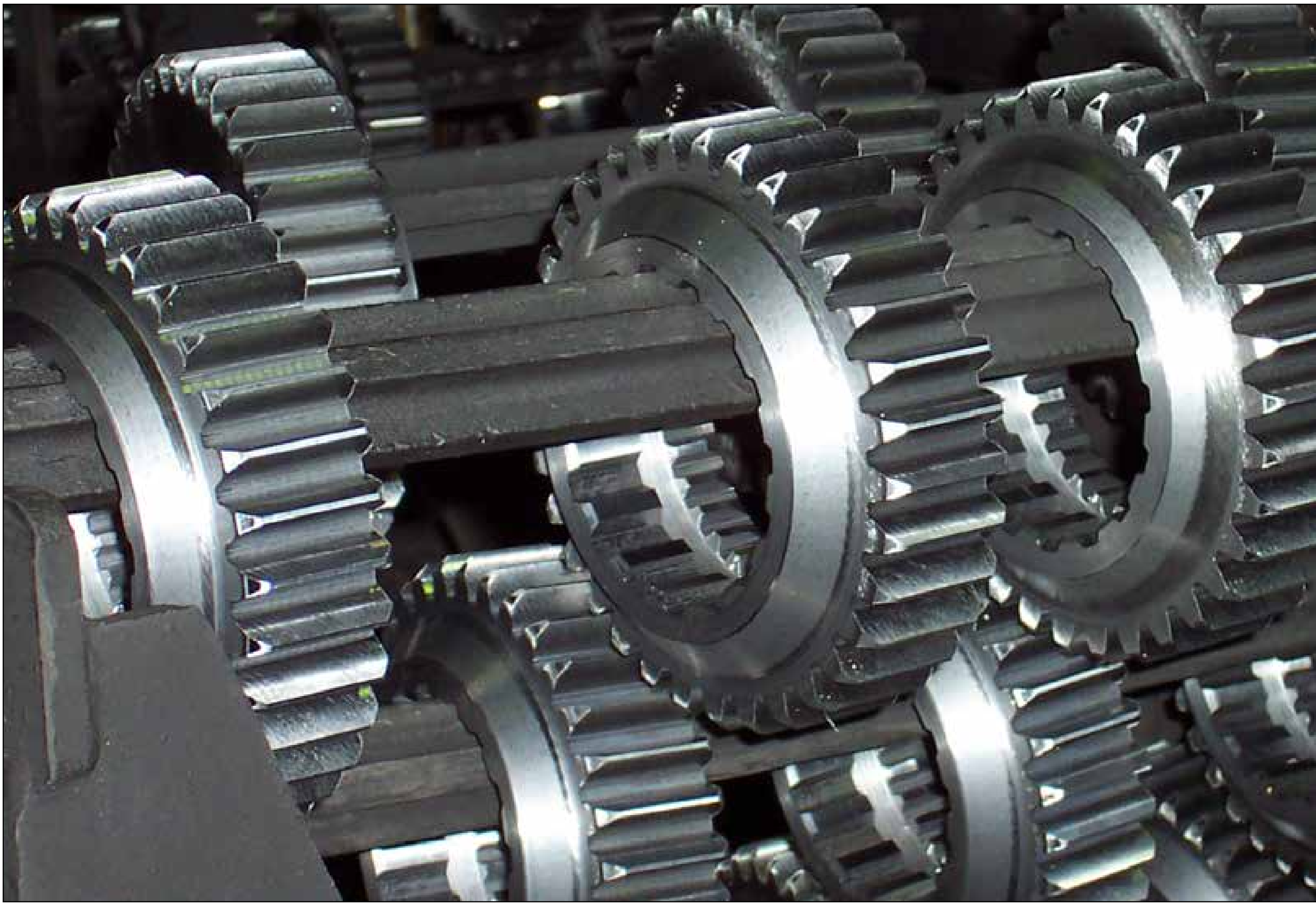

Variety of Furnaces Can Be Used for Heat Treatment of Gears

By Daniel H. Herring

Design engineers are able to choose from a number of heat treat processes and furnaces for different gear materials and designs. Selection of the appropriate furnace or material is often defined by availability, cost, and application requirements.

