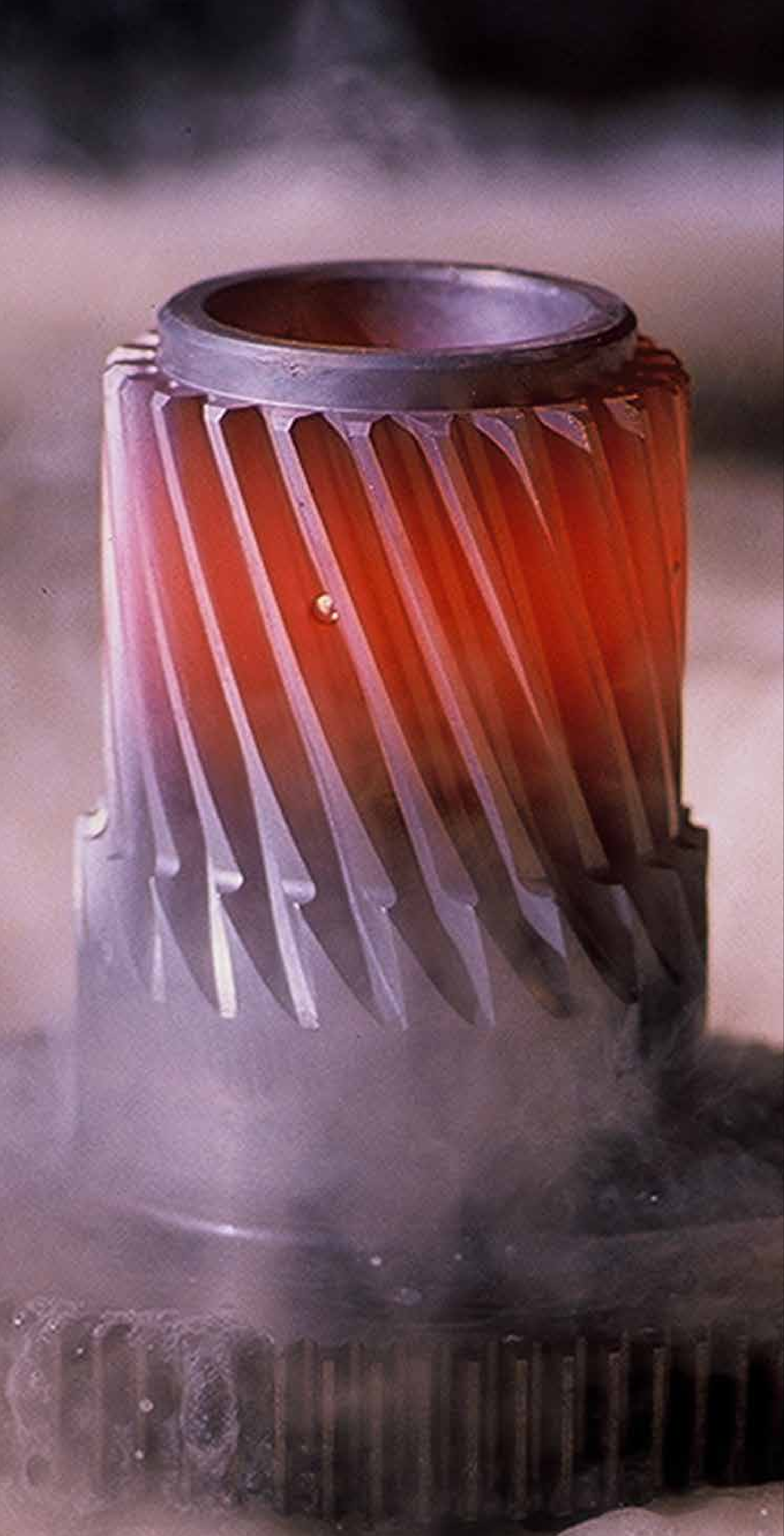
Thermal Processing for Gear Solutions

Spring/Summer 2014



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Spring/Summer 2014

thermalprocessing.com

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Liebherr's Biberach plant has established the new standard for the manufacture of very large slewing rings and bearing races with the successful startup of its new EloRing™ induction hardening system from Elotherm. The EloRing™ efficiently hardens workpieces up to 6 meters in diameter, weighing up to 20 tons with virtually no emissions.

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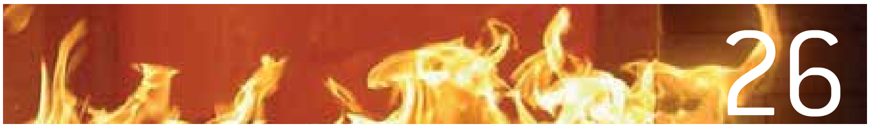
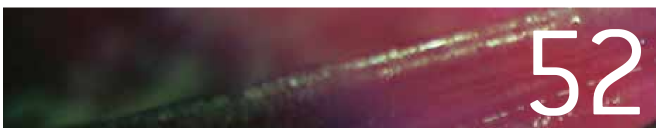
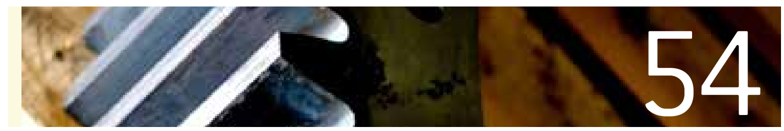
FEATURES

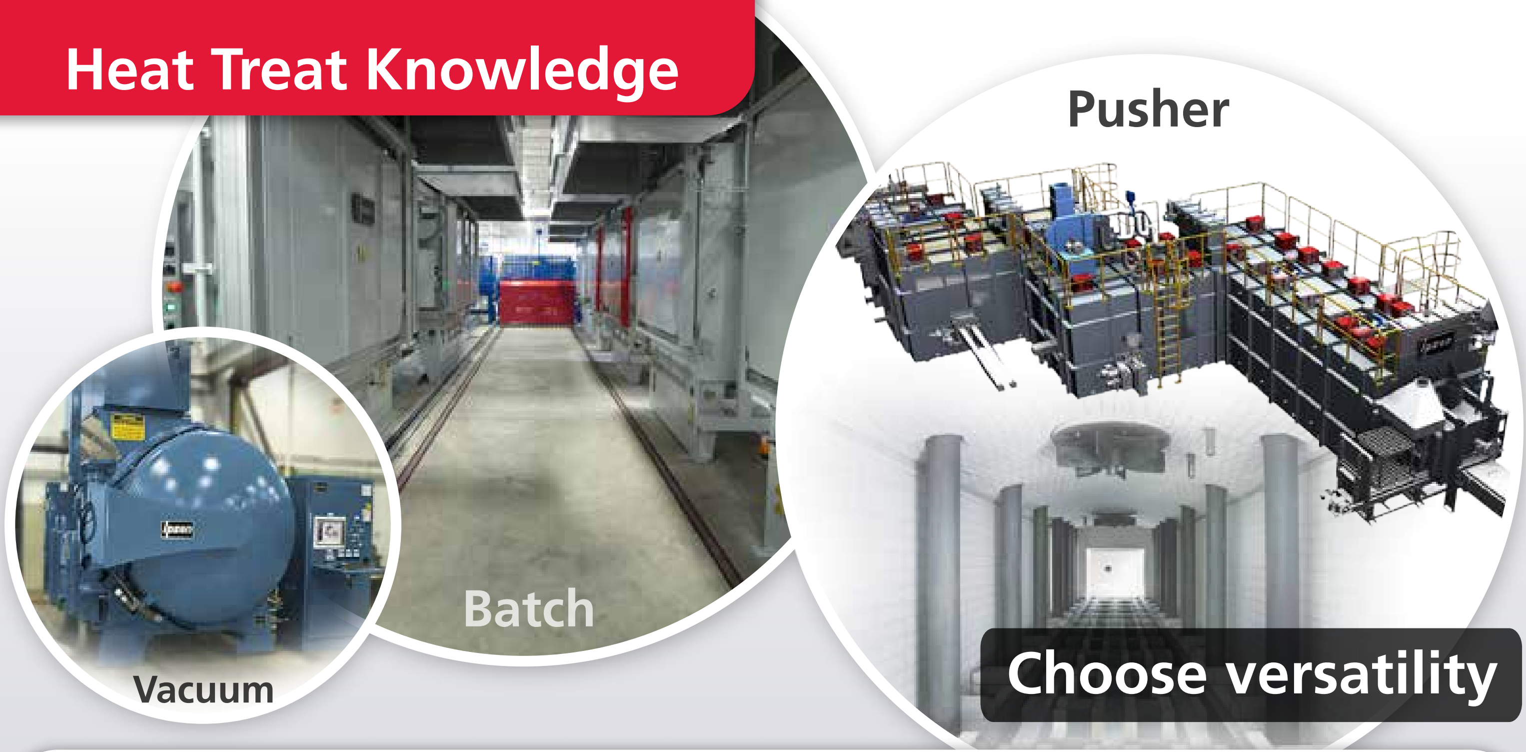
Spring/Summer 2014







Heat Treat Knowledge



Heat Treating Challenges

When it comes to the mass production of components that are integrated in large, heavy-duty machines to execute critical functions, these components need to meet strict industry specifications. Being able to carburize, nitride and harden parts with different materials, case depths, hardenability and geometries also requires flexibility.

At Ipsen, we know the challenges you face and design equipment that allows you to achieve low cost per part, while maintaining the quality and flexibility you need and your customers demand.

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Batch Furnaces
When your heat treating production mix has several recipes, Ipsen Atmosphere Batch furnaces deliver flexibility, with production lines that run different processes simultaneously and can expand as production demands increase.

Vacuum Furnaces
Ipsen delivers proven vacuum technology that allows you to achieve maximum flexibility by executing processes including brazing of heat transfer devices, sintering of components and hardening or annealing of parts and tools for your specific needs.

Atmosphere and vacuum solutions to fit your every need: medium-to-high production throughputs or flexible production for specialized parts

- Lowest cost per part
- Highest energy-efficient equipment
- Most comprehensive global service and support network to keep your equipment running at peak performance

Choosing Ipsen means choosing a partner in success.
Visit www.IpsenUSA.com for more information.

DEPARTMENTS

Spring/Summer 2014
Volume 3 / Number 1

RESOURCES

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Cover photo: Michael D'Angelo, courtesy of Penna Flame

LETTER FROM THE EDITOR

I grew up in Pelham, Alabama, about 20 minutes south of Birmingham. My dad was an engineer for Southern Company. Then he retired. After that, he decided to become an engineer again. Then he retired again. He's like Brett Favre, but a Southern Baptist Brett Favre. A civil engineer by trade, he's a skilled mathematician, working mostly with structural designs and safety standards. I've been admiring members of the scientific community from afar my whole life. In other words, I consider myself an expert on knowing people who are experts on something.

It's amazing to hear them speak. Engineers, architects, composers, sculptors—they all seem to follow the same principle: "Start with the end in mind." Or, as my dad said when I asked him how to build a birdhouse: "Take a block of wood and cut away everything that isn't a birdhouse."

The "end in mind" for a gear manufacturer is the perfect gear—an infinitely efficient, durable, consistently reliable gear. The perfect gear *will* require heat treatment. That's why we put these magazines in the same bag. It's not because heat treaters and gear manufacturers are exactly alike. We're not trying to push one market onto another through polybagging magazines in the spring and fall. These industries themselves are inherently inseparable, and the more each learns from the other, the greater the outcome for everyone.

The spring *Thermal Processing for Gear Solutions* features the widest range of articles we've ever published. For starters, to provide those who may be unfamiliar with the basics of heat treating gears (or those who may just need a refresher), Midwest Thermal-Vac president Fred Otto and "The Heat Treat Doctor" Dan Herring have put together a primer for us. "Heat Treat 101" is an in-depth but highly-readable point-by-point explanation of thermal treatment of gears. Otto and Herring walk through the basic principles of material selection, hardening, and post-hardening processes, while providing an extensive vocabulary of heat treat terms for the novice.

For those a little further along in the industry, we've put together articles covering heat treat topics such as: carbon composite materials; tooth-by-tooth induction hardening of gears; and vacuum carburizing large gears to heat treatment of large components. We've interviewed the presidents of Park Thermal International and DMP CryoSystem, Brian Reid and Bob Wells, about their philosophies on the heat treat process; SMS Elotherm has provided us with a paper on the advantages of induction hardening on highly loaded surfaces; and Bruce Curry of Penna Flame has contributed a short but powerful expose' on the merits of flame hardening a gear.

When you heat treat metal—whether it's a gear or a sword—you strengthen it best when the results are uniform, burning off all extraneous elements so that the final product is nothing but the "end in mind" you knew was possible from the beginning. These industries are cheering for each other, benefiting from each other's successes. It's what someone in your marketing department calls "synergy." *Thermal Processing for Gear Solutions* is meant to highlight the history and possibilities between these industries. In time, who knows what we'll discover? Imagine: metallurgists and thermodynamicists working together in 2050. I can't wait to see those gears.

Thanks for reading,

Tim Byrd
managing editor
Thermal Processing for Gear Solutions magazine
editor@thermalprocessing.com
(800) 366-2185 x205

Thermal processing for *Gear Solutions*

David C. Cooper
PUBLISHER

Chad Morrison
ASSOCIATE PUBLISHER

EDITORIAL
Stephen Sisk
EDITOR

Tim Byrd
MANAGING EDITOR

SALES
Chad Morrison
ASSOCIATE PUBLISHER

Mike Barker
REGIONAL SALES MANAGER

CIRCULATION
Teresa Cooper
MANAGER

Kassie Boggan
COORDINATOR

Jamie Willett
ASSISTANT

ART
Jeremy Allen
CREATIVE DIRECTOR

Rebecca Allen
GRAPHIC DESIGNER

Michele Hall
GRAPHIC DESIGNER

CONTRIBUTING WRITERS
BILL ANDRESKI
BRUCE CURRY
DANIEL H. HERRING
MICHAEL LIFSHITS
DAVID LYNCH
SANDRA MIDEA
JIM OAKES
FREDERICK J. OTTO
NELS PLOUGH
GERHARD L. REESE
TORSTEN SCHAEFER
DIRK M. SCHIBISCH
FRED R. SPECHT
JACK TITUS
WILLIAM WARWICK

Media solutions

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David C. Cooper
PRESIDENT

Chad Morrison
VICE PRESIDENT

Teresa Cooper
OPERATIONS

UPDATE

New Products, Trends, Services, and Developments

Solar Manufacturing Delivers Custom Furnace to Coatings Company

Solar Manufacturing recently delivered and successfully started-up a uniquely designed vacuum furnace required by a major specialized coating services company. Working with the customer on specific concerns of their cobalt and nickel based coating processes, Solar Manufacturing engineers provided custom trapping designs to collect and isolate contaminants resulting from their processes.

The furnace was a Solar Manufacturing Model HFL-5772-2EQ horizontal, front loading vacuum furnace with a work zone measuring 36"w x 36"h x 72"d with a hearth designed to accommodate up to a 3,500 pound workload. The entire hot zone utilizes a Flexshield hot face backed by five (5) layers of ½" thick graphite felt insulation all supported in a heavy-duty stainless steel ring structure. The heating elements are a thin, durable, curved graphite design allowing for a maximum operating temperature of 2600°F.

The specialized vacuum pumping system consists of a Busch Cobra Model NC0400 B Screw Type mechanical pump backed by a Stokes 615 Booster blower with in-line traps for binder and contaminant collection. Also included is a bypass roughing line for initial pumping of the system to improve cycle times. A Varian Model HS-20 diffusion pump is also installed for high vacuum performance to the 10-5 torr range. An external gas cooling system was included incorporating a 150 HP quench motor, a high speed radial fan and a high capacity heat exchanger capable of cooling workloads in argon gas at 2 bar positive pressure. A SolarVac 5000™ PC-based interactive control system was provided for control and monitoring of all furnace functions.

For more information on Solar Manufacturing visit them online at www.solarmfg.com.

Companies wishing to submit materials for inclusion in Industry News should contact Tim Byrd at editor@thermalprocesing.com.
Releases accompanied by color images will be given first consideration.

A Full Spectrum Of Metal Analysis Techniques

The Chemical Analysis department of Keighley Labs offers an independent, bespoke service to aerospace manufacturers, the energy sector, rail industry, foundries, plating companies, galvanisers, component importers and general engineers, providing a fast turnaround and precise material verification. In addition to classic wet chemistry, it employs advanced Inductively Coupled Plasma, Atomic Absorption and Glow Discharge spectroscopy to ensure the optimum method for a particular application, as well as industry standard techniques for carbon, sulphur, oxygen and nitrogen analysis.

Part of Keighley Labs' UKAS-accredited Metallurgical Laboratory Services capability, the chemistry department's scope of accreditation covers an extensive range of ferrous and non-ferrous metallic materials, including iron, steel, stainless steel, aluminium and aluminium alloys, copper, cobalt, lead, nickel, tin and zinc alloys. Non UKAS accreditation also covers plating solutions, air quality filters and foundry consumables. It works in tandem with the company's in-house Mechanical Testing, Metallography, Weld Testing, Problem & Failure Investigation and Heat Treatment departments to provide an all-encompassing technical service, housed on one site.

Headed by Chief Chemist, John Whitaker, and his senior colleague Graham Woodward, each with almost 40 years' industry experience, the department combines in-depth scientific knowledge and practical expertise. Submitted specimens range in size from a minute speck of material, to a test bar or finished component of virtually any size; the team then determines the appropriate testing technique, according to material type, sample size, required turnaround time and complexity of analysis.

For further information, contact lstott@keighleylabs.co.uk, or visit www.keighleylabs.co.uk.

Sinterite Renews ISO/IEC Accreditation

Sinterite, a Gasbarre Furnace Group Company, is proud to announce the renewal of its ISO/IEC 17025:2005 Accreditation, allowing the furnace maker to perform certified calibrations for furnace users, which is required by many of the Group's customers.

The accreditation is with the Laboratory Accreditation Bureau (LAB), headquartered in Fort Wayne, Indiana. LAB specializes in the ISO Standard. The ISO 17025 Accreditation is similar to the 9001 Standard, held by several other Gasbarre companies, but is more specific in requirements for competence. It applies directly to organizations that produce testing and calibration results. This is the primary ISO Standard used by testing and calibration laboratories. Laboratories use this standard to implement a quality system aimed at improving their ability to consistently produce valid results Since the standard is about competence, accreditation is simply formal recognition of a demonstration of that competence. Like the other standards, ISO 17025 allows accredited companies to carry out procedures in their own way, but an auditor may ask the company to justify its methods. Sinterite's accreditation proves the methods are valid and acceptable, and the calibration technicians are competent.

For more information on how Sinterite can provide custom-engineered solutions contact Jeff Danaher, (814) 834-2200 or visit our websites at www.sinterite.com or www.gasbarrefurnacegroup.com for additional information.

New Hot Box Thermal Barrier TS08 for Temperature Profiling

Temperature profiling systems are typically used to measure product temperature throughout the brazing cycle and consist of thermocouples attached to the aluminum product, conveying temperature information to a data logger, which travel together with the product, through the furnace to produce the thermal profile.

Built specifically for use in controlled atmosphere brazing (CAB) furnaces, where aluminum components for automobile cooling and air conditioning systems are brazed, the TS08 thermal barrier range addresses the problems that can occur with profiling systems traditionally used to monitor product temperatures in these furnaces. These problems include:

Fast deterioration of the high temperature cloth inside the thermal barrier due to hydrofluoric acid attack (caused by chemicals in the flux combining with moisture from inside the barrier). This cloth protects the microporous insulation and when worn through, will allow the thermocouples to directly abrade the insulation, widening the exit of the barrier and allowing more heat into the system. This will damage the data logger that the thermal barrier is meant to protect.

Out-gassing of oxygen from air inside the 'hot box' or thermal barrier into the nitrogen atmosphere of the furnace. This can affect the quality of the braze in the products surrounding the system.

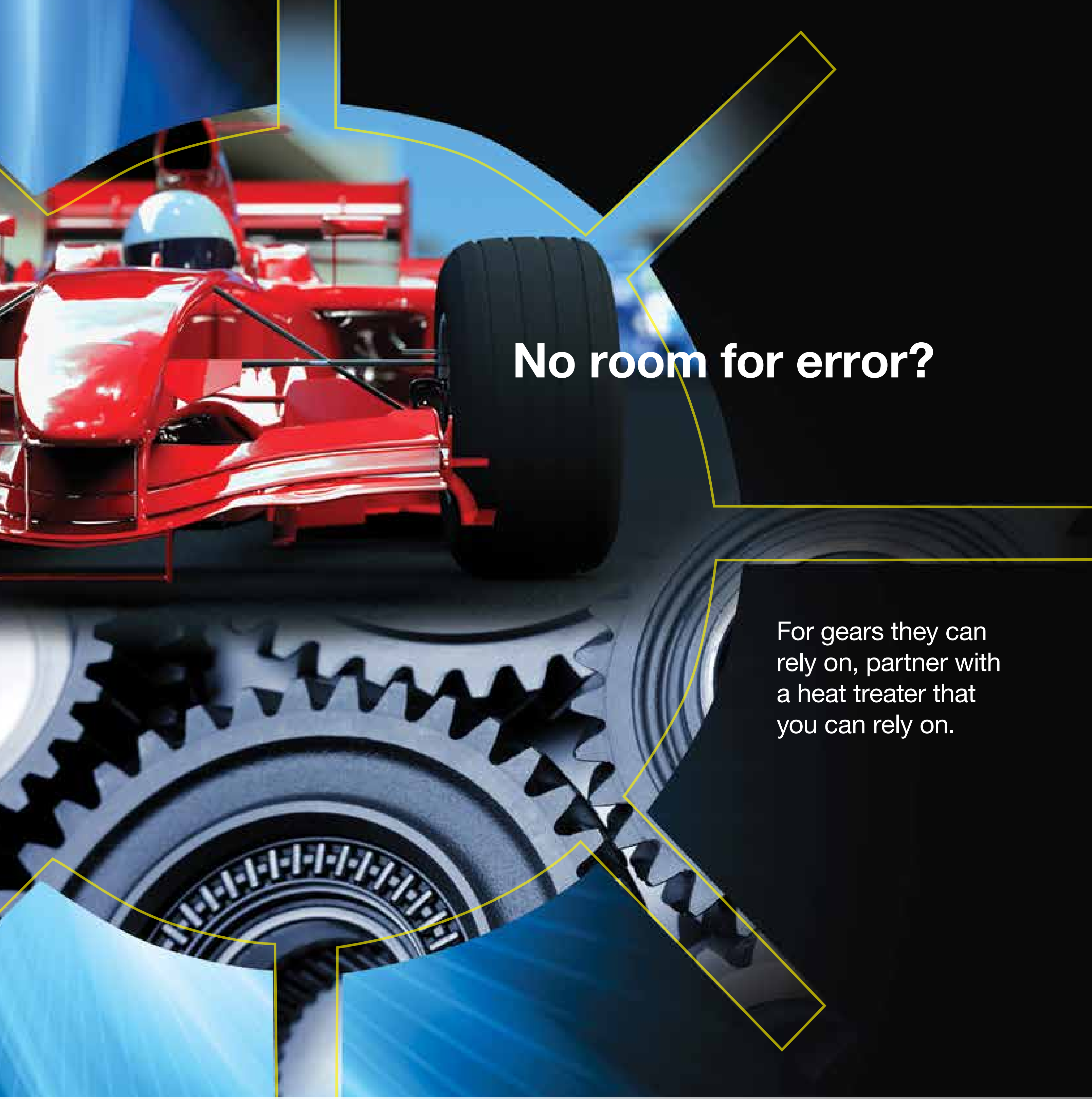
These problems have been addressed by Phoenix™ in the design of the new TS08 'Hot Box' thermal barrier:

All high temperature cloth exposed to the furnace atmosphere has been removed, and thermocouples exiting the barrier rest on a stainless steel casing rather than abrading any insulation.

Oxygen is removed from deep in the microporous insulation by heating the insulation in a high vacuum, then back filling with nitrogen. Further to this the thermal barrier is fitted with a nozzle which allows it to be purged with a low pressure nitrogen flow just prior to placing in a furnace.

The TS08 thermal barrier also features thermocouple separators to prevent thermocouples 'bunching' when the barrier is closed, and makes it easy to identify the individual thermocouples (see photo below). A major US auto manufacturer has been using the Phoenix™ TS08 thermal barrier in their furnaces for the last 18 months and reports that they have carried out around 2000 successful runs during this period.

For more information contact Stephen Biggs, National Sales Manager at Phoenix LLC. His email address is stephen.biggs@phoenixtm.com, (727) 608-4314 or visit online www.phoenixtm.com.



At Solar Atmospheres, your critical specs get the specialized expertise they deserve. From stress relief to case hardening, we'll help assure that your gears can go the distance. Precise carbon control and aerospace-qualified pyrometry produce uncompromised quality. Harness our leading-edge vacuum technology to improve the uniformity of your case depths, minimize distortion and enjoy clean parts with no IGO (intergranular oxidation). ISO 9001 / AS 9100, Nadcap accredited.

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Ipsen Congratulates February Grads of Ipsen U

The first Ipsen U class of the year, held in February, was a huge success for attendees. Sixteen attendees completed the course, including individuals who traveled from all over the globe to glean information from Ipsen's experts. Students came from all over the world!

During the class, instructors not only presented information, but also offered visual, hands-on experiences for the attendees. One highlight from this Ipsen U was a hands-on, leak testing exercise. Several leaks were pre-established and a volunteer worked his way around a furnace to find them. This was a great learning experience particularly for those expecting new furnace shipments.

Ipsen U addresses all levels of experience in an open-forum environment that encourages attendees to ask questions about specific equipment and processes. The class follows a modular format that allows participants to interact with several Ipsen experts. Ipsen U allows customers direct access to information that transfers furnace maintenance and upkeep into their own hands.

For more information, visit www.ipsenusa.com.

Davron Continuous Conveyor Oven Cuts Labor Cost and Energy Comsumption

Davron Technologies, Inc. designed and manufactured the DTI-775, a gas-fired continuous conveyor oven, to cure disc brake pads for an automotive Tier 1 supplier. Previously, the customer cured the product using a batch process in which parts were staged, loaded onto carts, and transported to batch ovens. The DTI-775 continuous conveyor oven eliminated the labor cost and work-in-process associated with staging, loading and unloading, and moving the parts in and out of the batch ovens. By loading parts into the DTI-775 immediately after the press cycle, the customer can retain the heat absorbed by the parts when they are pressed, reducing the energy required to cure the product.

Featuring one natural gas full-modulating burner, the custom oven can be programmed to operate between 300º and 662ºF. The oven includes two circulation fans delivering heated air to the product in a vertical top-down pattern. For the conveying system, the oven utilizes a custom tray arrangement that accommodates eight parts per tray. The parts stand on edge, reducing the space required for each part, as well as the oven footprint. The conveying system moves product through the curing chamber and the cooling chamber. The cooling chamber utilizes ambient air to cool the parts to approximately 130ºF immediately after the curing cycle is complete. The oven is designed to process 384 parts per hour.

The useable dimensions of the oven, including the cooling chamber, are 6'7" wide x 0'6" high x 10'8" long. The interior of the oven is made out of 16-gauge aluminized steel backed by six inches of eight-pound density mineral wool insulation. The exterior is constructed of 16-gauge carbon steel backed by a structural steel frame and finished with high temperature paint. The oven includes two doors that provide access to the heated chamber for maintenance.

Davron designed the DTI-775 continuous conveyor oven based on three criteria provided by the customer: the production rate per hour, the temperature range, and the time required for curing. Once the continuous conveyor oven was manufactured, Davron did acceptance testing and training with the customer at Davron headquarters in Chattanooga, Tenn., prior to shipment.

Visit www.davrontech.com for more information about Davron's continuous conveyor oven capabilities. Or, if you'd like to discuss your own industrial oven project, please call Davron's Vice President, Jimmy Evans, at (888) 263-2673, or fill out Davron's online spec submission form.

Nitriding Process Temperature Trending Using a Data Logger

Last November, CAS DataLoggers supplied the industrial data logging solution to Northeast Coating Technologies in Kennebunk, Maine. NCT is a surface treatment company specializing in Salt Bath Nitriding Melonite QPQ among other processes to produce high-durability metal components including piston rods, axles and more. Engineer Conrad Woodman is using our dataTaker DT80 Intelligent Data Logger to continually monitor NCT's production Melonite® line, specifically the salt bath area. The dataTaker is recording tank temperature from multiple thermocouples and using these readings to trend the run data to prove best practices to customers.

The MELONITE® QPQ process forms a nitrocarburized layer around components comprised of an outer compound layer (iron, nitrogen, carbon and oxygen compounds) and a diffusion layer underneath. Initially the process preheats components to raise their surface temperature before they're placed in a tank containing liquid Melonite salt (MEL 1/TF 1 bath) to start the nitrocarburizing process. Alkali cyanate is the active constituent in the salt bath, and this step is regulated at 896-1166°F with a standard temperature of 1076°F. The components react with the salt and start to diffuse nitrogen and carbon into the substrate. After a preset period of 1-2 hours the components have the proper compound layer thickness and case depth. After immersion in the salt bath, the components are placed in a cooling bath (AB 1 bath) maintained at 700 - 800°F for oxidative treatment which forms a magnetite layer on the components to improve corrosion resistance.

Tank temperature is the treatment parameter NCT needed to monitor and trend for each of its 3 Melonite salt tanks and the AB 1 oxidizing bath tank. With this in mind CAS DataLoggers provided the facility with a Series 3 dataTaker universal data logger to automate their data collection.

CAS DataLoggers Applications Specialist Pat Picciano comments, "The dataTaker's software is internal so everything this application needs is there in the dataTaker unit itself. Now they have the memory, the data trending capability and the alarming feature. That's why the DT80's our workhorse."

