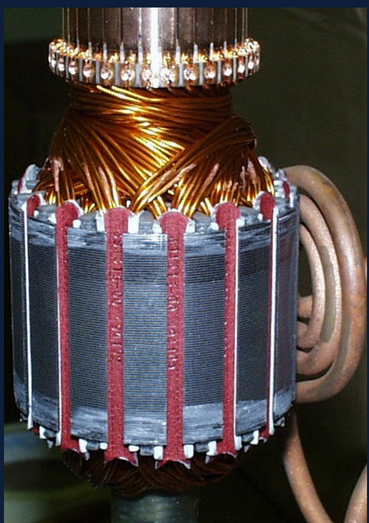
Ambrell Induction Solutions – from Electric Motors to Electric Vehicles (EVs)

Ambrell®
INDUCTION HEATING SOLUTIONS
an inTEST Company



Experience the Excellence.™

Table of CONTENTS

Ambrell Induction Solutions – from Electric Motors to Electric Vehicles (EVs)

Electric vehicles (EV) are steadily gaining in popularity. They offer significant environmental advantages. Hybrid vehicles generate significantly reduced emissions and electric vehicles produce none at all. A few years back it would have been hard to imagine the emergence of EVs at this speed. It is now clear they are here to stay. The manufacturing process has presented new challenges which have required unique and creative solutions. An electric vehicle uses power from a battery pack inside the car to power an electric motor that turns the wheels, thus eliminating the need for an engine. A typical EV has about 90% less moving parts than an internal combustion engine. In a manufacturing environment this means less parts to assemble, less complexity and a lighter package. EVs produce instant torque, so the drive start is quick. Conventional technology, however, can produce the same torque, but at speed. Therefore, a lot of electric cars feel lighter to drive along with numerous other advantages in manufacturing.

The drive train of an electric vehicle is coupled directly to the electric motor. The electric motor is comprised of a housing, a stator and a rotor. The stator is the stationary part as the name suggests, and the rotor is the rotating/moving part that spins a shaft, which creates torque and turns the wheels. The stator and the rotor interact magnetically so as to convert electrical energy to mechanical energy. The electric motor receives its electrical energy from an inverter, which in turn receives its energy from a battery pack resident on the electric vehicle.

Induction heating is a popular method for heating metal parts in the manufacturing processes of electric vehicles. A typical induction heating system is made up of an induction heating power supply, matching circuit and an induction heating coil. The induction heating coil is made of a water-cooled copper tube that has a high frequency alternating current flowing through it. This alternating current in the induction coil creates an intense magnetic field near the copper. The magnetic field produces an alternating current (eddy current) in the metal part placed in its vicinity. The eddy currents flow against the resisitivity of the metal and produce heat. Induction heating is used because of its speed, accuracy, repeatability and efficiency.

Shrink Fitting

Shrink fitting is a popular method to join two or more parts without the use of fasteners or other mechanical fastening devices. Historically, it was recognized that this method for joining parts was practical, easy and the produced parts that were not expensive. Wooden carriage wheels used a steel ring on the outer circumference for example, to create a barrier between the road and the wheel that could withstand wear and tear. The steel rings were heated to expand them and then slipped over the wooden wheels. Once cooled the rings created a strong fit between the two. The same technology has been in use in manufacturing ever since to assemble parts that require true concentric operation.

Housing to Stator Shrink Fitting

The requirement for a lightweight motor housing in an electric motor is obvious. Any reduction in fastening devices not only reduces the weight but also eliminates expensive and time-consuming labor. The stator, being a magnetic device, is made of steel laminations with an intricate arrangement of copper wires to carry the current. It is then fitted inside the aluminum stator using shrink fitting. The aluminum housing also allows for efficient heat removal from the components inside. Aluminum housings are heated to 200-300 °C (350-550 °F) depending on the interference fit between the housing and the stator. The aluminum expands and allows for the stator to be placed easily inside the housing. An internal diameter (ID) induction coil is typically used to heat the aluminum housing. Since the ID induction coil is not as efficient as an outer diameter (OD) induction coil, the clearance between the coil and the aluminum surface has to be minimized. The smaller the gap, the faster the heating of the aluminum, or smaller the induction power supply required for the application. An OD coil is also not recommended in cases where the aluminum housing walls may have cooling channels to maintain moderate temperatures.

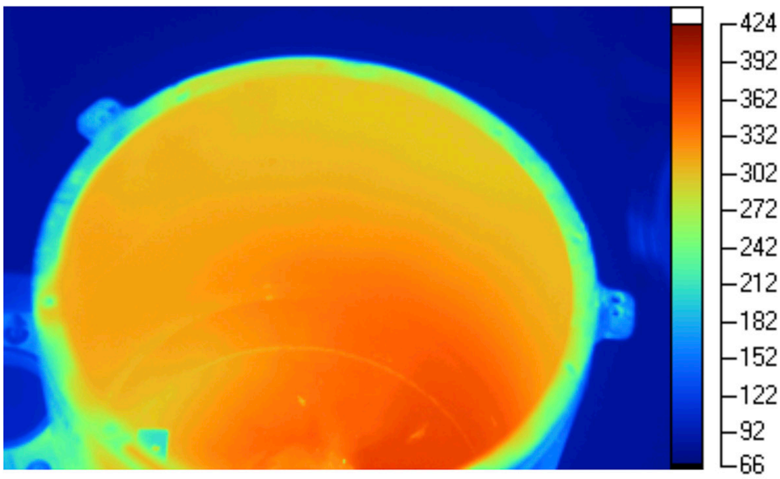


Figure 1: Thermal map of the heat migration inside an aluminum housing of an electric motor. Temperatures are shown in degrees Fahrenheit.