Gear heat treatment can be done in a wide variety of different types of industrial furnaces, each with its own unique characteristics. This article focuses on the similarities and differences of each of these styles.

CLASSIFICATION OF HEAT-TREATING FURNACES

Heat-treating furnaces can be grouped into two main categories: batch and continuous. The fundamental difference between these two styles is not in their materials of construction, although there are some differences due to inherent design requirements. Instead, the key difference lies in how workloads are positioned in the units and how they interact with the atmosphere within the furnaces.

In addition, there are two (2) primary sources of energy to heat the equipment, namely (natural) gas and electricity. Alternative energy sources, such as oil and other hydrocarbon fuels (e.g. propane, propane/butane mixtures) can also be used. Heat-treating furnace equipment can further be divided into furnaces (atmosphere & vacuum), ovens and applied energy methods (flame, induction, laser). Furnaces can be classified in a number of ways as summarized in Table 1.

BATCH FURNACES

Batch units (Fig. 1) process a wide variety of gears and tend to involve large, heavy workloads processed for long periods of time. In a batch unit the work charge is typically stationary so that interaction with changes in the furnace atmosphere are performed in near equilibrium conditions.

Batch furnace types include:

- Bell furnaces;
- Box furnaces;
- Car bottom furnaces
- Elevating hearth furnaces;
- Fluidized bed furnaces;
- Gantry furnaces;
- Mechanized box furnaces (also called “sealed quench” or “integral quench” or “in-out” furnaces);
- Pit furnaces;
- Salt pot furnaces;
- Split or Wraparound furnaces;
- Tip-Up furnaces;
- Vacuum furnaces.

Of all the batch furnace types, integral quench furnaces are the most common. Many different types of gears (Fig. 2) are hardened and case hardened (i.e. carburized or carbonitrided) in these types of units due the cycle flexibility. Effective (50 HRC) case depths up to 0.060” (1.5 mm) are common although deeper case depths are certainly possible.

CONTINUOUS FURNACES

Continuous furnaces (Fig. 3) are characterized by the movement of the workload in some manner and the environment surrounding the workload changes dramatically as a function of the position of the work charge.

Continuous furnace types include:

- Cast link belt furnaces;
- Humpback furnaces;
- Mesh belt furnaces;
- Monorail furnaces;
- Pusher furnaces;
- Roller hearth furnaces;
- Rotary drum (rotary retort) furnaces;
- Rotary hearth furnaces;
- Shaker hearth furnaces;
- Vacuum furnaces;
- Walking beam furnaces.

Of all the continuous furnace types, pusher furnaces (Fig. 4) are the most common. Gears of common sizes and case depths are most often run (Fig. 4) and either hardened and case hardened (i.e. carburized or carbonitrided). Typical effective (50 HRC) case depths in the 0.025” (1.5 mm) – 0.035” (mm) range. Again, deeper case depths are certainly possible.

In addition, there are a number of special purpose furnaces including:

- Continuous slab and billet heating furnaces;
- Electron beam surface treatment equipment;
- Induction heating systems;
- Laser heat treating equipment;
- Quartz tube furnaces;
- Resistance heating systems;
- Rotating finger furnaces;
- Screw conveyor furnaces;

ATMOSPHERE FURNACES

Atmosphere furnaces are characterized by their use of a “protective” atmosphere to surround the workload during heating and cooling. The most common furnace atmosphere, however, is air. Often times, nothing more is needed. When an air atmosphere is used, such as in a low temperature tempering operation, the final condition of the material’s surface (or “skin”) is not considered important.

Furnace atmospheres play a vital role in the success of the heat-treating process. It is important to understand why we use them and what the best atmosphere for a specific application is. There are many different types of atmospheres being used, and it is necessary to understand how a particular atmosphere was chosen as well as its advantages and disadvantages and to learn how to control them safely.

The purpose of a furnace atmosphere varies with the desired end result of the heat-treating process. The atmospheres used in the heat-treating industry have one of two common purposes:

- To protect the material being processed from surface reactions, that is, to be chemically inert (or protective).

