
Photo courtesy of Metlab

Manufacturer's Guide to Heat Treating Large Gears

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The large gears found in mining, steel, construction, off-road, marine and energy applications—massive and robust in nature—need to tackle the greatest production demands. This, in turn, means that a special emphasis must be put on the heat treating methods used to increase the wear resistance and strength properties of gears this size. So what process works best and why? Companies like Metlab, Surface Combustion, Stack Metallurgical Services and Ipsen offer services/advice on the unique challenges of heat treating large gears.

"No single process can be singled out as having the greatest advantage, but the optimum selection depends upon design requirements, production requirements and quality issues," says Jim Conybear, director of operations at Metlab, located in Wyndmoor, Pennsylvania.

While the heat treating methods have rarely changed since the early days, it's the technology that has offered significant improvements. "Better insulation and heating technologies, improved process control sensors and better quench modeling/design," says John Gottschalk, director special products at Surface Combustion, Inc. "As such, the temperature uniformity, carburizing or nitriding potential uniformity and quenching are significantly better than in the past."

Heat Treating Large Gears

What methods work best for heat treating large gears? *Gear Technology* posed this question to these companies and found that the heat treating of large gears can be achieved through processes like carburizing, nitriding, induction hardening and through hardening. "Each one is selected to achieve the maximum benefit of the properties imparted by the particular process," Conybear says.

Carburizing is used to ensure maximum wear and pitting resistance of the gear tooth while maintaining the maximum possible ductile core for bending strength and impact resistance according to Marc Angenendt, vice president of operations at Ipsen.

"The benefits of carburizing are higher mechanical properties, strength and resistance. The drawback to carburizing is that quench can cause distortion and the need for a second process, like grinding. Some companies anticipate distortion and engineer the part for the distortion, but all of this can increase costs."

The carburizing process consists of imparting carbon to the surface of the gear, and diffusing the carbon into the teeth until the appropriate depth is achieved. "Carburizing is generally carried out at temperatures between 1,650 and 1,750 degrees F," adds Mark Podob, vice president marketing and sales at Metlab. "When the carburized case depth has been achieved, the temperature of the furnace is lowered, the part allowed to equalize and then it is quenched and tempered. Carburizing is selected for maximum wear protection of the gear teeth. It also is a choice over through-hardened gears as it can handle significantly more load than a through-hardened gear."

"Large gears have typically been done in pit furnaces," says Nels Plough, president and general manager at Stack Metallurgical Services, Inc., "However, we are now doing large gears in a vacuum carburizing furnace with an oil quench. This process method offers advantages for some applications that have critical surface requirements and are difficult to finish machine on all surfaces."

Nitriding is a surface only hardening application that develops a very thin layer at the surface part. "The layer is much harder than a carburized surface with additional benefits of wear and corrosion resistance over carburizing," says Gottschalk at Surface Combustion. "The nitriding process can be done after quench and temper processes, with some losses to the material core strength, based on tempering of the product at nitriding temperaratures (≈950 degrees F)."

Nitriding gives a higher surface hardness and avoids distortion. "The drawback to this process is that certain metallurgical results cannot be achieved but are sometimes required—especially when it comes to larger shafts and gears. However, the nitriding process is ideal for larger ring gears."

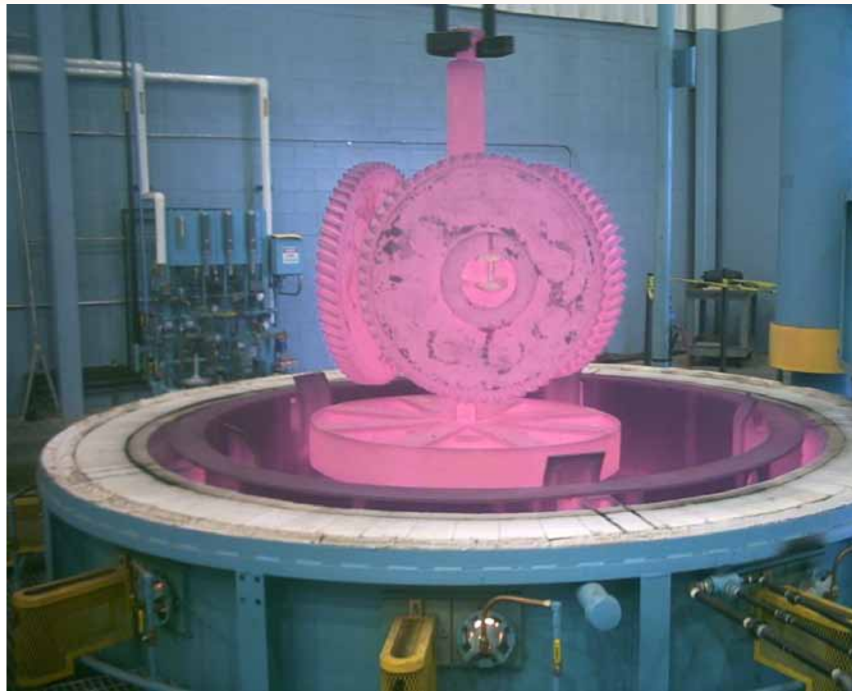
Through hardening is a historical process where gears are generally heated under a protective atmosphere to minimize the potential for decarburizing in the austenitic range, then quenched in oil or a similar media, and tempered, according to Conybear at Metlab. "The hardness specified for the gear is normally a function of the carbon content of the steel. For large gears, there is an inevitable compromise between the surface strength required and the core properties of the part. To achieve properties similar to case hardened parts, more expensive materials are required, which also are more difficult to form and fabricate."