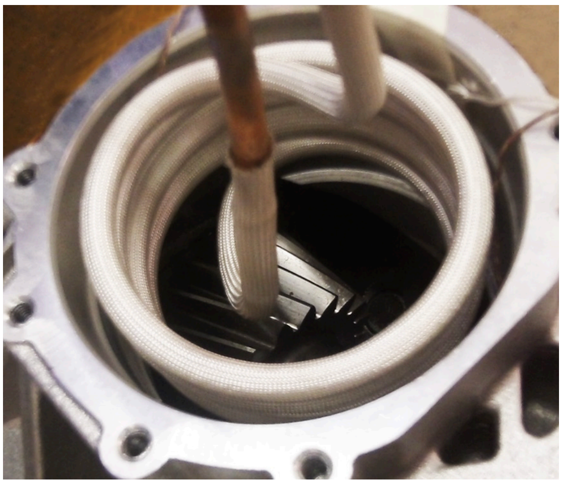


Figure 2: Induction heating coil setup for heating aluminum assembly for a shrink fitting application.

Shrink Fitting

Shrink Fitting of a Steel Shaft Inside the Rotor

The rotor inside the stator of an electric motor is made of steel laminations to reduce the eddy current heating during operation, as it is difficult to remove the heat produced. The shaft is fitting inside the rotor thanks to induction shrink fitting. Often the steel shaft is cooled in conjunction with the heated rotor to maximize the temperature differential for the process. The rotor has slots and features to not only house the permanent magnets but also to reduce the weight.

The steel rotor assembly stack has two options for induction heating. An induction coil can be designed to heat the steel from the outside or from the inside. Since the heat produced by induction is limited to a few millimeters from the coil surface, an OD induction coil is not recommended as it overheats the thinner sections between the magnet spaces and the circumference. To avoid this, overheating energy has to be delivered at a slow rate. This increases the heating time, and the reduced energy input to the rotor assembly makes the induction heating process impractical.

The only viable way to heat the steel laminations in the rotor assembly is using a coil from the ID of the assembly. While there are impediments to uniform heat transfer throughout the surface, this ID heat allows for better energy delivery to the assembly. The higher rate of energy delivery allows for the lamination assembly to be heated to temperature quickly, even though multiple heating stations have to be employed in numerous installations.

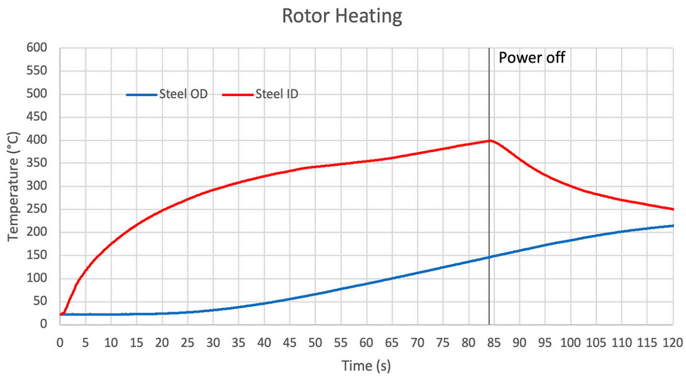


Figure 3: Temperature conduction through a steel rotor with an ID induction coil. The OD takes a long time to reach temperature.

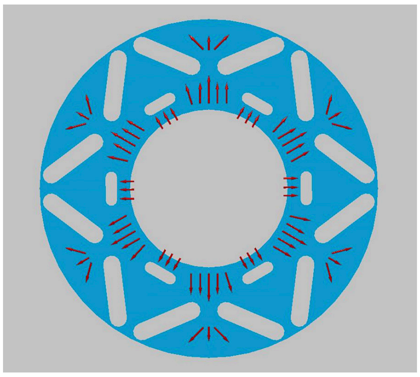


Figure 4: Heat transfer through the steel laminations of a steel rotor with ID heating.

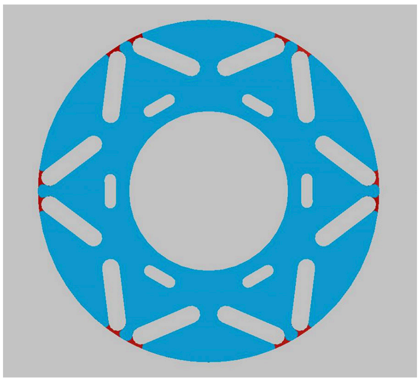


Figure 5: Heat transfer through the steel laminations of a steel rotor with OD heating. This is not possible as the thin sections on the OD concentrate currents and overheat.

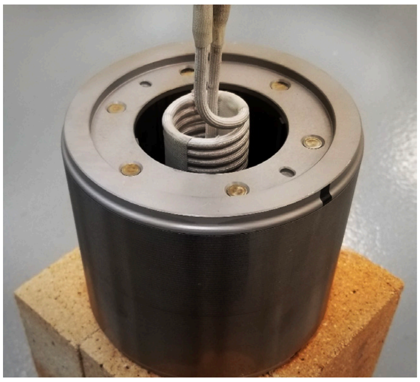


Figure 6: ID heating of a steel rotor with induction.