- To allow the surface of the material being processed to changed or be chemically active (or reactive).

The types of atmospheres used in heat-treating furnaces are summarized in Table 3.

Some atmospheres on the list such as argon and helium are often associated with vacuum furnaces and are used at partial pressure (pressure below atmospheric pressure). Others, such as sulfur dioxide are used for very special applications.

Generated atmospheres produce combinations of gases of specific composition prepared on site by use of Gas Generators that are designed for this purpose. The “feed” stock (hydrocarbon fuel gas used in combination with air to create the atmosphere) is typically natural gas or propane.

During operation, the volume of protective atmosphere required for safe use in a particular heat treating furnace depends to a great extent on the:

- Type and size of furnace;
- Presence or absence of doors and/or curtains;
- Environment (especially drafts);
- Size, loading, orientation, and nature of the work being processed, and Metallurgical process involved.

In all cases, the manufacturer’s recommendations should be followed since they have taken these factors into

Figure 1: Typical Batch Style Furnaces.

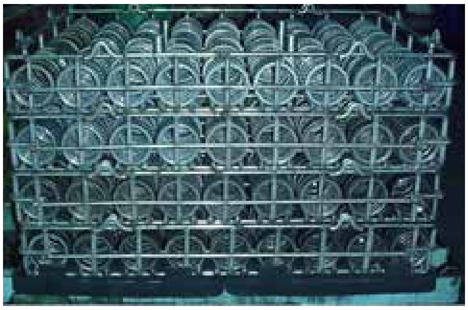

Figure 2: Typical Load of Timing Integral Quench Furnace.

Figure 3: Typical Continuous Style Furnaces. (Photograph Courtesy of Surface Combustion, Inc.)

account during the design of the equipment. Remember that to purge air out of a furnace prior to introduction of a combustible furnace atmosphere requires a minimum of five (5) volume changes of the chamber. This is to ensure that the oxygen content of the chamber is below 1 percent prior to the introduction of the atmosphere.

Generated atmospheres are classified according to the relative amounts of the individual gases produced. Table 4 below provides a list of these classifications according to the American Gas Association (AGA). The gases are divided into six (6) main classes.

Exothermic reactions produce heat while endothermic reactions require heat to promote the reaction. The composition of the atmospheres produced can be changed in a number of ways. Varying the gas/air ratio, or using a different "feed" stock (natural gas or propane for example) will cause the chemistry of the gas to change.

VACUUM FURNACES

Vacuum furnaces (Fig. 5) can be classified, according to the mode of loading into horizontal and vertical and can be further subdivided into batch or continuous (multi-chamber) designs.

Heat treatment in vacuum furnaces is characterized by special conditions with regard to the design of the furnaces as well as the control of temperature and vacuum level during the heat treatment. The design of the furnaces generally depends on the size of the load, the pressure and temperature to be attained, and the medium to be used in cooling the load.

The main parts of a vacuum furnace include:

- Vessel;
- Pumping system;
- Hot zone;
- Cooling system.

Vacuum furnace vessels can be grouped into so-called hot wall and cold wall designs. Typical hot wall furnaces have no water-cooled shells or have a retort into which the workload is placed that is commonly metallic or ceramic dependent on the temperature. The heating system is typically located outside of the retort and consists of resistive heating elements or an induction coil. Limitations of this retort-type furnace are the restricted dimensions of the heating zones and the restricted temperature range of the retort, usually limited to 2000F (1100°C) maximum. With cold wall furnaces, the vacuum vessel is cooled by a cooling medium (usually water) and is kept near ambient temperature during high temperature operations.

In comparison to the hot wall furnace, the features of the cold-wall furnace are:

- Higher operating temperature ranges with 2400°F (1315°C) standard and 3000°C (1650°C) or higher practical.
- Lower heat losses and less heat load released to the surroundings.
- Faster heating and cooling performance.
- Greater temperature uniformity control.

The construction of the pumping system depends on the following factors:

- Volume of the vessel.
- Surface area of the vessel and the type of furnace internals.
- Outgassing of the workload and related fixturing.
- Time required for evacuation down to the final pressure.