For more information on the dataTaker DT80 Intelligent Universal Data Logger, or to find the ideal solution for your application-specific needs, contact a CAS Data Logger Applications Specialist at (800) 956-4437 or visit the website at www.DataLoggerInc.com.

Ipsen Exhibits at 19th Annual MRO Americas Conference and Exhibition

Ipsen appeared at booth #2501/2503 near the entrance of the pavilion. Their representatives were on hand at this three-day event to feature their vacuum brazing equipment, which can perform a variety of heat treatment processes to meet customers' needs. Vacuum brazing, carried out in the absence of atmosphere, uses a specialized furnace and delivers significant advantages: extremely clean, flux-free braze joints of high integrity and superior strength. Other benefits of vacuum brazing include heat treating or age hardening of the work piece as part of the metal-joining process, all in a single furnace cycle. Like conventional brazing, vacuum brazing is easily adapted to mass production, making it a popular choice in the aerospace industry.

For more information on brazing, please visit them online at www.IpsenUSA.com/Brazing.

Bill Euliano Named Aftermarket Director for North America at SECO/WARWICK Corp.

In this role, Mr. Euliano is responsible for all aftermarket services including technical rebuilds and upgrades, renewal parts and field service. He joined SECO/WARWICK in 2011 as Operations Manager. Mr. Euliano has a bachelor's degree in mechanical engineering from Gannon University, Erie, PA. He also completed graduate degree courses for an MBA from Gannon University, and he has an associate degree in elementary education from Butler County Community College. He has worked in the automotive, fabrication, LED lighting, and heavy truck industries as well as furnaces for the glass industry. He has served in various roles throughout his career, including manufacturing engineer, quality manager, engineering manager, materials manager and plant manager.

Mark Hemsath has been appointed Thermal Group General Manager for North America with SECO/WARWICK Corp. in Meadville, PA, USA. In this role, Mr. Hemsath will direct the sales, design and production for traditional heat treat and atmosphere furnaces. In addition, Hemsath will continue to be the sales point of contact for the southeastern United States. Mr. Hemsath brings over 25 years of experience in industrial furnace Sales and Design to SECO/WARWICK as owner/President of MH Thermal, Hemsath Corp., and Lee Wilson and Thermotech Industries (all Furnaces related). He has worked as a Business Manager for Indugas, Inc. (a Furnace design company), Business Development Manager for LEWCO, Inc. (Conveyors and Ovens), and VP/CFO of Lumberjack Mordam Music Group. Hemsath earned his B.Sc. in Business Administration at Miami University and MBA with a concentration in Finance and Project Management from the University of Toledo.

Andrew Paris has joined SECO/WARWICK Corp. as Chief Operations Officer at the Meadville, Pennsylvania engineering and manufacturing facility. As COO, Mr. Paris is responsible for all functional operations including project management, purchasing, estimating and manufacturing for North America. Paris is a graduate of Grove City College where he earned a BSME. His 17 year career at GE Transportation began as part of the Operations Management Leadership Program and progressed into various supply chain leadership roles in the locomotive and mining businesses. Most recently, he served as Manger of Locomotive Production, Sales, and Inventory.

TAV SpA./Press Release. TAV ships heat treatment and brazing furnaces to a large aerospace company; Italian vacuum furnace manufacturer TAV SpA, is shipping a special vertical vacuum furnace with working dimensions of 2300 mm x H 3000 mm for heat treatment and brazing to a long time customer and well known aerospace company in France. All these furnaces are completely designed, manufactured and tested by TAV qualified personnel in compliance with the required norms and regulations.

For more information on SECO/WARWICK, visit www.secowarwick.com.

UTTIS Industries SRL and NOXMAT GmbH Form a New Partnership

The two companies would like to announce that UTTIs, a furnace manufacturer from Romania and NOXMAT, a leading manufacturer of industrial gas burners from Germany have formed a strategic partnership. UTTIS will take over the Sales and Service activities for NOXMAT industrial gas burners in the territory of Romania. The partnership includes: Mr Octavio Schmiel (Head of Business Development, NOXMAT), Mr Matthias Wolf (General Director, NOXMAT), Mrs Petruta Druga (General Director, UTTIS), prof. Leontin Druga, Ph.D. (President of the Romanian Heat Treatment Association, UTTIS), Mr Cristian Badina (Production Manager, UTTIS).

For more information visit UTTIS at www.uttisheat.com.

Ben Crawford Joins J.L. Becker Company as Sales Manager

J.L. Becker, a Gasbarre Furnace Group Company, is pleased to announce the hiring of Ben Crawford for the position of Sales Manager. Prior to working for J.L. Becker, Ben has served in management roles for companies providing commercial heat-treating and brazing solutions to a diverse customer base, including automotive, aerospace, agricultural and power generation. Ben's experience at all levels of management with all types of customers provides him the knowhow needed to recognize and embrace the challenges Becker's customers are faced with. He is also a member of Corps Group, as well as the Metal Treating Institute Board of Trustees.

For more information call 814.590.6282, or visit the websites www.jlbecker.com and www.gasbarrefurnacegroup.com.

SONA BLW Precision Forge Invests in AFC-Holcroft Batch Furnace Line

SONA BLW Precision Forge, located in Selma, North Carolina, USA, has purchased a new AFC-Holcroft UBQ (Universal Batch Quench) furnace and support equipment for their existing heat treating facility.

SONA set out to find equipment that met their needs for flexible production and high quality, and had added features they required. AFC-Holcroft teams met with SONA personnel to discuss their specific requirements in depth.

Following site visits to view UBQ lines in operation in the region, SONA BLW Precision Forge selected AFC-Holcroft to provide their new heat treat equipment.

AFC-Holcroft customized a standard UBQ furnace, typically rated at 3,500 lb. load capacity, to the 4,000 lb. capacity the customer required. The new equipment consists of a UBQ integral quench batch furnace with an effective work zone of 36” wide x 48” long x 36” high with all the standard features, two UBTN Universal Batch Nitrogen Temper Furnaces, a UBW Universal Batch Spray-Dunk Washer, and a 2-module array of “E-Z Series” endothermic gas generators providing 9000 cubic foot/hour of endothermic gas.

Mike Neumann of AFC-Holcroft stated “This equipment showcases AFC-Holcroft’s ability to take a proven, standardized product and customize it to meet the individual needs of the customer while providing the fast delivery time possible.”

AFC-Holcroft has one of the most diverse product lines in the heat treat equipment industry. They are fully equipped to design, manufacture, ship, install, and service all types of custom and standard heat treat systems. AFC-Holcroft is a privately held company, headquartered in Wixom, Michigan, USA. Our state-of-the-art facility is not only our engineering hub for global business, but also has a large manufacturing facility, custom built for the construction of heat treatment equipment.

SONA BLW GROUP’s strategy is to continue to be one of the leading precision forge worldwide, to take an active part in our customers’ globalization strategies and to offer first class worldwide supply. We are pleased to have the opportunity to guide you through the world of precision forging on the following pages.

We are prepared to respond to the increasingly global market environment.

To learn more about SONA BLW or AFC-Holcroft, visit them online at www.sonblw.com or www.afc-holcroft.com.

Successful Start-Up Of Two 350t Hot-Dip Galvanizing Pots For Automotive Line At European Steel Strip Producer

Ajax TOCCO Magnethermic successfully started up the Phase Two galvanizing equipment for an automotive line at a major steel producer in Europe. The line is now able to produce galvanized strip with two types of coating alloy.

In 2009 Ajax TOCCO Magnethermic supplied and commissioned the Phase One of the project working in conjunction with a major steel industry line builder, which consisted of the following.

- •Coating pot with a zinc capacity of 350T which was rated at 1000kW and equipped with two 500kW "TE" Jet-flow inductors. The coating pot was statically mounted on the Lift Platform initially, but designed to allow for easy integration of transfer bogie wheels for mobilization in Phase Two
- •Hydraulic lift platform for raising and lowering the coating pot between the operating and the down (off-line) positions, allowing for easy and safe access to the snout for maintenance work.
- •Platform / pot movement control panel was designed and supplied for dual pot capabilities, allowing quick conversion from Phase One to Phase Two
- •Snout access platform that also operated as an insulating cover for the coating pot when in the down (off-line) position. The snout access platform was mounted to the ceiling of the cellar on rails and motorized to allow movement over the coating pot when it is in the down (off-line) position. This meant maintenance on the snout could be performed safely above the coating pot.
- •7 T/h ingot charger, with close loop with metal level detector to keep constant metal level in the pot +-2mm. The charger was designed with an 8 ingot storage conveyor system.

In 2012 the customer awarded Ajax TOCCO Magnethermic directly with an order for the Phase Two conversion, which included adding a second coating pot for Zinc Aluminum Magnesium alloy. The Phase Two equipment, supplied and commissioned in 2013, consisted of the following.

- •Transfer bogie wheel set to mobilize the Phase One coating pot. These allow for Horizontal movement from the down (off-line) position to an ambush (Park) position, thus allowing the other coating pot access to the lift platform and the operating position.
- •Flexible power cables, to replace the existing fixed cable, which allowed the horizontal movement of the coating pot between operating and ambush (Park) positions.
- •Mobile coating pot with a zinc capacity of 350T that was rated at 1000kW and equipped with two 500kW "TE" Jet-flow inductors. The coating pot was designed for operating with Zinc Aluminum Magnesium alloy. It was supplied complete with transfer bogie wheels, flexible cables, and services to allow the coating pot to move between operating and ambush (Park) positions.
- •Coating pot ambush cover. This is an insulated cover that is mounted to the ceiling of the cellar above the ambush (Park) position to reduce the heat losses for the coating pot. It also protects the cellar ceiling from radiated heat.

For more information, visit www.ajaxtocco.com

Sulzer Sells Coatings Unit for $949 Million

Swiss machinery manufacturer Sulzer (SUN.S) agreed to sell its coatings unit Metco to peer Oerlikon (OERL.S) for around 850 million Swiss francs ($949 million) in cash, as it seeks to focus on it three main businesses. The deal is based on a enterprise value - equity plus debt -of 1 billion Swiss francs. Sulzer put Metco up for sale last year to concentrate on more lucrative businessesmaking pumps and equipment and providing services for the oil and gas industry. "We are pleased that we have found a new owner for the Sulzer Metco division that will leverage the strengths of the business in the best possible way," Sulzer Chief Executive Klaus Stahlmann said. Metco, the world's largest maker of thermal spray coatings for the car, chemicals and energy industries, had sales of 690 million francs and earnings before interest, tax, depreciation and amortization of 91.7 million francs in 2012. It employs around 2,400 people. Buyout group EQT was also said to have submitted a bid for Metco, according to three people familiar with the transaction. In a separate statement, Oerlikon said it plans to combine Metco with its existing coatings business to increase its market access. The combined business will operate around 130 facilities and employ some 6,000 people. "This step marks an important milestone for the Oerlikon Group, creating the technologically leading global product and service company for Surface Solutions," said Oerlikon CEO Brice Koch. The deal, which is subject to regulatory approval, is expected to close in the third quarter.

For more information, visit www.sulzer.com.

FURNACE ATMOSPHERES AND TEMPERATURE ARE WHAT DETERMINE METALLURGICAL RESULTS

by Jim Oakes

GETTING THE RIGHT PROTECTIVE AND CARBURIZING ATMOSPHERE

The makeup of a furnace's atmosphere in the heat treating process varies based upon the application. For carburizing, sensor technology allows for the in-situ monitoring of furnace atmospheres but many assumptions are made when calculating carbon potential based on the prepared atmosphere being used.

ENDOTHERMIC ATMOSPHERE

Typical endothermic gas generators supply an atmosphere using air and hydrocarbon gas which are mixed and passed over nickel bearing catalyst at about 1900°F. Using methane (CH4) mixed at an air-to-gas ratio of 2.77:1, a properly functioning generator will in theory produce an endothermic gas consisting of 20% carbon monoxide (CO), 40% hydrogen (H2), and 40% nitrogen (N2). Using propane (C3H8) instead of CH4 and an air-to-gas ratio of 7.16:1, the resulting endothermic gas composition will be approximately 24% CO, 32% H2 and 44% N2. The gas is then cooled to maintain the integrity of the gas composition. Correct cooling of the gas is critical to preventing carbon monoxide from reversing into carbon (soot) and CO2. This is the base atmosphere used in the carburizing process; nearly all calculations for the carbon potential are based on the composition of the prepared atmosphere. The need for continuous control of the endothermic generated atmosphere is a major factor driving many industry requirements and customer specifications. The common control parameter on the generator is dew point, which can be monitored using oxygen sensors or dew point analyzers.

A few assumptions must be made when determining carbon potential in the furnace with a supply of endothermic gas. Measuring this atmosphere can be accomplished in a number of ways; the focus of this article involves the use of oxygen sensors, dew point, and infrared measurement. Regardless of the method of measurement, the endothermic gas needs to be continuously monitored and controlled in order to create a consistent controllable atmosphere in the furnace.

NITROGEN METHANOL

When using nitrogen methanol in a furnace at the typical operating temperatures, the methanol immediately dissociates into carbon monoxide and hydrogen. When mixed, 33% methanol (CH3OH), 66% nitrogen, and endothermic equivalent atmosphere are formed in the furnace. When using sensors and when the base atmosphere in the furnace is under equilibrium conditions, these assumptions must be consistent, known, and repeatable.

To determine the amount of methanol and nitrogen required, the Total Required Flow (TRF) of gas, which is usually posted on the furnace nameplate, is divided by 1.60. The resulting value is then multiplied by 0.33 to determine the amount of methanol required in standard cubic feet per hour (SCFH). That same value (TRF divided by 1.60) is multiplied by 0.66 to determine the nitrogen required in SCFH.

As with an endothermic atmosphere, the nitrogen methanol system should be delivering a consistent composition to the furnace. Most flow rates for the system are set up to deliver approximately the same mixture of 20% carbon monoxide (CO), 40% hydrogen (H2), and 40% nitrogen (N2).

CARBON CONTROLLER CALCULATION

Dew point, shim stock, NDIR (non-dispersive infrared) analyzers, and carbon sensors have traditionally been used to measure the endothermic atmosphere in a furnace. The carbon sensor actually measures the oxygen content in the furnace, which is why the terms oxygen probe and carbon probe are often used interchangeably. An oxygen probe used in-situ for a furnace application has been the industry standard for years. Because of its durability, reaction time, and continuous measurement, the oxygen probe is the most common method of obtaining measurements.

There are many variations in the way carbon is calculated based on the atmosphere in a furnace. We just defined the two most common practices for a prepared base atmosphere in the previous sections with nitrogen methanol and endothermic gas. These play a significant role

ABOUT THE AUTHOR: Jim Oakes is vice president of business development for SSi SuperSystems, where he oversees marketing and growth in multiple business channels and helps develop product innovation strategies in conjunction with customer feedback. Jim has extensive experience working in the heat treating and software/IT industries. For more information, email him at joakes@supersystems.com or go to www.supersystems.com.

> *"As with an endothermic atmosphere, the nitrogen methanol system should be delivering a consistent composition to the furnace."*

when it comes to calculating carbon. In most cases, the atmosphere in a furnace is measured using an in-situ sensor made of zirconia. This zirconia sensor is actually measuring the oxygen. Based on oxygen content and a number of other assumptions, carbon potential can be calculated.

The calculation of carbon using the oxygen probe includes the millivolts produced by the probe based on the partial pressure of oxygen in air versus partial pressure of oxygen in the furnace, the furnace temperature, and a calculation factor referred to as COF (CO Factor), PF (Process Factor), or Gas Factor.

All carbon controllers provide some sort of a calculation factor which can be adjusted and should be based on metallurgical results, shim, coil, or other technologies that are used to measure the carbon-based atmosphere. The purpose of the COF is to restore a repeatable measurement of carbon that is verified using an alternate method.

Other considerations influence the readings; these include sensor condition, furnace condition, part preparation, and part surface area. The most pronounced influence on the calculation is the prepared atmosphere mentioned earlier in this article. Because the CO has the most significant influence on carbon activity, the carbon calculation can be adjusted based on the amount of CO produced by the prepared atmosphere. Using the example of COF (CO Factor), you will find that the carbon calculation increases or decreases based on this setting; in many cases, COF is directly related to the amount of CO produced by the endothermic generator or the nitrogen methanol system (CO values from nitrogen methanol are influenced by furnace temperature, so this also can be a factor).

For additional information on furnace atmospheres, visit our website at www.supersystems.com. For furnace calculations, visit www.supersystems.com/calculators.html or download our SuperCALC app from Google Play or the Apple App Store.

SOME WORKPIECES ARE TOO LARGE AND EXPENSIVE TO FIT INTO CONVENTIONAL BENCHTOP HARDNESS TESTERS

by Fred R. Specht

PORTABLE ROCKWELL HARDNESS TESTING OF LARGE INDUCTION HARDENED WORK PIECES

The previous article identified many factors related to benchtop Rockwell hardness testing practices. This article covers work pieces that are one of a kind or are too large and too expensive to cut into small enough pieces to fit into the conventional benchtop hardness tester. The Leeb /rebound portable testers are excellent for testing both ferrous and non ferrous metals for these very large work pieces.

With the evolution of controls for induction hardening equipment it is becoming common practice to not cut every set up to check case depth and only check surface hardness. The modern induction control system allows exact measurement of kW at the coil, quench flow, quench pressure, quench temperature, scan speed etc. These real time measurements use quality control signatures. These signatures have preset high and low set points that if any deviation occurs, that the induction process will fault and give an indication of which parameter is out of tolerance. Each part number recipe has its own distinct set of signatures. The process parameters and signatures are all stored in the hard drive for future analysis for SPC comparisons. These computer features greatly reduce and can eliminate cutting and mounting of samples for micro hardness analysis. Many induction houses use an acid etch, sandblasting or shot peening the work piece surface so the induction hardened zone is exposed and the final appearance shows the length of zones that have been induction hardened. Combine these powerful computers with hand held hardness testers can make for higher productivity and eliminate cutting of workpieces to confirm hardness case depths and the length of the heat treated zone.

The electronic testers can convert hardness and have optional test heads with different ball diameters for softer materials and diamond for the Rockwell "C" & "B" scale, Vickers, Brinell and Shore. A large test block is also provided as bench type test blocks are too small for their use with portable testers. The attachments for confined spaces and upside/sideways testing are also available.

Portable hardness testing equipment has come a long way since the author worked in the heat treat department. Old school "Shore" and "C" clamp style testers have been replaced with portable electronic

Fig. 1: A polished surface after acid etching shows an induction case termination at top left.

Fig. 2: Work piece firmly sitting on a solid flat surface while checking hardness.

ABOUT THE AUTHOR: Fred R. Specht has over 40 years of experience in all aspects of induction heating and melting, and is a specialist in induction heat treating pattern development. A seminar speaker on induction heat-treating at many ASM Heat Treating Conferences, he is presently the chairman of ASM -HTS Applied Energy Committee. He can be reached at (847) 606-9462 or fspecht@ajaxtocco.com.

Fig. 3: Large casting for hardness testing.

Fig. 4: Light grinding and polishing is needed for hardness testing of a large "one of a kind" casting.

testers. They are more accurate and have higher precision but some basic preparation rules again apply. These include:

1. Clean flat surface, ground or polished and use a scotch bright pad to remove all scale.
2. All machining marks, groves and tooling marks must be removed.
3. Work piece firmly sitting on a hard flat surface.
4. Special ordered set of rings are required to check hardness on concave or convex work pieces.
5. Separate rings may be needed for different diameters or angles on large round parts.
6. When changing from a ball to a diamond you must use the supplied test block.
7. These portable testers are not well suited for very thin parts like sheet metal or thin walled tubing.

Finally it should be brought out that training is critical to any industrial process. Whether it is a bench or a portable hardness tester, the importance of training can't be stressed enough. This should include a complete understanding of the hardness test theory, machine maintenance, proper surface preparation, environmental implications and safety.

EACH FURNACE TYPE REQUIRES A TOTALLY DIFFERENT MAINTENANCE MINDSET

by Jack Titus

WHEN A HEAT TREAT MANAGER or anyone responsible for purchasing heat treating equipment makes a buy decision, they must first consider the process required, then spreadsheet items such as capital and operating cost. However, I'd venture to say little—if any—attention is paid to the maintenance required, labor expertise, material handling, and their associated cost.

I've said it many times over the years: any heat treat company is only as good as their maintenance department. Up time or available operating time must be 95%, with few exceptions. Available up time is generally computed with scheduled down time in mind. There are 8,760 hours in one year, and when you consider the real operating time, that number of hours can become 85% of that 8,760. That's 7,466 hours, equal to six days per week on average.

Once started, many furnaces are expected to run continuously until forced to shut down, even though no scheduled maintenance is planned. This operating option can work, as long as the failed component is located outside of the hot zone and has a spare resting in the maintenance department's stores. This situation is what causes major grief for the production supervisor, and only experience and familiarity with the equipment can anticipate this. Assistance is generally provided by the OEM furnace supplier by a suggested spare parts list. For example, for every furnace sold by AFC-Holcroft its AMD (After Market Department) provides in addition to assembly drawings, a complete vendor listing and recommended spare parts list. This list is produced via historical data on runtime. Then about two (2) month prior to the warranty expiration AMD and AFC-H marketing alerts the customer of the impending date. Obviously the purchaser must make the final decision taking into account their experience and inventory in the maintenance department.

Carburizing furnaces can be divided into two major genres: atmosphere and vacuum. Each furnace type requires a totally different maintenance mindset; one that uses a tape measure and crowbar the other a Vernier caliper and white gloves. Atmosphere furnaces batch or continuous are designed anticipating that they likely will not receive kid-glove treatment whereas vacuum furnaces with their many sealing penetrations, water cooling cavities and critical tolerances require more attention.

Atmosphere furnaces for this discussion use endothermic gas for carburizing while vacuum systems employ vacuum pumps, acetylene and nitrogen. From a maintenance standpoint material handling will be the primary focus on atmosphere furnaces for uptime having load transfer devices inside and outside of the hot zones. Pusher furnaces as the name implies push tray-on-tray throughout the system. However, since the pusher mechanism is located outside of the hot zone, Figure 1, the condition of trays is the weak link. For that matter the same applies for atmosphere batch furnaces; trays are a major cause for unexpected but avoidable downtime events. Pusher screws or chains do fail but they can be repaired on the fly without sacrificing the parts in process, if spares are available.

With the interest in distortion control LPC and HPGQ (high pressure gas quench) systems have become more accepted, however, the carbon-carbon trays that are typically used also have a finite life that is not predictable as they are with alloy atmosphere furnace trays. Alloy trays degrade slowly over time and their condition can be readily observed so countermeasures such as inverting or rotating 180 degrees can prolong their life. Carbon-carbon trays do not bend in service, are primarily brittle and are removed when they break rendering them forever useless and unrecyclable. Alloy trays are routinely recycled back to the OEM foundry decreasing the cost of new trays. Carbon-carbon trays are extremely expensive costing tens of thousands of dollars for just one batch load of a few hundred parts.

Second to material handling are the effects of carbon on the refractory – alloy radiant tubes, fans and hearth wheels are items of concern. But again rarely due these fail without warning; symptoms of excess carbon will be evident even without analyzing the parts. A bright orange and sparkly effluent, sooty or plugged view ports, carbon pickup in quench oil are just a few indicators when using endo gas.

Endo carburizing does not have to be a dirty process. Properly sized hoods prevent carbon and oil vapor from collecting on ceilings. Routine air burnouts can reduce or eliminate soot buildup inside and out of the furnace and quench tank, especially when high CP or boost/diffuse recipes are used. Consistent use of shim analysis will indicate when the primary CP control sensors require calibration. In general the cleaner the outside of the furnace is maintained the easier it will be to monitor the interior.

ABOUT THE AUTHOR: Jack Titus can be reached at (248) 668-4040 or jtitus@afc-holcroft.com. Go online to [www.afc-holcroft.com] or [www.ald-holcroft.com].

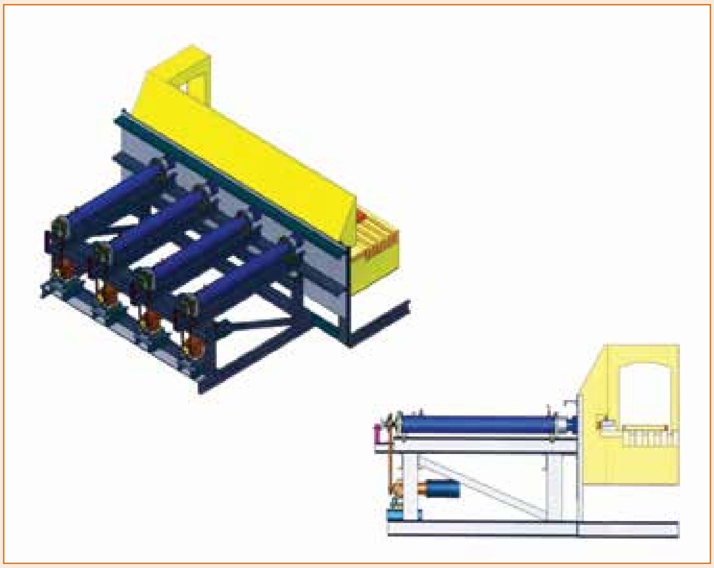


Fig 1: Properly sized hoods prevent carbon and oil vapor from collecting.

Fig 2: As carbon accumulates, it can increase evacuation time.

Years ago semi-continuous LPC systems employed very complex internal handling systems requiring hot internal sealing doors but their runtime to failure was so poor that few remain in operation today. Material handling for batch vacuum furnaces will reside outside of the chambers on floor-rail mounted pick & place transfer cars or fork lift devices.

Vacuum pumps, vacuum tight valves, pressure sensors, O-ring, filters, nitrogen and acetylene gas valves must be the recipient of careful monitoring for proper operation and accuracy in LPC systems. No matter what LPC carburizing gas is used acetylene or propane, carbon will eventually find its way into the vacuum pump booster. The first stage booster is a "Roots" pump where the counter-rotating lobes are spaced 0.004" (.01 mm) apart. Contamination such as oil soaked carbon will at first improve evacuation time but soon will cause the pump to seize if left unchecked. The second stage can be a high RPM sliding vane pump or slower rotating reciprocating piston pump. Vane pumps due again to the small clearances can little withstand any contamination. This was a problem decades ago when ridged graphite insulation was supplied without the proper seasoning plus the sealing compound used to coat cut edges caused outgassing and clogged the vane pumps making them all but useless. Sliding piston pumps on the other hand can take more abuse. Both require routine oil replacement, filters and controlled water cooling to maintain a 160°F (71°C) operating temperature to avoid water contamination of the pump oil.

In both furnace systems carbon is the nemesis, however, it affects each furnace type quite differently: In endo gas furnaces batch and continuous, carbon is the byproduct of the CP (carbon potential) not accommodating the saturation limit in the austenite; 1.25% carbon at 1700°F (925°C) and the austenite /pearlite region below the hypo-eutectoid A3 and hyper-eutectoid Acm temperatures on the Fe-C phase diagram. If the CP is too high for the temperature excess carbon is produced since the steel part's microstructure cannot accommodate the quantity of carbon available in the atmosphere. In LPC (low pressure carburizing) carbon is produced when the acetylene flow is too high for the surface area and temperature of the load. In addition, a portion of the hot acetylene and especially propane will crack or decompose resulting in carbon depositing in the cool space between the insulated chamber and the water jacket. As carbon accumulates it can increase evacuation time by absorbing moisture. Worse, carbon can bridge the electrically isolated heating element lead-ins and the enclosure wall creating a short circuit that can severely damage the vessel.

Pusher furnace systems can preheat the load but is not a requirement therefore the first zone is always dedicated to heating and adds no enriching gas to raise the CP, that occurs in zones two, three and so on. Atmosphere batch furnaces generally receive a cold load but there too with a new load the atmosphere is at a low default level to minimize soot drop out. The overwhelming numbers of vacuum furnaces are of the single chamber type therefore the load enters a cold environment or at least a hot chamber void of acetylene in stand-alone multi-cell systems. Since the 1960's many multi-zone LPC or vacuum furnace configurations have been developed all with varying degrees of success, with hot doors especially being the weak link.

In the U.S. and many installations around the world, atmosphere furnaces are gas fired with radiant tubes or when required at AFC-Holcroft an electric bayonet element is inserted into the radiant tube, Figure 21. Either way carbon never reaches the actual energy production source, not so with LPC furnaces where graphite heating elements are located in direct contact with the carburizing atmosphere.

