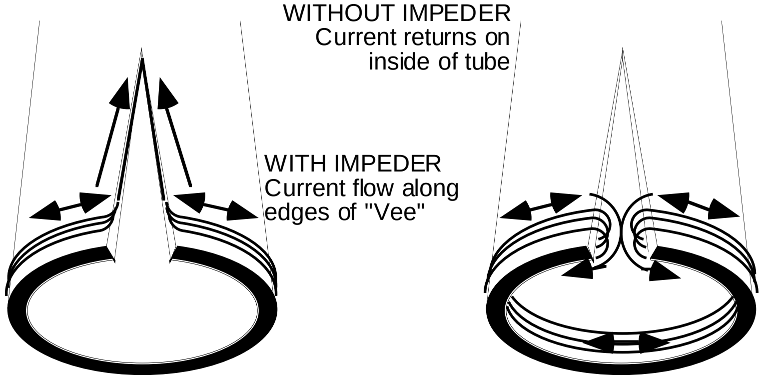
We receive a lot of questions from our customers concerning the operation of impeders, as well as other topics relating to high frequency welding. The following are a selection of the most common questions, together with our responses.

## *Why are impeders needed for induction welding?*

Impeders dramatically improve the efficiency of the welding process by directing more energy towards the edges of the strip. The high frequency magnetic field created by the work coil induces a current which flows around the outer surface of the tube. Since the tube is still open at this point, the current then transfers onto the edges of the strip and flows along them to the point where they are forced together by the weld rolls. The behavior of electrical currents at high frequencies causes most of the current to be confined to a very thin layer right at the surface of the strip edge, so rapid heating takes place owing to the resistance of the metal.




At 450 kHz., the typical operating frequency for induction welding, 90% of the current travels within a few thousandths of an inch of the material surface, so the current "sees" the inner & outer surfaces of the strip (or O.D. & I.D. of the tube) as separate conductive paths which are effectively isolated from each other. Without an impeder. the current which is induced onto the outside surface of the tube can complete the circuit by returning on the inside surface. This causes the entire tube to heat up, rather than just the edges, and the energy wasted in doing so may divert enough power away from the edges of the strip to make welding impossible.

Little can be done to increase the resistance of the inside surface of the strip, but fortunately we are dealing with high frequencies where resistance is not the only way of opposing current flow. Any electrical circuit has inductive reactance, which like resistance, is measured in Ohms, and which opposes current flow in a similar manner. Inductive reactance is zero for direct current, but increases linearly with frequency, and can be further increased by the introduction of a magnetic core. Ferrite is normally used for this purpose because it is a poor conductor of electricity and does not therefore heat up to the extent that an iron or other metallic core would. An impeder is simply one or more ferrite cores contained within a suitable non-metallic housing.

## *Is it possible to induction weld without using impeders?*

Impeders are less necessary when welding non magnetic materials. This because the degree of high frequency "skin effect" varies among different materials and is most pronounced in carbon steels. Below Curie temperature, 90% of the current flow in carbon steel is confined to within 0.005" of the surface. The skin depth is greater for non magnetic materials, typically 0.040" in the case of aluminium. Since current cannot flow in two opposite directions at the same time, materials that are thinner than twice the skin depth have less need for impeders, and light walled aluminium tubing is often welded without them. There is always some benefit to be gained from using an impeder. In addition to opposing current flow around the inside surface of the tube, an impeder increases the transfer of energy from the coil to the strip by "focusing" the energy in the area where it is needed. The coil has to produce a much stronger (and larger) magnetic field if an impeder is not used, and this causes wasteful and destructive heating of the weld rolls and other steel parts in the vicinity.

There are a few instances where weld quality may be improved by not using an impeder, and the higher power requirements may be a worthwhile trade-off. Under normal circumstances the tube edges are heated to a forging temperature that is well below the melting point of the material, but because the high frequency skin effect concentrates so much energy at the strip edge, the surface will sometimes melt, and this molten material is forced out of the weld area as a result of the pressure applied by the squeeze rolls, causing a large, rough weld bead to occur. This overheating may also cause oxidation and if oxides are not forced out into the bead, weld defects will occur. The heating can be made more gradual by either moving the coil, the impeder or both, or in some cases eliminating the impeder altogether. If impeders are not used, the R.F. voltage across the coil will be much higher, and care must be taken to avoid flashovers.

