one turn about the bolt stacks and snugged down with a nut on top of the element leads. This connection board is now ready for the power to connect to these bolt stacks.

If you build a connection board as shown in figure 28 and figure 29 the kind of problems encountered in the previous paragraph are eliminated. This system is designed to keep the connections cool in temperature and structurally sound and rigidly positioned. Begin by mounting the board on a pair of two inch deep sheet metal brackets so the board runs parallel to and vertically up the back of the kiln over the area where the element leads go through the kiln wall. For each element lead drill a hole in the marinite for the lead to come through. Next to this drill another hole in which you mount a bolt and nut. Tighten these bolts with washers and a lock washer so they are firmly affixed to the marinite board. Then attach the element lead to the bolt by wrapping the lead around the bolt once, clip off the remaining lead tail, and tighten another nut on top of the element lead. There should be room above this connection to attach the electrical power.

The marinite connection board built correctly will promote a natural draft up the back of the kiln. The space between the marinite board and the kiln wall should be about 1-1/2" deep. As the kiln heats up, this space will heat up, too, and this causes the air in this chimney-like space to rise up drawing in cool air in the bottom. This is a natural draft system which is made more effective with a cover which is screened on the top and bottom. You can see what a covered marinite board looks like in figure 26 in the small highlighted circle. This simple vent system will make a big temperature differential between

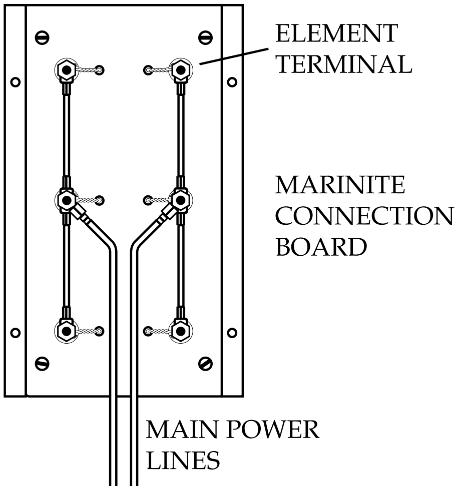
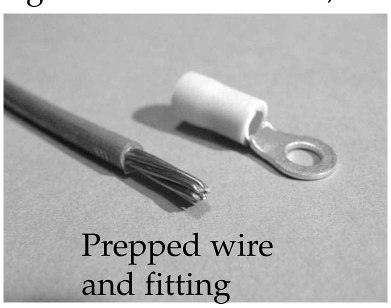


Fig. 29 The main power lines are connected to the bolt stacks and distributed to the other element terminals. The main lines are heavier than the distribution lines as per wire chart, see fig.25.

the kiln wall and the otter space which lies beyond the marinite, which will remain almost at room temperature. Keep your electrical lines in this outer, cooler vented space and you will not need high temperature insulation wires. Rate your wires using the chart in figure 25. I recommend using rubber covered multi-strand wire and high quality crimp fittings. After crimping always solder the fittings to the copper wire which makes a life-time connection. Use resin-core electrical solder. This method of using crimp fittings on copper wire is shown here in figure 29 (and this is an alternate technique to the bus bar in figure 26, large circle highlight).

You might ask why take the time to solder these guys? The answer resides in the facts already mentioned. A standard crimp fitting is made of tinned copper. When this is crimped it is just a friction fit. Over time this connection ages and oxidizes which is accelerated with the modest heat generated with each cycle of the kiln. In time this can become a sketchy connection which could fail. Mind you we are not wiring a 50 watt light bulb. These connections will carry 30, 60, or even 100 amps of power where a poor connection can cause a serious problem. But once soldered the connection is no longer subjected to oxidation or physical separation as the parts in question are fused together in an electrically continuous unit. This little five minute soldering job gives our connection board a true professional finish and will add immeasurably to the life of your kiln elements. This soldering job is pictured below in figure 30 with a before, during and after view.



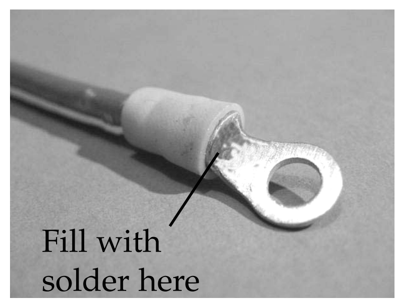


Fig. 30 Before, during and after soldering a crimp fitting

In Summary: This paper covers the many nuances of element installation from measuring and stretching your first element to securing the element in a variety of ways to minimize element movement and distortion. It further covers how to calculate the wattage needs of a kiln to attain temperatures and discusses the overall plan and positioning of a kiln's power supply components. Finally we have discussed the need for a secure, cool connection board. A variety of connection board ideas have been presented.

We all know elements break, but when pressed for more information it is goes like this: "the element popped out of the groove and broke when I pushed it back in." Or, "I don't know what happened but when I got up this morning the studio smelled hot. Everything in the kiln was a puddle of glass." I had one guy with a mystery. He would turn the kiln on and 12 minutes later it would pop the breaker. Every time it would work for a short while and then pop. In the back where he was using split nut connectors the leads were moving around as the elements heated up and the unsupported leads would touch each other. Pop. By the time he looked in back they would be cool and separate and not look guilty. He was lucky nothing more serious happened.

