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# Precision Induction Heating With Advanced Solid State Technology

*By Girish Dahake, Ph.D.*

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## *How New Technology Improves Heating Accuracy, Flexibility & Speed*

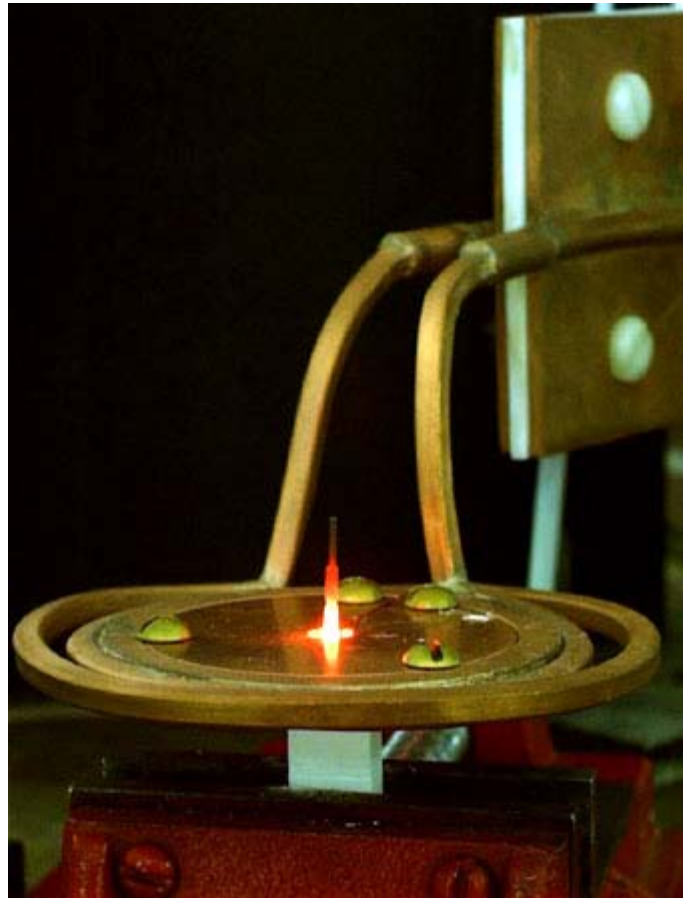
High Frequency & Rapid Tuning  
Improve Annealing Process For  
Copper Crimp Connectors

Brazing Small Diamond Tips on  
Cutting Tools Using High Frequency,  
Solid State Power

RS-485 Connection Simplifies Epoxy  
Curing With Induction Heating

Small Remote Heat Station Solves  
RF Connector Soldering Issues on  
Conveyor Line

Closed Loop Temperature Control  
Improves Tempering Process For  
Steel Punches



*Annealing Copper Crimp Connectors*

# Precision Induction Heating

## With Advanced Solid State Technology

By Girish Dahake, Ph.D.

### Introduction

The purpose of this Tech Note is to demonstrate the advantages of Ameritherm's new Nova Star technology for precision induction heating applications. In each section, we will show how a particular aspect of this new technology makes a crucial difference in running a specific process or application successfully.

Ameritherm was the first North American manufacturer to introduce all solid state induction heating RF power supply technology in 1986, and we have pioneered its use in a diverse range of processes. Today, Ameritherm systems are known worldwide for their speed, reliability and consistency. Our new Nova Star technology advances the industry standard for induction heating performance to a new level of cost-effective precision.

Among the many advantages of the new technology, this document will focus on six: rapid digital tuning, advanced microprocessor control, high frequency operation and closed loop temperature control, as well as the RS-485 interface and flexible remote heat station which are standard with every Nova Star power supply.

In the first section, Nova Star's rapid digital tuning and high frequency operating range produce faster throughput and increased production rates in an annealing process for copper crimp connectors. Next, the new technology's high frequency operation allows induction heating to be used for brazing miniature diamond tips on cutting tools.

The Nova Star standard RS-485 interface allows the user to download process data into a computer for statistical process control. The epoxy curing process described in the third section illustrates

the benefits of this feature. The next section shows how the Nova Star remote heat station, which can be located up to 200 ft. away from the power supply, offers significant advantages for a conveyor line manufacturing operation. Finally, the fifth section illustrates how closed loop temperature control improves a tempering process for steel punches.