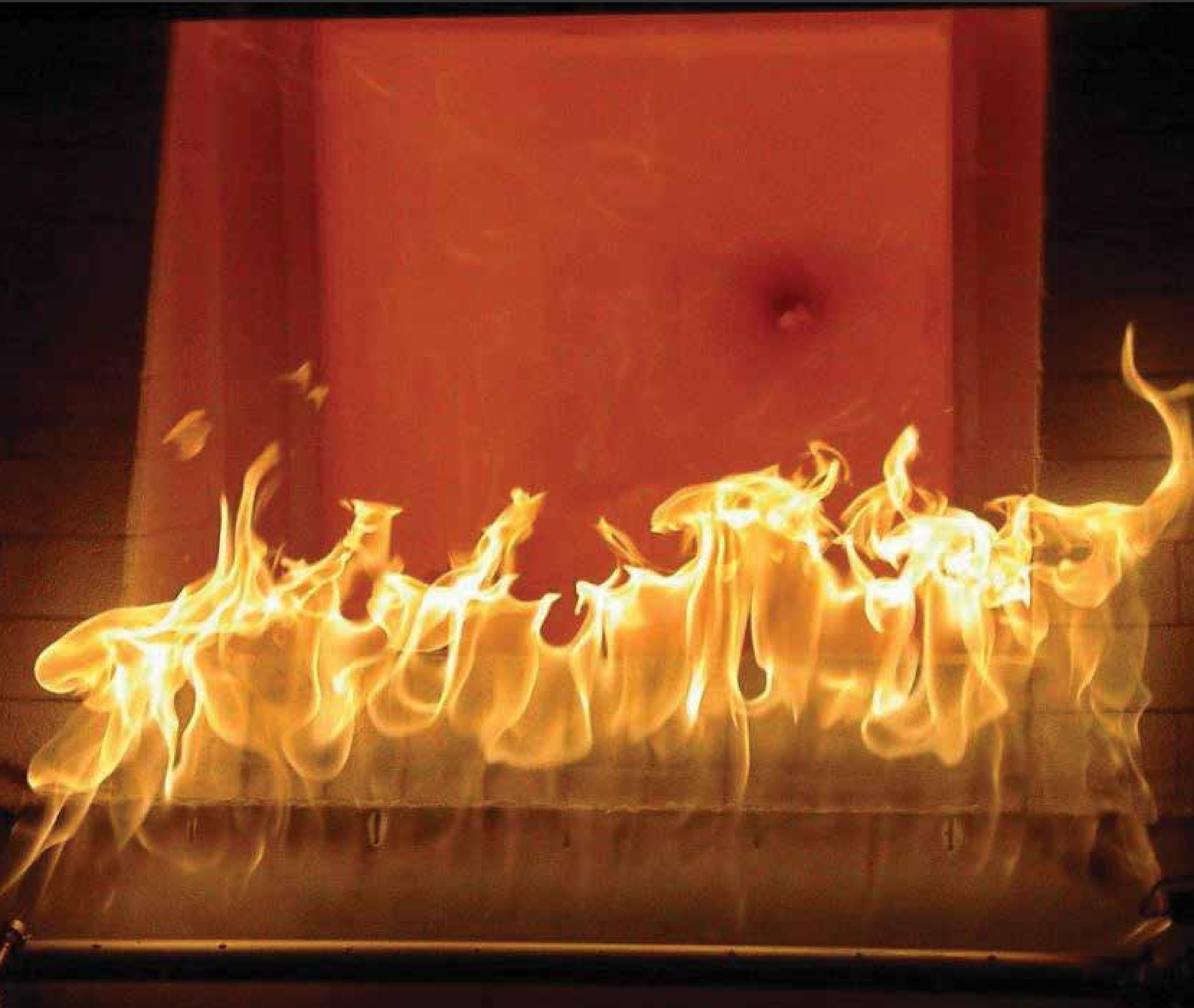
Multi-cell LPC systems, as well as the few semi-continuous vacuum LPC furnaces in production vacuum pumps, are where the excess carburizing atmosphere removed from the hot zone ends up. Inline filters and other traps can remove carbon but some still reaches the pump. Refractory lined atmosphere furnaces by comparison are burned out with air at specific intervals usually monthly or at some consistent frequency.

When either carburizing process, endo or LPC will satisfy the hardening requirement common sense dictates additional due diligence: Never overlook the maintenance. Economic and expertise are required.

Park Thermal International

Park Thermal has been an innovator in the field of heat treatment since 1938. Today, its products and services are found all over the world.

By Tim Byrd



Heat treating salts, on-site service, engineering support, alternative financing solutions—Park Thermal International is the definition of a "one-stop-shop" for heat treating needs. But company president Brian Reid knows this kind of reputation doesn't happen overnight.

"Day in, day out, a few parts or a huge batch—the only way you'll establish yourself in the industry is with consistency," said Reid. "Understand the process and get it down to a science so that it happens on every part you produce, every day."

Reid and his partner—company CEO Jay Mistry—have a combined 75 years' experience in the industrial heat treat industry. Georgetown, Ontario's Park Thermal International is a leading North American supplier of thermal process technology. Started in 1938, manufacturers around the world today rely on Park Thermal for thermal processing equipment solutions. Reid believes many heat treating difficulties are a result of too many steps involving too many outside sources.

"When somebody buys a heat treat device used to process gears, like an integral quench furnace, you need quenching oil to quench the parts," said Reid. "If there's a problem in achieving uniform Rockwell hardness, where does the fault lie? The furnace guy? The oil guy? Where do you start?"

Reid and Mistry got tired of that breed of uncertainty, so they did the sensible thing and took it right out of the equation. "Today, we provide everything ourselves," said Reid. "Not only do we supply the capital equipment, we supply the quenching oil for carburizing furnaces and the salt for austempering furnaces, which provides ductility to parts.

"When you're heat treating large batches of gears, you want every one to be the same when the batch comes out of the process," he said. "It's difficult to do that if you don't understand heat treat concepts such as fixturing."

Fixturing, according to Reid's definition, is similar to the delicate balance of filling an ice tray. "You can't throw all the ice cubes into the tray and have them touching and expect the results to be uniform," he explained. "They have to be staggered. The distribution of the air and the heat and atmosphere is critical to get uniform results."

Reid started at Park Thermal International in 1971. Over the years, the company has purchased two companies out of Michigan—one called The Metal Works (Roseville, Mich.) and another called AF Holden Company (Milford, Mich.)

"They were using many of the same processes that we were, but a little bit differently," said Reid. "They allowed us to add to our list of product mix to make us a better company. Both of the gentlemen that own those companies have stayed on with us."

The year 1971 has another significance for Park Thermal International. Until that time, the insulation inside of furnaces had always been refractory brick. The company decided to take a step forward and experiment with a product called ceramic fiber.

"Today, just about every furnace built by anybody uses ceramic fiber," said Reid. "It heats up faster and retains the heat better. Back in the day, we didn't make changes as quickly as we do today, so it was quite a step forward. We're proud to be the first company in the world to try ceramic fiber in a heat treating furnace."

Reid recalls another example of Park Thermal's unorthodox approach to heat treat problem solving. A customer came to him interested in furnaces, but concerned about her lack of space.

"'Have you ever thought about knocking out one of the block walls out of your building?' I suggested. 'You could

pour a pad outside, put a door down, and we'll put this and it won't take up any of your existing plant space.'"

It just so happened the customer had four shipping doors at the back of her building.

"There's the answer! You just saved yourself several hundred square feet of space.' That's the small things we bring to the table," said Reid.

Reid is a member of the MTI and the ASM, both of which have heat treating conventions on an annual basis. At the AGMA Gear Expo in Indianapolis last year, where the room was split between heat treating and gears, Park Thermal got to share the room with the "gear gangsters" as Reid calls them.

"It was really educational," he said. "I'm not a fan of standing on my feet for eight hours, so I circulated the room, conversing with the gear gangsters and coming up with different heat treat strategies and techniques.

Reid, who also teaches metallurgy at the university level, says the key to being a successful furnace builder is understanding the entire metallurgical process.

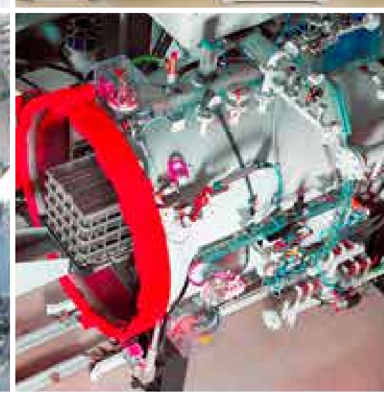
"If you don't know what you're doing, the part won't be any good for the application," he said. "TT=T. That's what heat treating is all about—time at temperature equals transformation. There are thousands of books written on heat treating, but that's it in a nutshell.

"We're dedicated to advancing the art of thermal processing," said Reid. "It's what drives us. After 40 years, you have to learn something, right?"

FOR MORE INFORMATION: Contact Park Thermal International Corporation, visit www.parkthermal.com or call (905) 877-5254.







Increased Productivity Combining C/C Fixturing and LPC

By William Warwick, Michael Lifshits, and Daniel H. Herring

Carbon/carbon composite materials offer unique technical advantages over other materials.

Carbon/carbon and graphite materials are used in a variety of applications throughout the high temperature furnace industry. Entire vacuum hot zones are manufactured from these materials as well as individual components such as insulation, lining materials, nozzles, fasteners and hearth supports. Fixtures and grids are also commonly manufactured from these materials and can offer a variety of benefits to the heat1treating industry. These fixtures are specifically designed to allow for higher processing temperatures, increased part loading, increased production rates (via shorter cycle times), energy savings and lower overall cycle costs.[1] In all of these areas, carbon/carbon composite materials offer unique technical advantages over other materials: higher processing temperatures; increased part loading; increased production rates; energy savings; and lower overall cycle costs.

CARBON/CARBON COMPOSITE BASICS

Carbon/carbon composite (C/C) material consists of two primary components, carbon fibers and a carbon matrix (or binder). Carbon fibers are extremely thin strands of carbon atoms, typically 0.005 mm–0.010 mm (0.0002”–0.0004”) in diameter. They are interlaced in such a way as to provide mechanical strength, stiffness, and thermal conductivity. The carbon matrix that encases them allows for uniform weight transfer and chemical resistance to attack. Mechanical and physical properties are dependent on whether they are measured parallel or

Low Pressure Vacuum Carburizing Installation at ALD Thermal Treatment

perpendicular to the surface and must be considered carefully when evaluating the quality of a composite material.

Carbon/carbon composite material has low thermal mass, high strength-to-weight ratio at temperature and negligible thermal deformation creating favorable net/tare load weight ratios when used for fixtures and grids. This allows for rapid heating and cooling rates, heavy part loading, and improvements in part distortion. C/C also has excellent fatigue resistance minimizing issues with crack propagation. Various manufacturers offer a variety of sizes, shapes, and grades. Purity levels in the range of 300 ppm total impurities are acceptable for general purpose heat treating with specialty applications available to as low as 10 ppm. The material can be supplied as fully densified or non-densified depending on the application.

CHOICES FOR FIXTURES AND GRIDS (UNIGRID® OR PRESS-FIT)

Two primary types of fixtures are used in the heat treatment industry: press fit grid style fixtures and single plate fixtures. Carbon/carbon fixture design is extremely important in determining which type of fixture style to use. Experience has shown that it is important to first identify the "worst case support scenario" for any fixture application during the initial product selection and subsequent engineering design phase. Unlike alloy fixtures that bend when over loaded, C/C fixtures break if they exceed their designated weight threshold.

Press-Fit Grid System

Press-fit grid fixtures (Figure 1) are made up of plate material. The plate material is cut into strips of various lengths, widths and thicknesses and press fit together to form a strong interlocking grid. These fixtures can be designed to carry heavy loads for applications such as high temperature brazing of heat exchangers (Figure 2). In this example the load weight is 3000 kg (6615 lbs.) This type of fixture is typically custom designed for each application and as such can be offered in a wide variety of furnaces, applications and load configurations.

Single Plate Grid System

The UniGrid® (Figure 3) is an example of a single plate style grid system and differs from press fit fixtures. Each grid is made from a single unidirectional cord of carbon fiber that is wound into preforms and molded into its final configuration. Since there is no overlapping of the carbon/carbon cord, the fibers are stiffer and can support even heavy loads at a fraction of the thickness of press fit grid assemblies. The reduction in layer thickness can allow for additional layers to be added into a furnace load. This translates into increased throughput with every furnace cycle and lower power consumption.

The UniGrid® comes in two configurations and rather than being cut from a plate, it is a molded-to-shape product. The grid, like most C/C fixtures, is designed as a modular, stackable system that can be configured to fit into most any standard furnace size (Table 1). It is currently being used in applications such as honeycomb brazing of aerospace seal rings, turbine blade brazing and

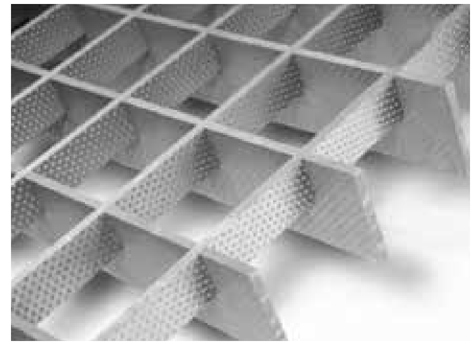


Fig 1: Press-fit Grid Style

Fig 2: Load of Heat Exchangers for Brazing

carburizing of automotive transmission gears, to name a few. Depending on the process and fixture configuration, loads can vary from 1 kg (2.2 lbs.) to 100 kg (220 lbs.) or more per layer.

ADDITIONAL APPLICATIONS FOR CARBON/CARBON FIXTURES

Depending on the temperature and application, carbon/carbon fixtures may work well in conjunction with alloy components. Combining both materials in a fixture can be favorable using the strengths of both materials while minimizing the weaknesses of each.

Multi-purpose fixtures lend themselves to the aerospace and automotive industries (with high volumes of similar parts to be run) but are also used in medical, small motor, commercial heat treat operations, and heavy industrial industries.

STRENGTHENING MECHANISM FOR C/C COMPOSITE MATERIALS (K VALUE)

Carbon fiber is manufactured by converting synthetic fibers (polyacrylonitrile or PAN for short) into carbon through the process of pyrolysis (that is, the thermochemical decomposition of an organic material at elevated temperature in the absence of oxygen). The result of this irreversible process is a change in both the chemical composition and physical phases of the

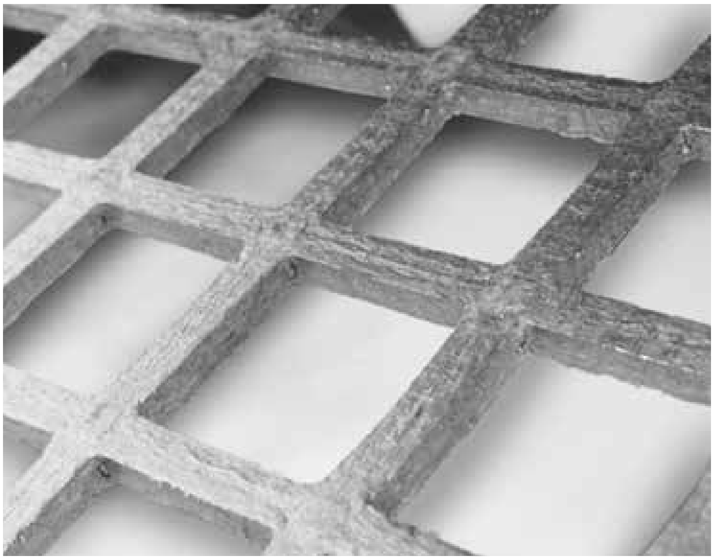


Fig 3: UniGrid® Style

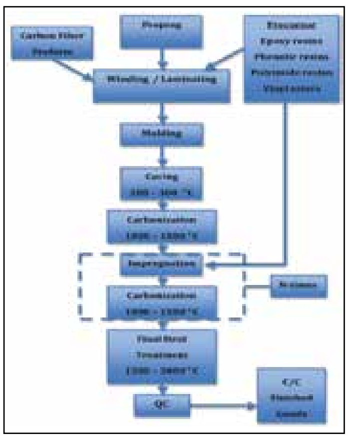


Fig 4: Flow Chart for the Manufacturing of Carbon/Carbon Composite Material

Fig 5: TUS Fixture

Batch Vacuum Style				
Horizontal	Height mm (inches)	Width mm (inches)	Length mm (inches)	Percentage
	305 (12)	305 (12)	610 (24)	5
	610 (24)	610 (24)	915 (36)	20
	915 (36)	915 (36)	1220 (48)	35
	1220 (48)	915 (36)	1830 (72)	30
	1220 (48)	1220 (48)	1830 (72)	10
Vertical	Diameter mm (inches)	Height mm (inches)		
	1525 (60)	1525 (60)		40
	1525 (60)	3050 (120)		10
	1830 (72)	1830 (72)		40
	1830 (72)	3050 (120)		10
Continuous Vacuum Style				
Horizontal	Height mm (inches)	Width mm (inches)	Length mm (inches)	
	150 (6)	205 (8)	355 (14)	20
	230 (9)	455 (18)	610 (24)	65
	510 (20)	610 (24)	915 (36)	10

Table 1: Common Types and Sizes of Vacuum Furnaces

resultant material. This process causes the carbon atoms to bond microscopically in crystalline form. It is the tight crystal alignment of these atoms that gives the carbon fiber its high tensile strength.

When choosing a carbon fiber plate for a given application, there are various types of carbon fiber cloth used in the manufacture of the plate material. Many of these materials are made from laminating layers of woven (so-called long fiber) cloth sheets together in a resin matrix that will also be converted to carbon during its processing. The various woven cloth materials have a "K" value associated with them, such as 3K, 6K or 12K for example. This "K" value represents the amount of carbon fiber strands there are in every tow (cord) of carbon fiber in each layer of cloth. 3K means there are three thousand individual strands of carbon fiber that make up each cord in the woven cloth. As such, 6K means 6,000 and 12K means 12,000 strands of carbon fiber per cord in the cloth. As the number of strands increases, the diameter typically increases. Schunk Graphite offers a unique 12K product that uses a cord which is a wide/flat oval rather than a larger diameter, allowing it to lay up flatter than the 6K product resulting in slightly better strength.

The reason why the K-value is so important is that when dealing with carbon fiber material it is strongest when it is in a straight (i.e. linear) shape. As the material is woven into a cloth sheet, in every location where the cords overlap and intertwine throughout the weave pattern, there will be a slight bend to the material, which weakens the fiber. So, the smaller the diameter of the cord material in the weave, the less bending there will be in that cord when woven through the cloth material. Fewer bends will offer a stiffer, stronger material.

For example, Schunk Graphite often uses 3K material (Grade CF222) to manufacture nuts and bolts while 6K and 12K material (Grades CF226 and CF227 respectively) are used as furnace lining materials in a non-fully densified state or for furnace fixtures when fully densified (Table 2).

Whether to use a fully densified and non-fully densified product is a question often asked. While the process steps for carbon/carbon manufacturing (Figure 4) are different, there are reasons to use both of these materials in the high temperature furnace industry Typically, the denser the material, the stronger it will be Some applications like furnace lining material, which is not a load bearing application, can use a non-densified material.

An example of densified material is the use of C/C as a TUS (temperature uniformity survey) fixture (Figure 5). Heat treaters are interested in the uniformity of their furnaces and do not want the fixture deforming over time or influencing the results. In this example a 457 mm x 610 mm x 457 mm (18" x 24" x 18") fixture weighs 4 kg (8.8 lbs.). When performing surveys above 1050°C (1920°F), ceramic inserts must be used to avoid eutectic formation.

The process of manufacturing C/C composite material starts with a carbon fiber preform or carbon fiber cloth pre-impregnated with resin (i.e. so-called carbon fiber pre-preg material), then impregnating them with a precursor material (i.e. one of a variety of resins or esters) that will convert to carbon during the furnace cycle Depending on the process, the material is sent for winding

Material Grade	CF222	CF226	CF227
Bulk Density	1.55 g/cm^3	1.50 g/cm^3	1.55 g/cm^3
Porosity	8%	8%	8%
Flexural strength	200 MPa	120 MPa	170 MPa
Fracture behavior	pseudoplastic	pseudoplastic	-
Interlaminar Strength	8 MPa	8 MPa	9 MPa
Final Heat Treat Temperature	2000°C	2000°C	-
Coefficient of thermal expansion in the range of 25° C - 1000°C (parallel to plane of reinforcement)	0.8 x 10-6/°K	0.8 x 10-6/°K	1.1 x 10-6/°K
Coefficient of thermal expansion in the range of 25° C - 1000°C (perpendicular to plane of reinforcement)	7.0 x 10-6/°K	7.3 x 10-6/°K	-
Thermal conductivity (parallel to plane of reinforcement)	40 W/m°K	40 W/m°K	-
Thermal conductivity (perpendicular to plane of reinforcement)	10 W/m°K	5 W/m°K	-

Table 2: Property Comparison for Different Graphite Materials

Manufacturer	Fixture Type [a]	Total Run (number of pieces)	Rejected Parts [b]	Rejection %
Brand X	Finger-joint	404,199	822	0.20
Schunk Graphite	UniGrid®	102,515	65	0.06

Table 3: Study of C/C Fixture Manufacturers

Fig 7: Typical Load of Automotive Drive Gears on UniGrid® C/C Fixturing

or laminating and then off to molding The green material will then be cured and run through its initial carbonization cycle It is after this first carbonization cycle that the material is classified as non-densified and will have an open porosity of about 20%. To create a fully densified material (which is not 100% dense), the impregnation and carbonization cycles are repeated multiple times until the open porosity is about 8%.

Manufacturing time for a non-densified material is typically in the range of 4–6 weeks To manufacture fully densified material, the process time can take 4–6 months or longer The ability to use a non-densified material over a fully densified material will always be determined by the application and its end use, which is why it is important to have standard shapes/sizes readily available. The most noticeable difference to the customer will be in the lead-time and cost of material

PROPER HANDLING AND CARE OF C/C COMPOSITE FIXTURES

Eutectic melting can occur with C/C materials at temperatures exceeding 1050°C (1922°F) but is highly dependent on the alloy(s) being run. Using ceramic barrier layers (e.g. tile, cloth), Refrasil® cloth and, in some cases, 300 series stainless steel alloy mesh screens often negates the concern over eutectic reactions. C/C fixtures can be run at or above the processing temperatures used for alloy fixtures with significantly heavier loading. If 304SS alloy screens are used as barriers, temperatures should not exceed 1120°C (2050°F).

Care must also be taken when attempting to unload these materials into open air at temperatures above 350°C (662°F) as C/C readily oxidizes over time thus destroying or severely degrading mechanical properties.

Physical damage is another concern, whether due to extremely rough handling, inadvertent dropping of the fixture or during loading/transport. Using hoist hooks, for example, is never recommended. When performing these types of operations, the breaking off of corners is one of the most commonly reported problems.

Finally, users should also keep records of the service history of their grids, baskets, fixtures, and internal furnace components including a history of duty cycles as a function of application, performance life and failure modes of the material. This field data helps the suppliers add to their technical expertise and improve the useful product life.

CASE STUDY—LOW PRESSURE VACUUM CARBURIZING

Real world experience with carbon/carbon composite fixtures is invaluable and one of the leading commercial heat treat shops, ALD Thermal Treatment in Port Huron, MI has been using carbon/carbon composite fixturing for almost 10 years in their modular low pressure vacuum carburizing furnaces (see opening spread). During this time they have learned many lessons, one of which is that not all C/C composite manufacturers produce the same product quality.

Powertrain transmission gears are one of many important products run by ALD Thermal Treatment. Given their customer's robotic assembly operations that occur directly after heat treatment, out of roundness or any other form of dimensional change are a major concern and have the potential to damage tooling and cause unwanted downtime on the assembly line. With a rejection target of 0%, ALD Thermal Treatment has found the UniGrid® style of fixture to outperform competition (Table 3).

Automotive drive gears (Figure 7) of SAE 5120 are one of many examples of products that are routinely run in high volumes at ALD Thermal Treatment. Total gross load weight is 445 kg (980 lbs.). A processing temperature of 940°C (1725°F) is used to achieve the case depth requirement of 0.5 – 0.9 mm (0.020" – 0.035") at the pitch line. Metallurgical requirements include no bainite in 70% of the case depth, less than 30% retained austenite at the tip of the gear tooth, and only finely dispersed carbides are allowed.

Fixture flatness and strength at temperature over time are major considerations. The UniGrid® design with its large openings and narrow support-ribs allow uniform heat up and improved cool down. These fixture features result in extremely repeatable part quality for all types of gears processed.

Production loads of reaction internal gears (Figure 8) are another example. In this case these parts are run on thin C/C plates. Here the material is SAE 5130 and the gears involved are 152 mm (6") in diameter with 103 internal teeth (Figure 9). The specification requirements are for an effective case depth of 0.3 – 0.6 mm (0.012" – 0.024") with a surface hardness

Fig 8: Load of Reaction Internal Gears

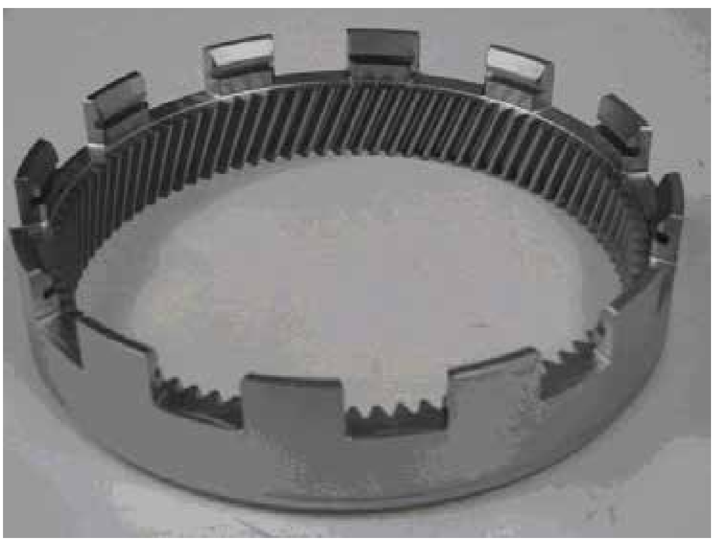


Fig 9: Internal Reaction Gear Configuration

of 79 – 83 HRA. The microstructure must be free of carbides and have a maximum of 30% retained austenite. The surface must be tempered martensite with no bainite present within 0.2 mm (0.008") from the surface. The out of roundness requirement is 150 μm.

In a detailed study[2], parts throughout the load were analyzed for ovality and helix angle variation before and after vacuum carburizing and high pressure dynamic gas quenching. The maximum change in ovality was 41 μm with an average change of 7 μm (Figure 10). C/C fixturing proved that, over time, not only could ovality be repeated load after load but that helix angle variation remained consistent and well below specification allowances (Figure 11). The result of this testing is that since 2006 no post heat treatment hard machining is necessary. The parts go directly to assembly after heat treatment, which is a significant cost savings to the automotive manufacturer.

FINAL THOUGHTS

The Heat Treater continues to have choices when it comes to fixtures and furnace components. With service life expectancies

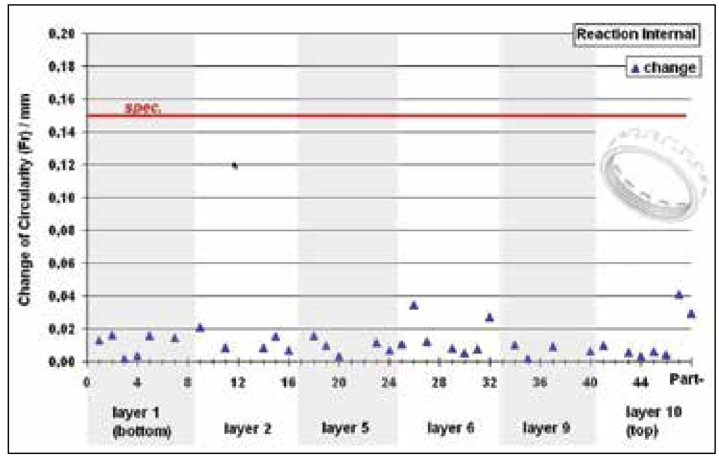


Fig 10: Reaction Internal Gears—Ovality Study

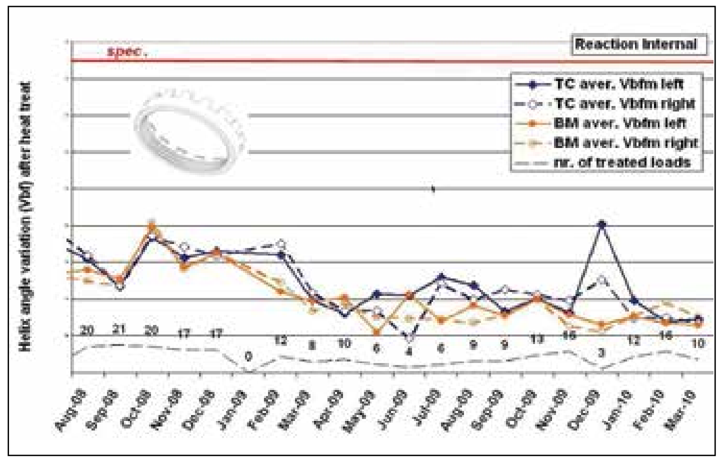


Fig 11: Distortion Monitoring in Production—Helix Angle Variation After Heat Treatment (Averaged Per Month of Production)

of 5 to 10+ years, the applications for carbon/carbon composites are virtually limitless. Not only do carbon/carbon fixtures work extremely well for all types of vacuum applications, but they can also be used for certain controlled atmosphere applications (e.g. atmosphere integral quench furnaces)

As with all other advanced technology solutions, one must match the materials capabilities with the production requirements and process application being run. In this way, maximum life and minimal problems will occur.

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ABOUT THE AUTHOR: Bill Warwick is product manager at Schunk Graphite Technology. Mike Lifshits is the director of R&D and a metallurgical engineer for ALD Thermal Treatment Inc. Dan Herring, also known as "The Heat Treat Doctor," is president of The HERRING GROUP, Inc. He can be reached at (630) 834-3017 or dherring@heat-treat-doctor.com. Go online to www.heat-treat-doctor.com.

Vacuum Carburizing Large Gears

By Nels Plough, Stack Metallurgical

Manufacturing large, high precision gears requires an investment of machine time, materials, and design.

Throughout the machining process, great care is taken to achieve and maintain critical dimensions. The gears are then handed over for heat treatment. Exposing the parts to a high temperature environment, changing the material chemistry, and rapidly cooling in oil to harden is necessary to produce the high strength and long wear life expected in large gears. Heat treating, while critical to gear performance, is a step that puts an enormous amount of stress on the part and must be done correctly to produce an acceptable part.

One of the most frequently asked questions is "How much will this distort?" This is very difficult to answer completely. Factors like material chemistry, prior thermal and machining history, geometry, fixturing, case uniformity and quenching process all play a role in determining how much the gear moves. The heat treater can control the last three variables, and help minimize the size change of the part. Vacuum carburizing can effectively address these.

Vacuum Carburizing is a solid alternative to conventional endothermic gas carburizing in an integral quench or pit furnace. Stack Metallurgical Services uses a Seco Warwick two chamber, vacuum carburizing, oil quench furnace to process large gears (see Figure 1). The furnace is capable of running parts up to 70" diameter, 80" long and 8,000 lbs.