The ideas presented here will eliminate 99.9% of your potential trouble spots and will make your element installations professional, long lasting, and dependable. Happy Kiln Building.

Addendum: Wiring Diagrams

There are a great many tools available to help us better understand electricity and most of us are exposed to these in science class by the 8th grade. We have talked about a few of these in this paper: the amp meter, the volt meter and continuity tester light. Other items off the top of my head: the milliamp meter (simple pyrometer when connected to a thermocouple), a testing board and Ohms Law. But one thing stands out as a particularly useful tool and that is the ability to make a wiring diagram so we can logically discuss what is really going on with our power supply.

From *A Glassblower's Companion*, page 89, we have an image of a kiln with a single 120 VAC element installed with an accompanying electrical diagram that describes the components of the kiln. These are shown here as figure 31.

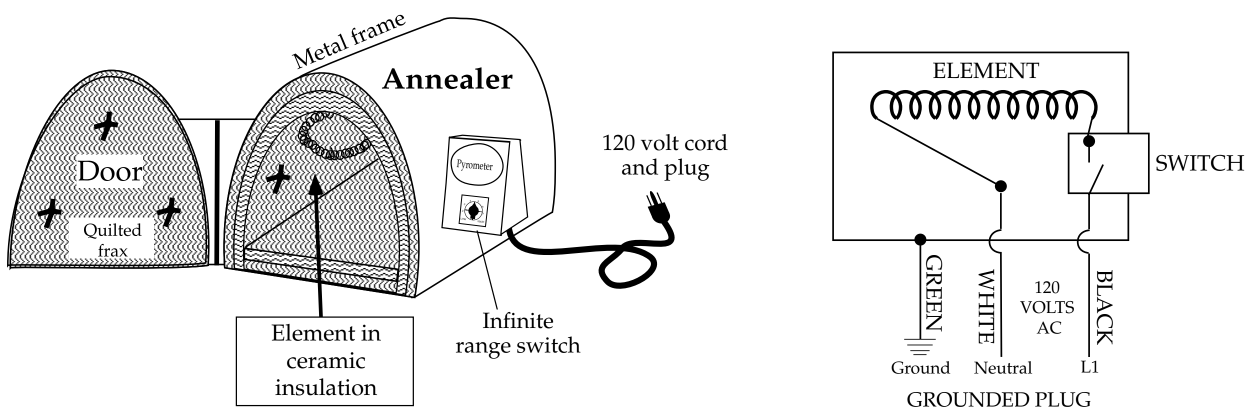


Fig. 31 The idea of diagraming an electrical circuit. Here a simple 120 volt element is shown installed in a Labino style annealing oven on the left and its simple resistance circuit is shown on the right.

Today when a customer calls me and wants to electrify his/her kiln I go through the parameters of the project:

- What is the kiln is made of, i.e., soft brick, frax or the like? And wall thickness?
- What temperature do you plan to achieve?
- What are the dimensions of your kiln?

With this information and the application of ideas from figure 22, page 10, we can determine the watts necessary to fire the kiln successfully. I then produce a sketch of the element in rudimentary form that represents the kiln element installation. Below is our Labino kiln example rendered to show the element, donuts and rods, switch, marinite connection board and power supply system .

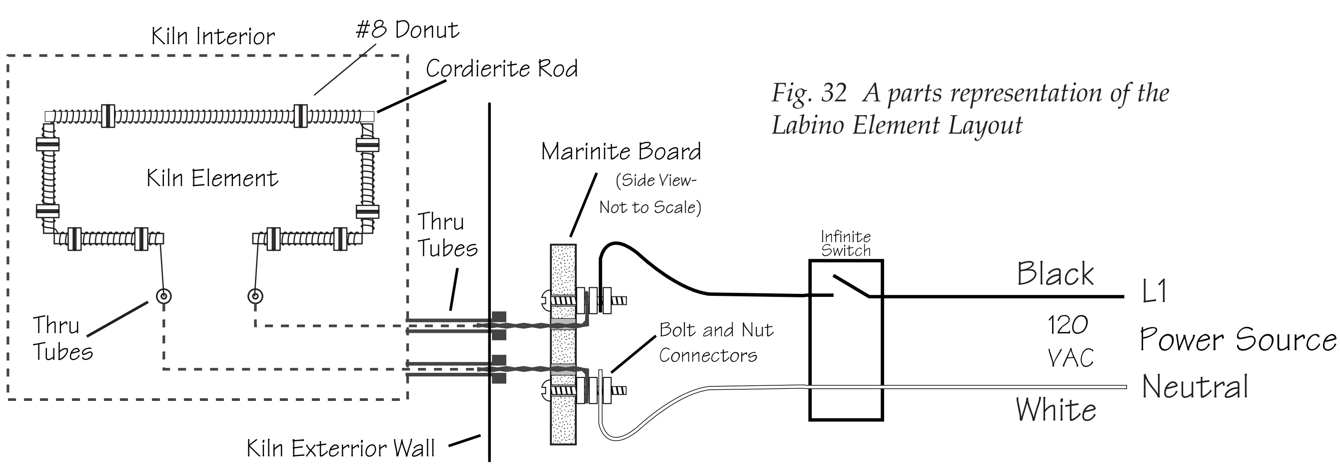


Fig. 32 A parts representation of the Labino Element Layout

More Wiring Diagrams:

Here are a pair of 120 volt elements wired in parallel. This illustrates the limitations of the 120 volt wiring scheme. Here we will need 30.5 amps supply (by the 85% rule) and usually 120 VAC circuits are limited to 15 amps, sometimes 20 amps but there is no 31 amp fuse or circuit for 120 volts. The wiring for this is also an issue. Most 120 volt x 15 amp circuits are wired using 14 gauge copper. Even if we pop in a 30 amp fuse or breaker and use 12 gauge wire it is not safe. The wire will certainly overheat because to carry 26 amps we should be using at least a 10 gauge wire. The solution is to use a 240 volt circuit.

