

Applications of Induction Heat Treating

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Overview

- Advantages of Induction Heating Compared to Other Methods
- How induction heating works
- Applications of Induction Heat Treating
- Conclusions

Specific Features of Induction Heating

- Heat generation occurs inside the part
- Heating is contactless
- Method can provide very high power densities
- Heating may be highly selective in the depth and along the surface
- Any processing atmosphere (air, protective gas, vacuum)
- Very high temperatures may be created
 - NASA currently using induction to test survivability of NTP fuel elements at 5000 F to ensure safety for a trip to Mars – NTREES Program

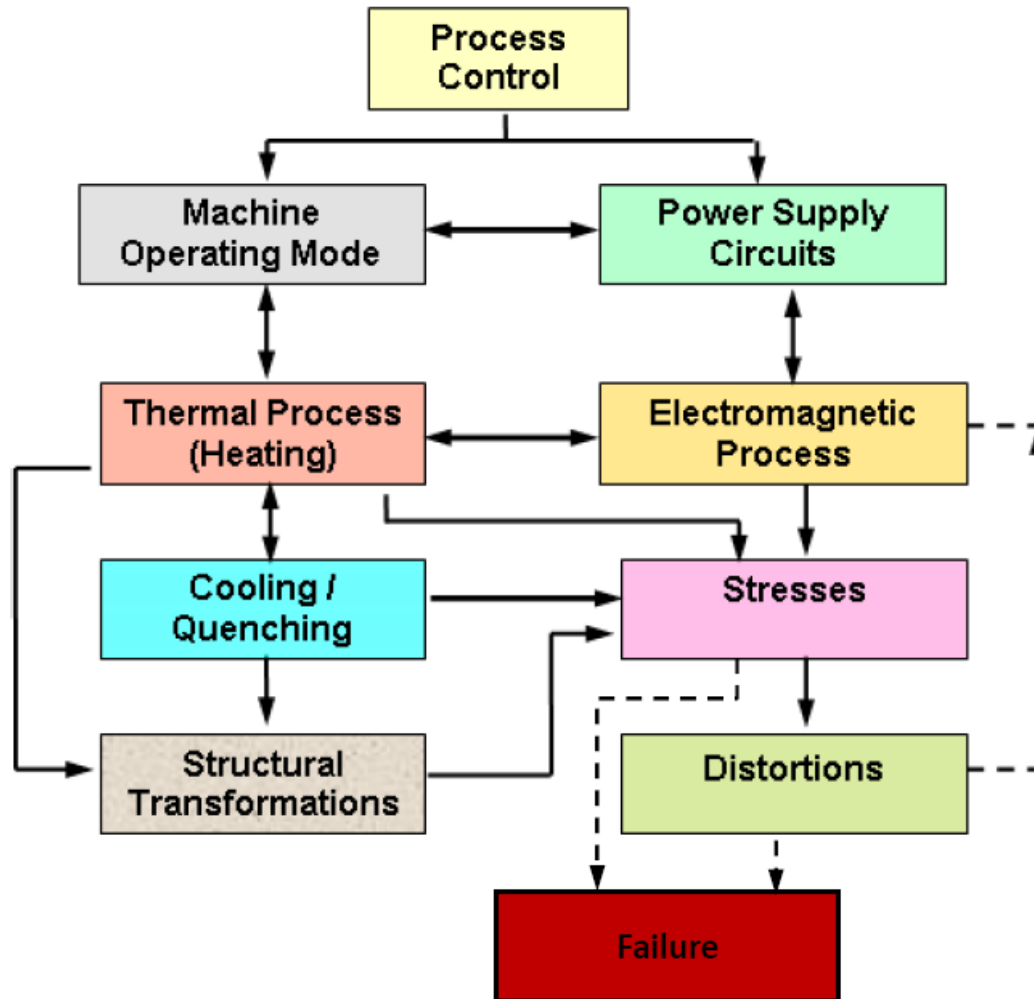
What is Induction Heating?

Induction Heating is a Contactless Heating Method of bodies, which absorb energy from an **Alternating Magnetic Field**, generated by Induction Coil (Inductor)

There are two mechanisms of energy absorption:

- generation of close-loop (eddy) currents inside the body which cause heating due to electrical resistance of the body material
- hysteresis heating (for magnetic materials ONLY!) due to a friction of magnetic micro volumes (domains), which rotate following orientation of external magnetic field

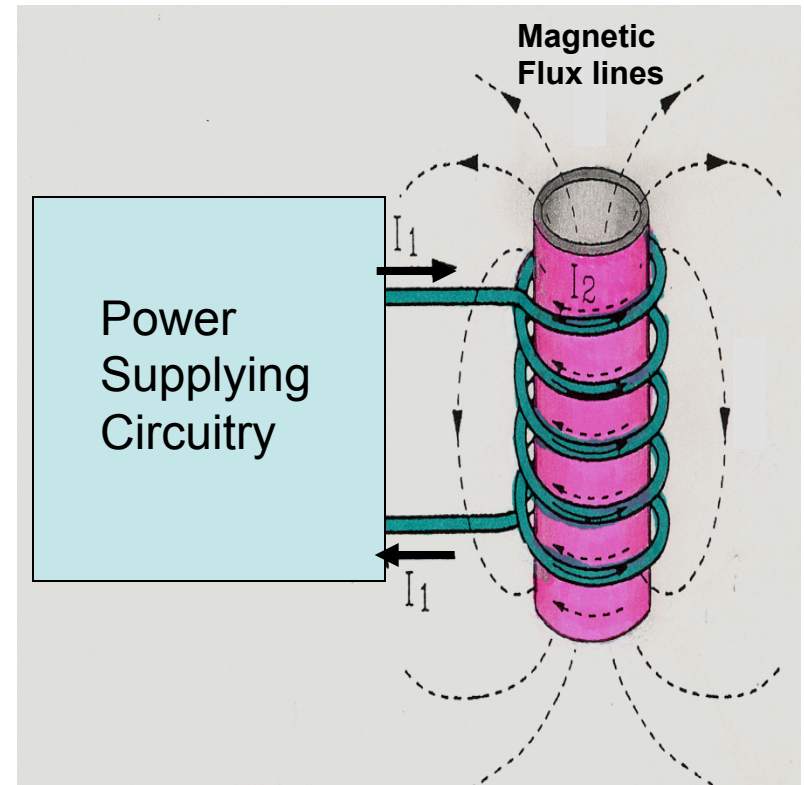
Mutually Coupled Phenomena in Induction Heating Process



Principle of Induction Heating

Chain of phenomena:

1. Power supply delivers current (I_1) to induction coil
2. Coil currents (ampere-turns) generate magnetic field. Lines of field are always closed (**law of nature!**) and each line goes around the current source – coil turns and workpiece
3. Alternating magnetic field flowing through the part cross-section (coupled to the part) **induces** voltage in the part
4. Induced voltage creates eddy currents (I_2) in the part flowing in direction opposite to the coil current where possible
5. Eddy currents generate heat in the part