It is important to note that the pumping system must maintain the process vacuum level without being overwhelmed by the

Figure 4: Typical Load of Truck Transmission Gears Processed in a Pusher Furnace.

Figure 5: Vacuum Hardening and/or Carburizing of Gears. (Photograph Courtesy of Solar Manufacturing)

Criteria	Distinguishing Feature	Remarks
Method of Heating	Combustion of Fuel	Gas (natural, other hydrocarbon, manufactured, tank) or oil (tar)
	Electricity	Electrical resistance (metallic, ceramic, other); Electric arc (melting); Electrical induction (heat treating, melting)
Method of Handling Charge	Batch	Work remains stationary
	Continuous	Work moves continuously within the equipment.
	Intermittent	Work moves periodically
Internal Atmosphere	Air	
	Other	Generated, synthetic, elemental, mix
Exposure of Charge to Atmosphere	Open	Exposed charge, single heat transfer.
	Closed	Muffle design (isolated charge, double heat transfer)
Type of Hearth	Stationary	Slab, skid, rails.
	Moveable	Belt, car, roller, rotating table, screw, shaker.
Liquid Bath	Salt	
	Other	Molten lead, fluidized bed

Table 1: Classification of Furnaces.

outgassing of the workload. Pumping systems are usually divided into two subsystems, pumps for rough vacuum (micron range) and pumps for high vacuum (sub-micron range). For certain applications a single pumping system can handle the entire range and cycle. The pumps themselves are usually classified in two general categories, mechanical pumps and diffusion pumps. There are other specialized types of vacuum pumps for use in achieving higher vacuum ranges such as ejectors, ion pumps, cryo-pumps, turbo-molecular pumps, and “chemical getter” pumps.

For the insulation of the heating chamber, or hot zone, the following designs and materials are in common use:

- All metallic (radiation shields)
- Combination radiation shields and other (ceramic) insulating material
- Multiple-layer (sandwich) insulation
- All graphite (board, fiber, carbon-carbon composite)
- Radiation shields are manufactured from:
- Tungsten or tantalum having a maximum operating temperature of 4350°F (2400°C),
- Molybdenum having a maximum operating temperature of 3100F (1700°C),
- Stainless steel or nickel alloys having a maximum operating temperature of 2100°F (1150°C).

Most all-metallic designs consist of a combination of materials, for example, three molybdenum shields backed by two stainless steel shields would be typical for 2400F (1150°C) operation. Radiation shields adsorb only small amounts of gases and water vapors during opening of the furnace. They are, however, expensive to purchase and maintain and often require greater pumping capacity to remove any moisture trapped between the shields. Compared with other types of insulation, their heat losses are high and become higher with loss of emissivity (reflectivity) due to the gradual contamination of the shields.

Graphite fiber insulation designs are the most popular style today. With inherently lower heat losses, a smaller thickness of insulation is sufficient. In these designs, the absorption of gases and water vapor is considerably reduced. Furthermore, the heating costs are lower, and the lifetime of this type of insulation is much longer. The maximum operating temperature is around 3630F (2000°C). The lifetime depends strongly on the purity of the graphite.

In general, the heating elements for heating systems in vacuum furnaces are made from one of the following materials:

- Nickel/Chromium alloys that can be used up to 2100°F (1150°C). Above 1475F (800°C) there is a risk of evaporation of chromium.
- Silicon carbide with a maximum operating temperature of 2200°F (1200°C). There is a risk of evaporation of silicon at high temperatures and low vacuum levels.
- Molybdenum with a maximum operating temperature of 3100°F (1700°C). Molybdenum becomes brittle at high temperature and is sensitive to changes in emissivity brought about by exposure to oxygen or water vapor.
- Graphite can be used up to 3630°F (2000°C). Graphite is sensitive to exposure to oxygen or water vapor resulting in reduction in material thickness due to the formation of carbon monoxide (CO) that will be evacuated by the pumps. The strength of graphite increases with temperature.
- Tantalum has a maximum operating temperature of 4350°F (2400°C). Tantalum, like molybdenum, becomes brittle at high temperatures and is sensitive to changes in emissivity brought about by exposure to oxygen or water vapor.