In figure 34 we have the 240 volt circuit drawn. Note we do not need the neutral line. The element pattern shown on the left side of drawing is a typical install where you have the need to split the heat source for more even distribution such as in the top and walls or in a front loader where you might want a butterfly wing pattern, left side and right side. These various motifs are shown in figure 35 below.

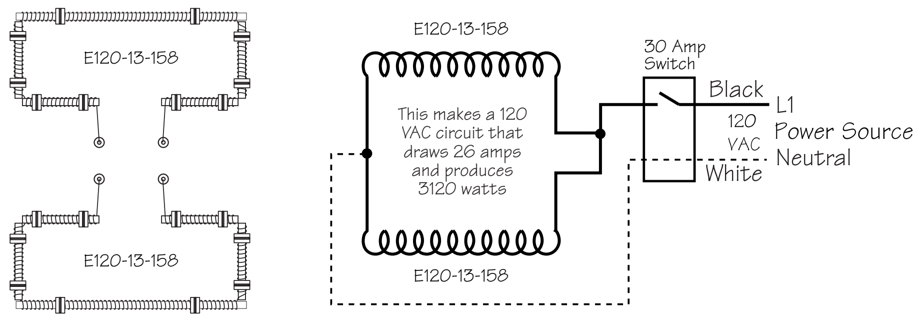


Fig. 33 The dilemma of what to do with a 120 volt kiln circuit. We have put two 13 amp by 120 VAC elements into a kiln. Wired in parallel this will draw 26 amps and (by the 85% rule) will overpower most 120 volt power sources. To cover this much amperage wires leading to it should be at least 10 gauge. The solution is a 240 volt circuit.

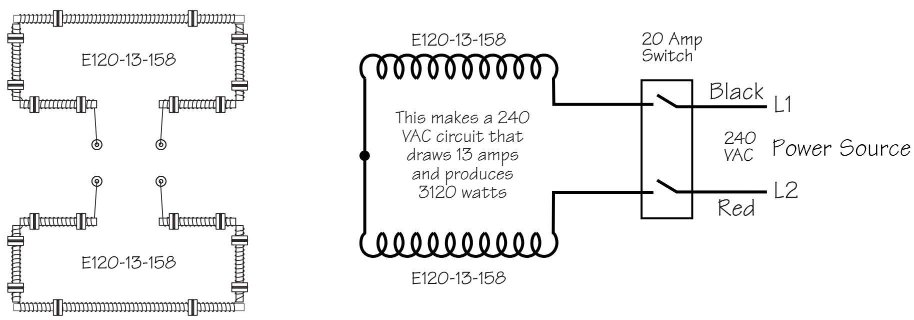


Fig. 34 By connecting the two elements in a series and applying a 240 VAC power source we can deliver the same number of watts (3120) to the kiln, but because we now are only drawing 13 amps we can get by with a 12 gauge supply line.

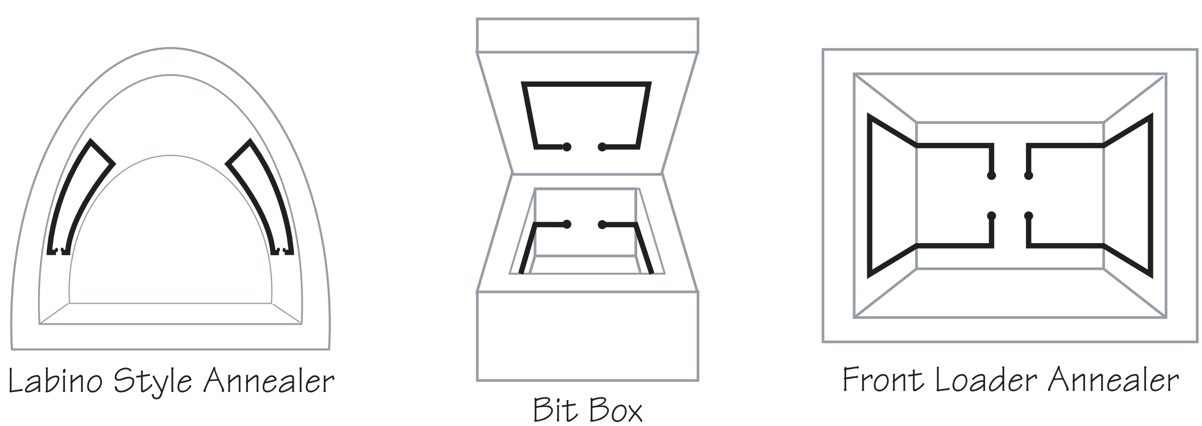


Fig. 35 Here are three examples of the butterfly wings installation. Well the bit box is stretching the concept a little, but it is similar in all other respects. These are 240 volt circuits made of 120 volt components. These kilns are all in the 1 to 3 cubic feet and are mostly used in the annealing to slumping ranges.

