# Induction Heating and Heat Treating of Fasteners

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In the past decade, heating by means of electromagnetic induction has become an increasingly popular process applied in numerous applications including the fastener industry[1]. Induction heating offers rapid, high intensity, contactless heat generation directly in the surface and subsurface of the fastener at well-defined regions on and in the workpiece. This is a very attractive feature of this technology leading to high productivity with repeatable quality. Highly controllable heat intensities that range from moderate rates (e.g., as low as 3°C to 5°C/s for some tempering applications) to high heat intensities (e.g., exceeding 800°C/s in hardening applications) allow the implementation of optimal process recipes.

Induction heating (IH) is also more energy efficient and inherently more environmentally friendly than most other heat sources including gas-fired furnaces, salt and lead baths, just to name a few. Any smoke and fumes that may occur as a result of residual lubricants or other surface contaminants can be easily removed with exhaust handling equipment. A considerable reduction of heat exposure to the worker is another factor that contributes to the environmental friendliness and ergonomics of induction heaters. IH systems are compact systems offering shop floor space savings and usually require far less start-up and shut-down time, eliminating or dramatically reducing idle periods of unproductive heating. No energy is needed to build or to maintain heat in the heating zone in nonoperating conditions.

Advantages in safety (neither combustion nor environmental contaminants are used) in combination with high production, reduced labor cost for machine operators and improved efficiency make electromagnetic induction an attractive investment with great returns[1].

Industrial applications of IH for the fastener industry can be divided into three groups: pre-heating prior to hot and warm working, heat treating and special applications (**Figure 1**). A short description of each group and several case studies are provided below.

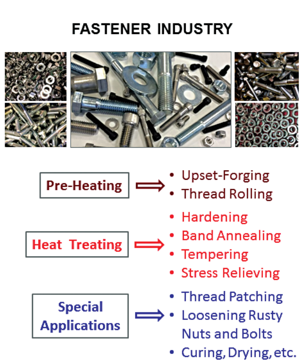


**Fig. 1 — Industrial applications of induction heating for fastener industry.**

## Pre-Heating Prior to Hot and Warm Working

Steel components by far represent the majority of hot worked parts for which IH is used as a source of heat generation. At the same time, titanium, aluminum and copper as well as many other nonferrous metallic materials including Ni-based super alloys are also inductively heated for a number of commercial applications.

Target temperatures depend on the alloy grade and application. For example, for steel fasteners, the required temperatures before hot working (such as upset forging or hot heading) normally vary from 1050°C (1922°F) to 1150°C (2100°F), but for warm working (e.g., thread rolling) the target temperatures are commonly specified within 340°C (650°F) to 550°C (1020°F) range. For aluminum fasteners, temperatures are usually in the range of 480°C (900°F) to 580°C (1080°F). Temperatures of 900°C (1650°F) to 1000°C (1830°F) and 950°C (1740°F) to 1050°C (1920°F) are typical temperatures for heating copper and titanium components, respectively[1]. At the same time, temperatures outside of these ranges can also be specified to suit particular application subtlety.

Instead of heating the entire component, IH permits heating selective regions of the workpiece (e.g., ends or middle area) to elevated temperatures for a subsequent operation (e.g., a press or hammer to form the end of the workpiece into the desired shape as is done in hot heading or upsetting of bolts and screws or in thread rolling applications). Placing the region of the workpiece that needs to be heated (for example, its end) in an induction coil and heating it for a specified amount of time generally accomplishes selective heating minimizing energy consumption.

Some end heating applications require specific temperature profiles along the length of the workpiece including the sharp cutting off of the heat. Other end heating applications favor a gradual transition.

Multiple ends can be heated in a single-turn or multi-turn oval induction heating coil as well as in a channel-type inductor (also referred to as a slot or skid coil), or utilizing multi-nest arrangements with two, three, four or more individual conventional solenoid coils. Multiple coils are used to increase the production rate.

For example, **Figure 2**, bottom, shows an example of a compact three-position induction system for heating selected areas of bars to hot and warm working temperatures.

While **Figure 2**, top, illustrates a high production channel-type inductor for heating ends of steel rods permitting easy entry and exit. Rods are continuously processed side-by-side.