For tube diameters in the 3/4" to 2 1/2" range, induction welding without impeders will normally require 50% to 100% more power.

## *Are there any special requirements for induction welding stainless steels?*

Stainless steels present a number of problems. From a mechanical aspect, they have much in common with high carbon alloy steels, and they require special roll designs to overcome their resistance to cold forming and to compensate for spring back.

Because stainless steels have greater hot yield strength, more pressure has to be applied by the weld rolls to create the weld upset. This can be a serious problem with thin-walled tubing because the thin material has very little column strength, and cannot transfer the necessary pressure without buckling.

Stainless steels contain between 5% and 20% Chromium, which oxidizes very readily at the temperatures needed for welding. In fact it is this oxide layer that protects the surface of the metal from corrosion, giving it its "stainless" properties. Oxide inclusions cause weld defects and they must either be forced out of the weld, into the bead, or preferably prevented in the first place. The higher the chromium content, the more difficult it is to weld. Oxidation can be prevented by enclosing the weld area in a low pressure inert shielding gas such as nitrogen. Simply blowing a jet of nitrogen onto the heated part of the tube is not very effective because additional oxygen from the surrounding air is usually mixed in with the inert gas. Oxygen should be displaced from the inside of the tube as well, since air is carried along with the strip.

Some tubing manufacturers believe that using a lower welder frequency can improve weld quality, but the same effect can be achieved by moving either the coil or the impeder or both upstream to provide a longer heat soak.

## *How long should an impeder last?*

This is one of the most frequent questions we get asked, and one of the hardest to answer. Nothing actually gets "used up" in an impeder as a result of being exposed to high frequency magnetic fields. All

impeder failures occur because the ferrite or casing becomes damaged by mechanical means or exposure to heat. If it is protected from these elements, an impeder should last indefinitely, but as we all know, they don't, so we should concentrate on extending the life as much as possible.
The primary cause of failure is overheating. Impeders should be provided with clean water at a minimum of 40 PSI. There is no need to use chilled water, but the inlet temperature should not exceed 75°F and should be kept reasonably constant because the magnetic characteristics vary with temperature.

Impeders should also be properly supported inside the tube. Simply hanging one on the end of four feet of twisted and kinked copper tubing will greatly shorten the life due to vibration and abrasion against the tube.

## *Can they be recycled?*

Impeders smaller than about 1-1/2" in diameter are inexpensive, and are not worth trying to salvage. There may be some purpose in recycling the brass components, but they are usually worn or distorted to the point that their only value is a scrap metal.

Ferrite could theoretically be recycled by re-milling it and forming it into new rods, but the economics are just not there yet. Ferrite is essentially rust - just oxides of iron, nickel & manganese, all of which are cheap & plentiful. The price of ferrite is a reflection of the highly complex and controlled manufacturing process, which would be equal or greater if recycled material were to be used.

Larger impeders are usually constructed in such a way that they can be repaired by replacing any ferrite that has been damaged, as well as the outer casing.

**What makes some impeders perform better than others?**

Many different types of ferrite are available to suit a variety of purposes, but very few are suitable for use in impeders. Using the wrong grade of ferrite can cause an apparent loss of weld power, as well as premature failure of the impeder*.

Proper cooling design is also very important. The magnetic characteristics of ferrite vary widely with temperature.