Uniformity of temperature is of great importance to heat treatment results. The construction of the heating system should be such that temperature uniformity in the load during heating is optimal; it should be better than ±10F (5°C) after temperature equalization. This is realized with single or multiple temperature control zones and a continuously adjustable supply of heating power for each zone.

In the lower temperature range, below 1550°F (850°C), the radiant heat transfer is low and can be increased by convection-assisted heating. For this purpose, after evacuation, the furnace is backfilled with an inert gas up to an operating pressure of 1-2 bar, and a built-in convection fan circulates the gas around the heating elements and the load. In this way, the time to heat different loads of gears, especially those with large cross sections to intermediate temperatures, for example 1000°F (550°C), can be reduced by as much as 20 – 30%. At the same time the temperature uniformity during convection-assisted heating is much better, resulting in less distortion of the heat-treated part.

The following quench media (listed in order of increasing intensity of heat transfer) are used for the cooling of components in vacuum furnaces:

- Vacuum
- Sub-atmospheric cooling with a static or agitated inert gas (typically Ar or N2)
- Pressurization (up to 20 bar or more) cooling with a highly agitated, recirculated gas (Ar, N2, He, H2 or mixtures of these gases).
- Oil, still or agitated

After heating in vacuum, the bright surface of the components must be maintained during the cooling. Today, sufficiently clean gases are available for cooling in gas with impurity levels typically in 2 ppm of

Furnace Style	**Application Use**
Bell	Aging, Bluing, Hardening, Nitriding, Solution Heat Treatment, Stress Relieving, Tempering
Box	Aging, Annealing, Carburizing, Hardening, Malleabilizing, Normalizing, Solution Heat Treatment, Stress Relieving, Tempering
Car Bottom	Annealing, Carburizing, Hardening, Homogenizing, Malleabilizing, Normalizing, Spheroidizing, Stress Relieving, Tempering
Cloverleaf	Annealing, Carbon Restoration, Carbonitriding, Carburizing, Hardening, Normalizing, Tempering
Continuous Slab	Carburizing, Homogenizing, Solution Heat Treatment
Conveyor	Austempering, Annealing, Brazing, Carbon Restoration, Carbonitriding, Carburizing, Hardening, Homogenizing, Spheroidizing, Tempering
Electron Beam	Hardening (surface)
Elevator Hearth	Aging, Annealing, Hardening, Malleabilizing, Solution Heat Treatment, Stress Relieving, Tempering
Fluidized Bed	Carbonitriding, Carburizing, Hardening, Nitriding, Nitrocarburizing, Steam Treating, Tempering
Humpback	Annealing, Brazing, Hardening, Stress Relieving, Sintering
Induction	Hardening, Tempering
Integral Quench	Austenitizing, Annealing, Carbon Restoration, Carbonitriding, Carburizing, Hardening, Nitrocarburizing, Normalizing, Stress Relieving, Tempering
Ion	Carbonitriding, Carburizing, Nitriding, Nitrocarburizing
Laser	Annealing
Monorail	Annealing, Hardening, Normalizing, Stress Relieving, Tempering
Pit	Annealing, Bluing, Carbon Restoration, Carbonitriding, Carburizing, Hardening, Homogenizing, Nitrocarburizing, Nitriding, Normalizing, Solution Heat Treatment, Steam Treating, Stress Relieving, Tempering
Pusher	Annealing, Carbon Restoration, Carbonitriding, Carburizing, Hardening, Malleabilizing, Metallizing, Nitrocarburizing, Normalizing, Solution Heat Treatment, Sintering, Spheroidizing, Stress Relieving, Tempering
Quartz Tube	Hardening, Sintering
Resistance Heating	Aging, Annealing, Carbonitriding, Hardening, Normalizing, Stress Relieving
Roller Hearth	Bluing, Carbon Restoration, Carbonitriding, Carburizing, Hardening, Malleabilizing, Normalizing, Solution Heat Treatment, Spheroidizing, Stress Relieving, Tempering
Rotating Finger	Annealing, Hardening, Normalizing, Stress Relieving, Tempering
Rotary Hearth	Annealing, Austempering, Carbon Restoration, Carbonitriding, Carburizing, Hardening, Tempering
Salt Bath	Austempering, Carbonitriding, Carburizing, Hardening, Malleabilizing, Martempering, Nitrocarburizing, Normalizing, Tempering
Screw Conveyor	Annealing, Hardening, Stress Relieving, Tempering
Shaker Hearth	Annealing, Carbonitriding, Carburizing, Hardening, Normalizing, Stress Relieving, Tempering
Split	Annealing, Stress Relieving
Tip-Up	Annealing, Hardening, Malleabilizing, Normalizing, Spheroidizing, Stress Relieving, Tempering
Vacuum	Annealing, Brazing, Carbon Deposition, Carbonitriding, Carburizing, Degassing, Hardening, Nitrocarburizing, Normalizing, Solution Heat Treatment, Sintering, Stress Relieving, Tempering
Walking Beam	Annealing, Hardening, Normalizing, Sintering, Stress Relieving, Tempering

