Dual Frequency Induction Gear Hardening

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Introduction

In the typical gear production facility, machining of gear teeth is followed by heat treatment to harden them. The hardening process often distorts the gear teeth, resulting in reduced and generally variable quality. Heat treating gears can involve many different types of operations, which all have the common purpose of producing a microstructure with certain optimum properties. Dual frequency induction hardening grew from the need to reduce cost while improving the accuracy (minimizing the distortion) of two selective hardening processes: single tooth induction and selective carburizing.

Single tooth induction hardening is performed with a shaped intensifier that oscillates back and forth in the gear tooth space. It is usually done with the gear submerged in quench. The process is relatively slow because only one gear tooth space is processed at a time.

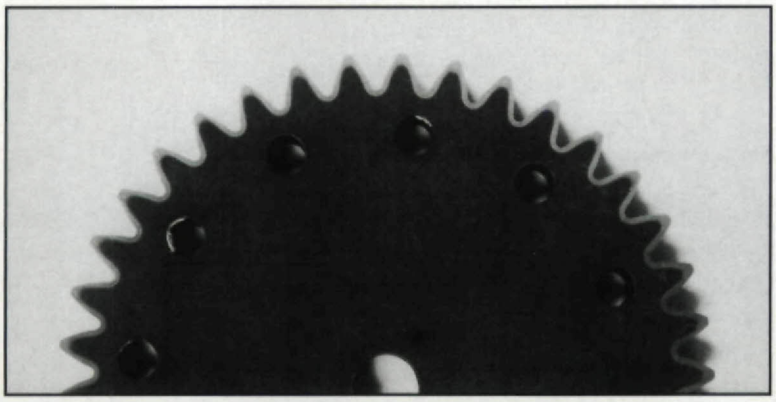

Fig. 1 - Contour gear hardening pattern.

Selective carburizing is an industrial standard most widely used to selectively harden gears. The process involves covering the surfaces to be protected against carburizing with a material that prevents the passage of active carbon during the furnace operation. The most widely used method to stop carbon activity is copper plating. A gear is copper plated on all surfaces except the teeth, then carburized. The part is then copper stripped, finish machined, re-copper plated all over, furnace hardened, and quenched.

Dual frequency heating is the fastest known way of heating a gear. Heating times range from .14 to 2.0 seconds. Because it is so fast, surfaces remain clean and free from carbon-depleting and scale, and the core material retains its original properties.

The focus on manufacturing today is to make consistently high quality products at lower costs. This article describes the dual frequency process along with comparisons of other heat treating processes and actual heat cycle data.

Dual Frequency Process

The principle of dual frequency heating employs both high and low frequency heat sources. The gear is first heated with a relatively low frequency source, providing the energy required to pre-heat the mass of the gear teeth. This step is followed immediately by heating with a high frequency source. When applied, the high frequency source will rapidly final heat the entire tooth contour surface to a hardening temperature.

The gear is then quenched to a desired hardness. Figs. 1 and 2 show a typical "dual frequency" contour hardened pattern.

The total time cycle is dependent upon the surface area to be hardened. See Table I.

Material Requirements

There have been vast amounts written about material requirements in terms of wear, machinability, mechanical properties, and the ease with which complicated shapes may be produced by casting methods. In general, a wide variety of materials can be used for the production of gears. For technical and economic reasons, steels have attained a major importance.

The transformation which the structure of steel undergoes during heating and subsequent cooling, particularly the formation of martensite on quenching, is essential for the hardening and tempering of steel. The carbon content of steel establishes the maximum hardness that the steel can reach. Commonly used induction steel requires a carbon content of .40/.50/.60%, depending on the desired surface hardness.

Parts which have to be hardened by quenching after local heating must be made of a steel which contains the carbon necessary to achieve a desired hardness, as shown in Table II.

Heat Cycle Test

Ideal contour induction processes rapidly heat with only the required energy to transform a desired volume of material; i.e., the contour surface of a gear, and allow for extreme, rapid quenching to take place. This "mass quenching" effectively produces a maximum surface hardness from the material and the best condition of microstructure available (fine grain martensite).

The real problems associated with the heat treating of gears are the result of the numerous processes added to the manufacturing sequence to correct for distortion caused by heat. Most gear producers work from green specs and hard specs, before and after heating, in the hopes of accurately predicting the amount of change that will take place because of heating. This typically involves machining over/between pins, lead, and involute dimensions to values different from final print requirements. In this mode of operation, the manufacturer treats the symptoms and not the true problem. In treating the symptoms, a sizeable increase in gear production cost is generated. The major elements that produce the increased costs include materials, time, energy,