Induction hardening—in which the surface or areas requiring high strength or wear resistance are heated to the hardening temperature using localized induction fields—is another method for large gears. "This process is often used to produce a hard layer on the gear tooth surface and root while maintaining a softer, tougher core to avoid tooth breakage and provide reasonable wear resistance," Conybear adds. "By considering the design requirements and the design of the specific part, all of these heat treating processes can often be interchanged or used in combination."

Distortion and Other Challenges

Once a process has been determined, it is equally important to know what changes can occur during the different stages of the heat treat. Gottschalk at Surface Combustion says that part geometry plays an important role in dimensional change but is not the only factor. "Previous processing steps such as forging, machining, stress relieving/normalizing, hardening and quenching processes will all affect the final dimensional variance. Elimination of unpredictable residual stresses from as many of these processing steps as

A 39,000 pound gear is lifted out of the carburizing furnace (courtesy of Metlab).



Gears leaving a Surface Combustion pit carburizing furnace (courtesy of Merit Gear).

possible will be required to improve the final part dimensions," Gottschalk says. "With gears increasing in size, distortion challenges are greater, as the same percentage of distortion equates to a much larger absolute distortion. All steps with regard to the process need to be evaluated, as the final heat treating step can make the distortion worse, but generally is not capable of improving distortion characteristics."

Larger gears often require deep case depths, which means that the process time will be relatively longer, especially in the wind turbine business. It is not uncommon to first create a large case depth and later apply a hard machining process in order to eliminate distortion, but at the same time reducing the case depth again.

"This is just one example to show how crucial distortion is for very large gears. Besides distortion, the major challenges are temperature uniformity, which is harder to achieve if there is a massive load in the furnace; uniformity of carbon within the process gas;, transport of very large gears from one furnace component to the other, especially due to the fact that the transport time is always crucial; investment costs/running costs; handling equipment and construction of the quenching equipment," Angenendt at Ipsen says.

According to Podob, "The challenges also include the capital investment and operating expenses of large furnaces.

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The large furnaces at Metlab used for carburizing are 15' in diameter by 12' deep and use 4,000,000 BTU/hour. The other issues related to heat treating large gears are the physical size of the gears and equipment required for lifting out of the furnace and into quench tanks, cryogenic tanks and tempering furnaces; and the expertise necessary for heat treating large parts without damage."

"Geometry dictates heat treat method, which then determines alloy options for a given part. For example, large ring gears are extremely difficult to successfully oil quench without huge distortion. This means that nitriding or induction hardening must be used. Part orientation and uniform quenching are important when designing part fixturing (hanging vs. laying flat, etc.)" Plough says. "Distortion control is one of the most difficult challenges. Also, the capital cost of equipment and facility. Effective equipment and processes are available, but are very expensive for large parts."

In-House Vs. Outsourcing

Many large gear manufacturers keep heat treatment in house if the floor space is available and they have the capital to pull it off. If in-house heat treatment isn't a viable option, there are commercial partners available for the heat treatment of large gears. There are several factors to consider when deciding which route is best for the organization.

"If a very high quality is required, it might be easier to achieve this requirement if there is an in-house heat treating facility where the furnaces can be optimized for a certain product," says Ipsen's Angenendt. "Another major factor is the volume of parts. This means that if a company has enough through-put to utilize a heat treatment line, the decision is often to do in-house heat treatment. Additionally, the availability of a commercial heat treater close by—this applies especially to large gears where it can be quite expensive to transport them to a commercial heat treater."

"In house heat treating requires a large capital outlay for equipment, plant improvements and personnel, including not only heat treat specialists and technicians, but a metallurgist to develop and implement the processes and parameters. As an example, to duplicate the furnace installations at Metlab including a 12' deep pit, overhead crane, furnace and quench tank, would be an investment in excess of $3 million. The second draw back towards such an installation is that for a captive manufacturer, the number of large gears for heat treating is somewhat limited, hence payback of the initial investment may not be justified," Podob says.

"Internal vs. external heat treating evaluation is most often reduced to three conditions: delivery time of the service being outsourced, cost of the service, and final part quality. Internal heat treating has the advantage of faster turnaround due to reduced transportation times and routine scheduling issues at commercial heat treaters for furnace time. Total quantity of parts is the biggest driver of both equipment and service costs. If production volumes are low, it virtually never makes sense to bring heat treating inside," Gottschalk says. "Final part quality can be the biggest factor in the decision as internal heat treating processes tend to be specifically designed for a given part. Commercial processors typically have universal equipment to allow for more flexibility with a variety of customers and processes, which may or may not provide the best technical solution."