Table 2: Common Applications of Heat Treating Furnaces [21]

oxygen and 5-10 ppm of water (by volume) range. Nitrogen is commonly used as a cooling medium because it is inexpensive and relatively safe. Helium is also used in systems and recycling is necessary.

Multi-chamber furnaces equipped with an integral oil quench (Fig. 6) or high pressure gas quenching are commonly available. If used in vacuum, oils are specially formulated (evaporation-resistant) for vacuum operation.

One other variation worth noting is the plasma or ion furnaces. Plasma furnaces exist in all styles, horizontal in single or multiple-chamber configurations, as well as vertical designs such as bell furnaces and bottom loaders. The basic differences between these designs and conventional vacuum furnaces are the electrical isolation of the load from the furnace vessel via load support isolators; the plasma current feed-through; the high-voltage generator, which creates the plasma; and the gas dosage and distribution system. Plasma furnaces also utilize conventional vacuum furnace chamber and pumping systems.

Depending on the specific application, they are either low temperature furnaces (1400F (750ºC) for plasma (ion) nitriding or high temperature furnaces up to 2400ºF (1100ºC) for plasma (ion) carburizing. Low temperature furnaces for plasma nitriding are constructed as cold-wall or hot-wall furnaces. High temperature furnaces are usually cold-wall furnaces with water-cooled double walls. They can be equipped either with a high-pressure gas quench system or an integrated oil quench tank.

The generator needed to create a plasma glow discharge inside a plasma furnace has to be a high-voltage dc generator (up to 1000 volts). Currently there are two types of generators in use; one type has continuous-current outputs and the other has pulsed-current output.

INDUCTION 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.

Of the various types of applied energy processing, induction hardening (Fig. 8) is the most common. Induction heating is a process, which uses alternating electrical current that induces a magnetic field, causing the surface of the gear tooth to heat. The area is then quenched, resulting in an increase in hardness within the heated area. This process is typically accomplished in a relatively short time. The final desired gear performance characteristics are determined not only by the hardness profile and stresses but also by the steels composition and prior microstructure. External spur and helical gears, bevel and worm gears, racks and sprockets are commonly induction hardened.

The hardness pattern produced by induction heating is a function of the type and shape of inductor used as well as the heating method. Quenching or rapidly cooling the work-piece can be accomplished by spray or submerged quench. The media typically used for the quench is a water based polymer. The severity of this quench can be controlled by the polymers concentration. Cooling rates are usually somewhere in between what would be obtained from pure water and oil. In some unusual situations compressed air is used to quench the work-piece.

The most common methods for hardening gears and sprockets are by single shot or the tooth-by-tooth method. Single shot often requires large kW power supplies but results in short heat/quench times and higher production rates. This technique uses a copper inductor (coil) encircling the work-piece. An inductor, which is circumferential, will harden the teeth from the tips downward.

