INDUCTION HEATING

For industrial inductive heating applications

GENERAL

Induction heating is used since more than 50 years for comercial applications, but nevertheless it is not well known to the wide public.
For induction heating the working piece must be electrically conductive such as metal or semiconductive as silicon. The high frequency-energy is transmitted by way of an induction coil to the work piece. The induction coil or simple "inductor" is geometrically adapted to the shape of the work piece, in most applications it consists of a bent cupper pipe and is water-cooled.
Due to technical advances (semiconductors, transistors) the size and weight of present-day equipment could be minimized about to about 10% (with respect to previous models). The compact design, small weight and flexibility of the equipment and its advantageous price makes it possible to use induction heating for many applications.
In the following we try to show you some of the most frequently used ranges of activities, and at the same time help you to imagine the use of induction heating for your own purposes. There are a lot of various possible applications, and with the advances of induction heating many existing processes could also be improved with this technique!

What is induction heating?

Induction heating is basically different with respect to most other heating processes. The heat develops in the work piece itself, there is no need for a transmission medium (such as air, water or a mechanical connection) The electrical energy is transmitted to the work piece trough a magnetic field.

The alternating current flowing through the induction coil generates an alternating magnetic field that produces a current in the work piece. The electrical energy through the coil is converted to magnetic energy, and this magnetic energy is converted back to heat in the work piece. The current density in the work piece follows the "Skin-effect", a phenomenon, whereby most current flows on the work piece surface. Towards the center the current density decreases exponentially. In the center of the work piece the current flow is nearly 0.

The heating power (P) transmitted to the work piece is:

$$P = k \cdot I^2_{Ind} \cdot \sqrt{\mu \cdot \rho \cdot f}$$

P = Heizleistung [W]
K = Konstante
I_{Ind} = Strom in der Induktionsspule [A]
μ = relative Permeabilität vom Werkstück
ρ = spezifischer Widerstand vom Werkstück $[\frac{\Omega \cdot mm^2}{m}]$
f = Frequenz [Hz]

The penetration depth of the current is:

$$\delta = 503 \cdot \sqrt{\frac{\rho}{\mu_r \cdot f}}$$

δ = Eindringtiefe [mm]
ρ = spezifischer Widerstand vom Werkstück $[\frac{\Omega \cdot mm^2}{m}]$
μ_r = relative Permeabilität vom Werkstück
f = Frequenz [Hz]

The formula is adapted to the case that the work piece diameter is at least double the penetration depth of the current.

Three inductors are connected in line (equal current for every coil). The equation D > 2 x δ is only valid for the first coil (left side). The work piece in the last coil (right side) is not heated, because D < 2 x δ.

The relation between heat energy, work piece-temperature and heat-up time is:

$$P = \frac{m \cdot \Delta E}{t}$$

P = Leistung [kW]
m = Werkstückmasse [kg]
ΔE = Energieaufwand um 1kg des Materials in 1s um ΔT zu erwärmen $[\frac{kW \cdot s}{kg}]$
(z.B. Stahl: $\Delta E_{600°C}$=0.4; $\Delta E_{1400°C}$=1.33)
t = Gewünschte Aufwärmzeit [s]

The energy provided to the induction coil is much greater than the energy transformed to heat in the work piece. High currents in the induction coil develop large losses in the copper (induction coils are mostly made up of copper-pipes). Therefore the maximum efficiency of a cylindrical coil is about 90% (work piece made of steel) and about 40% (work piece made of copper). The alternating current is produced by an RF generator with an efficiency of 90 to 95% (coil power/line power).

TN-Design

The static frequency converter is designed for different induction heating and melting processes. The compact, nearly totally enclosed design allows to use the converter in industrial ambient conditions, also in case of difficult locations. All components are contained in one case, ready to connect for power and cooling water supplies.

The handling and indicating devices are located on the front side of the generators. The clearly arranged buttons, status lamps and status indications allow easy handling.

The reliability of the converter is ensured with a 2-step supervising system for all relevant electrical and thermal working-states. The technique of the frequency conversion is based on a parallel-oscillating circuit on the working side with power capacitors and an induction coil. The values of inductance and capacitance of this device determines the working frequency of the generator. The load-oscillating circuit is connected to a power source. The power source comprises a 6-pulse rectifier, chopper, ferrite-transformer and smoothing-device.