A key component of successful distortion management is fixture design. In Stack's vacuum carburizing furnace, the load is suspended from an overhead trolley (see Figure 2). This gives an opportunity for innovative fixture design. There is no grid

	0.050" ECD predicted		0.095" ECD predicted		0.125" ECD predicted	
	Stack	Customer	Stack	Customer	Stack	Customer
Loads sampled	3	2	4	3	4	3
Coupons tested	6	4	6	6	6	6
Average	0.053"	0.054"	0.100"	0.105"	0.135"	0.137"
Maximum	0.056"	0.055"	0.107"	0.107"	0.141"	0.142"
Minimum	0.051"	0.054"	0.095"	0.100"	0.126"	0.130"
Standard deviation	0.002"	0.001"	0.004"	0.002"	0.005"	0.004"

Table 1: Process repeatability

Figure 1: Vacuum carburizing furnace

assembly, so the parts contact the oil without any interference or turbulence. The heat removal is very symmetrical, which helps reduce the distortion. Parts are arranged and supported to minimize movement or creep during the heat treating cycle, and provide efficient load densities that allow rapid cooling.

The vacuum carburizing process has very good repeatability. All process parameters are controlled by a set recipe. This recipe can be modified during process development to optimize case profiles. Once established, the recipe is locked, and the resulting case depths repeat within a very narrow range (see Table 1).

The first stage of the procedure is heating to the process temperature, which is done under vacuum. The load is ramped up and held until the parts have reached a uniform temperature before beginning carburization. Vacuum carburizing is a non-equilibrium process using a series of boost and diffuse cycles. During the boost cycle, a unique mixture of carburizing gases is introduced under low pressures. Carbon additions are based on the surface area carburized. Enough carbon is present to fully saturate the surface of the part, providing rapid carburizing and uniform case depths. The duration of the boost cycle is relatively short, and longer diffusion times are used to allow distribution of the carbon into the part. After carburizing to the required depth the parts are cooled using nitrogen gas, and then reheated to the hardening temperature. When the parts have reached uniform temperature, the load is quenched in oil.

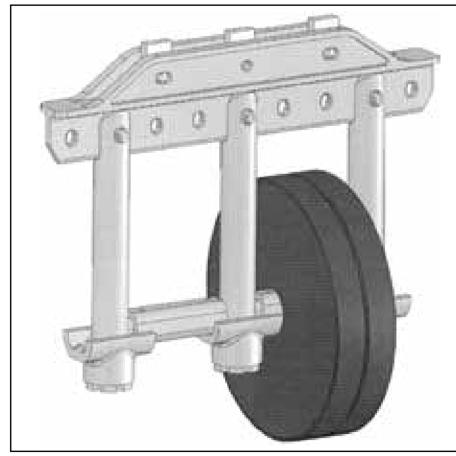


Figure 2: Hanging fixture

CASE COMPARISON

Carburized case profiles and uniformity differ between vacuum and conventional gas processing. There are several reasons that contribute to this. In endothermic atmosphere furnaces, the carburizing gas is typically present while the load is heated to the elevated carburizing temperature. As the parts increase in temperature, the thin sections (tips of teeth) heat faster and begin carburizing before the thicker sections (roots). This results in root to flank case depth ratios of around 65%. In vacuum, the ratio is about 90% because the parts are fully heated before carburizing.

Carbon distribution in the case dictates the hardness profile. Vacuum carburizing provides more carbon at the surface of the part for short intervals (boost cycle). This produces higher carbon levels deeper into the case than endothermic atmosphere carburizing, resulting in a higher sustained hardness levels. Boost and diffuse processing is also used in endothermic furnaces, and is a single long boost cycle at an elevated carbon level, followed by a diffuse cycle at a lower carbon level. The case depth comparison charts (Figures 3 and 4) shows two different effective case depths, each with vacuum carburizing and atmosphere carburizing out of an endothermic batch IQ furnace. The endothermic processes used boost/diffuse cycles. For both examples, the vacuum carburizing process resulted in significantly higher case hardness and the levels above 60 HRC were maintained to around 50% of the effective depth (50 HRC). The transition of the carburized case to core is much steeper. After heat treatment, some grinding is typically required to produce the necessary dimensional tolerances. When higher case hardness is held deep into the case, better hardness is retained after grinding and wear performance is not reduced.

DISTORTION CONTROL

The most difficult challenge in heat treating gears is minimizing distortion. Four primary factors contribute; residual stress, size change due to martensitic transformation, heat removal, and high temperature creep. Martensitic transformation and heat removal are most significant.

Residual stress in the material cannot be controlled by the heat treater, but can cause significant issues during hardening. The best way to address residual stress is by a pre-machining thermal treatment. Typical processes include a combination of normalizing, sub-annealing, quench and temper, and full annealing.

When quenched after carburizing, the higher carbon case has a larger volume increase as it

	Pre-carb span		Post carb span		Variation		Pre-carb OD	Post carb OD		Variation	
	Min	Max	Min	Max	Min	Max		Min	Max	Min	Max
Vac carb	14.6175	14.620	14.611	14.626	-0.0065	0.006	42.784	42.798	42.816	0.014	0.032
Vac carb	14.6175	14.620	14.612	14.630	-0.0055	0.010	42.796	42.800	42.821	0.004	0.025
Pit carb	14.615		14.630	14.631	0.0150	0.016	42.786	42.838	42.850	0.052	0.064
Pit carb	14.613		14.635	14.639	0.0220	0.026	42.489	42.813	42.829	0.024	0.040
Pit carb	14.616		14.639	14.645	0.0230	0.029	42.791	42.857	42.873	0.066	0.082

Table 2: Distortion variation by carburizing method: vacuum vs. pit

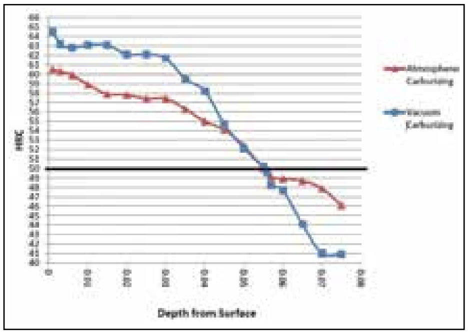


Figure 3: Case comparison, vacuum vs. atmosphere carburizing, 18CrNiMo7-6, ECD 0.055"

transforms to martensite than the rest of the material. This causes enormous stress on the material and results in distortion or size change.

The most effective way to minimize this is maintaining case depth uniformity on the entire part profile. Stresses caused by hardening are more evenly distributed, and part movement is reduced. Some size change will occur.

Heat removal, if not done uniformly, can cause significant part movement. When the gear contacts the oil, the transformation to martensite begins and the material structure is completed. As the quenchant continues up the part, more material transforms, and the internal stresses increase. If the heat removal is not symmetric across the gear cross section, the stress from martensite formation will cause the part to distort. Fixtures must be designed to allow the gear to enter the oil with minimum turbulence and oriented so the quench flow is even along all sides.

High temperature creep occurs when parts are not properly supported during the carburizing process. Cycle times are extremely long—in excess of 100 hours for some case depths. Metal will move or creep at this temperature, and the result is increased ovality. Once again, proper fixture design is key.

The vacuum carburizing process done in the furnace at Stack Metallurgical results in significant distortion improvements when compared to parts processed in pit furnaces (see Table 2). When the distortion is consistently less, pre-heat treating machining adjustments can be made so post heat treat grinding is

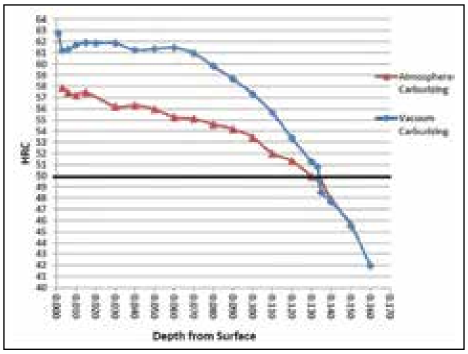


Figure 4: Case comparison, vacuum vs. atmosphere carburizing, 18CrNiMo7-6, ECD 0.130"

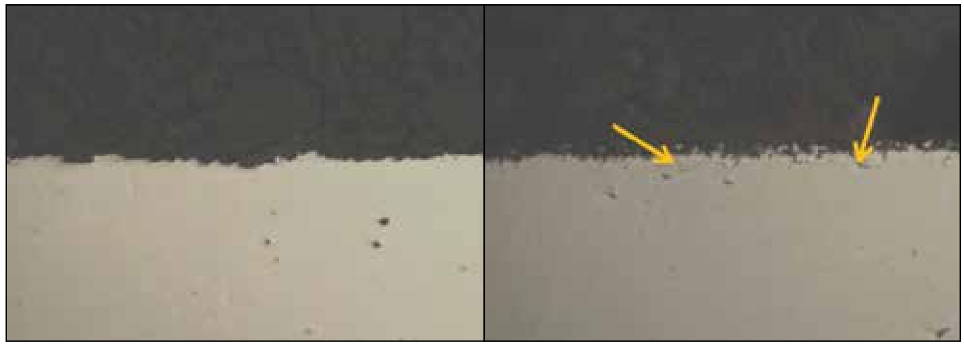


Figure 5: Intergranular oxidation

reduced. In addition, case depth allowances for grinding can be adjusted resulting in shorter heat treat cycle times and lower costs.

MICROSTRUCTURES

The flexibility of vacuum carburizing process variables allows each cycle to be designed to optimize the performance of the alloy being heat treated. Size and distribution of carbides in the carburized case can be carefully controlled. Hardness distribution and depth can be predicted and adjusted to meet each specification.

Since the process is done in a vacuum environment, no oxygen is present. This eliminates the occurrence of intergranular oxidation (IGO) that is typical of endothermic atmosphere processing (see Figure 5).

The presence of IGO requires post heat treat operations such as full profile grinding or shot peening. Eliminating this can lower costs.

CONCLUSION

The vacuum carburizing process offers solutions to some of the challenges facing gear manufacturers when their parts are heat treated. Innovative fixture design, uniform case formation, reduced distortion and elimination of IGO yield better parts. The repeatable, predictable process can be used to address and solve some of the most difficult manufacturing problems.

ABOUT THE AUTHOR: Nels Plough is currently the president of Stack Metallurgical Services, a heat treat company located in Portland, Oregon. Stack Metallurgical heat treats a wide range of products, ranging from aerospace and knife & tool, to heavy industry applications including gear components. He has been with Stack over 16 years, beginning as staff metallurgist, and also serving as operations manager. Previous positions also include work in the steel foundry and steel service industries. Nels received a Bachelor's degree in Metallurgy from the University of Washington. He has been a member of ASM for over 20 years, and has taught various classes in Metallurgy, Heat Treatment, and Failure Analysis for the local Oregon chapter.

Heat Treat 101: A Primer

By Frederick J. Otto and Dan Herring

The manufacture of precision gearing depends, to a great extent, on heat treating as a core competency.

Gears play an essential role in the performance of many products that we rely on in our everyday lives. When we think about gears, we generally separate them into two categories: motion-carrying and power transmission. Motion-carrying gears are generally nonferrous or plastics, while load-bearing power transmission gears are usually manufactured from ferrous alloys. The focus here is on heat treating gears intended for heavy duty service.

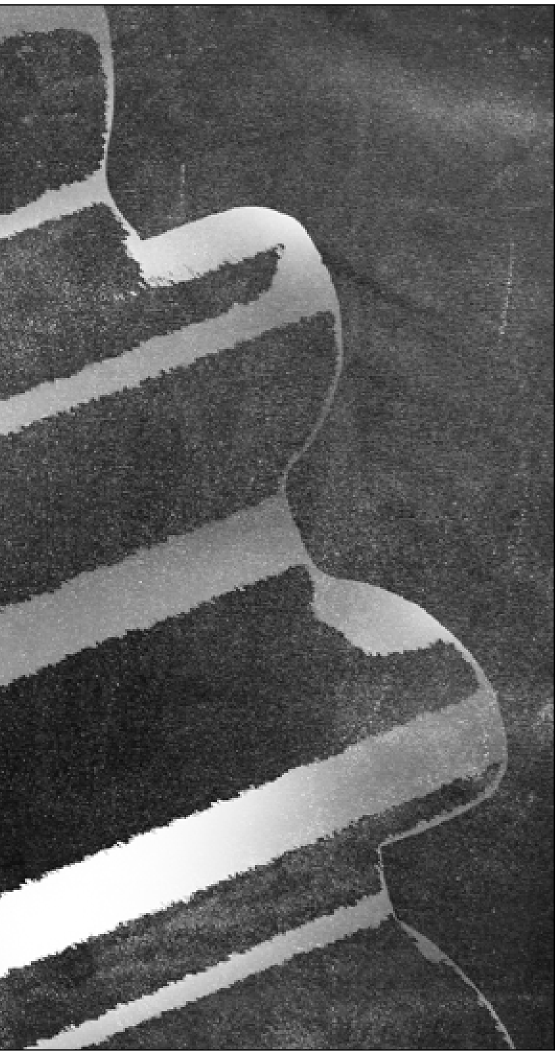
To understand why heat treating is important, consider the model of material science (Figure 1), represented as a series of interlocking rings underscoring the interdependence of each element in the model. We see that the end use of performance capability of the product is defined by its mechanical, physical, and metallurgical properties, which are determined by the part microstructure, produced by a specific heat treatment process.

It is clear from this model that the manufacture of precision gearing depends, to a great extent, on heat treating as a core competency. Its contribution is vitally important for cost control, durability, and reliability. Heat treating represents a significant portion—about 30%—of a typical gear manufacturing cost (Figure 2). If not properly understood and controlled, it can have a significant impact on all aspects of the gear manufacturing process (Figure 3).

PROCESS SELECTION

Pre-hardening Processes

Several heat treatments are normally performed during the gear manufacturing process to prepare the part for the intended manufacturing



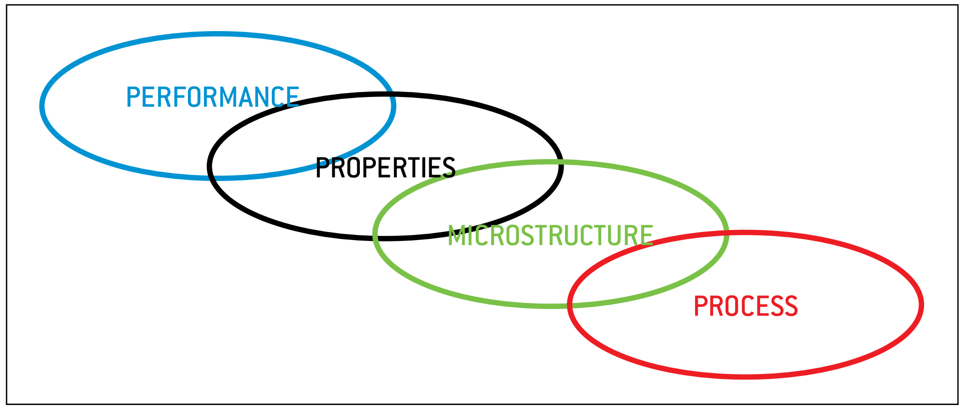


Figure 1: Model of material science

steps. These are essential to the manufacture of a quality gear.

Annealing

Annealing consists of heating to and holding at a suitable temperature, followed by cooling at an appropriate rate, primarily intended to soften the part and improve its machinability. Supercritical or full annealing involves heating a part above the upper critical temperature (AC3)—that is the temperature at which austenite begins to transform to ferrite during cooling, and then slowly cooling in the furnace to around 600°F. Intercritical annealing involves heating the part to a temperature above the final transformation temperature (AC1), the temperature at which austenite begins to form during heating. Subcritical annealing heats the part to just below the AC1 point, followed by a slow cool in the furnace. The rate of softening increases rapidly as the annealing temperature approaches the AC1 part.

Normalizing

Normalizing involves heating the part above the upper critical temperature and then air cooling outside the furnace to relieve residual stresses in a gear blank, and for dimensional stability. Normalizing is often considered from both a thermal and microstructural standpoint. In the thermal sense, normalizing is austenitizing followed by cooling in still- or slightly-agitated air or nitrogen. In a microstructural sense, normalizing produces a more homogenous structure. A normalized part is very machinable but harder than an annealed part. Normalizing also plays a significant role in the control of dimensional variation during carburizing.

Stress Relieving

Stress Relieving involves heating to a temperature below the lower transformation temperature, as in tempering, holding long enough to reduce residual stress and cooling slowly enough, usually in air, to minimize the development of new residual stresses. Stress relief heat treating is used to relieve internal stresses locked in the gear as a consequence of a manufacturing step.

HARDENING PROCESSES

Various heat treatment processes are designed to increase gear hardness. These usually involve heating and cooling and are typically classified as through hardening, case hardening (carburizing, carbonitriding, nitriding, nitrocarburizing) and hardening by applied energy (flame, laser, induction).

Through or Direct Hardening

Through or direct hardening refers to heat treatment methods, which do not produce a case. Examples of commonly through hardened gear steels are AISI 1045, 4130, 4140, 4145, 4340, and 8640. It is important to note that hardness uniformity should not be assumed throughout the gear tooth. Since the outside of a gear is cooled faster than the inside, there will be a hardness gradient developed. The final hardness is dependent on the amount

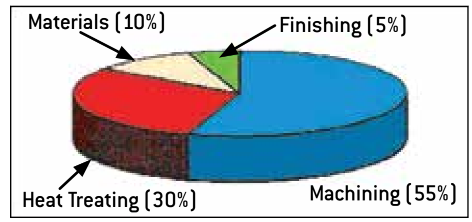


Figure 2: Typical gear manufacturing costs

of carbon in the steel; the depth of hardness depends on the hardenability of the steel as well as the quench severity.

Through hardening can be performed either before or after the gear teeth are cut. When gear teeth are cut after the part has been hardened, surface hardness and machinability become important factors, especially in light of the fact that machining will remove some or most of the higher hardness material into the austenitic range, typically 815 to 875°C (1500 to 1600°F), followed by quenching and tempering.

Case Hardening

Case hardening produces a hard, wear resistant case or surface layer on top of a ductile, shock resistant interior, or core. The idea behind case hardening is to keep the core of the gear tooth at a level around 30 to 40 HRC to avoid tooth breakage while hardening the outer surface to increase pitting resistance. The higher the surface hardness value, the greater the pitting resistance. Bending strength increases for surface hardness up to about 50 HRC, after which the increase in bending strength is offset by an increase in notch sensitivity.

Carburizing

Carburizing is the most common of the case hardening methods. A properly carburized gear will be able to handle between 30-50% more load than a through hardened gear. Carburizing steels are typically alloy steels with approximately 0.10% to 0.20% carbon. Examples of commonly carburized steels include AISI

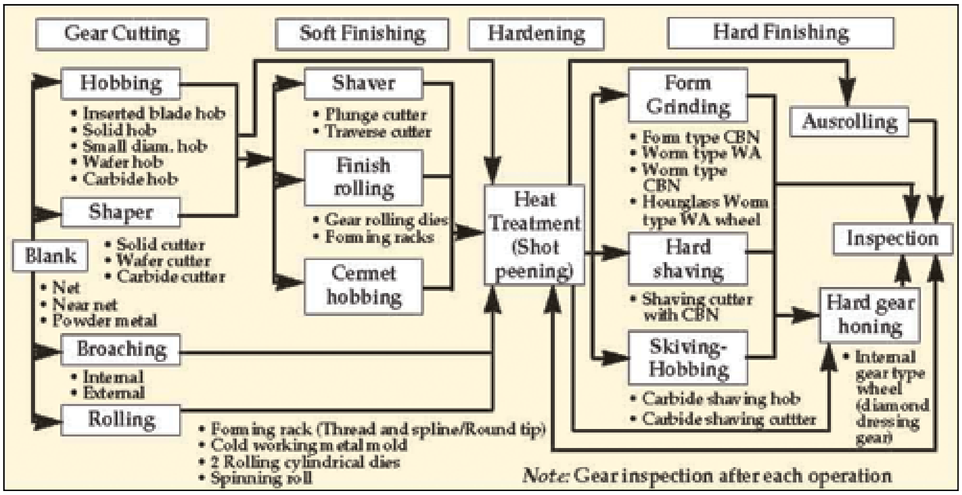


Figure 3: Current gear manufacturing processes

10148, 4320, 5120, 8620, and 9310 as well as international grades such as 20MnCr5, 16MnCr5, ZF-7B, 20MoCr4, and V2525.

Carburizing can be performed in the temperature range of 1475-2000°F (800-1090°C). Common industry practice today finds the majority of carburizing operations taking place at 1600-1850°F (870 to 1010°C). Carburizing case depths can vary over a broad range, 0.005 to 0.25 in. (0.13 to 8.25 mm). However, it is common to use the carbonitriding process for case depths below 0.015 in. (0.4 mm).

Carbonitriding

Carbonitriding is a modification of the carburizing process, not a form of nitriding. This modification consists of introducing ammonia into the carburizing atmosphere to add nitrogen to the carburized case as it is being produced. Examples of gears steels that are commonly carbonitrided include AISI 1018, 1117, and 12L14.

Typically, carbonitriding is done at a lower temperature than carburizing, or between 1330-1650°F (700-900°C), and for a shorter time. Because nitrogen inhibits the diffusion of carbon, what generally results is a shallower case than is typical for carburized parts. A carbonitrided case is usually between 0.003-0.030 in. (0.075-0.75 mm) deep.

Nitriding

Nitriding is another surface treatment process that increases surface hardness. Since rapid quenching is not required, dimensional changes are kept to a minimum, which is a major advantage. It is not suitable for all gear materials. One of its limitations is the extremely high surface hardness or "white layer" produced, which has a more brittle nature than the surface produced by carburizing. Despite this, nitriding has proved to be a viable alternative for numerous applications. Commonly nitride gear steels include AISI 4140, 4150, 4340, 7140, 8640, and AMS 6475 (Nitralloy N).

Nitriding is typically done in the 925-1050°F (495-565°C) range. Three factors that are extremely critical in producing superior and consistent nitride cases and predictable dimensional change are steel composition, prior structure, and core hardness. Case depth and case hardness properties vary not only with the duration and type of nitriding being performed but are also influenced by these factors. Typically, case depths are between 0.008-0.025 in. (0.20-0.65 mm) and take from 10 to 80 hours to produce.

Nitrocarburizing

Nitrocarburizing is a modification of nitriding, not a form of carburizing. Here, nitrogen and carbon are simultaneously introduced into the steel while it is in a ferritic condition, that is, at a temperature below that at which austenite begins to form during heating. A very thin "white" or compound layer is formed during the process, along with an underlying diffusion zone. Like nitriding, rapid quenching is not required. Examples of gear steels commonly nitrocarburized include AISI 1018, 1141, 12L14, 4140, 4150, 5160, 8620, and certain tool steels.

Nitrocarburizing is normally performed at 1025-1110°F (550-600°C) and can be used to produce an equivalent 58 HRC minimum hardness, with this value increasing dependent on the base material. White layer depths range from 0.00005-0.0022 in. (0.0013 to 0.056 mm) with diffusion zones from 0.0013-0.032 in. (0.03-0.80 mm) being typical.

Figure 4: Model of gear engineering

APPLIED ENERGY HARDENING

Various methods of hardening by use of applied energy are used in the manufacture of gears, including flame hardening, laser surface hardening, and induction.

Flame Hardening

Flame hardening can be used for both small and large gears either by spinning or by a pro-

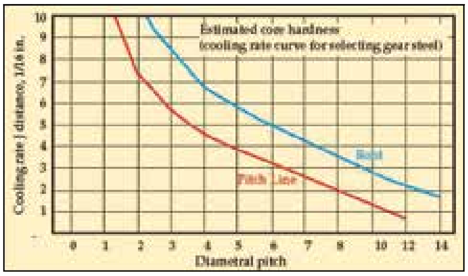


Figure 5: Material selection design aid (T-section gear)

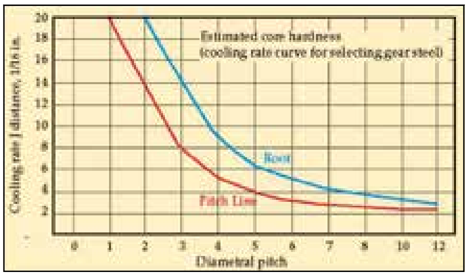


Figure 6: Material selection design aid (solid section gear)

Typical industrial application	Gear design type	Typical material choice
Differentials		
Automotive	Hypoid, spiral/straight bevel	4118, 4140, 4027, 4028, 4620, 8620, 8622, 8626
Heavy Truck	Hypoid, spiral/straight bevel	4817, 4820, 8625, 8822
Drives		
Industrial	Helical, spur rack and pionion, worm	1045, 1050, 4140, 4142, 4150, 4320, 4340, 4620
Tractor-accessory	Crossed-axis helical, helical	1045, 1144, 4118, 4140
Engines		
Heavy truck	Crossed-axis, helical, spur, worm	1020, 1117, 4140, 4145, 5140, 8620
Equipment		
Earth moving	Spiral/straight bevel, zerol	1045, 4140, 4150, 4340, 4620, 4820, 8620, 9310
Farming	Face, internal, spiral/straight bevel, spur	G3000, D5506, M5003, 4118, 4320, 4817, 4820, 8620, 8822
Mining, paper/steel mill	Helical, herringbone, miter, spur, spur rack and pinion	1020, 1045, 4140, 4150, 4320, 4340, 4620, 9310
Starters		
Automotive	Spur	1045, 1050
Transmissions		
Automotive	Helical, spur	4027, 4028, 4118, 8620
Heavy truck	Helical, spur	4027, 4028, 4620 ,4817, 5120, 8620, 8622, 9310
Marine	Helical, helical conical, spiral bevel	8620, 8622
Off highway	Helical, internal, spiral/straight bevel spur	1118, 5130, 5140, 5150, 8620, 8822, 9310
Tractor	Herringbone, internal, spur	4118, 4140, 8822

Table 1: Guide for gear materials as a function of end-use

gressive heating technique. In the progressive heating method, the flames gradually heat the gear in front of the flame head. Sometimes this effect must be compensated for by gradually increasing the speed of travel or by precooling. A wide range of gear materials can be hardened by this technique, including plain carbon steels, carburizing grades, cast irons, and certain stainless grades.

The principle operating variables are rate of travel of the flame head or fork; flame velocity and oxygen-fuel ratios; distance from the inner flame cone or gas burner to the work surface; and the type, volume, and angle of quench. The success of many flame hardening operations for small production runs is dependent on the skill of the operator.

Laser Surface Hardening

Laser surface hardening is used to enhance the mechanical properties and surface hardness of highly stressed machine parts like gears. The use of lasers for surface treatments is relatively limited due to the high cost of large industrial lasers and the .16–.20 in. band of material that can be hardened without multiple overlapping passes. Lasers are not very efficient from an energy standpoint, adding to the expense. Gear materials such as AISI 1045, 4340, and cast irons (gray, malleable, and ductile) are good candidates for this technology.

Induction Hardening

Induction hardening is commonly used in the heat treatment of gears. This process uses alternating current to heat the surface of a gear tooth. The area is then quenched resulting in an increase in hardness in the heated area. It is typically accomplished in a relatively short period of time. The type of steel, its prior microstructure, and the desired gear performance characteristics determine the required hardness profile and resulting gear strength and residual stress distribution. External spur and helical gears, bevel and worm gears, racks, and sprockets are commonly induction hardened. Typical gear steels include AISI 1050, 1060, 4140, 4150, 4350, and 5150, stress relieving or tempering as soon as possible after induction hardening reduces the risk of cracking.

The hardness pattern produced by induction heating is a function of the type and shape of the inductor used as well as the heat mode. One technique for induction hardening of gears is the use of a coil encircling the part. In practice, this circumferential inductor hardens the teeth from the tips downward. While this pattern is acceptable for splines and some gearing, heavier loaded gears where pitting, spalling, tooth fatigue, and endurance are an issue need a hardness pattern more like that found in a carburized case. This type of induction hardening is called contour hardening and is produced via tooth-by-tooth or gap-by-gap techniques by applying either a single-shot or scanning mode. Pattern uniformity is very sensitive to coil positioning.

An alternative that has the same effect as contour hardening utilizes dual frequency. A preheat using 3 or 10 kHz brings the core temperature up to just below austenitizing temperature. Then the unit changes to medium or high frequency depending on the requirement of the gear. The advantage of this method is shorter cycle times. In a very large gear, contour heating will be more cost-effective since coils become very expensive as they increase in size.

POST-HARDENING PROCESSES

After hardening, gears typically undergo several thermal and mechanical processing steps.

"J" distance, 1/16in.	8620 RH, HRC min.	8620 RH, HRC max.	8822 RH, HRC min.	8822 RH, HRC max.
1	47	42	49	44
2	45	39	48	43
3	41	35	47	40
4	38	30	43	35
5	34	26	40	31
6	31	24	37	29

Table 2: Selected material hardenability data

Tempering

Any temperature under the lower critical temperature (AC1) can be used for tempering, but it is the balance of hardness, strength, and toughness required in service that determines the final tempering temperature. Tempering in the range of 300–400°F (150-200°C) is common for gearing, producing a slight increase in toughness that is adequate for most applications requiring high strength and fatigue resistance where loading is primarily compressive. Double tempering is sometimes performed on gears to ensure completion of the tempering reaction and to promote stability of the resulting microstructure.

Subzero Treatment

Two types of cryogenic treatments are used today: "shallow" cooling at -120°F (-85°C) and "deep" cooling at -300°F (-185°C). In some instances, this treatment is combined with subsequent temper operations.

The purpose of cryogenic treatment is to transform retained austenite and raise the hardness of the as-quenched structure. In addition, better dimensional stability is often achieved. Sub-zero treatments have as their ultimate goal an increase in wear resistance, improved bending fatigue life, and minimal residual stress. The use of cryogenic treatments is common today for high performance gearing.