Shrink Fitting

In some cases, it is practical to heat the steel rotor with a coil on the outer diameter of the assembly. In such cases maximum energy efficiency is achieved from the induction heating setup. Manufacturing and maintenance of the induction coils is much easier. Temperature difference between the outer and internal diameter is determined by the thermal conduction of the metal matrix. Steel, being the material of choice, limits how fast the heat can propagate thru to the center.

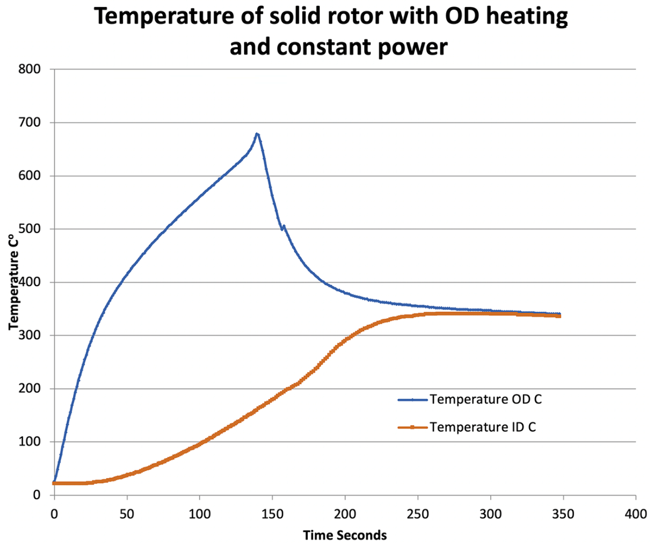


Figure 7: Thermocouple comparison of the OD (blue) vs the ID (red) with OD coil, heat on a 6 inch diameter steel rotor.

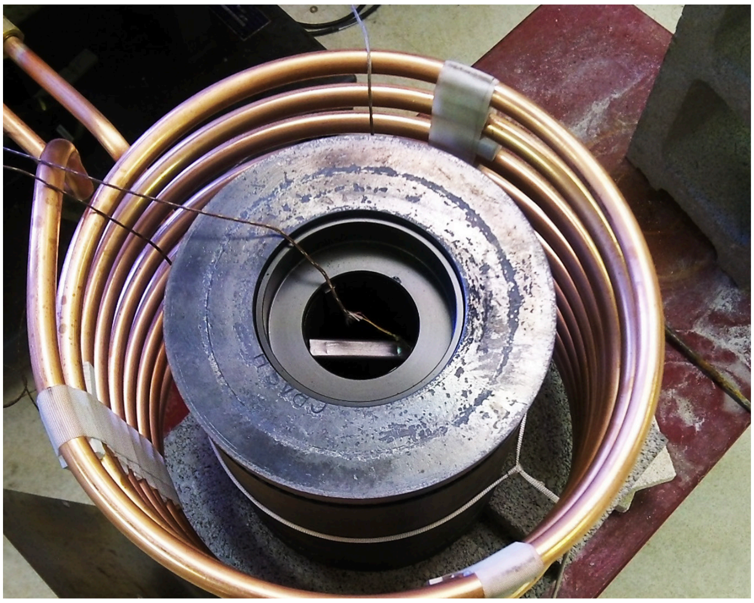
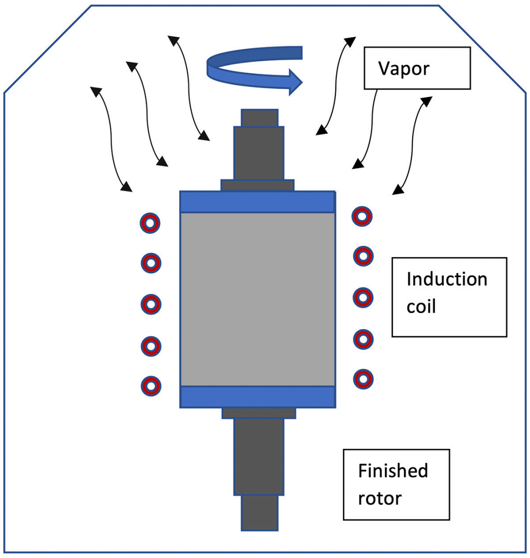


Figure 8: Heating of 6-inch diameter steel rotor using an OD coil.

Drying

Induction is used to heat the steel rotor assemblies to remove the machining fluids after they are machined to the tight tolerances required for efficient motor operation. Induction is able to tightly control the temperature of the rotor using closed loop control. An optical pyrometer is used to measure the temperature of the rotor during the heat cycle. This temperature input is fed to a controller. A special algorithmic PID control loop is used to prevent overheating of the rotor assembly as the amount of machining fluid trapped from the previous operation varies from part to part.



Varnish or Wax Dripping on Rotors and Stators

To eliminate the vibrations between the copper wires and the stator laminations, or to avoid shifting of the copper wires inside the grooves of the laminations, it is often necessary to fill the empty gaps using a varnish or a wax or an epoxy. If the steel laminations are at room temperature, the filler material does not flow very well and ceases. Heating the steel laminations and the copper wires helps the flow of the filler material. This makes the rotor or the stator impervious to incoming contaminants, and to make the windings rigid and tight, and to dissipate heat. A number of different induction setups can be used to heat the stators or rotors. Large parts require time for the heat to penetrate, as the conduction path through the laminations is the lamination thickness. Since smaller lamination thickness is desired for higher motor efficiency, time is required for heating the entire mass.