### High Frequency and Rapid Tuning Improve Annealing Process For Copper Crimp Connectors

#### The Problem

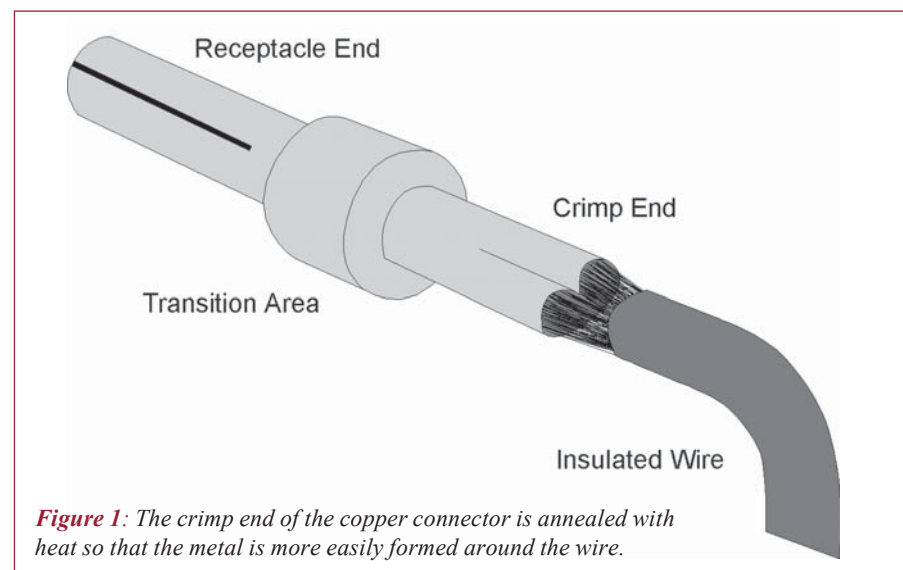
Existing induction heating processes for annealing copper crimp connectors often produce inconsistent results and unsatisfactory yield. In this section we will show how the Nova Star's high frequency operating range and rapid digital tuning combine to increase throughput and improve consistency for this type of process.

Crimping is the metallurgical compression of a terminal around the

conductor of a wire to create a common electrical path of low resistance and high current carrying capability. This technology was developed to provide a high quality terminal-to-wire connection at a relatively low cost, replacing the soldering process and its associated problems.

Before the crimp connector and wire are joined, the end of the connector is annealed or softened with heat so that the metal is more easily formed around the wire. The annealed end is then compressed around the conductor of the wire to produce an electrical path for the current. As shown in Figure 1, the other end of the connector is typically the female receptacle for a plug. This end compresses onto the pins in the plug to provide the electrical contact.

Crimp-style connectors are typically made of beryllium copper. Unlike other materials, which sacrifice formability to achieve favorable spring characteristics, beryllium copper is easily stamped and formed. Once formed into the desired contact shape, the part can then be heat-treated to obtain the required properties.



*Figure 1: The crimp end of the copper connector is annealed with heat so that the metal is more easily formed around the wire.*

Most existing annealing systems utilize multi-turn pancake style coils and are powered by large, relatively inefficient vacuum tube power supplies. The output is often inconsistent and constant adjustments are needed to maintain product quality. The Nova Star series power supplies automatically tune their frequency of operation to the load during every cycle, providing optimized precision heat to every part. Digital frequency synthesis and microprocessor control deliver repeatable results, part after part, cycle after cycle. As a result, a 3kW Nova Star solid state power supply can often replace a much more powerful older machine, thus reducing cost.

**Materials & Process**

To selectively anneal the crimp end of the connector without affecting the receptacle end, the Nova Star 3H power supply is used along with a specially designed, plate concentrator induction coil. The power supply delivers 3kW at the process frequency of 600kHz, providing a precise band of heat to the end of the connector. The exact process temperature will range from 900°F to 1300°F depending on the amount of annealing required. Note that the position of the connector inside the induction coil will determine the size of the annealing zone; the coil’s concentrator plate should be placed just above the tip of the crimp end of the connector as shown in Figure 2.

The use of fewer turns in the coil increases the operating frequency and reduces copper loss. The higher operating frequency of the power supply and coil increases the coupling efficiency of the magnetic field to the part, and increases the efficiency of the entire process. This reduces the time required to heat to the proper annealing temperature.

Since copper is a very good conductor of heat, the annealing cycle needs to be fast. As shown in Figure 3, the Nova Star 3H power supply was programmed to maintain a total process cycle of 0.6 seconds with an annealing temperature of 1300°F. Note that the power supply requires only .02 seconds for digital tuning and that the power supply is fully on within .12 seconds from the start of the heating cycle. To rapidly dissipate heat, the