While the single shot method is acceptable for splines and some gearing, the larger, heavier-loaded gears where pitting, spalling, tooth fatigue, and endurance are an issue need a hardness pattern which is more profiled like those produced with carburizing. This type of induction hardening is called tooth-by-tooth hardening. This method is limited for gear tooth sizes up to 5 or 6 DP using frequencies from 2 to 10 kHz and about 10 DP using a range of 25 to 50 kHz. The lower the frequency; the deeper the case depth. This is a slow process due to the number of teeth and index times, and is usually reserved for gears and sprockets that are too large to single shot due to power constraints. The process involves heating the root area and side flanks simultaneously, while cooling each side of the adjacent tooth to prevent temper-back on the backside of each tooth (Fig. 7b). The induction system moves the coil at a pre-programmed rate along the length of the gear. The coil progressively heats the entire length of the gear segment while a quench follower immediately cools the previously heated area. The distance from the coil to the tooth is known as coupling or air-gap. Any variation in this distance can yield variation in case depth, hardness, and tooth

Type	Chemical Symbol	Remarks
Air	$N_2 + O_2$	Air is approximately 79% nitrogen, 21% oxygen
Argon	Ar	Argon is considered an inert gas
Carbon Dioxide	CO_2	
Carbon Monoxide	CO	
Custom blends		Alcohols, Combinations of N_2 + Other Gases
Generated atmospheres		Endothermic, Exothermic, Dissociated Ammonia
Helium	He	Helium is considered an inert gas
Hydrocarbons	CH_4, C_3H_8, C_4H_{10}	Methane (CH_4), Propane (C_3H_8), Butane C_4H_{10})
Hydrogen	H_2	
Nitrogen	N_2	
Oxygen	O_2	
Products of combustion		A mixture of a hydrocarbon fuel gas and air whose composition is dependent on the air/gas ratio.
Steam	H_2O	Water vapor
Sulfur Dioxide	SO_2	
Synthetic atmospheres		Nitrogen/Methanol
Vacuum		Vacuum is the absence of an atmosphere

Table 3: Common Types of Furnace Atmospheres.

distortion. The gear is indexed after each tooth has been hardened, often skipping a tooth. This requires at least two full revolutions in the process to complete the hardening of all teeth. Straight, spur, and helical gears up to 210" (5.33 m) and up to 15,000 lbs. (6800 kg) have been processed with this method. The entire process yields a repeatable soft tip of the tooth with hard root and flank. In other applications, the tip and both flanks can be hardened simultaneously and yield a soft root.

OVENS

Ovens (Fig. 9) may be designed for intermittent loading, that is, one batch at a time, or for a continuous flow of work using some form of conveyance through the unit. Today, oven construction can be used in temperature applications up to 1400°F (760°C) although 1000°F (538°C) to 1250°F (675°C) is a traditional upper limit. Oven technology utilizes convection heating, that is, the circulation of air, products of combustion, or an inert gas as the primary means to heat a workload to temperature. Oven construction also varies considerably from furnace construction.

Oven equipment sizes also vary dramatically, from small bench top units in laboratory environments to huge industrial systems with thousands of cubic feet of capacity. (cubic meters) of capacity. Ovens operate with air atmospheres but may be designed to contain special atmospheres such as nitrogen or argon, or incorporate special construction, such as adaptations for retorts, that allow the use of special atmospheres for the processing of very specialized applications.

The source of heat may be derived from combustion of fuel or electricity. Heat is transferred to the work primarily by natural gravity or forced convection, or by radiant sources if the temperature is high enough. As stated earlier, oven construction can be used in temperature applications up to 1400°F (760°C) although temperature ratings of 1250°F (675°C) or 1000°F (538°C) are more common.

Selection of the type of oven involves the careful consideration of several variables including:

- Quantity of material to be processed;
- Uniformity in size and shape of the product;
- Lot size;
- Temperature tolerances;
- Effluent evolution, if any

Figure 6: Typical Vacuum Hardening and Case Hardening Furnace. (Photograph Courtesy of SECO/WARWICK Corporation)

Batch systems may be classified as:

- Bell;
- Bench top;
- Cabinet;
- Truck;
- Walk-in;

Continuous systems include:

- Belt;
- Drag chains;
- Monorail;
- Pusher;
- Roller hearth;
- Rotary drum (or retort);
- Screw;
- Walking beam

There are several design criteria for oven construction that includes:

- Operating temperature;
- Heating method;
- Thermal expansion of materials;
- Atmospheres;
- Airflow patterns

The range of operating temperature is one of the main determinants of oven construction. Typically, all ovens are constructed of a double wall of sheet metal with insulation and reinforcing members sandwiched between the sheets. The insulation may be glass fiber, mineral wool or lightweight fiber material. The sheet metal lining for ovens may be of low carbon steel, galvanized steel, zinc-gripped steel, aluminized steel, or stainless steel depending on the temperature requirement.