Shot Peening

Shot peening is a cold working process in which the surface of the gear is bombarded with small spherical media called shot. Shot peening is a controlled process in which the size, shape, and velocity of the media are carefully monitored and controlled. A common requirement for shot peening of gears is to peen the tooth roots with overspray allowed on the flanks. Shot peening should not be confused with shot blasting, a cleaning process.

Shot peening induces a residual compressive stress on the gear surface, thereby enhancing tooth bending fatigue properties. The residual compressive stress offsets the applied tensile stress that may cause bending material failure.

Material Selection

Power transmission gears use a wide variety of steels and cast irons. In all gears the choice of material must be made only after careful consideration of the performance demanded by the end-use application and total manufactured cost, taking into consideration such issues as machining economics. Key design considerations require an analysis of the type of applied load, whether gradual or instantaneous, and the desired mechanical properties, such as bending fatigue strength or wear resistance, all of which define core strength and heat treating requirements.

Different areas in the gear tooth profile see different service demands. Consideration must be given to the forces that will act on the gear teeth, with tooth bending and contact stress, resistance to scoring and wear, and fatigue issues being paramount. For example, in the root area, good surface hardness and high residual compressive stress are desired to improve endurance, or bending fatigue life. At the pitch diameter, a combination of high hardness and adequate subsurface strength are necessary to handle contact stress and wear and to prevent spalling.

Numerous factor influence fatigue strength, including:

- Hardness distribution, as a function of case hardening, case depth, core hardness
- Microstructure, as a function of retained austenite percentage, grain size, carbides (size, type, distribution), nonmartensitic phases.
- Defect control, as a function of residual compressive stress, surface finish, geometry, intergranular toughness

In the total manufacturing scheme, a synergistic relationship must exist between the material selection process, engineering design, and manufacturing as illustrated in the model of gear engineering (Figure 4). A balance of the priorities in each discipline must be reached to optimize the ultimate performance of a gear design. This is often not an easy task.

Although material represents only a small percentage (about 10%) of the cost to manufacture a typical gear, material selection must be a perfect combination of raw material cost and performance capability. Insights into the selection process can be found in Table 1 for common steels. Knowledge of the function of each of the alloying elements present in the material and their effect on the physical properties of the alloy is critical in material selection. Properties to be balanced by material selection include tensile, yield, and impact strengths, as well as elongation.

For many gear applications, core hardness, that is the cross-sectional center of the gear tooth, in the 30 to 40 HRC range is desired. To achieve this hardness, the part section size and gear pitch size need to be considered when making the selection of a material. If the core hardness is too low, it will not support the case under high load; if too high, "chipping" of the gear teeth at the case/core interface can occur.

Material selection design aids (Figures 5 and 6) assist in determining the influence of part section size and gear pitch. They enable using the material's Jominy hardenability data, which is based on the water quenching test, to yield reliable core hardness values when the material is oil or high pressure gas quenched. However, verification by testing actual samples should be done when first using these charts to confirm that the core hardness is correct.

A ring or pinion gear, a typical "T" shape of four pitch size, can be used to illustrate this selection procedure. Any materials can be considered, but here two restricted hardenability materials, 8620RH and 8822RH are compared. Table 2 provides Jominy data on these steels. From Figure 5 the horizontal axis value for a diametral pitch of 4 is selected and a line is extended up to intersect the curve for the pitch line. The Jominy distance of the vertical axis is found at approximately J4.5. From table 2, the material which best fits the desired 30–40 HRC core hardness range is selected. In this case, 8822RH is the best choice. For a 6-pitch gear, however, 8620RH material is an acceptable choice. If this gear were "solid," the selection process would change and an alternative material could be considered.

ABOUT THE AUTHOR: Dan Herring, also known as "The Heat Treat Doctor," is president of The HERRING GROUP, Inc. He can be reached at (630) 834-3017 or dherring@heat-treat-doctor.com. Go online to www.heat-treat-doctor.com. Frederick J. Otto is president of Midwest Thermal-Vac. Go to www.mtvac.com for more information.

Tooth-by-Tooth Induction Hardening of Gears (and How To Avoid Some Common Problems)

By Sandra J. Midea, P.E. and David Lynch

For induction hardening of gears, the devil is in the details.

Tooth-by-tooth induction hardening of gears is a complex process. Variations of any of kind may be sufficient to cause the process to run out of control and produce gears that are out of specification. Since heat treating occurs late in the production cycle, process failure is an expensive proposition. This article highlights some of the most common, and perplexing, problems that we encounter as a company that provides commercial process development, inductor design, fabrication, repair and general process troubleshooting for the industry. Many of the specific examples will be tooth-by-tooth hardening for small DP gears; however, most of this information can be directly applied to other forms of gear hardening.

The induction heat treating process begins with the heat treatment specification. The gear designer determines what case depth is required, where it is required (i.e. root, tip, flank), and what hardness is required (which is also influenced by alloy selection). The requirements may be determined by the initial design criteria, or may be a response to minimize a particular type of failure being experienced in the field. But in general, the hardening pattern specification is developed by the gear engineers.

Hardening encompasses the heating of steel above a critical temperature, then cooling it (quenching) at a rate that causes particular, desired microstructural phases to form in the steel. The mechanical properties strongly correlate to the microstructure. Induction hardening differs from other heat

Factors to Minimize Back Tempering	
Process Issue	**Questions to ask**
Correct & Repeatable placement of quenches	Can quench position be verified? Are the quenches positioned by the operator based on experience (has this placement been documented?) Can quench location be replaced by a more robust method?
Verification of quench flow	Is the quench flowing freely through the quench system? Are the quench holes blocked? Are the flow meters reading accurately?
Integrity of the quench	Was the percentage polymer measured? Is the quench quality okay? Is the quench contaminated?
Inductor design	Is the inductor designed to minimize heat on the tip? Is the quench effectively cooling the part?
Retained heat	Is a skip tooth hardening pattern being used to minimize residual heat in the induction hardening zone? Is the scan speed appropriate?

Table 1: Factors to minimize back tempering

treating processes because the required heat is supplied via magnetic fields induced in the part from an external power source and inductor. This inductor may be referred to by other names including coil, block, intensifier, nest, and occasionally a few well-chosen expletives. Because the magnetic field is limited to the outer surface of the work piece, specific areas of the work piece can be selectively hardened and the resulting shape of the hardened zone can be controlled with the proper choice of power, frequency, time, scan rate and a properly designed inductor.

Several factors that have a profound influence on our ability to achieve a specific heat treat pattern are described below. These include some unexpected variables that can significantly influence the process when induction hardening gears.

EFFECT OF PART TEMPERATURE

Gears of all types are generally hardened starting at ambient (room) temperature; however some materials and/or geometries may drive the decision to preheat the gears prior to hardening particularly for large gears. Preheating provides two functions. First, it can help reduce the thermal shock that can lead to cracking. Secondly, it can produce a deeper case than can be achieved when starting from ambient temperature. While preheating is an obvious benefit for some situations, it can be a rogue process variation for others. For example, a large gear requiring low frequency deep case hardness coupled with a slow scan rate may retain heat as it is scan hardened. The target case depth may overshoot due to this elevated part temperature. Furthermore, maintaining a stable preheat temperature throughout the mass may be difficult.

Figure 1 illustrates the impact of preheating a good hardenability steel to 350°F and then induction scan hardening. All other process parameters were held constant. A horizontal line is scribed on the photo at 7 mm depth. As can be seen, preheating produced a deeper case.

EFFECT OF QUENCHING, QUENCH HEAD POSITION AND BACK TEMPERING

Various quench media are used to harden gear teeth, but the following discussions will be referring to commonly used polymer quenches. A specially designed quench delivery system is built and incorporated with the gear inductor to accomplish adequate quenching. Heat migrates across the gear tooth tip during scan hardening for two reasons. First, the induction field couples closely to the sharply pointed edges of the tip. Inductors can be designed to minimize the influence of the geometric coupling, which is an increasing issue with higher frequencies. Second, the heat passes readily through the small land of the tip via thermal conduction. Thermal conduction can be controlled via quenching by using specially designed side quenches integral to the gear inductor.

The hardening pattern can be seen by cutting, polishing and etching a gear cross section, a process known as macroetching. Quenching is used to control the hardening pattern, however, the heat from hardening in one tooth space conducts through the tip and tempers back the adjacent tooth spaces that were previously hardened. Back tempering will reduce the hardness on the adjacent tip and this effect may range from a few to over 10 HRC. Some factors to help minimize back tempering are summarized in Table 1.

Multiple types of quenches may be required to achieve the desired scan hardening pattern. (Figure 2) The primary quench is usually machined from solid brass to match the gear tooth profile, with internal baffled water passages that provide even quenching along flanks and root areas. Tip quenches are matched pairs of solid machined brass with drilled quench holes, and occasionally narrow slots, to control the heat at the tip and on the adjoining tooth flank. These quenches help prevent tempering back hardness previously hardened teeth. Blade quenches are often required for smaller gear teeth (2.5 DP and smaller) to add additional quench on the adjoining tooth flank to prevent back tempering. Blade quenches are matched pairs of solid machined brass with internal baffled water passages that provide a "blade" of quench cooling that can be positioned where

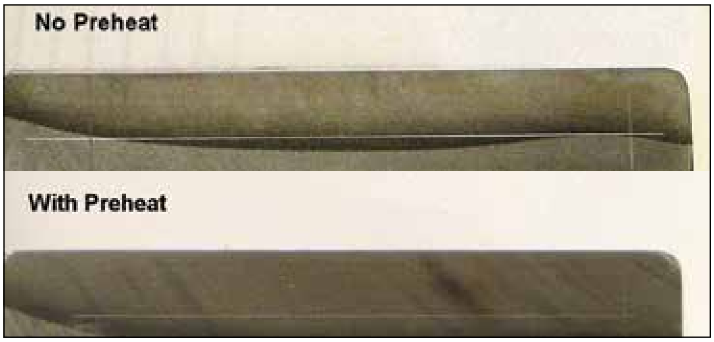


Figure 1: Macroetched cross-section showing differences in induction hardened case depth due to a 350°F preheat. All process parameters were the same for each trial. Horizontal line is at 7 mm inch depth. (10% Nitric acid etchant)

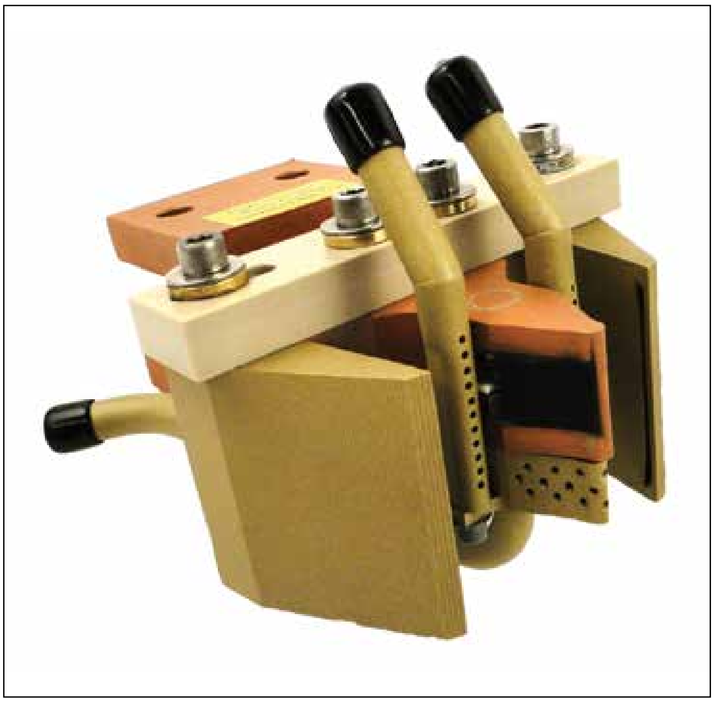


Figure 2: Straight gear tooth scanning inductor with solid machined primary, flank and tooth tip quench heads provide quenchant, where needed, to cool the tip and flank to achieve the desired hardening pattern and minimize back tempering.

required. It is critical to locate and lock the position of these quenches for repeatable results. We regularly see installations where bent copper tubing and/or plastic snap fittings are used to control the back temper. At best, this should be considered an uncontrolled process that is highly subjective and operator dependent.

Figures 3a and 3b illustrate the effect of quenches on a small DP tooth space. Figure 3a shows the mass heating pattern produced by the inductor alone without any quenching. A mass quench pattern provides an idea of the inductor capability. Quenching controls hardness as well as the thermal migration through the tooth tip (Figure 3b).

EFFECT OF INDUCTOR ALIGNMENT

Whether the operator uses pin gages or an automated "touch-touch" system to locate the inductor to the correct gap, presentation of the inductor to the part is a critical parameter. Not only is the alignment within the gap critical, we have seen many examples where the inductor is not dead center in the tooth space. The result is an offset pattern with deeper case on one side. The inductor may be presented straight into a tooth space, however the tooth space itself may be at a slight angle due to the relationship of the equipment and work piece such as curvature of the gear. This condition can also develop because of difficulty visually aligning the inductor/gear orientation due to physical constraints in the operation. Misalignment creates a difference in case depth side-to-side and may result in hardness variations due to a shift in the quench position. Alignment is important for all gear tooth sizes.

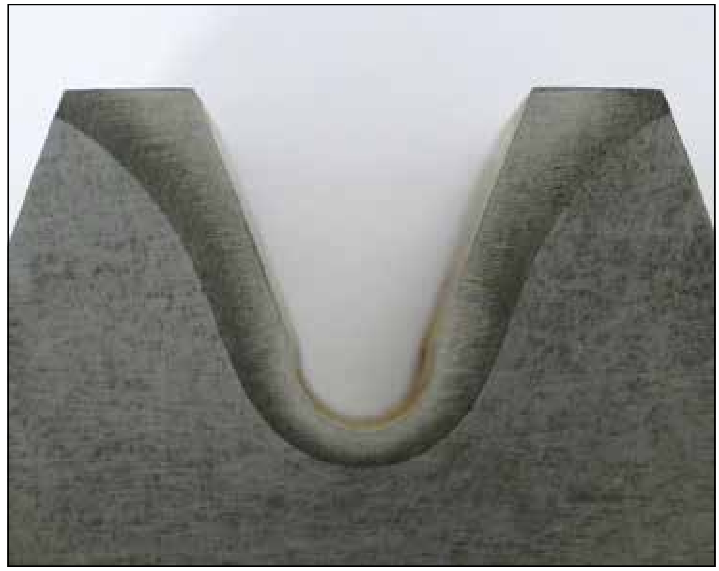


Figure 3a: Induction heating pattern produced where no quenching was used to control the pattern. This gives a true indication of the inductor capability.

Figure 3b: Carefully positioned quench heads provide quenchant where needed to cool the tip and the flank to achieve the desired hardening pattern and minimize back tempering.

IMPACT OF INDUCTOR DESIGN FOR SMALL DP/MOD GEARS

When a gear requires:

- tight compliance to case depth minimum and maximum values;
- case depths near the maximum capability of the material;
- tightly controlled run out requirements; or
- is processed on equipment near the limits of its capability,

a careful inductor design may be the most critical influence on successful and repeatable hardening results. An accurate design requires exact detail about each gear tooth based upon the actual profile presented at the time of heat treat. This profile usually includes grinding stock and can be different from the finished print. It is highly recommended and sometimes required that a mold of the gear tooth profile is made before the inductor is designed. It is important to make the mold properly, using a memory silicone material like Plastique® or Plaster of Paris. The surface of the gear must be cleaned with a non-oily solvent and treated with a mold release spray. When making a mold, it is important to push the material tightly into the root removing any air pockets. It is also critical to overlap the top of the part, which will enable the mold to retain its shape and the relationship between the adjoining teeth. Silicone will be flexible when removed; however, Plaster of Paris will shrink slightly and bind to the gear; removal is easy with a rubber mallet. The mold will be used to create a CAD drawing of the actual gear tooth profile for use in the inductor design. Exact dimensions are critical, since the gap between the inductor and gear surface may be as close as 1 mm.

IMPROVING INDUCTOR LIFE

A robust, bullet-proof inductor is the ultimate goal. Recent advancements in technology have allowed fabrication of advanced, robust designs that provide superior performance and increased inductor longevity. Our designs are created in both 2D and 3D CAD software with detailed engineering drawings which provide high quality, consistent and repeatable manufacturing. Our 5-Axis CNC machines produce solid machined water-cooled copper inductors; thereby eliminating many of the braze joints that can be potential points of failure. A wire EDM is capable of producing cooling passages in complex inductor shapes which have been proven to increase inductor life. Furthermore, a fundamental understanding of when and where to use Silicon Steel Laminations and soft magnetic composites like Fluxtrol® is necessary to enhance induction hardening efficiency. A systematic approach to improving inductor life is sometimes accomplished by analyzing the mode of failure and making corrective changes.

NUTS, BOLTS AND FITTING FAILURES

Only non-magnetic stainless steel fasteners and brass or plastic fittings should be used in and around the induction process. Carbon steel bolts and fittings can heat up or melt if exposed to stray induction fields. A prudent approach to avoid an expensive inductor failure is to simply pass a hand held magnet over the bolts and fittings to check for anything magnetic. Every operator should have one. Recently, we have encountered several cases of imported fittings that appear to be brass; however were actually anodized carbon steel.

INDUCTOR COOLING WATER COMPLICATIONS

Water cooling is the lifeblood of the induction system. High-production, high-power single shot and scanning inductors need efficient cooling for a long life. A good pump and a clean cold water supply together with a precise inductor cooling chamber design will promote gear inductor longevity. Often inductors are connected directly to the same water system that cools the power supply and work head. Unfortunately, this water supply is at the end of a cooling manifold servicing many internal components, and modern power supplies usually require deionized, distilled or reverse osmosis (RO) water supplies

Figure 4a: (Left) Photograph of a contact severely damaged by arcing. (Right) Arcing caused by a damaged insulator occurred across dirt accumulated over time.

Figure 4b: (left) Well-maintained inductor contacts with special breakaway mounting bolts. (right) Arcing caused by a damaged insulator occurred across dirt accumulated over time.

for cooling, sometimes containing a cooling additive. The power supply/work station cooling temperature is specified to be above the local dew point and sometimes set as high as 90°F/32°C to prevent condensation within the unit. The gear inductor does not need to maintain a low dew point since it is usually drenched in quench fluid. However, for a gear inductor prone to cooling failure, this temperature is too high and the supply pressure is too low. In addition, a deionized distilled water system is not necessary to cool the inductor. A good fix is a dedicated cooling supply, injecting pressurized cold (70°F/21°C or lower) filtered water from a separate source, directly to the inductor. Consider a properly sized, pressure boost pump at 250 psig/17 bar which is available from several sources including a quality inductor manufacturing company.

Absence of cooling (no water) happens more often that one would expect. In high power applications, with no water-cooling, the inductor immediately fails with melted copper and blown braze joints. If the water system was not turned on, a flow monitor in the inductor cooling line might have prevented this failure. For inductors with small cooling passages, a flow monitor may not be sufficiently sensitive to prevent failure. A pressure monitor does not guarantee flow; therefore a visual flow indicator is useful to prevent gear inductor failures. All cooling water to the inductor should be filtered. If the water was turned on but contaminates created an obstruction, the flow may not be sufficient. For most gear inductors we recommend a 25 micron cartridge filter before the inductor inlet and a 100 micron filter for small gear inductors with tiny cooling passages.

IMPORTANCE OF INDUCTOR MAINTENANCE

Gear inductors wear over time and can be damaged from accidental contact with the gear surface. It is important for the machine operator to watch for signs of wear or contamination on the surface of the inductor. Flux intensifiers will degrade over time. If the flux intensifier becomes damaged or missing, the induction hardness pattern can be significantly affected. The machine operator should check the condition of the inductor at regular intervals. In most cases, gear inductors can be rebuilt to like new condition. A typical rebuild can take several days to complete and consists of replacing the water-cooled copper nose, fixing leaks, and replacing flux intensifiers and insulators. All components are cleaned, and contacts are silver-plated. The assembly is pressure-checked water tight and dimensionally inspected. All quench passages are cleaned of any obstructions and checked for proper flow and function. Spare inductors are recommended for high volume gear production to prevent down time during an inductor rebuild period.

PREVENTING ARCING

The output transformer is the initial point of electrical contact in the system and this is where power is connected to the gear inductor. Often, the inductor is bolted directly to the transformer. Sometimes bus extensions and inductor adapters are used, which involve several additional points of electrical contact. Each of these contacts must be kept clean and properly bolted or clamped to prevent damage to the contact area. Figure 4a is an example of what can happen to an improperly bolted contact and from arcing caused by a damaged insulator occurred across dirt accumulated over time. The resultant arcing caused extensive damage not only to the contact, but also to the transformer mounting foot, requiring replacement of the transformer. Figure 4b shows well-maintained inductor contacts and appropriate mounting bolts.

Properly bolted contacts require the use of both a proper bolt and washer. As part of preventative maintenance, the threaded inserts in the inductor foot should be inspected for damage before installation to the transformer. Tapped holes in the transformer foot are often blind holes; therefore the threaded hole depth should be measured with a depth gage, or more conveniently, with a pencil point. Using this measurement, the bolt must be shorter than the sum of the contact thickness and the total hole depth. The bolt must fully engage the threaded insert usually 3/8 to ½ inch (approx. 10 to 12 mm) and tightened to 155 or 178 N. Because over-tightening can cause damage to the threaded insert, special breakaway bolts are available (Figure 4b). Made from 300 series stainless steel, they are designed to snap off at the head at a 245 N torque; thereby preventing costly damage to the transformer thread. Since copper crushes easily, special thick washers work with the bolt to protect the copper. Electrical contact maintenance is further achieved by relocating the power transformer away from quench fluids, oil, smoke and dirt. A specially designed bus interconnect is then used to make the connection to the gear inductor. Most of our suggestions can be easily incorporated into a good preventative maintenance program to help prevent arcing failures.

QUENCH MAINTENANCE HEADACHES

If the inductor is the brain of the induction heating system and water is the lifeblood; then the quench system is the heart. Just like a human heart, it is important to keep the quench well maintained and clean of any debris and buildup. Often neglected, sometimes due to budget constraints, the quench system can become polluted, foul smelling, and ineffective. A well-maintained filter system helps, but polymer quenchants do break down over time and the quench system must be drained and cleaned. Before refilling the quench tanks, filter housings and plumbing should be pressure washed to remove scale and scum. While this maintenance is expensive, it is absolutely necessary to produce robust process.

It is equally important to remove any metallic debris from the quench. Metallic debris comes with the part being processed in the form of turnings, foundry and grinding dust. They are deposited into the quench fluid by repeated quenching of the gears. Some of these particles can be very fine (about the consistency of copy toner) and can pass through a bag filter. If not removed, these electromagnetically accumulate on the surface of the inductor and cling to the walls of the quench system. Trouble begins with arcing at the gear inductor and components. A magnetic particle separator or a bar magnet in the bag filter are both good methods to address this issue. At the very least, a rubber coated strong permanent magnet can be installed on a hangar off of the tank bottom near the return.

CONCLUSION

Tooth-by-tooth gear hardening is one of the most complex induction hardening processes. Any number of relatively minor variations can force the hardening process out of specification. Proper operator training, adequate maintenance and a fundamental understanding of the hardening process are all part of the equation. For induction hardening of gears, the devil is in the details.

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ABOUT THE AUTHOR: Sandra Midea is staff metallurgist and lab manager with over 25 years experience in production heat treating technologies. David Lynch is the V.P. engineering with over 25 years of inductor design and fabrication experience. Induction Tooling Inc. is a premier manufacturer of inductor and tooling for induction heat treating. ITI houses design and fabrication operations along with a fully appointed commercial induction development laboratory and ISO 17025 accredited commercial metals testing laboratory.

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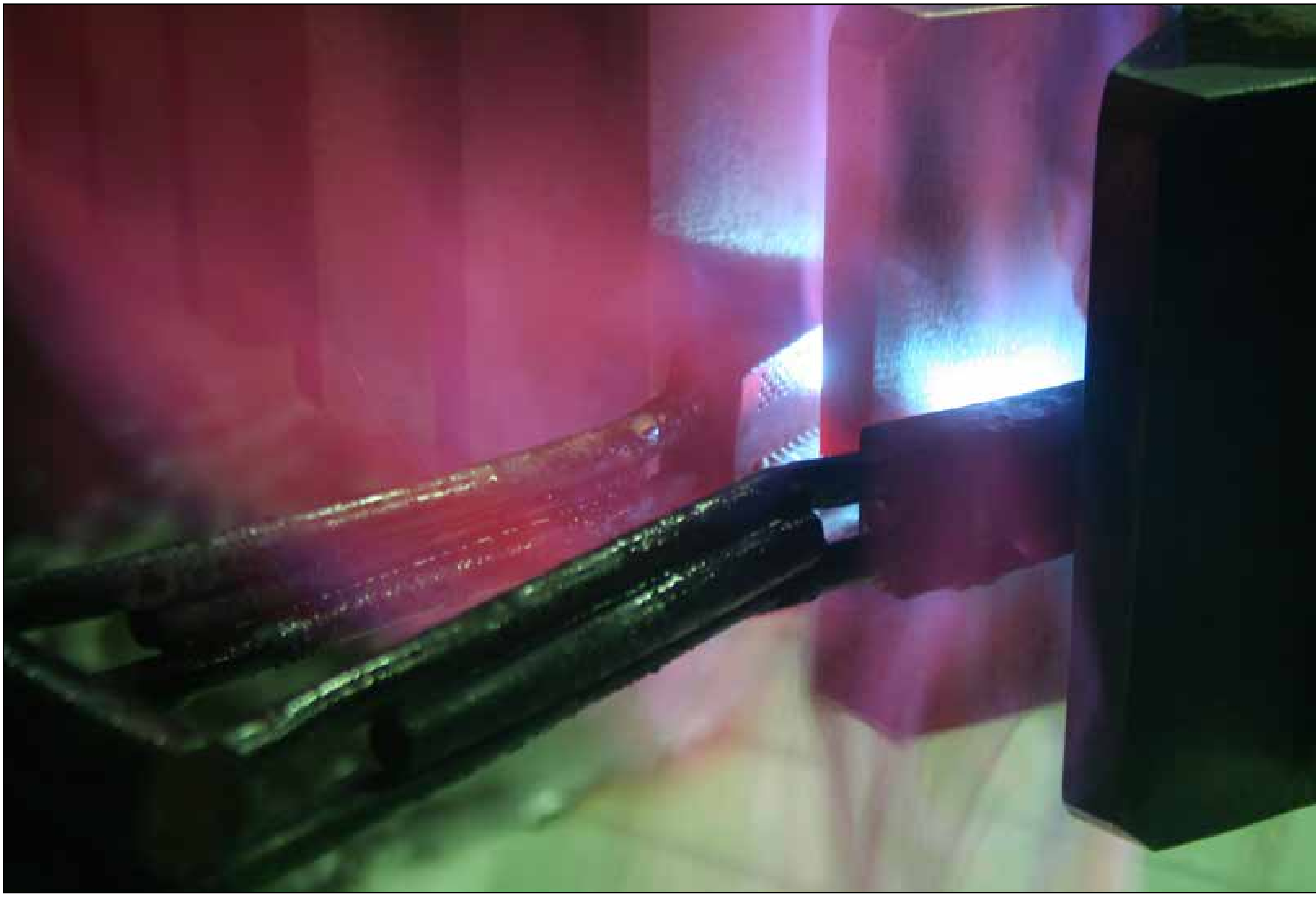


Flame Hardening Gears

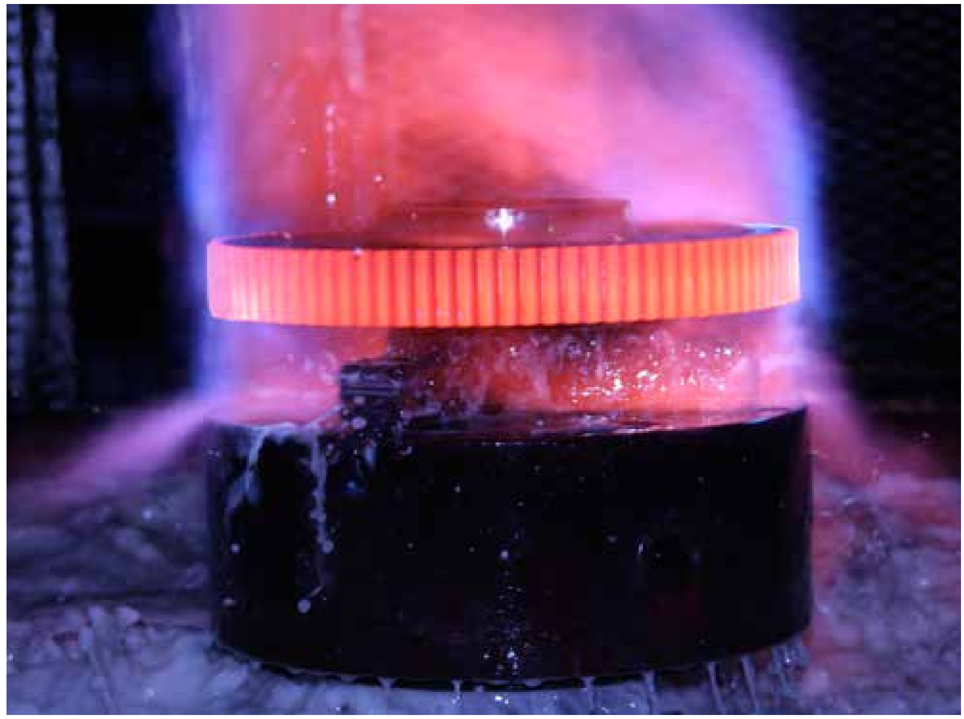
By Bruce Curry

For gear manufacturers in particular, the ability to focus the heat and scan each tooth with the upmost precision every time is especially beneficial.

