Fahrenheit 451: Gear Up For Induction Hardening

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So, you've been assigned the task to buy an induction heating system for heat treating: It's an intimidating, but by no means impossible, assignment. With the help of the information in this article, you should be able to develop common ground with your supplier and have the tools to work with him or her to get the right machine for your jobs.

Begin your task by asking questions, lots of them. Your induction heating equipment manufacturer possesses a wealth of information and experience that he or she is only too willing to share.

What Is Induction Heating?

Induction is a noncontact electromagnetic process where metal pieces to be heat treated are passed through a magnetic field that emanates about a copper induction coil. The coil is fed current at a specified frequency and power level to cause the heating. Most of the heating is due to currents induced into the part. Some heating is due to hysteresis. The induction method requires no warm-up, is fast, predictable, clean and like resistance heating, is an in-line process, eliminating the need to store inventory between operations. Likewise, the induction method is a noncontact process and can be readily used with atmospheres to eliminate or reduce scale.

When Should a Gear Manufacturer Consider Induction?

Most gears must be heat treated to maximize strength and minimize wear. Inexpensive, medium carbon steels are easily machined and hardened and are compatible with induction heat treat processes.

Warning: all cutting, forming and hobbing should be done prior to induction hardening. Whenever possible, heat treating should be the final step.

The two methods used to heat treat gears are in furnaces or by induction.

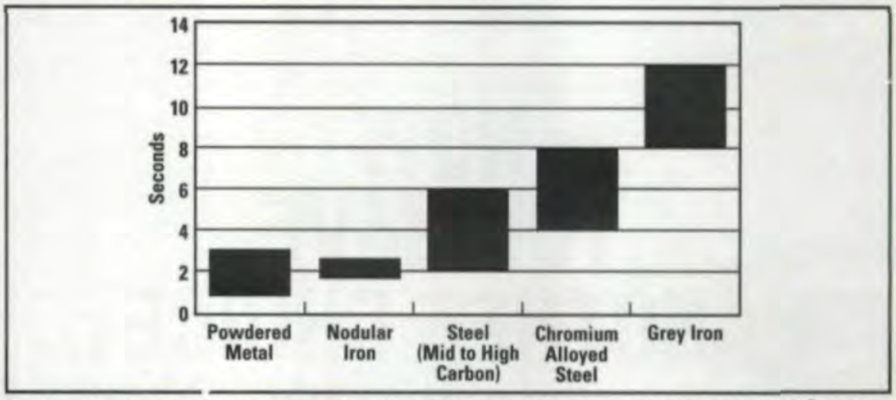

Fig. 1 — Nominal heat times to get carbon into solution for induction hardening at 10 kW/in² nominal power density.

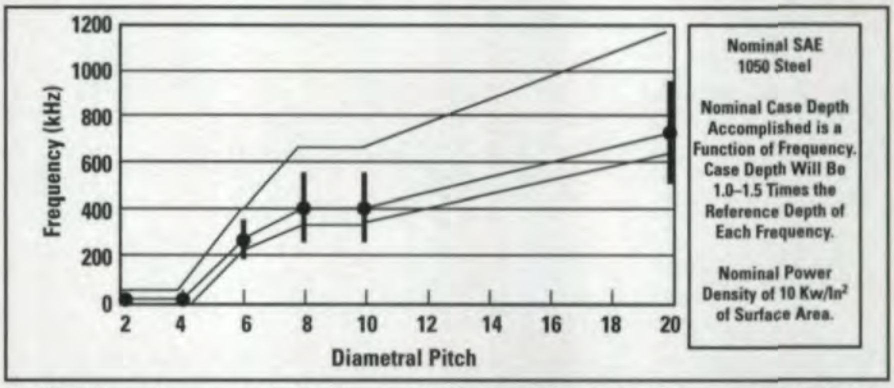

Fig. 2 — Proper frequency selection is needed to accomplish even heating across the tooth face. Selecting a frequency that is too low will only heat the tooth root as a result of field cancellation at the tips. Too high a frequency will overheat the gear tooth tips and not heat into the roots sufficiently.

Table 1 — XYZ Gear Part #945

Variables	Specifications
Part Measurements	4" x 1/2" face width, 6 D.P.
Production Rate	45,000 pieces/mo.
Part Material	SAE-5135
Case Depth	0.15–0.30 mm below root
Hardness Required After Heating	Rc 55 at 1/2 depth

Table 2 — Estimated Cycle Time (in seconds) = 20.0 180 parts/hr.

Unload/Load Machine	7.0
Initiate Cycle	1.0
Towers Raise	2.0
Heat On	3.0
Quench Gear	5.0
Lower Tower	2.0
Total Cycle Time	**20.0**
Parts Per Hour	**180.0**

Induction heating is often the method of choice for a number of reasons.