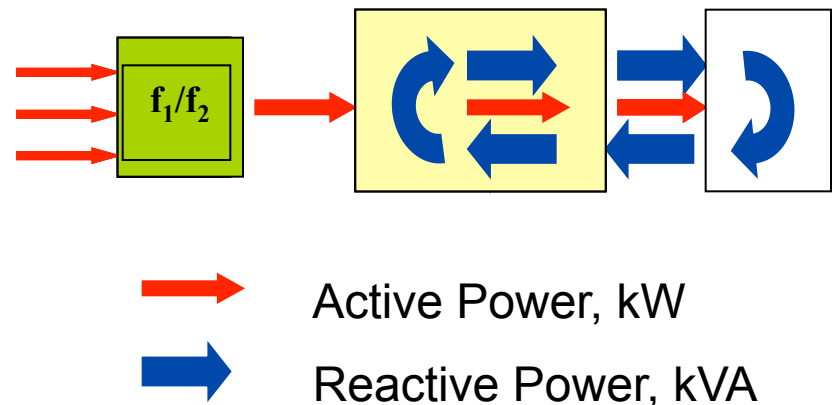
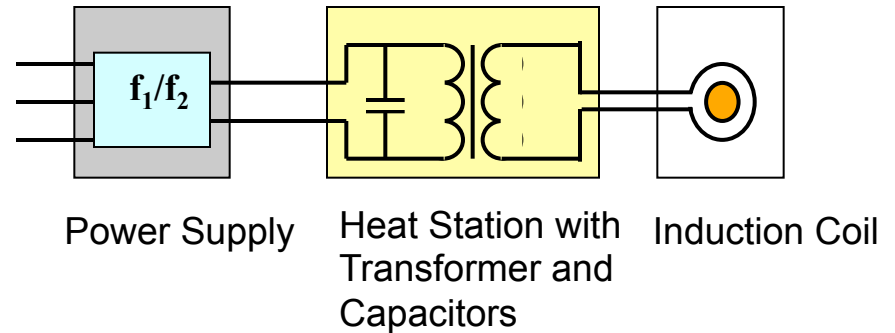


Power Flow in Induction Heating Installations

Alternating current changes direction twice during each frequency cycle. If frequency is 1kHz, current changes direction 2000 times in a second.

A product of current and voltage gives the value of instantaneous power ($p = i \times u$), which oscillates between the power supply and the coil. We can say that power is being partially absorbed (**Active Power**) and partially reflected (**Reactive Power**) by the coil. Capacitor battery is used to unload the generator from the reactive power. Capacitors receive reactive power from the coil and send it back to the coil supporting oscillations.

A circuit “coil-transformer-capacitors” is called **Resonant** or **Tank** Circuit.

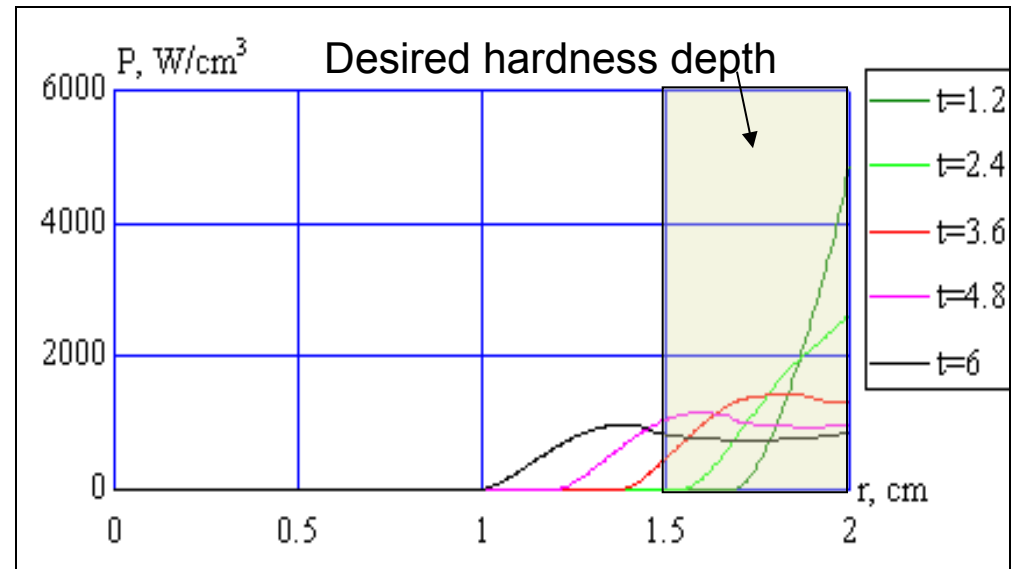


Power Density Curves for Induction Surface Hardening Process

Effectiveness of induction surface hardening strongly depends on frequency selection.

At the end of heating cycle when utilizing the optimal frequency the maximum value of power density must be just beyond the required hardness depth (5 mm in the case on right).

For simple cases of flat and round pieces and traditional steels, there are graphs and formulas for frequency selection. However, computer simulation is a much more powerful, universal and accurate design tool.



Part diameter 1.6" (4 cm), frequency 4 kHz,
Required hardness depth – 0.2" (5 mm)

ELTA simulation program

Recommended Frequency for Different Case Depths

Optimal frequency corresponds to **Case Depth = 0.5δ**

Good frequency range corresponds to $0.3 \delta < \text{Case Depth} < 1 \delta$

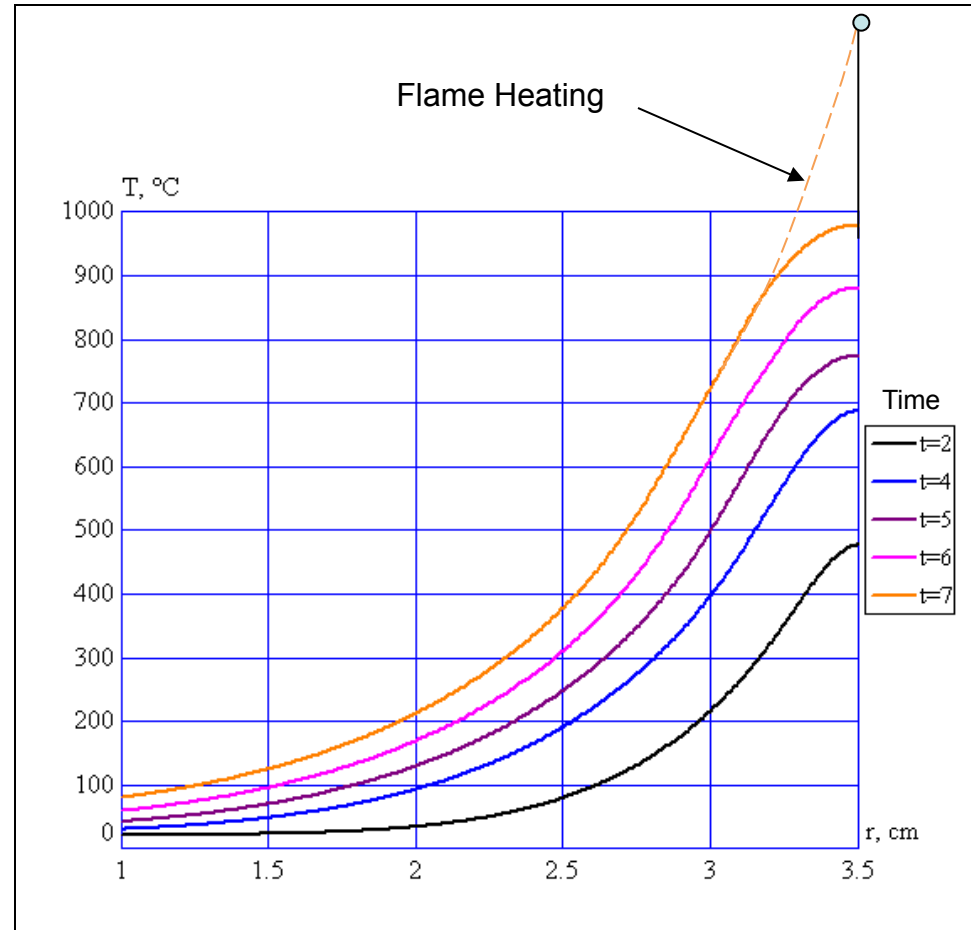
Case Depth	Frequency, kHz					
	1.0	3.0	10	30	100	300
Min mm	5.0	2.7	1.5	1.0	0.6	0.5
Opt mm	8.0	4.5	2.5	1.6	1.0	0.8
Max mm	15	9.0	5.0	3.0	1.6	1.2