Long gone are the days when a machine operator sat in a dark corner of the shop staring at the cherry red glow of a gear being flame hardened. Typically the "craftsman" would wear dark welding glasses and make the decision that the color looked good just before the water spray quench completed the hardening process. This was an acceptable practice many years ago, but one that Penna Flame was eager to improve upon with the use of new technology.

In 2007 Penna Flame started to investigate how to automate manual scanning of parts, which included gear teeth, lead to a partnership with Robert Morris University's robotic engineering department. Faculty and engineering students worked together with Penna Flame to design and develop a robotic flame hardening cell that was installed in April 2008. This robotic flame hardening cell allowed for unmatched uniformity and repeatability in the "precision surface hardening" of steel products such as gears, races, rings and other high volume production runs. For gear manufacturers in particular, the ability to focus the heat and scan each tooth with the upmost precision every time is especially beneficial. The process has been so successful that Penna Flame now has a total of three robotic cells, the most recent installed in 2011.

Before processing, gears (of all sizes) are pre-heated in an oven for several hours. They are then loaded on an indexing table that is programmed to work in conjunction with a robot. Once the robot completes the scanning of a tooth (achieving a flank or a root pattern) the table indexes so the teeth are not hardened in sequence. This helps to limit the amount of distortion by evenly distributing the heat evenly around the circumference of the part. Throughout the



hardening process, the gear temperature is controlled. Once all teeth are scanned, the gears are placed into an immediate holding temper. Inspection the following day, of as quenched hardness, will determine the final tempering temperature.

In addition to the robotic individual tooth scanning process, depending on the diameter and DP, gears are often hardening using the spin flame hardening technique. Gears are again pre-heated for several hours and then placed on a spin hardening machine. The gears will rotate in front of several heating heads for a period of time. Temperature is monitored and once the predetermined austenitizing temperature is reached, the gear is dropped into an agitated polymer quench bath. Once removed from the quench, the gear is placed into an immediate hold temper and allowed stabilization. This process typically through hardens the gear teeth, but in many applications, that is acceptable and often desired.

A gears as quenched structure prior to tempering is very hard and brittle and lacks good mechanical properties--namely toughness, ductility, and is highly stressed and dimensionally unstable. Proper furnace tempering coordinating both furnace time and temperature with the gears chemical grade and specification requirements optimizes surface properties while hitting the required surface hardness for a particular application.

Over the years, Penna Flame has added controls to their gear hardening process that have been quite significant. Utilizing digital regulators, flow controls, quench temperature regulation, and digital, high speed non-contact infrared thermometers is as much a key to process control as the robot and spin hardening machine. Each pyrometer is equipped with laser sighting, which allows for pinpoint placement for extreme accuracy of surface temperature monitoring. Pre-heat temperature, austenizing temperature at time of quenching, and residual temperature are all key elements in the gear hardening process.

Working closely with the manufacturers on the latest technology has been the key to both the success of the precision surface hardening process and the end product to the customer.

ABOUT THE AUTHOR:

Bruce Curry is vice president of sales at Penna Flame industries. Dedication to quality and years of experience have combined to solidify Penna Flame Industries as a flame hardening industry leader.

For more information about products and services from Penna Flame, visit them online at www.pennaflame.com, or call (724) 452 8750.

Heat Treatment of Large Components

Bill Andreski, Gerhard L. Reese and Härterei REESE Bochum

There are three important surface hardening methods used to improve and expand the technical use of gear components. Design and material engineers must decide which hardening method to use.

Large gear components can be offered in many applications such as marine, wind power, steel rolling mills, power plants, transportation, railroad, aircraft, cement crushers, mining, and oil industry applications. There are three important surface hardening methods, as seen in Figure 1, used to improve and expand the technical use of gear components. Design and material engineers must decide which hardening method to use. Case hardening is normally the first choice because of the highest load capacity. However, case hardening also poses challenges that must be acknowledged. Therefore, it is good to know that there are three options for very large components. So first, let´s compare these methods.

THREE METHODS COMPARED

Case hardening is normally carried out at temperatures between 880°C to 980°C for carburizing, and 780°C–860°C for hardening. The standard procedure is gas carburizing. By diffusion of carbon into the surface and quench hardening, the process produces a strong hard surface layer of martensite of up to 10 millimeters. This thermochemical method adds defined quantities of carbon to the workpiece by using a carbon enriched gas (i.e. methane (CH4) or propane (C4H8)). After carburization, the components are hardened and tempered to the required surface hardness to relieve internal stresses. In addition to a high surface hardness (max 850 HV) and

abrasion resistance, the heat-treated workpieces exhibit good reverse bending and fatigue strengths due to residual compressive stress. Specific time and temperature variations in the carburizing, hardening, and tempering processes can be introduced to optimize the material properties and minimize the changes in dimensions associated with the respective charging techniques—hereto lies the art of hardening. Nitriding treating temperatures range from 500°C–580°C for gas nitriding, and from 400°C and up for plasma nitriding and plasma nitrocarburizing. Nitriding is a method for enriching the surface layer of ferrous materials with defined quantities of nitrogen or, in the case of nitrocarburizing, of nitrogen and carbon. This not only enhances the hardness, but also the abrasion resistance, fatigue strength, corrosion resistance, and antifrictional properties. Furthermore, there are no microstructural transformations from austenite to martensite, so high dimensional stability is ensured.

Normally, nitriding penetrates to a maximum depth of 0.8 mm. "Profundinieren", a deep nitriding method developed by Dr.-Ing. Helmut Reese, penetrates to depths exceeding 1.0 mm, depending on the material. Provided that the corresponding steels are used, non-deforming nitriding is in many instances a viable alternative to case and surface hardening. Nitriding steels are listed under DIN 17211 and EN 10085.

Surface hardening is carried out at treating temperatures 50°C–100°C above the material-specific hardening temperature. The heating can be done by flame, induction, laser, or electron beam. These processes produce a hard surface layer of martensite. These methods can also be used to harden large components or complex geometries. Induction or flame heating is applied to the heavily loaded areas (specific surfaces) of the workpiece until the respective hardening temperature is reached, after which the workpiece is quenched. Much experience is necessary for optimizing the methods and finding component-based solutions for both flame and induction hardening. Therefore, the evaluation and consistency of test samples is essential and is greatly enhanced by specific definitions of machine parameters. In summary, surface hardening is a technical and economical alternative to conventional case hardening in many instances. A side-by-side comparison of the three surface hardening methods can be seen in Table 1.

For the load capacity of a component, the important factors are hardness, case depth and core strength:

- If the load capacity of the gear is vital, case hardening is the first choice, even if the hardening distortion during nitriding is less.
- If Hertzian pressures are low, as in hydraulic cylinder applications, and low hardness depths are sufficient, nitriding is the first choice.
- Large hardness depths in a short time, partial hardening of large components, and flexibility are assets of the surface layer hardening
- The load capacities of the three hardening methods can be compared using Figure 2 where fatigue strength is measured against hardness.
- Because of the highest load capacity, case hardening is the first choice for the treatment of large transmission components.

Three main aspects for case hardening of big gear components have to be considered:

- Hardenability (material selection and geometrical influence)
- Weight (as much as necessary, as little as possible)
- Dimensional changes and distortion

HARDENABILITY

Large components are normally quenched in oil. Cooling below the alloy Ms temperature through to the core often takes longer than one hour, depending on the size of the cross sections. During this time, the heat is conducting through the surface. Therefore, a steel must be selected, with its ferrite/pearlite nose as far to the right as possible. Otherwise, there will be a significant decrease of the surface hardness and case depth. The larger the cross-sections, the more it is necessary to utilize high-alloyed steels.

According to the experience at Reese, for large components with a cross section more than 100 mm, 18CrNiMo7-6 or 18CrNi8, or similar steel qualities with HH-alloying-scatter-band, must be chosen. The two time-temperature-transformation diagrams (see Figures 3 and 4) exhibit the

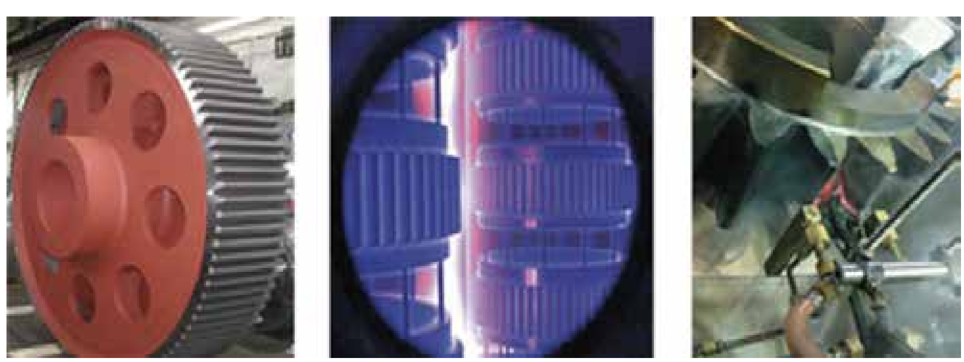


Fig 1: The three important surface hardening methods from left to right are case hardening, nitriding, and induction-flame-hardening respectively.

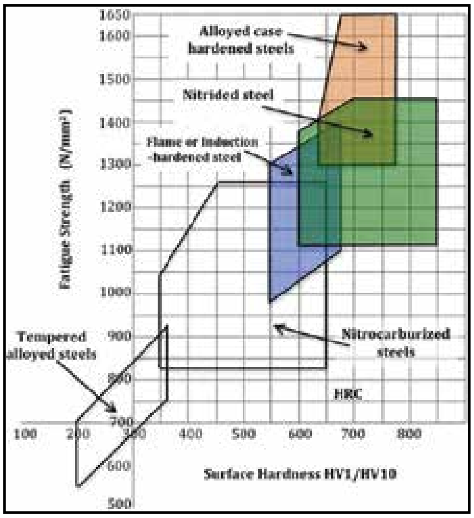


Figure 2: Load capacities of the three hardening methods: fatigue strength vs. hardness

differences between a high alloyed and low-alloyed case hardening steel.

The alloying elements Cr, Ni, Mo, Mn and V increase the hardenability, and V, Ni and Mo additions increase toughness. If a steel is selected with insufficient hardenability, regardless of intensive quenching in oil with very good

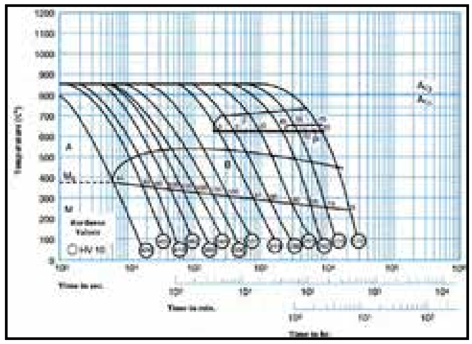


Figure 3: Time-temperature-transformation (TTT) diagram for the high alloyed case hardening steel 18CrNiMo7-6

cooling and circulation, the result will be an unacceptable drop of hardness and hardness depth of large components. This hardness reduction is evident in gear parts especially below the pitch circle down to the tooth base, to a hardness of partially well below 52 HRC. The components can fail after a short period of time by pitting, flank fractures and tooth root fractures. Using the same alloyed steels from Figures 3, 4, 6, and 7, display the relationship of hardness as a function of the distance from the quenched end. As seen, there is an

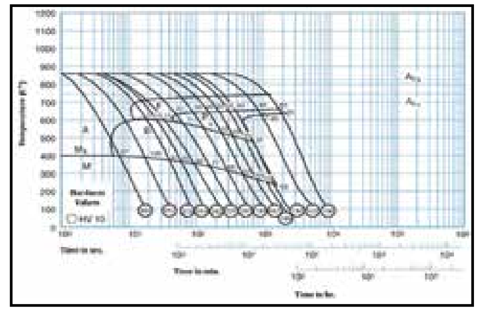


Figure 4: TTT diagram for the low alloyed case hardening steel 16MnCr5.

obviously much larger decrease in hardness as the distance between the quenched end grows with the low alloyed case hardening steel. The graphs created are a result of the Jominy hardenability test (Figure 5).

In the area of decreasing hardness to the tooth root, the CHD cannot be adequately modeled by the cylindrical geometry of a sample coupon. In particular, the geometric conditions and their influence on the cooling rates in massive components cannot be compared with small cylindrical test pieces. Case hardening results of the tooth base and tooth flank in comparison with a small cylindrical sample coupon

	Case hardening	Surface hardening	Nitriding
Pros	· Large case-hardening depths (CHD) of up to 10 mm, which can be achieved within treatment times of 10 to 200 h · Very hard surface layer · Very tough core · Excellent fatigue resistance by surface compressive stresses · Good under impact stresses · High surface pressure	· High surface hardness depths (SHD): 2≥30 mm is possible, which can be reached in a short time of treatment with a relatively low energy consumption. · Hard surface layer · Tough core · Good fatigue strength · Good bending and torsion resistance	· Low treatment temperatures result in minimal dimensional and shape changes and therefore rework is seldom necessary · Limited accessible areas can be hardened · very hard surface layer, depending on the material · Tough core · Good fatigue properties · Improved corrosion resistance · Very thermostable · Improved sliding properties
Cons	· Due to the high processing temperatures, martensitic transformation and quenching, considerable dimensional changes and hardening distortions can occur. · Not to be used above tempering temperature · Little corrosion resistance	· Hardness depths below 2 mm difficult · Only with inductor or flame can easily accessible areas be hardened · Increased risk of cracking · Expensive sample hardenings for reproducible results	· Low nitriding depths with a relatively long treatment time, · NHD by definition only 50 HV above core hardness => 1mm NHD is considerably less than 1mm in CHD · Under excessive stress, crack and fracture risk due to high surface hardness

Table 1: Comparison of three surface hardening methods (pros and cons)

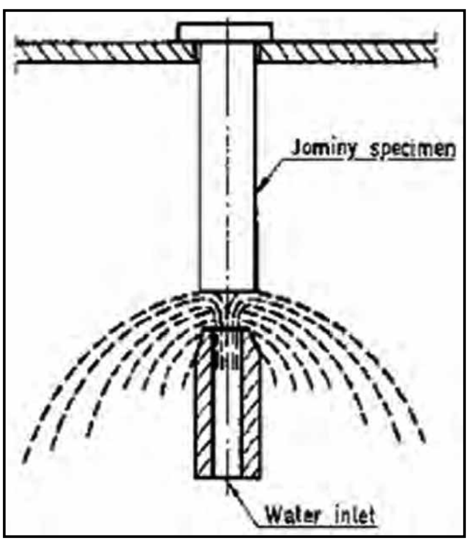


Figure 5: Jominy hardenability test

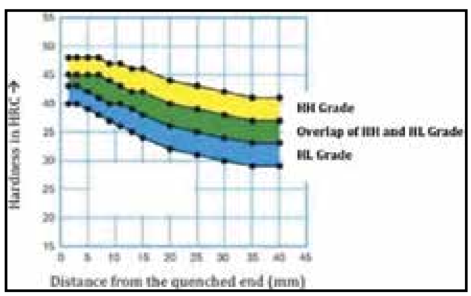


Figure 6: Hardness as a function of distance from the quenched end for 18CrNiMo7-6

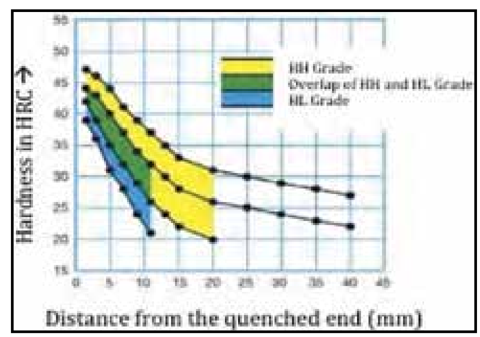


Figure 7: Hardness as a function of distance from the quenched end for 16MnCr5

are not a sufficient match of the carbon depth profile. The coupon sample should therefore be shaped such that it, in addition to a custom size, also has a greater geometrical resemblance to the tooth base. A comparison of flank and root-CHD and CHD of a ∅35 mm sample coupon can be seen in Table 2. A-F represents six companies that participated in a collaborative study FVA 501. Steel hardenability has a big influence on shape changes (shrinking and growing). Case hardening steel plants with modern computer controlled melting can specifically adjust the hardenability. It makes sense to require hardenability, grain size, and purity.

The cost is neutral for the specification for the lower 2/3 or the upper 2/3 band of hardenability. Even more favorable for the subsequent shape change, but subject to a cost surcharge, is the agreement about closer hardenability limits. Figure 8 displays possible shape change values when using case hardening steel as a function of the hardenability.

In conclusion, when selecting the material for large gear components, the geometrical influence must be taken into consideration and the following objectives must be achieved:

1. A sufficient hardenability of the material must be chosen
2. The material cross sections must be kept as small as possible
3. The geometry must ensure dimensional stability.

Also:

- Grade steel (not "quality" steel) according to EN 10020
- Electromagnetically stirred and cooled with fan
- Fine grain steel
- Pre-hardening and annealing in oil or emulsion to estimate dimensional changes

	A Flank/30°, mm	B Flank/30°, mm	C Flank/30°, mm	D Flank/30°, mm	E Flank/30°, mm	F Flank/30°, mm
CHD_{min}	2.75/2.03	3.14/2.20	3.35/2.40	3.05/2.06	3.35/2.28	2.97/2.28
$CHD_{\varnothing 35}$Coupon	4.32	3.43	3.45	3.19	3.50	3.53
CHD_{root}/CHD_{flank}	0.74	0.70	0.72	0.68	0.68	0.77
CHD_{flank}/CHD_{35}	0.57	0.91	0.97	0.95	0.96	0.84
CHD_{root}/CHD_{35}	0.47	0.64	0.69	0.65	0.65	0.65

Table 2: Comparison of flank and root-CHD and CHD of a ∅ 35 mm sample coupon

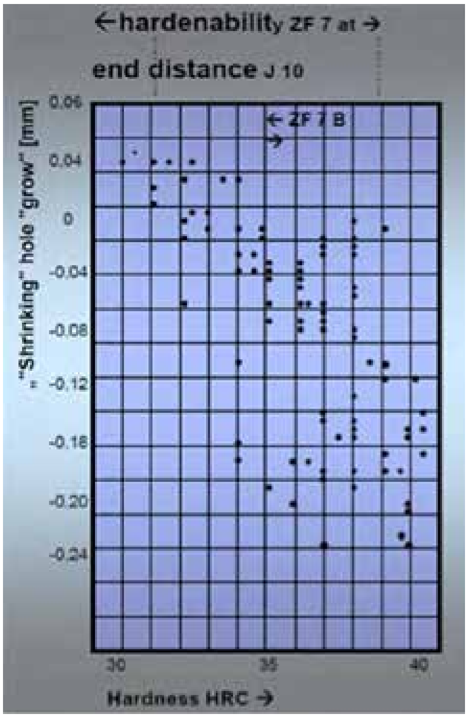


Figure 8: Shape changes when using case hardening steel as a function of the hardenability

Figure 9: Medium gears that have been made as a solid structure

WEIGHT

The weight is critical in the first line for efficiency. Weight reduction should be sought in any case, but this must not be at the expense of stability. For large gear components, weldments have been proven to be efficient and are now standard.

Small and medium sized gears, as seen in Figures 9 and 10, are usually made solid. Larger gears are usually designed as welded constructions.

Figure 10: Smaller gears made as a solid structure, no weldments necessary

Figure 11: Example of a larger gear designed as a welded construction

The welds must be protected against carburization to avoid cracking during case hardening. See Figures 11, 12 and Figure 13 for examples of larger gears containing weldments. Welding is limited, however, by maximum preheating temperature of 350–400° C. Weldments are the design of choice today. They have good dimensional stability and reduce weight.

Figure 12: Example of a larger gear designed as a welded construction

PRETREATMENT OF THE MATERIAL

According to our experience the following pretreatments have proven effective for big gear components and should be examined in detail on costs and benefits:

- 3-D forging (stretching and compressing with deformation to the core), leads to a more uniform part, reduction of segregation, reduction of pores, and refined structure to the core.
- Do not air cool after forging, but let the part temperature drop to 840°C. Then soak and harden in oil followed by tempering at 650°C.
- If this is not possible, then in addition to the forging shop, pre harden and temper at or higher that 840°C then oil quench and temper at 650°C to improve the toughness. One can draw conclusions about the dimensional change and distortion behavior by measuring before and after this process.
- Avoid the range of the irreversible temper embrittlement between 250–400°C during the entire process, i.e., rapid traveling across this range in all process stages. If possible cool from the annealing temperature of 650°C, in oil.

Direct hardening	**(top Figure 18)**
Single hardening or...	**(middle Figure 18)**
Hardening after isothermal transformation?	**(bottom Figure 18)**

Results of the FVA (Research Association for Drive Engineering, Research Project No. 373 "Heat Treatment of Large Gears")
Direct hardening
Has similar tooth root strength as single hardening or hardening after isothermal transformation. **Shows no reduction of tooth strength compared to single hardening and hardening after isothermal transformation.** **Shows a significantly better distortion behavior on a 3D coordinate measuring machine.** **Meets the total requirements of case hardened gears of quality MQ meet DIN 3990 Part 5.**

Table 3: Positive effects due to choice of hardening procedure

Figure 13: Rim materials, e.g., 18CrNiMo7-6, hub and rim materials e.g., C35, C45, 34CrMo4, 42CrMo4, 36CrNiMo8

- Avoid microcracks, cavities, voids, dendrites and impurities to reduce the risk of hydrogen embrittlement and fatal delayed fractures.

DIMENSIONAL CHANGE AND DISTORTION

The reduction of dimensional change and distortion is becoming increasingly vital, depending on the size of a component. Both Figures 14 and 15 display deformations from simulation of a gear by horizontal charging.

Dimensional change means growth or shrinkage. Distortion means:

- Tapering
- Ovality
- Axial runout
- Concentricity
- Dents of support tools caused by heavy weigh

A distortion of 1 per micron at a gear with a diameter of 1000 mm (40") is only 1 mm (0.040"). A 1 per micron distortion for a 5000 mm (200") diameter gearwheel will result in a 5 mm (0.200") dimensional deviation. But 5 mm (0.200") is often the whole case hardening depth CHD. That would mean that the total hardness would have to be ground away to keep the geometry. Therefore, the goal is to minimize distortion and to anticipate dimensional changes.

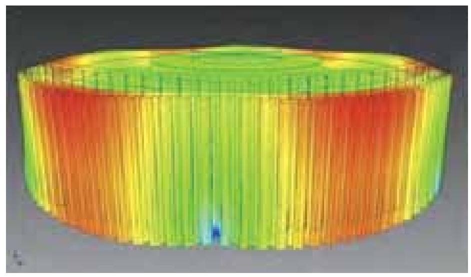


Figure 14: Deformations seen from a simulation of a gear by horizontal charging

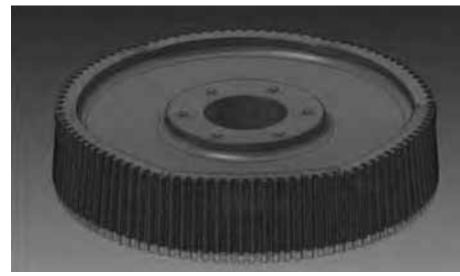


Figure 15: Deformations seen from a different view of a simulation of a gear by horizontal charging

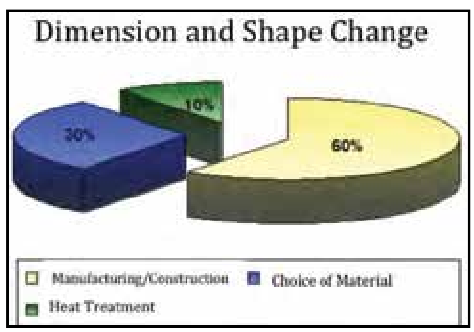


Figure 16: Factors responsible for dimensional changes after hardening process

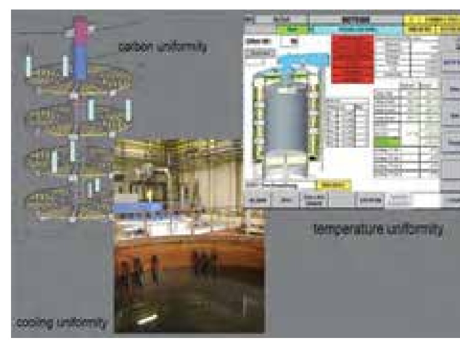


Figure 17: The key aspects of the technical features of a hardening plant: atmosphere control, temperature control, and quenching/cooling control

Factors that influence dimensional change and distortion as seen in Figure 16:

- Over 60% of the induced tensions are due to the design and manufacturing phase.
- Up to about 30% is based on the choice of the material and its quality
- Only about 10% of the influencing variables are born out of heat treatment.

Growth and shrinkage are dimensional changes caused by microstructural transformation and thermal stresses during the heat treatment process. These factors definitely determine the dimensional behavior of a workpiece, but remain mostly unavoidable during heat treatment. Distortions are caused by many factors. High residual stresses and differences in alloy concentration are among these factors as well as the choice of the material and its quality. Additionally, geometric asymmetry and non-uniform temperature distribution during the manufacturing process can result in distortions as well. However, they can be avoided by taking the appropriate measures in the steel order, construction and the workpiece production. During the heat treating process key aspects are plant engineering, process engineering and the type of charging (fixturing). These three factors however can outweigh the other factors. Thus, the hardening distortion gains a crucial importance for the success of the entire manufacturing process of big gear components.

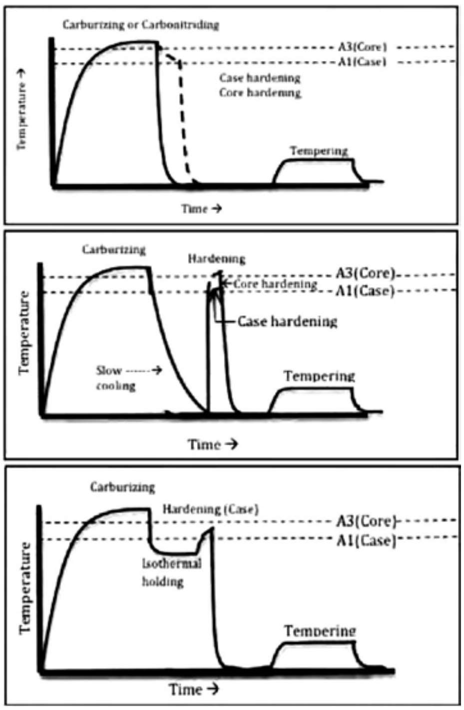


Figure 18: Positive effect due to choice of hardening procedure. The differences in hardening procedures can have a great effect on the outcome of a gear

Figure 19: Example of different possible charging method (horizontal charging)

Figure 20: Example of different possible charging method (horizontal charging)

Atmosphere control, temperature control, and quenching/cooling control are the key aspects of the technical features of a hardening plant. As seen in Figure 17, all aspects are thoroughly reviewed and considered before the heat treatment process can begin.

Figure 21: Example of different possible charging method (horizontal charging)

Figure 22: Example of different possible charging method (vertical charging)

Figure 23: Example of different possible charging method (vertical charging)

POSITIVE EFFECTS DUE TO CHOICE OF HARDENING PROCEDURE

The differences in hardening procedures can have a great effect on the outcome of a gear. The process/environment a gear can be put through can very as seen in Figure 18. Table 3 compares direct hardening to other methods.

POSITIVE EFFECT DUE TO CHARGING FOR HEAT TREATMENT

Various charging (fixturing) methods can be seen in Figures 19 through 24. The possible charging methods include:

- Horizontal
- Vertical
- Hanging
- Standing
- Customized Charging Devices
- Batching Tools
- Custom-Made Charging Systems

PRACTICAL EXPERIENCE OF THE SHOP MANAGER (CASE STUDIES)

For the successful low distortion heat treatment, it takes a lot of experience, and here are a few practical experiences of the REESE shop manager Klaus Hölken. Many German customers have expressed that Reese treated gears have better dimensional stability compared to competitors, and captive heat treating facilities.

PROCESS ENDORSEMENT

1. A Canadian gear manufacturer contacted Reese about gear rings with up to 30 mm distortions, mainly in the form of ovality. The question was posed, "What could be done to improve such deviations?" The gear heat treatment was completed with deviations below 0.30 mm with respect to wobble and ovality.
2. A French gear manufacturer only gave us pinion shafts for treating in the early stages. The first wheels were not very good, but still at a good quality. The growth scattered and tapering, ovality, and runout (out of flatness) were not as good compared to gears for other customers. The shop manager gave extensive material recommendations and advice for the pre-treatment and also stated that Reese would harden wheels

of around 2 m in diameter vertically—not horizontally. The customer showed a mass of gears the competition had previously hardened with 5 mm tapering. Although the optimization possibilities of the material were not fully implemented yet, Reese achieved an average runout, tapering and ovality of <0.5 mm with a maximum chance of values of 0.7 mm. The ovality and tapering of up to 0.7 mm was caused due to the remaining bandings in the material. Uncontrolled growth is reduced by narrowing the hardenability (alloy) scatter bands and is now available in narrower limits.

3. The gear wheels of a customer in Spain have come out very well, according to the measurement capabilities.

4. Another long-time customer in France had bad experience with Reese competitors. There was dissatisfaction with the core strengths of their case-hardening process. The customer has now completely committed to the Reese program.