1. Because of their size and heat output, furnaces are often located in remote dedicated areas of the plant away from the production line. Induction lends itself to synchronous, in-line, cell-type manufacturing. The inductor can be mounted on the line, in several places if necessary, for uninterrupted flow.

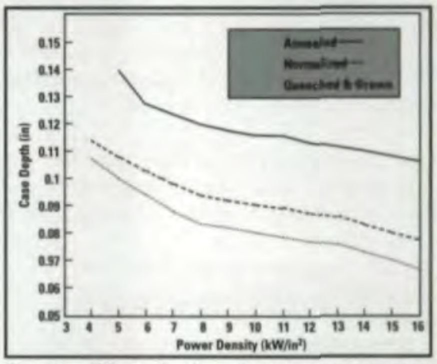

Fig. 3 — Effect of prior microstructure on case depth.

2. Fewer processes are needed with induction. Stop-off paints and copper plating operations are entirely eliminated as selective areas of the gear can be hardened.

3. While furnaces require batches of product to heat, one gear at a time can be processed with induction. Individual parts are accepted or rejected based on the correct process parameters being applied.

4. Induction equipment does not produce emissions.

5. Induction equipment is more efficient than furnaces, as only the area of the part to be hardened is heated (opposed to the entire part). Ambient air is not heated. As the induction unit is idle about 75% of the time, much less energy is consumed.

6. Gas furnaces need to be preheated; induction machinery does not.

7. Induction heating causes minimal distortion of gears.

What Does Your Induction Heating Machinery Supplier Need To Know?

Your potential short-, medium- and long-term applications. Mention all of these to your supplier even if they are not confirmed. Induction equipment can process different types of gears (with retooling); however, the supplier must know your needs beforehand.

Measurements of the gear(s) to be heat treated. Drawings and process sheets are very helpful. Your induction equipment supplier will study your gear prints and use your specifications to determine process parameters for the application.

Production rates. Determine how many parts need to be produced (by day, week or month). Specify the number of shifts the plant runs per day. From this data, your induction heat supplier can determine how many pieces need to be processed per machine cycle and calculate the power supply needed to meet this rate. The best information to have for your supplier is the total gross hourly production rate required of the equipment.

Part material. Carbon content, alloying elements and prior microstructure will affect the amount of power and time required to heat the gear. Gears with lower carbon content (below 0.2%) can undergo carburization prior to induction heating to speed up the heating rate in applications involving hardening.

Fig. 1 shows approximate heat times for various types of metals. Of course, actual times will vary based on the diameter, thickness and area of the part to be heated.

Case depth (depth of heating). Frequency selection is very important to obtain specified results. Too low a frequency will leave the tooth tips unheated. On the other hand, heating with too high a frequency will not heat the root area, but it will overheat the tips. There is a direct correlation between diametral pitch and frequency.

Frequency determination starts with carefully evaluating the desired or specified pattern. Take special note of these details: Is through-hardening of the tooth tip desired, or is the pattern profiled along the face of the gear? Is hardness required in the root? If so, to what depth?

Hardness required after heating. Hardness is dependent on material and is generally specified by the buyer. Carbon content, alloying elements and prior microstructure all affect hardness.

Application needed. A variety of applications can be handled by induction. Your equipment supplier will need to know which ones you will be using. Among those possible with induction heating are

- Surface hardening. Heating the surface of a component above transformation temperature, then rapidly quenching to create a hardened case on the surface.
- Through-hardening. Heating the entire workpiece above transformation temperature, then rapidly quenching to harden the part from surface to core.
- Tempering or stress relieving. Heating to a low temperature (120°–600°C) and allowing the heat to soak into the piece to relieve residual stress and reduce surface hardness to prevent cracking.
- Normalizing. Heating above transformation temperature and allowing piece to air cool.
- Annealing. Heating above transformation temperature and using controlled cooling.

What Will Your Induction Heat Machinery Supplier Determine?

A typical induction heat treat application is governed by the following equipment process parameters: Heat time, power level, power frequency, quench flow part position/rotation, and quench concentration. Your equipment supplier will need the range of these settings used in your applications–specifically:

1. Cycle Time. The induction heat treat process comprises the following primary elements:

Load/unload	6–10	seconds
Index in/out of coil	2–4	seconds
Heat	1–10	seconds
	(material	dependent)
Delay to quench	0–2	seconds
Quench	2–10	seconds
TOTAL	11–36	seconds*

*If tempering is needed, add six to eight seconds.

Actual time will be based on production rates, part material, power supply, etc. (See Fig. 2.)