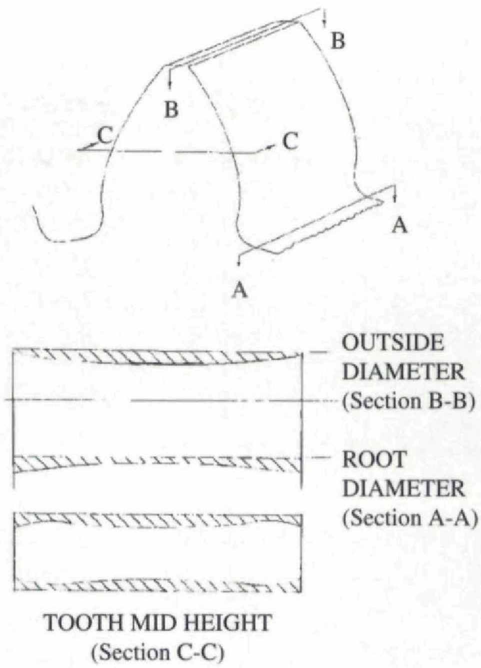

Fig. 2 - Typical tip and root pattern.

Table I - Dual Frequency Process

Gear Data

Number of teeth	58
Outside diameter	7.500
Root diameter	6.930
Face width	.490
Material	SAE5150

Approximate surface area = 27 square inches

Dual Frequency Cycle Process

		(spindle rpm)
* Pre-heat	10 seconds	300
* Dwell	3 seconds	
* Final heat	.455 seconds	400
* Quench	15 seconds	5
* Temper	3 seconds	300

Dual Frequency System

* Pre-heat low frequency generator (3-10k)
* Final heat high frequency generator (100-230kc)
* Work station with quench system
* Computer control station

Table II

RC	CARBON
50	.40%
55	.45%
60	.51%

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Table III

Comparison of Dual Frequency Induction Gear Hardening and Selective Carburizing

DIE QUENCH OPERATION	FREE QUENCH OPERATION	DUAL FREQUENCY OPERATION
1. Rough Machine	1. Rough Machine	
2. Degrease	2. Semi-finish Gear Teeth	1. Rough Machine
3. Mask	3. Copper Plate	2. Core Treat
4. Copper Plate	4. Unmask	3. Degrease
5. Unmask	5. Inspect Plate	4. Draw
6. Inspect Plate	6. Load Carburize Furnace	5. Finish Machine (final size)
7. Load Carburize Furnace	7. Quench	6. Load Induction Machine
8. Slow Cool	8. Draw (temper)	7. Unload
9. Clean	9. Degrease	8. Inspect
10. Copper Strip	10. Shot Blast	
11. Finish Machine Gear Teeth	11. Copper Strip	
12. Load Hardening Furnace	12. Shot Blast	
13. Die Quench	13. Inspect	
14. Degrease	14. Required Finishing Operations	
15. Draw (temper)		
16. Shot Blast (clean)		
17. Inspect		
18. Required Finishing Operations		

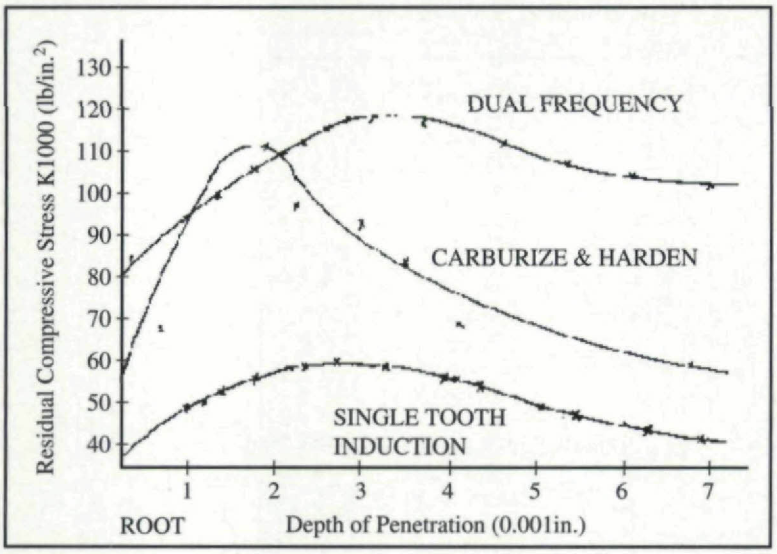


Fig. 3 - Residual compressive stresses.

and added processing.

The dual frequency gear hardening process treats the problem by reducing or eliminating the distortion of gear teeth through heating to levels acceptable in most gear final print tolerances. Table III shows the operations required to manufacture gears utilizing three different hardening methods.

To selectively harden gear teeth utilizing the selective carburizing process, they must be handled (load/unload) a minimum of 16 times. In addition to handling the part, numerous inspection and support personnel are needed to maintain plating solution and equipment.