The next evolution of this element architecture is a single 240 volt element that wraps around the entire inside of the kiln such as the two examples in figure 36 to the right. The bit box has an element that comes in from the back and goes around twice before exiting the back. The front loader enters from the back, travels around all three walls before exiting the back.

There are a good number of reasons for preferring this arrangement shown in figure 36 over the previous design of figure 35. The first is it is cheaper and there are fewer thru-tubes. This would also make the connection board less work to construct with two verses four leads to connect.. With most electrical ideas, simple is better.

The wiring diagram for the designs of figure 36 is shown in figure 37 in the simplest of terms. Of course you will want to install a connection board like one shown in figure 32 and numerous items like switching, but from here on we are going for simplicity in our schematic designs.

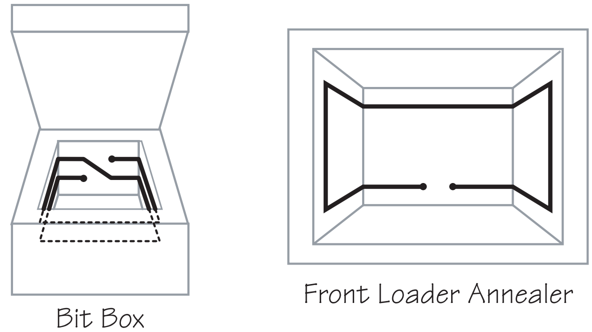


Fig. 36 Here is a diagram of the most simple single element arrangements commonly used. A single 240 volt element drawing 13 amps (3120 watts) is sufficient to power a 1 to 3 cf kiln for most glass shop usages.

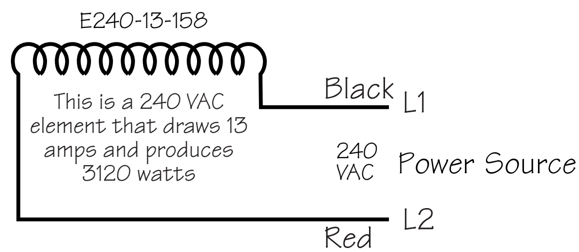


Fig. 37 The gist of the 240 volt scheme: a simple resistive element powered by a 240 VAC (volts, alternating current) power source. I would probably put this on 12 gauge copper supply line on a 20 amp breaker.

The next step up in power comes by adding more elements. A typical soft brick annealer (with 1” frax backing) with an interior of 40” wide x 20” deep x 20” high, about 9 cubic feet, will need two elements of the E240-13-158 configuration where each element provides 3120 watts. This works out to somewhere around 700 watts per cubic foot. If it is a front loader you might choose either of the patterns from figure 38. The wiring diagram in figure 39 accurately portrays the parallel wiring configuration.

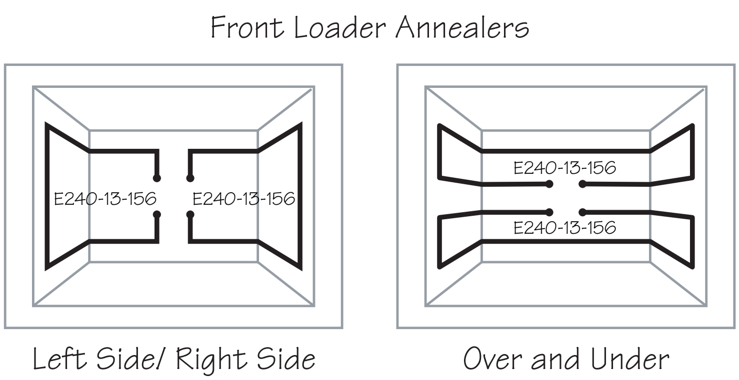


Fig. 38 These two images show the variety of element pattern. One overriding idea is to have the thru tubes mounted in one location so the connection board can be as compact as possible. With both of these patterns the marinite connection board could be as small as 4” by 4”. Another idea is to have the element arrangement distribute the heat evenly. The “over and under” pattern on the right is more effective to that end.

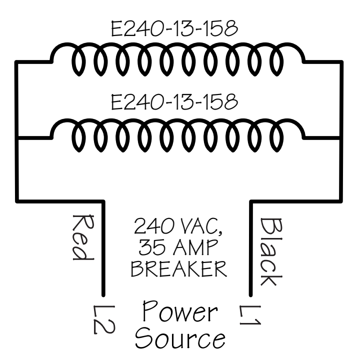


Fig. 39 This wiring diagram describes two 240 volt elements wired in parallel.

With larger kilns the wiring pattern gets more elaborate. Lets take a front loader of about 27.5 cubic feet. Here we will want some power in all 3 walls plus the door. This kiln is designed for casting so our target temperature is 1650˚F. Input will be about 825 watts per cubic foot.