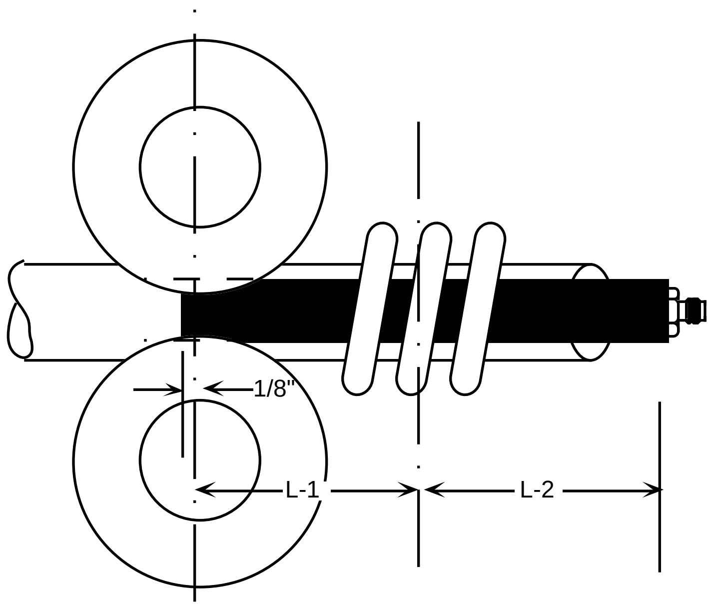
## *What are the ideal positions for a coil and impeder for various tube sizes?*

The position of the coil is usually dictated by the design and size of the weld roll assembly. For maximum weld efficiency, the coil should be as close as possible to the weld point. In practical terms, this is usually about equal to the radius of the squeeze rolls. The coil will heat the rolls and support structure if it is too close, so it should be far enough way to minimize this.

Impeders should be positioned so that the end of the ferrite is just beyond the weld point. (See diagram on the following page.) Extending the ferrite too far down the tube has no adverse effect, but having it too short will cause a dramatic reduction in weld speed. The length of the ferrite should be sufficient that it extends beyond the coil for the same distance upstream and downstream.

Impeders are usually positioned close to the centerline of the tube. There is a small gain in efficiency if the ferrite is above centerline, as close as possible to the edges of the strip, but it is more vulnerable to heat and mechanical damage in this position.

* see our publication "Ferrimagnetic Materials for Induction Welding"




**L-1 should be as short as possible - L-2 is equal to L-1.**

## *What type of ferrite should be used in an impeder?*

Because impeders operate at very high levels of magnetic flux, ferrite materials intended for high frequency power transformer applications are the most suitable. These grades have fairly high permeability and will not become magnetically saturated at the power levels used in most induction welding situations. They also have low electrical losses at 200-500kHz., the frequencies used by most welders. TDK Corporation, who are one of the largest ferrite manufacturers in the world, manufactures a grade of ferrite specially formulated for induction welding, where the various parameters have been optimized for this application. This is a manganese/zinc ferrite with particularly high Curie temperature, and a very flat temperature/permeability curve. Nickel/zinc ferrites are intended for use at much higher frequencies and low power levels, and they do not perform very well in impeders.

## *What material works best for impeder casing?*

The casing serves to protect the ferrite, and to direct coolant around it. All materials used in impeders should be poor conductors of electricity, although they don't have to be insulators in the normal sense. Any metal present in the vicinity of the coil will be induction heated. Most impeder cases are made from silicone or epoxy glass laminates because these are inexpensive and easy to fabricate, while having good resistance to heat and abrasion. Some specialized impeders use quartz or ceramic tubes to enclose the ferrite. While these have excellent resistance to heat, they are sensitive to mechanical damage, are very difficult to machine, and are quite expensive.

A special ferrite filled epoxy/glass tubing has been available for a number of years, which can boost impeder performance as a result of the additional mass of ferrite in the casing itself. In the case of very small impeders, this can account for 30% to 40% of the total weight of ferrite, and can increase weld speeds by a like amount. The additional ferrite present in the casing itself is located very close to the tube I.D., where it is most effective.

## *Why do impeders require cooling and what pressure & flow are required?*

A theoretically perfect ferrite material would not require cooling, but unfortunately this isn't a perfect world, and such a material doesn't exist yet. Heat is generated within the ferrite by two causes. When ferrite or any other magnetic material is within an alternating magnetic field, the material reverses polarity at twice the frequency of the field. Since all magnetic materials retain some magnetic "charge", this residual magnetism has to be overcome by the energizing field, and the energy required is converted to heat. At low frequencies, not much heat is produced, but at 450 kHz, it is the major cause of ferrite heating.

Manganese/zinc ferrites conduct electricity to some extent, so eddy currents are induced in them by the work coil. These currents flow around the outer circumference of the ferrite, causing further heating due to the resistance of the material. Eddy current heating can be reduced by using ferrite which has longitudinal slots, which increase the length of the current path. The slots also provide additional surface area for cooling.