Figure 24: Example of different possible charging method (vertical charging)

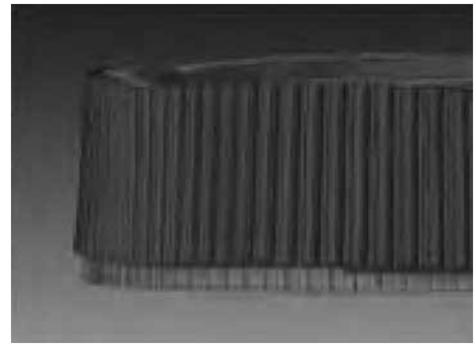


Figure 25: Simulation of the hardening distortion of a spur wheel gear with horizontal charging

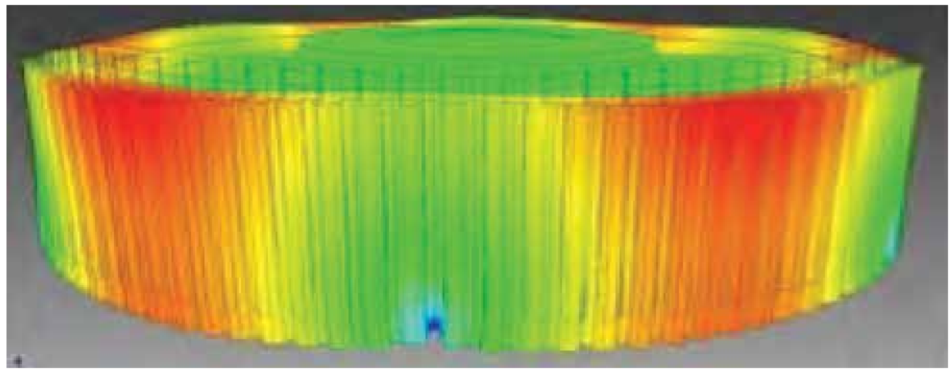


Figure 26: Simulation of the hardening distortion of a spur wheel gear with horizontal charging, stress marks shown with different colors

Figure 27: Statistical evaluations after heat treatment of gear wheel hardened horizontally.

Figure 28: Statistical evaluation of identical gear wheel as Figure 27 hardened vertically.

Some parts are among the relatively smaller group of components, but are still very distortion sensitive.

PROCESS OUTCOMES

Vertical hardening that has been implemented on a large scale with specially designed charging methods is much better than the horizontal versions in many cases. Also, wheels that can only be treated horizontally because of the geometry, can now be hardened much better because of special adjustable supports used. Solid wheels grow in general the larger the tooth face width. If the tooth width is relatively small in relation to the diameter the wheels grow by about 1-1.5 mm. If the tooth width is larger, growth will rise to 2-2.5 mm. For very large tooth widths, such as gears for turbo transmissions, growth trends to 3-3.5 mm and more can be reported.

Welding constructions generally keep their dimension or grow up to one millimeter. Materials from 16/20MnCr5, (solid wheels and weldments) without banding or largely free of banding, grow only slightly by <1mm. In the presence of banding or even mixed grain sizes, growing can occur as well as contraction (directed growth). A safe prediction is not possible, and often results in scrap. The directed growth may be a result of a smaller outer diameter, a smaller bore or greater tooth widths.

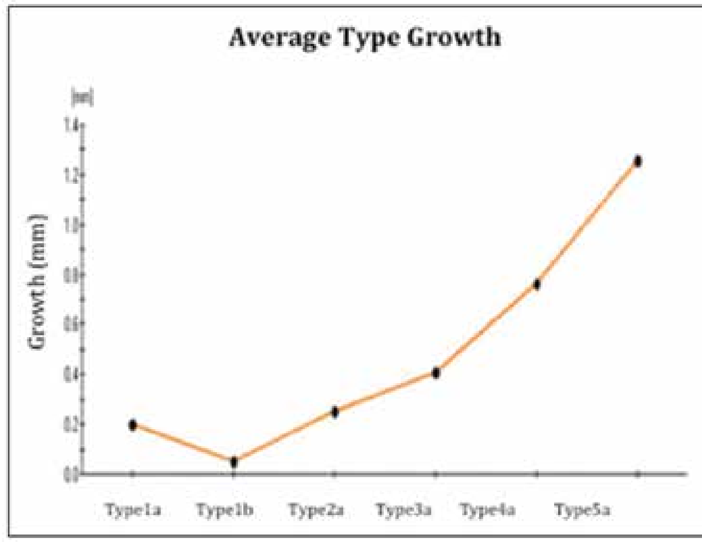


Figure 29: Simulation trend graph for dimensional changes.

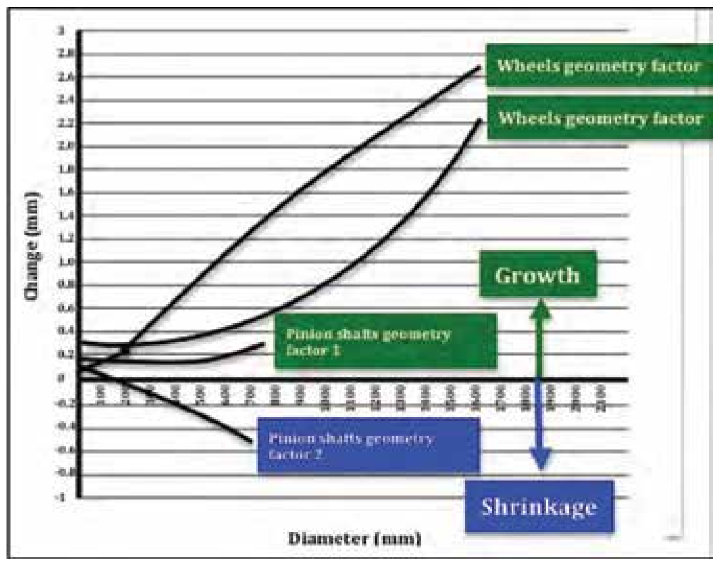


Figure 30: Simulation trend graph for dimensional changes of case hardening steels prehardened in oil (average dimensional development of 50 pieces)

When using a 18CrNiMo7-6 in the tempered state (thus largely free from banding and mixed grain), in the version as HH-quality and with a vertical charging, Reese has experienced runout flatness, roundness and conicity/tapering of well below 1 mm. Banding in the material can lead to ovality and tapering.

An angular deviation of the toothing is also recorded with banding structure and with a lack of supporting material, or if the surfaces are too small below the teeth. If the tooth width is very small compared to diameter, angular deviations occur in the teeth. Also, the bore diameter and the hub have an influence on strength of the angular deviation of the toothing. Reliable predictions of dimensional developments can be made very accurately when: the material is good and ordered under reproducible conditions; it is measured before

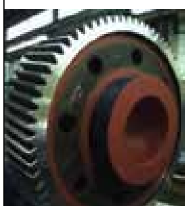
Types	Various gear	Spread within the types
1		Relatively large wheels with relatively small tooth widths and relatively small holes (spur wheels)
2		Wheels with large holes and no rings/ rims planet gears
3		Wheels with relatively large tooth widths and no rings/rims planet gears
4		Large bores

Table 4: Spread within the types of various gears

and after heat treatment; and hardening of a good recurring alike is ensured. High quality and exceptional charging methods along with heat treatment uniformity helps achieve optimal quality of production and material ordering.

SIMULATIONS

Computer programs are available to simulate possible results, as seen in Figures 25 and 26, based on different charging techniques before treatment. An example of a simulation of the hardening distortion of a spur gear with horizontal charging can be seen in:

- Conicity up to 3.5 mm
- Axial run-out up to 3.8 mm
- Damages due to supporting points

STATISTICAL EVALUATIONS

After the heat treatment, regular sampling evaluations are performed. In Figures 27 and 28, the same gear wheel was evaluated after both vertical and horizontal loading. By vertical batching of gear wheels the axial runout and conicity, induced by heat treatment, can virtually be eliminated. Also ovality can be minimized with special measures. From the statistical tests and simulations, typologies (Table 4) and trend graphs for dimensional changes are derived. Figures 29 and 30 both exemplify trend graphs for dimensional changes.

CONCLUSIONS

Because of the highest load capacity, case hardening has proven to be first choice for the treatment of large transmission components. Steel selection, conditioning heat treatment, hardenability, weight, dimensional changes and distortion are the main aspects that must be met before case hardening results are optimal. If these factors are perfectly harmonized the existing technical limits can be exceeded, which opens up entirely new possibilities for the gear manufacturers.

In this process, I particularly came to a decisive and crucial factor: the distortion during the hardening process. The hardening distortion has proven to be the crucial problem in the past. Reese Bochum has created the conditions to master this crucial problem of hardening distortion by the technique of vertical hardening. In addition, very low hardening distortion results can be achieved through special techniques, even with horizontal charging of gear rims and bevel gears.

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ABOUT THE AUTHOR:

Gerhard Reese is co-owner and managing director of Härterei Reese Bochum GmbH, a heat treating specialist in Germany, founded in 1948 by his father Dr.-Ing. Helmut Reese. He has studied mechanical engineering at the Ruhr-Universität Bochum and specialized in material science. Since then he has worked and specialized towards optimizing the available and developing new heat treatment techniques of gears and all kinds of drivetrain and other mechanical components in his heat treating shop. He also researched in the field of partial inductive hardening and other heat treating techniques on gear components.

William Andreski is the president of MetConsult, LLC.

Advantages of Induction Hardening with No Soft Zone on Large Bearings

By Torston Schaefer and Dirk M. Schibisch

In contrast to conventional carburizing, induction hardening is performed only on the highly loaded surfaces where it is needed, such as bearing races and gear teeth.

Large bearings are required to carry large axial and radial forces and their resulting torques. Typical applications include general machinery and construction equipment, as well as onshore and offshore energy technologies. These diverse applications have one thing in common: their components are highly stressed mechanically, and are therefore induction hardened to increase their dynamic strength and wear resistance. In the past, conventional progressive induction scan hardening necessarily left a small, unhardened zone in the bearing race. This soft zone compromised the bearing's load-bearing capacity and smoothness. SMS Elotherm has solved this problem with a new induction hardening technology to fully harden the bearing raceway with no soft zone. This scan hardening with no residual soft zone is essential; where systems do not allow any vibration (e.g. magnetic resonance imaging, or MRI technology), where extremely high mechanical stresses need to be considered (e.g. tunnel drilling machines), where continuous rotation is required, or where challenging environmental conditions mandate maintenance-free systems with high lifetime (e.g. offshore technology such as wind turbines, tidal plants or oil platforms).

The process of induction scan hardening with no soft zone has been patented [1] by SMS Elotherm and ensures–together with other proprietary systems such as workpiece energy measurement and closed-loop inductor positioning control – an easy integration into customer's production and quality assurance processes.

THE INDUCTION SURFACE HARDENING PROCESS

Induction hardening is comprised of two process steps: inductive heating, followed by rapid cooling (quenching) with a quenching fluid. Inductive heating is caused by alternating current flowing through a coil (sometimes called an inductor) that is sized and shaped according to the workpiece. The alternating coil current creates a corresponding changing magnetic field, which in turn creates eddy currents inside the workpiece piece. These eddy currents produce heat inside the workpiece. The heating depth is inversely proportional to frequency. Higher frequencies produce shallower heating in the workpiece. This phenomenon is known as the "skin effect". Because the heat originates inside the workpiece, it does not have to be transferred into the workpiece via radiation or convection at the surface. The induction heating period is kept short (e.g. a few seconds) to prevent unwanted heating of the workpiece core (Fig. 1 and 2).

Before hardening, the steel workpiece contains a mixture α-iron (ferrite) and cementite (Fe3C) at room temperature. The induction coil heats the surface material to a temperature of at least 723°C (the eutectoid temperature), causing the ferrite to transform into γ- iron (austenite). The steel is thus austenitized. At the same time, carbon from the available cementite is able to dis- solve into the austenite, because carbon has a much higher solubility in austenite than in ferrite. This dissolved carbon is essential. A steel workpiece must contain at least 0.02% carbon to be hardenable.

In the next process step, quenching, the austenitized steel is rapidly cooled at acontrolled rate. This rapid cooling prevents the diffusion of carbon atoms and the reformation of original ferrite and cementite mixture. Dissolved carbon atoms are trapped in the ferrite, causing the ferrite body-centered cubic (bcc) crystal structure to deform into a body-centered tetragonal (bct) structure called martensite. The temperature difference and the cooling rate (which can be controlled by selecting the right quenching medium such as oil, or water with additives) determine the level of martensite formation. Faster cooling below the transformation temperature produces more martensite. The fresh martensite is very hard and brittle. Tempering (controlled heating to prescribed moderate temperatures for defined time periods) reduces this brittleness and gives the steel the desired combination of hardness, strength, and toughness (Fig. 3).

ADVANTAGES OF INDUCTION HARDENING

Some conventional heat treat shops use case carburizing to harden rings up to three meters in diameter. This process suffers from five major problems. First, it requires long periods—sometimes several days—in the carburizing furnace. Second, it produces large workpiece distortions, which must be corrected by expensive and time-consuming straightening operations. Third, larger workpieces cannot be hardened due to practical limits in the size of the furnace. Fourth, carburizing necessarily treats the entire workpiece, including surfaces that should not be treated. Fifth, carburizing is energy intensive, with high emissions. Induction hardening overcomes all of these problems.

In contrast to conventional carburizing, induction hardening is performed only on the highly loaded surfaces where it is needed, such as bearing races and gear teeth. Resulting advantages are faster process times (for example, about one hour for a ring with a diameter of several meters), substantially lower energy consumption, and better of

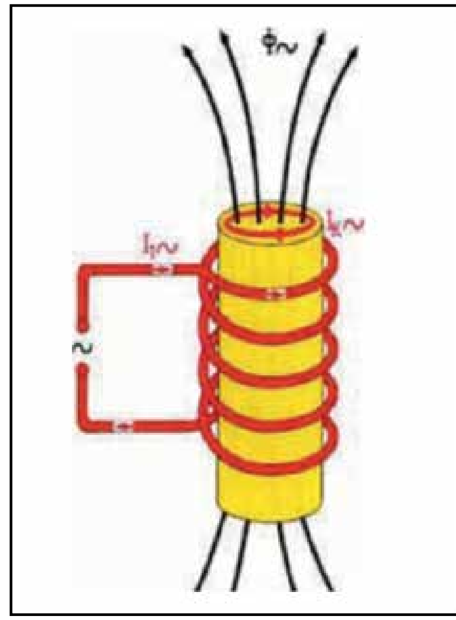

Fig. 1: Induction principle

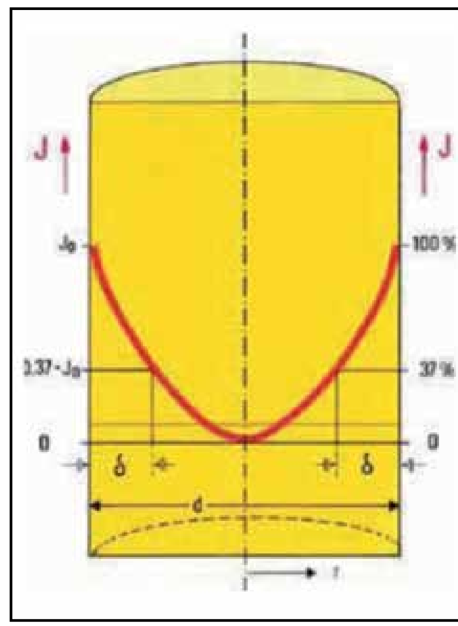

Fig. 2: Skin effect

control of workpiece distortion. Induction hardening benefits from rapid and uniform workpiece heating. The inductors with integral quench sprays can be optimized for the application, producing well-defined and reproducible hardening results. For mission-critical components in offshore technology, maintenance or repair operations would be extraordinarily expensive or technically infeasible. This is exactly the type of application where precise and accurate formation of hardened zone must be achieved and documented with online quality control.

SMS Elotherm's patented Workpiece Energy Measurement (WEM) [2] continuously monitors the electrical power that contributes to net heating of the part. This system

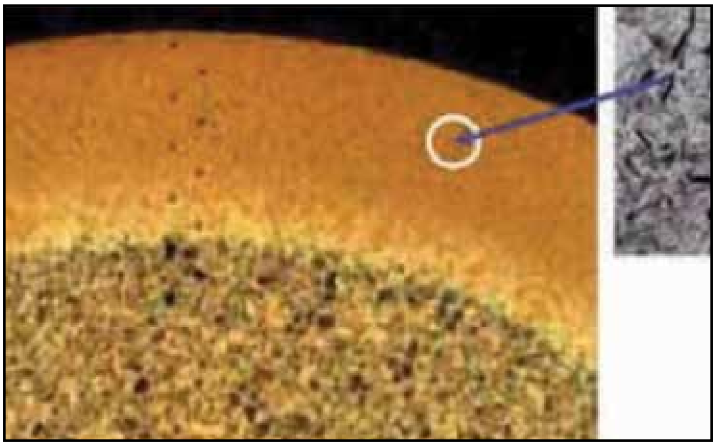

Fig. 3: Martensitic microstructure after induction surface hardening.

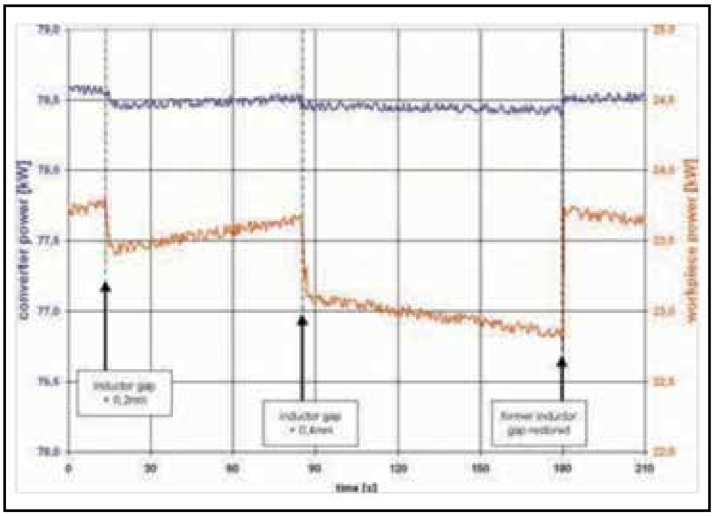

Fig. 4: Working principle of the SMS Elotherm Workpiece Energy Measurement

automatically accounts for the total energy loss between the system input power and the inductor, and the remaining net workpiece energy is continuously monitored and recorded. Unlike other methods that simply measure the inverter output, WEM provides 100% online quality control of the hardening process without having to destroy the workpiece. Small changes in the inductor–workpiece standoff distance can lead to significant hardening zone variation. Figure 4 illustrates how the SMS Elotherm Workpiece Energy Measurement detects small inductor position changes. By contrast, the conventional inverter power monitor (blue trace) is largely insensitive to this source of process variation. For critical components where induction hardening with no soft zones is requirement, Workpiece Energy Measurement gives the manufacturer a reliable system to fulfill the stringent requirements of modern quality control audits and part/process traceability.

OVERVIEW OF CONVENTIONAL INDUCTION HARDENING METHODS FOR BEARING RACES

Scan Hardening

Scan hardening with a remaining soft zone is the standard process for hardening single raceway and multi-raceway large bearings. Other than a linear axis to compensate for different workpiece diameters, the inductor/spray head assembly is stationary. The ring rotates with a low, constant tangential velocity past the inductor. A small soft zone (unhardened area) necessarily remains

Fig. 5: SMS Elotherm Ring Hardening Machine for large bearings up to 6 m, swiveling design

at the end of the scan path. With less than 100 kW of power a 3 m diameter bearing race can be hardened in less than one hour (Fig. 5).

Complete Surface (Single Shot) Hardening

With single shot hardening the workpiece rotates past one or more stationary inductors, or a complete 360° ring inductor interfaces with the entire workpiece. The ring is heated to the appropriate hardening temperature and then the entire workpiece is quenched.

Quenching may be done by submerging the workpiece in a bath or by using spray nozzles that are integrated into the inductors and tailored for the process requirements. The single shot process is best suited for workpieces with a diameter less than 2 m. The electrical power requirement grows quadratically with increasing workpiece diameter. For example, single shot hardening of a 2 m diameter ring would require about 1.5 MW of power. Compared to scan hardening, the single shot process with its high power is very fast, typically a few minutes.

INDUCTIVE SCAN HARDENING WITH NO SOFT ZONE

As previously described, traditional scan hardening is inadequate for mission-critical components with stringent requirements for smoothness and heavy loads due to the remaining soft zone. Carburizing is limited as a process alternative by furnace size and long process times. Single shot induction hardening is impractical due to its high power requirement. A better hardening method is needed to efficiently and reliably harden large, high-value rings. In response to this need, SMS Elotherm developed and patented a process several years ago to scan harden arbitrarily large rings with no remaining soft zone [3]. This process differs from conventional scan

Fig 6: Setup of the two inductors for induction hardening with no soft zone

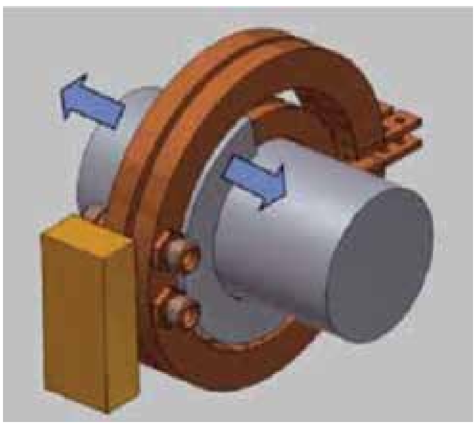

Fig. 7: Illustration of the inductor setup with flux concentrators and shower heads during the starting sequence.

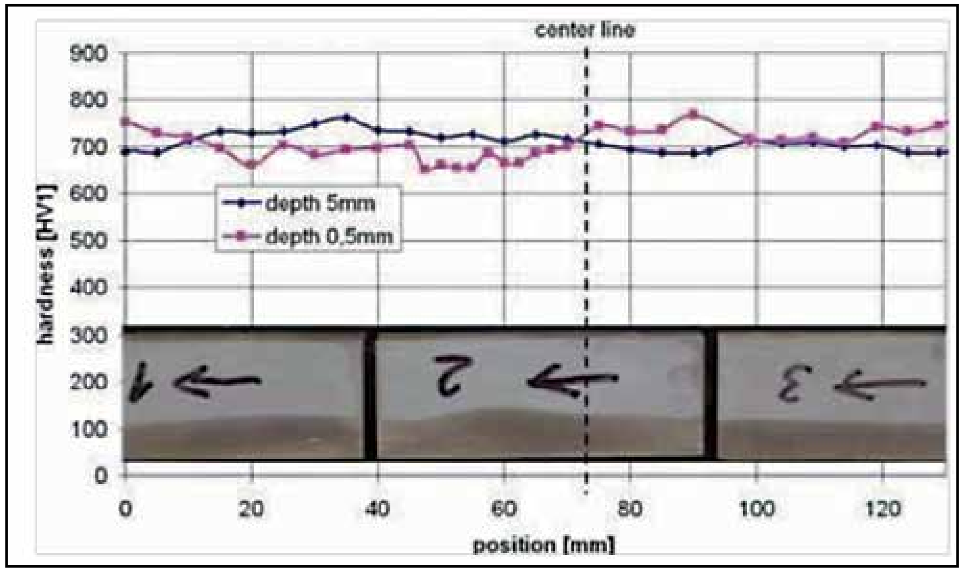

Fig 8: Polished section and hardening depth of a ring segment after the starting sequence show uniform hardening with no soft zone

hardening primarily at the start location and end location of the scan, where special sprays and techniques completely quench the austenitized steel while avoiding unwanted tempering and changes in the hardened zone microstructure.

Comparing this process to single shot induction hardening, we find that even a 6 m diameter ring can be processed with a 200 kW scanning system, which is about factor 7–8 times less power than the single shot process would require. In contrast to carburizing, which would require several hundred hours in the furnace, the time required for the scan hardening process (less than two hours) is negligible. Moreover, the cost-intensive and time consuming straightening operation to clean up the distortion caused by carburizing can be avoided altogether.

This induction hardening system is universal and modular, so in addition to scan hardening with no soft zone, conventional scan hardening and tooth hardening on both the inside and outside diameters of the workpiece can be done on the same machine. Manufacturers of large ring bearings with small production runs appreciate this flexibility and the freedom to process diverse workpieces while holding equipment costs at a minimum (Fig. 6).

CHARACTERISTICS OF THE INDUCTION SCAN HARDENING WITH NO SOFT ZONE

The SMS Elotherm patented process for scan hardening with no soft zone requires only two inductor assembles, each comprised of an inductor and a spray head. This differs from three- inductor systems, which require more complex mechanical and control systems. The inductors are narrow to create a compact hardening zone. Flux concentrators focus the magnetic field for one-sided hardening. Each inductor is accompanied by an independently positioned spray head. A single stationary spray head completes the assembly.

START SEQUENCE

The inductor assembles are brought together back-to-back and then energized with independent power supplies. Both assembles travel side-by-side in the same direction for a short distance. One of the assemblies reverses directions, so the inductor assemblies travel in opposite direction, each accompanied by its spray head. This technique avoids the formation of a soft zone at the start location (Fig. 7).

Fig. 8 depicts the hardening result with the etched case (below) and with two hardening passes along the workpiece axis at 0.5 mm and 5 mm depths after tempering. The start location is still recognizable and one can see that the entire area has been hardened with a relatively constant case depth (Fig. 8). With this special process technique for the inductors and sprays we create uniform hardening with no soft zone at the start location. The next critical process is at the end location where the two inductor assemblies come together.

END SEQUENCE

Like the start sequence, the end sequence relies on precise control of the quenching sprays and the tight motion control of the inductors and sprays to achieve a uniform case depth with no soft zone at the end location (Fig. 9 and 10). The resulting bearing surface meets the requirements for high loads and smooth operation.

CONCLUSION

Induction hardening has proven itself in the manufacturing of high-value, large ring bearings. Wind power certainly owes it success in part to surface hardened bearing races and gear teeth. Construction equipment would wear out quickly, and aerospace would entail unacceptable risks without the benefits of induction hardening. Alternative hardening methods for large ring bear-ing often struggle with furnace dimensions and extraordinarily long process times. Conventional scan hardening with its remaining soft zone and single shot induction hardening with its high power requirement are ill suited to meet the growing demand for very large ring bearings. The SMS Elotherm patented process for scan hardening with no remaining soft zone bridges the gap between conventional hardening methods and the growing demand for very large bearings with high load ratings, low noise, and longer service lives. The patented technique of using two inde- pendently controlled inductor/ quench heads to achieve uniform hardening at the start and end of the scan is essential to the success of this method.

Future developments in renewable energy such as onshore and offshore wind power and photovoltaic systems equipped with positioning

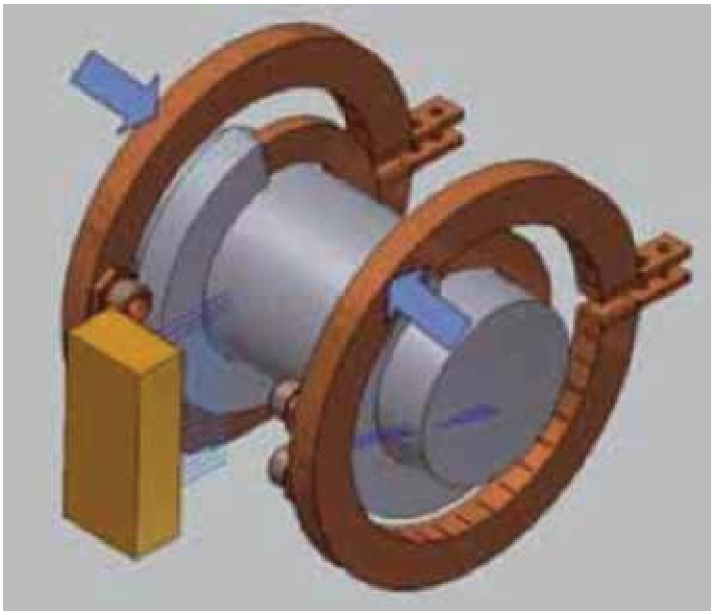

Fig. 9: Inductor movement and shower setup during the end sequence of induction hardening

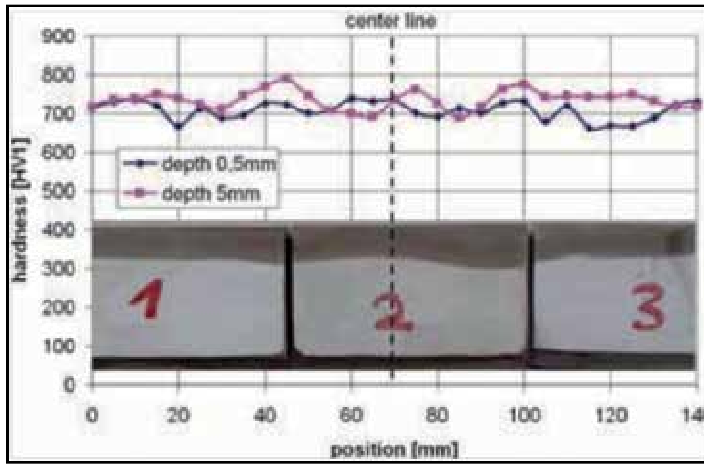

Fig. 10: The result of the end sequence of induction hardening is uniform hardening with no soft zone

systems to track the sun will accelerate the trend toward larger, more durable rotary joints. These high-value components will be economically, reproducibly, and traceably manufactured with uniformly hard wear surfaces created by induction scan hardening with no soft zone.

ABOUT THE AUTHOR:

Torston Schaefer is vice president of sales and and service at SMS Elotherm. He has a joint masters degree in Business Administration and Electrical Engineering.

Dirk M. Schibisch is vice president of sales for SMS Elotherm. He is married and has two children. With its developments and system solutions, Elotherm has set standards in induction technology for decades. The medium-sized internationally operating company is part of the SMS group. As a technology leader, Elotherm combines all competences when it comes to induction. For more information, visit www.sms-elotherm.com.