Temperature Evolution During an Induction Hardening Process

Compared to furnace heating induction hardening provides much faster heating when optimal frequency is used.

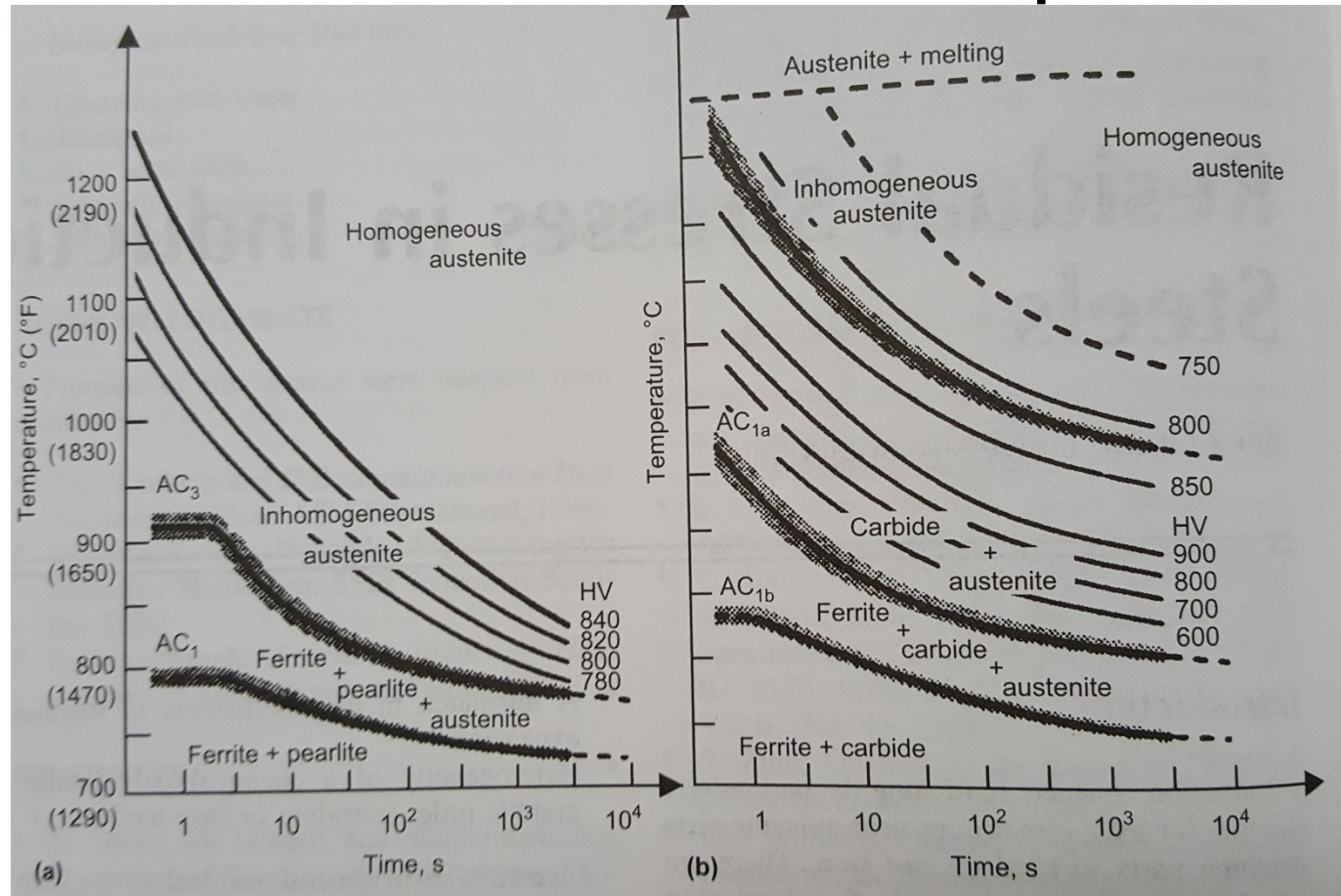
Using direct flame method, in order to achieve required temperature at a needed depth, surface must be strongly overheated or even melted.

When using induction, due to the cold core, surface compressive residual stresses are much higher than for through heated, furnace hardened components



ELTA simulation program

Effect of Short Time Heat Treatment on Transformation Temperature



Hypoeutectoid steel CK45 left, hypereutectoid steel 100Cr6 right
Source – ASM Handbook Volume 4C - Grum

Improved Mechanical Properties Possible when Using Non-Equilibrium Structures



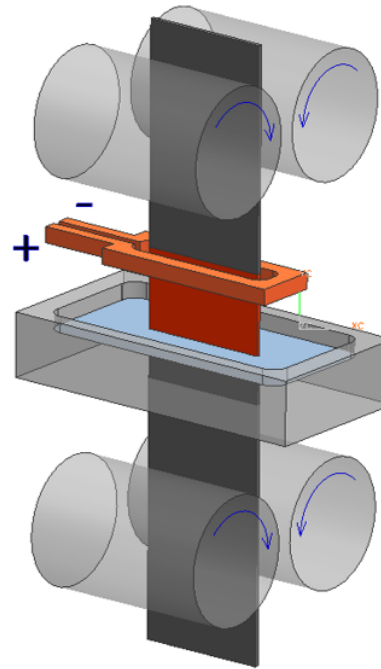
What is *Flash® Processing?*

... Flash Processing starts with commercial off the shelf steels like AISI1010, 1020, or 4130

... using Induction Heating technology the steel is rapidly heated in approx 2-3 seconds to temperatures over 1000C, typically 1070C to 1200C

... within a few seconds, the austenized steel is quenched with a water spray or bath.

... by limiting austenization time, the natural heterogeneity of the steel is preserved to create an engineered micro-segregation of both chemistry and phase in a matrix that combines the strength of martensite with the ductility of bainite.