CHANNEL STYLE HEATING: This type of heating relies on a number of parts being heated at one time on a moving conveyor or a lead screw type setup. As the parts travel through the length of the coil, the gentle heat input allows for the entire mass to come to temperature in a uniform manner.

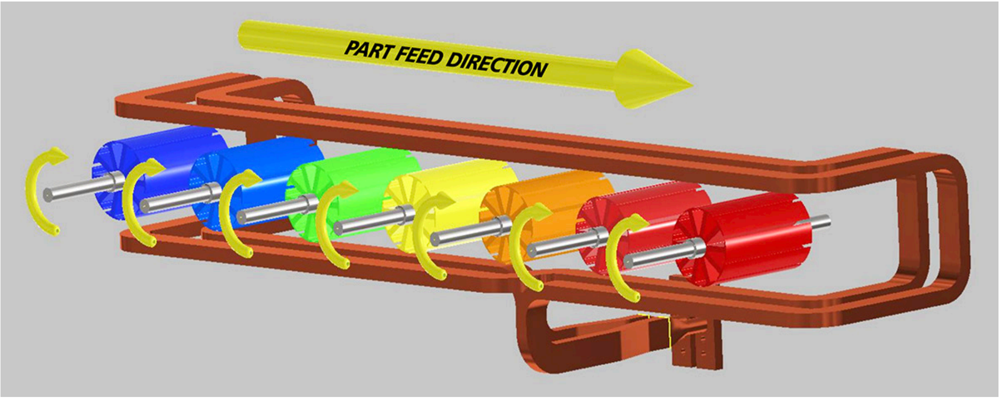


Figure 10: Steel rotors being heated in a channel style induction coil for a high volume preheat application.

»Varnish or Wax Dripping on Rotors and Stators

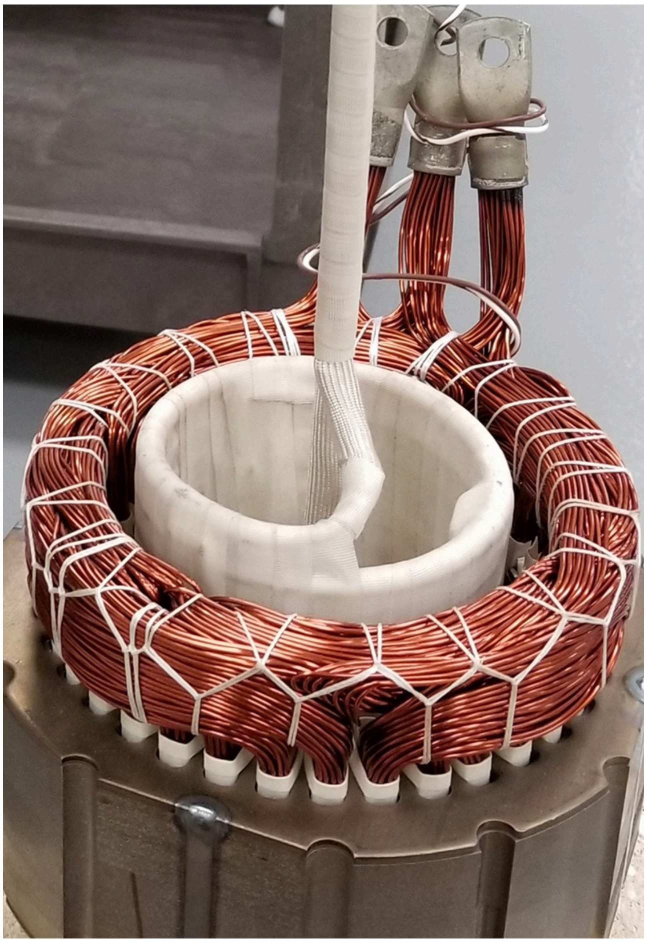


Figure 11: ID coil to heat a steel stator with copper wires before a varnish dripping process.

INTERNAL BORE COIL: Several larger parts cannot be moved in the manner shown in figure 12 to facilitate channel style coil heating. The cantilevered weight of the parts, requirement for multiple massive handling fixtures, and just the availability of floor space may require one to look for a different solution. Also, the material thickness towards the outer circumference may not allow for efficient delivery of the induction power (as seen before). In such cases, the only available way to heat with induction is to have an induction coil on the inside of the part. Even though this type of coil heating is not very efficient, it is still highly desirable when compared with the option of oven heating and other forms of heat generation. In such cases not only the part is heated, but the associated fixturing, and conveying mechanisms all get heated. This is not desirable for long term, repeatable problem-free performance of the system. A coil that heats from the inside can be stationary during the heat cycle if it is designed specifically for the lamination stack height of the part. Care must be taken during the design of such coils to not overheat or underheat the ends of the assemblies.

Figure 12: Induction heating of steel stator using an ID coil. One induction coil that oscillates back and forth is used to heat various diameter and length parts.

Figure 13: Induction heating of steel stator using an ID coil. The setup allows for different diameter and length parts to be run on the same station without changeover concerns.

Varnish or Wax Dripping on Rotors and Stators

Manufacturing setups having to deal with multiple length and diameter parts have the option of either having an individual coil designed for each part, which leads to changeovers, or having an induction coil designed for the smallest diameter or length. This type of coil can then be traversed back and forth to heat larger parts, thus eliminating a huge inventory of coils and changeover concerns.

HELICAL COIL WITH OD HEATING: In the few cases where the design and construction of the part allows for heating the laminations with an induction coil from the outside, a smaller induction power supply can be used, as this type of coil is extremely efficient. The turn spacing of the copper has to be adjusted to provide uniform heat to the part.