The following physical characteristics were evaluated on six diametral pitch production gears for the automotive industry:

- Residual stress level
- Microhardness gradient
- Pattern depth of penetration
- Before and after dimensional characteristics

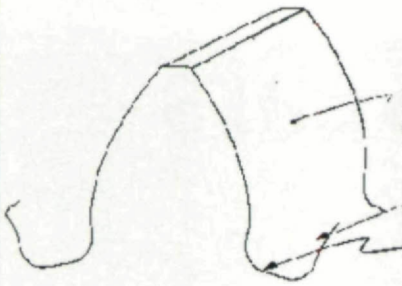
The residual stress evaluation was made on a comparative basis to determine relative root residual stress levels in gears hardened via different methods. Residual compressive stress is favorable because it tends to subtract from an intensity of the tensile stresses during operation of the gear. Residual stress levels were measured by the "Fastress" method to determine root compressive stress. The dual frequency method was found to have 120,000 psi compressive at 1.003 inches. Fig. 3 shows the comparison between the carburize and harden method, single tooth induction, and dual frequency hardening.

Fig. 4 shows the microhardness gradient at three positions across the teeth. Figs 5a and b are gear inspection charts taken from a CNC universal gear checker. They show the "before" and "after" lead, involute, and runout checks.

Conclusion

Even in an age of high technology, heat treating of gears leaves much to be desired. Invariably, the imperfections of the process create dimensional distortions, which, in addition to other difficulties, can yield a production "fallout" of 10% to 20% or can lead to rework operations in an effort to salvage the gears.

Until now, industry just had to live with the



Microhardness Gradient

PROFILE (Center) DEPTH (ins.)	RC	ROOT (Face) DEPTH (ins.)	RC	ROOT (Center) DEPTH (ins.)	RC
.000	60.4	.000	60.5	.000	61.5
.010	58.2	.010	60.0	.010	61.2
.020	56.7	.020	60.4	.020	60.4
.040	58.2	.040	57.4	.040	55.9
.060	56.7	.060	56.2	.060	52.1
.080	33.7	.080	34.2	.080	33.7
.100	33.7	.100	34.2	.100	33.7
.120	33.7	.210	34.2	.120	34.2

Depth of penetration - parts were sectioned, and the following depths were measured:

SERIAL NUMBER	PRE-HEAT TIME (sec.)	FINAL HEAT TIME (sec.)	AVG. CASE DEPTH ROOT (ins.)	AVG. CASE DEPTH TIP (ins.)
1	45	.75	.046	.120
2	40	.75	.046	.108
3	32	.75	.042	.080
4	35	.45	.028	.090
5	35	.70	.035	.092
6	40	.85	.048	.092
7	40	.70	.045	.108
9	42	.70	.045	.113
12	38	.65	.032	.094
13	40	.55	.030	.106
15	44	.60	.032	.117
20	38	.80	.044	.103
26	38	.75	.042	.105
27	36	.75	.040	.090
29	32	.75	.040	.080

Fig. 4 - Microhardness gradient.

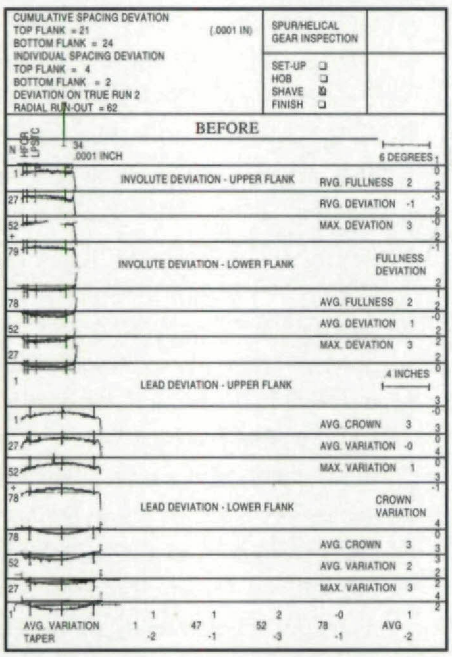


Fig. 5a - Gear inspection chart - "before."

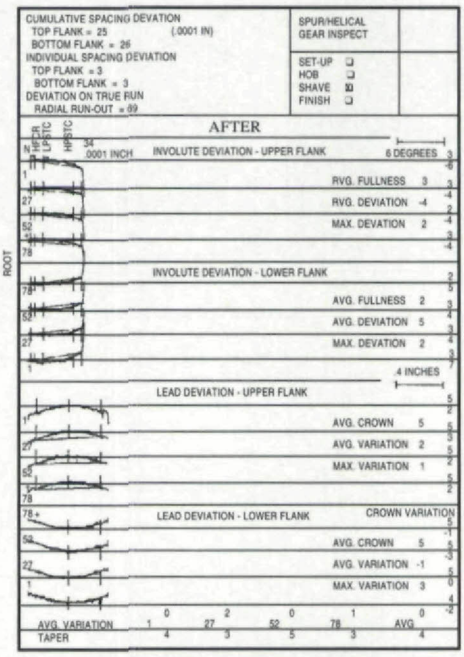


Fig. 5b - Gear inspection chart - "after."

problem. Now a new heat treating system has overcome those traditional limitations, not with untried technology, but with an innovation on established technology. The system provides advanced induction heating with the total, repeatable accuracy of programmable microprocessor control. ■

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