**Figure 2**, middle, shows hot forged blank for a headed bolt of large diameter.

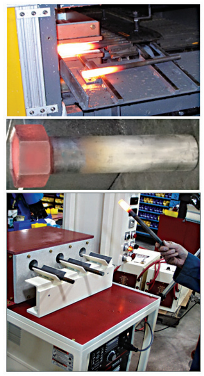

**Fig. 2 — A compact three-position induction system for heating selected areas of bars to hot and warm working temperatures (bottom); A high production channel-type inductor for heating ends of steel rods permitting easy entry and exit (top); Hot forged blank for a headed bolt of large diameter (middle).**

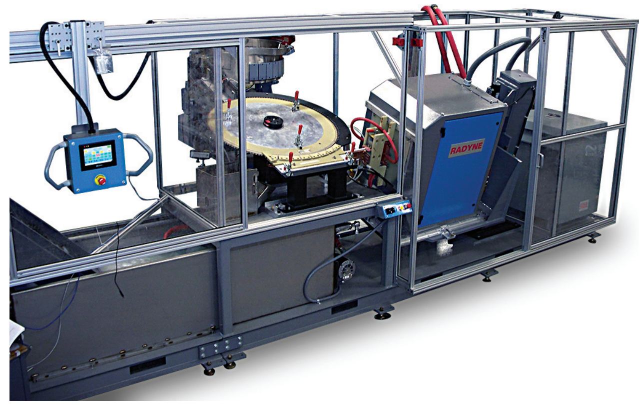


**Fig. 3 — Radyne's state-of-the-art continuous fed induction system for heat treating fasteners.**

## Heat Treating Applications

The term heat treating is associated with a large family of processes[1]. Induction heat treatment of fasteners is typically associated with four subgroups of applications: hardening, band annealing, tempering or stress relieving (**Figure 1**).

***Induction hardening.*** Hardening may be done for purposes of obtaining a certain combination of engineering properties. In some cases, it is required to harden an entire cross section of the workpiece (so-called through hardening) as in the cases of pins, nails, locking bolts, screws and some other fasteners. However, in other applications, only certain selected areas need to be hardened (e.g., surface hardening).

Besides other factors, the ability of the component to be hardened through depends on the hardenability of material, quenching conditions and geometry. The ability to achieve a sufficiently uniform through-heating is another critical factor.

Selection of the appropriate frequency is particularly important in achieving a sufficiently uniform "surface-to-core" temperature distribution in the shortest time with the highest heating efficiency. It is reasonable to assume that in order to simplify the task of obtaining a sufficiently uniform "surface-to-core" temperature distribution in through-hardening applications, it would be advantageous to use lower frequencies that would result in more "in-depth" heating. However, there are some limitations in selection of the heating frequency. Too low frequency can result in cancellation of eddy currents induced within the part by the induction coil. This can result in a dramatic reduction in the electrical efficiency and even inability to reach appropriate temperatures. Guidelines related to frequency selection are discussed in detail in Reference 1.

One of the main goals of surface hardening is to form a martensitic layer at the surface and near-the-surface areas of the workpiece to increase the hardness, wear resistance and contact fatigue strength while allowing the remainder of the part to be tough and ductile. Surface hardening occurs when a surface layer of the workpiece made of suitable steel grade is heated to a temperature required for a phase transformation to austenite, taking into consideration the heat intensity and prior microstructure[1], and then rapidly quenched.

As an example, **Figure 3** shows a Radyne state-of-the-art continuous fed induction system for heat treating fasteners. This advanced system delivers consistency and enhanced controllability resulting in high quality for a wide range of fasteners lengths and diameters and is quickly becoming a new fastener industry standard for induction heat treating. This particular unit produces a uniform concentric hardness pattern and includes four sizes of tooling required for the rotary fixture and the traverse tooling: M6, M8, M10, and M12. It is adjustable for a wide range of diameters and lengths (12 to 102 mm [0.5" to 4.0"]) and is capable of production rates of up to 600 fasteners per minute[2].

The unique proprietary coil design developed by **Radyne Corp.** maximizes electrical efficiency and system flexibility while preventing stray heating of electrically conductive surroundings that may potentially cause undesirable heating of structures and malfunction of electronic devices.

This fully automatic system includes a vibratory bowl feeder, rotary part indexing, induction heater with recipe based servo controlled positioning, a range of heating coils to meet the heating pattern requirements of various common fasteners, integrated quench, conveyor unload, touch screen control panel and a chart recording system. The adjustable speed rotary table contains advanced safety features to prevent damage and meltdown.

The Coil Quick Disconnect is designed to allow quick changeover between coils for maximum uptime and flexibility. Simple to install, the assembly bolts directly to the power source output and allows coils to be easily changed without the use of tools or attachment of water connections. Solid construction and a heat-resistant composite alignment plate assure correct and consistent positioning of the coil relative to the component position. Special design features allow the operator to loosen or tighten the tooling for fixed placement of coil assembly[2].

A 100 kW/200 to 400 kHz power source features digital meters for monitoring voltage, current, frequency and power. The system is controlled through a controls package and HMI for part setup and storage of different programs. Through this HMI, the power source coil "Z" (height) adjustment can also be stored and adjusted for different bolt lengths assuring superior quality fasteners.

The quench assembly allows adjusting the quench flow for the utmost in quench control. After spray quenching, parts are stripped from the traverse assembly and dunk quenched into the tank for final cooling to room temperature.