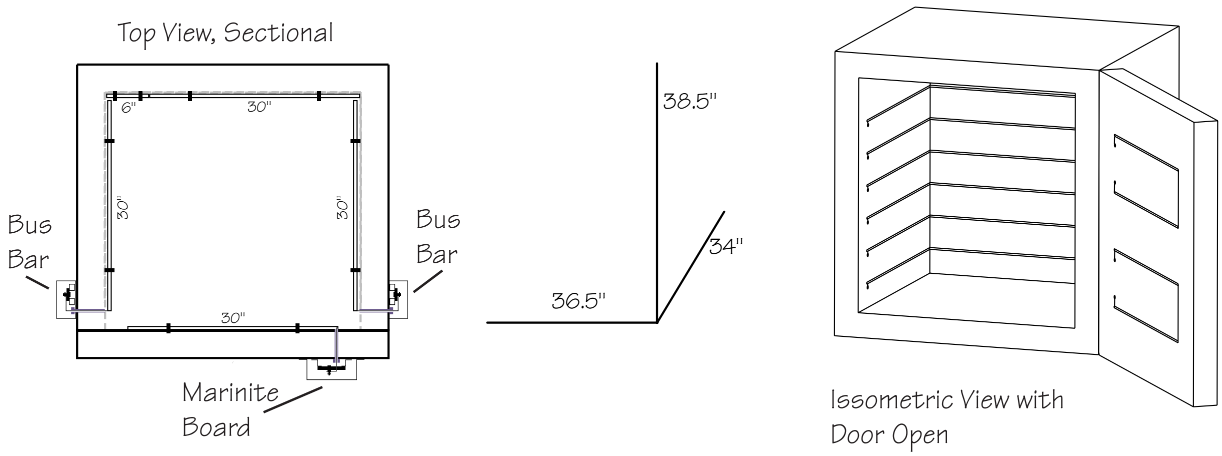


Fig. 40 Three drawings showing the size and scope of an 8 element installation in a front loader kiln. The actual positioning of the element support structure is shown in the drawing on the left. Dimensions are given in the drawing in the middle and an isometric rendering of the kiln with the door open is shown on the right. Six of the elements are in the main body of the kiln and two are in the door. Usually casting kilns are top loaders, but our customer for some reason wanted this to be front loading.

The wiring of this front loader is made simple by the use of bus bars, connection bars that run up the vertical length of each side of the kiln. Using a 240 VAC schematic shown in figure 41 we see how easy it is to visualize and then execute the plan. The overall effect of this approach is to see and analyze, then implement a logical approach. Here the kiln will provide a balanced amount of power from all four walls, a necessary ingredient for a casting kiln.

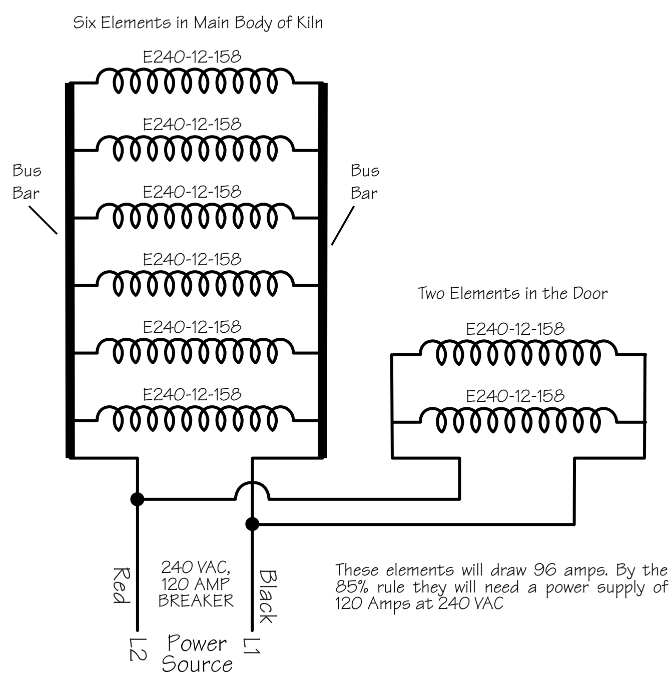


Fig. 41 This schematic shows the distribution of power: the six elements on the left are wired using a bus bar scheme, while the two on the right are simply wired in parallel using a marinite board as was done in figure 39.

There are a few more configurations that are useful to study in this element placement discourse. Figure 42 is a casting kiln, top loader with elements in the top, walls and floor. The main idea here is to have the elements evenly surround the molds. The useable space is cube-like. The schematic in figure 43 accurately describes the arrangement.

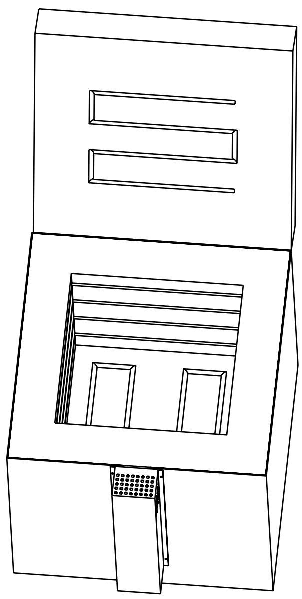


Fig. 42 A cube shaped casting kiln with power in the walls, lid and floor. This even distribution of power will allow for the best chance for even heating of your glass molds, especially on the uptick when the floor can be the coldest spot.