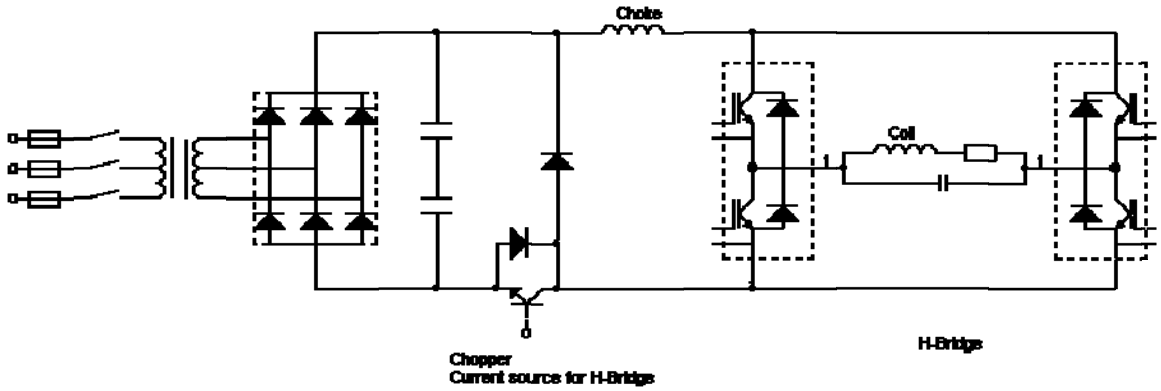

figure 1

With the use of a mains transformer there is a potential-separation between the mains and the working circuit. Due to this design there is no short-circuit in case of an earth link at the induction-coil. The switching of the H-bridge is achieved with the switching of the chopper. Due to this solution it doesn't matter how often and under which power states the high frequency is switched on or off. There are no mechanical switches employed.

Applications/advantages of induction heating

From the wide range of possible working constellations with middle and high frequency converters for induction heating some typical applications:

Applications

	Application	Advantages of induction
1	**Stretching metals** Shrinking rings, cases and wheels. Sections are warmed up evenly. With natural cooling or contact cooling from touching the colder work pieces, there results a mechanical contact with colder work pieces (e.g. installing roller bearing rings onto the axle).	- Rapid-ready status - Short heating-up cycles - No "hot spots" - Accurate controllable and high reproductibility heating process - small heat losses to environment
2	**Blue annealing of steel strips, saw blades,.....** Corrosion protection by surface oxidation of the steel strips. Blue annealing is feasible also with hardened steel, thereby no hardness waste occurs. Heating up process with work piece-	- Rapid-ready status - No developing of hot exhaust gases as during the indirect flame heating - No developing of ecologically harmful materials as with chemical blue annealing.

	rates (line speed) of 10 to 100 m/min.	- Accurate dosage and reproductibility of the heating-up process (with line speed feedback our generators keep surface temperature of steel sheet stable in case of line speed changes)
3	**Hardening** Today induction hardening is the most economical procedure for hardening of a section of the work piece surface.	- Rapid-ready status - Very short handling time - No scaling - Subsequent treatments (leveling, sanding off and annealing) are not necessary - Continuous hardness quality
4	**Heat-connecting:** - **Soldering** As compared with furnace and flame, there is the following relation for the heating-up rate of the work piece: 1 : 200 : 1000 (furnace, flame, induction) - **Welding** Longitudinal welding at round and square tubes from steel, brass and light alloys	- Rapid-ready status - High soldering/welding speed - Economic also for larger series - Continuous quality of soldering/welding - Small energy costs during breaks and standby - No direct contact to the work material ->no wear through contact
5	**Elimination of stress in metals** - Pre-/post heating in welding processes - Prevention of stress-/hardening zone-developing by proportioned heating - Soft-annealing (reduction of hardness) - Recristallization-annealing. Reduction of stress after cold-forming/-drawing	- Rapid-ready status - Partial annealing without heat drift into surrounding zones
6	**Heat up of slugs** before warm-forming in pressing and cutting machines	- Rapid-ready status - Clean work pieces - Small edge carbonization - Constant forging temperatures - Fewer breaks in comparison with the air furnace - Increased transition-solidity and notching impact strength

7	**Melting** - Melting of metals: Al, Au, Ms, Cu and Ag in graphite-crucibles. Nickel and steel in aluminum-oxide crucibles. Platin and palladium in zirkodium-oxide crucibles - Outmelting of cores (e.g. in automotive- industry to make intake manifolds)	- Rapid-ready status - Accurate temperature control - Elektrodynamic mixing of melting materials - Short melting times
8	**Miscellaneous** - Melting of non-metallic materials (e.g. glass) - Epitaxy machines for semiconductor-production - Sintering (making compounds) - Tool-heating for plastic machines - Inductive cover gluing (e.g. yogurt cover)	

Advantages of induction

1. Accuracy of dosage

This is the most important advantage of induction heating. The supplied heat may be adjusted independently and in closest boundaries with respect to the fluctuations of the current supply or the like. Any temperature gradients can be copied by application of the pyrometer (measurement of the temperature by infrared radiation) and a temperature regulator.

2. Max. productionspeed

The heating-up energy can be supplied as fast as the material permits. In comparison to radiation heating this causes an increase of the production rate by a factor of up to 1000.