Courtesy of
SFP Works
dba
FlashBainite

Cold Formed AHSS Components

Current Production Design Seating Components

Flash® 1550 Room Temp “Crash Formed” in Prototype Steel Tools



No noticeable
“Thinning”



Courtesy of
SFP Works
dba
FlashBainite

Able to Produce More Cost Effectively Complex Structures

Why can Flash® Bainite form parts this Strong?

Heterogeneous complexity can lead to ~

“Maximum Strength” in Steel

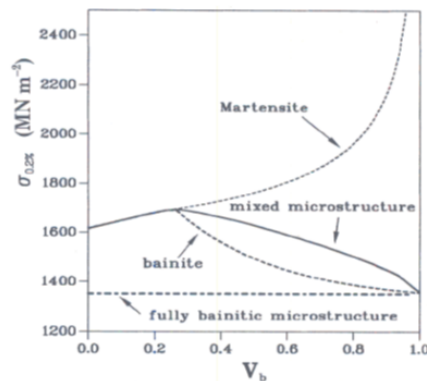
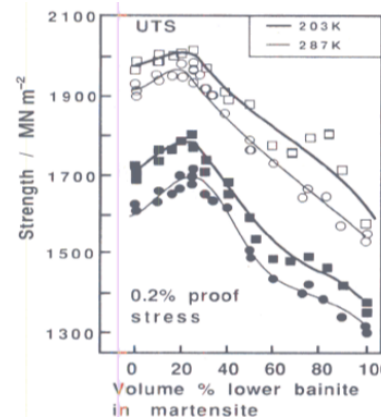


Illustration of contributions of bainite and martensite to overall strength of mixed microstructure

Research by: Tomita and Okabayashi



Young and Bhadeshia

It has been known for 30 years that ~25% Bainite and ~75% Martensite is stronger than ~100% Martensite

Courtesy of
SFP Works
dba
FlashBainite

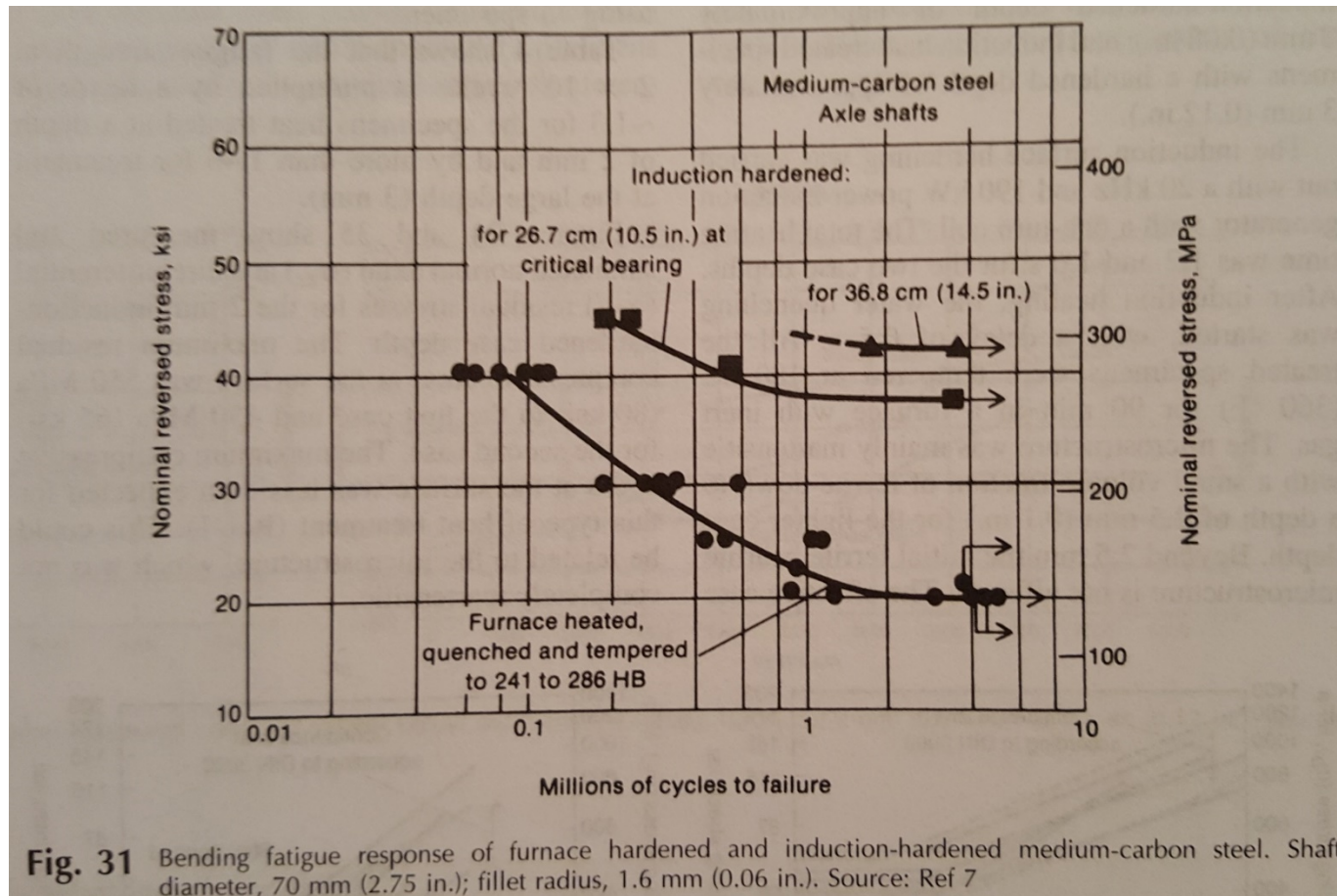
Specific Features of Induction Heating Ctd.

- Stand-by losses of equipment are very low
- Fast start-up (instantaneous in most cases)
- Heating may be easily programmed and automated
- No contamination of treated material may be provided (important for medical material, semiconductors, ultrapure metals, etc.!).)
- Environmentally friendly
 - If electricity is generated by renewable resources, zero greenhouse gas process!