Several distinct changes occur in oven construction as the temperature increases. Problems with expansion and sealing of interior joints (e.g. heat and atmosphere) become much more significant at higher temperatures. For example, an oven designed for operation at 400°F (205°C) will have mineral wool insulation, 4" (100 mm) thick. By contrast, for a 700°F (370°C) operating temperature, a thickness of

Figure 7: Typical Load of Gears for LPC Carburizing. (Photograph Courtesy of ALD Thermal Treatment)

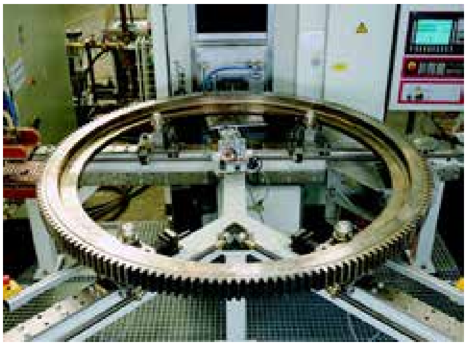

Figure 8: Typical Induction Heat Treated Gear. (Photograph Courtesy of EMA Induction Technology)

Class	Base Type	Description
100	Exothermic	An atmosphere created from the products of partial or complete combustion of an air-gas mixture in a water-cooled combustion chamber.
200	Nitrogen	A prepared atmosphere using an exothermic base with a large percentage of the carbon dioxide and water vapor removed.
300	Endothermic	An atmosphere created by partial reaction of an air-gas mixture in an externally heated, catalyst-filled chamber.
400	Charcoal	Uncommon today. Formed by passing air over a bead of incandescent charcoal.
500	Exothermic-Endothermic	An atmosphere created by complete combustion of a mixture of gas and air, removing a large percentage of the water vapor, and reforming most of the carbon dioxide to carbon monoxide by reaction with fuel gas in an externally heated catalyst reactor.
600	Ammonia	Any atmosphere created using ammonia as the primary constituent, including nascent (raw) ammonia, dissociated ammonia, or partially or completely combusted ammonia with a large percentage of the water vapor removed.

Table 4: Classification of Gases. (see original for this chart)

Figure 9: Typical Ovens Used for Tempering Gears. (Photograph Courtesy of Wisconsin Oven Corporation)

7" (175 mm) is required. Thermal expansion in large ovens is generally compensated for by the use of telescoping panel joints in the walls, ceiling, and floor. Door construction must incorporate similar expansion joints.

The type and quantity of airflow is important. For example, ovens designed for handling explosive volatiles such as paint drying or solvent extraction have special considerations including large air flow volumes to dilute the volatile, explosion relief hatches, purge cycles, powered exhausters, airflow safety switches and fresh air dampers.

Several different patterns of airflow can be used depending on the workload configuration. Of critical importance to overall temperature uniformity is air velocity (inlet and return). These are:

- Horizontal
- Vertical
- Combination (uniflow)

The method of heating an oven often depends not only on the availability of a particular fuel but also on the process itself. Many processes cannot tolerate products of combustion from direct fired systems so indirect (radiant tube) firing or alternate energy sources need to be considered. In addition, some means of heat transfer, such as microwave heating, are severely limited in the type of product that can be processed. Ovens are commonly heated by fuel (natural gas or other hydrocarbons), steam, or electricity. Infrared heating and microwave (radio frequency) are also used.

IN CONCLUSION

Today, the design engineer has the good fortune of being able to choose from a number of heat-treatment process as well as equipment choices for any given type of gear material and gear design. The selection of the best type of equipment for gear heat treatment is often defined by such factors as availability, unit cost (own & operate or outsource cost) and/or requirements based on the end-use application.

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