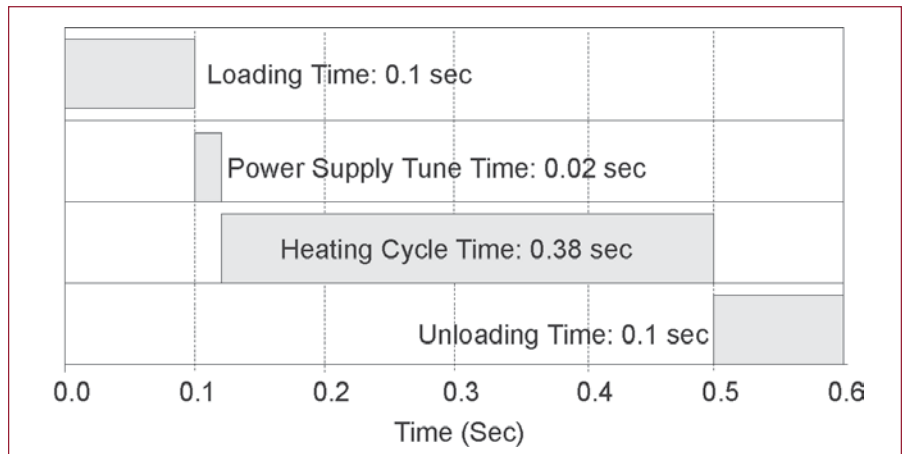
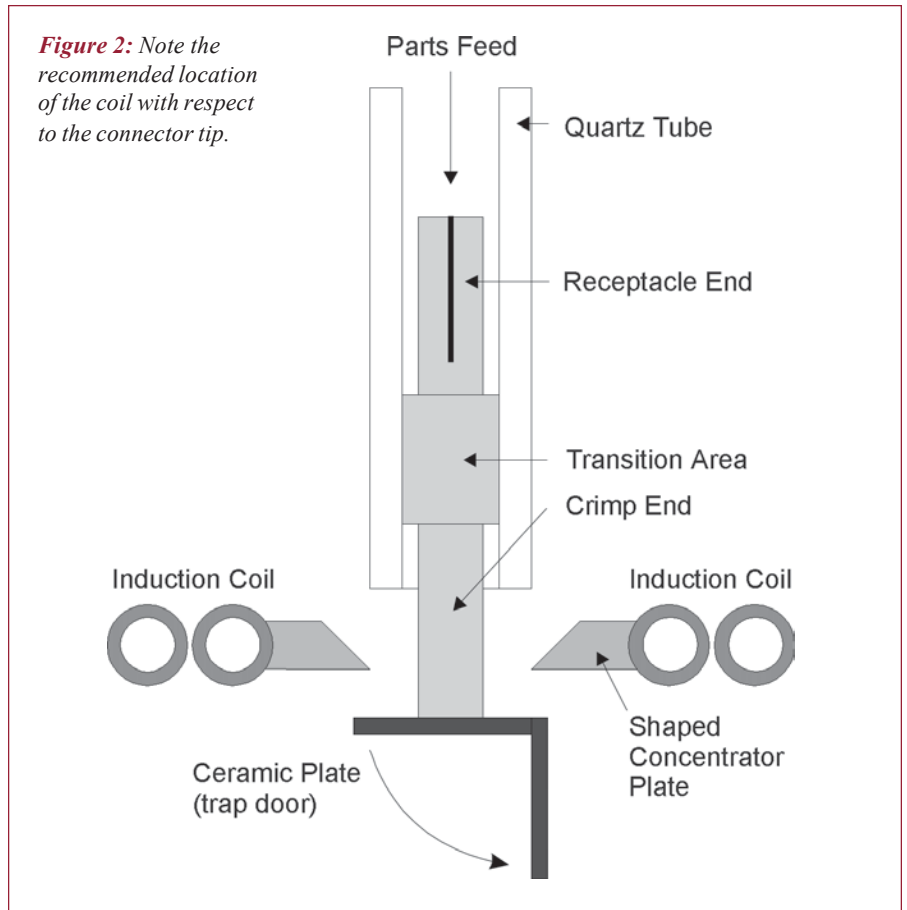


Figure 3: The Nova Star 3H was programmed for a short 0.6 second heat cycle, and required only 0.02 seconds for digital tuning.

connectors should be quenched with water immediately following the heat cycle. This short heating cycle increases throughput, strictly limits the annealed area and maintains good strength associated with cold forming in the remaining section.

**Conclusion**

Ameritherm’s new Nova Star technology has specific advantages for this type of annealing process. The high operating frequency and rapid digital tuning of the Nova Star 3H power supply reduce both time-to-temperature and the heating cycle, thereby improving process repeatability and increasing throughput.

## Brazing Small Diamond Tips On Cutting Tools Using High Frequency Solid State Power

### The Problem

The operating frequency range of existing induction heating power supplies is too low for effective brazing of small parts such as diamond tips for precision cutting tools. In this section, we will show how the high frequency range of Ameritherm's Nova Star technology brings the advantages of induction heating to this type of process.

To manufacture polycrystalline diamond (PCD) and polycrystalline diamond boron nitride (PCBN) cutting tips for high-speed machine tools, small (0.03" across) synthetic diamonds are brazed to the corners of carbide inserts or steel shanks as shown in Figure 4. The diamond acts as the cutting tip while the carbide insert or steel shank mounts to the fast-moving machine head. The braze joints are ductile, able to withstand considerable vibration and shock, and are easy to remove when the diamond tip breaks or wears in use. The brazing is done at relatively low temperatures to reduce the possibility of thermal damage to the PCD or PCBN section. A braze preform is used as the filler metal.