Most impeders are designed to operate satisfactorily at 40-60 PSI of water pressure. Pressures in excess of 100 PSI may rupture the casing, or cause leakage due to expansion of the casing away from the fittings.

## *Can impeders be air cooled?*

Cooling by air or other gas is not generally effective because of the very high volume needed to remove all the heat which is being generated. The specific heat of gasses is only about 1/800 that of water, so 800 times the volume is required to achieve the same rate of heat removal. This can be reduced somewhat by chilling the cooling gas, but the quantities required are still very large.

The formation of oxides during welding is the cause of many weld defects, and using air to cool impeders only makes this problem many times worse. If impeders must be gas cooled, an inert gas such as nitrogen should be used, and the temperature at which it is introduced to the impeder should be 40° F or lower. For situations that demand a tube with a dry interior, return flow liquid cooled impeders are available, and are usually a much better choice.

## *Is it possible to test an impeder before installing it on the mill?*

A simple and effective test is to place the impeder inside a coil, and then measure the inductance of the coil using a suitable instrument. The meter should first be calibrated using a new impeder that is known to be good. Electronic Heating Equipment manufactures an inexpensive inductance meter for testing impeders.

## *What effect does frequency have on induction welding?*

The operating frequency of induction welders is usually in the 200 to 800 kHz range, with the vast majority operating at 450 kHz. This frequency was chosen more because it is unlikely to cause interference with radio communication than because of its inherent suitability for welding. Although the "skin effect" is dependent on frequency, the effect on welder efficiency is less than might be expected due to thermal conduction.

There is however a major difference in the performance of impeders as the frequency is increased. Impeders work by increasing the inductive reactance of the inside surface of the tube, and reactance is directly proportional to frequency, all other things being equal. Because of this, a given mass of ferrite will be twice as effective if the frequency is doubled, say from 400 kHz to 800 kHz. If a mill is to be used for the production of small diameter tubing, where it is difficult to accommodate the necessary amount of ferrite, increasing the frequency of the welder will have a major effect on weld speeds.

## *Some tubing shows "stitching" on the weld seam. How can this happen with H.F. welding?*

One of the big selling points of induction welding used to be that it eliminates the stitching effect that occurs with low frequency ERW. Stitching occurs on ERW because welders operate on alternating current, typically at a frequency of 180 or 360 cycles per second (Hz). This means that the current that heats the tube rises from zero to peak, then goes back to zero twice for every cycle. When the current is zero, no heating takes place, and these cold spots will occur every 1/360 or 1/720 of a second. With a mill operating at 200 feet per minute, the "stitches" are spaced 1/9 of an inch apart at 180 Hz. At the frequency of induction welding, the stitches should be so close together that they are integrated to produce a completely smooth weld, but under some circumstances, stitching may still occur.

The reason lies in the fact that welder power supplies operate off 60 Hz line current, and any imbalance between the 3 phases can cause a ripple to appear on the high voltage D.C. supply used by the welder. It is not uncommon for one of the three phases to be 20 volts lower than the others, and this will cause very noticeable stitching on thin walled tubing. The SCR controllers used on most current welders can also cause stitching if they are not properly balanced. A 2% voltage change causes a 4% variation in power, so even a small amount of ripple can have a very noticeable effect on weld quality. Most induction welders use filters to remove the 360 Hz. ripple from the SCR phase angle controllers, but few are equipped to filter out the 60Hz. ripple caused by phase imbalance, although some SCR controllers can compensate for this.

## *Are there any health risks associated with working near H.F. welders?*

There is a lot of concern these days about the long term health effects of exposure to low frequency, non ionizing radiation of the type generated by power lines, computer monitors and even cellular phones. Induction welders have the potential to produce the same type of radiation, particularly in the vicinity of the coil, transmission lines and tank circuit components. So far there is no proven link between this type of radiation, and any type of health hazard, but avoiding unnecessary exposure is probably a wise precaution. Electromagnetic radiation drops off very rapidly with distance from the source, and at the 3 to 10 ft. distance at which mill operators are exposed, the risk to health is minimal.