3. Heating up of objects otherwise unattainable:

Metal parts in plastic/vacuum/water/wood etc.

4. Small space requirement

In comparison to conventional heating methods

5. Improvement of working-conditions

- No development of dirt and smoke
- Low heat radiation because the heat is generated in the work piece itself

6. High efficiency

- No heat losses

- No heat transfer to the environment

7. Uniform quality

Since the characteristics mentioned above cause a local delimitation of the heating process, exact dosage, large operating speed and no deformation of the work piece, the products are characterized by uniform continuity and quality.

RF Generators TNX-Series

High-frequency generators are built to provide inductive heat treatment for magnetic as well as for non-magnetic metal materials, mainly for hardening, soldering, tube welding etc.

Generator	Nominal power	Frequency range	Mains power	Cooling water	Weight	Dimensions
[Type]	[kW]	[kHz]	[kVA]	[L/min]	[kg]	WxDxH [mm]
TNX 5	5	10-150	6	4	40	370x500x580
TNX 10	10	10-150	11	8	40	370x500x580
TNX 15	15	10-150	16	11	50	370x500x715
TNX 20	20	10-150	23	15	54	370x500x715
TNX 30	30	10-150	34	22	60	370x500x715
TNX 50	50	5-150	57	36	500	850x800x1500
TNX 60	60	5-150	69	43	500	850x800x1500
TNX 100	100	5-20	120	72	780	900x1000x1500

TNX 150	150	5-20	175	107	850	1000x1400x1500
TNX 200	200	5-20	235	142	900	1000x1400x1500
TNX 300	300	5-20	350	214	1000	1000x1400x1500
TNX 330	330	5-20	380	235	1000	1000x1400x1500
TNX 600	600	5-20	700	430	2000	1400x1000x3000

TNX 5 - 30

Industrial standard

Internal and remote user panel

TNX 5-20 Compact with external resonance circuit

60% smaller

With remote panel

TNX 60-600

Massive construction

Internal and remote user panel

The main advantages of our frequency converter design:

- Cooling water input temperature up to 40°C
  - No need of an external heat exchanger or an additional cooling device
- The charging current doesn't flow through the semiconductors (IGBT's)
  - Low switching losses
- The working frequency is equal to the resonant-frequency of the oscillating circuit used
  - No switching losses for the IGBTs of the H-bridge
  - You can use the same capitors for different induction coils
- The working circuit is protected against over current and overvoltage
  - No problem in case of overload or running without load
- Direct control of the RF-power (feed-back loop)
  - The heating-up of the work piece is proportional to the power-reference

- The generator startup is at the resonance frequency
  - No problems with over current at startup
- Soft start system
  - Reduced stress for electrolytic capacitors and semiconductors
- Minimum mains disturbance (noise)

RF Generators IG-Series

Generator	Input	Frequency	Output	Cooling water	Weight	Dimensions
Type	[kVA]	[MHz]	[kW]	[l/min]	[kg]	LxDxH [mm]
IG 114 W 5	11	0.2-2	5	12	330	607x613x1705
IG 214 W 12	25	0.2-2	12	14	550	807x813x1905
IG 214 W 18	36	0.2-2	18	16	590	807x813x1905
IG 314 W 25	47	0.2-2	25	20	750	800x1010x1900
IG 314 W 30	57	0.2-2	30	25	800	800x1010x1900

IG

IG inside

IG

Advantages of RF-generators

- Modern type based on extensive experience in the development of RF-generators
- Functional, compact design
- Totally enclosed, dirt & waterproof casing
- Quite running
- RF module totally shielded to minimize interference
- Rugged construction
- Equipped with protected performance tubes
- Water cooling monitored and closed air circuit
- Infinitely variable adjustment of power output from 0 % to 100 %
- Briefly overloadable to 150%
- Inductors are quickly removable for exchange

Applications

Wood

	Advantages
Drying	3 times shorter process time than with hot air no overheating (the heating energy is negligible when water is out)
Gluing	100 to 20 times shorter process time no overheating selective heating
Restoration	elimination of parasites without chemicals no toxic process

Polymers

	Advantages
Welding	
Thermoforming	Shorter process time
Curing	

Food

	Advantages
Defrosting	shorter process time (factor 50) lower bacterial contamination possible with packed food
Backing and post backing	shorter process time separate control of surface and core heating rates
Pasteurization	shorter process time possible with already packed

	food

Various

	Advantages
Textile dryers	moisture removal in roving and bale form no overheating
Fiberglass drying	moisture removal in roving and bale form no overheating
Elimination of parasites in corn	no toxic process
Paper drying	No overheating
Book drying	No overheating
Tobacco drying	No overheating
Paint drying	Short process time No overheating