TECHNICAL BULLETIN

EHE

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COOLING CONSIDERATIONS FOR IMPEDERS & COILS

Impeders require cooling for several reasons. The most obvious one is that they operate in close proximity to hot material however this only contributes a small fraction of the total heat which must be removed by the cooling medium.

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 main causes - hysteresis heating & eddy current heating. Some additional heat may be produced as a result of magnetorestriction if the ferrite is cycled through saturation.

Hysteresis Heating

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 a major cause of ferrite heating. The ability of the magnetic domains to align themselves with the applied field is affected by temperature. As temperature is decreased, more energy must be applied to change the magnetic polarization of the domains, so more heat is produced. Because of this, it is counterproductive to cool ferrite excessively, as this actually produces more heat! Most ferrites intended for use in impeders operate most efficiently at temperatures in the 80° to 120°C range.

Eddy Current Heating (Resistance Heating)

All 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 (fluted ferrite), as this increases the length of the current path. The slots also provide additional surface area for cooling. The electrical resistivity of ferrite is dependant upon formulation, processing parameters & density. The higher the resistivity, the less eddy current heating will be produced.

For any given flux density, hysteresis heating is proportional to the rate of change (or frequency) of the applied field, however eddy current heating increases with the *square* of the frequency. In induction welding, higher frequencies require lower flux densities so the square law does not apply fully, however it is still true that hysteresis heating predominates at low frequencies, whereas eddy currents are the primary source of heat at higher frequencies.

Ferrite Loss Factor

The total losses in ferrite vary considerably according to grade and manufacturer. These losses are generally quoted in watts per kilogram, or watts per cubic centimeter. Most ferrite materials have a density of 4.8 to 5 grams per cubic centimeter.

The total losses in one popular grade of impeder ferrite, measured at a frequency of 200 kHz. & a flux density of 200mT, are in excess of 10 kW/kg., whereas EHE's Ferromax™ 2000 grade, which was specifically engineered for low loss, has total losses of 1.3kW/kg. The Ferromax™ 2000 material therefore only requires 1/8 as much cooling. In the case of large impeders, where plenty of coolant flow is available, this may not have a noticeable effect on performance, however with small impeders, especially in return flow or gas cooled applications, the low loss ferrite has obvious benefits & may even determine whether a particular product can be succesfully induction welded or not!

Flux Density

The flux density within the ferrite is higher in induction welding than in most other ferrite applications, and a portion of the ferrite is usually magnetically saturated. Since the heat produced in the ferrite is a function of flux density, any steps that can be taken to reduce this without otherwise affecting production speed or weld quality, are of benefit.

Flux enters the impeder through the open "vee" of the tube, so the amount of magnetising force applied to the ferrite is to some extent dependent of the "vee" area. Keeping the "vee" length short and the approach angle as small as possible not only increases the efficiency of the induction heating process, but also minimizes impeder heating and even the degree to which an impeder is required.

Water Cooling

Most impeders are cooled by water or mill coolant, and are designed to operate satisfactorily at 40-60 PSI of coolant pressure. Pressures in excess of 100 PSI may rupture the casing, or cause leakage due to expansion of the casing away from the fittings. In the case of return flow impeders, excessive pressure will cause some inflation of the impeder casing, possibly resulting in leaks at the seals.

Cooling System Design

The central coolant system on most mills does not provide adequate pressure or filtration for impeder cooling. A turbine or multi stage centrifugal pressure boost pump is generally required & these are available from ourselves, and from many other sources. A 1 horsepower pump will provide plenty of impeder cooling for mills up to 6". We also recommend that a 250 micron or finer filter be installed, as well as a flow switch interlocked to the welder run enable circuit, so that the mill cannot be operated if there is insufficient flow.

Chillers are not generally required for impeder cooling, however they may be of benefit when using very small impeders, especially if these are return flow types. By chilling the coolant delivered to the impeder, cooling may be accomplished at much lower flow rates. Chillers can be extremely beneficial for work coil cooling since the resistivity & hense the losses in copper increase dramatically with temperature.

Gas Cooling

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 volume specific heat of gasses such as nitrogen 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. A typical small impeder requiring 0.5 gallons/minute of water cooling will require in excess of 15 cubic feet per minute of air or nitrogen!

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. Using cryogenic liquified gas does not work well because the magnetic (hysteresis) losses in the ferrite increase at lower temperatures. (see Hysteresis Heating)

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