Manufacturers have used flame brazing for this type of process, despite its inconsistencies and limited yield, because no induction heating power supply could operate above the critical

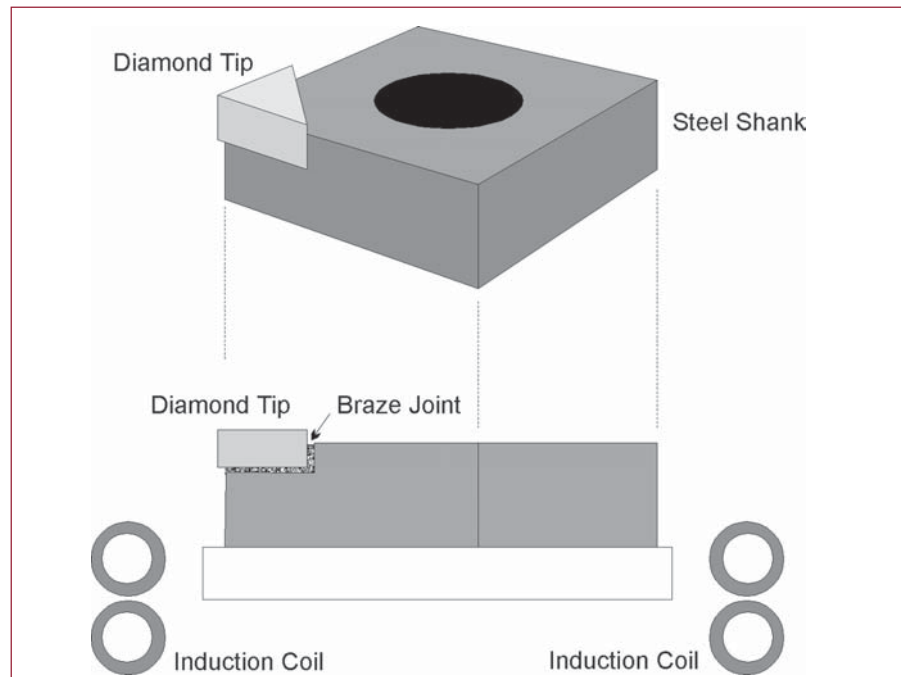


Figure 4: Diamond tips are brazed to the corners of steel shanks for high-speed machine tools.

cutting tools with precision and advanced repeatability. Digital frequency synthesis and microprocessor control deliver repeatable results, part after part, cycle after cycle. Nova Star's continuous digital tuning provides more efficient heating, particularly as small parts go through Curie.

### Materials & Process

The diamonds are typically 0.03" triangle-shaped and the carbide inserts or steel shanks vary greatly in size and shape. The shape of the coil along with the proper selection of the operating frequency delivers sufficient heat into the parts for

increases. Another factor which must be considered is skin depth, which is defined as the outer layer of the material within which 80% of the induced power is dissipated. The skin depth is given by this fundamental equation:

$$d = 3160 \sqrt{\frac{\rho}{\mu \cdot f}}$$

where

$d$  is the skin depth in inches

$\rho$  is the resistivity in ohm-inches

$\mu$  is the permeability of the material

and  $f$  is the operating frequency in Hz

This formula dictates that for optimum heating of small parts the operating frequency of the induction equipment should be above 50kHz. However, it is important to realize that the optimum frequency for heating a part changes as the part goes through Curie. In this application, the carbide insert or steel shank becomes non-magnetic above 1370°F and loses the heating effect due to hysteresis losses. Only eddy current heating occurs above this temperature. When taking into account the overall size of the diamond tip and carbide insert or steel shank, the size and design of the coil and the resulting low coil inductance, higher operating frequencies in the 400-700kHz are required for efficient energy transfer in this process.

***“Historically, the industry standard has been torch (flame) braze joints. We have used both torch and induction brazing and we are convinced that the numerous advantages offered by the Ameritherm Nova Star provide us with a superior braze joint.”*** Michael A. Yokum, Production Supervisor Cutting Tools, CITCO Operations of Landis/Gardner

frequency of such a small part (critical frequency is the operating frequency above which there is no cancellation of induced magnetic field inside the part; the smaller the part, the higher the critical frequency).

Ameritherm's new Nova Star technology provides high frequency coverage up to 1.2MHz to efficiently heat small parts such as diamond tips for

this brazing application. The water-cooled coil sets up a magnetic field which induces an eddy current in the part. This eddy current flows against the resistivity of the material and produces heat. With magnetic materials, the eddy current heating is complemented by heating due to magnetic hysteresis. The induced magnetic field in the part is strongest on the surface and drops off exponentially as part depth

The Nova Star 3L was selected for this application, operating at 403kHz and programmed to produce 1400°F. The miniature diamond tips were successfully brazed to a steel shank with a ten-second heat cycle. At this rate, well over 200 parts could be brazed per hour.