High Stakes Heat Treat

Heat treating large gears can come with its own set of high stakes challenges as well. These gears must adhere to strict inspection requirements and tight deadlines. In many situations, the customer may have needed the end product three weeks ago. "Prior experience, proper quality control procedures and internal company auditing procedures are a *must* for any commercial or captive heat treating. They become even more important with large gears because of the tremendous amount of time and expense to get the product up to this point in manufacturing. Any failure at this time correlates to incredible costs," Gottschalk says.

"Many heat treat companies handle work that comes from a wide range of industries, each having their own specification requirements. For heat treat companies with a strong quality system, such as NADCAP, spec review and compliance is routine and expected. Designing heat treat processes that meet spec requirements and produce good properties with minimum distortion are the result of experience and expertise with a wide variety of materials," Plough says.

"In defense and military applications, for example, strict inspection is required as well as tight deadlines for project completion. What better prepares a heat treat company for these unique applications and the inherent obstacles that come with each job? Metlab uses its own internal process specifications developed individually for each and every heat treatment job. For any of the processes which are done on gears, these process specifications are based on AMS specifications as well as MIL specs and in-house experience. We also rely on not only our own expertise, but that of our customers as well, working in partnership to develop the processing parameters to produce quality parts," Conybear says.

"Under normal circumstances the specification of very large gears are fixed and the related processes to achieve this specification were developed by some preliminary trials. It is always easier if the process, as well as the specifications, is well established and it is a proven fact that the specification can be reached. However, under certain circumstances it is necessary to develop further already existing recipes in order to achieve an even more demanding specification," Angenendt at Ipsen says.

Design and Metallurgical Collaboration

Another key factor in heat treating large gears is to plan ahead, discuss the design and metallurgical issues early and often, preparing for the challenges to come. "Design, manufacturing processes and metal chemistry will all play a critical role in final part performance, so it is best to discuss these issues in the early planning stages of the project. In many cases, required part properties cannot be physically achieved based on limitations in the heat treating process or selected metal chemistry," Gottschalk says.

"There should always be close communication between a gear design engineer and a gear metallurgist in order to prevent gear specifications and load assumptions on gears which can never be achieved," Angenendt at Ipsen says. "Besides the communication between a gear design engineer and a gear metallurgist, it is always wise to consult a general heat treatment expert in certain cases in order to ensure that the gear or shaft, which was developed by the gear design engineer and then by the gear metallurgist, can be produced and heat treated. In order to achieve this target, all three parties need to communicate closely."

"There is no question that gear designers and the gear metallurgist need to work together to ensure a successful product. This includes ensuring that the metallurgical results can be achieved, the part can physically be processed and distortion can be minimized," Conybear says. "As an example, Metlab recently worked with one gear manufacturer to carburize and harden a 75,000 pound reduction gear for a steel mill. The final gear measured about 12" diameter, was a double helical gear, with an 18" face width, and total gear thickness of 48". In working closely with the manufacturer, it was decided to produce the gear in two halves, each 24" tall to first allow for ease in lifting into and out of the furnace, particularly when the gear was hot, reduce the volume of oil required for a successful quench, and to minimize the potential for distortion. These were fabricated gears, and producing the gears in halves allowed for thicker webs and an increased number of stiffening supports, again aimed at minimizing distortion."

New Developments in Larger Sizes

What does the future hold for the heat treating of large gears? "An installed equipment base of larger size must be developed to meet the increasing production demands," Gottschalk says. "Unfortunately, this will be a slow devel-

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Test load of ring gears for a customer order (courtesy of Ipsen).

opment as many companies will not make the large capital investments necessary to process these larger parts. Firm commitments will be required regarding both part quantity and future market changes. This growth must be driven by product end users as return on investment is reduced if new large product manufacturing cells are under-utilized. In addition to larger processing equipment, it is expected that better material grades will be developed, making it easier to achieve more demanding process standards."

"There is a trend in the market to heat treat larger and larger parts. There will be a requirement for bigger furnaces capable of handling larger loads than today. This trend was seen in the past and will be further developed in the future. These larger furnaces also require bigger loading and unloading systems as well as bigger surrounding equipment. To develop these bigger furnaces and the related auxiliary equipment will be the challenging task in the future. In general the race will be to make the parts/machines as 'small' and 'light' as possible, because 'big' and 'heavy' requires a lot of energy and money," Angenendt at Ipsen says.

"The main technological advance has been the implementation of sophisticated models of the processes that can be used in real time for on-line process control." Conybear says. "Coupled with industrial hardened controllers and high speed computers, the processes can be run with high predictability and reproducibility with low initial cost and low maintenance. In the early nineties, such models were only usable in the laboratory, ran at speeds that could not reach to the process changes."

Adds Plough at Stack Metallurgical, "Heat treaters need to push for additional alloy development for large cross-section gears. The ability to gas quench thick sections and attain high core properties will open the door to additional process refinements and distortion control."

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Stack Metallurgical opened in 1984 with a couple of atmosphere furnaces and has become a versatile provider of heat treat services, particularly in large gears (courtesy of Stack).