Advantages of Induction Heating

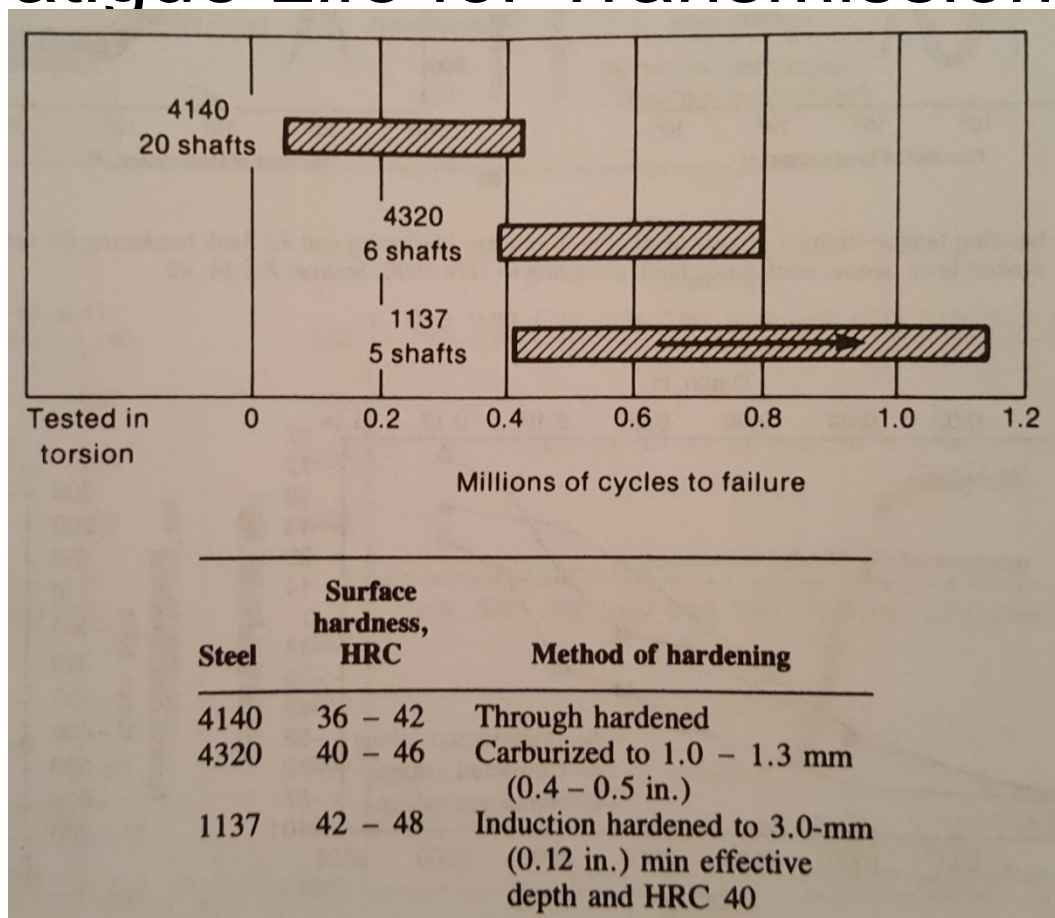
- Short heating cycles and high production rates
- Electromagnetic forces can be used in combination with heating to stir or contain molten metal
- Better metallurgical results due to fast and clean heating
- Energy savings due to selectivity and high efficiency
- Good control and repeatability
- Minimal or no surface oxidation and decarburization
- Lower distortions for surface or local hardening
- Favorable for industrial environment (in-line heating, no pollution, “push button” performance)
- Some processes may not be accomplished other than by induction

Comparison of Through and Induction Hardened Bending Fatigue



Source – ASM Handbook Volume 4C - Grum

Comparison of Through, Case and Induction Hardened Fatigue Life for Transmission Shafts



Source – ASM Handbook Volume 4C - Grum

Major Applications of Induction Heating

- Melting
- Continuous casting
- Investment Casting
- Galvanizing
- Forging & Forming
- Preheating
- Welding
- Shrink-fitting
- Hard facing/coating
- Bonding
- Brazing
- Heat Treatment
- Plasma Processing

Where Is Induction Used?

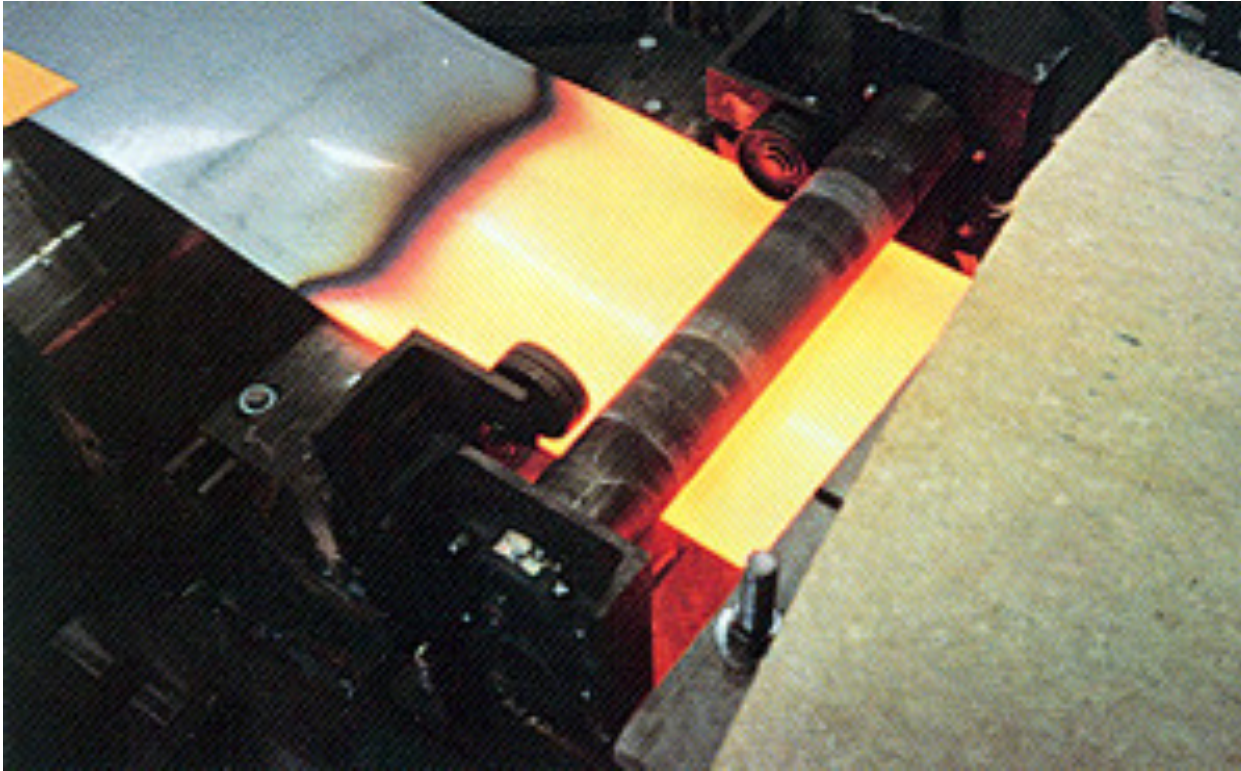
- Automotive
- Off-Highway/Construction
- Aerospace
- Metallurgical Plants
- Oil & Gas Component Manufacturing
- Special Applications

Vehicle Induction Heat Treating

- Engine
- Axles
- Bearing Assemblies
- Drivetrain Assemblies
- Steering Components
- Structural Components
- Fasteners
- Gears
- Etc.