### Conclusion

The high operating frequency range of the Nova Star 3L makes it possible to use induction heating to braze very small parts such as the diamond tips required for this brazing process. Other similar manufacturing processes can also now benefit from the advantages of modern induction heating: improved repeatability, faster cycle time, pinpoint accuracy, selective heating, flexible setup and environmental cleanliness.

## RS-485 Interface Simplifies Epoxy Curing With Induction Heating

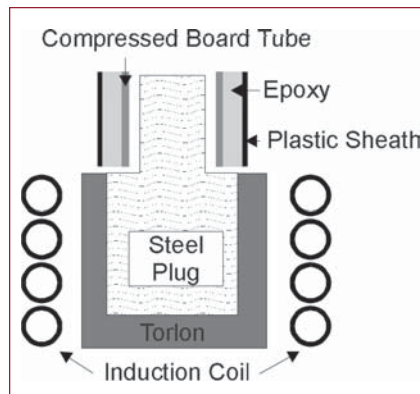
### The Problem

Epoxy curing in high-volume applications poses significant problems for existing heating technology. It has been difficult to maintain precise curing temperatures for several minutes and still maintain throughput. Because of the high production volumes required, a dedicated heat source for each part is not practical. Since oven heating is also often impractical because of the inefficiencies of radiant and convective heat transfer, a better solution is required for high-volume applications.

The Nova Star 3L Power Supply with its available RS-485 interface can solve this process problem. In this section we will show how to use the standard Nova Star 3L with an optical pyrometer to determine precisely how much heat is required to maintain the proper curing temperature for this process.

### Materials & Process

The Nova Star serial RS-485 interface allows the power supply to be fully controlled from a personal computer or system controller with software packages such as Procomm<sup>®</sup> or HyperTerminal<sup>®</sup>. Full operational control is available, with commands to set the voltage, control the heat, start and stop the heat cycle, and set the heat cycle timer. Full status readout is



**Figure 5:** The steel plug transfers its heat to the epoxy for curing.

also available by using the “READ” command. The Nova Star 3 responds with a data stream consisting of DC voltage, DC current, DC power, operating frequency, heat-on time, power supply status, and internal fault diagnostics. Since the data request, gathering and transmission take approximately 100ms, the full heat cycle characterization is achievable.

This application involves heating a small steel plug, which in turn provides the thermal energy for curing the epoxy on the part. As shown in Figure 5, the plug is 1.125” in diameter and rests in a Torlon plastic mold. For a complete cure, the temperature at the epoxy surface must be maintained at 400°F for six minutes. Figure 6 illustrates the tooling at the production site: a rotary table with space for 30 steel plugs placed equidistant along the

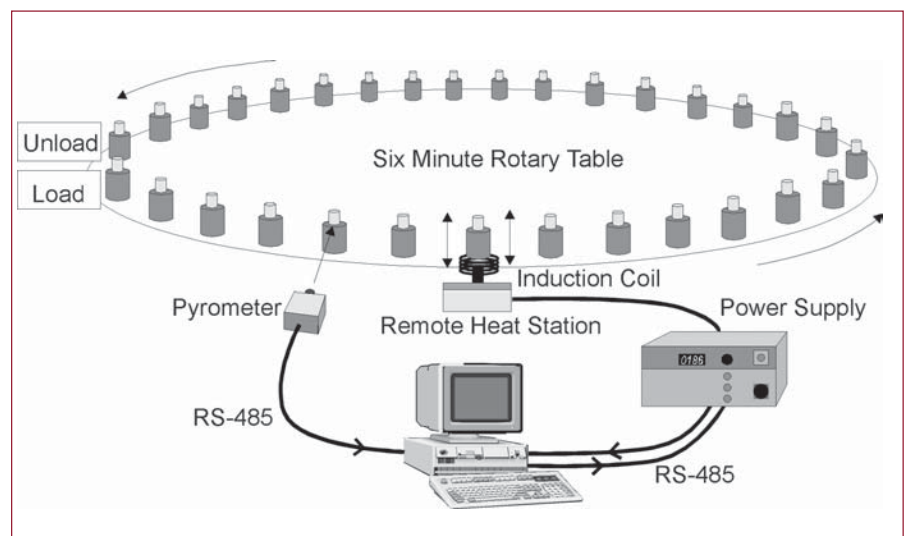
circumference. The process allows for 4 seconds of heating time per 6-minute cure cycle. The parts are loaded on the steel plugs at one station and heated to a surface temperature of 450°F in 4 seconds.