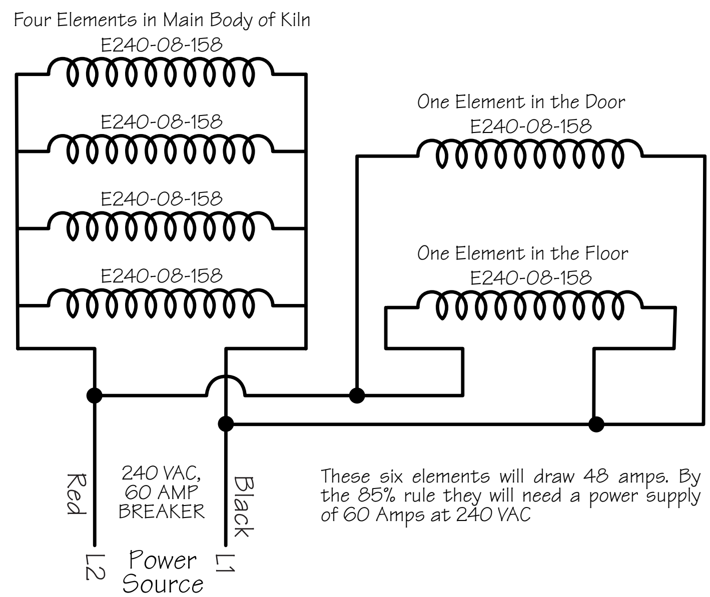


Fig. 43 This is an electrical diagram of the six elements evident in the design in figure 42. It is quite common to have independent controls on both the lid and floor elements. By using a diagram you can see where you would place these controls.

Several times a year I get customers who have 480 volt power and we have to sort through the following information to reach a design solution. The initial problem from a manufacturing perspective is a 480 volt element, if made out of 15 gauge wire or heavier will be a very long element indeed (uses about 145 feet of wire and weighs about 1-1/4 lbs). Go back to our solution in figure 34. By placing two 120 volt elements in a series we constructed a 240 volt element circuit. Here by placing two 240 volt elements in a series we can make a 480 volt element circuit. The advantages of using 480 volts is echoed in the wisdom of moving from 120 to 240. By doing this we can reduce the size of our feeder lines and other components. For example to deliver 12 Kw to a kiln by 240 VAC you will need lines, relays, etc., capable of carrying 60 amps. But if you have 480 VAC you can reduce the size of the feeder lines and all the components to 30 amps which can be a big savings.

Needless to say, most of these 480 volt situations are three phase installations, but first we are going to map out the simple single phase 480 VAC element circuit shown in figure 44 to the right.

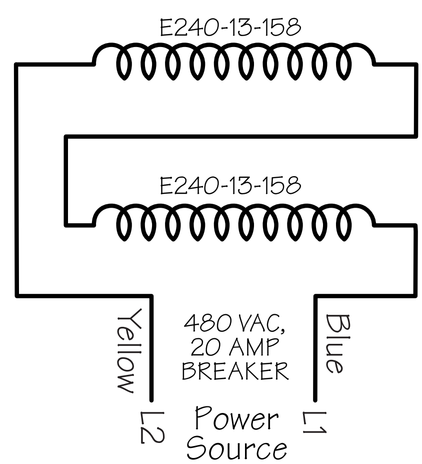


Fig. 44 This is how to form a 480 VAC element circuit using two 240 VAC elements wired in a series. This circuit will draw 13 amps at 480 VAC.

We are now going to discuss three phase element placement. Please review pages 101 and 102 of *A Glassblower's Companion*. The big idea here is we have three feeder lines called phase one, phase two, and phase three connected to three elements. The three elements are connected in a kind of parallel scheme that looks like a triangle, the source for calling this the delta scheme. This basic building block, the delta triad, is shown in figure 45 and 46. Initially these two diagrams look different but they are the same.

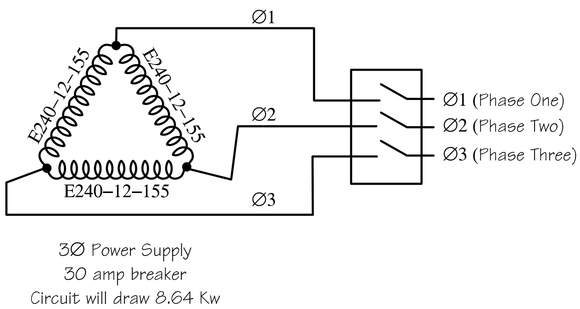


Fig. 45 The typical three phase delta connection where each element is connected to two different phases: phase one to two, phase two to three, and phase three to one.

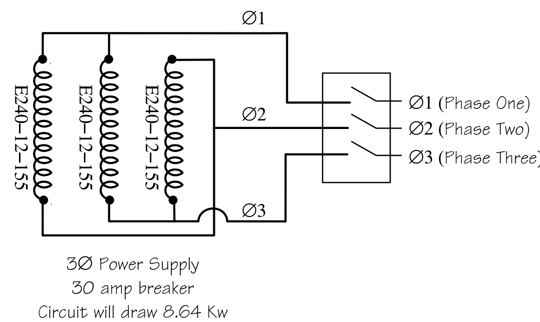


Fig. 46 This is another way of writing the delta connection. If you examine this closely you can see it is the same as figure 45.