***Induction tempering and stress relieving.*** The tempering process takes place after the steel is hardened, but is no less important in the heat treatment of the component. The transformation to martensite through quenching creates a hard structure. Untempered martensite might be too brittle for some applications, exhibiting a lack of toughness and ductility and retaining a significant amount of residual stresses.

Tempering is a form of subcritical heat treatment producing a desirable combination of microstructures and mechanical properties. Recognizing the fact that conventional furnace/oven batch tempering is a proven and the most frequently used process for tempering and stress-relieving of fasteners, there are some cases where induction tempering might exhibit its own advantages and also found to be a viable commercial process[1]. The optimal power supply frequency for hardening may be different than the optimal frequency for tempering. Generally lower heat intensity and longer heating time is used for induction tempering compared to hardening.

***Band annealing.*** Some special applications such as manufacturing of quality rivet sleeves, rivet nuts, sleeve nuts, rivet stems, pins, blind rivets, just to name a few, may require localized heating to adjust strength and microstructure at certain locations (for example, after rolling). Materials used for fabrication of these components range from steels and super alloys (Monel, Inconel, etc.) to Ti, Al, Cu and their alloys. Diameters commonly range from 4 to 12 mm (0.14" to 0.5").

Frequently, it is required to minimize stray heat flow to regions adjacent to areas required to be heat treated. This task might not be as simple as one might think taking into consideration short distances for the heat flow and high thermal conductivity of some materials.

Application of short heat times helps to minimize an impact of thermal conductivity. Coil copper profiling and an application of properly designed magnetic flux concentrators help to minimize leakage of an external magnetic field outside of induction coil. Flux concentrators "act" as an electromagnetic shield.

***Case Study.*** **Figure 4**, top, shows the results of computer modeling of a heat source distribution within a fastener heated by a single-turn bare coil. Unfortunately, due to an electromagnetic proximity effect, the external magnetic field causes substantial heat source generation within the fastener's head, which results in corresponding undesirable heating there and potentially leading to unwanted metallurgical changes[3].

**Figure 4**, bottom, shows impact of positioning C-shaped external magnetic flux concentrator around the coil conductor. The flux concentrator squeezes the coil current to its "open surface" according to the electromagnetic slot effect[1]. Current concentration at the inductor surface facing the workpiece results in improved electromagnetic coupling and enhances

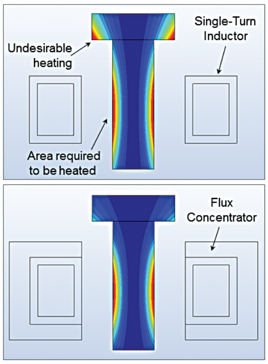


**Fig. 4 — Results of computer modeling of a heat source distribution inside a fastener heated by a single-turn bare coil (top) and an impact of positioning C-shaped external magnetic flux concentrator (bottom)[3].**

the electrical efficiency. Besides that, since the magnetic flux concentrator provides a low reluctance path for a magnetic field, a much smaller portion of that field will link with adjacent areas, dramatically reducing their heating.

Depending on a component's geometry and coil design specifics, it is reasonable to expect a four to 12-fold reduction in the power density induced in an adjacent head compared to using a bare coil. This substantially reduces the probability of undesirable softening of the head. Therefore, flux concentrators allow decoupling of the induction coil to the adjacent electrically conductive regions while noticeably improving effectiveness of heating areas being enclosed by an inductor.

Further reduction of the flux leakage can be achieved by using a combination of C-shaped magnetic flux concentrators and Faraday rings ("robber" rings)[1]. This technique is illustrated in **Figures 5**, which shows a side-by-side comparison of heat source distribution when applying only C-shaped magnetic flux concentrator (left image) vs. applying a combination of C-shaped flux concentrator and a Faraday ring (right image).

## Special Applications

Curing, drying, loosening rusty nuts and bolts and thread patching are some applications that belong to a subgroup of special applications of IH for the fastener industry. Space does not permit discussing subtleties of all these processes. Only a few remarks will be provided here.

Curing of paints and varnishes (drying/evaporation or polymerization) on workpiece surfaces or curing powder coating materials (e.g., used in thread patching of fasteners) requires special design considerations related to ensuring the quality of curing and avoidance of uncontrolled overheating. In addition, when curing some paints and varnishes, there might be the potential for a fire if a spark occurs. Surfaces must be properly prepared to ensure that the coating will adhere to the base metal.