The Nova Star 3L delivers 3kW of power at 186kHz for this application. As the table rotates each plug away from the induction coil, they gradually transfer their heat to the epoxy assemblies and torlon plastic. At the end of the cycle, the parts are unloaded off of the steel plugs, and then a new heat cycle begins with fresh parts.

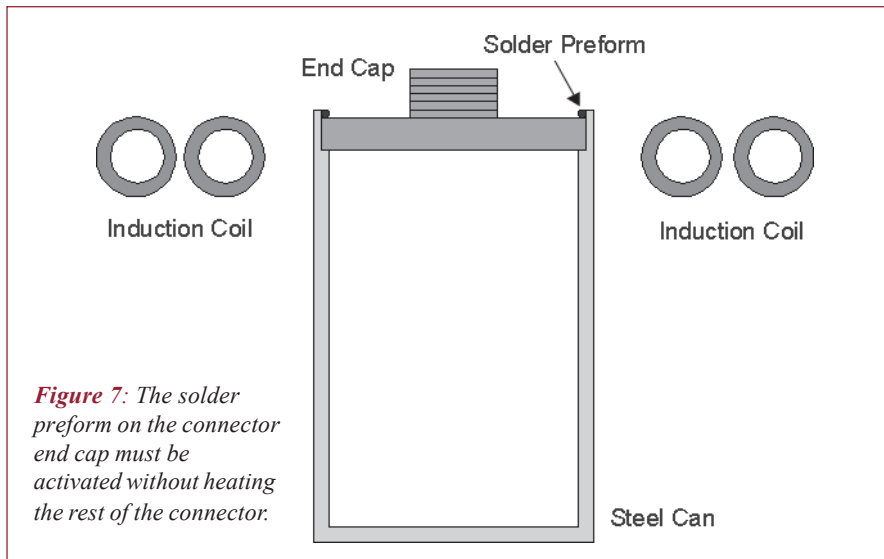
Each steel plug retains some of its heat from one heat cycle to the next. An optical pyrometer measures the temperature of each plug just before it enters the induction heating coil. Using the RS-485 interface, a determination is made as to how much energy needs to be delivered to the plug to bring its temperature back to 450°F. The Nova Star 3L is instructed through the RS-485 interface to deliver the right amount of heat for the predetermined time to each steel plug.

### Conclusion

The Nova Star 3L’s RS-485 interface connection, together with the optical pyrometer’s heat measurement, enabled induction heating to be used successfully for this application. With the necessary temperature data and communications link, the power supply can precisely maintain the temperature of the steel plugs for correct curing of the epoxy.



**Figure 6:** The computer instructs the power supply to deliver the required energy to heat the steel plug to 450° F.



**Figure 7:** The solder preform on the connector end cap must be activated without heating the rest of the connector.

## Small Remote Heat Station Solves RF Connector Soldering Issues On Conveyor Line

### The Problem

Assembly line production of RF connectors is difficult to handle with existing induction heating systems. The flux fumes produced by the process are highly corrosive and damaging to both the power supply and its attached induction coil. Also, the high voltage requirements of most existing power supplies produce excessive arcing. In this section, we will show how a low voltage, compact remote heat station available for Nova Star power supplies can make the crucial difference for this induction heating process.

### Materials & Process

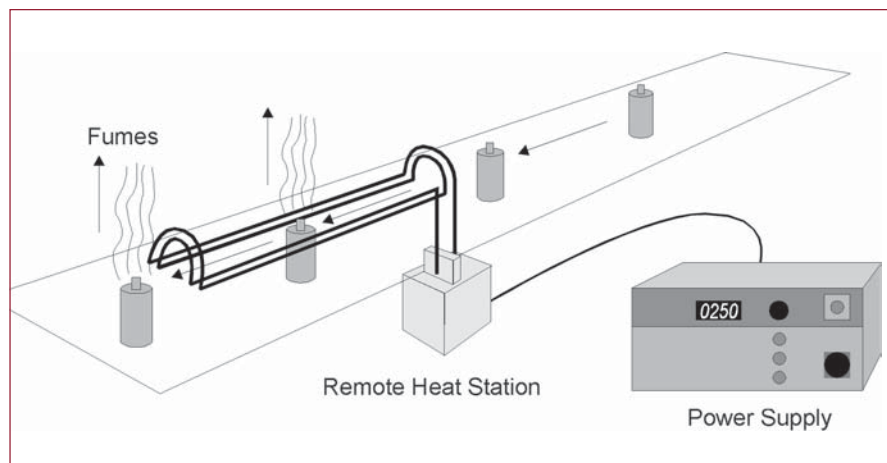
The RF connectors produced during this process are steel cups about 1.0" in diameter and 3" long, travelling at a rate of 1800 pieces per hour on a conveyor system. As shown in Figure 7, the end cap needs to be soldered onto the can to form a hermetically-sealed connector. A solder preform is placed on the joint area before it reaches the induction heating coil. The end of the connector is placed flush with the coil turns to ensure proper heating of the two pieces.