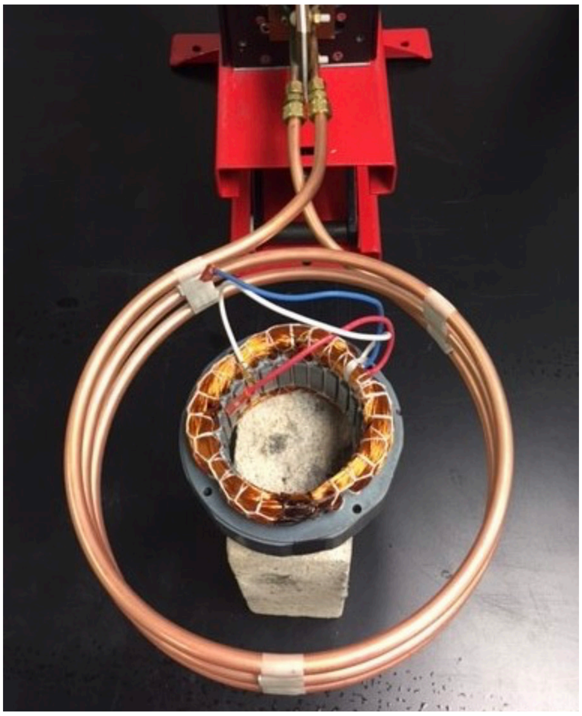


Figure 14: Stator heating inside a helical coil. The extra space between the OD of the part and the ID of the coil allow for automatic handling systems.

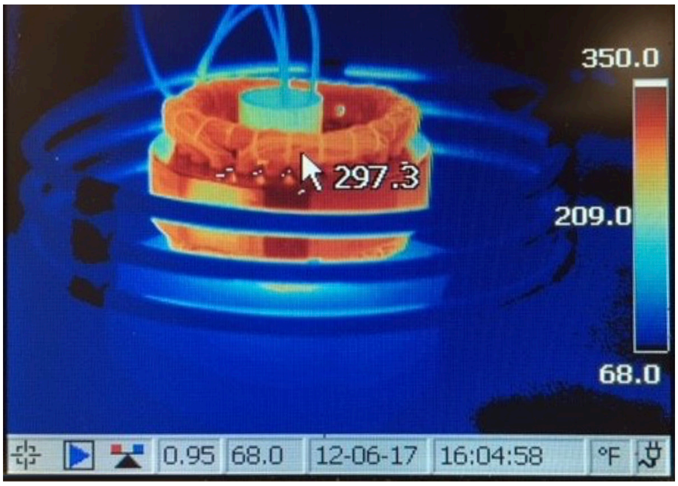


Figure 15: Thermal image of the stator for varnish impregnation using an OD induction heating coil. The copper windings on the top and the bottom, as well as the steel laminations are heated to a uniform temperature.

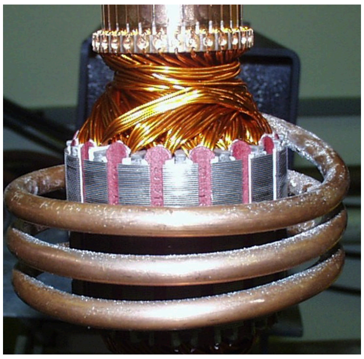


Figure 16: Laboratory setup to prove feasibility of heating a steel rotor before wax dripping process. Temperature uniformity between the steel and the copper wires is critical for proper impregnation of the liquid wax.

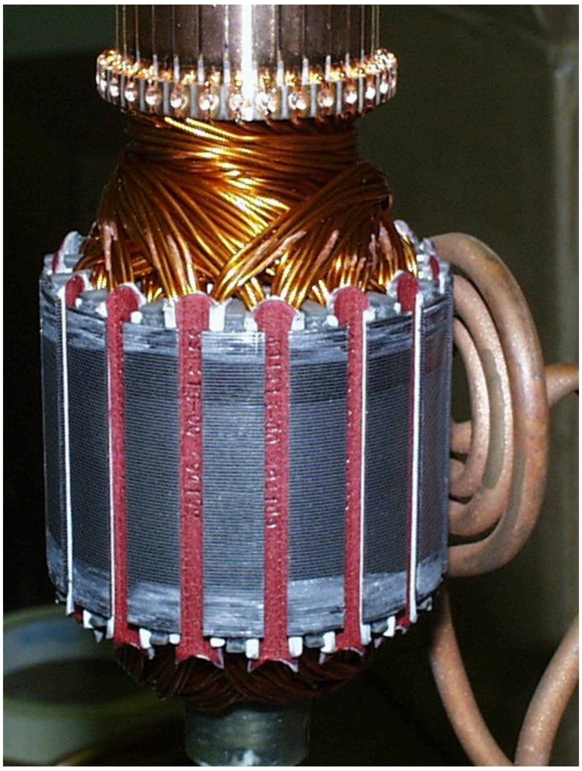


Figure 17: Pancake style coil for preheating a steel rotor.

Battery Manufacturing

Induction is used in the manufacturing process of batteries for electric cars. The battery pack provides the stored energy that is converted to mechanical energy to the wheels. A typical electric vehicle has a lot of individual batteries all connected to provide this energy. Induction heating is used to heat the battery casings for several different applications. The most important is to remove the moisture before the internal guts of the battery can be placed. A typical setup involves heating the battery casings on a continuous line using a specially designed channel style coil. This allows for bowl feeders to orient parts for the high-volume manufacturing that is required. In some applications individual batteries are soldered together to form cells using induction.