There is a certain savings that can be realized by shifting from single phase to three phase. It is a fact that you can push more watts through the feeder lines much like our shift from 120 VAC to 240 VAC where we can reduce feeder line size. For big projects the savings can be significant. Examine the elements in figure 45. On a three phase scheme these pull 20.76 amps and they could all be run through 30 amp components. And if you wired these up in single phase they would pull 36 amps and by the 85% rule would need to fit into 50 amp components.

With three phase power we try to run a balanced load on all three phases. This results in matching sets of three elements, so a kiln will have three, six, nine, or twelve elements. This is not cast in stone, but it is a general rule. Below, in figure 47, we have a six element installation in the crown of a slumping kiln. Figure 48 shows the two choices for weaving the three phase feeder lines to these six elements.

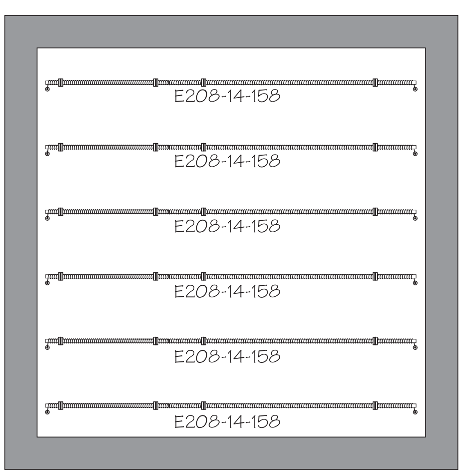


Fig. 47 This is a six element installation in the crown of a large slumper oven. These element when made for three phase installs should be made is sets of three: like three, six, nine, etc. This provides a balanced load on the power supply side of things.

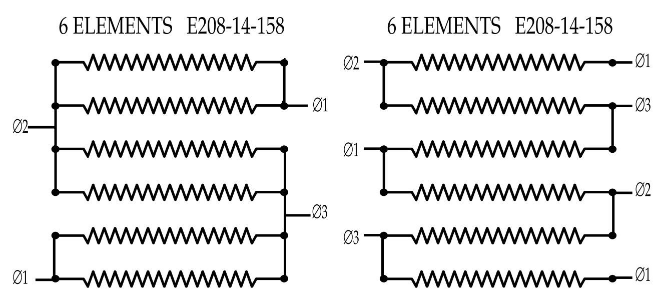


Fig. 48 This diagram represents the two ways you can weave the three phase power to six elements. Sometimes there is what is called a "high leg," where one leg has a higher voltage than the other two. If this were your case and you wanted even heat in the kiln, use the pattern on the right as it would distribute the uneven voltage more evenly.

Our most recent large kiln project was a casting kiln with a three phase power supply of 480 VAC. The solution to the element layout for this kiln is a culmination of many of the techniques we have already discussed. The 480 VAC elements were made by connecting pairs of 240 VAC elements. It is a relatively large top loader (inside dimensions: 86 long x 33 wide x 26 tall, 43 cubic feet) so the elements are designed to go all around the kiln in rows. We have a small connection board in the front for making the matched pairs of 240 volt elements into six 480 volt element units. The main connection board is in back for weaving the three phase power.

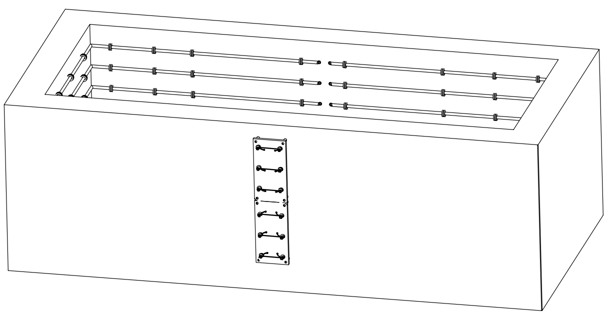


Fig. 49 This is a front view of the 43 cubic foot casting kiln looking at the connection bars hooking up pairs of 240 VAC elements to make sets of 480 volt element circuits. There are six pairs of these.

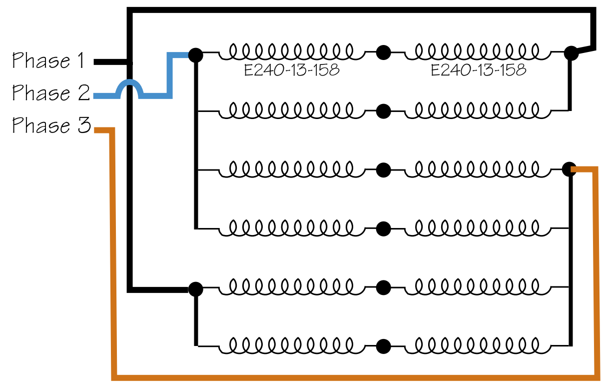


Fig. 50 This is the wiring plan for this large 480 volt casting kiln. Each row of elements is made of two E240-12-158 elements to make six pairs in all. They are wired similarly to the left pattern in figure 48.

The back side of this kiln is where the power connection boards are located and figure 51 depicts the actual pattern as it would appear. Figure 52 shows the double delta wired in parallel, another way for grasping what is actually going on with this electrical scheme.