A good solder joint is achieved only if both pieces simultaneously reach the soldering temperature of 600°F. The solder is flux core type tin-lead wire; the flux outgasses during the heating cycle.

Selective heating is required to melt the solder onto the end cap of these connectors. Oven heating is not practical because it heats the entire connector and destroys the electronic components inside. Flame heating will not produce repeatable results. Induction heating is therefore a good heating solution for this process, but the corrosive effects of the flux and arcing tendencies of existing induction power supplies must be overcome.

To minimize arcing tendencies, Ameritherm's new Nova Star power supplies operate at lower, safer voltages than most older equipment. To remove the power supply from the conveyor line area and the corrosive effect of the solder flux, a variety of compact remote heat stations are available. The power supply can actually be located up to 200 feet away from the induction coil, depending on the application.

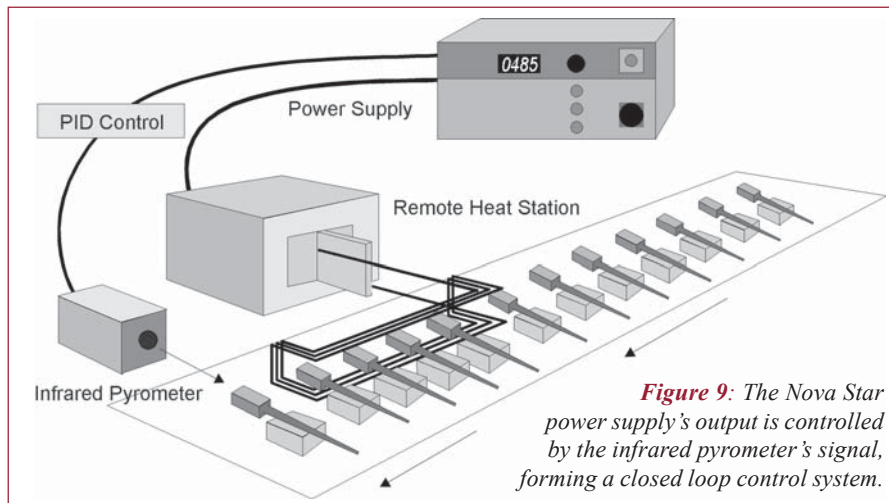
For this soldering application, a Nova Star 3L power supply produced 3kW at 250kHz. A small remote heat station and a channel-type induction coil were used to heat the top end of the RF connector and the end cap. As shown in Figure 8, corrosive flux fumes evaporate off the part and will tend to condense on any cool metal surface in the vicinity. The heat station can be located underneath the conveyor line, outside of the natural path of the flux fumes, and connected to the power supply with a flexible, low-voltage cable. A fume hog is recommended on top of the induction coil to vent the flux fumes coming off the joint area. To provide additional protection against arcing, a non-conductive sleeve is slipped over the copper coil turns.



**Figure 8:** Both the low-voltage power supply and remote heat station can be located out of the path of the corrosive flux fumes produced by this soldering application.

### Conclusion

Nova Star technology eliminates the RF connector soldering issues associated with this process. By reducing the power supply's voltage requirements and removing both the power supply and heat station from the path of the solder flux fumes, the RF connectors can be produced with high throughput and improved yield without damage to the heating components.



**Figure 9:** The Nova Star power supply's output is controlled by the infrared pyrometer's signal, forming a closed loop control system.

## Closed Loop Temperature Control Improves Tempering Process For Steel Punches

### Introduction

Manufacturers of steel punches have problems processing the head of the punch to the proper hardness. If the steel is left too hard, it will crack on impact; if too soft, it mushrooms over. The ends are therefore tempered after hardening to achieve the optimum hardness and toughness. There are manufacturing problems with achieving a consistent hardness from punch to punch because the power output from most older induction systems tends to drift over time.

In this section we will show how Ameritherm's Nova Star power supplies accept control signals from an infrared pyrometer, forming a closed loop temperature control system to solve this application's repeatability problem.