Heat Treat Equipment – REF #101
Phone: 734-331-3939 • Fax: 734-331-3915
Email: john@heattreatequip.com
Website: www.heattreatequip.com

Summit Products, Inc. – REF #102
65 Greenside Drive, Grand Island, NY 14072
Phone: 716-867-4312 • Fax: 716-867-4312
Email: summit@roadrunner.com

The W.H. Kay Company – REF #103
30925 Aurora Road, Cleveland, OH 44139
Phone: 440-519-3800 • Fax: 440-519-1455
Email: sales@whkay.com
Website: www.whkay.com

Furnaces, Ovens & Baths, Inc. – REF #104
4790 White Lake Road Clarkston, MI 48346
Phone: 248-625-7400 • Fax: 248-625-4030
Email: sales@fobinc.com
Website: www.fobinc.com

BATCH OVENS & BOX TEMPERING FURNACES

8” 18” 8” Lucifer Elec. 1250 F. **REF #103**
12” 16” 18” Lindberg Elec. 1200 F. **REF #103**
12” 16” 18” Lindberg (3) Elec. 1250 F. **REF #103**
12” 18” 12” Lucifer Elec 1250 F. **REF #103**
14” 14” 14” Gruenberg -Solvent Elec. 450 F. **REF #103**
15” 24” 12” Sunbeam (N2) Elec. 1200 F. **REF #103**
19” 19” 19” Prec.Scientific Elec. 617 F. **REF #103**
20” 18” 20” Blue-M (2) Elec. 400 F. **REF #103**
20” 18” 20” Blue-M (2) Elec. 400 F. **REF #103**
20” 18” 20” Blue-M (Inert) Elec. 600 F. **REF #103**
20” 18” 20” Despatch (Solvent) - 2 Avail Elec. 650 F. **REF #103**
20” 18” 20” Blue-M Elec. 800 F. **REF #103**
20” 18” 20” Blue-M Elec. 1200 F. **REF #103**
20” 20” 20” Grieve Elec. 500 F. **REF #103**
20” 20” 20” Michigan/Grieve Elec. 1000 F. **REF #103**
20” 20” 20” Grieve Elec. 1250 F **REF #103**
24” 24” 36” New England Elec. 800 F. **REF #103**
24” 26” 24” Grieve Gas 500 F. **REF #103**
24” 36” 24” Demtec (N2) Elec. 500 F. **REF #103**
24” 36” 24” Grieve Elec. 850 F. **REF #103**
24” 36” 24” Paulo Gas 1250 F. **REF #103**
25” 20” 20” Blue-M Elec. 650 F. **REF #103**
25” 20” 20” Blue-M Elec. 650 F. **REF #103**
25” 20” 20” Blue-M - Inert Elec. 1100 F. **REF #103**
25” 20” 25” Gruenberg Elec. 500 F. **REF #103**
26” 26” 38” Grieve (2) Elec. 850 F. **REF #103**
28” 24” 18” Grieve Elec. 350 F. **REF #103**
28” 48” 28” Wisconsin (3) Elec. 800 F. **REF #103**
30” 30” 30” Hevi-Duty Elec. 1500 F. **REF #103**
30” 38” 48” Gruenberg (2) M21 Elec. 450 F. **REF #103**
30” 48” 22” Dow Elec. 1250 F. **REF #103**
34” 19” 33” Poll.Ctrls Burnoff Gas 900 F. **REF #103**
36” 36” 35” Despatch Elec. 400 F. **REF #103**
36” 36” 120” Steelman Elec. 450 F. **REF #103**
36” 48” 36” Grieve Elec. 350 F. **REF #103**
36” 60” 36” CEC (2) Elec. 650 F. **REF #103**
37” 19” 25” Despatch Elec. 500 F. **REF #103**
37” 25” 37” Despatch Elec. 850 F. **REF #103**
37” 25” 50” Despatch Elec. 500 F. **REF #103**
38” 20” 24” Blue-M Elec. 1200 F. **REF #103**
38” 26” 38” Grieve Elec. 1000 F. **REF #103**
48” 24” 48” Blue-M Elec. 600 F. **REF #103**
48” 30” 42” Despatch Gas 850 F. **REF #103**
48” 48” 48” CEC (N2) Elec. 1000 F. **REF #103**
48” 48” 60” Gasmac Burnoff (2) Gas 850 F. **REF #103**
48” 48” 72” Despatch (2) Elec. 500 F. **REF #103**
48” 48” 72” Lydon Elec. 500 F. **REF #103**
54” 68” 66” Despatch Elec. 500 F. **REF #103**
54” 108” 72” Despatch Elec. 500 F. **REF #103**
56” 30” 60” Gruenberg Elec. 450 F. **REF #103**
60” 60” 72” ACE Burnoff Gas 850 F. **REF #103**
72” 72” 72” Michigan Gas 500 F. **REF #103**
120” 168” 120” Wisconsin Oven Gas 500 F. **REF #103**

BOX FURNACES

J.L. Becker Slot Forge Furnace, 1986, Brand New, Never Used **REF #101**
L & L Special Furnace Electrically Heated Box Furnace, 1991 **REF #101**
J.L. Becker Box Temper Furnace, 1989 **REF #101**
Sunbeam Electric Box Furnace, good running condition **REF #101**
Surface 30-48-30 Electric Temper Furnace, good/ very good condition **REF #101**
Atmosphere Furnace Co. 36-48-30 Electric Temper Furnace, good/ very good condition **REF #101**
Atmosphere Furnace Co. 36-48-30 Electric Temper Furnace, good/ very good condition **REF #101**
Atmosphere Furnace Co. 36-48-30 Electric Temper Furnace, good/ very good condition **REF #101**
Surface Combustion 30-48-30 Gas Fired Temper Furnace, good/ very good condition **REF #101**
Surface 30-48-30 Gas Fired Temper Furnace, good/ very good condition **REF #101**
8” 18” 8” Blue-M Elec. 2000 F. **REF #103**
12” 24” 8” Lucifer-Up/Down (Retort) Elec. 2150/1400 F. **REF #103**
12” 24” 8” C.I. Hayes (Atmos) Elec. 1800 F. **REF #103**
12” 24” 12” Hevi-Duty (2) Elec. 1950 F. **REF #103**
12” 24” 12” Lucifer-Up/Down Elec. 2400/1400 F. **REF #103**
3” 24” 12” Electra-Up/Down Elec. 2000/1200 F. **REF #103**
15” 30” 12” Lindberg (Atmos) - Retort Elec. 2000 F. **REF #103**
17” 14.5” 12” L & L (New) Elec. 2350 F. **REF #103**
22” 36” 17.5” Lindberg (Atmos) Elec. 2050 F. **REF #103**
24” 36” 18” Thermnlyne (2) - Unused Elec. 1800 F. **REF #103**
36” 48” 24” Sunbeam (N2) Elec. 1950 F. **REF #103**
36” 72” 42” Eisenmann Kiln (Car) Gas 3100 F. **REF #103**
60” 48” 48” Recco (1998) Gas 2000 F. **REF #103**
60” 96” 60” Park Thermal Elec. 1850/2200 F. **REF #103**
126” 420” 72” Drever ”Lift Off”-Atmos (2 Avail) Gas 1450 F. **REF #103**
Lindberg, 20”W x 18”H x 24”L, Recirculating Box Furnace, 1250°F, Electric **REF #104**
Despatch, 20”W x 18”H x 36”L, Recirculating Box Furnace, 1350°F, Electric **REF #104**
Electra, 8”W x 6”H x 30”L, High Temperature Box Furnace, 3000°F, Electric **REF #104**
Sunbeam, 24”W x 18”H x 36”L, Atmosphere Box Furnace, 1950°F, Electric **REF #104**
CM Furnace, 15”W x 12”H x 18”L, Atmosphere (H2) Box Furnace, 2100°F, Electric **REF #104**
Sunbeam, 48”W x 48”H x 54”L High Heat/48’W x 48”H x 54”L Low Heat, Titanium Quench Line, 2200°F/1200°F, Electric **REF #104**
Lindberg, 12”W x 10”H x 24”L, Atmosphere Box Furnace, 2000°F, Electric **REF #104**
Lindberg, 15”W x 12”H x 30”L, High Temp Box Furnace, 2500°F, Electric **REF #104**
Lindberg, 15”W x 12”H x 30”L, High Temp Box Furnace, 2500°F, Electric **REF #104**
Accutherm, 18”W x 18”H x 36”L, Box Furnace, 2000°F, Electric **REF #104**
Sunbeam, 24”W x 18”H x 42”L, Atmosphere Box Furnace, 1950°F, Electric **REF #104**
K.H. Huppert, 8”W x 10”H x 12”L, Atmosphere High Temp Box Furnace, 1649°C/3000°F, Electric **REF #104**
Harper, 9”W x 9”H x 20”L, High Temp Box Furnace, 3000°F, Electric **REF #104**
McEnglevan/MIFCO, 18”W x 18”H x 24”L, Recirculating Box Furnace, 1200°F, Gas - Radiant Tube **REF #104**
Johnson, 9-1/2”W x 7”H x 16”L, High Temp Box Furnace, 2300°F, Gas - 180,000 BTU’s Natural Gas **REF #104**
Grieve, 12”W x 8”H x 24”L, Atmosphere Box Furnace, 2000°F, Electric **REF #104**
Lindberg, 15”W x 12”H x 30”L, Atmosphere Box Furnace, 2000°F, Electric **REF #104**
Trent, 18”W x 18”H x 24”L, Recirculating Box Furnace, 1750°F, Electric **REF #104**
Wisconsin Oven, 36”W x 36”H x 72”L, Recirculating Box Furnace, 1250°F, Electric **REF #104**

CAR BOTTOM FURNACES

Holcroft 48-144-48 Car Bottom Furnace **REF #101**
Sauder 48-144-48 Car Bottom Furnace **REF #101**
72x84x108 CIM 1000F Gas **REF #104**
48x84x84 KMI 1000F Gas **REF #104**

CHARGE CARS

Surface Combustion 30-48 Charge Car (Double Ended), fairly good condition **REF #101**
Atmosphere Furnace Company 36-48 Charge Car (Double Ended) **REF #101**
Surface Combustion 30-48 Charge Car (Double Ended) **REF #101**

CONTINUOUS ANNEALING FURNACES

Wellman Continuous Mesh Belt Annealing Furnace **REF #101**
Aichelin-Stahl Continuous Roller Hearth Furnace & Conveying System, 1996 **REF #101**
Park Thermal Continuous Mesh Belt Furnace, 2005, Excellent Condition – New – Never been used **REF #101**

CONTINUOUS HQT FURNACES

Tokyo Gasden Ro Continuous Mesh Belt HQWT Furnace Line, 1989 **REF #101**

CONTINUOUS TEMPERING FURNACES

Surface Combustion Mesh Belt Temper Furnace **REF #101**
J.L. Becker Conveyor-Type Temper Furnace with Ambient Air Cool Continuous Belt, 1997 IQ Furnaces **REF #101**
Surface Combustion 30-48-30 Pro-Electric IQ Furnace **REF #101**
AFC 36-48-30 IQ Furnace with Top Cool **REF #101**
AFC 36-48-30 IQ Furnace **REF #101**
Surface Combustion 30-48-30 IQ with Top Cool, Excellent Condition, 2000 **REF #101**
Surface Combustion 30-48-30 IQ Furnace, Excellent Condition **REF #101**

ENDOTHERMIC GAS GENERATORS

Lindberg 1500 CFH Endothermic Gas Generator, 1992, good condition **REF #101**
Lindberg 1500 CFH Endothermic Gas Generator, 1996, excellent condition **REF #101**
Surface Combustion 5600 CFH Endo. Gas Generator **REF #101**

Surface Combustion 5600 CFH Endo. Gas Generator **REF #101**
Surface Combustion 5600 CFH Endo. Gas Generator **REF #101**
Surface Combustion 5600 CFH Endo. Gas Generator **REF #101**

EXOTHERMIC GAS GENERATORS

J.L. Becker 12,000 CFH Exothermic Gas Generator w/ Dryer, w **REF #101**
Thermal Transfer 30,000 CFH Exothermic Gas Generator, 1994, excellent condition **REF #101**

FREEZERS

Webber 36-48-36 Chamber Freezer, 1980 **REF #101**
Cincinnati Sub Zero 36-48-36 Chamber Freezer, 1995 **REF #101**

MESH BELT BRAZING FURNACES

Lindberg Continuous Mesh Belt Brazing Furnace **REF #101**
J.L. Becker 26" Mesh Belt Brazing Annealing Furnace, 2007 **REF #101**
10" J.L. Becker Mesh Belt Furnace with Muffle, 1988 **REF #101**
24" J.L. Becker Mesh Belt Furnace **REF #101**

MISC. EQUIPMENT

Atmosphere Furnace Co. 36-48 Stationary Holding Stations, 1987, 36"W x 48"L work area **REF #101**
Atmosphere Furnace Co. 36-48 Stationary Holding Stations, 1987, 36"W x 48"L work area **REF #101**
Atmosphere Furnace Co. 36-48 Stationary Holding Stations, 1987, 36"W x 48"L work area **REF #101**
Atmosphere Furnace Co. 36-48 Scissors Lift Holding Stations, 1987, 36"W x 48"L work area **REF #101**
Atmosphere Furnace Co. 36-48 Scissors Lift Holding Stations, 1987, 36"W x 48"L work area **REF #101**
Surface Combustion 30-96 Stationary Load Tables, 96-inch rail length, 15-inch rail centers **REF #101**
Surface Combustion 30-96 Stationary Load Tables, 96-inch rail length, 15-inch rail centers **REF #101**
Surface Combustion 30-96 Stationary Load Tables, 96-inch rail length, 15-inch rail centers **REF #101**
Surface Combustion 30-48 Scissors Lift Table, 48-inch rail length **REF #101**
8xxx 2.400 CFH 12 oz (2) North American 1/3HP **REF #103**
8xxx 3.000 CFH 12 oz (3) North American 1/2HP **REF #103**
8xxx 5.400 CFH 4 oz North American 1/3HP **REF #103**
8236 12.000 CFH 12oz (3) North American 1/2HP **REF #103**
8712 15.600 CFH 37 oz, North American 5HP **REF #103**
8193 19.500 CFH 32 oz, Spencer 5HP **REF #103**
8245 23.400 CFH 8 oz. North American 1,5HP **REF #103**
8185 24.000 CFH 24 oz. Buffalo Forge 7.5HP **REF #103**
8251 45.600 CFH 16 oz. Spencer 5HP **REF #103**
8252 66.000 CFH 24 oz . Snencer(New) 10HP **REF #103**
8253 66.000 CFH 24 oz. Spencer 10HP **REF #103**
8250 150.000 CFH 16 oz. Hauck 15HP **REF #103**

PARTS WASHERS

J.L.Becker Gas-Fired Tub Washer **REF #101**
48-72-48 Gas Fired Spray Washer **REF #101**
Dow Furnace Co. 30-48-30 Electrically Heated Spray, Dunk & Agitate Washer **REF #101**
Atmosphere Furnace Co. 36-48-30 Spray/Dunk Washer **REF #101**
Atmosphere Furnace Co. 36-48-30 Spray/Dunk Washer **REF #101**
Surface Combustion 30-48-30 Electrically Heated Spray Dunk/ Dunk Washer **REF #101**
Surface Combustion 30-48-30 Electrically Heated Washer **REF #101**
Proceco/Taylor Gaskin, 26" Diameter x 36"H, Table Washer, N/A, Electric **REF #104**
Surface Combustion, 30"W x 30"H x 48"L, Spray Only Batch Washer, N/A, Steam - Can be converted **REF #104**
Holcroft, 24"W x 24"H x 36"L, Dunk & Spray Washer, UNKNOWN, Electric **REF #104**
FMT - Findlay Machine & Tool, 23" Diameter Drums x 15'L (2), Stainless Steel Rotary Drum Washer, 180-F Wash & Rinse, 180-F Blow Off, Wash & Rinse: Steam, Blow Off: Electric **REF #104**
Midbrook, Inc., 24" Diameter Drum x 8'L Wash x 6'L Rinse x 8'L Blow Off, Stainless Steel Rotary Drum Washer, N/A, Wash & Rinse: Gas, Blow Off: Electric **REF #104**

PIT FURNACES

Lindberg 28" x 28" Pit-Type Temper Furnace **REF #101**
14" 60" Procedyne - Fluidised Bed Elec. 1850 F. **REF #103**
16" 20" Lindberg Elec. 1250 F. **REF #103**
22" 26" L & N Elec. 1200 F. **REF #103**
28" 48" Lindberg Elec. 1400 F. **REF #103**
38" 48" Lindberg Elec. 1400 F. **REF #103**
40" 60" L & N -Steam/N2 Elec. 1400 F. **REF #103**
40" 60" Wellman-Steam/N2 Elec. 1400 F. **REF #103**
48" 48" Lindberg (Atmos) - Fan Elec. 1850 F. **REF #103**
Lindberg, 25" Diameter x 20" Deep, Pit Temper, 1250°F, Electric **REF #104**
Leeds & Northrup, 22" Diameter x 26" Deep, Pit Steam, 1250°F, Electric **REF #104**
Leeds & Lorthrup, 22" Diameter x 26" Dp., Pit Temper, 1400°F, Electric **REF #104**
Lindberg, 33" Diameter x 36" Deep, Pit Carburizer, 1750°F, Gas **REF #104**
Lindberg, 33" Diameter x 36" Deep, Pit Carburizer, 1750°F, Gas **REF #104**
Lindberg, 33" Diameter x 36" Deep, Pit Carburizer, 1750°F, Gas **REF #104**
Lindberg, 33" Diameter x 36" Deep, Pit Carburizer, 1750°F, Gas **REF #104**
Surface Combustion, 36" Diameter x 72" Deep, Pit Carburizer, 1750°F, Gas **REF #104**
Leeds & Northrup/Lindberg, 40" Diameter x 60" Deep, Pit Steam, 1250°F, Electric **REF #104**
Leeds & Northrup/Lindberg, 40" Diameter x 60" Deep, Pit Steam, 1250°F, Electric **REF #104**
Lindberg, 28" Diameter x 72" Deep, Pit Carburizer, 2000°F, Electric **REF #104**
Lindberg, 38" Diameter x 84" Deep, Recirculating Pit Furnace w/ Atmosphere & Cooling, 1250°F, Electric **REF #104**
Lindberg, 38" Diameter x 36" Deep, Pit Temper, 1400°F, Gas - 495,000 BTU's **REF #104**

VACUUM FURNACES

Brew/Thermal Technology Vacuum Furnace **REF #101**
Abar Ipsen 2-Bar Vacuum Furnace, 1986, good condition **REF #101**
24"W x 36"D x 18"H Hayes (Oil Quench) Elec. 2400 F. **REF #103**
48" Dia 60" High Ipsen (Bottom Load) Elec. 2400 F. **REF #103**
Lindberg, 24"W x 18"H x 36"L, Vacuum Furnace, 2400°F, Electric **REF #104**
Abar Ipsen, 30"W x 30"H x 48"L, Horizontal Front Loading Vacuum Furnace, 2400°F, Electric **REF #104**

ENDOTHERMIC GAS GENERATORS

Surface Combustion, 5600 CFH, 1950°F, Gas **REF #104**
Lindberg, 750 CFH, 1850°F, Gas **REF #104**
Lindberg, 1000 CFH, 2000°F, Gas - 390,000 BTU's **REF #104**
Lindberg, 1500 CFH, 2050°F, Electric **REF #104**
AFC/Holcroft, 2500 CFH, 1950°F, Gas Fired **REF #104**
Gasbarre/Sinterite Furnace Division, 3000 CFH, 1950°F, Electric **REF #104**
Surface Combustion, 3600 CFH, 1950°F, Natural Gas **REF #104**
Lindberg, 3000 CFH, 2000°F, Gas Fired **REF #104**
Surface Combustion, 3600 CFH, 1950°F, Gas Fired **REF #104**

INDUCTION HEATING

American Induction, 750 kW/6 kHz, Induction Heating, N/A, Electric **REF #104**
Ajax Magnathermic/Pachydyne, 25 kW/3-10 kHz, Induction Heating, N/A, Electric **REF #104**
Pillar Industries, 500 kW, 10 kHz, Induction Heating, N/A, Electric **REF #104**
American Induction, 75 kW, 10 kHz, Induction Heating/Mono Forge, N/A, Electric **REF #104**
Lepel/Inducto-Heat, 20 kW/450 kHz, RF Induction Heating, N/A, Electric **REF #104**
I.P.E./Inducto-Heat, 200 kW, 450 kHz, RF Induction Heating, N/A, Electric **REF #104**
Tocco, 300 kW, 9.6 kHz, Induction Heating, N/A, Electric
Raydyne, 40 kW, 40 to 50 kHz, Induction Heating/Brazing System, N/A, Electric **REF #104**
Bone Frontier, 50 kW, 10 kHz, Induction Heating, N/A, Electric **REF #104**
Raydyne, 7.5 kW, 410 kHz, RF Induction Heating, N/A, Electric **REF #104**
Lepel/Inducto-Heat, 7.5 kW, 450 kHz, RF Induction Heating, N/A, Electric **REF #104**
Lepel/Inducto-Heat, 7.5 kW, 100 kHz to 400 kHz, RF Induction Heating, N/A, Electric **REF #104**
Lepel/Inducto-Heat, 7.5 kW, 100 kHz to 400 kHz, RF Induction Heating, N/A, Electric **REF #104**
Ajax Magnathermic/Tocco, 30 kW/50 kHz, Induction Heating, N/A, Electric **REF #104**
Inducto-Heat/Lepel, 40 kW, 3 to 10 kHz, Induction Heating, N/A, N/A **REF #104**
Welduction, 100 kW, 450 kHz, RF Generator, N/A, N/A **REF #104**
Pillar Industries, 200 kW, 3 kHz, Induction Heating for Tube/Pipe, N/A, Electric **REF #104**

ATOMOSPHERE GENERATORS

750 CFH Endothermic Dow Elec. **REF #103**
750 CFH Endothermic Insen Gas **REF #103**
1000 CFH Exothermic Gas Atmosphere **REF #103**
1000 CFH Ammonia Dissociator Lindberg Elec. **REF #103**
1000 CFH Ammonia Dissociator Drever Elec. **REF #103**
1500 CFH Endothermic (Air Cooled) Ipsen Elec. **REF #103**
1500 CFH Endothermic Ipsen Gas **REF #103**
3000 CFH Endothermic air Cooled) Lindberg Gas **REF #103**
3000 CFH Endothermic (Air Cooled) Lindberg (2) Gas **REF #103**
3000 CFH Endothermic (Air Cooled) Lindhera Gas **REF #103**
3600 CFH Fnclothermic (Air Cooled) Surface (2) Gas **REF #103**
3600 CFH Endothermic Surface Gas **REF #103**
5600 CFH Endothermic Surface (3) Gas **REF #103**
6000 CFH Nitrogen Generator (2000) Gas Atmospheres Gas **REF #103**
10 000 CFH Exothermic Seco-Warwick Gas **REF #103**

INTERNAL QUENCH FURNACES

24"W 36"D 18"H Dow (Slow Cool) Line Elec. 2000 F. **REF #103**
24"W 36"D 1 8"H Ispen T-4 - Air Cooled Gas 1850 F. **REF #103**
24"W 36"D 18"H Ispen T-4 - Air Cooled Gas 1850 F. **REF #103**
24"W 36"D 18"H Isoen T-4 - Air Cooled Gas 1850 F. **REF #103**
24"W 36"D 18"H Ispen T-4 - Air Cooled Gas 1850 F **REF #103**
30"W 48"D 30"H Surface Allcase Elec. 1750 F. **REF #103**

CONTINUOUS/BELT FURNACES + OVENS

5"W 36"D 2"H BTU Systems (Inert Gas) Rec. 1922ºF **REF #103**
12"W 48"D 2"H Lindberg (Inert Gas) Elec. 1022ºF. **REF #103**
12"W 15'D 4"H Sargent&Wilbur'94(Mufflel) Gas 2100ºF. **REF #103**
16"W 24'D 4"H Abbott-Retort (1996) Elec 2400ºF. **REF #103**
24"W 12'D 6"H Heat Industries Elec. 750ºF. **REF #103**
24"W 40'D 18"H Despatch Elec. 500ºF. **REF #103**
24"W 40'D 18"H Despatch Gas 650ºF **REF #103**
60"W 45'D 12"H Roller Hearth Annealer (Atmos) Gas 1700ºF **REF #103**
72"W 30'D 15"H Unitherm Gas 500ºF **REF #103**

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What are some factors one should consider in cryogenic processing of gears?

First off, what is the size I need? Secondly, how do I want to load it? Front load swing, front load guillotine, top load chest-style? Also, what am I going do with it, and what temperature range do I want?

When a customer calls up and says, "Hey, I want a top load, I'm going to use a crane, I need to put in a 40-inch diameter gear, and all I'm going to do is freeze," I try to talk them into buying the CryoTemper. If they take that frozen gear out, it's going to frost up because it's cold. It's exposed to humid room atmosphere, which turns to frost in it. The only way to get rid of the frost is to thaw the entire thing out. The frost turns to water, drips on the floor—condensation that eventually is on the part. If it's a steel part, you'll likely have some oxidation or rust starting. I always recommend someone use at least enough heat to bring it back to ambient in a nitrogen atmosphere, hence the CryoTemper.

When you're dealing with bearings and gears, rust is bad news.

Very bad news. Additionally, you're handling a gear that could be 100°C below zero. You can't handle it without somebody getting freezer burns, or wearing gloves. When the gear thaws out, you've got water spots and maybe a puddle on the floor, depending on the mass of the parts you take out. With a CryoTemper or CryoFurnace, the part goes in, it's dry, it's clean, there's no oil or lubricant, no rust inhibitor on it, it comes out at room temperature looking just the way it went in, and no secondary cleaning.

We delivered a machine to a guy who does brake rotors. These are cast iron, which rusts very easily. He'd freeze them in another brand machine, but he always had the need to put rust inhibitor on them. After deep cryogenic treatment, he had to wash them to get the inhibitor off so it wasn't putting oil on the pads. When he bought our machine and we went up there for training and installation, on the maiden run he wanted to run 1,000 pounds of brake rotors. He was very pleased to find no rust on the parts when the doors opened up.

So it's complete thermal cycling?

Absolutely. You can control the time you want to stay at a temperature, or change them both. All these together—10, 15, 20 different segments so that you get a freeze, a temper, back to room temp, another temper, back to room temperature, and so on. When it's all finished, it doesn't make any difference what the weather is outside—you've started the second segment at the end of the first one, knowing every component is treated exactly the same, start to finish, every time.

Because we also use a PLC or programmable controller to control the temperature, we're going down in temperature at exactly the rate you want, whether it's plugged in as degrees per minute, or a set point at such and such time, "I want to be at minus 300 degrees in five hours" it will do what you tell it. Furthermore, the parts were loaded in 1 machine and all the thermal cycling was completed without having to move the load back and forth from different machines.

DMP CryoSystems employs the use of liquid nitrogen. What do you find most beneficial about this approach?

Well, the use of nitrogen reduces the oxygen and moisture content in the chamber until it is nearly a pure nitrogen atmosphere. So as long as the door is kept closed throughout the process, the parts are never exposed to moisture.

Also, most heat treat facilities already have a liquid nitrogen bulk tank, and while they're normally set at higher pressures because of the volumes of gasses that they need in their vacuum furnaces and other equipment, they have an established supply of cooling energy.

The nitrogen cooling is much faster, and more controllable than refrigeration. Refrigeration coils can't handle the high temperatures that we have in our CryoFurnace and the maintenance of the compressor can become much more expensive than that of the solenoid valve

DMP CryoSystems' machines are very adjustable. Tell our readers about their dynamic uses.

We can modify the loading conditions. If somebody wants to use a manual loader, which is typically the case when they've got a vacuum furnace, it's very gentle on the furnace. We can set up the loader guide rails and hearth rails and spacing so that they use the same loader from one, put ours alongside, and it'll load exactly the same way. If they want to do a lights out scenario, where they've got an automatic feed charge car, we can do the same thing, so that we have light reflector indicators or stop paths or something on the front of the machine. Chain guides and roller rail system on the inside so that it operates exactly the way somebody else's does. We also have Ethernet communication so that we can easily connect to the customer network for DATA collection If the customer wants to tie onto the internet, we can look at it remotely, from our office to help troubleshooting.

When it's all finished, it doesn't make any difference what the weather is outside—you've started the second segment at the end of the first one, knowing every component is treated exactly the same, start to finish, every time.

FOR MORE INFORMATION: For more information on CryoSystems products and services, visit them online at www.cryosystems.com, or call (800) 851 7302.

BeaverMatic

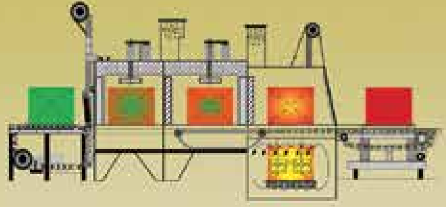
Flexible and Rugged IQF Equipment Designs

Multiple and flexible Internal Quench (IQF) Furnace designs that are engineered for your application:

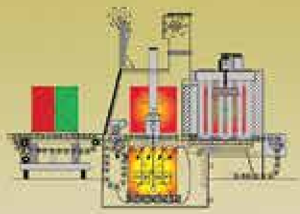
1) **Straight-Thru Design**
2) **In and Out Design using grids with a roller hearth**
3) **In and Out Design using baskets with refractory hearth**

Performance proven IQF designs, originally developed by Jack Beavers over 50 years ago, now include automated systems similar to the one pictured above.

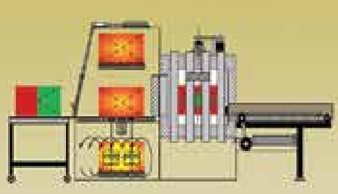
www.beavermatic.com



1) Straight-Thru Design



2) In and Out Design using grids with a roller hearth



3) In and Out Design using baskets with refractory hearth