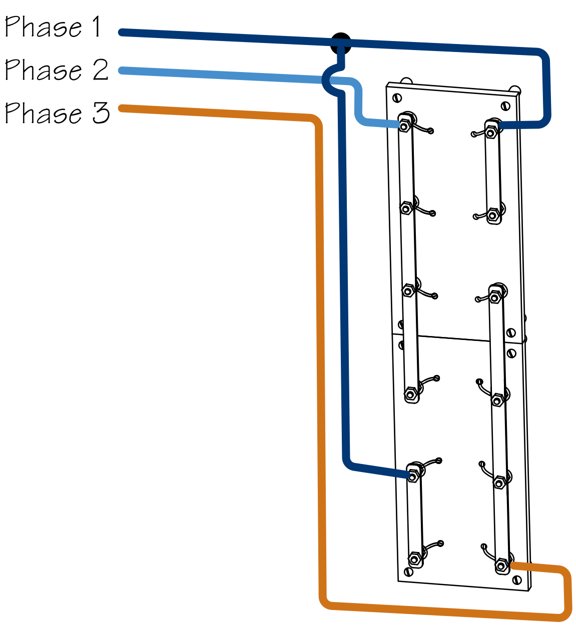


Fig. 51 The connection board for kiln shown in figure 49. This is located in the back of the kiln in the middle of the wall.

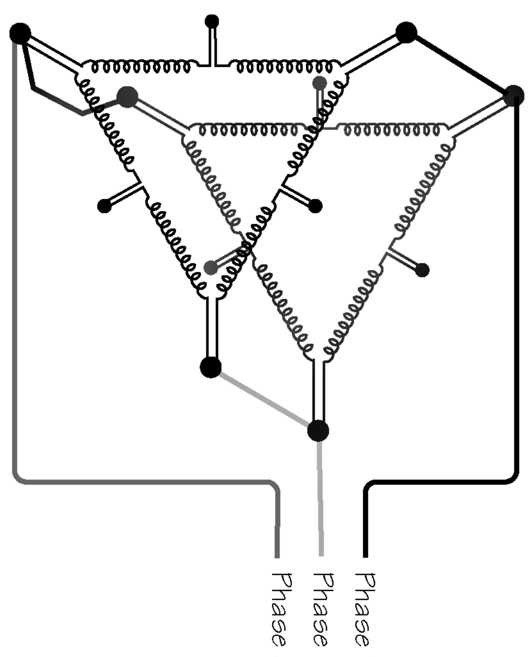


*Fig. 52 This wiring diagram shows the double delta wiring scheme where we have used pairs of E240-12-158 to make a 480 volt x 12 amp element unit. The kiln will draw 24 x 1.73 = 41.52 amps 3 phase and with the 85% rule will fit in 50 amp components (ref. p. 102, **A Glassblower's Companion**).*

The final item I want to incorporate in this paper is called a sectional element. Though not terribly common, it is something I have used to solve difficult installation problems in the last few years. Seeing it diagrammed opens the mind to a very wide range of possibilities. The example given is from a test furnace of about 1.5 cubic feet made of soft brick with a hard brick floor. The element name is E240-15-155/6 which means when it is all hooked up it is a 240 volt element that draws 15 amps made of 15 gauge wire wound on the 5/16" arbor, divided into 6 parts. The overall element requires 16 ohms of resistance so each section draws 16/6 = 2.67 Ohms. Basically it is a matter of tying together a bunch of little short elements. The diagram is shown on the right.

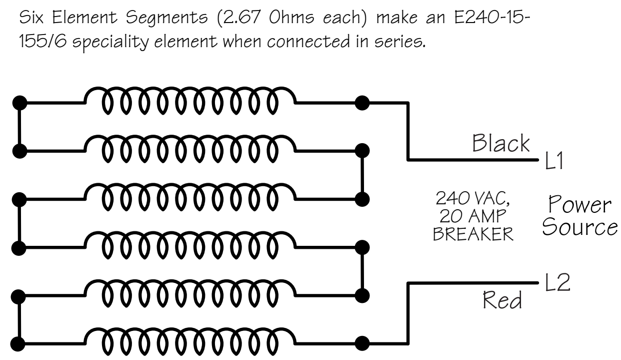


Fig. 53 This is a kiln schematic using a sectional element called the E240-15-155/6. The purpose of showing this example is to see the varied possibilities of element design.

This technique can be used in several ways: a sectional element may incorporate parts made of different wire gauges, or for that matter of different materials, like Kanthal and Nichrome for different sections of a kiln. I have used this in one of my lower temperature casting kilns where I buried an element section in the floor of the kiln which was made of Mizoo Castable. Hooked in series to an element in the upper kiln chamber it gives great all around heat for making refractory castings where a heated floor is important.

In Summary: This addendum to Dudley's Element Paper is presented to help the craftsperson better understand the wiring structure of kilns and to get a better grasp of what is possible. Another really positive aspect of this addendum is to push the craftsperson to grapple with wiring diagram imagery and concepts such as power source, 85% rule, single phase and three phase power, etc. With this diagramming shorthand one can begin to map out the overall electrical arrangements for all his workshop kilns and make better choices for power feed lines and breaker boxes and give a better overall understanding of the electrical limitations and possibilities.

For more information and for personal help with your kiln elements, design ideas, etc., call:

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