At close range, induction welders can affect the operation of certain types of cardiac pacemakers. If you have one of these, you should not work in the vicinity of a high frequency tube welder without first consulting your doctor.

Induction welders concentrate a lot of energy into a very small area, and the voltages and currents applied to the work coil are very high. The high frequencies used by welders are not generally considered to constitute an electrical shock hazard but serious deep burns will result if you touch any part of the coil, coil clamps or bus bars while the welder is operating. These burns can be severe enough to completely incinerate a finger! No part of the body should be brought closer than 6" from any metal object that is electrically connected to the welder output terminals.

*If the welder uses an SCR phase angle controller, and the B+ voltage is not adequately filtered, the high frequency output may be modulated at some multiple of the line frequency. This presents a very high shock hazard.*

## *What is ferrite?*

A natural mineral form of ferrite called magnetite has existed since the Earth's early beginnings, and was the "lodestone" used by ancient navigators in primitive compasses. Commercially used ferrites are all manufactured products, and were developed independently by scientists in Japan and Holland during the 1940's.

There are two main types of ferrite, which are referred to as "hard" and "soft" ferrites. These terms do not refer to physical hardness, but rather to their abilities to retain magnetism. Soft ferrites retain very little permanent magnetism, and are the type used in impeders.

All ferrites are ceramic crystal structures formed from ions of iron, manganese, nickel, chromium, zinc and oxygen. There are not alloys or mixtures of metals. Physically they are hard, dense and brittle, and can only be machined using diamond or cubic boron nitride saws and grinders.

Ferrites have similar but superior magnetic properties to the iron or steel laminations used in low frequency transformers, with the additional advantage that they have much higher electrical resistivity than metals, so eddy current heating is reduced. They can also be easily formed in a variety of intricate shapes.

Ferrites are relatively expensive because of the complex and critical manufacturing processes involved, although the raw materials are plentiful and cheap. A simplified overview of the manufacturing process is as follows:

> High purity oxide powders of iron, zinc, manganese, cobalt and nickel are mixed and blended.
>
> The mixture is then calcined - heated in a kiln at 900° C to 1100 °C - to start the process of forming the ferrite crystal lattice.
>
> The calcined material is ground to a fine powder in a ball mill, then dried, mixed with a binder and formed into shapes either by extrusion or pressing.
>
> The shaped pieces are dried, then sintered in a controlled atmosphere furnace at 1200° to 1400° to form the spinel crystal structure. During this phase, the material shrinks by as much as 40%.
>
> Final grinding and polishing may be applied if necessary to meet critical dimensional requirements.

## *What causes some materials to be "magnetic"?*

The origin of magnetism lies in the atomic structure of the elements that make up the material. All atoms have electrons that spin in discrete orbits around a nucleus. Since electrons can be represented as electrical charges in motion, they produce a weak magnetic field. In most elements, electrons act in pairs with equal and opposite moments, so the weak electromagnetism is canceled out, however a few elements have electron orbits which are not paired, and which align in the same direction producing a very weak magnetic bulk effect.

Ferromagnetism, a property of only a few metals such as iron, nickel, cobalt and manganese, is a bulk effect where large numbers of atoms group together and combine their spin moments so that they are aligned in the same direction. These regions may contain as many as $10^{14}$ atoms, and are called magnetic domains. The atomic alignment tends to decrease as temperature increases, until a temperature is reached called Curie point, at which ferromagnetism ceases.

When the magnetic domains are aligned and locked within the crystal lattice, the material retains a “permanent” magnetic state, and will attract or repel other ferromagnetic material. If the domains are not locked within the lattice, the material will be attracted to “permanent” magnets, but will retain little or no magnetism itself. Materials that have the property of ferromagnetism “conduct” magnetic flux in a manner similar to that in which electrical conductors carry electricity.

Ferrites are more complex than bulk metals. There are oxygen atoms as well as metal atoms in the ferrite crystal lattice, and these interact in a manner called ferrimagnetism. In a bulk sense, they form domains similar to ferromagnetic materials, but they retain special properties that are unique to ferrites, such as high resistivity and in the case of soft ferrites, very low retentivity. These properties make them ideally suited to use in impeders.

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