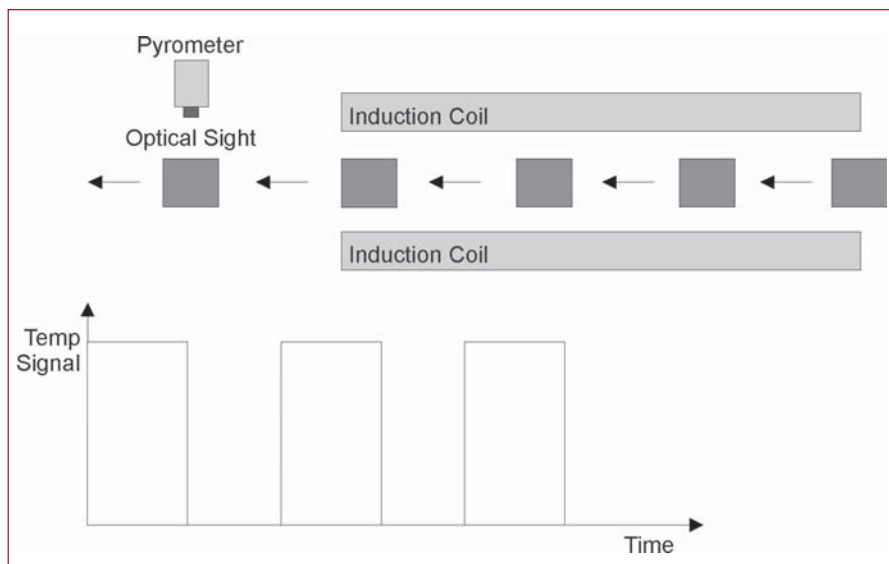
### Materials & Process

The steel punch has a 0.25" square head and a tapered steel end. After the punches are manufactured from raw steel, they undergo an intensive heat treating cycle. Both ends are selectively hardened to 60+ on the Rockwell scale. The head of the punch is then tempered to a lower hardness by heating it to  $900^{\circ} \pm 10^{\circ}\text{F}$ . The parts are then air-cooled to obtain the desired hardness.

As shown in Figure 9, the punches are indexed through the channel-shaped induction coil. Each part is in the coil for four seconds; the coil accommodates four parts at a time. The index length is 1.5 inches with a 1-second dwell at each location. The parts are loaded and unloaded during the dwell time. An infrared pyrometer measures the temperature of the punches. The pyrometer is set on peak picker mode so that it can correctly read temperature even if the work piece is moving and is only in the field of view for a short time. It is also capable of viewing parts with variable spacing, which occurs if there is an empty location due to a misfeed.

The Ameritherm Nova Star 3L solid state induction heating power supply accepts multiple control signals from an infrared pyrometer and other external sources with 0-20mA, 4-20mA, 0-10V or 0-5V input control signals with excellent resolution. This results in a closed loop temperature control system which transfers power with accuracy and precision to the punches passing through the coil.

Figure 10 shows how the pyrometer works in peak picker mode. The pyrometer's circuitry responds to the highest instantaneous value of the temperature and holds this value even if the temperature source is interrupted by one of the conditions listed above. The indicated temperature can be set not to decay during the index cycle of the punches (when there is no temperature readout) by adjusting the peak picker decay rate control. The pyrometer sends a control signal to the power supply which regulates the power output. The pyrometer also compensates for process temperature fluctuations such as those due to varying amounts of quench left over on some parts from the preceding hardening cycle.



**Figure 10:** The peak picker mode of the infrared pyrometer picks the "peak" temperature of each part and controls the power supply to maintain the part temperature at  $900^{\circ} \pm 10^{\circ}\text{F}$ .

### Conclusion

The Nova Star 3L power supply accepts the pyrometer's control signal to form a tight closed loop temperature control system. The system consistently regulates the temperature of the steel punches so that the tempering process is successful and throughput can be maintained with excellent repeatability.

# RF Power Supplies

## *For Precision Induction Heating*



- **Reliable**  
*Solid State Design*
- **Wide Range**  
*50-450kHz Frequency*
- **Precise**  
*Microprocessor Control*
- **Fast**  
*Automatic Tuning*
- **Flexible**  
*Remote Heat Station*
- **User-Friendly**  
*Low Voltage Coil*

MODEL	Deliverable Power	DC Voltage	DC Current	Frequency	AC Line Input 50/60Hz	Ship Weight
Nova 1	1kW	0-200V	0-6.5A	50-450kHz	1-phase 110/220	100 lbs
Nova 2	2kW	0-350V	0-13A	50-450kHz	1-phase 220	100 lbs
Nova Star 3L	3kW	0-200V	0-18A	50-485kHz	3-phase 220/440	90 lbs
Nova Star 3H	3kW	0-200V	0-18A	515kHz-1.2MHz	3-phase 220/440	90 lbs
Nova Star 5L	5kW	0-350V	0-18A	50-485kHz	3-phase 440	90 lbs
XP 7.5	7.5kW	0-350V	0-25A	50-450kHz	3-phase 220/440	735 lbs
XP 10	10kW	0-300V	0-40A	50-450kHz	3-phase 220/440	1100 lbs
XP 15	15kW	0-350V	0-50A	50-450kHz	3-phase 220/440	1100 lbs

*higher power models available with output up to 60kW*

**Free  
Feasibility  
Testing**

Let us show you how we can improve your production time! Send your part samples to our lab and we will test the viability and efficiency of RF induction heating for your application. We'll even send you a videotape that shows your parts being heated with our precision solid state power supplies! For more information, call us at 585-889-9000 or visit our website at [www.ameritherm.com](http://www.ameritherm.com).