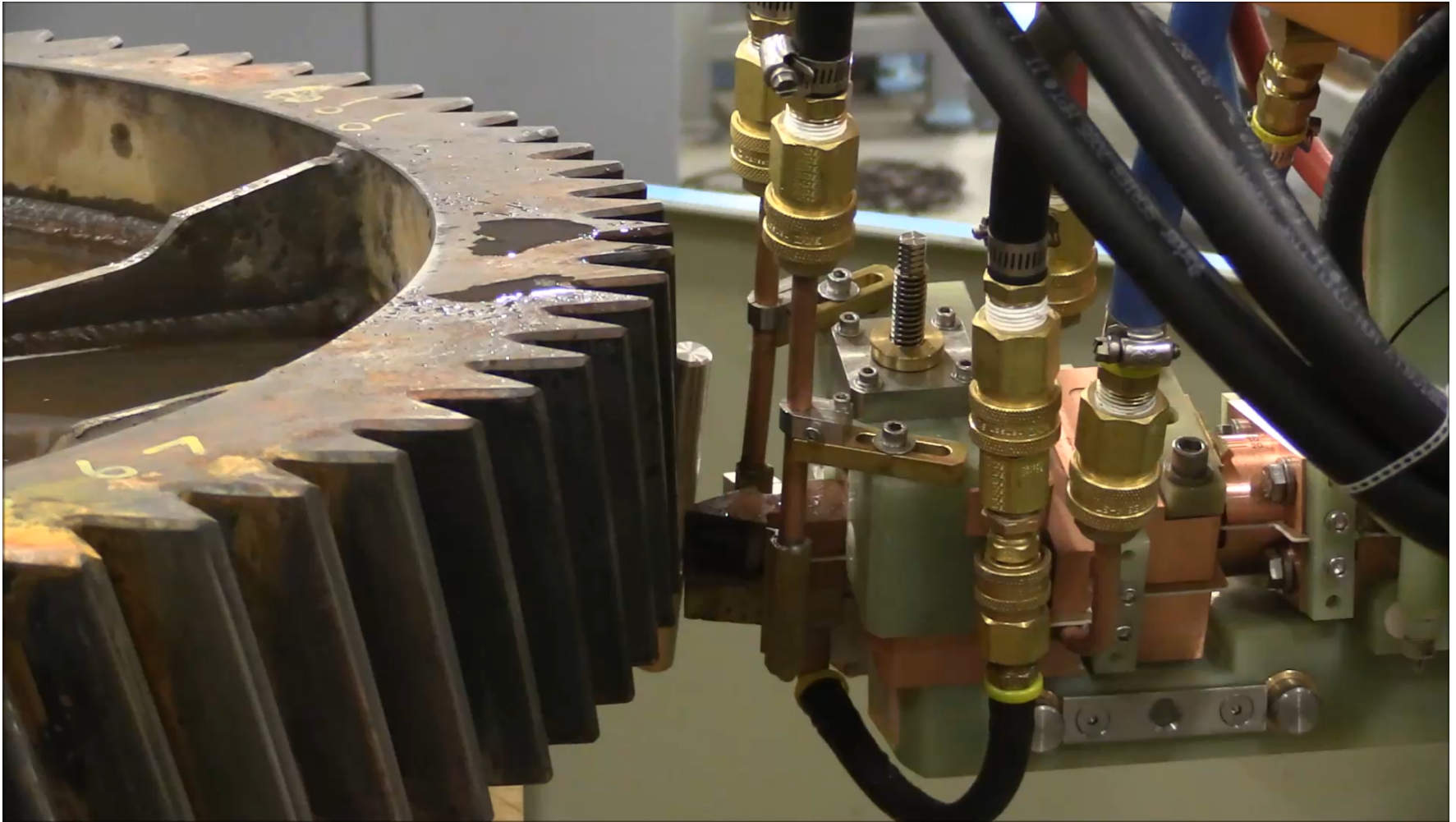


Strip Heating



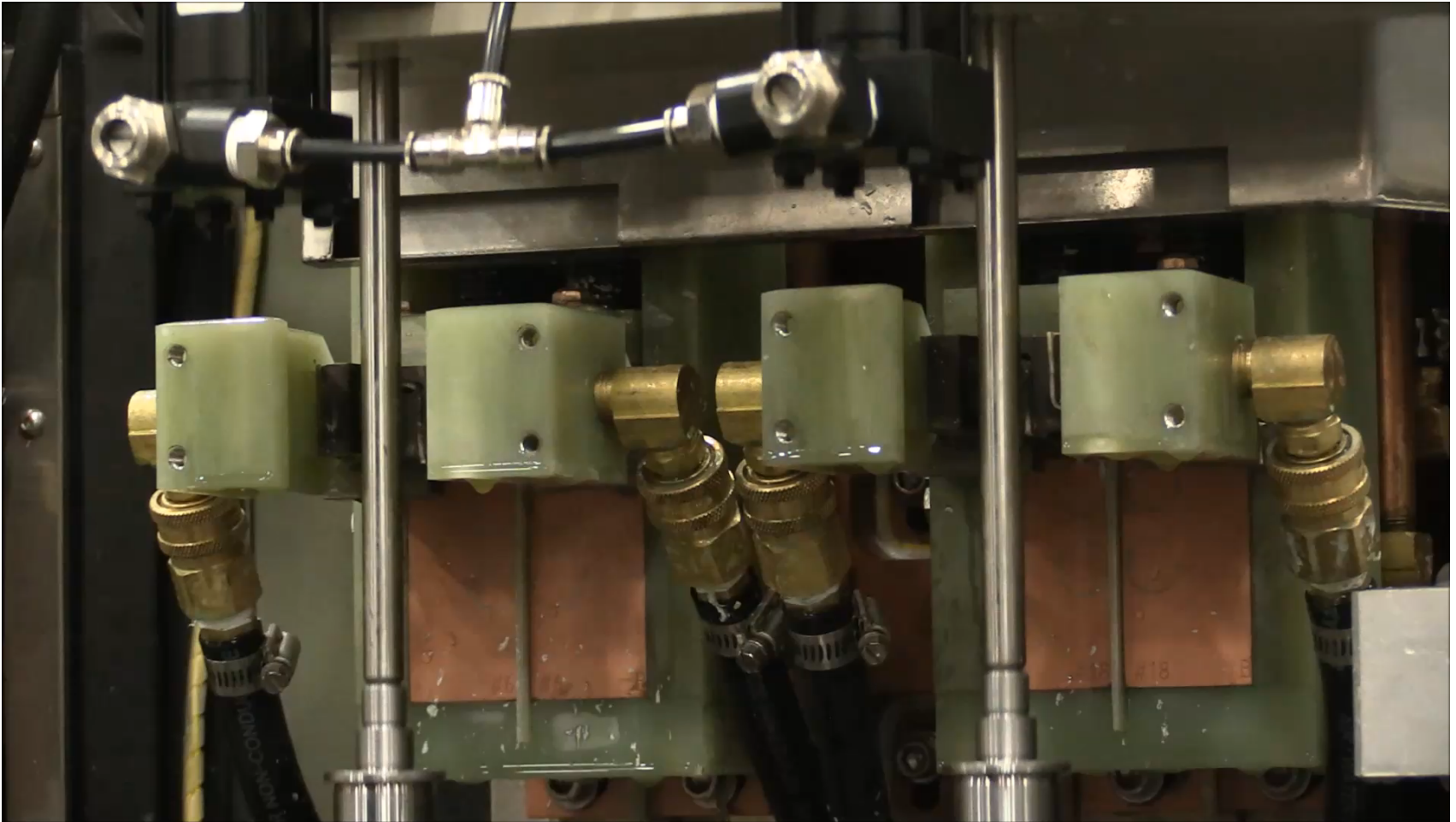
AjaxTocco Magnethermic

Large Gear Heat Treatment



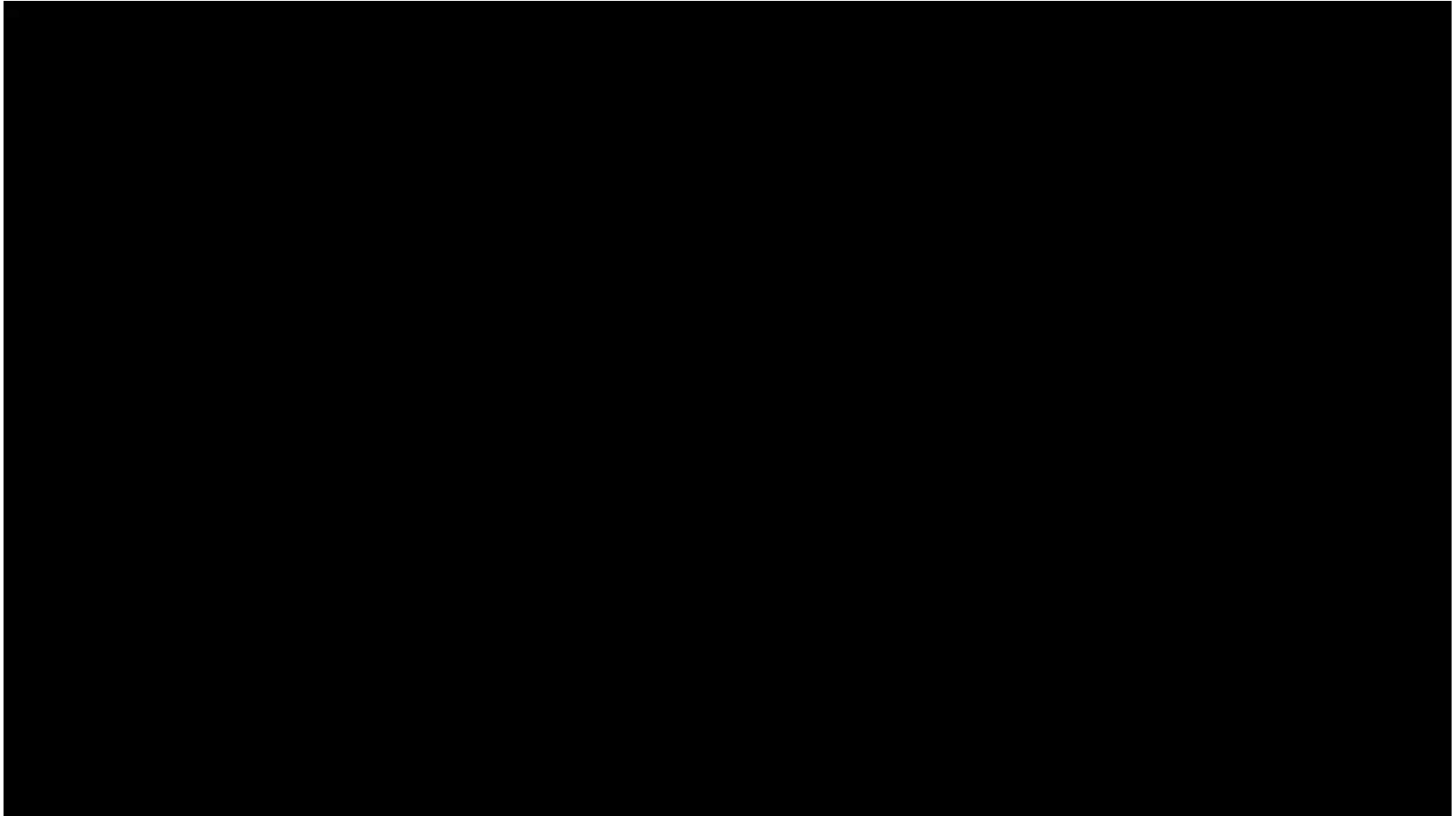
Courtesy of Inductoheat

Local Hardening



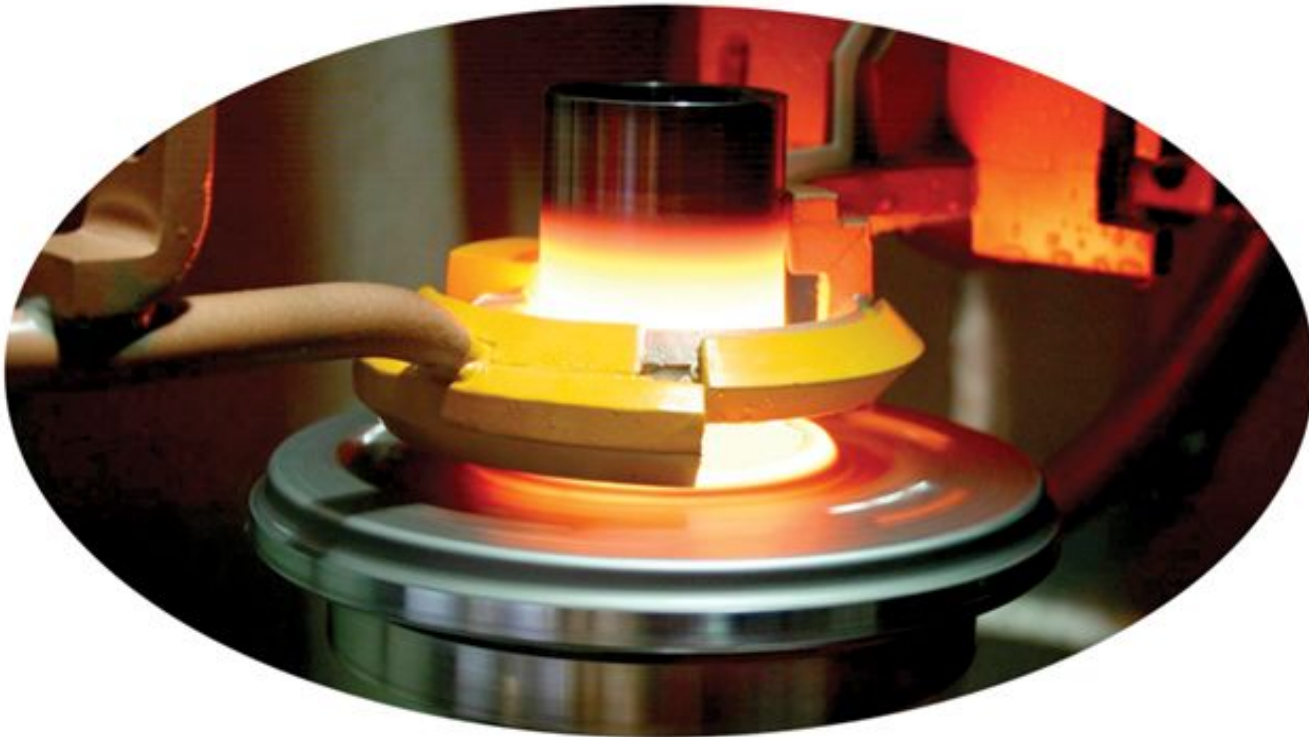
Courtesy of Inductoheat

Gear Contour Hardening

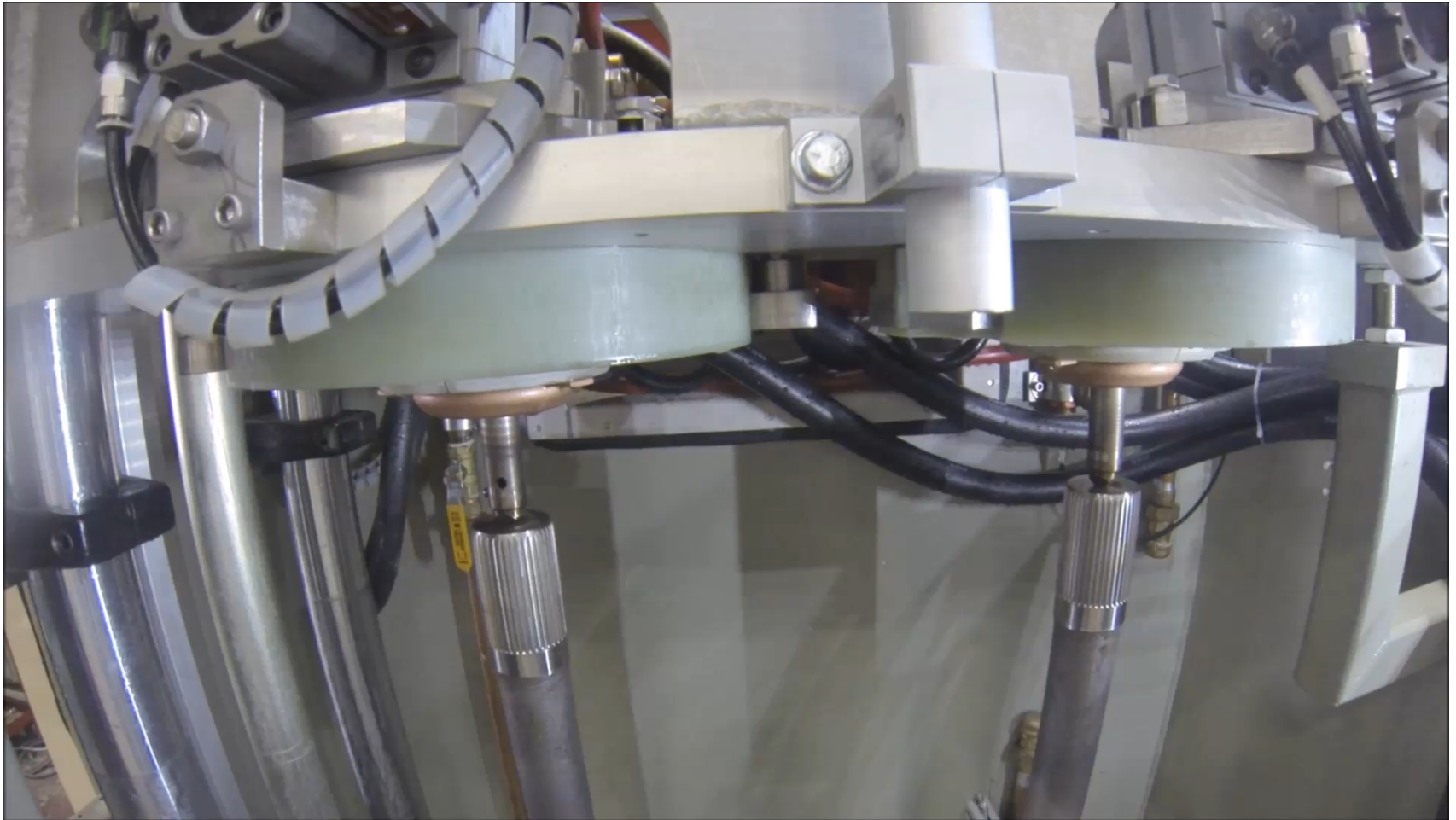


Courtesy of Inductoheat

Automotive Wheel Hub Heating time 5 seconds

