Spin hardening: a 6-inch-diameter gear being flame hardened with spinning method.
Flame Hardening

By Mark M. Sirrine

Flame hardening is a viable, cost-efficient solution for heat treating difficult gear designs and for lower production volumes. Here, an overview on flame hardening, as well as spin hardening and robotic gear hardening, is discussed.

**HEAT TREATING GEARS INCREASES THEIR DURABILITY** and strength, and there are many heat treating options to suit different applications. To achieve the best return on investment, factors that should be considered include production volume, gear or shaft design, and hardness pattern and depth specified for the parts. Also, determining the number of parts that will be hardened annually and whether the process will be done in house or outsourced are not only cost considerations, but also quality and delivery considerations. When examining these critical issues, flame hardening can be an effective niche solution for handling difficult gear designs.

Heat treating falls into two broad categories: furnace hardening and localized hardening (also known as case hardening). The best choice is a matter of matching the particular manufacturing process and product with a method that turns out products within quality specifications and meets budget and production quotas.

For high production volumes of one specific gear weighing less than 100 pounds, furnace and induction hardening are most commonly used. Induction is used in the majority of localized hardening applications dealing with high volumes of the same gear designs. Furnaces can accommodate many different gear shapes and sizes, while induction coils and flame hardening flame heads must be custom designed to meet the part hardness pattern specification. Gears can suffer from distortion and cracking in furnace heat treating. The smaller the area of a gear exposed to heat, the better chance of avoiding distortion problems.

Flame hardening occupies a special heat treating niche. It is ideal in lower production volume applications and those involving specialized, irregularly shaped pieces. Induction hardening and furnace heat treating typically do not provide the cost benefit needed in special cases like these. A new flame-treating solution usually costs considerably less than induction or furnace heat treating, making it ideal for low volume and specialized applications.

Flame hardening has a long history in the industry, but it has made significant advancements since the days of using a welding torch and a water tank for quenching. Today’s flame-hardening process provides programmable cycle controls, polymer quench options, and a variety of designs that produce predictable, consistent results, even for large and irregular gears or worm shafts. Flame hardening suits a wide variety of parts because it is more economical to design flame heads for a variety of applications than to add more induction coils or furnaces. Lower volumes, greater variability among parts, and larger mass of particular parts all point to considering flame hardening.

**FLAME HARDENING PROCESSES** Flame hardening is a niche application and a viable option because the global economy continues to put pressure on lowering manufacturing costs. For gear manufacturers, flame hardening offers a solution at the lowest price point for a quick return on investment. Two applications of flame hardening include spinning and tooth-at-a-time processes.

Spin hardening machines include a chuck where gears are held and then spun in front of flame heads that heat the teeth all the way through. After heating, gears either are dropped into a quench bath or are spray quenched. Similar to other case hardening techniques, a hardened case of a specific pattern is produced on the part as shown in Figure 1. This hardness pattern with the correct hardness and depth is achieved consistently gear after gear. The pattern determines how the gear teeth will wear in the field.

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**Figure 1:** Hardness pattern using spinning flame hardening method

**Figure 2:** Hardness pattern using root/flank flame hardening method, one tooth at a time

**Figure 3:** Hardness pattern using flank flame hardening method, one tooth at a time
In this case, spinning creates a pattern through the entire tooth and into the root. Flame hardening also produces a wider transition area between the case-hardened root and the rest of the gear, which helps increase tooth durability. Process speed is an attractive reason to choose spinning machines for gears. A spin hardener offers the highest volume production level of any flame hardening solution, and produces the most consistent results because it is the same cycle for the entire gear. But because more heat is applied by the spinning method than the tooth-at-a-time method, it is best suited for gears with enough mass to absorb that heat without excessive distortion.

Tooth-at-a-time machines heat and quench the tooth itself, which limits the amount of heat going into the gear. For a hardness pattern that provides more strength along with durability, tooth-at-a-time is a beneficial flame-hardening solution. The tooth is not heated all the way through. The flame head is designed to either encircle the tooth or penetrate to the root, keeping the hardness pattern confined to the edge of the tooth. If added strength is needed to handle the load on the gear, the pattern shown in Figure 2 should be produced, where the flame head provides both root and flank hardening. If the base material meets the load expected in the field, the pattern shown in Figure 3 should be produced, hardening only the flank, which increases only the durability of the tooth, not the strength of the whole gear.

**APPLICATION EXAMPLES**

Tooth-at-a-time applications are especially suited to very large gears. For an example, Flame Treating Systems worked with Oliver Gear, Inc. (Buffalo, N.Y.) to flame-harden the flanks of large gear teeth to a depth of 0.125 inches on the pitch line without hardening the gear hub. The gears, weighing from 80...
to 3,500 pounds with diameters from under 13 inches to almost 55 inches, are used as pinions on reducers. The flame-hardening system consisted of two water-quench brass flame heads; controls for oxygen/fuel rates, flame temperatures, and heating times; a water-cooled heating torch mounted on a scanner mechanism; a quench collection tank with pumps and turntable; and a heat exchange assembly. In operation, gears are locked in place on a free-spinning turntable for flame-hardening. The hardening process time ranges from one to two minutes per tooth. Flame Treating Systems also helped Fundiciones Universo (Yumbo, Colombia) with even more massive gears of 24 inches in diameter and wheels weighing up to 8,000 pounds. (See Figure 4.)