2. Power level. Power level is a function of surface area:

Surface area = πdh x 2 (for gears)

For example, if a gear measures 4" wide by 1/2" high,

Surface area =

3.14 x 4 x 1/2 x 2 =

12.5" x 10 = 125 kW.

(The actual formula for determining definitive gear surface is more complex than this, but for the purposes of this article, we are using a simplified version.)

In some cases, the specific heat of the material, along with the weight of material to be processed and temperature to be reached, is used to determine the power supply size. (See Fig. 3.)

3. Power frequency. Based on case depth, the required level of hardening depth is calculated. Frequency is a function of case depth. The higher the frequency, the shallower the case depth. If

the frequency is too low, the piece does not get heated properly (Fig. 2).

4. Part position/rotation. Based on production volume and mix, budget requirements, plant standards and other information, the supplier will suggest ways to best meet production with manual or automated loading. Among other factors to consider are these: Manual loading is less expensive, but automation is more dependable.

5. Quench flow. This is critical only to hardening applications. Heat must be extracted very rapidly and precisely from the steel. The rate of heat extraction is largely a function of quench flow.

6. Quench concentration and filtration method. Quenchants are application specific. Water, polymer-water, soluble oil, salt water oil and even lead can be selected as quench alternatives. A few applications, such as low-hardenability materials, are best suited for a straight water quench. Polymer quenchant manufacturers should be consulted for each application to assure compatibility with other fluids that may be introduced.

Filtration of quench is necessary to assure process consistency and extend the useful life of the quenchant. Particles in the quenchant can block the small holes on quench barrel assemblies. Quench hole size is considered with selecting strainers and/or filters on quench water systems. Strainer hole size must be smaller than the quench hole size to prevent blockages.

Other less critical factors to be considered include quench temperature and quench time.

Additional Information

The cost of induction heat treating equipment can vary from $100,000 to $500,000, depending on production rate. The average price is $250,000. If XYZ Gear were to manufacture 200,000 gears a year over five years (or 1,000,000 gears), the cost per gear would be 25 cents.

When purchasing induction heat treating equipment, it is helpful to note additional budget items: Electricity, cooling tower or chiller water, quenchant, disposal of quenchant, inductor coils and part touch tooling, floor space, cost of preventative maintenance, operator/attendant costs, maintenance and daily destructive evaluation of production samples.

A Case Study

XYZ Gear needs to induction heat treat gear #945, which is 4" wide and 1/2" high (See Table 1).

ABC Induction Supplier determines the needed machine using the following calculations.

1. Power supply. The general rule is 10 to 15 kW per square inch. (Metric measurements need to be converted into the English system.)

4" x 1/2" x 3.14 x 2 = 12.56 in^2 x 10 = 125.60 kW.

Based on standard tables, a 150kW/30 kHz power supply is selected.

2. Production rate. XYZ Gear operates two 6.5 hour shifts, five days per week and is open 4.3 weeks per month.

45,000 pieces/mo = 162 pieces/hr at 279 hrs/mo.

A piece must be processed every 22.2 seconds.

Given the production rate, the power supply and company experience in this type of job, the applications engineer calculates the cycle time as shown in Table 2.

What Do You Need To Know About Commercial Heat Treaters?

Perhaps your production is low enough to consider outsourcing heat treating. Commerical heat treaters charge somewhere between 50 cents and $3.00 per gear. Companies can work out the economic feasibility based on an approximate cost of $2.50 per gear versus an investment in the capital equipment of $250,000 (the average price of induction heat treating equipment), plus ancillary costs.

Other factors should be considered before outsourcing. Are you willing to give up control of this process? Can you trust an outside heat treater to process gears that meet your standards?

A good place to begin is by consulting the directory included in this issue of *Gear Technology* or the *Directory of Commercial Heat Treaters*. Keep the following in mind:

- Make sure your commercial heat-treater has the proper equipment and experience.
- Make sure the skill set and equipment needed reside within the commercial heat treater now. Don't let anyone experiment with your project or use your job as a "learning experience."
- Make sure quality systems are in place. ○

References:

ASM Handbook. Vol. 4 *Heat Treating*. ASM International, Materials Park, OH 1991.

Interview with Deborah A. Erzen, applications engineer, Welduction Corporation, Farmington Hills, MI, September, 1997.

Welduction Corporation, *Induction Heat Treat Equipment Specification Guide*, January, 1998.

Williams, Daniel J. "Quench Systems for Induction Hardening," *Metal Heat Treating*, July-Aug., 1995.

Williams, Daniel J. and Traverse, Gilbert J. "Fundamentals of Specifying Induction Power Supplies for Wire and Rod Heating," *Wire Journal International*, June 1997, pgs. 92–99.

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