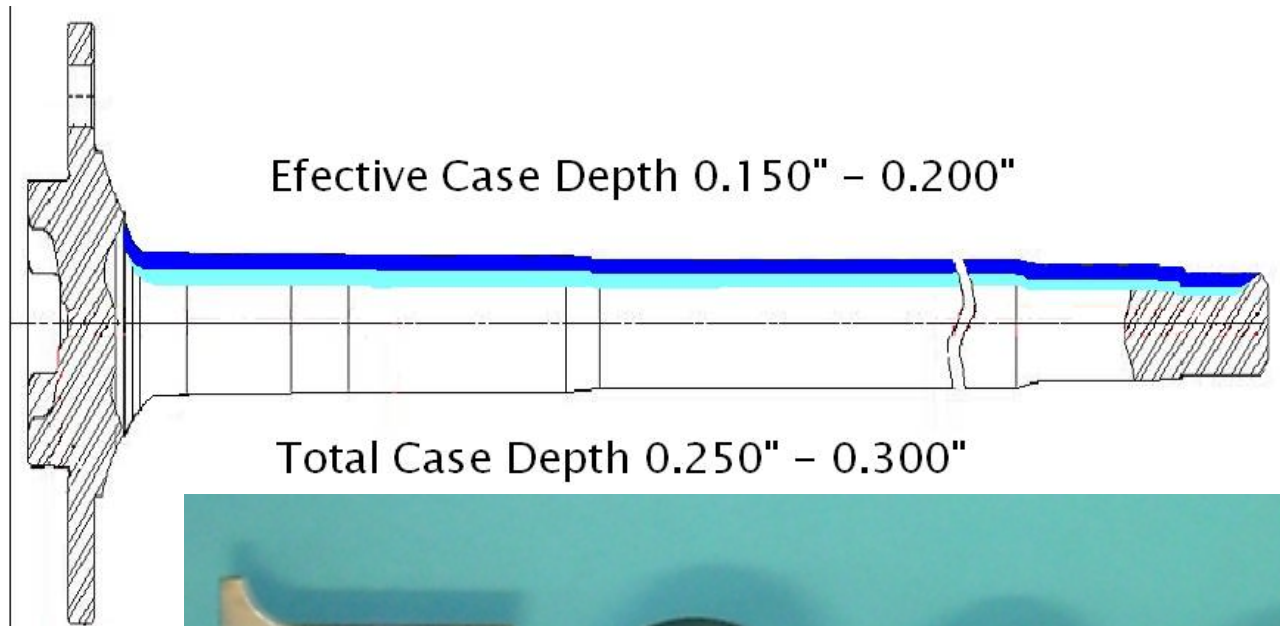


Scan Hardening of an Axle Shaft



Courtesy of Inductoheat

Typical Axle Heat Treat Pattern and Cut Results



Conclusions

- Induction heating is a widely used technology for heat treating
- Despite the presentation contains only steel components, any conductive or magnetic material can be inductively heated
- Induction heating has advantages over other technologies due to its environmental friendliness, ease of in-line incorporation, high available volumetric power densities and ability to control locally the distribution of heat and power

Acknowledgements

- Many of the slides in this presentation were taken from the “Basics of Induction Heating Parts I & II” prepared by Dr. Valentin Nemkov (www.fluxtrol.com)
- Most of the videos are Courtesy of Inductoheat (www.inductoheat.com) and other Inductotherm group companies (www.inductotherm.com)