Figure 18: Battery casings with 400 °F temperature paint before heat testing.

Figure 19: Typical channel type induction setup for battery shell heating.

Figure 20: Battery shells after passing through a channel type induction coil. Paint turns clear when parts reach temperature.

Fuse Manufacturing

Electric vehicles, as the name implies, rely on electric energy for all its functions, whether they are for display, safety, lights, air conditioning or power. Due to all these electric circuits, it has become increasingly important to protect the mains battery from any malfunctions. Fuses are therefore used to protect all these circuits. Induction heating is used in the manufacture of these fuses. Applications vary from melting solder on filaments to soldering the filaments to end caps in certain applications. Heat ties are typically in the 1-3 second range to prevent excessive heat in neighboring components.

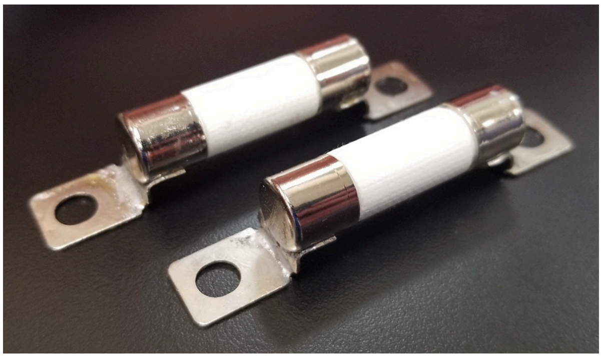


Figure 21: Induction soldering of the tabs on fuses. Typical cycle is 3-4 seconds.

Figure 22: Close-up of good solder flow in a copper-to-copper joint inside a fuse with induction.

Induction Brazing of Battery Cooling Circuits

In the batteries for an electric vehicle, the discharge of energy from the battery generates heat. The higher the energy demand, the more heat is produced. Also, if the batteries are at different temperatures they discharge at different rates, thus creating more chances for overheating. The batteries are therefore cooled for safety and peak performance. A single aluminum extrusion is used to reduce the risk of leaks in the battery compartment. The material of choice for the cooling circuit is aluminum. The aluminum cooling channel can be extruded in long lengths, however the ends of these channels have to interface with conventional tubes to introduce and remove the cooling fluid. The end fittings on these aluminum channels must be joined to maintain no leaks and safety during different working conditions. Brazing is a common method used to join the end fitting to the aluminum channel. Since the channel and the fitting materials are aluminum, the few braze alloys that wet and join to aluminum are also alloys of aluminum. A braze alloy preform is used to provide consistency of the joining alloy to each joint. The induction heating coil is designed to deliver uniform temperature to the end fitting and the channel, as the best joint is only achieved if the two parts being joined reach the brazing temperature concurrently. Given the large difference in the mass of the two parts, coil design is extremely critical.

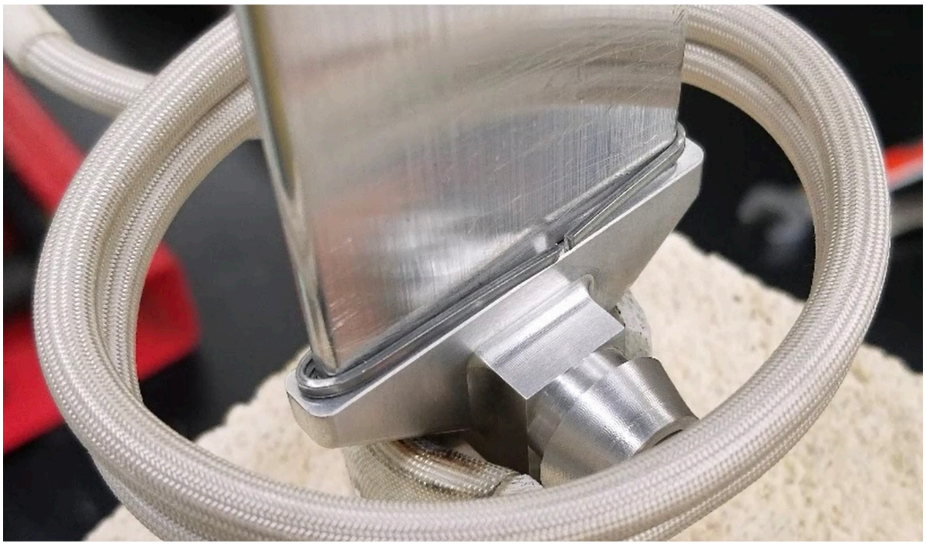


Figure 23: Aluminum induction brazing setup for the cooling channel to end fitting.