**MANAGING DISTORTION**

Distortion is a natural by-product of changes in temperature. Heat expands material and cold contracts it, and this happens with gears during heat treating. All forms of heat treating expands the part. A good heat treating solution engineers the process to work with the distortion so that the end result still meets tolerances.

Gears are most susceptible to distortion when they have smaller mass and more irregular shapes. The larger the mass, the more evenly the heat is distributed and absorbed. Problems arise when the part shape or mass allows more heat to be absorbed in one area than another.

With flame hardening, processes can be adjusted to work with distortion rather than against it. For example, Edgerton Gear (Edgerton, Wisconsin) experienced gear growth of 0.003 inches over DP with spin hardening. The company decided to machine that amount of stock off the gears before spin hardening. Because spin hardening gave consistent results, it produced gears consistently within specified tolerances. Another way Flame Treating Systems managed excessive distortion with the spinning method involves a counter-intuitive approach; that is, adding more flame heads so the time the gear spends in the heat cycle is shortened. The faster it is heated, less heat is absorbed in locations where it is not wanted and less heat goes into the entire part. More flame heads reduce the time the part spends under extreme heat, so less heat is absorbed and distortion is limited.

Improper quench design and materials can also contribute to excessive distortion. If spray quenching is done from one side, cooling occurs faster on that side, and nonuniform cooling usually creates excessive distortion just as nonuniform heating. Also, if a harsher quench like straight water is used, more distortion can occur. A polymer quench slows the cooling process, and oil is slower still. Air cooling is slowest and is most often successfully applied to steels with high alloy content. These factors should all work together to control excessive distortion.
CONCLUSION
The most important considerations for heat treating are production volume and gear material and design. High-volume production and low-carbon steels weighing less than 25 pounds and 24 inches in diameter might be more suited to carburizing furnaces. High-volume gears made of AISI 1045 carbon steel and other steels in that carbon range might benefit from induction. Lower-volume gears with irregular surfaces, larger diameters and weight, and a wide variety of sizes lend themselves to flame hardening.

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Spin Hardening

By Jackie Orr

Rotating the gear while applying flame to specified areas (or spin hardening) is a reliable process for uniform hardness.

Once the flame is finished being applied, the gear is placed in a quench bath to complete the hardening process. Penna Flame Industries created a process called Uni-Max to accommodate unique pieces. It operates similar to the spin bay with the added element of the flame moving vertically or horizontally to harden the gear. Surface temperature is measured using infrared devices while maximum surface hardness and case depth uniformity is all computer controlled. The diameter of the part and DP are critical factors in deciding whether the spin bay is ideal for the part.
Robotic Gear Hardening

The robot has revolutionized the flame hardening industry by providing precision, dependability, and constant hours of production.

Parts that require more specific or intricate hardening get filtered to the robot bay where three specifically programmed robots are hard at work. The robot has the ability to work around a part and selectively harden only the areas for which it has been programmed. This precision provides quality results on jobs that were previously too difficult to accomplish with conventional machinery. The robot arm is capable of reaching complex angles and shapes that older machines cannot. Robotics hardening provides an important benefit for gear manufacturers in that it is able to harden the precise intervals between teeth dependably and swiftly. Many companies still treat gears the old-fashioned way, manually by hand. This leads to operator error, loss of focus, and fatigue. Remaining in that position for long periods of time can also lead to back problems and ergonomic injuries.

Figure 7: Gear progressively flame hardened by robotics

The first step in the robotics hardening process is preheating gears in an oven and then place on an indexing table synchronized with the robot. The table indexes in order to distribute heat evenly around the circumference of the part. The robot coupled with the indexing table allows for continuous movement. This is especially important for bevel, herringbone, helical, or any gears with an odd shape. The indexing table is controlled by the robot and follows the contour and shape.

Figure 8: Cut and etched sample of a flank pattern: progressively flame hardened

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with exact precision. For gears with distortion concerns, the table indexes and skips teeth to even out the process and minimize stresses. The number of teeth are divided into quadrants and the robot mixes the pattern from quadrant to quadrant. Once the teeth are scanned, gears are placed in a holding temper with inspection and final tempering occurring the following day.

Fuel gases used in the process can vary from natural gas, propane, propylene, or acetylene and are mixed with oxygen. All mixed fuel is delivered to the precision burning tooling through solenoid valves and then through digitally controlled regulators, rather than flow control units that were unreliable as they quickly became contaminated with impurities in the fuel. The digitally controlled pressure regulators allow the fuel to be changed instantaneously. This is beneficial when there is a change in section thickness. Programming allows the robot to accomplish multiple, intricate tasks simultaneously that a human being physically cannot. These robots provide an automation system that helps decrease production time while maintaining the highest quality in precision surface hardening. It is also great for high-volume production orders in which every part can be hardened exactly the same way.

ABOUT THE AUTHOR: Jackie Orr is a senior at Elon University in North Carolina pursuing a degree in business management. She serves as a marketing advisor for Penna Flame Industries and has been contributing to the family business since she modeled for advertising materials at age 5. She plans to pursue a career in sports business upon graduation, utilizing the business skills she has gained at Penna Flame.