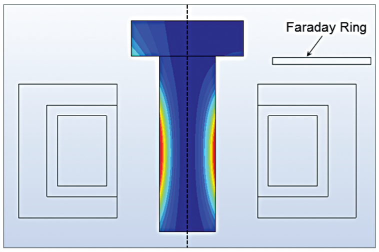


**Fig. 5 — A side-by-side comparison of heat source distribution when applying only C-shaped magnetic flux concentrator (left) vs. applying a combination of C-shaped flux concentrator and a Faraday ring (right)[3].**

An induction curing system for fastener patching applications usually applies a channel-type or split-return inductor and often comprises two coil arrangements. The first inductor is relatively short, allowing preheating of selective areas of continuously processed fasteners before spraying. The second inductor provides suitable final thermal conditions, ensuring proper powder flow after spraying. Care must be taken to design the process to match the characteristics of the materials being cured to ensure that it is done at a suitable speed and temperature to ensure quality results.

There is a fundamental difference between IH and convection/radiation/infrared furnaces used for curing heating paints and varnishes. The difference lies in the ability of IH to generate the heat internally in the substrate, beneath the patching/coating. The heat flows from inside to the outside, allowing any outgassing without pinholes and resulting in better quality. Solvents can evaporate much more rapidly than curing with alternative processes, which heat from the outside in. When heating the outside first, the surface of the coating is cured and hardened, trapping the solvents between the substrate and the coating skin, making it far more difficult and time consuming for the solvent to evaporate from the coating.

The mechanical movement of the patched/coated surface must be constrained and the heating coil opening should be sufficient to allow adequate clearance for the painted component to move within limits without physically touching any solid surfaces and avoid surface damage until the process of curing is completed.

During the process of evaporation, the fumes should be removed properly and care must be taken to ensure that aqueous residuals and condensed water do not excessively accumulate above the processed strips and drip on the as-cured surfaces.

***Power Supplies.*** One of the most critical parts of any induction heating machine is the power supply. The old saying, "It only takes a mouse in the elephant show to ruin the whole circus," can be rephrased as, "It only takes a bad power supply to ruin the most sophisticated induction heating process. The power supply affects practically all critical parameters of the induction system including reliability, system flexibility, energy efficiency, product quality, compactness and cost.

Many different power supply types and models are available on the market. However, only a few of them are considered to be acknowledgeable as the "cream of the crop". The VersaPower®-Xtreme™ is one of those devices, suitable for a wide range of fastener heating applications (**Figure 6**). It is a highly versatile tabletop induction power supply offering never before seen flexibility via on-unit or remote controls, optional right or left coil mounting positions, advanced safety features and more, the VersaPower-Xtreme induction power supply is in a class of its own[2].

Excelling in highly repetitive processes, the VersaPower-Xtreme power supply is able to accelerate processing speeds by precisely and consistently focusing heat on parts to deliver an exact internal thermal profile. Equipped with Radyne's intuitive Digital-iQ™ controller technology, it is the ultimate in high-speed control technology. Digital-iQ Controls sample system voltage and current 160 Million times per second with sub-microsecond control loop response which enables it to ramp from 0% to 100% of rated power in as low as 30 milliseconds in medium-frequency applications and sub millisecond in some high-frequency applications to deliver maximum accuracy. Regardless of the process, precision controls provide the ability to achieve uniform metallurgical quality, while instant operation without heat up time allows for an adaptable system that keeps up with varying production speeds and changes. Quality Assurance System (QAS) offers real-time processing against limits and fault/trip on process step to help deliver higher quality parts and enhanced repeatability.

**Fig. 6 — The VersaPower® Xtreme™ induction power supply for 20 to 80 kHz or 100 to 400 kHz applications. (Courtesy of Radyne Corp., an Inductotherm Group Company).**


The Versapower-Xtreme offers added flexibility with its lightweight design, optional right or left coil mounting positions and variety of standardized models suitable for precisely matching the desired induction heating application.

Space limits to provide an exhausted description of fastener applications as well as electromagnetic and thermal subtleties of applying induction heating. We suggest interested professionals to visit Radyne's website: *www.radyne.com* or review content of the newly published second edition of the *Handbook of Induction Heating*, **CRC Press**, 2017[1].
*www.radyne.com* **FTI**

## *References:*

*[1] Rudnev, V., Loveless, D., Cook, R., Handbook of Induction Heating, 2nd Edition, CRC Press, 2017.*

*[2] www.radyne.com*

*[3] ASM Handbook, Vol.4C: Induction Heating and Heat Treating, ASM Int'l, 2014.*

***Company Profile:***
***Radyne*** *has developed unmatched skill and facilities in the field of induction heating. Radyne maintains a dynamic, integrated, solutions-driven team equipped with the tools essential for rapidly delivering innovative products, services and engineered solutions. The company is a world leading manufacturer and pioneer in the development of advanced induction and controlled atmosphere heating equipment. Offering general-purpose to full-turnkey induction systems for almost every industry, Radyne offers customers industry expertise, process engineering, induction equipment, inductor design and development and 24/7 service and support in one location.* ***www.radyne.com***