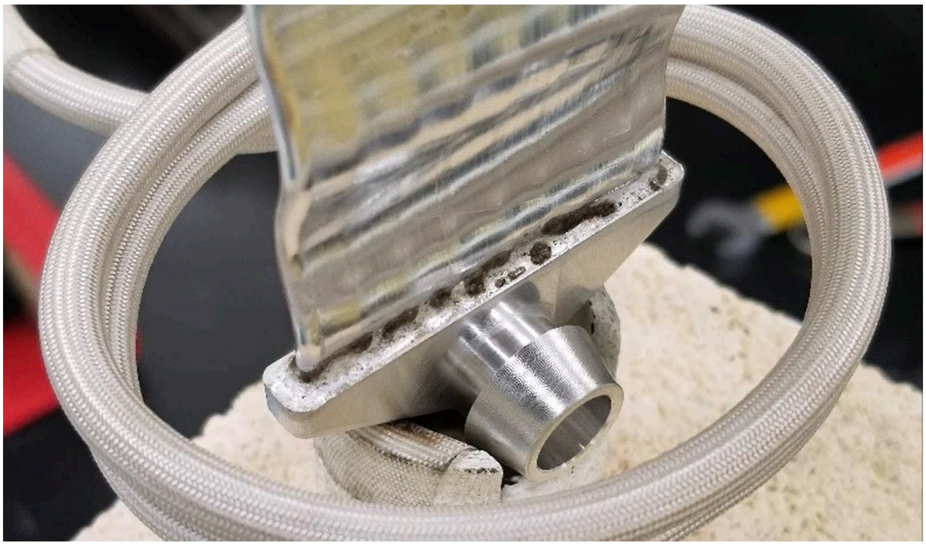


Figure 24: Finished Induction braze joint on an aluminum assembly. Braze alloy has flowed well, wetting all surfaces.

Metal to Plastic

In modern cars, a lot of parts like the headlights, taillights, door handles, grills and bumpers are made with plastics. These plastics have very good strength and are extremely lightweight. These plastics can be tailored to suit the different strength and performance requirements. Even though the plastics are strong and lightweight, it's still difficult to anchor them to the structure of the electric vehicle. Small metal inserts with specialized knurl patterns on the outside surface are fitted to the plastic parts for this purpose.

Traditionally ultra-sonics were used to fit the metal inserts into the plastic assemblies. However, it is getting more and more difficult to use this technique for reduced wall thicknesses on modern plastic parts. Induction heating is used to heat the metal inserts (brass or steel or aluminum) to then effortlessly push them into the plastic assemblies. A plastic assembly could have as many as 5-7 inserts depending on its design.

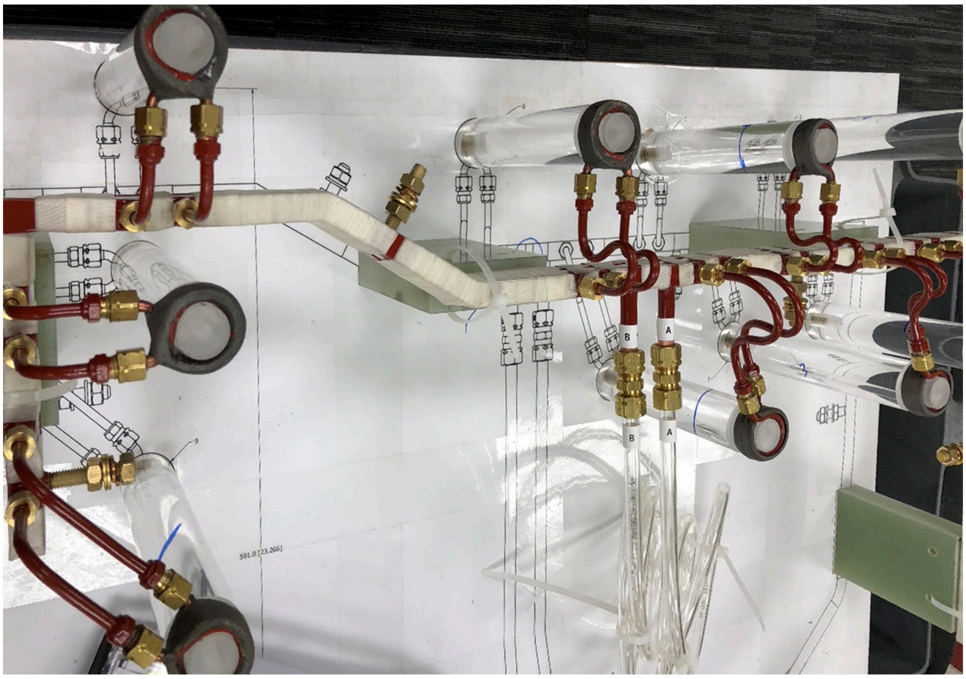


Figure 25: Multiple position induction heating coil with split water cooling circuit to heat metal inserts for metal to plastic insertion.

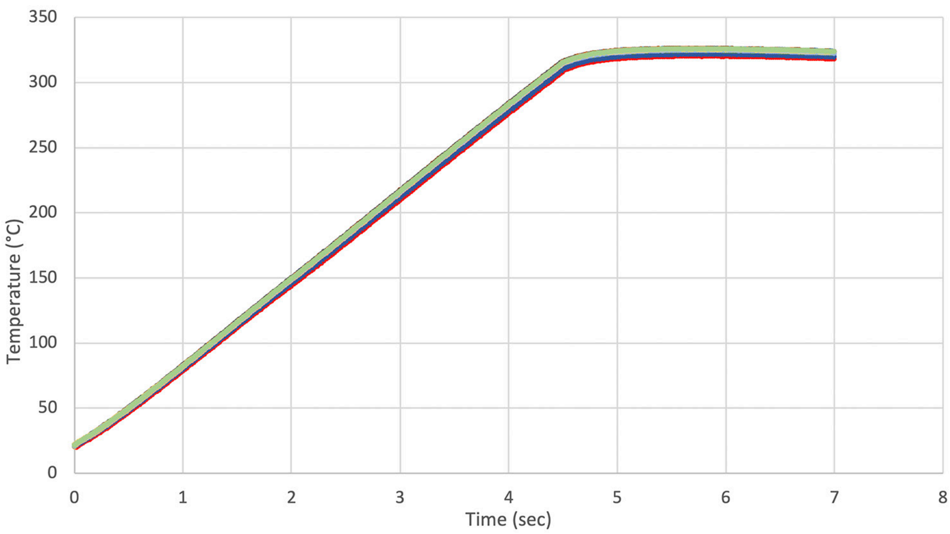


Figure 26: Temperature rise on a steel insert with multiple heat cycles, showing the repeatability of induction heating.

»Silicon Carbide (SiC) Manufacturing

Induction heating is used in the manufacturing of semiconductor devices used to convert the direct current battery output to an AC signal to drive the motor. Phase vapor transport (PVT) is one such method where the raw materials are heated and melted in a graphite crucible. The induction heating setup is designed to provide more heat to the bottom of the crucible and less heat to the top of the crucible. This gradient forces the molten liquid to vaporize and condense in the lower temperature area. A seed crystal of the semiconductor is strategically placed towards the top of the crucible. The condensing vapor grows the crystal which is then processed in subsequent operations to produce the semiconductors.

Within the crucible there is a powder source material and a seed crystal. Induction heating allows for a controlled heat of the source material in order to create a melt whilst also allowing the seed crystal to increase in temperature. This positioning of the induction heating coil is critical in order to achieve the required temperature distribution within the crucible. It is required to promote a slightly lower temperature at the top, where the seed crystal is located, in order to promote the condensation of vapor. These temperatures could be measured via optical pyrometers on the top lid and bottom of the crucible. In additional to the measuring and monitoring, it can easily be utilized to control the induction heating equipment with a ramp to setpoint.

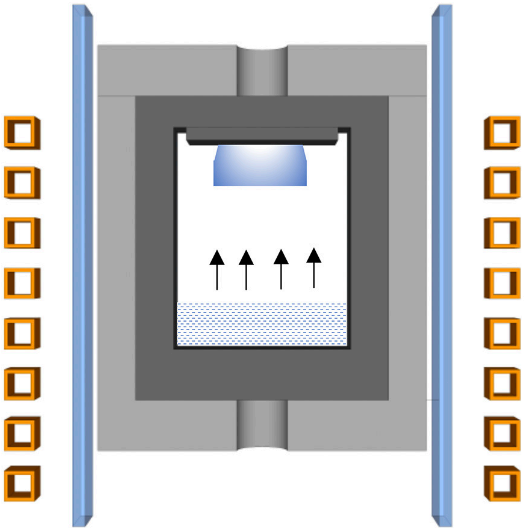


Figure 27: Simple PVT system for crystal growth.

Figure 28: PVT crystal growth setup using induction.

»Conclusion

In summary, induction heating has numerous uses in the manufacture of different components of electric motors for automobiles and other industries and also other components. Newer applications are being developed every day that benefit greatly from the repeatability, reliability, ease of use, and the consistency of the induction heating process.

» Ambrell Power Supplies for Electric Vehicle Manufacturing

Ambrell manufactures a wide assortment of power supplies, both low and high power, for an array of electric vehicle manufacturing applications. Ambrell's EASYHEAT™ power supplies range from 1-10 kW and are used for applications like brazing and soldering, while the Ambrell EKOHEAT© power supplies range from 10-1,000 kW and are often used for applications that require more power like shrink fitting and metal-to-plastic insertion.

Ambrell power supplies have movable workheads so the coil can be placed a distance from the power supply, a high power factor to ensure efficient heating, significant versatility with multiple capacitor and tap configurations, and repeatable, reliable heating with agile frequency tuning. Additionally, systems are compact and easy-to-integrate into manufacturing processes. Systems are manufactured at Ambrell's ISO 9001:2015 certified facility at its headquarters in Rochester, NY USA.

Complimentary Applications Testing

You can send parts to Ambrell's Applications Laboratory for a free half-day of testing. Testing is recorded and parts are sent back to you for inspection. Additionally, you are welcome to visit during testing to see induction shrink fitting live.

After testing, you will receive a tailored system recommendation. The recommendation will be based on your process requirements, including process time, cycle time and temperature.

THE LAB at Ambrell has considerable experience with electric vehicle applications. So take advantage of that expertise and send in your parts for risk-free applications testing today.

About Ambrell

Founded in 1986, Ambrell Corporation, an inTEST Company, is a global leader in the induction heating market. We are renowned for our application knowledge and engineering expertise. In addition, our exceptional product quality and outstanding service and support are at the core of our commitment to provide a superior customer experience.

We are headquartered in the United States with additional operations in Europe including the United Kingdom and the Netherlands. All Ambrell products are designed, engineered and built at our manufacturing plant in the United States, which is an ISO 9001-certified facility. Over the last three decades we have expanded our global reach through an extensive distribution and OEM network, and today we have more than 15,000 systems installed in over 50 countries.

ISO 9001:2015 CERTIFIED

Ambrell®
INDUCTION HEATING SOLUTIONS
an inTEST Company

www.ambrell.com

Ambrell Corporation
United States
Tel: +1 585 889 9000
Fax: +1 585 889 4030
sales@ambrell.com

Ambrell B.V.
The Netherlands
Tel: +31 880 150 100
Fax: +31 546 788 154
sales-eu@ambrell.com

Ambrell Ltd.
United Kingdom
Tel: +44 1242 514042
Fax: +31 546 788 154
sales-uk@ambrell.com